

The Atomic Mass Evaluation (AME) The HINA experiment – Collab TITAN

Sarah Naimi

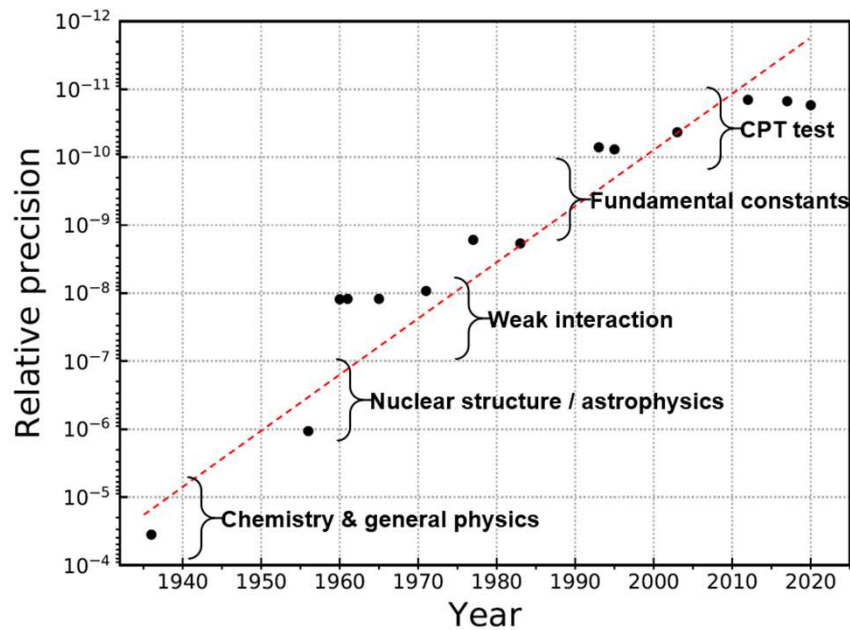
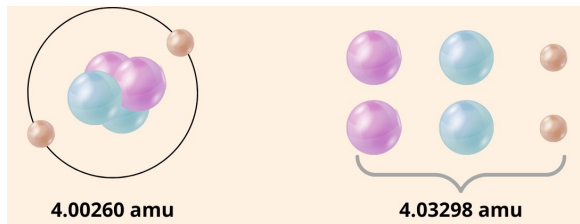
IJCLab

CNRS NPAT IRL Satellite Workshop April 23, 2026



Atomic mass: Important input for astrophysical calculations

$$AM = Zm_p + Nm_n + Zm_e - BE$$



Where do you get the atomic mass values?

International Atomic Energy Agency
Nuclear Data Services
 Section Données Nucléaires, AIEA

IAEA.org | NDS Mission | Mir

Databases » ENSDF | XUNDL | NuDat | LiveChart | NSR | Nuclear Wallet Cards | Related » ENSDF Manuals | Codes | Nuclear Data Sheets | EXFOR

Links
 AMDC web site
 LiveChart
 Q-values calculator

AMDC
 Atomic Mass Data Center

This page contains data provided by the Atomic Mass Data collaboration.
 Please refer to the collaboration websites at [ANL](#) and [IMP](#) for further information about AME and NUBASE

Atomic Mass Evaluation - AME2020
 The evaluation has been published in [Chinese Phys. C 45 030002 \(2021\)](#) [CR](#), and [Chinese Phys. C 45 030003 \(2021\)](#) [CR](#).

The four main ASCII files of AME2020 are

1. [mass_1.mas20](#) - atomic masses
2. [massround.mas20](#) - atomic masses "rounded" version
3. [rct1.mas20](#) - reaction energies, table 1
4. [rct2_1.mas20](#) - reaction energies, table 2

Additionally, the [covariance.mas20](#) zip file is downloadable.

Any work that will use these files should make reference to these papers and not to the electronic files.

Nubase Evaluation - Nubase2020
 The evaluation has been published in [Chinese Physics C 45 \(2021\) 030001](#) [CR](#).

NUBASE contains experimentally known nuclear properties, and some that have been estimated from extrapolation: mass, isomeric excitation energy, half-life, spin, parity, decay modes and intensities.

An ASCII file of the NUBASE table, for use with computer programs, can be downloaded.

- [nubase_4.mas20](#) - Nubase table

Nubase2020 Web version

Any work that will use the file should make reference to this paper and not to the electronic files.

The AMDC provides the [NUCLEUS](#) program to display NUBASE data

Duflo-Zuker mass formula software package
 Calculates the binding energies using the mass formulas of Duflo & Zuker (31 parameter and 10 parameter versions) as described in J. Duflo and A.P. Zuker, Phys. Rev. C 52 (1995) R23.



Why do we need the AME (Atomic Mass Evaluation)?

Mass measurement:

- ❌ absolute mass
- ✅ connection between masses

Atomic Mass Evaluation: a network of Links

Masses are connected by measurements.

Adding a new measurement shifts all masses, depending on the weight of the link.

All data available for ^{135}Ba

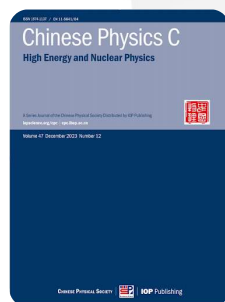
68de17	162731	48	C8 N O H9-135Ba
68de17	117822	77	C11 H3-135Ba
68de17	154160	46	C12 H7-135Ba O
28de20	288.43	0.32	135Cs-135Ba
66de10	-203860	20	135Ba-C10 H14
66de10	1177	2	135Ba-134Ba
68de17	1161	70	135Ba-134Ba
68de17	1168	78	135Ba-134Ba
77ko_A	6973.2	0.4	134Ba(n,g)135Ba
90ts07_Z	6972.17	0.18	134Ba(n,g)135Ba
93de01_Z	6971.84	0.17	134Ba(n,g)135Ba
93ch21	6973.24	0.22	134Ba(n,g)135Ba
96fi_A	6971.87	0.18	134Ba(n,g)135Ba
70vo04	4746	15	134Ba(d,p)135Ba
53li01	285	5	135Cs(�-�)135Ba
13Li01,*	1200	10	135La(�+)-135Ba
66de10	-1115	3	136Ba-135Ba
68de17	-1119	50	136Ba-135Ba
68de17	-1074	50	136Ba-135Ba
69de07	9106.4	0.8	135Ba(n,g)136Ba
90ts07_Z	9107.74	0.04	135Ba(n,g)136Ba
96fi_A	9107.73	0.19	135Ba(n,g)136Ba
70vo04	6886	15	135Ba(d,p)136Ba
10hc04	3089.1	0.6	137Ba 35Cl-135Ba 37Cl
66de10	143	3	137Ba-135Ba
68de17	69	63	137Ba-135Ba
68de17	106	46	137Ba-135Ba

Overdetermined systems

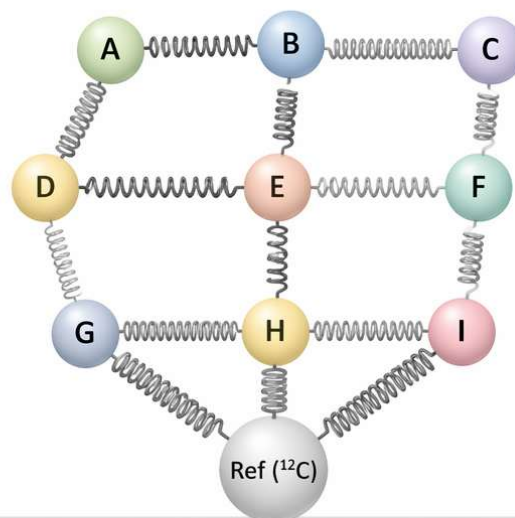
Least-squares method
find unique solution

Flow-of-information Matrix
Significance of uncertainties

Recommended
masses are published
in mass tables



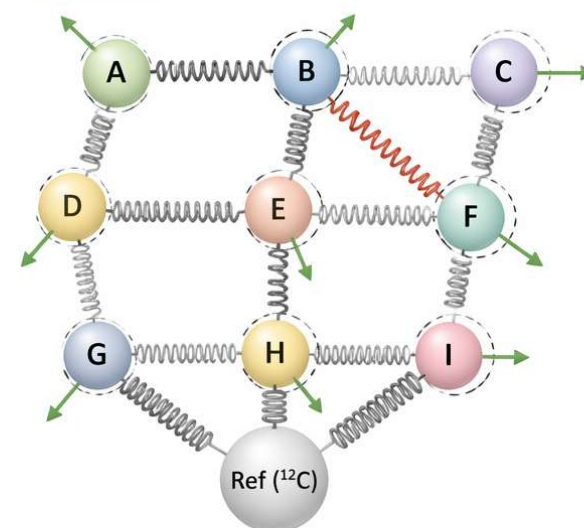
BEFORE Current network of measurements



- Very precise measurement (very strong link)
- Precise measurement (strong link)
- Less precise measurement (weak link)
- New measurement (given uncertainty)
- Reference mass (e.g. ^{12}C) – fixed (anchor)

AFTER New equilibrium of the network

Add a
new measurement
with a given
uncertainty (weight)



- When a new measurement is added, the whole network re-adjusts. All masses can move, but by different amounts.
- Dashed circles show the new positions (shifts are typically small).
- The reference mass (^{12}C) is so well known that it stays fixed, defining the scale.

The influence of the new link spreads through the network depending on the strength of the connections.



Brief history of AME (11 tables since 1955)

1955: A.H. Wapstra established least-squares method to solve the overdetermination problem

1986: G. Audi discovered the flow of information matrix

2006: A.H. Wapstra passed away

2008: G. Audi established the AME collaboration with China

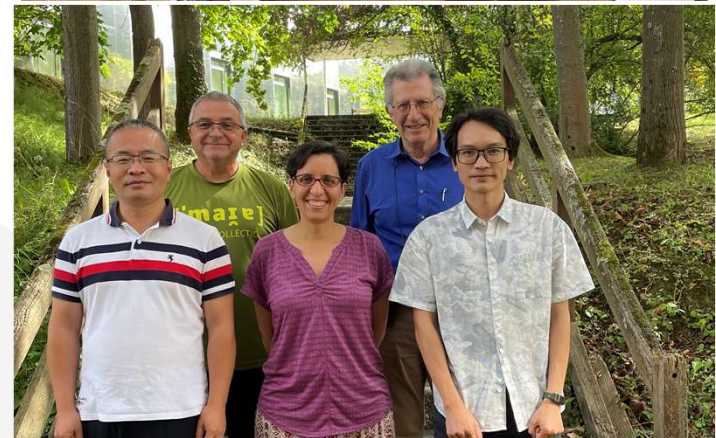
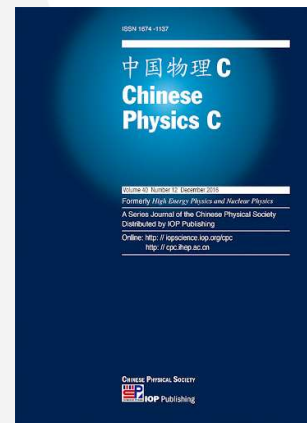
Tables: **AME1955, AME1961, AME1964, AME1971, AME1977, AME1983, AME1993, AME2003, AME2012, AME2016, AME2020**



A.H. Wapstra
(NIKHEF/Amsterdam)



Memorandum signing in China 2008



Collaboration meeting in Orsay Sep. 2023
Next collaboration meeting in Orsay May 2026



Recent History of the AME/NuBASE Collaboration

CPC(HEP & NP), 2012, 36(12): 1603–2014

Chinese Physics C

Vol. 36, No. 12, Dec., 2012

The AME2012 atomic mass evaluation *

(II). Tables, graphs and references

M. Wang^{1,2,3}, G. Audi^{2,8}, A.H. Wapstra^{4,*}, F.G. Kondev⁵, M. MacCormick⁶, X. Xu^{1,7}, and B. Pfeiffer^{8,‡}

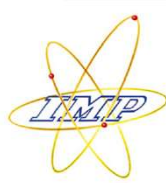


Chinese Physics C Vol. 41, No. 3 (2017) 030003

The AME2016 atomic mass evaluation *

(II). Tables, graphs and references

Meng Wang (王猛)^{1,2,1} G. Audi (欧乔治)³ F.G. Kondev⁴ W.J. Huang(黄文嘉)³ S. Naimi⁵ Xing Xu(徐星)¹

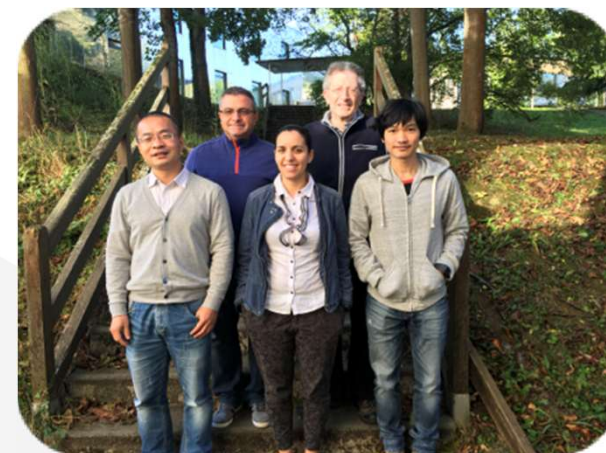


Kuwait 2013



coordinated by G. Audi (AME & NuBase)

Orsay 2016



coordinated by M. Wang (AME) and G. Audi (NuBase)



The most recent NuBASE and AME tables

The NUBASE2020 evaluation of nuclear physics properties**

F.G. Kondev^{1,*}, M. Wang (王猛)^{2,3,*}, W.J. Huang (黄文嘉)^{2,4,5,6}, S. Naimi⁷, G. Audi (欧乔治)⁶

The AME2020 atomic mass evaluation **

(I). Evaluation of input data, and adjustment procedures

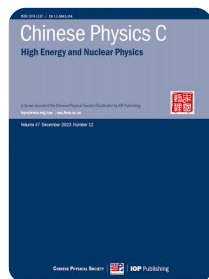
W.J. Huang (黄文嘉)^{1,2,3,4} Meng Wang (王猛)^{1,5,*} F.G. Kondev⁶ G. Audi (欧乔治)³ S. Naimi⁷

The AME2020 atomic mass evaluation **

(II). Tables, graphs and references

Meng Wang (王猛)^{1,2,*} W.J. Huang(黄文嘉)^{1,3,4,5} F.G. Kondev⁶ G. Audi (欧乔治)⁵ S. Naimi⁷

IOP
science



since March 5, 2021
Nubase 41,117 downloads!
AME I 26,038 downloads
AME II 57,651 downloads
Almost **125,000** downloads

Next edition AME2025
To be published Sep. 2026



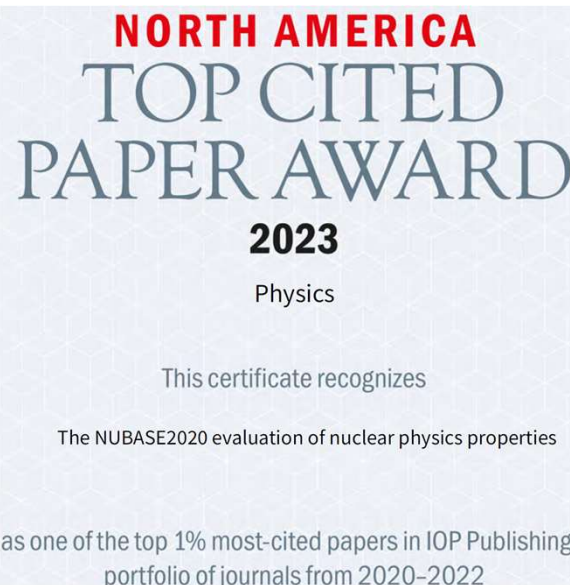
Coordinated by
M. Wang (AME)
and

F.G. Kondev (NuBase)

<https://www-nds.iaea.org/amdc/> (IAEA)

<http://amdc.impcas.ac.cn> (IMP)

<https://www.anl.gov/phy/atomic-mass-data-resources> (ANL)



The HINA experiment @DESIR/GANIL

Highly charged **I**ons for **N**uclear physics and **A**strophysics



Polynesian Goddess of the
Moon and Stars



Hinaupoko Devèze



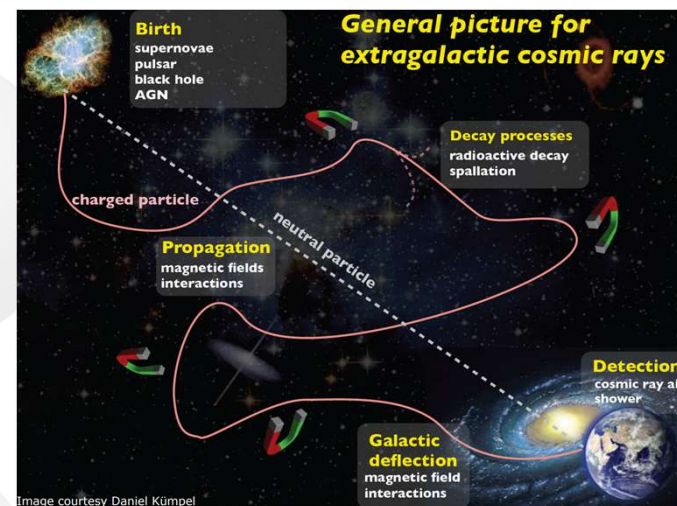


HICs: an exotic matter!

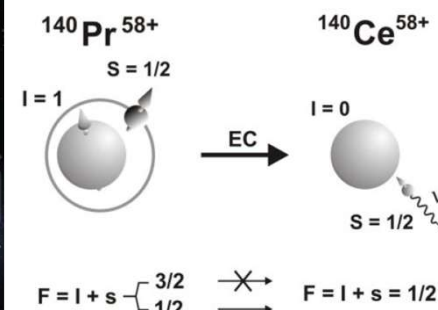
Where do we find them?



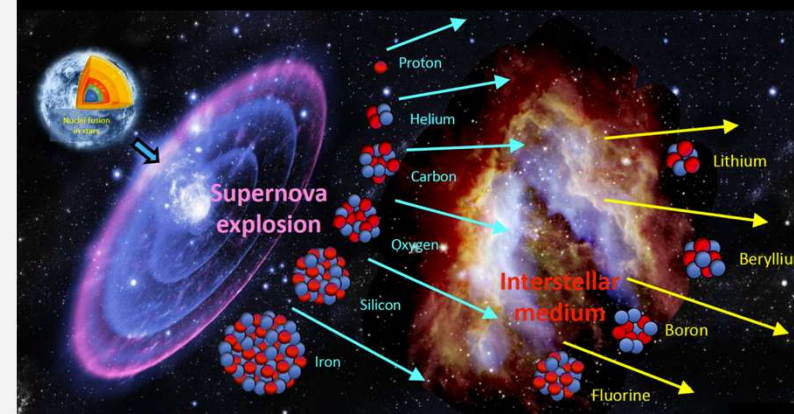
HINA: Nuclear decay of unstable HICs



Measured $\text{H-}, \text{He-}^{140}\text{Pr}$ at GSI
Litvinov+, PRL, 2007
Orbital EC in H-like ions



Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays, C, O, Ne, Mg, Si, ..., Fe, with the interstellar medium.

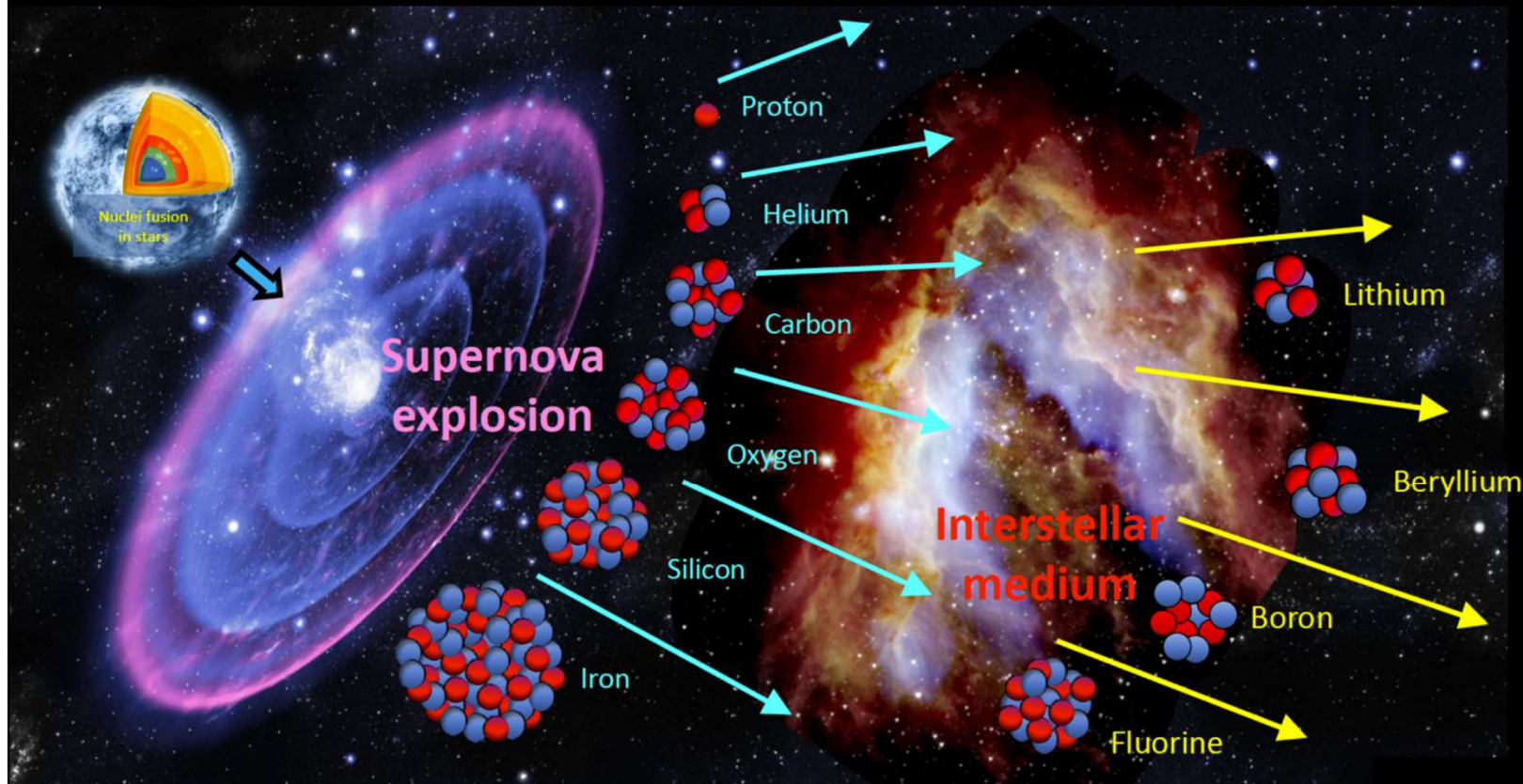


Measurements of the secondary cosmic ray nuclei fluxes and the secondary to primary flux ratios are important in understanding the propagation of cosmic rays in the Galaxy.



Galactic Cosmic rays propagation & decay of HCLs

Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays, C, O, Ne, Mg, Si, ..., Fe, with the interstellar medium.

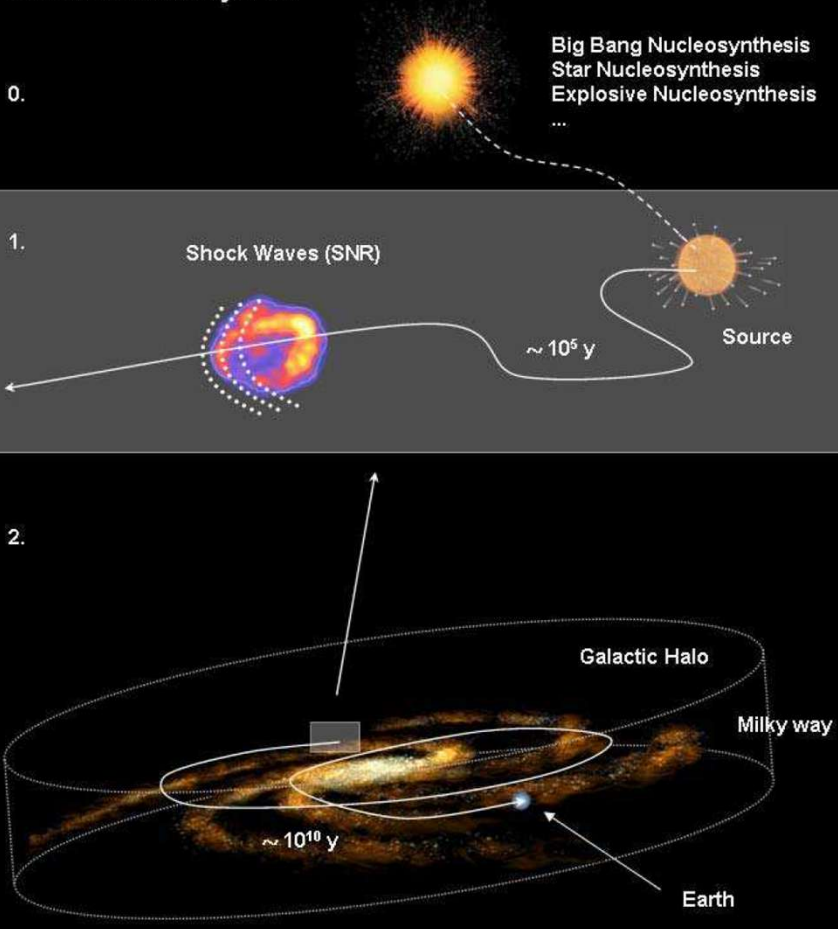


Measurements of the secondary cosmic ray nuclei fluxes and the secondary to primary flux ratios are important in understanding the propagation of cosmic rays in the Galaxy.



Astronomic Clocks: Galactic Cosmic Rays

Galactic Cosmic Rays Life

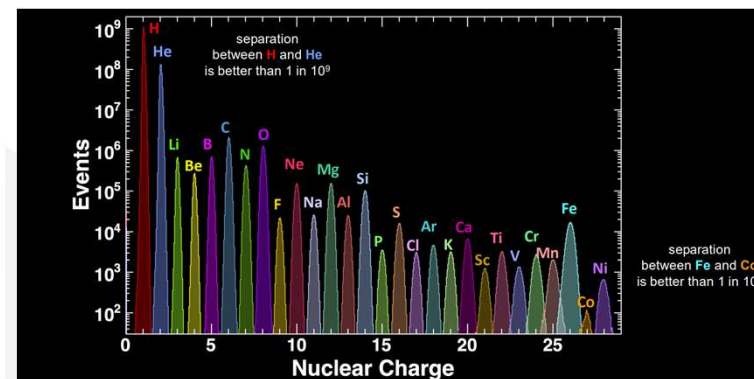
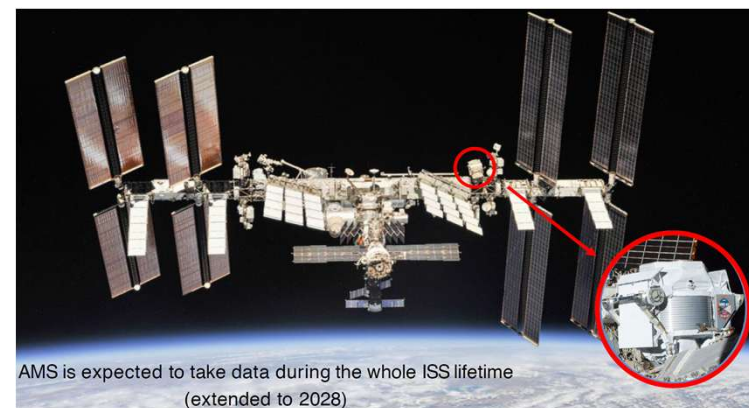


Most interesting GCRs (Astronomic Clocks)

Nuclide	Decay Mode	Half-life
^7Be	K-capture	53 days
^{10}Be	β^-	1.5 Myr
^{14}C	β^-	5730 yr
^{26}Al	β^+ K-capture	0.87 Myr 4.0 Myr
^{36}Cl	β^-	0.30 Myr
^{37}Ar	K-capture	35 days
^{41}Ca	K-capture	0.10 Myr
^{44}Ti	K-capture	49 yr
^{49}V	K-capture	330 days
^{51}Cr	K-capture	28 days
^{53}Mn	K-capture	3.7 Myr
^{54}Mn	K-capture β^+ β^-	312 days 400 Myr 0.8 Myr b
^{55}Fe	K-capture	2.7 yr
^{56}Ni	K-capture β^+	6.1 days ~ 1 yr
^{57}Co	K-capture	270 days
^{59}Ni	K-capture	76000 yr

A. Oliva PhD thesis 2007

Measurement is conducted at AMS-02 @ISS since 2011
<https://ams02.space/>



With the unprecedented statistics of ~240 billion events we have precise spectroscopy of all cosmic ray nuclei.

A.Oliva, talk in CRs and vs in MME conference, 2024



Consideration of EC in the GCRs propagation simulation

ANNUAL REVIEW OF NUCLEAR AND PARTICLE SCIENCE Volume 57, 2007

Review Article

Cosmic-Ray Propagation and Interactions in the Galaxy

Andrew W. Strong¹, Igor V. Moskalenko², and Vladimir S. Ptuskin³

Hide Affiliations

Affiliations:

¹Max-Planck-Institut für extraterrestrische Physik, 85741 Garching, Germany; email: aws@mpe.mpg.de

²Hansen Experimental Physics Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, California 94305; email: imos@stanford.edu

³Institute for Terrestrial Magnetism, Ionosphere and Radiowave Propagation of the Russian Academy of Sciences (IZMIRAN), Troitsk, Moscow region 142190, Russia; email: vptuskin@izmiran.ru

Starting with the heaviest primary nucleus considered (e.g. ^{64}Ni) the propagation solution is used to compute the source term for its spallation products, which are then propagated in turn, and so on down to protons, secondary electrons and positrons, and antiprotons. In this way secondaries, tertiaries etc. are included. (Production of ^{10}B via the ^{10}Be -decay channel is important and requires a second iteration of this procedure.) GALPROP includes K-capture and electron stripping processes, where a nucleus with an electron (H-like) is considered a separate species because of the difference in the lifetime. Since H-like atoms have only one K-shell electron, the K-capture decay half-life has to be increased by a factor of 2 compared to the measured half-life value. Primary electrons are treated

PHYSICAL REVIEW C 77, 014306 (2008)

Orbital electron capture decay of hydrogen- and helium-like ions

Zygmunt Patyk,¹ Jan Kurcewicz,² Fritz Bosch,³ Hans Geissel,³ Yuri A. Litvinov,³ and Marek Pfützner²

¹Soltan Institute for Nuclear Studies, Hoza 69, PL-00-681 Warsaw, Poland

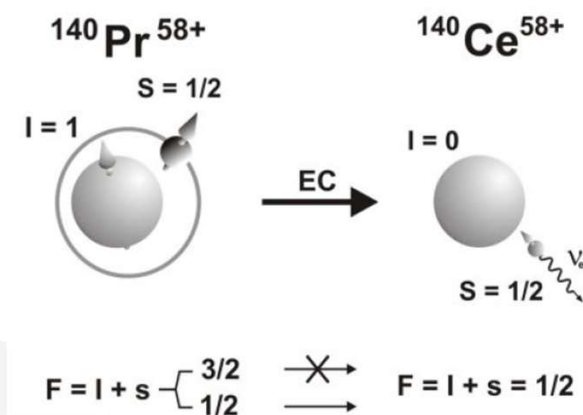
²Institute of Experimental Physics, Warsaw University, Hoza 69, PL-00-681 Warsaw, Poland

³Gesellschaft für Schwerionenforschung (GSI), Planckstrasse 1, D-64291 Darmstadt, Germany

(Received 3 August 2007; published 10 January 2008)

Measured H-, He- ^{140}Pr at GSI

Litvinov+, PRL, 2007



Ion	λ_{β^+} (sec ⁻¹)	λ_{EC} (sec ⁻¹)
$^{140}\text{Pr}^{59+}$	0.001 58(8)	...
$^{140}\text{Pr}^{58+}$	0.001 61(10)	0.002 19(6)
$^{140}\text{Pr}^{57+}$	0.001 54(11)	0.001 47(7)

Factor 2/3



HINA experiment @DESIR: What? How? Why?

HINA



Decay highly charged light ions

Trap-based setup

Nuclear physics
Astrophysics

High precision
New applications

HINA@GANIL

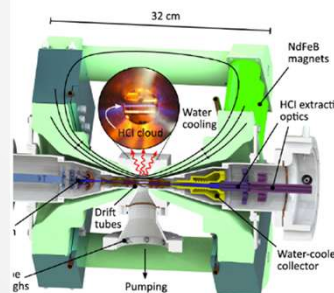
Cosmic Ray

H-like ion	$I_i^{\pi_i} \rightarrow I_f^{\pi_f}$	μ/μ_N	δE (eV)	$\tau_{1/2}$	$T_{1/2}$
^{19}Ne	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$	-1.89	0.004	3 d	17.3 s
^{37}Ar	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	+1.15	0.01	10 h	35 d
^{64}Cu	$1^+ \rightarrow 0^+$	-0.22	0.009	7 h	12.7 h
^{68}Ga	$1^+ \rightarrow 0^+$	+0.01	0.001	5 yr	67.7 min

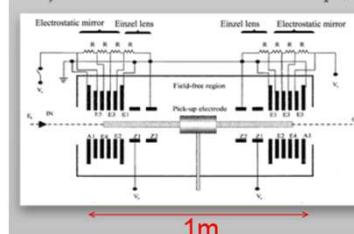
EC on H-,He-&Li-like ions
Nuclear physics, CR & PNC?

Traps as alternative to storage rings
Smaller, cheaper, eco & "outperform"

Focus on light ions



Zajfman's Electrostatic Ion Beam Trap (EIBT)





Preliminary HINA beamline @ DESIR

Pre-ANR

ANR Timeline 2025-2029

Post-ANR

Preparation
HINA beamline
Zajfman trap

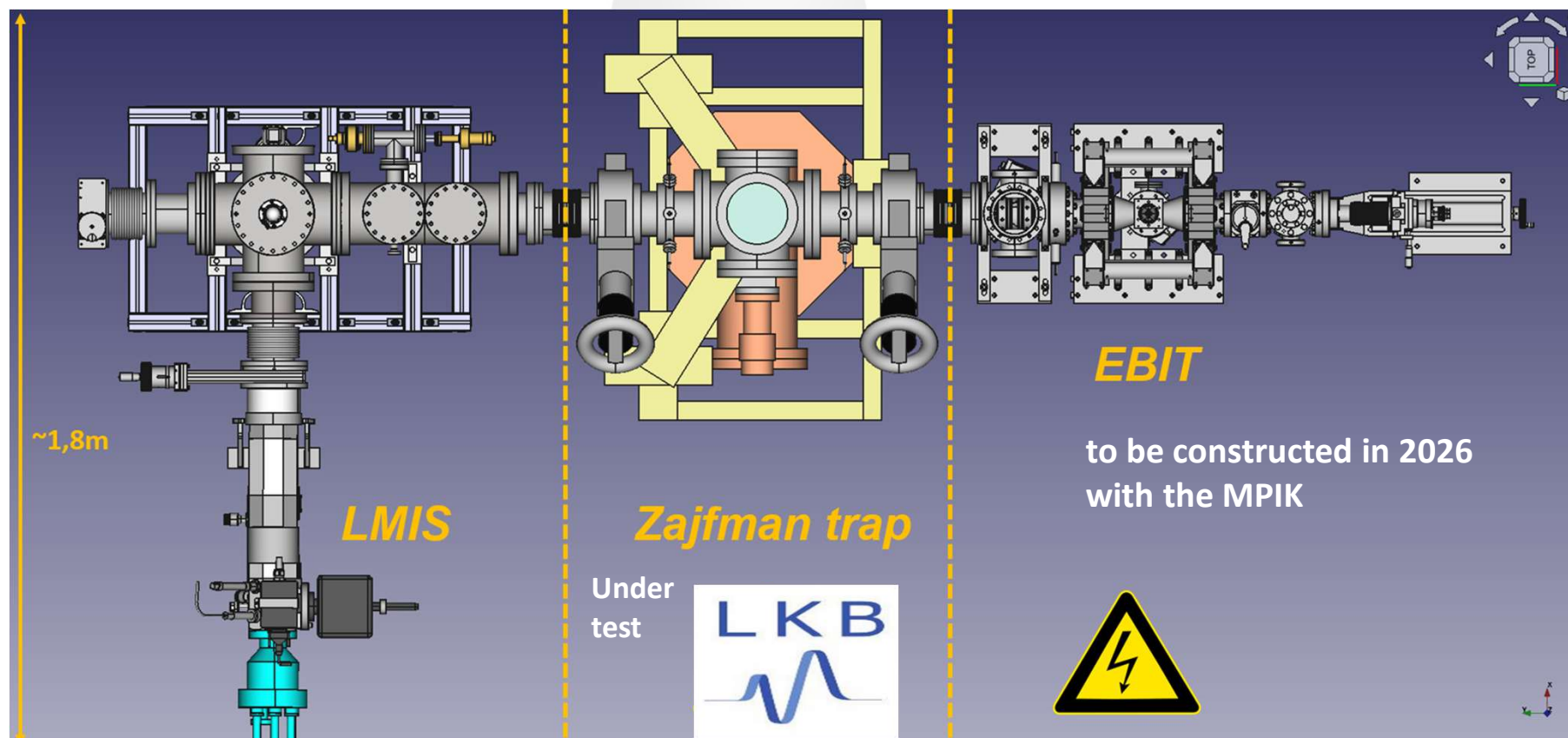
EBIT
construction

Assembly
Detectors tests

Test EBIT
w/ Ar beam

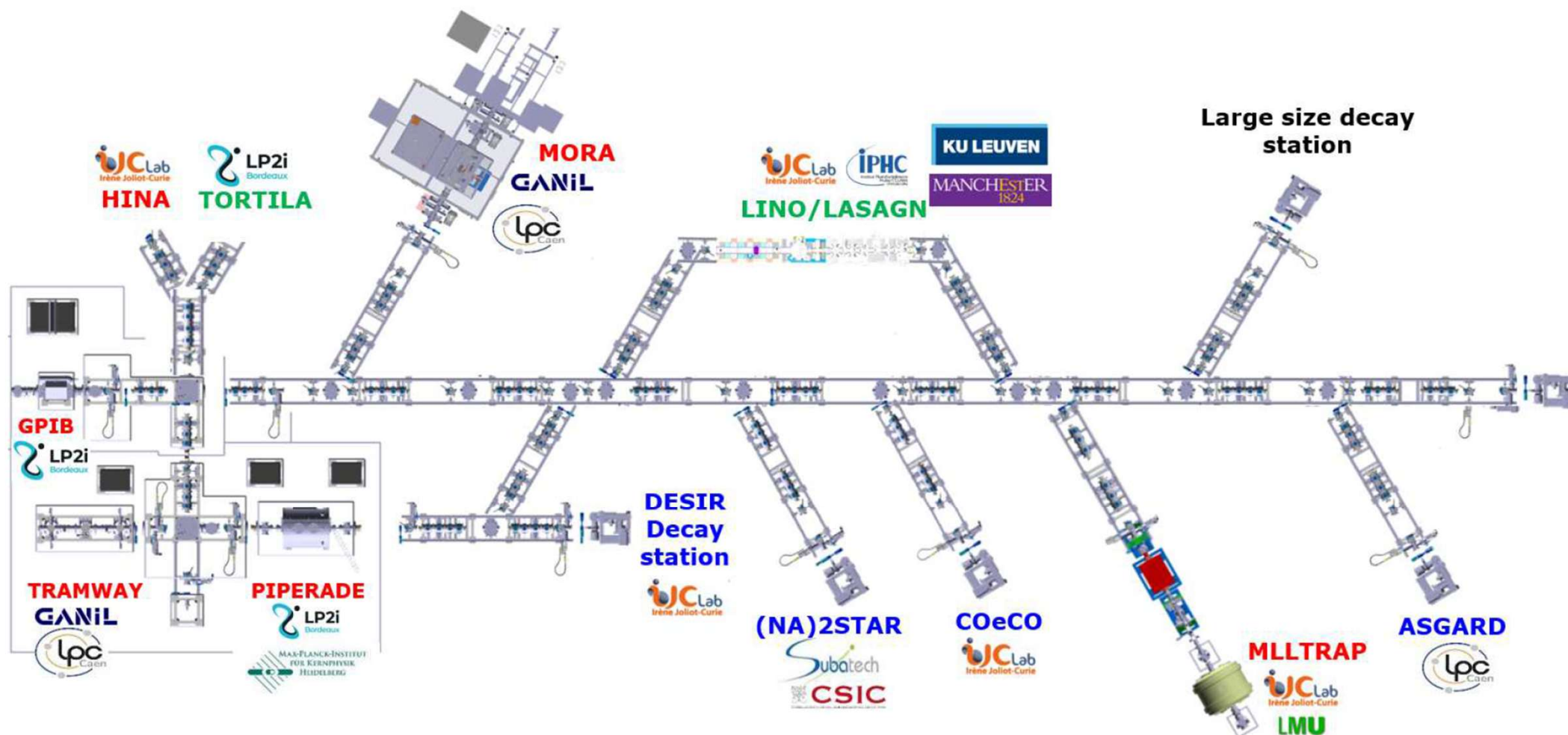
Production/trapping
He-/H-like Cu,Ga beam

Experiments
at DESIR





Preliminary beamline layout @ DESIR



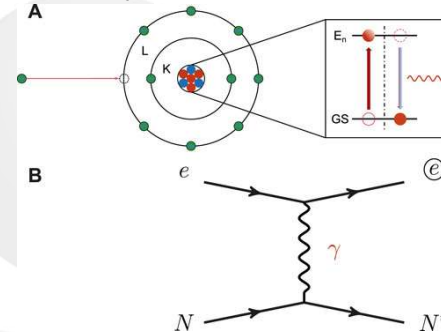


Collaboration NPAT-IRL : TITAN -- HINA

Sep. 2025



NEEC (Nuclear Excitation by Electron Capture)



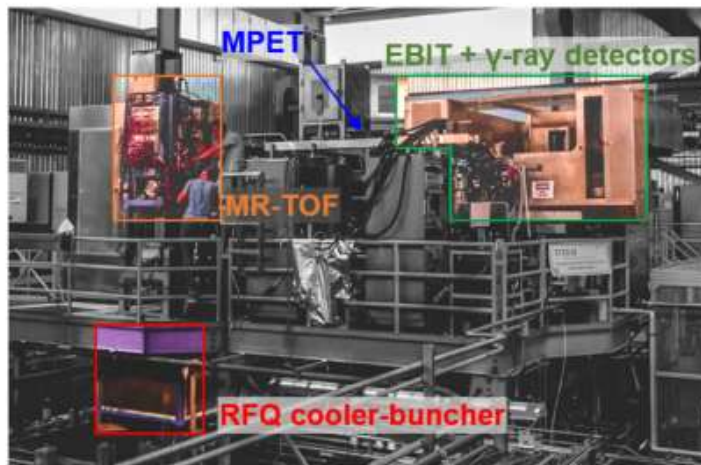
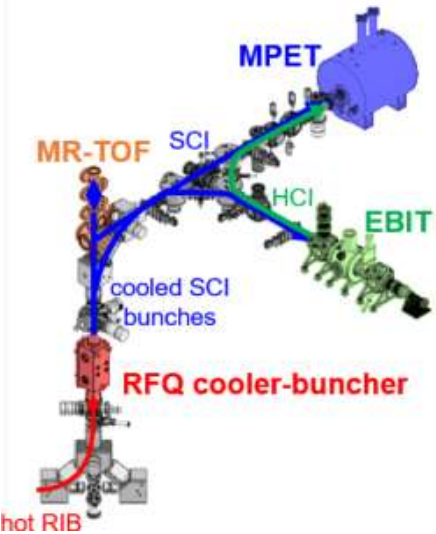
Energy storage:
nuclear battery?



Carol Jiseth
Ospina Uma a
(PhD candidate)

Astronomic Clocks GCRs

Nuclide	Decay Mode	Half-life
⁷ Be	K-capture	53 days
¹⁰ Be	β^-	1.5 Myr
¹⁴ C	β^-	5730 yr
²⁶ Al	β^+	0.87 Myr
	K-capture	4.0 Myr
³⁶ Cl	β^-	0.30 Myr
³⁷ Ar	K-capture	35 days
⁴¹ Ca	K-capture	0.10 Myr
⁴⁴ Ti	K-capture	49 yr
⁴⁹ V	K-capture	330 days
⁵¹ Cr	K-capture	28 days
⁵³ Mn	K-capture	3.7 Myr
⁵⁴ Mn	K-capture	312 days
	β^+	400 Myr
	β^-	0.8 Myr b
⁵⁵ Fe	K-capture	2.7 yr
⁵⁶ Ni	K-capture	6.1 days
	β^+	~ 1 yr
⁵⁷ Co	K-capture	270 days
⁵⁹ Ni	K-capture	76000 yr



TITAN-EBIT: in-trap spectro

