Perspektívy jadrovej a subjadrovej fyziky v SR

Jozef Masarik

seminár

pri príležitosti 50.výročia založenia Katedry jadrovej fyziky na UK

Bratislava 7. december 2011

My mind is my laboratory.

Albert Einstein

Information is knowledge.

Albert Einstein

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

FORWARD LOOK

Perspectives of Nuclear Physics in Europe

NuPECC Long Range Plan 2010

Paying tribute to its cultural heritage, Europe should continue to be at the forefront of promoting one of the most vigorous and fascinating fields in basic science, Nuclear Physics. Nuclear physics addresses the fundamental aspects of those particles that interact via the strong interaction. These hadrons constitute nearly 100% of the visible matter in the universe.

With the renewed (**???**) worldwide interest in nuclear technology (low-carbon energy: nuclear fission and nuclear fusion power generation, nuclear medicine: imaging and tumor therapy, security, materials studies with nuclear probes, etc.), Europe needs to preserve, and even enhance, its nuclear physics knowledge and skills basis in the future. A dedicated effort directed at the training of young people is mandatory.

In the middle of difficulty lies opportunity.

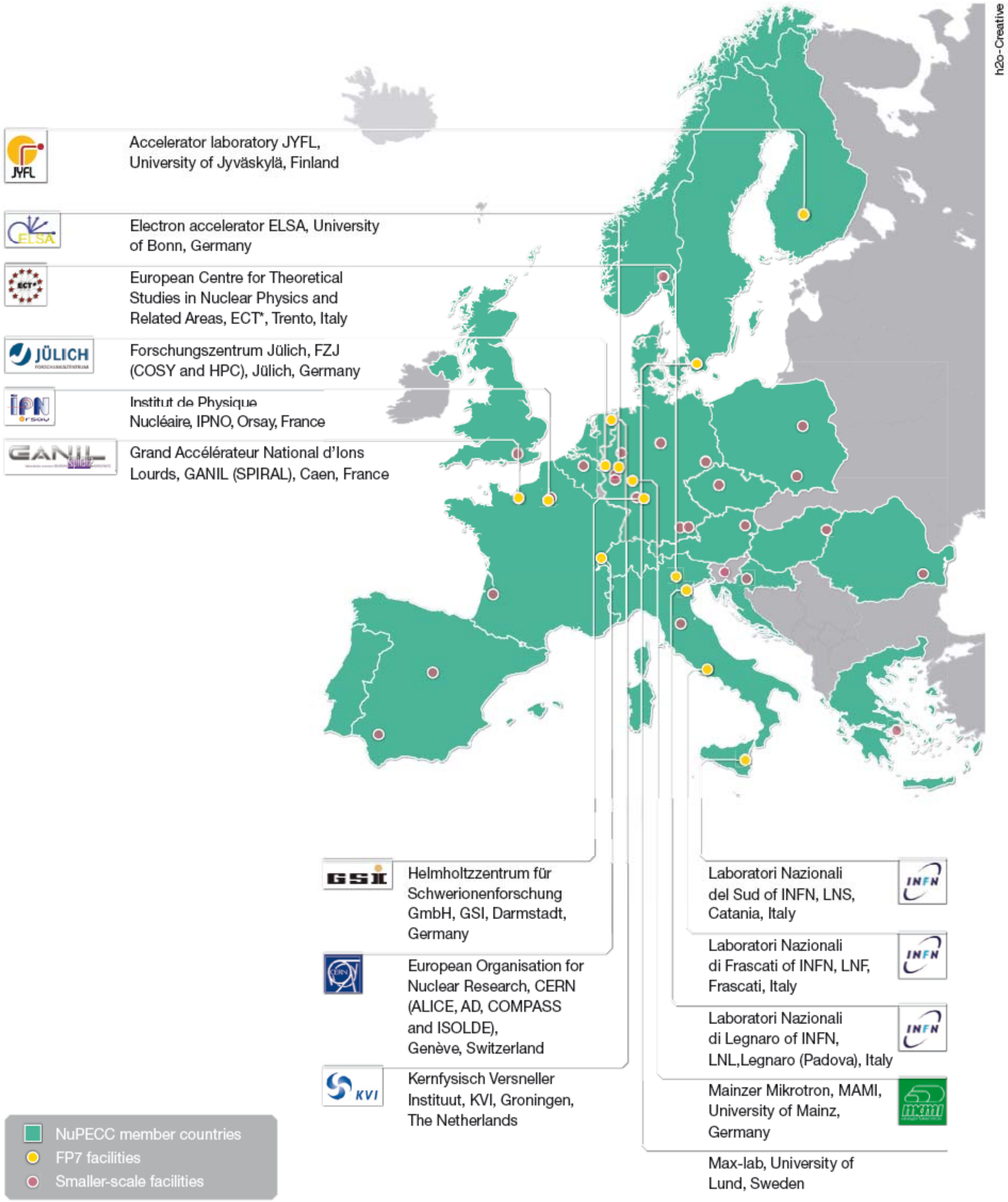
Albert Einstein

What I will speak about

- Basic research
- Applications
- Energy production

Research Infrastructures and Networking

Nuclear Physics in Europe is a vibrant field of basic and applied sciences – competitive at a global level – not least because it is well equipped with a network of large and smaller scale facilities that collaborate closely

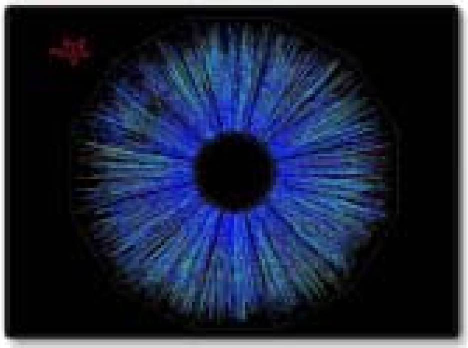
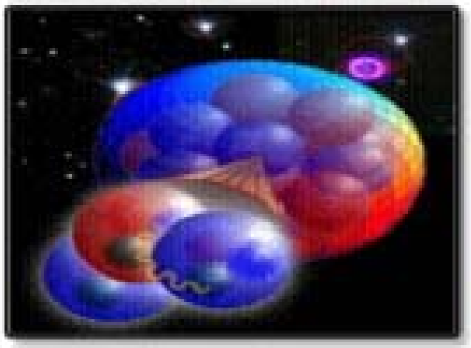
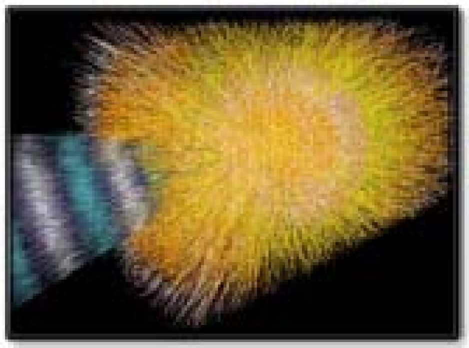
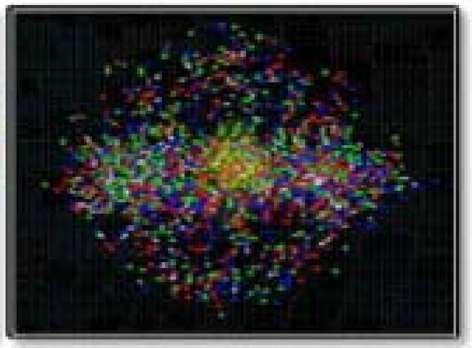

Accelerator laboratory JYFL, University of Jyväskylä, Finland
Electron accelerator ELSA, University of Bonn, Germany
European Centre for Theoretical Studies in Nuclear Physics and Related Areas, ECT*, Trento, Italy
Forschungszentrum Jülich, FZJ (COSY and HPC), Jülich, Germany
Institut de Physique Nucléaire, IPNO, Orsay, France
Grand Accélérateur National d'Ions Lourds, GANIL (SPIRAL), Caen, France
Helmholtzzentrum für Schwerionenforschung GmbH, GSI, Darmstadt, Germany
European Organisation for Nuclear Research, CERN (ALICE, AD, COMPASS and ISOLDE), Genève, Switzerland
Kernfysisch Versneller Instituut, KVI, Groningen, The Netherlands
Laboratori Nazionali del Sud of INFN, LNS, Catania, Italy
Laboratori Nazionali di Frascati of INFN, LNF, Frascati, Italy
Laboratori Nazionali di Legnaro of INFN, LNL,Legnaro (Padova), Italy
Mainzer Mikrotron, MAMI, University of Mainz, Germany
Max-lab, University of Lund, Sweden
NuPECC member countries
FP7 facilities
Smaller-scale facilities
h2o-Creative

Look deep into nature, and then you will understand everything better.

Albert Einstein

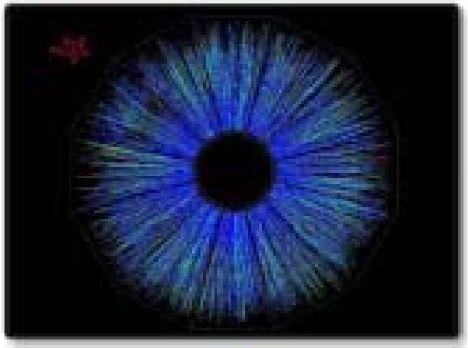
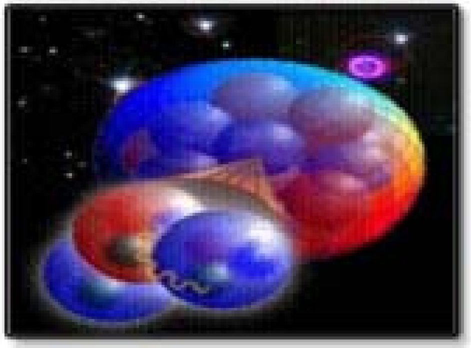
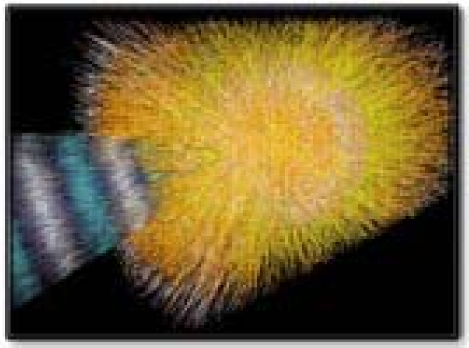
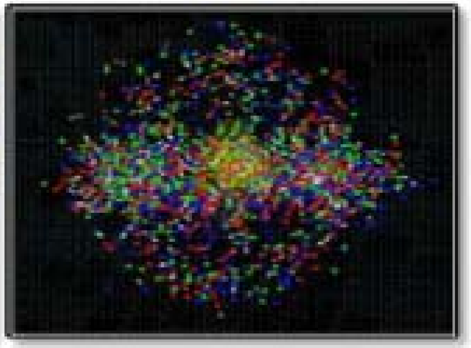
Basic research

- Studying the fundamental strong interaction (as described by QCD. Investigations of hadron internal structure and spectroscopy require both lepton (electron, positron and muon) on hadron and hadron on hadron scattering facilities as a tool.
- Better understanding the strong interaction by studying the phase-diagram of matter that primarily interacts via the strong force. Relativistic heavy ion beam facilities are the tools needed for such studies.

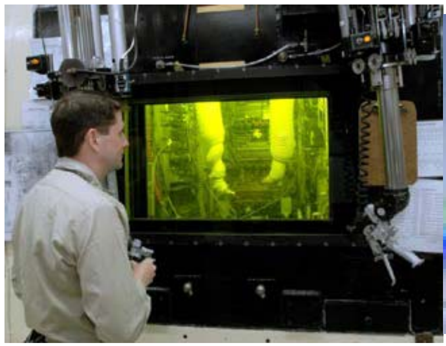
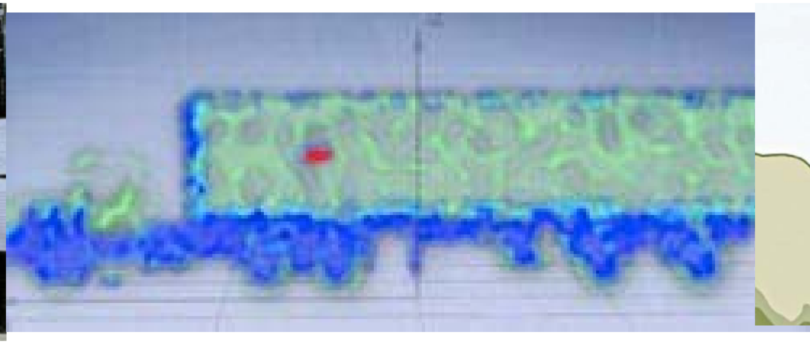
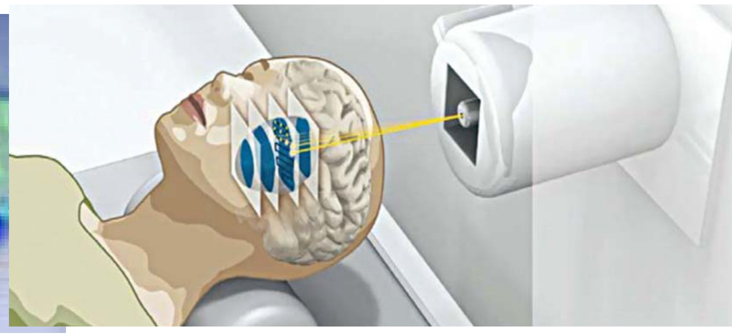
Basic research

- Investigating the structure of nuclei far from stability by using, in particular, radioactive heavy ion beams produced by both in-flight fragmentation and Isotope Separator On-Line, ISOL, techniques. In addition, the capabilities of high-intensity stable heavy ion beam facilities should be further improved, and plans should be developed for upgrading or building new small-scale accelerators dedicated to nuclear astrophysics.
- Studying key aspects of fundamental interactions and symmetries using nuclear physics techniques, e.g. investigations of matter-antimatter symmetry, the nature of the neutrino, and precision measurements of weak interactions. This will require new sources of low-energy antiprotons, improved underground laboratories, and access to upgraded and new facilities producing exotic nuclei.

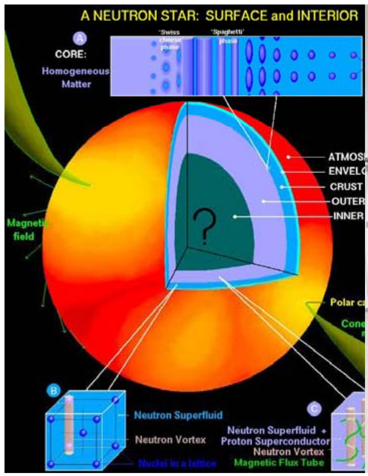
Applications (very limited and subjective list)

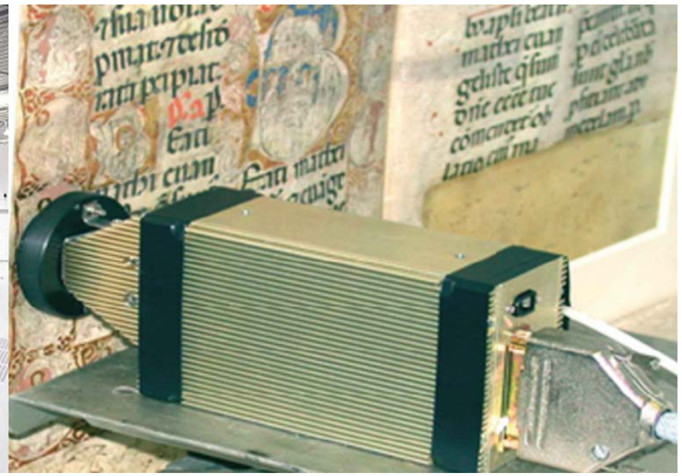
- Nuclear Techniques in Medicine and Life Sciences (Cancer therapy, new Imaging and Diagnostics Tools, radioisotope production);
- Applications of Nuclear Techniques in Art, Archaeometry and other Interdisciplinary fields;
- Nuclear techniques in Environmental Problems;
- Applications of Nuclear Techniques relevant for Civil security (contraband and explosive detection, search for Weapons of Mass Destruction, Nuclear Safeguards);

Applications (very limited and subjective I list)

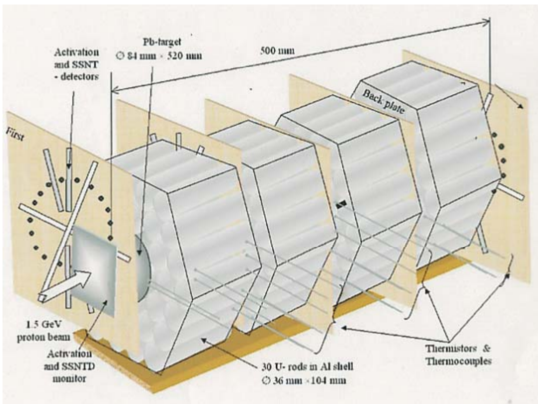
- Nuclear Applications in Space Research;
- Material and Structure Testing in Research and Industry;
- Emerging experimental techniques, new detectors and new modeling tools.

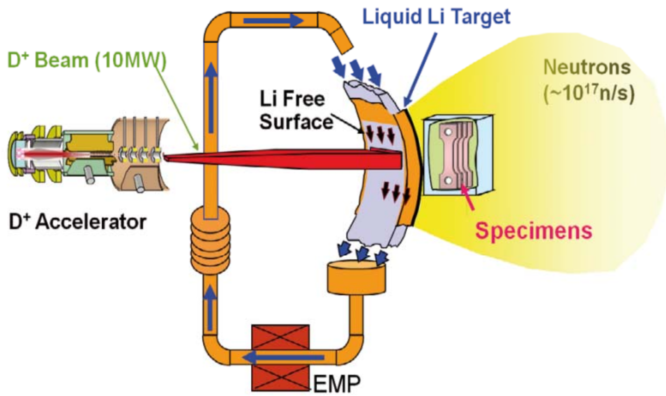




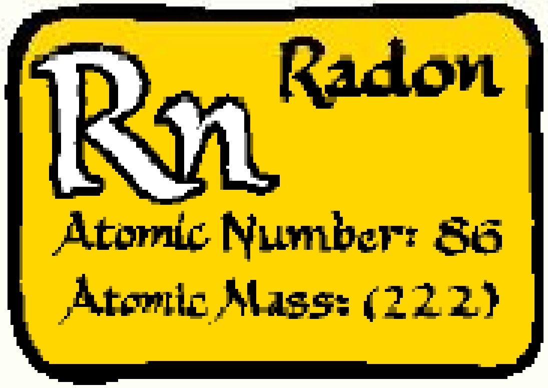
Energy production

- Accurate nuclear data for the design of new generation reactors
- Study and modeling of nuclear reactions involved in transmutation processes or new fuel cycles
- Modern Nuclear Physics tools (accelerators, detectors, modeling techniques,..) applied to the design and construction of next generation fission/fusion reactors and incineration factories





Radon as tool



Overview status radon as a tool

- Radon measurement and modelling with respect to indoor radon as a health issue are well developed.
- Radon is sometimes considered as a tool(precursor) for earthquake prediction
- Radon can in principle be used to obtain information about the media from which it originates. E.g. Concrete condition, oil contamination
- Radon is also contempleted as a indicator for water on Mars

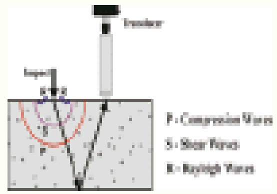
NDE of Concrete using radon

Why ?

- Durability
- Safety
- Economics

How ?

- Radar
- Impact echo
- Ultrasonics

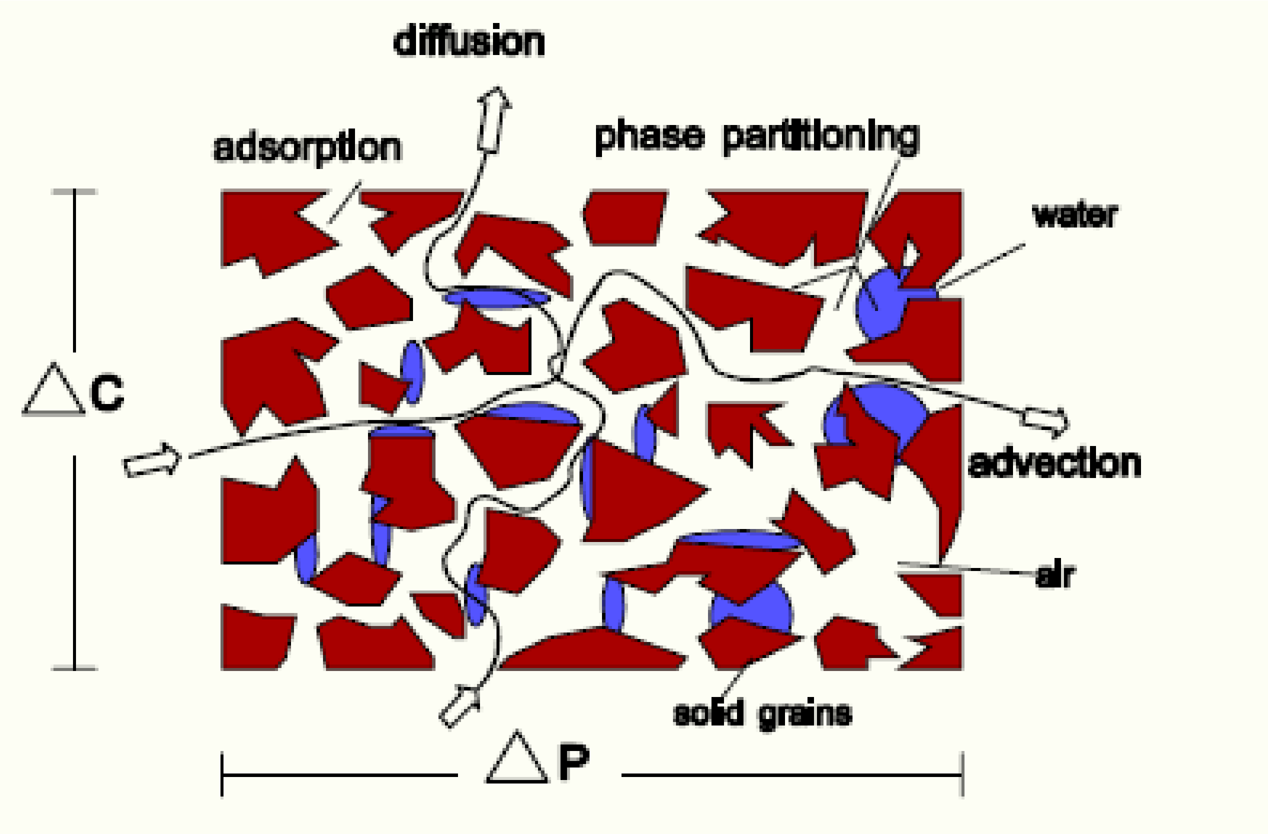


What ?

- Bridges
- Dams
- Walls

Radon transport modelling

- Media: Soil, building materials
- Multi-phase model: water, air, solid
- Transport: advection, diffusion



There is not the slightest indication that energy will ever be obtainable from the atom.

Albert Einstein

Relativity applies to physics to to ethics.

Albert Einstein

Policy

Energy of 1ton of oil equivalent

Toe = 11 700 $KWh_{Thermal}$ or 4000Kwh $_{Electrical\ or\ mechanical}$

1 liter of oil = 10$Kwh_{Thermal}$ or $ $kwh_{Electrical\ or\ mechanical}$

Sources of Energy:

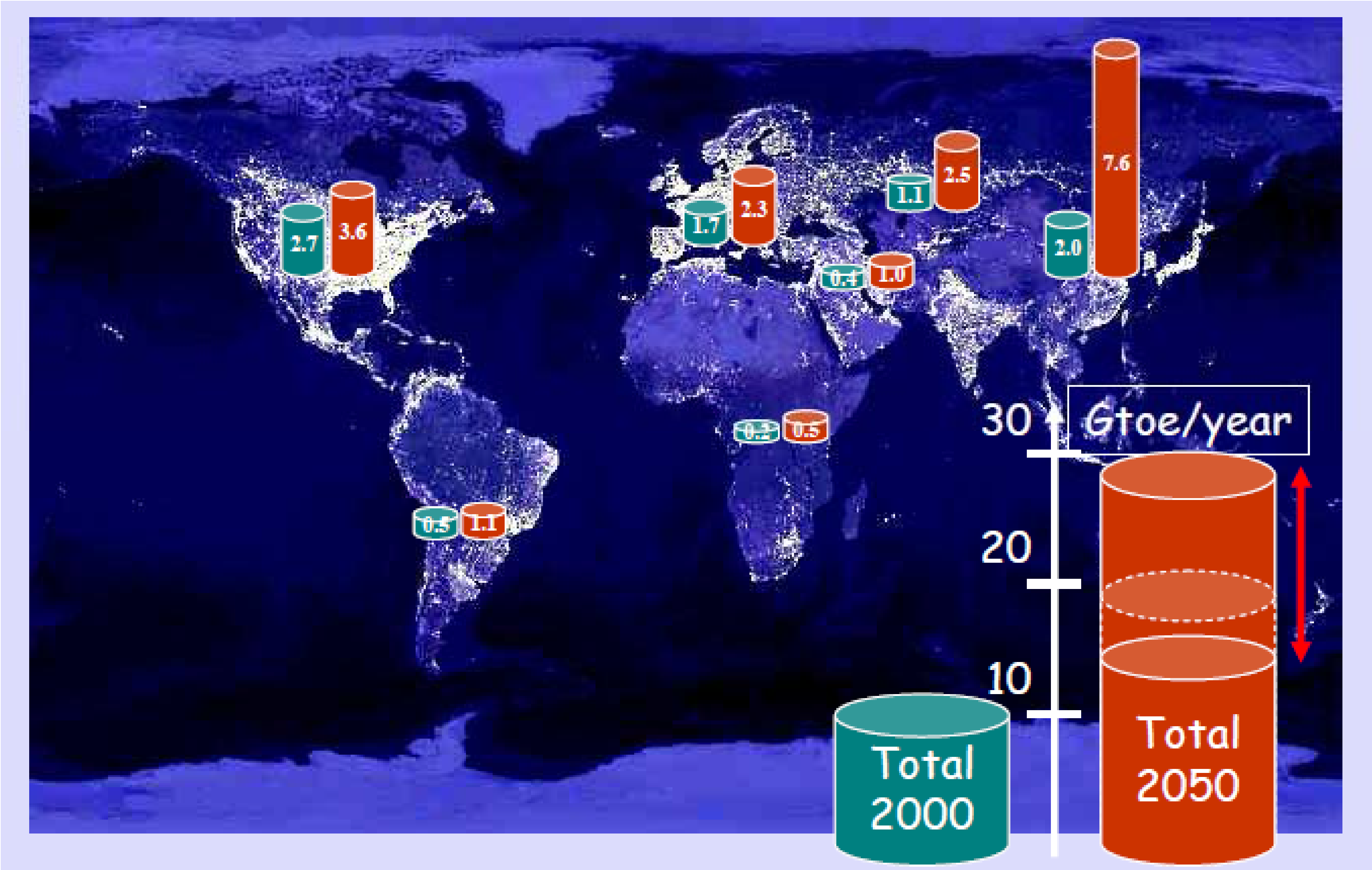
Fossils: Petrol, Gas, Coal, Nuclear Fisor Fus,

Solar: Biomass, Hydraulic, Wind, ……

- At the World level

Total Consumption(2000)	10 billions of toe/year
Consumption per capita	1.6 toe/year
Electricity per capita	0.5 toe/year or 0.250 Kw *averaged power*

World Population: + 165 000/ day	1000MWe to Install /20 days to *keep cte the averaged* ***consumption***



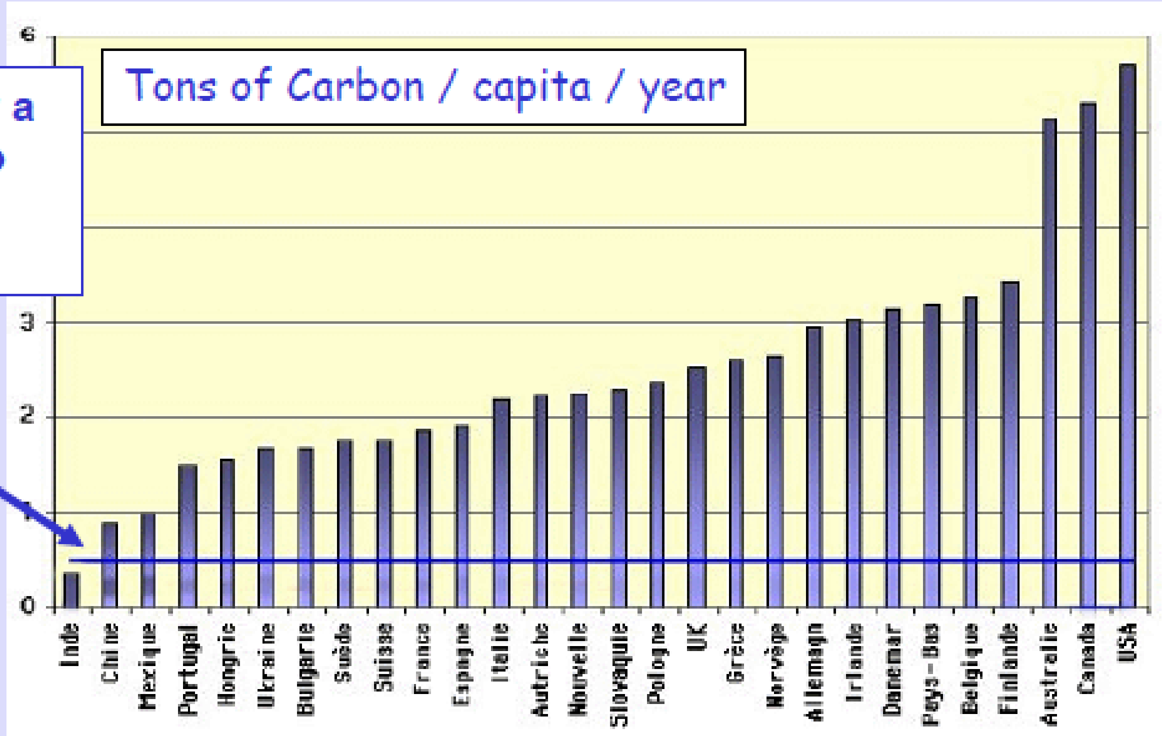
2.7
3.6
1.7
2.3
1.1
2.5
2.0
7.6
0.4
1.0
0.5
0.5
1.1
30
20
10
Gtoe/year
Total 2000
Total 2050

Green-House Gas Emission

→ Climatic change, temperature increase of 2°C unavoidable...
→ Green House Gas emission has to be reduced by a factor 2 in 50 years to stabilize the temperature to +2°C

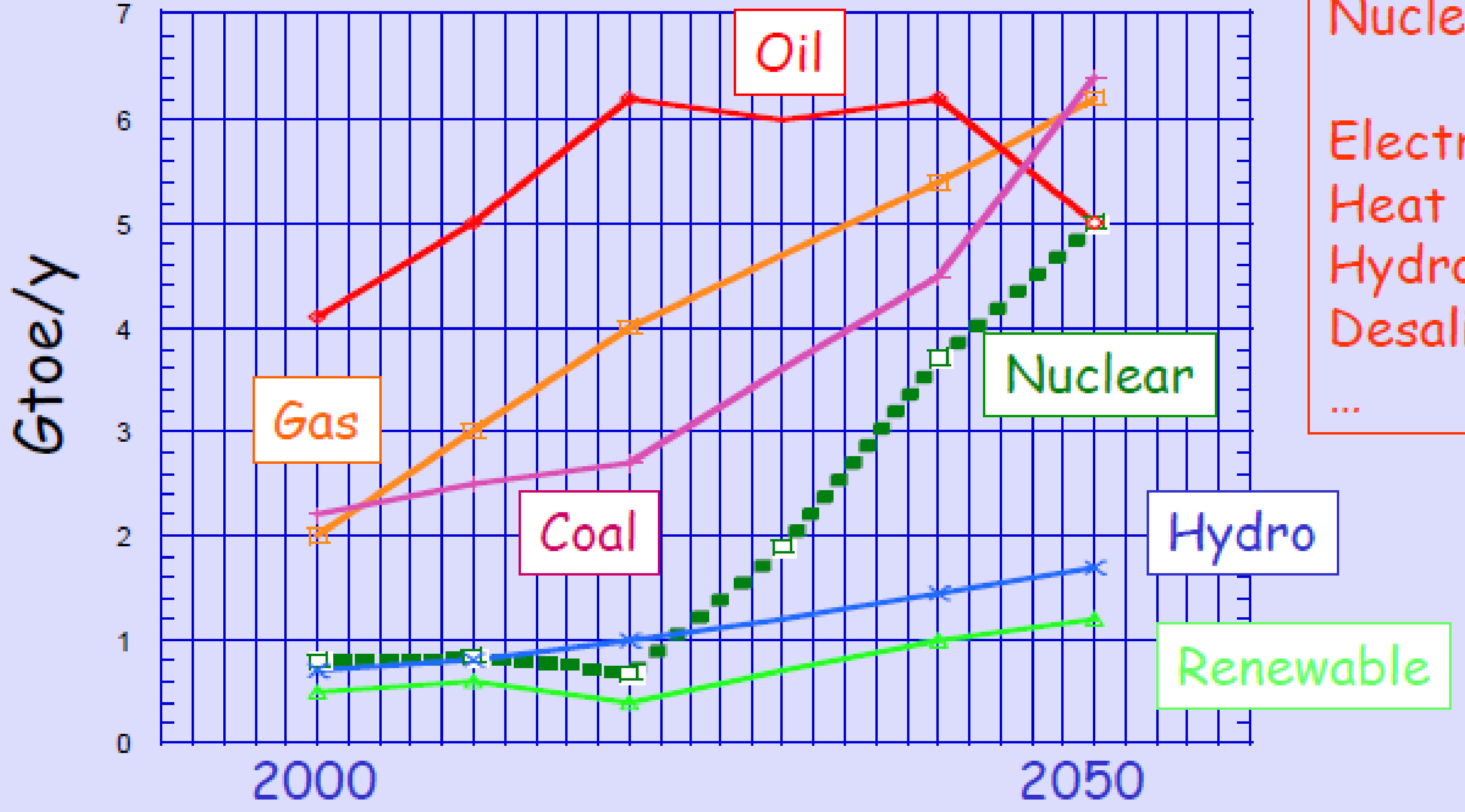
Maximal emission per capita for a 6 Billions population, in order to stabilize the CO_2 atmospheric concentration

Drastic reduction unless CO2 sequestration can be used at the needed scale



Ref: JM Jancovici, www.manicore.com

Ex: scenario TotalFinaElf, nuclear power 20% in 2050 (x8)



Nuclear power

Electricity
Heat
Hydrogen
Desalinated water
...

Ref: P.-R. Bauquis, TotalFinaElf

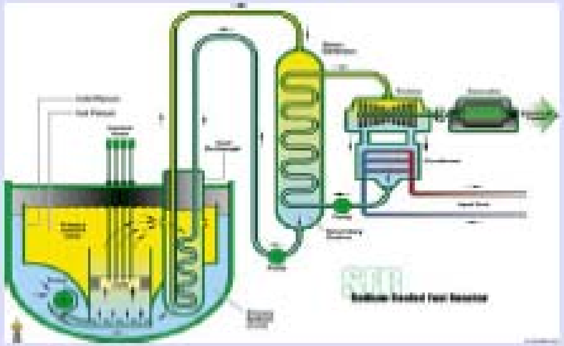
Uranium consumption

Uranium-235		0.7% of U ore	
Consumption	fissionned	1 ton	/(GWe.y)
	enriched	30 tons	/(GWe.y)
	natural	200 tons	/(GWe.y)
World Nuclear Production		285 GWe (full power equivalent)	
World U consumption		60000 t/y	
U reserves (RRA+RSE+speculatives)		16 millions of tons	
Production Potential (at present rate)		280 years	
Production Potential at present rate x10		≈ 50 years only !	

- Standard reactors are not sustainable if nuclear power increases by a factor 5 to 10 in 50 years
- **Breeding is unavoidable** for massive and sustainable production

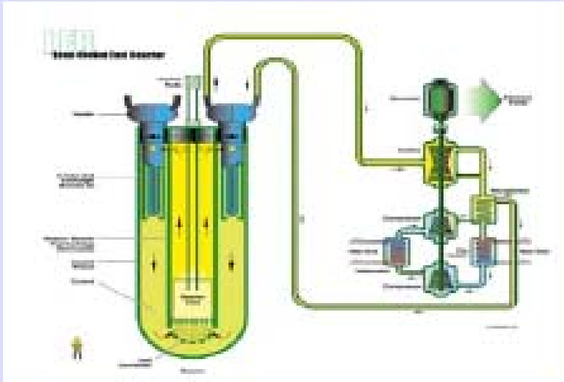
3 of the 6 « Gen 4 » concepts are Fast Breeder Reactors (FBR) based on U/Pu cycle

Na



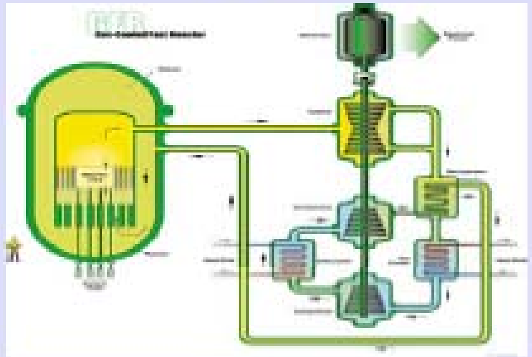
Technology avalaible but will remain complex

Pb

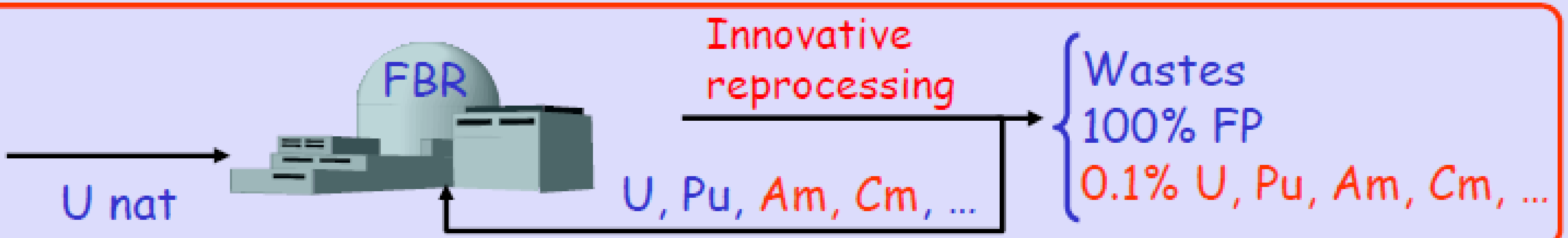


R&D needs :
Corrosion of structural material

He



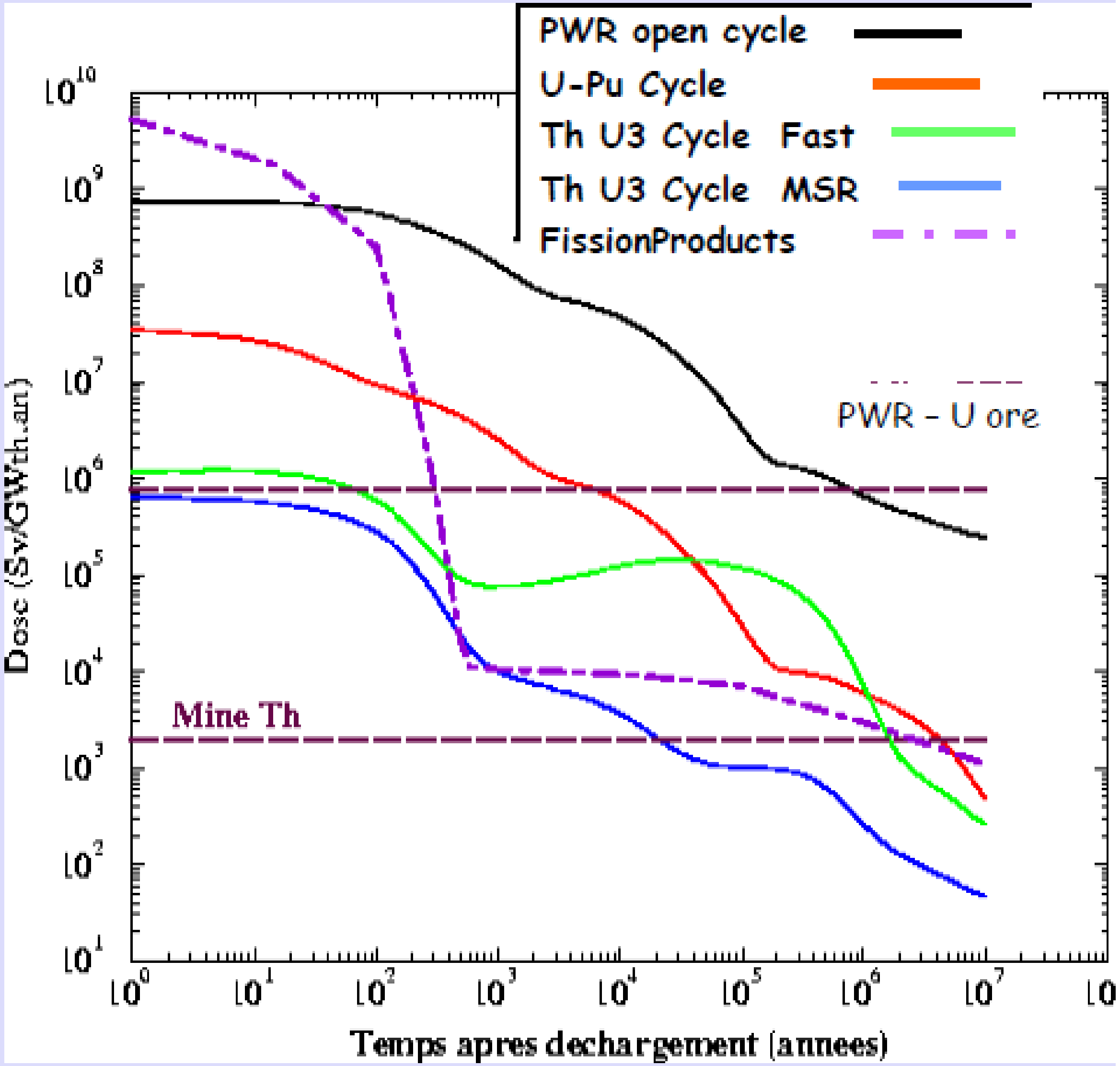
R&D needs :
Innovative fuel needed (high T, fast neutrons, …)

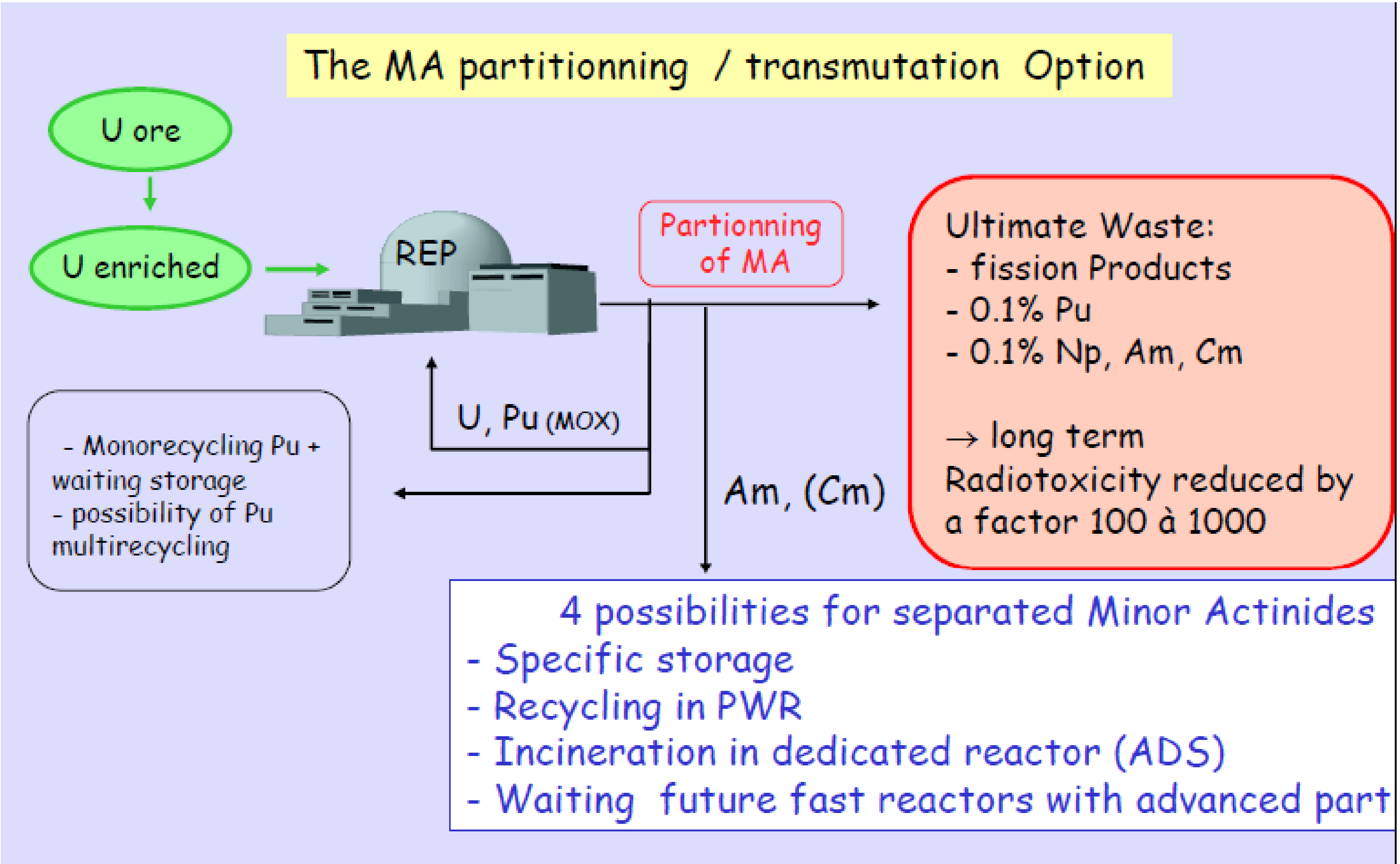


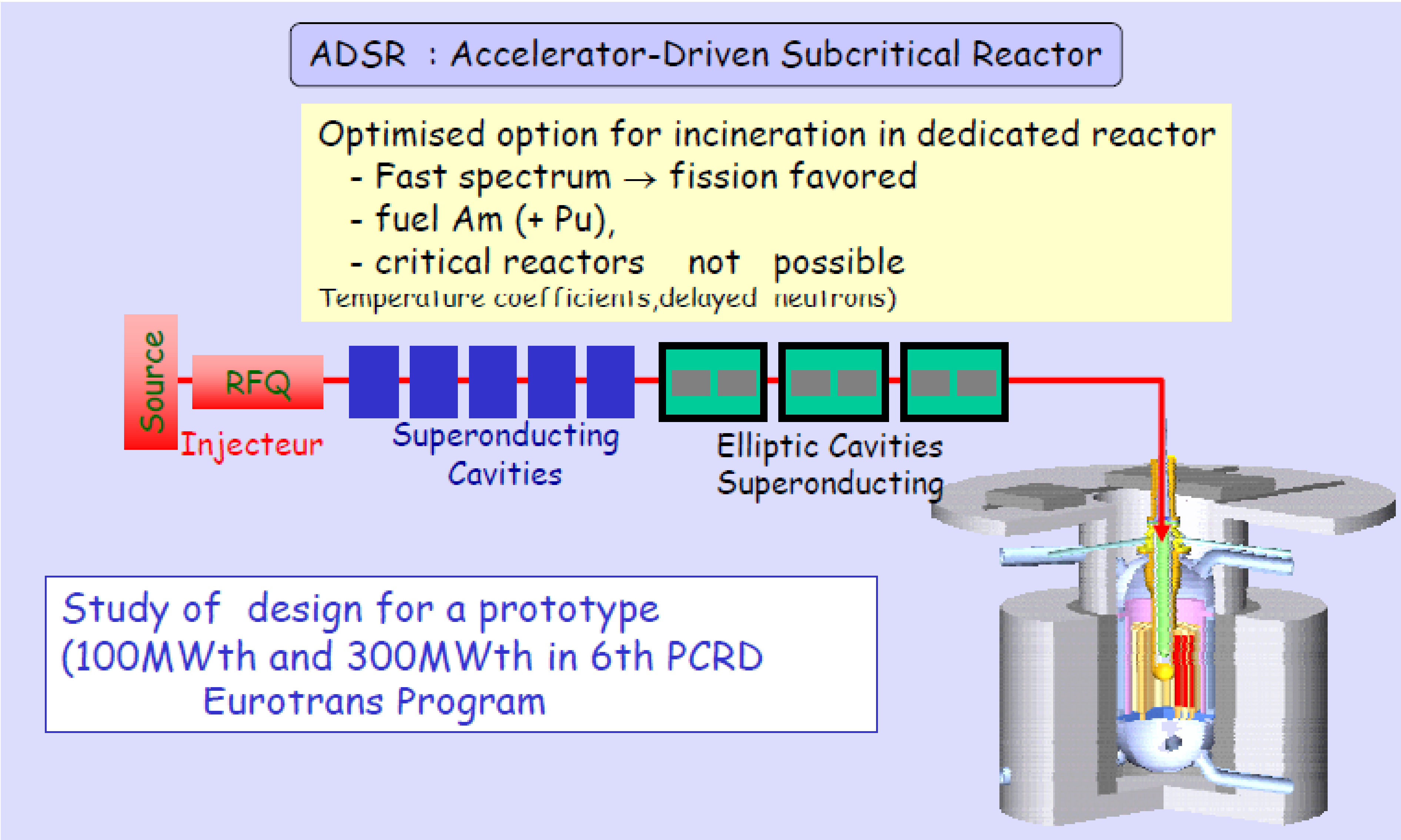
The total induced radiotoxicity depends strongly on the reprocessing efficiency (minimization of the actinides losses)

Wastes /GWe/y.

	FBR U/Pu	MSR Th/U
U	4kg	< 1 g
Pu	600 g	20 g
Am	200 g	1.3 g
Cm	50 g	5 g




The MA partitionning / transmutation Option
U ore
U enriched
REP
Partionning of MA
Ultimate Waste:
- fission Products
- 0.1% Pu
- 0.1% Np, Am, Cm
→ long term
Radiotoxicity reduced by a factor 100 à 1000
U, Pu (MOX)
- Monorecycling Pu + waiting storage
- possibility of Pu multirecycling
Am, (Cm)
4 possibilities for separated Minor Actinides
- Specific storage
- Recycling in PWR
- Incineration in dedicated reactor (ADS)
- Waiting future fast reactors with advanced part


ADSR : Accelerator-Driven Subcritical Reactor
Optimised option for incineration in dedicated reactor
- Fast spectrum → fission favored
- fuel Am (+ Pu),
- critical reactors not possible
Temperature coefficients,delayed neutrons)
Source
RFQ
Injecteur
Superonducting Cavities
Elliptic Cavities Superonducting
Study of design for a prototype
(100MWth and 300MWth in 6th PCRD
Eurotrans Program

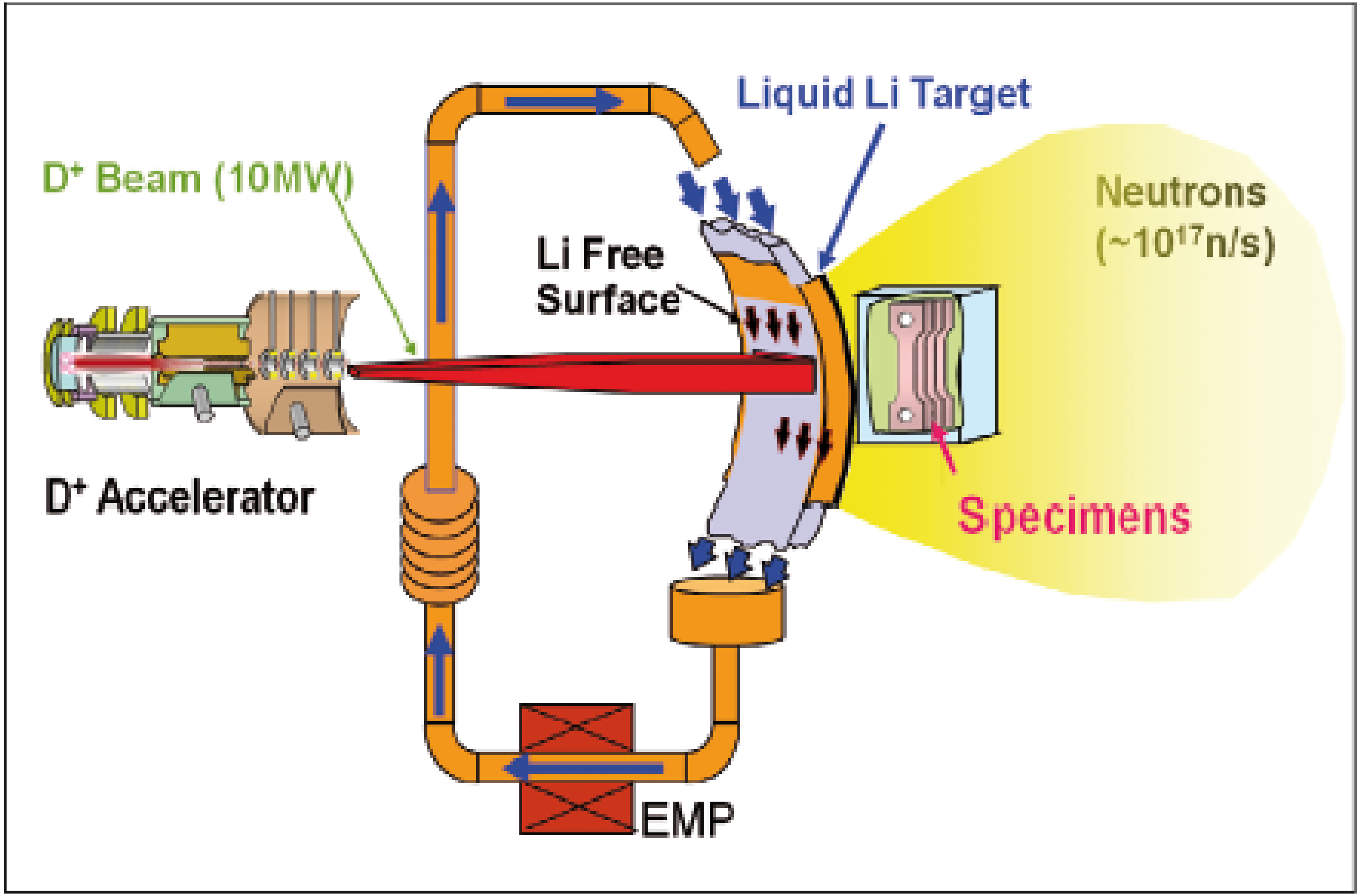


Figure 1. The IFMIF facility foreseen for testing materials for future fusion reactors.

Basic research

Hadron Physics

- How does the strong interaction confine quarks and gluons into hadrons?
- What precisely is the internal structure of hadrons in terms of fundamental quarks and gluon degrees of freedom?
- What is the role of quarks and self-interacting gluons in nuclei?

Phases of Strongly Interacting Matter

- What are the fundamental properties of strongly interacting matter as a function of temperature and density?
- How do hadrons acquire their mass and how is the mass modified by the medium they move in?
- What are the properties of the quark gluon plasma?
- Are there colour superconductors and highly dense gluonic objects in Nature?

Basic research

Nuclear Structure and Dynamics

- How can we describe the rich variety of low-energy structure and reactions of nuclei in terms of the fundamental interactions between individual particles?
- How can we predict the evolution of nuclear collective and single-particle properties as functions of mass, iso-spin, angular momentum and temperature?
- How do regular and simple patterns emerge in the structure of complex nuclei?
- What are the key variables governing the dynamics between colliding composite systems of nucleons?

Nuclear Astrophysics

- How and where are the elements made?
- Can we recreate on Earth, and understand, the critical reactions that drive the energy generation and the associated synthesis of new elements in the stars.
- What are the properties of dense matter in a hypercompact object such as a neutron star or a quark star?
- How does the fate of a star depend on the nuclear reactions that control its evolution?

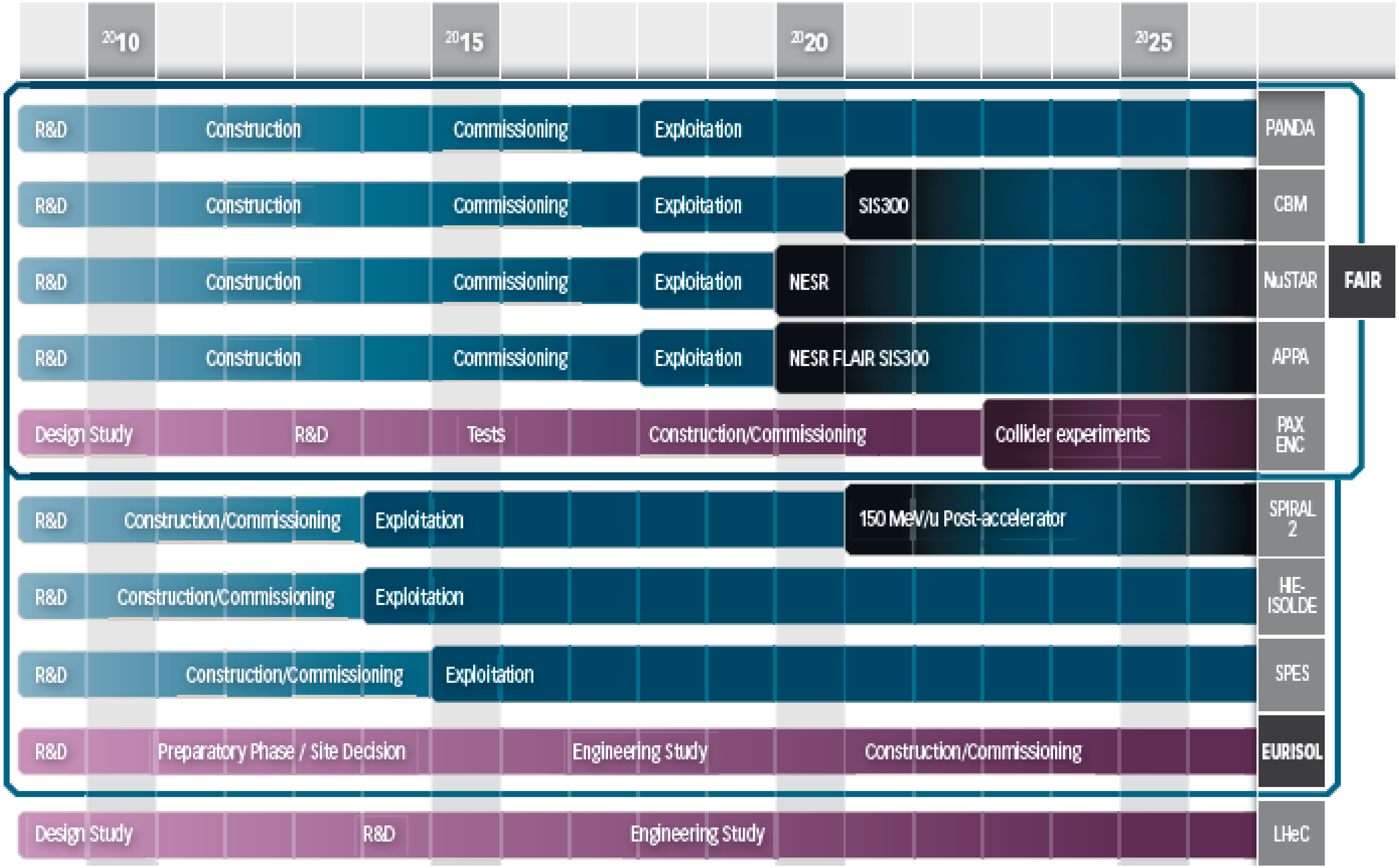
Fundamental Interactions

- What is the origin of the matter dominance in the universe?
- What are the properties of neutrinos and of antimatter?
- Are there other than the four known fundamental forces?
- What are the precise values of the fundamental constants?
- Which fundamental symmetries are conserved in nature?

Nuclear Physics Tools and Applications

- How can Nuclear Physics contribute to the sustainability and acceptability of the generation of nuclear energy?
- How can Nuclear Physics techniques improve medical diagnostics and contribute to cancer therapy?
- How can radiation hazards in Space be monitored and predicted?
- Can Nuclear Physics help understand and monitor climate change?
- Can neutrinos be used as a probe for non-proliferation control?
- Can Nuclear Physics help to visualize the dynamics of ion-beam processes when other methods fail?
- How can non-destructive and in-depth analysis of elements in materials samples be improved?

Facilities Roadmap



ISOLDE at CERN, Geneva, Switzerland

Present experiments mainly deal with nuclear structure questions, explored via measurements of ground state properties (mass, radii, moments), via decay studies or Coulomb excitation and transfer reaction studies at low energy. A sizeable part of the programme is devoted to other fields, such as nuclear astrophysics, and fundamental physics. Close to 20% the beam time is devoted to solid state physics and life sciences with broad societal benefits.

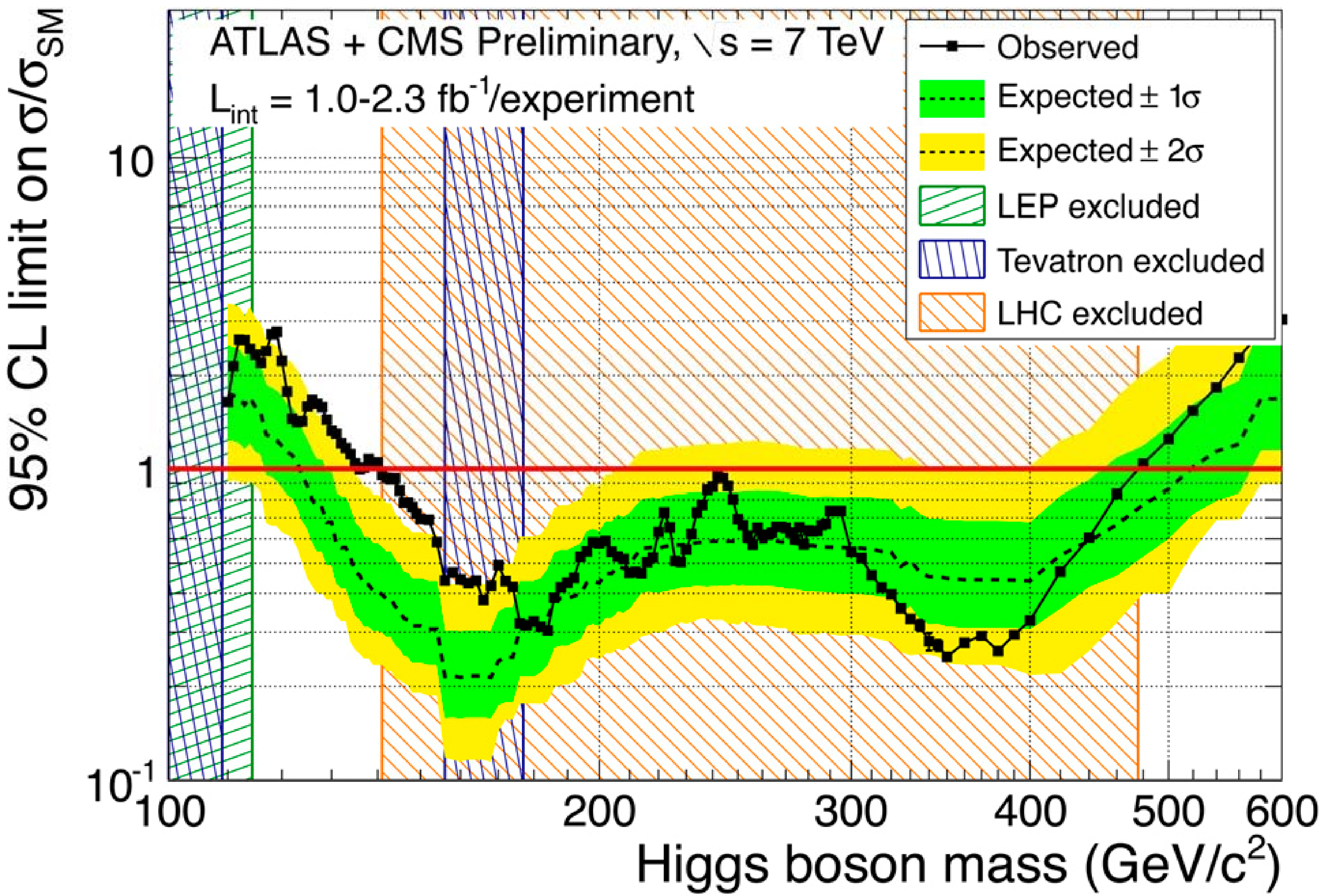
New instrumentation being currently installed includes a beta-NMR platform for nuclear and solid state physics with polarised radionuclides and a new laser spectroscopy set-up CRIS for low intensity bunched beams.

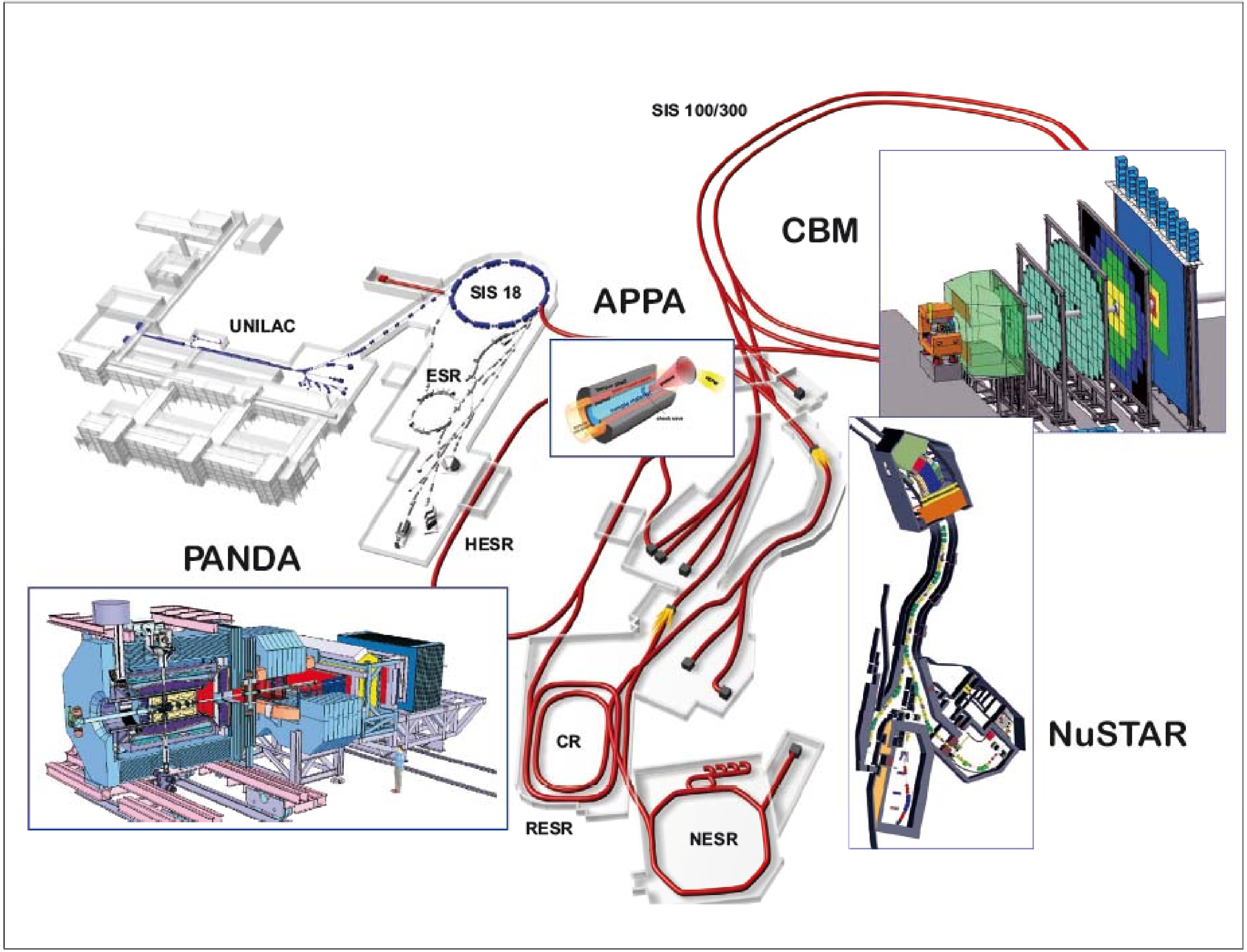
ALICE at CERN, Geneva, Switzerland

The ALICE Collaboration (31 countries, 111 institutes and over 1 000 collaborators) has built at CERN a dedicated multi-purpose heavy-ion detector to exploit the unique physics potential of nucleus-nucleus interactions at Large Hadron Collider (LHC) energies. It is the largest nuclear physics experiment in the world.

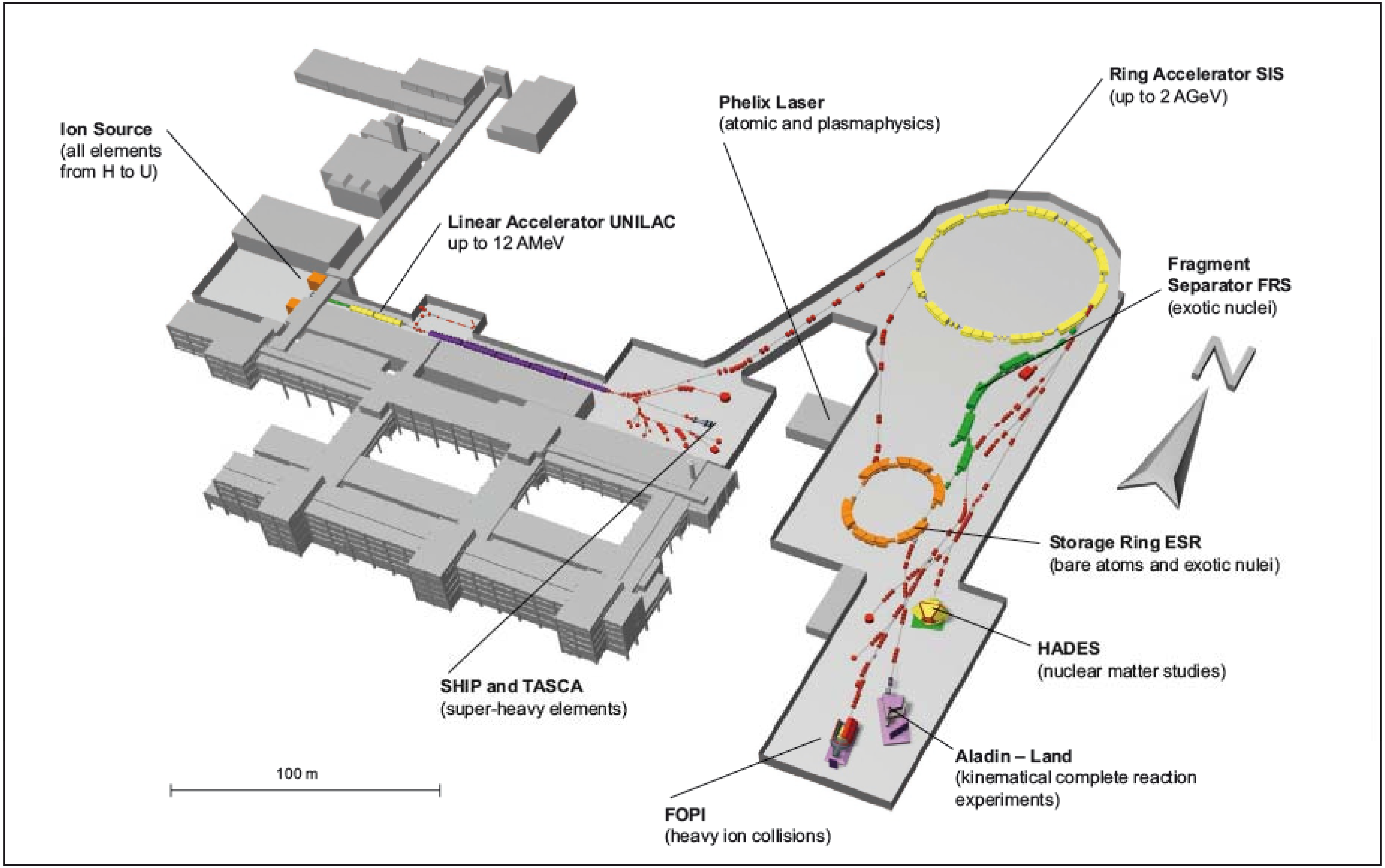
ALICE has initiated a vigorous and ambitious upgrade programme to enlarge the capabilities of this unique detector facility and its physics reach. These involve increasing the capabilities for tracking and particle identification (already a particular strength of ALICE as compared to other LHC detectors) and for jet reconstruction, and starting low-x physics measurements at high rapidity for studies of the Colour Glass Condensate.

ATLAS experiment at CERN





The FAIR accelerator/storage ring complex and the large experiments APPA, CBM, NuSTAR (including the Super-FRS) and PANDA (at the antiproton accelerator/storage ring HESR). GSI's UNILAC and SIS18 will serve as injectors into the SIS100/300 synchrotrons. Antiprotons or radioactive isotopes will be collected in CR, accumulated in RESR and accelerated or decelerated and stored in HESR and NESR.



Layout of the existing GSI facility with the UNILAC linear accelerator, the heavy-ion synchrotron SIS18, the fragment separator FRS, the experimental storage ring ESR, and various target areas (see text).

Neutrinoless double **β** decay

Establishing whether neutrinos are Dirac fermions (different from their antiparticle) or Majorana fermions (spin ½ particles identical to their antiparticles) is of paramount importance for understanding the underlying symmetries of particle interactions and the origin of neutrino masses. The only practical way to test whether neutrinos are Majorana particles is to search for neutrinoless double β decay ($0\nu\beta\beta$).

Name	Nucleus	Mass*	Method	Location		Expected start date	Expected final sensitivity (eV)
CUORE	^{130}Te	200 kg	Bolometric	LNGS	EU	2012	0.05–0.10
EXO-200	^{136}Xe	160 kg	Liquid TPC	WIPP	USA	2010	0.13–0.19
GERDA	^{76}Ge	35 kg	Ionization	LNGS	EU	2010	0.08–0.13
LUCIFER	^{82}Se	18 kg	Bolometric	LNGS	EU	2014	0.05-0.07
MAJORANA	^{76}Ge	30 kg	Ionization	DUSL	USA	2013	0.08–0.13
NEXT	^{136}Xe	100 kg	Gas TPC	LSC	EU	2013	u.e.
SNO+	^{150}Nd	40 kg	Scintillation	SNOlab	CAN	2011	0.1
SuperNEMO	^{82}Se or ^{150}Nd	100 kg	Tracking, calorimetry	LSM	EU	2013	0.04–0.15

Peace cannot be kept by force, it can only be achieved by understanding

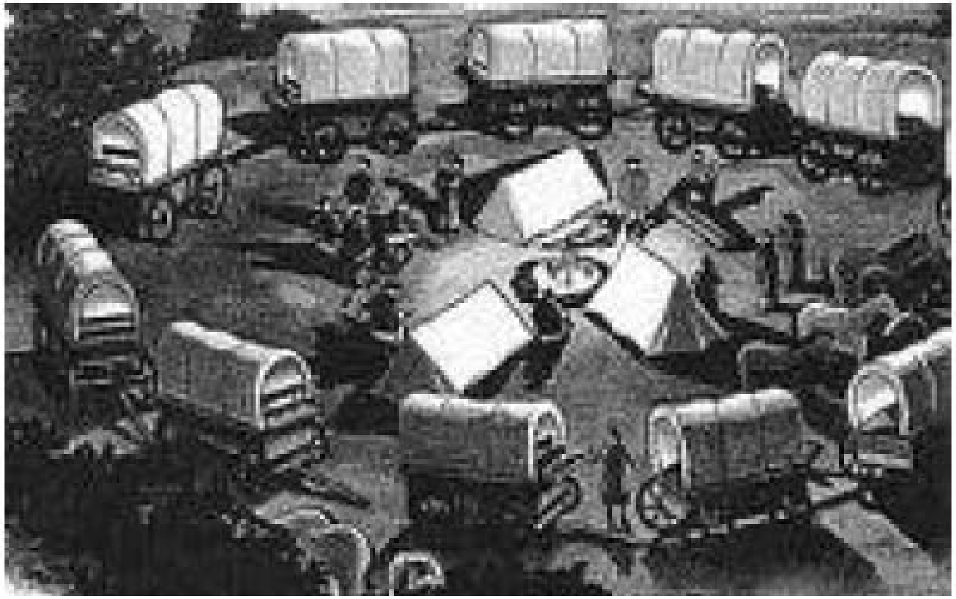
Albert Einstein

Force always attracts men of low morality

Albert Einstein

Translation:

- Keep doing the compelling science that got us here
- Keep demonstrating excellence in every thing we do (science, construction projects, R&D, outreach)
- Keep spreading the word (importance, relevance, value)



Also: previous experience shows
in challenging times it is very
Important to point the guns
In the right way direction
when the wagons are circled

As the Chinese proverb says:

A great tide floats all boats

Intellectual growth should commence at birth and cease at death.

Albert Einstein

In my experience, the best creative work is never done when one is unhappy.

Albert Einstein