Rewriting Nuclear Physics textbooks

one more step forward

Pisa (Italy), July 22nd – 26th, 2019

Program

- Nicolas Alamanos (IRFU-CEA-Saclay): Introduction to modern Nuclear Physics.
- Shawn Bishop (TUM, Munich): Reach for the stars by digging in the dirt.
- Luciano Canton (INFN, Padova) - Andrea Fontana (INFN-Pavia): Nuclear Physics applied to the production of Innovative Radio-Pharmaceuticals.
- G.A.P Cirrone (INFN-LNS, Catania): Hadron therapy: from the conventional approach to laser-driven applications.
- Maria Elena Fedi (INFN-LABEC, Firenze): How a small accelerator can be useful for interdisciplinary applications. Part II: cultural heritage studies.
- Paolo Finocchiaro (INFN-LNS, Catania): From nuclear physics to applications: new detectors for radioactive waste monitoring.
- Andreas Knecht (PSI, Zurich): Study of nuclear properties with muonic atoms.
- Franco Lucarelli (LABEC, Firenze): How a small accelerator can be useful for interdisciplinary applications. Part I: the study of air pollution.
- Miguel Marques (LPC, Caen): The extremes of neutron richness.
- Sandra Moretto (Padova University): Neutron Technique in civil security applications.
- Nicholas van der Meulen (PSI, Zurich): Radionuclides for nuclear medicine: the triumphs and challenges.
- Oliver Zimmer (ILL, Grenoble): Pedestrian neutrons - tool and object for fundamental physics.

Friday afternoon 26th July, visit to LABEC, Florence

Local Organizing Committee

Ignazio Bombaci, University of Pisa
Angela Bonaccorso, INFN - Pisa (co-chair)
Giovanni Casini, INFN - Firenze (co-chair)
Maria Agnese Ciocci, University of Pisa
Alejandro Kievsky, INFN - Pisa
Domenico Logoteta, University of Pisa
Laura Elisa Marcucci, University of Pisa
Valeria Rosso, University of Pisa
Michele Viviani, INFN - Pisa

SUMMER SCHOOL UNIVERSITÀ DI PISA — INFN PISA Istituto Nazionale di Fisica Nucleare Sezione di Pisa — EPJ .org your physics journal — Irfu

Lucia Lilli and Claudia Tofani, INFN, Pisa (Secretaries)

DE LA RECHERCHE À L'INDUSTRIE

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The 2019 School follows the 2017 and 2015 editions that were dedicated to the progress made on the understanding of the basic nuclear interactions and their link to nuclear processes in the cosmos and on earth and by Low Energy Nuclear Physics with Radioactive Beams during the last thirty years.

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DE LA RECHERCHE À L'INDUSTRIE

The third edition of the PISA Scholl

"Rewriting Nuclear Physics Textbooks"

is focused on

Part 1. Few selected Topics

And on

Part 2. Medical and Societal Applications

DE LA RECHERCHE À L'INDUSTRIE

Rewriting Nuclear Physics Textbooks: one more step forward

Part 1. Selected Topics

Taking as unifying picture : The cosmological model

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Part 1. Selected topics - The unifying picture : The cosmological model

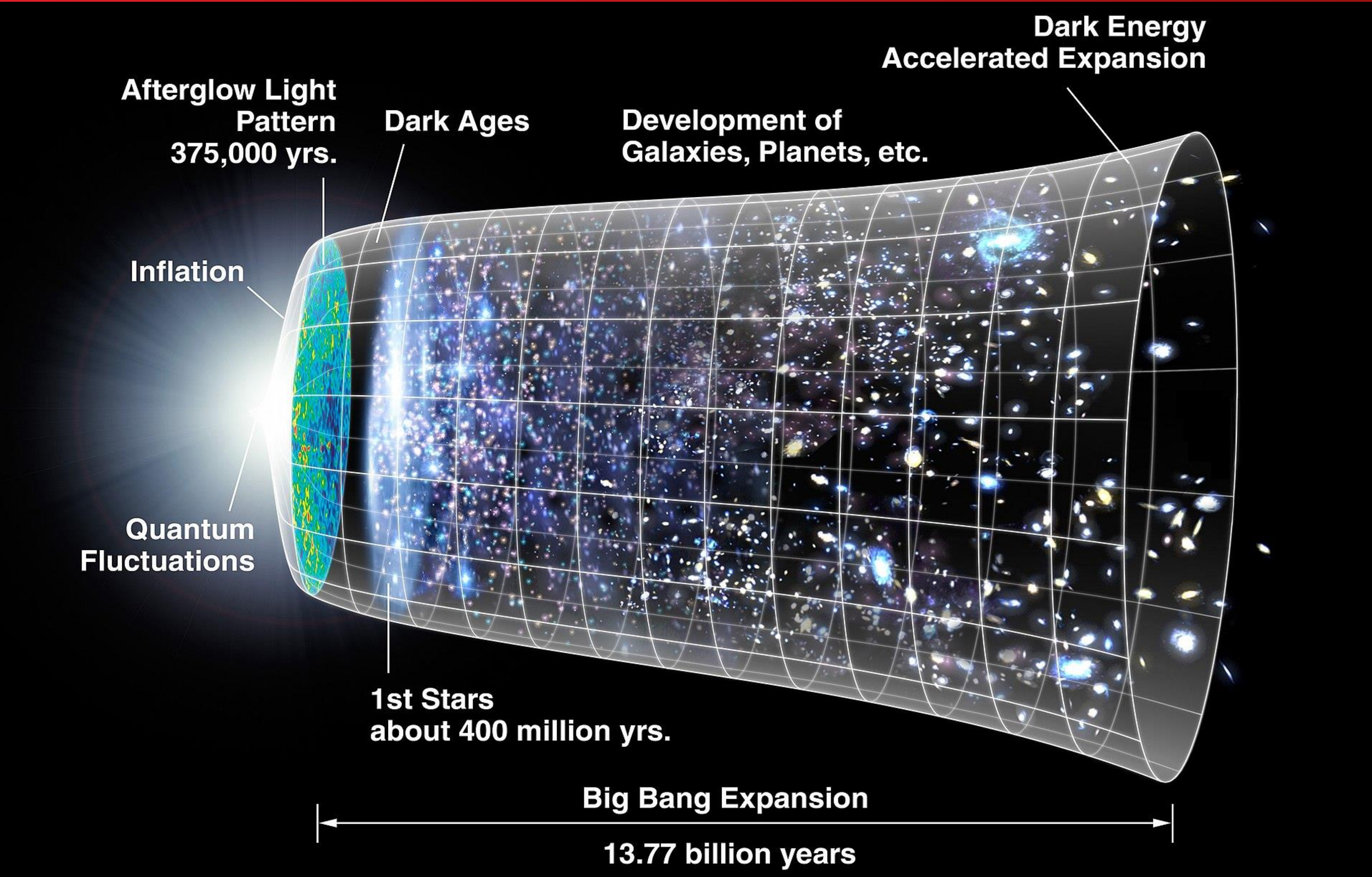
a) Pedestrian neutrons - tool and object for fundamental physics

b) Study of nuclear properties with muonic atoms

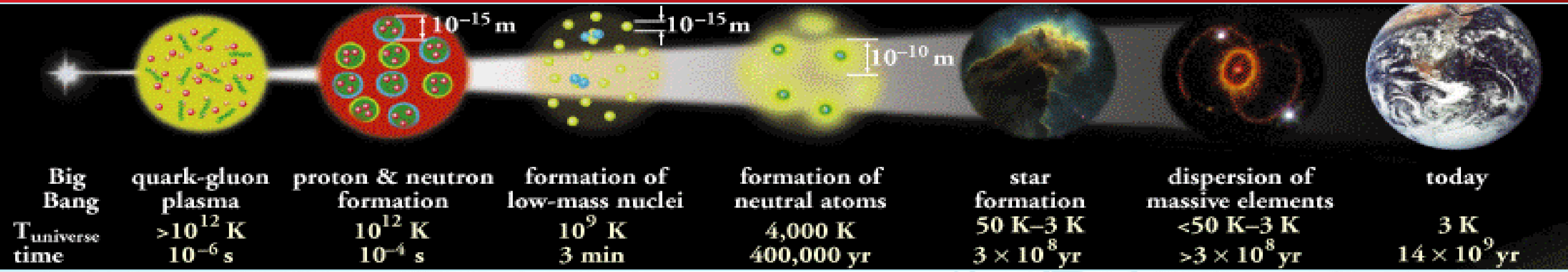
c) Reach for the stars by digging in the dirt

d) The extremes of neutron richness

The cosmological model



Nuclear physics at the electroweak-era



At the beginning, 13.7 billion years ago, there was the Big Bang

Up to 10^{-6} seconds: The electroweak-era.

The universe is composed of a plasma of quarks and gluons at a temperature of a thousand billion of degrees.

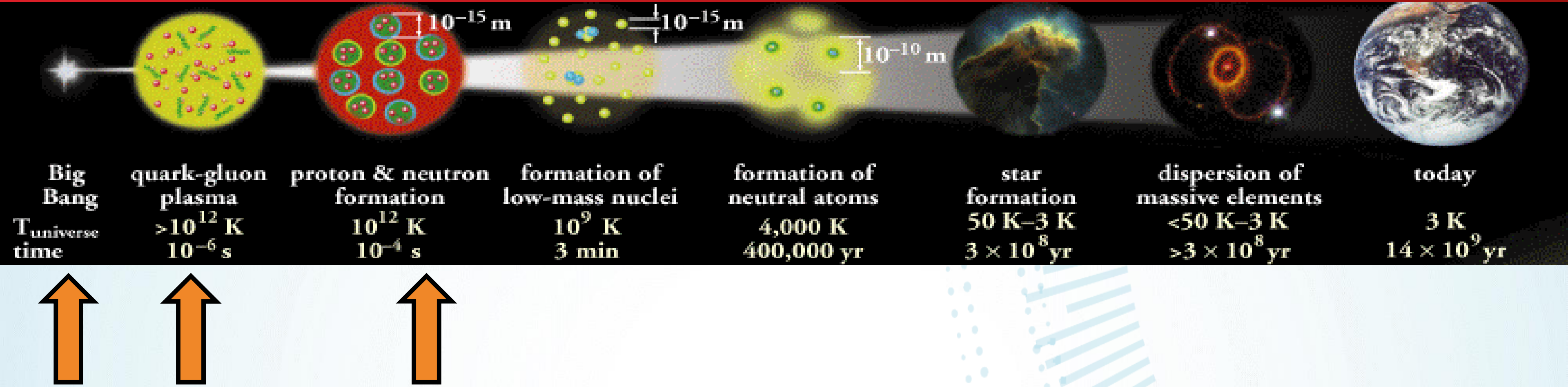
Because of this high temperature, quarks cannot bind to form mesons and baryons. The universe is filled up with a soup of elementary particles including photons, neutrinos, electrons, gluons, quarks.

Study of hot and dense baryonic matter

The experimental approach to study "this phase of the universe" made by a strongly interacting matter at very high temperatures involves collisions of hadrons at very high energy. The target energy is 4 to 11 GeV at the center of mass.

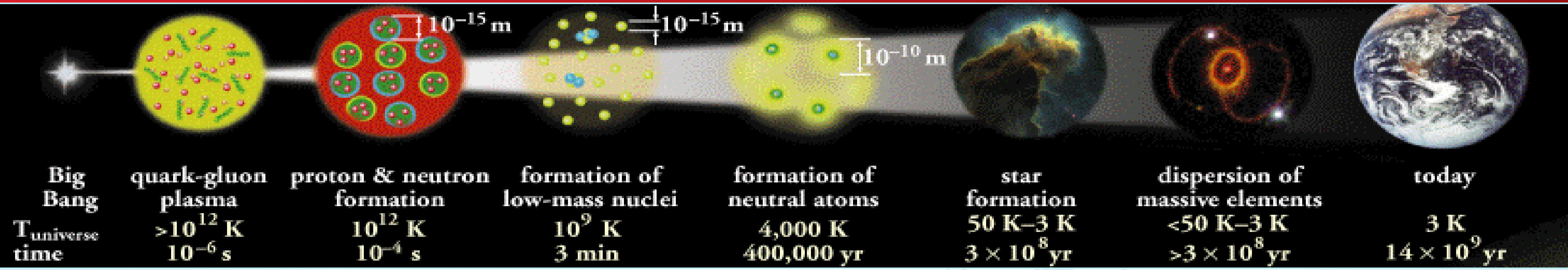
To summarize …. after 30 years of research with five accelerators, RHIC at Brookhaven, which started operating in 2000, has discovered a new state of matter (QGP). The matter is an almost "perfect" liquid of quarks and gluons with a shear viscosity-to-entropy density ratio near the quantum limit. The ALICE experiment at CERN started in 2010 and re-discovered this new state of matter.

From 10^{-6} seconds to 1 second, the hadronic era



From 10^{-6} seconds to 1 second, the hadronic era. The quarks are confined. They form baryons and mesons. Studying the internal structure of protons and neutrons is an essential step in understanding in a detailed way how the nuclear force, the one that binds protons and neutrons, emerges from QCD?

Cosmological model and Nuclear Physics



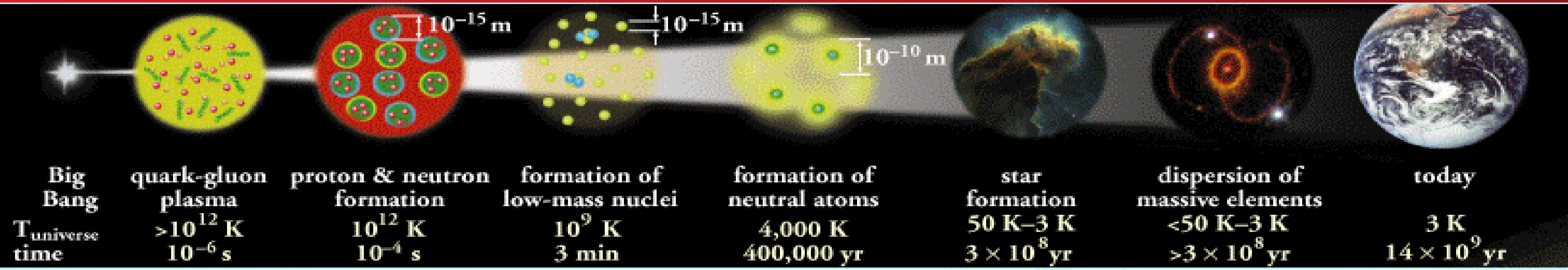
Among the fundamental questions ?

The question of confinement why free quarks have never been observed ?

The question concerning the origin of the mass and of the spin of the nucleons ?

The Higgs mechanism provides mass to the mediators of the weak interaction, to the quarks and to the leptons. But the quarks contribute very little to the mass of the nucleons, which provide the mass of the universe.

The Cosmological Model and N.Φ. The era of primordial nucleosynthesis: from 1 sec to 3 min



Protons and neutrons bind to form the first nuclei. They will interact via the reaction, $n + p \rightarrow d + \gamma + 2.226$MeV to create deuterons.

The universe is now composed essentially of protons up to ~75% and alpha particles up to ~25% as well as deuterons, ^{3}He and traces of ^{6}Li and ^{7}Li. A real bottleneck!!!!!

Part 1. Selected topics - The unifying picture : The cosmological model

a) Pedestrian neutrons - tool and object for fundamental physics

b) Study of nuclear properties with muonic atoms

c) Reach for the stars by digging in the dirt

d) The extremes of neutron richness

What do we know about the properties of the neutrons ?

Within the nucleus, protons and neutrons are bound together by the nuclear force. Outside the nucleus, free neutrons are unstable and have a mean lifetime of about ~14 minutes.

The neutrons decay into protons via the interaction: $n \rightarrow p + e^- + \bar{\nu}_e$

i) The decay into protons ($n \rightarrow p + e^- + \bar{\nu}_e$) tell us how atomic nuclei were created after the Big Bang.

ii) The lifetime of the neutron determines the primordial abundances of the light chemical elements after the big bang.

What do we know about the properties of the neutrons ?

Two main types of neutron lifetime measurements exist.

i) One type of estimate is made with a beam of neutrons

ii) The second involves trapping neutrons in a "bottle" and counting how many neutrons remain after some time.

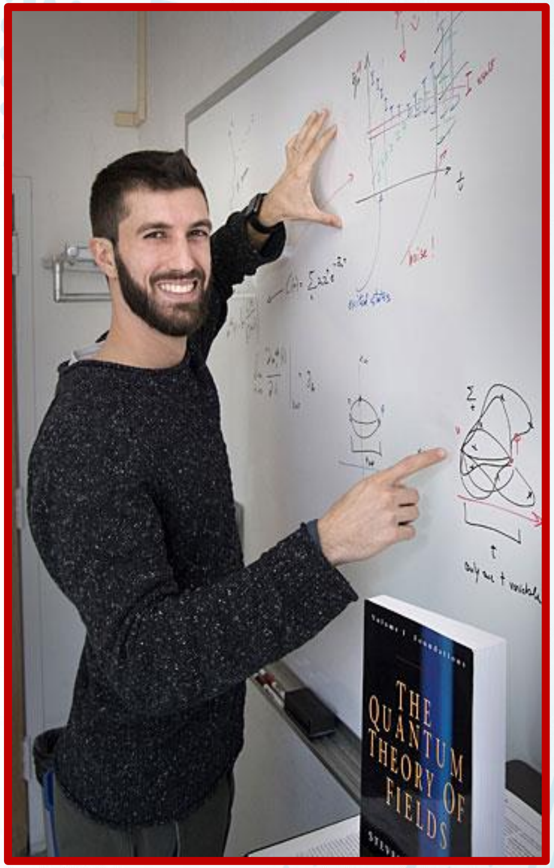
The first technique finds a lifetime about nine seconds longer than the second

What do we know about the properties of the neutrons ?

The actual theoretical value for the neutron lifetime is of:

14 minutes and 40 seconds with an error bar of 14 seconds. That is right in the middle of the values measured by the two types of experiments.

More powerful supercomputers, will drive the uncertainty margin down to about 0.3 percent.



May 30, 2018 - Enrico Rinaldi, at BNL post-doc involved in the new calculation determining neutron's lifetime.

Some thoughts on the properties of the neutrons.

While the neutron lifetime has been studied for decades, currently exists a lack of consilience on its exact value…..It is important to clarify the situation.

The search for a non-vanishing electric dipole moment of the neutron is another hot topic in this domain. The Standard Model predicts a tiny separation of positive and negative charge within the neutron leading to a permanent electric dipole moment. Currently, there are at least four experiments trying to measure the value of finite neutron electric dipole moment. Physics beyond the standard model ?

Lecture by: Oliver Zimmer

Oliver Zimmer: Pedestrian neutrons - tool and object for fundamental physics

Free neutrons moving at pedestrian speed, also called Ultra-Cold Neutrons (UCNs), have low enough energy to become confined and manipulated in traps. Being electrically neutral but being affected by all known fundamental forces they are an excellent probe to study fundamental symmetries and interactions…..Although started more than 50 years ago, the search for a non-vanishing electric dipole moment of the neutron is currently a hot topic …… Also the neutron lifetime is a key observable investigated with UCNs. It determines the primordial abundances of the light chemical elements after the big bang and is still astonishingly poorly known…….

a) Pedestrian neutrons - tool and object for fundamental physics

b) Study of nuclear properties with muonic atoms

c) Reach for the stars by digging in the dirt

d) The extremes of neutron richness

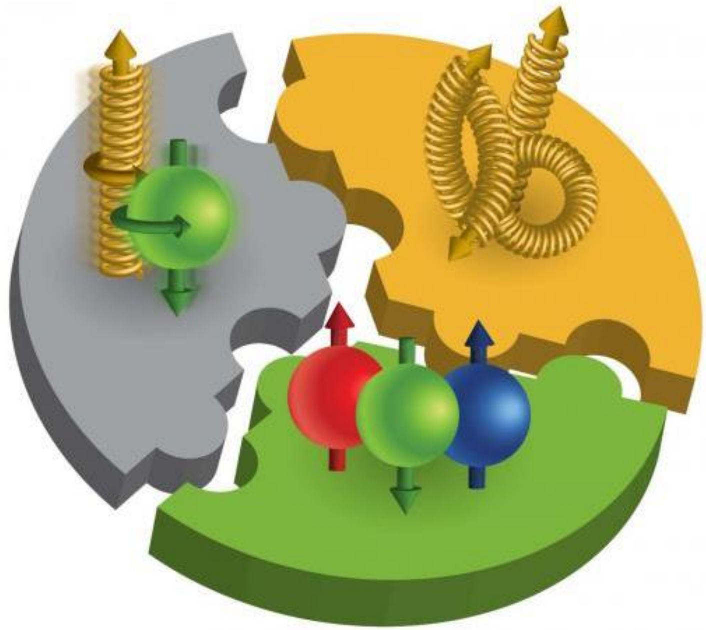
What do we know about the properties of the protons ?

How do the quarks and gluons carry the spin of protons? Physicists were expecting that the quarks carry all the proton spin. However, the European Muon Collaboration experiment (EMC 1987), has shown that only a very tiny fraction of the total proton spin was carried by quarks.

This surprising and puzzling result was termed as the "proton spin crisis".

An Example: The proton spin crisis

IFMIF



IUPAP Updated 2018, Hadronic Nuclear Physics Cédric Lorcé

How different constituents of the proton contribute to its spin, a fundamental property that plays a role in how these building blocks give rise to nearly all visible matter in the universe. Pieces of the puzzle include the orbital angular momentum of quarks and gluons (top left), gluon spin (top right) and quark and antiquark spin (bottom). The latest data from RHIC reveal that the antiquarks' contribution is more complex than previously thought.

What do we know about the properties of the protons ?

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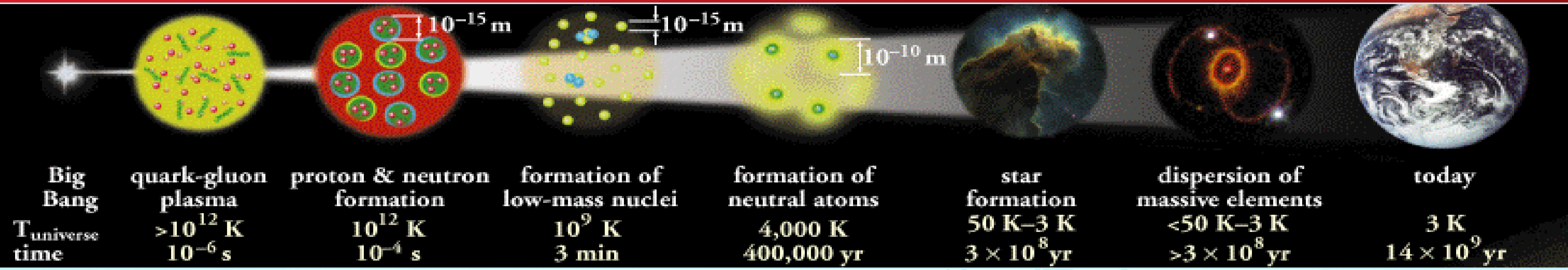
What is the value of the electric mean-square charge radius of the proton? The experiments measuring the proton radius converged to a value of 0.879±0.008 fm. This value was recently challenged by experiments utilizing line-splitting measurements in laser spectroscopy of muonic hydrogen. The obtained radius is 0:841±0:001. A discrepancy as large as 5 standard deviations. *The discrepancy termed as "The proton radius puzzle" remains unresolved, and is a topic of active ongoing research.*

Proposal for Measurements at the CERN SPS 2022-2024

Knecht Andreas: Study of nuclear properties with muonic atoms

Muonic atoms as laboratories for fundamental physics provide crucial input to quantum electrodynamics, the weak interaction and the strong interaction. Muonic atoms spectroscopy, i.e. the detection of the muonic X-rays emitted subsequently to the atomic capture of a negative muon, has been a very extensively used technique to determine the extent of the nuclear charge distribution…. Other properties such as its quadrupole moment can be extracted as well…… It will conclude with a description of the muX experiment where we aim to perform muonic atom spectroscopy with targets available only in microgram quantities such as the highly radioactive Ra-226 isotope.

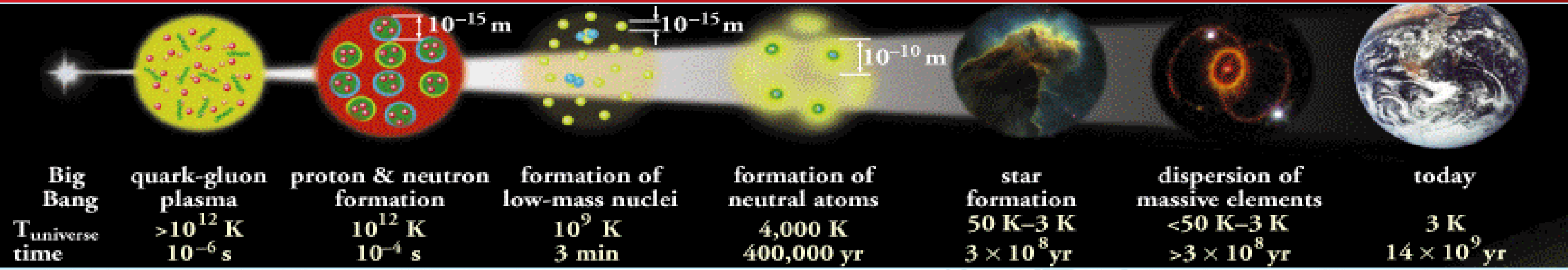
The Cosmological Model and N.Φ. From a million years after the Big Bang until today.



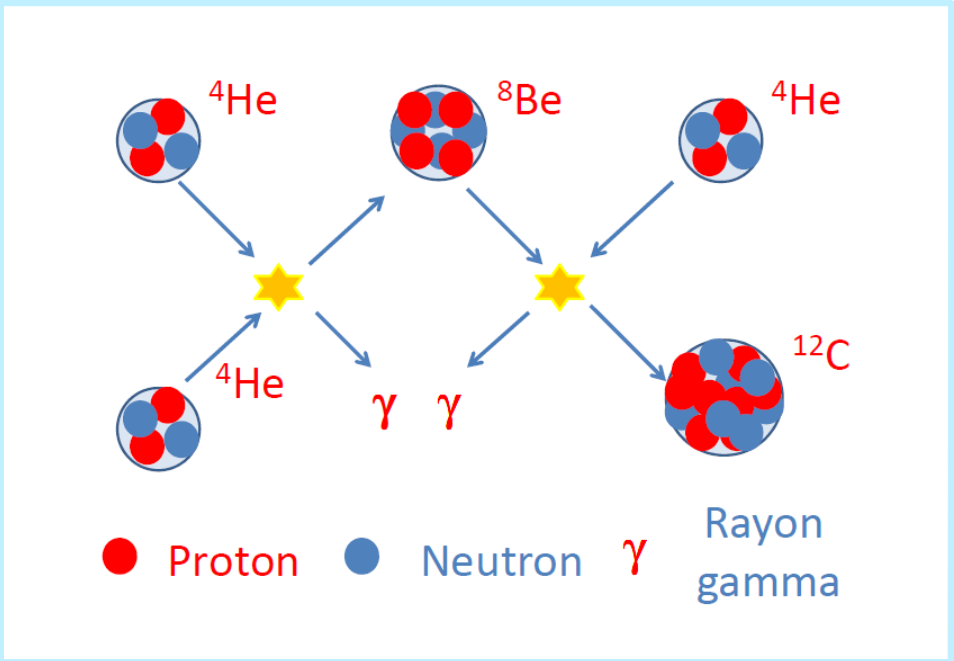
The clusters of matter form stars and proto-galaxies. Stars begin to synthesize heavier nuclei.

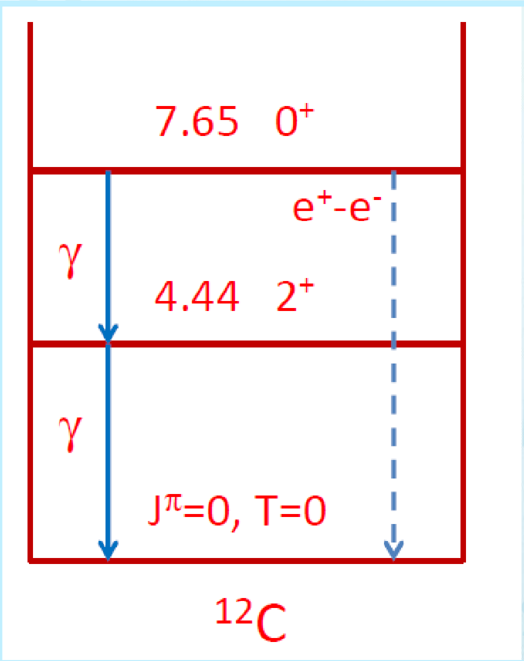
By what ingenuity does nature bypass the "bottleneck" of the primordial nucleosynthesis, (The universe is now composed essentially of protons up to ~75% and alpha particles up to ~25% as well as deuterons, ^{3}He and traces of ^{6}Li and ^{7}Li), to form nuclei like ^{12}C and then even heavier elements?

The Cosmological Model and N.Φ. From a million years after the Big Bang until today.



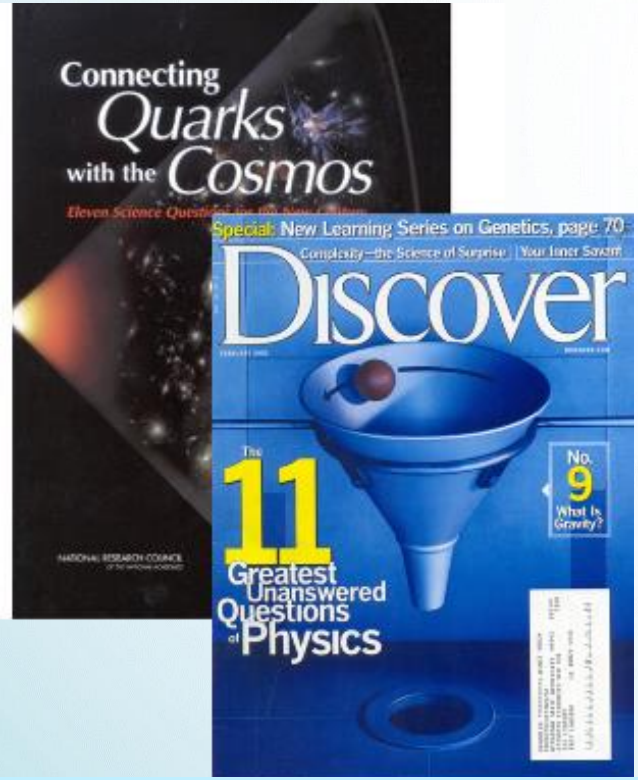
Sir Fred Hoyle

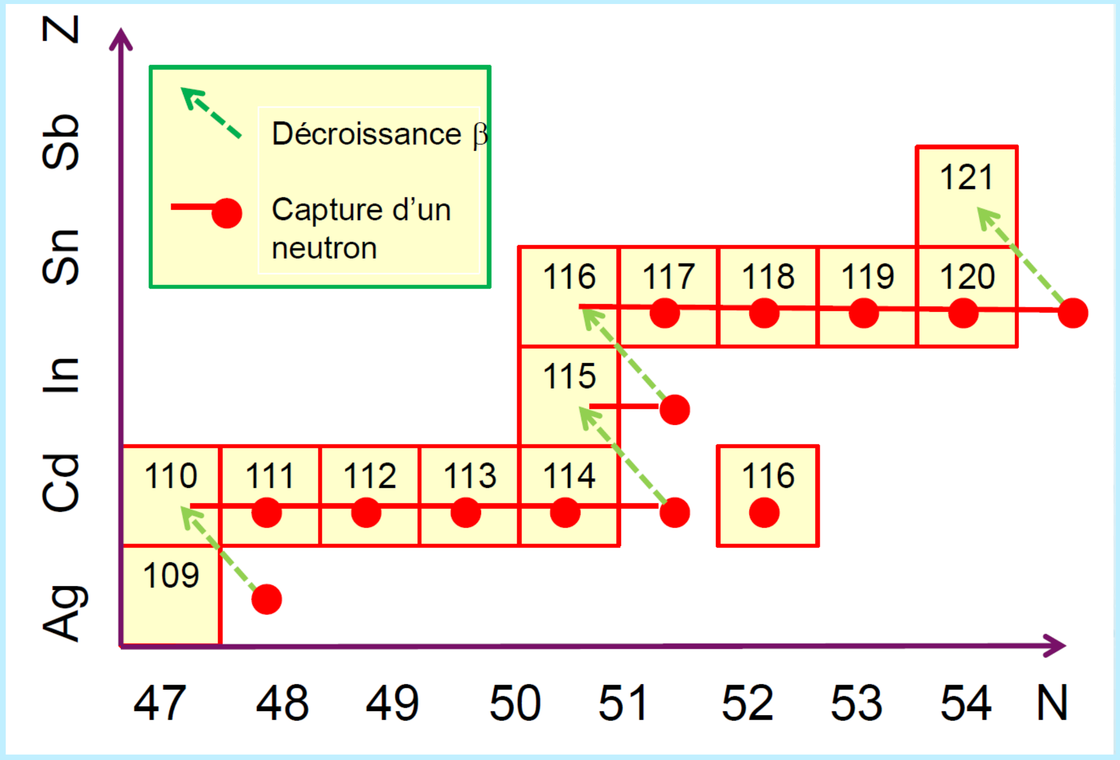




Neutron-capture process leading to elements heavier than iron

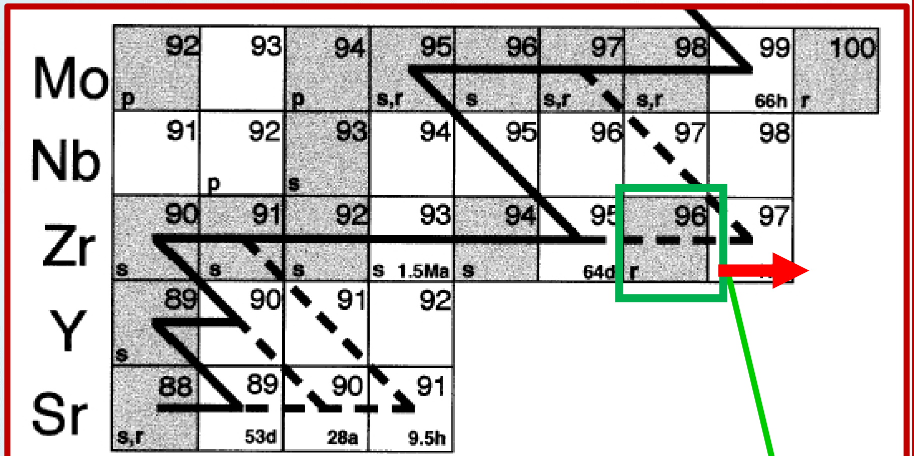
If fusion reactions are inefficient in producing elements heavier than Iron. Where and how these heavy elements are produced in the universe? This is one of the important Scientific Questions for the 21st century

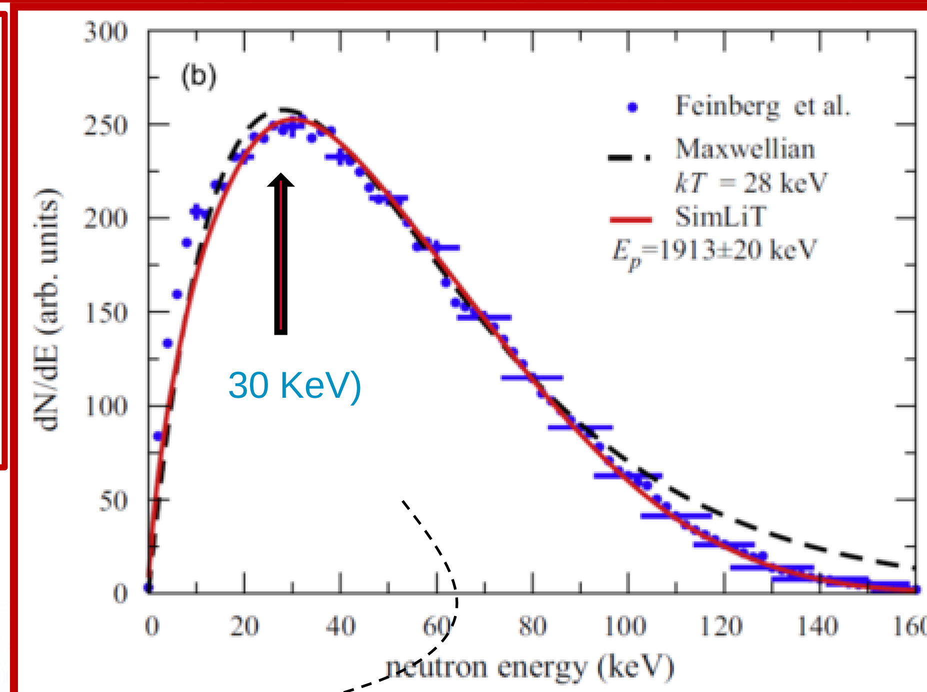




An example: Lab Mimicking stellar nucleo-synthesis with a high-power liquid-lithium target

A 30 KeV quasi-Maxwellian neutron spectrum,

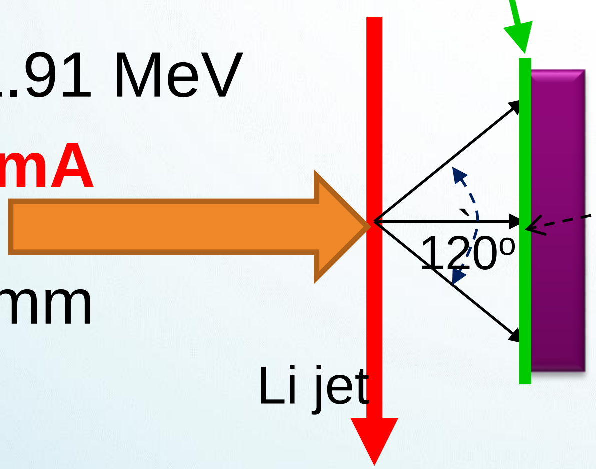




p @ 1.91 MeV

I ~ 2 mA

σ = 2 mm



A 30 KeV quasi-Maxwellian neutron spectrum, with an intensity of 3-5 x10^{11}n/s More than a factor 10 than present ^{7}Li(p,n) neutron sources

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The ^{60}Fe story - nucleosynthesis-clock isotope in galactic cosmic rays

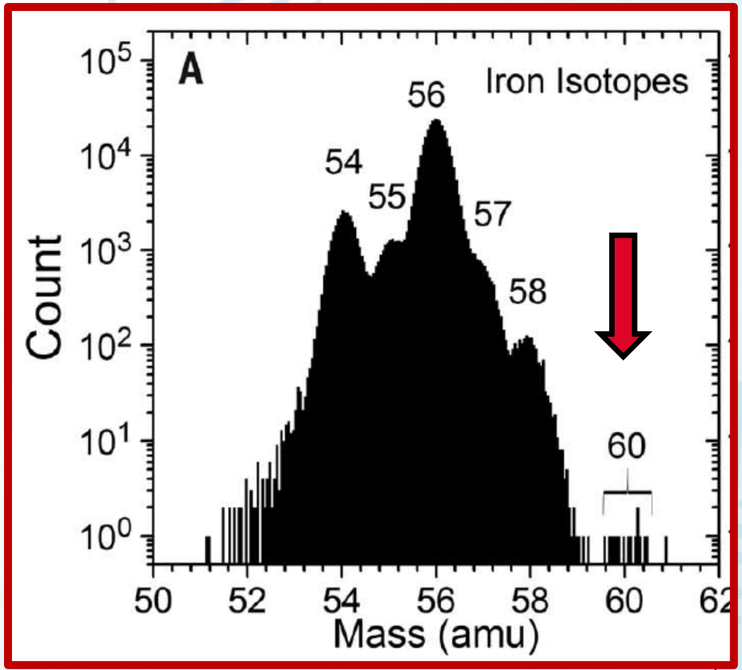
Signature of recent nucleosynthesis: The radioactive isotope ^{60}Fe is expected to be synthesized in core-collapse supernovae of massive stars with mass M > ~10 solar masses and ejected into space by supernovae, and thus be present in galactic cosmic rays near Earth, depending upon the time elapsed since nucleosynthesis and the distance of the supernovae.

It is the only primary radioactive isotope with atomic number Z ≤ 30 produced with a half-life long enough (2,62x10^6 years) to potentially survive the time interval between nucleosynthesis and detection at Earth.

The ^{60}Fe story - nucleosynthesis-clock isotope in galactic cosmic rays

Deep-sea manganese crusts have been found to harbor elevated ^{60}Fe levels in all major oceans of the world . Analysis of crust layers using accelerator mass spectrometry showed significant increases in the ^{60}Fe/Fe ratio 2.8 million years (My) ago.

It was also detected in lunar samples and in cosmic rays after a long period of data collection (17 years) achieved by the Cosmic Ray Isotope Spectrometer (CRIS) aboard NASA's Advanced Composition Explorer (ACE) space mission.



The ^{60}Fe story - nucleosynthesis-clock isotope in galactic cosmic rays

The present results reveal ^{60}Fe interstellar influxes onto Earth at 1.5–3.2 million years ago and at 6.5–8.7 million years ago.

Therefore, recent findings indicate multiple supernova and massive-star events during the last ten million years at distances of up to to 326 light-years

Interestingly, the older event coincides with a strong increase in ^{3}He and temperature change at about 8 Myr ago, while the more recent activity starting about 3 Myr ago occurred at the same time as Earth's temperature started to decrease during the Plio–Pleistocene transition (a period during which the Northern Hemisphere has been glaciated).

Shawn Bishop : Reach for the stars by digging in the dirt

Massive stars, which terminate their evolution in a cataclysmic explosion called a type-II supernova, are the nuclear engines of galactic nucleosynthesis. Among the elemental species known to be produced in these stars, the radioisotope ^{60}Fe stands out:

This radioisotope has no natural, terrestrial production mechanisms; thus, a detection of ^{60}Fe atoms within terrestrial reservoirs is proof for the direct deposition of supernova material within our solar system. We report, in this work, the direct detection of live ^{60}Fe atoms in biologically produced nanocrystals of magnetite …….

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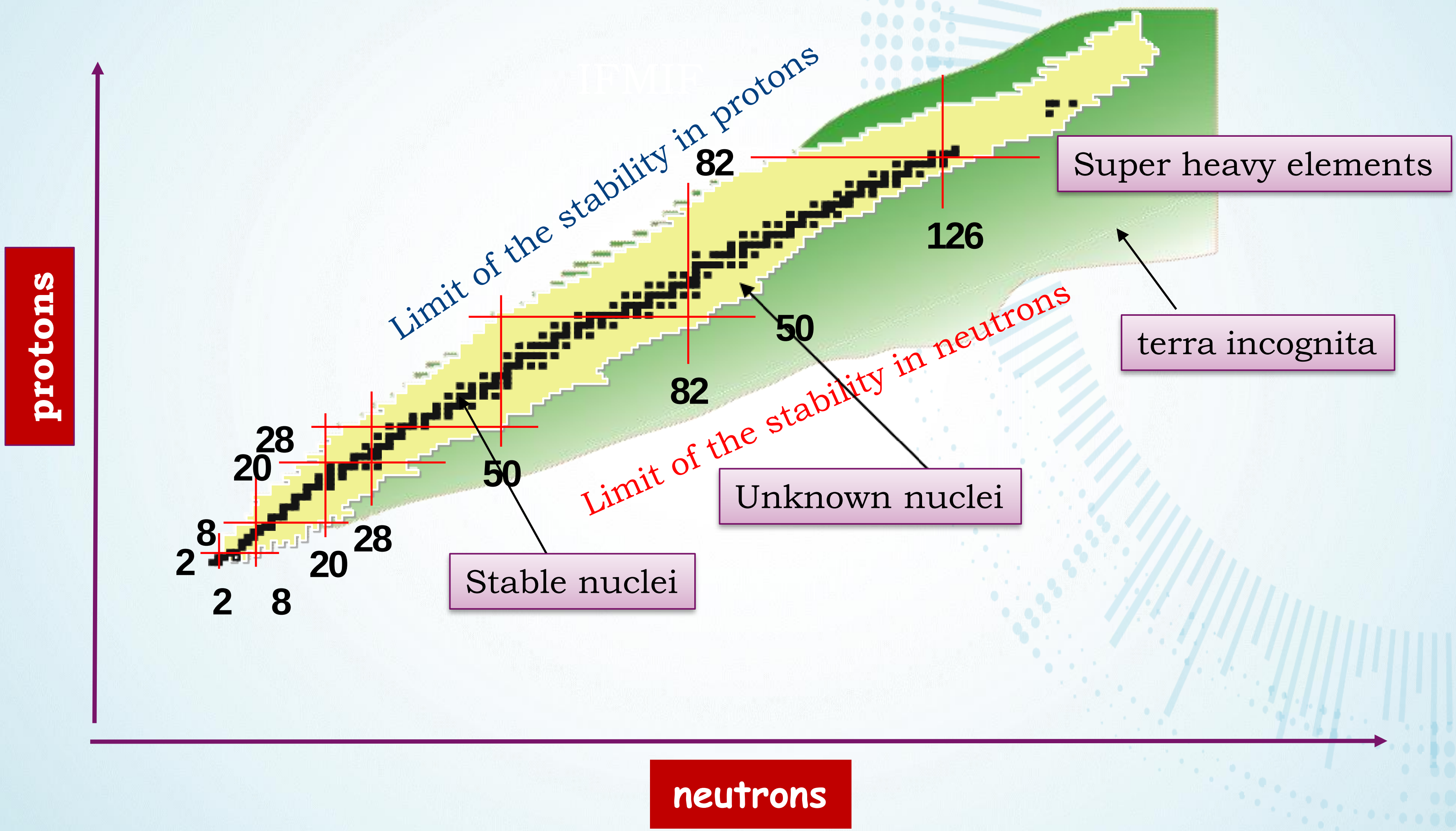
The landscape of the nucleus



Can matter be made up of neutrons only?

On their own, neutrons are very unstable and will convert into protons after several minutes.

However, it remains an open question for more than half a century whether a four-neutron system, i.e. tetra-neutron, as either a bound state or a resonance, exists or not.

Furthermore recent sophisticated supercomputer simulations have shown that four neutrons together can form a resonance, a structure stable for a short period of time ($5*10^{-22}$ seconds) before decaying.

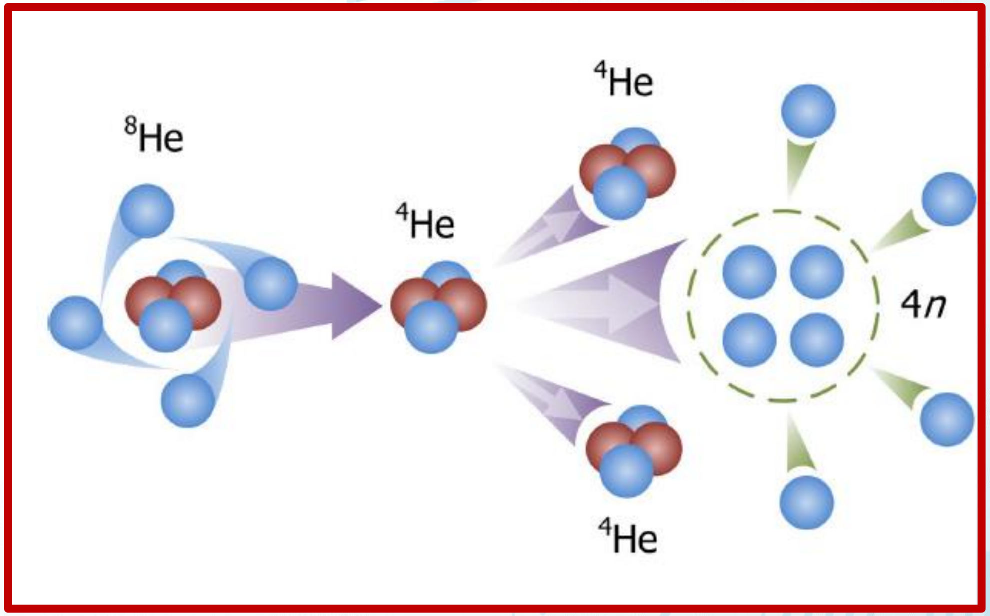
Can a nucleus be made up of neutrons only?

When you look at Wikipedia about tetraneutron you can read that : https://en.wikipedia.org/wiki/Tetraneutron …. « There is some empirical evidence suggesting that this particle does exist, based on a 2001 experiment by Francisco-Miguel Marqués……"

Indeed, in an experiment, in 2001, at the Large Heavy Ion National Accelerator in Caen Marqués with his collaborators observed in a breakup reaction $^{14}Be \rightarrow {}^{10}Be+4n$ six events that could be interpreted as a tetra-neutron system.

Can a nucleus be made up of neutrons only?

In February 2016 RIKEN has reported a new experimental observation of a resonant tetra-neutron state in the missing-mass spectrum obtained in the double charge-exchange reaction: $^{4}He(^{8}He,^{8}Be)$.

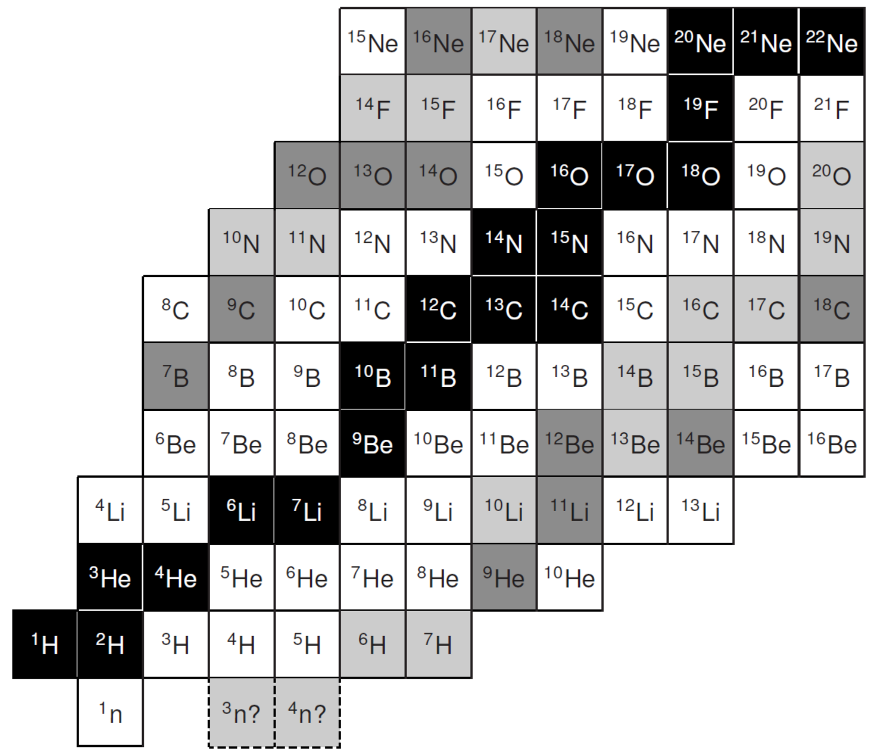


Can a nucleus be made up of neutrons only?

Because of this recent observation a new experimental program has been initiated at JPARK for investigating the pion double charge exchange reaction, i.e. ^{4}He(π−, π+), as an alternative way to populate tetra-neutron.

A part of the nuclear chart ($Z \leq 10$ and $N \leq 12$). Stable nuclei and long-lived ^{14}C, which was used as a target in past pion double charge exchange measurements, are represented by black squares. Gray squares correspond to nuclides accessible by the (p±, p∓) reaction.

Nuclides observed in pion double charge exchange reactions are highlighted in dark grey.



Can a nucleus be made up of neutrons only?

The study of the tetra-neutron opens up a whole new line of research. Studying the tetra-neutron will help us understand inter-neutron forces including previously unexplored features of the unstable two-neutron and three-neutron systems..

The only other known neutron structure is a neutron star (made by 10^{57}neutrons). The closest examples of neutron stars on earth are neutron rich nuclei and especially tetra-neutron systems. Although neutron stars are bound by gravity and not by the strong interaction, there may be a reciprocal theoretical interest in the study of neutron stars and neutrons rich nuclei.

Further research may explore if there are other numbers of neutrons that form a stable resonance along the path to reaching the size of a neutron star.

Lecture by: Miguel Marques

Miguel Marques: The extremes of neutron richness

A neutron star is like a huge nucleus overwhelmed by the number of neutrons, contrary to 'real' nuclei, that have a similar number of neutrons and protons. Is this true? What if we could find or create nuclei without protons? How far can we go in neutron richness? Our common sense tells us that these neutral nuclei should not exist, but if they do they would change our knowledge on neutron stars, on the properties of nuclei in general, and ultimately on the nucleon-nucleon interaction itself, the building block of matter.....

DE LA RECHERCHE À L'INDUSTRIE

Rewriting Nuclear Physics Textbooks: one more step forward

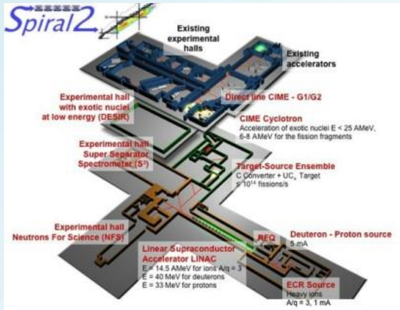
Part 1. Selected Topics

Instead of conclusions

List of unsolved problems in “Nuclei and nuclear astrophysics” (Wikipedia)

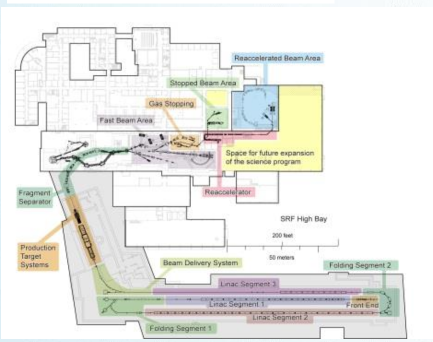
- Why is there a lack of convergence in estimates of the mean lifetime of a free neutron based on two separate- and increasingly precise- experimental methods?
- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
- What is the nature of exotic excitations in nuclei at the frontiers of stability and their role in stellar processes?
- What is the nature of neutron stars and dense nuclear matter?
- What is the origin of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

Radioactive beam facilities in the world (courtesy Grigorenko)



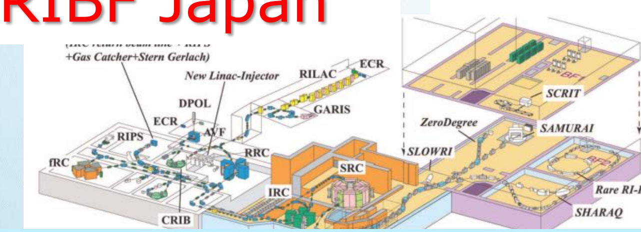
SPIRAL2 France

FRIB USA



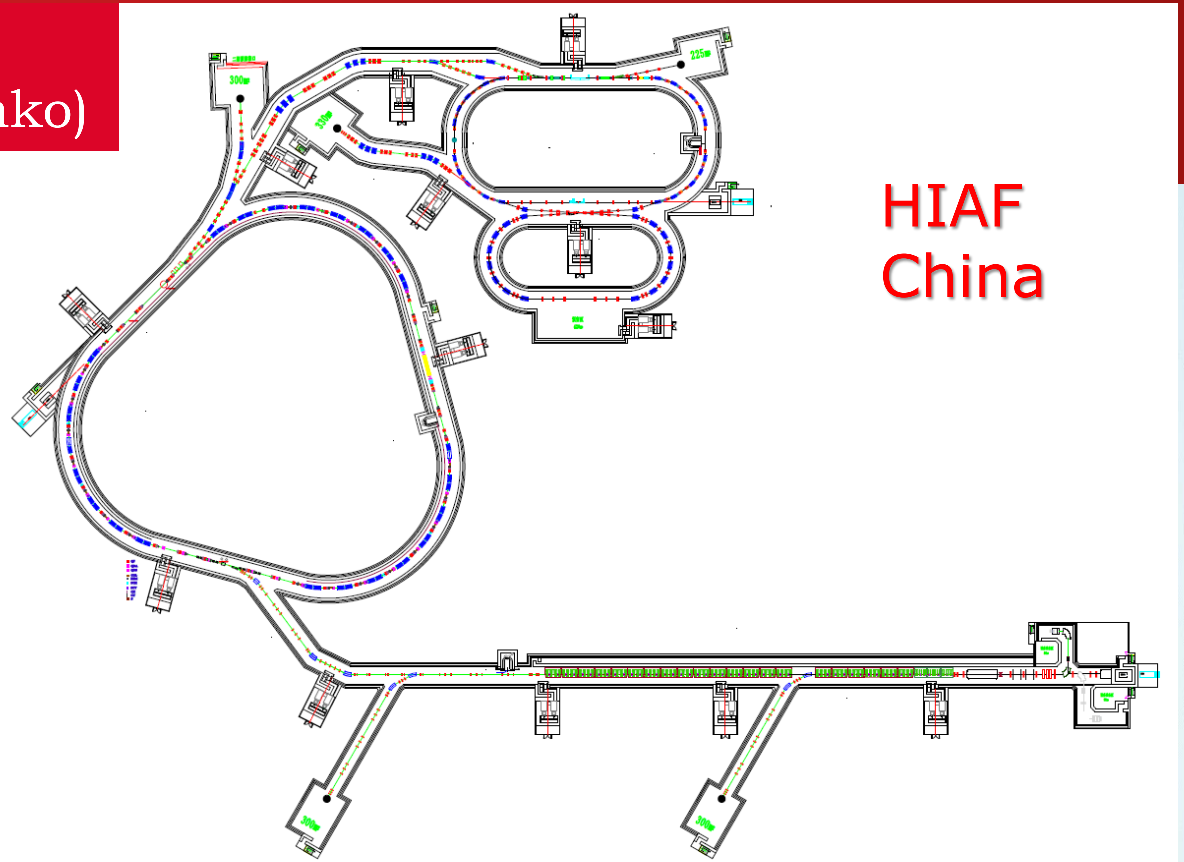
FAIR, Germany

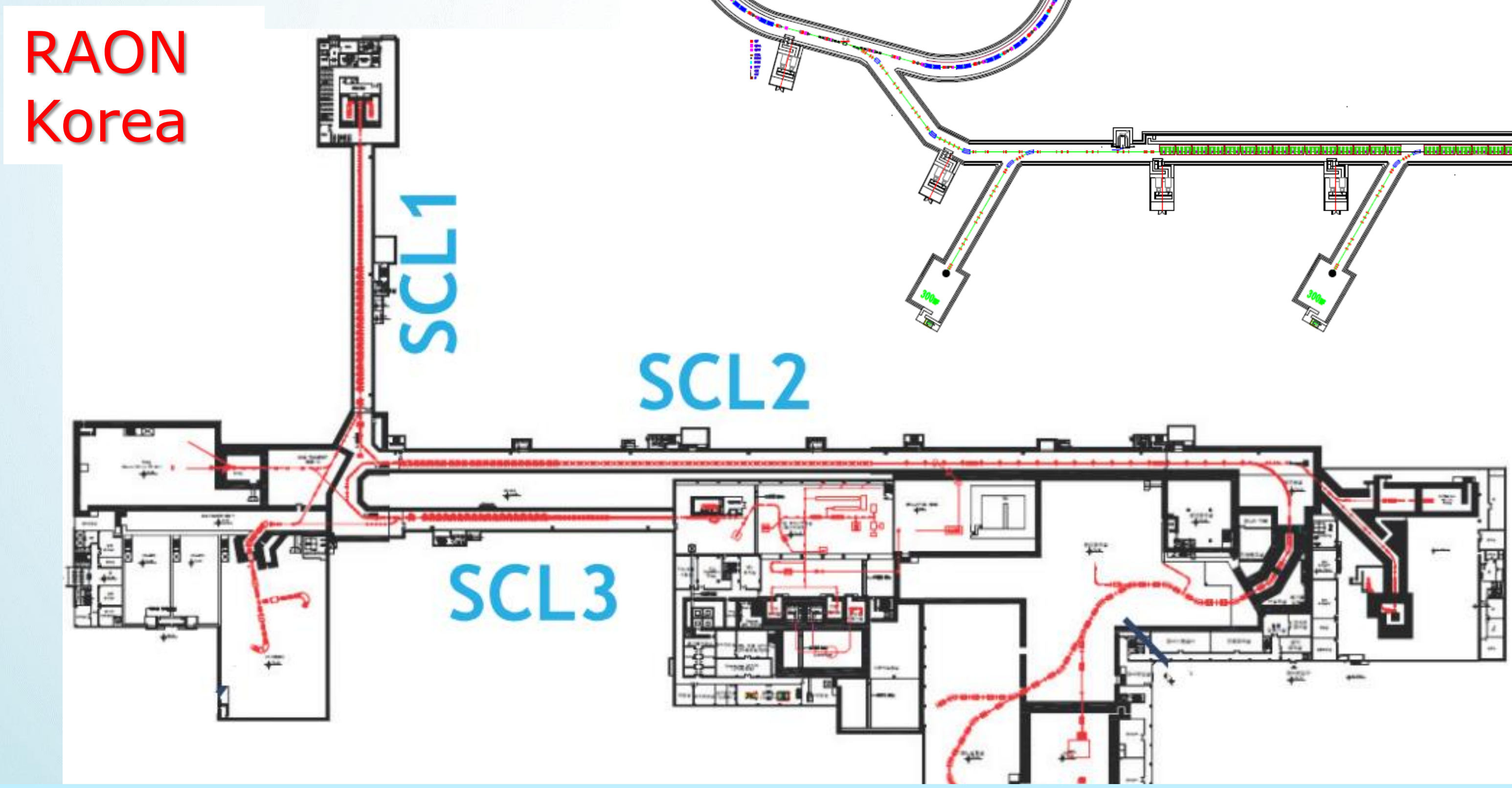
RIBF Japan



Even bigger (courtesy Grigorenko)

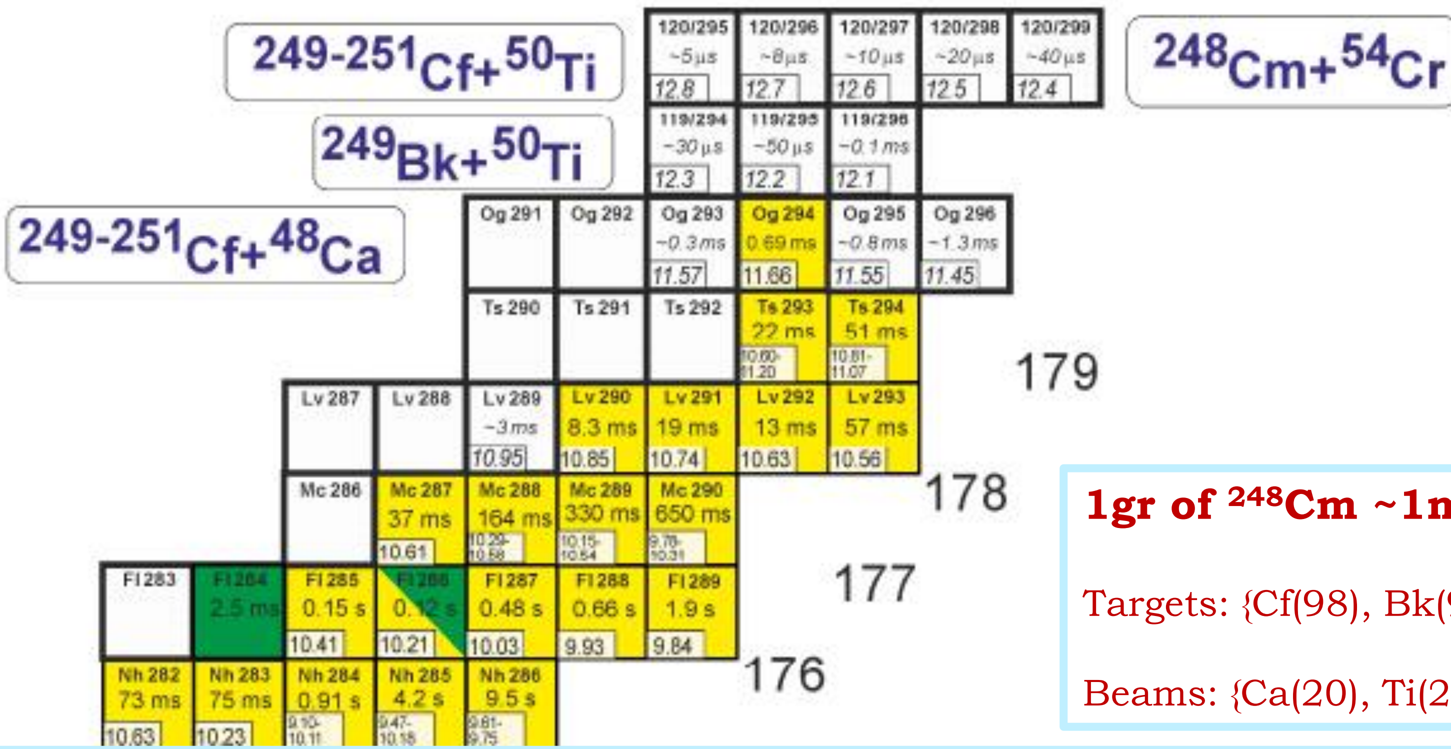
Horizontal scale of the slide ~1 km





RAON – KOREA July 2018

Synthesis of new elements 119, 120



1gr of ^{248}Cm ~1million $

Targets: {Cf(98), Bk(97), Cm(96)}

Beams: {Ca(20), Ti(22), Cr(24)}

The future research for the 119th and 120th elements will continue at the SHE factory at Dubna and RIKEN.

With Yuri Oganessian - Dubna Octobre 2018

Флеровий 114	Московий 115	Ливерморий 116	Теннессин 117	Оганесон 118
Fl	**Mc**	**Lv**	**Ts**	**Og**
Flerovium	Moscovium	Livermorium	Tennessine	Oganesson

ISOL facilities under construction or being planned and the anticipated ^{132}Sn production.

Type	Facility	Beam		Target(ISOL) or Beam current(PF)		Post acceleration		EXP Start
		Beam	Beam Power (kw)	Direct/ Conv/ PF	Fissions/s Beam pnA	MeV/A	^{132}Sn/s	
ISOL Coming	ARIEL	e 50MeV 10000mA p 500MeV 100mA	~100	Direct	$1*10^{14}$		$2*10^{9}$	2018
	HIE ISOLDE	p 1GeV 2mA	2	D&C	$4*10^{12}$	5-10	$2*10^{8}$	2017
	SPIRAL2	d 40MeV 5000mA	200	Conv	$1*10^{14}$	3-10	$2*10^{9}$	2018
	SPES	p 40MeV 200mA	8	Direct	$1*10^{13}$	10	$3*10^{8}$	2021
Super ISOL	EUR ISOL	p 1GeV 5000 mA	4M	D&C	$1*10^{15}$	20-150	$4*10^{11}$	?
	Beijing ISOL	Reactor	6M	reactor	$2*10^{15}$	>100	$5*10^{10}$	?
PF Coming	FRIB	U+33 200MeV	400	PF	8300 pnA	-	10^{8}~10^{9}	2020
	RISP	U+79 200MeV	400	PF	8000 pnA	-	10^{8}~10^{9}	2020
	FAIR	U+28 1500MeV	10	PF	50 pnA	-	10^{7}~10^{8}	2025
PF Running	RIBF 2015	U+86 345MeV	4	PF	100 pnA	-	$3*10^{6}$	running

Probably the beam Power will be limited at 30KW

Waiting for decision

IUPAP Updated 2018, NΦ Facilities around the World by Hideto En'yo (RIKEN)

DE LA RECHERCHE À L'INDUSTRIE

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Thank you