Istituto Nazionale di Fisica Nucleare

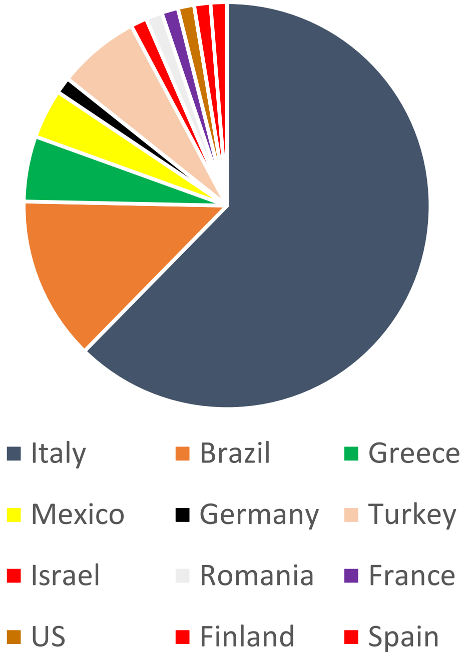
Report from LNS

G. Cuttone

PAC Meeting, DEC. 12 2017

The NUMEN project at INFN-LNS

77 Researchers
19 Institutions
12 countries

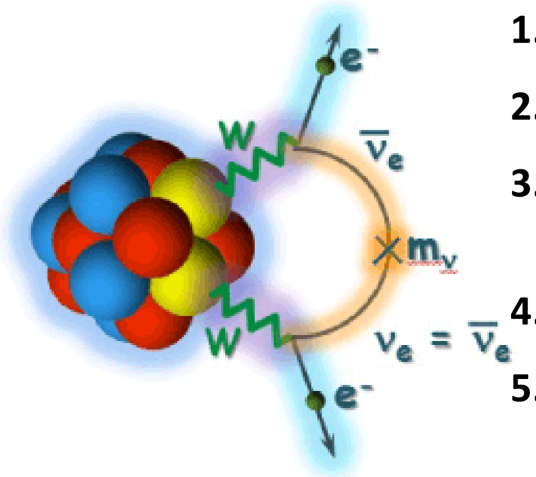


Spokespersons: F. Cappuzzello (cappuzzello@lns.infn.it) and C. Agodi (agodi@lns.infn.it)

The NURE grant of ERC

Principal Investigator: M. Cavallaro (manuela.cavallaro@lns.infn.it)

Neutrinoless double beta decay



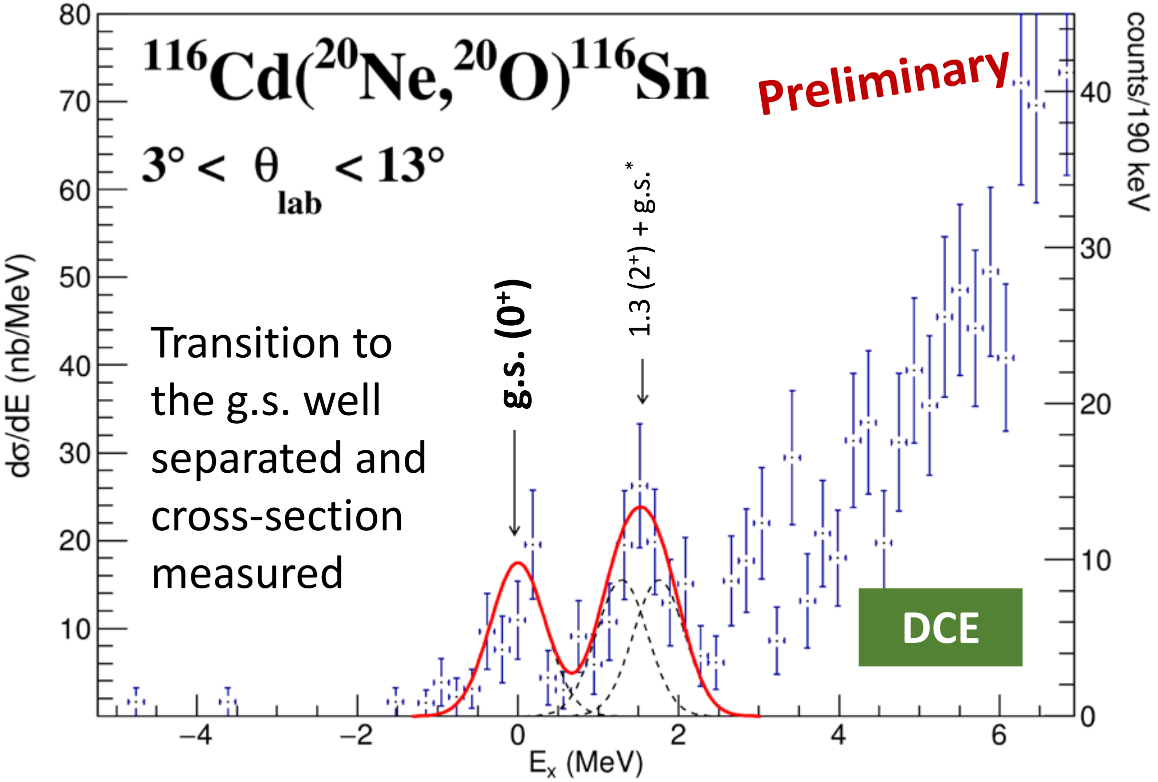
1. **Beyond standard model**
2. **Access to effective neutrino mass**
3. **Violation of lepton number conservation**
4. **CP violation in lepton sector**
5. **A way to leptogenesis and GUT**

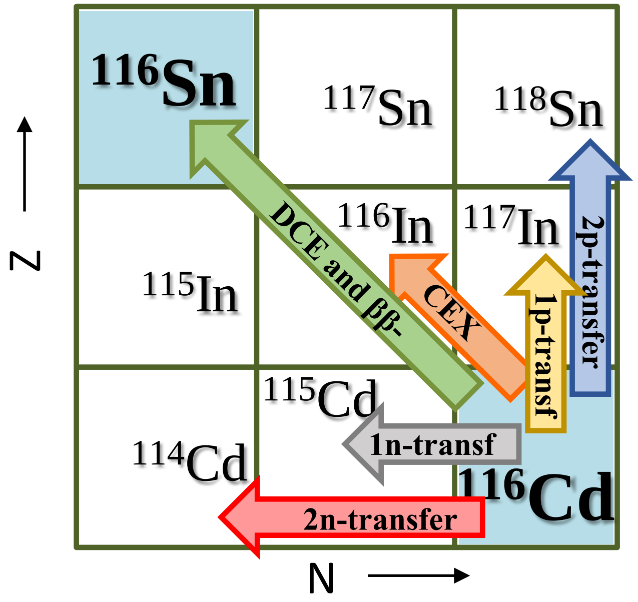
$$1/T^{0\nu}_{1/2}(0^+ \to 0^+) = G_{01}\left|M^{\beta\beta 0\nu}\right|^2 \left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

Numen experimental plan of Phase 2

	2016				2017				2018			
Reaction	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
$^{18}O + ^{116}Sn$		Done										
$^{20}Ne + ^{116}Cd$	**Test**			Done		Done						
$^{20}Ne + ^{130}Te$						Done						
$^{20}Ne + ^{76}Ge$												
$^{18}O + ^{76}Se$												
$^{18}O + ^{106}Cd$												

$^{20}Ne + ^{116}Cd$ reaction





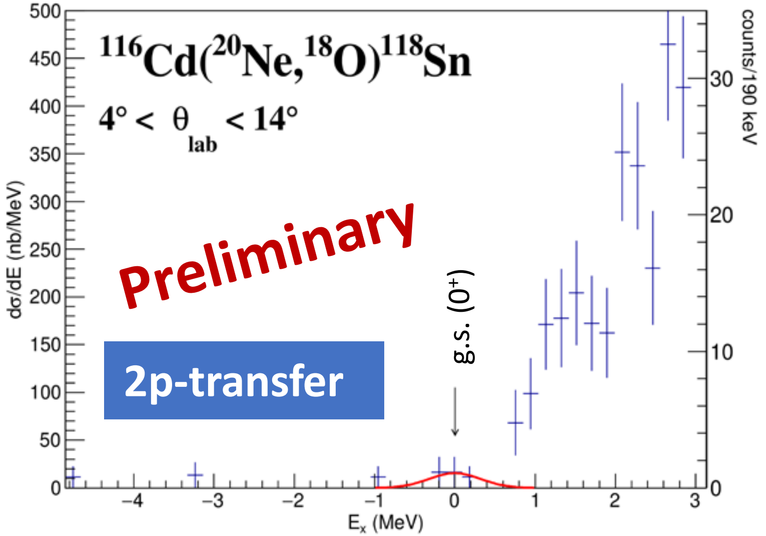
DCE and all competing channels measured.

Data reduction almost ready for DCE channel.

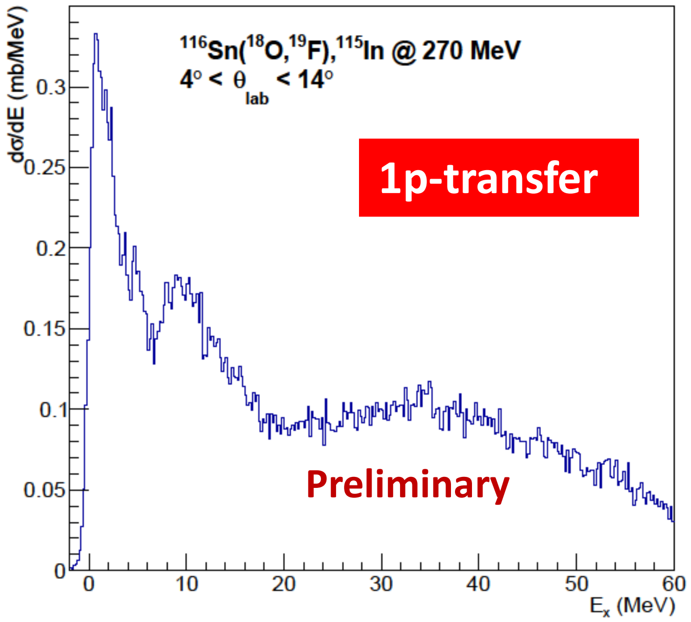
Comparison with theory in progress.

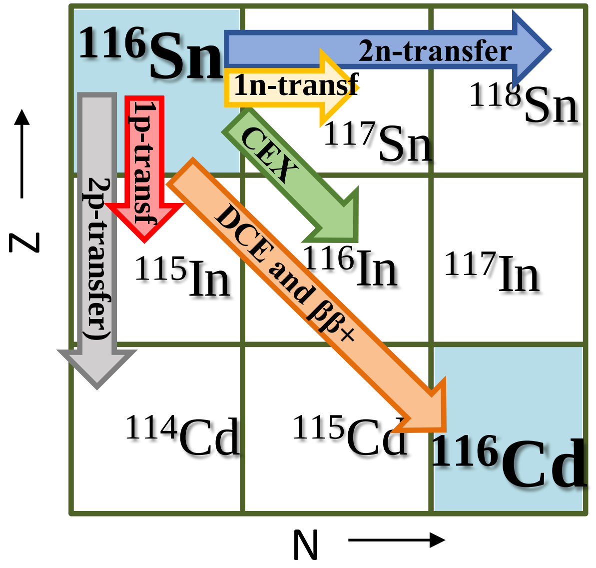
State (MeV)	Counts	Absolute coss section (nb)
g.s. (0^+)	30	12 ± 2
$^{116}Sn_{1.293\,(2+)}$ + $^{20}O_{1.673\,(2+)}$	61	22 ± 3

Transfer channels suppressed with respect to DCE

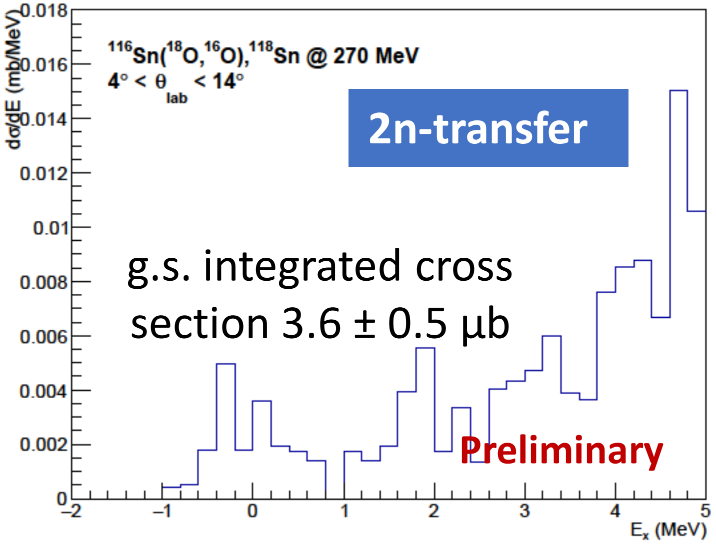


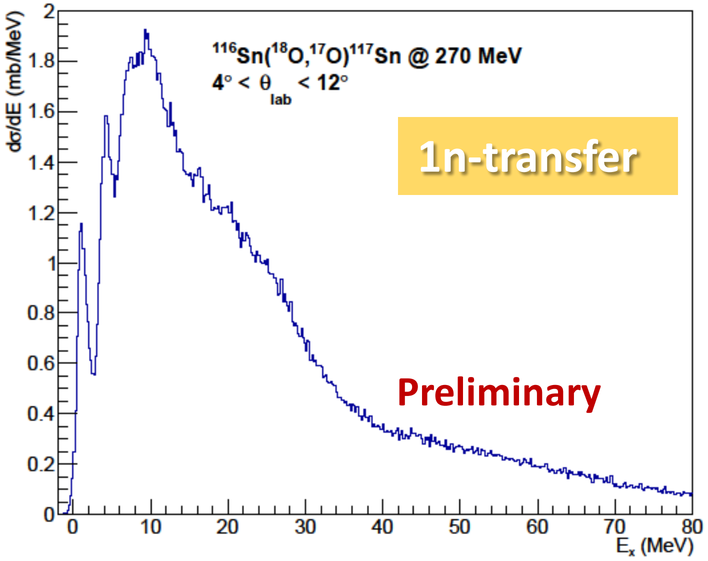
^{18}O + ^{116}Sn reaction

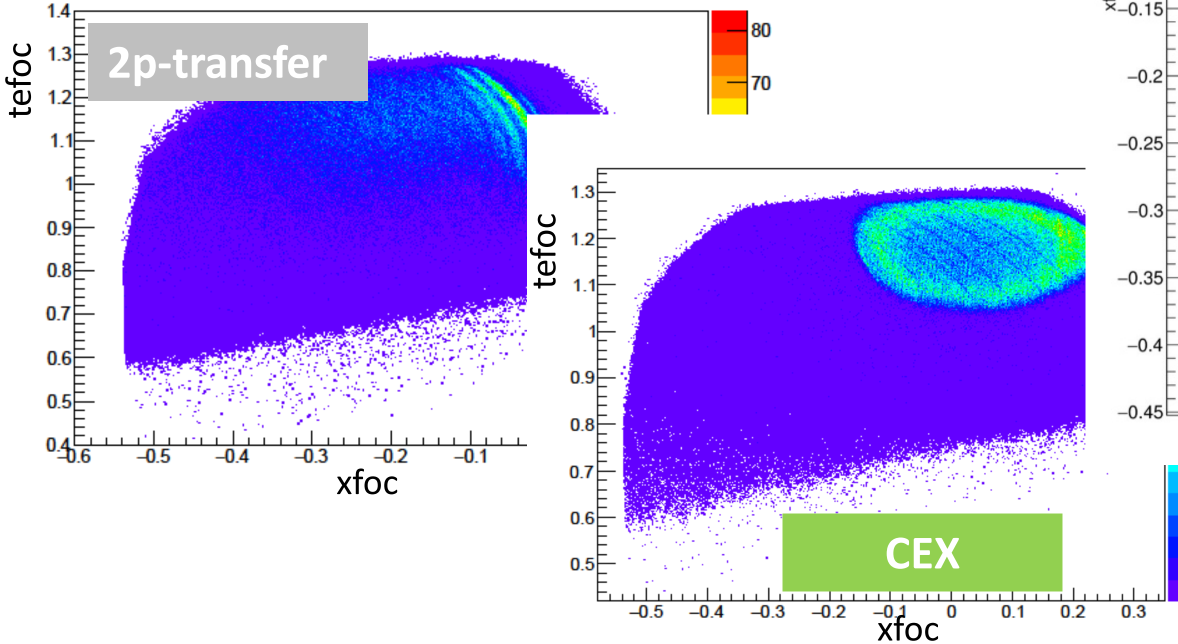


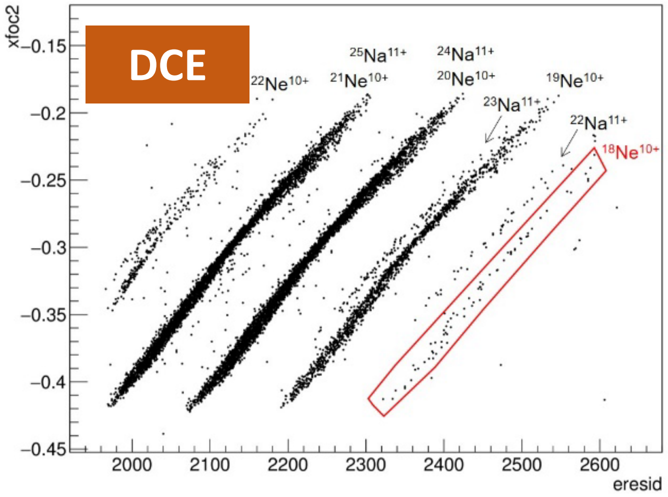


Double charge exhange (DCE) and all competing channels measured.







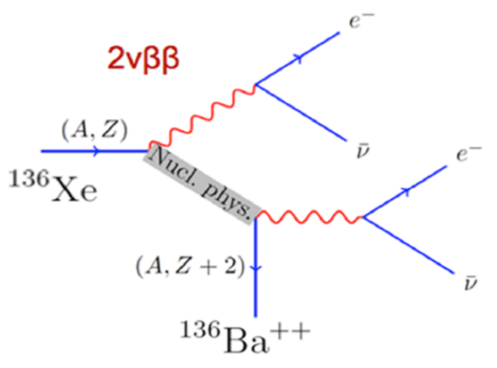


Data reduction in progress

The NUMEN project : Theory WP (Coordinator: M. Colonna, LNS)

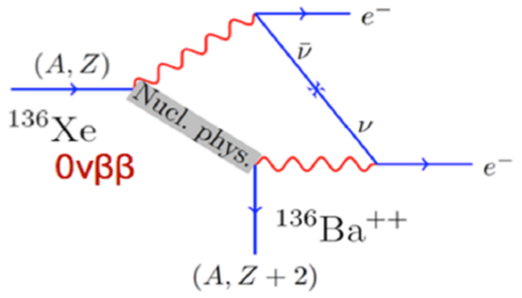
Double β-decay

Within standard model



Beyond standard model

(simple 0νββ mechanism)



- Single Charge Exchange (SCE) Nuclear Reactions are a well tested approach to probe single β decay

- ➢ MAGNEX at LNS allow to study Double Charge Exchange (DCE) and to probe double β decay nuclear matrix elements (NME)

$$1/T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) = G_{0\nu}\boxed{\left|M^{\beta\beta 0\nu}\right|^2}\left|\frac{\langle m_\nu\rangle}{m_e}\right|^2$$

Nuclear Matrix Element (NME)!

$$\left|M_{\varepsilon}^{\beta\beta 0\nu}\right|^2 = \left|\left\langle \Psi_f \left| \hat{O}_{\varepsilon}^{\beta\beta 0\nu} \right| \Psi_i \right\rangle\right|^2$$

- Cross section factorization obtained for SCE Heavy Ion Reactions

β decay strengths

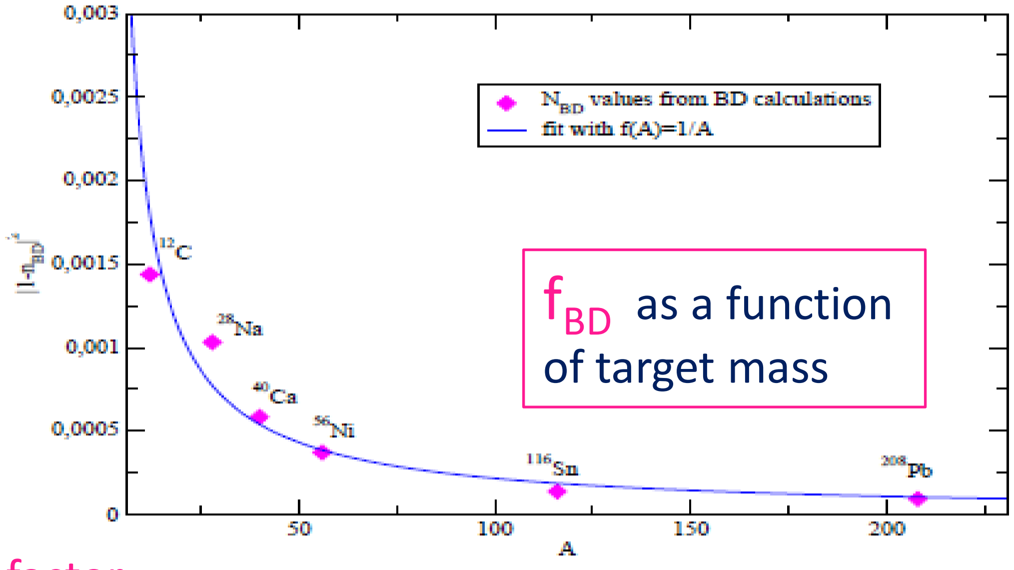
$$d\sigma_{\alpha\beta} = F(q_{\alpha\beta},\omega)\sigma_U \left|b_{0SS}^{(ab)}\right|^2 \left|b_{0SS}^{(AB)}\right|^2$$

$$\sigma_U = K(E_{lab},0)|V_{ST}^{(C)}(0)|^2 f_{BD}(R_{abs},R,\sigma)$$

distortion factor

- ➢ Results can be extended to **DCE**

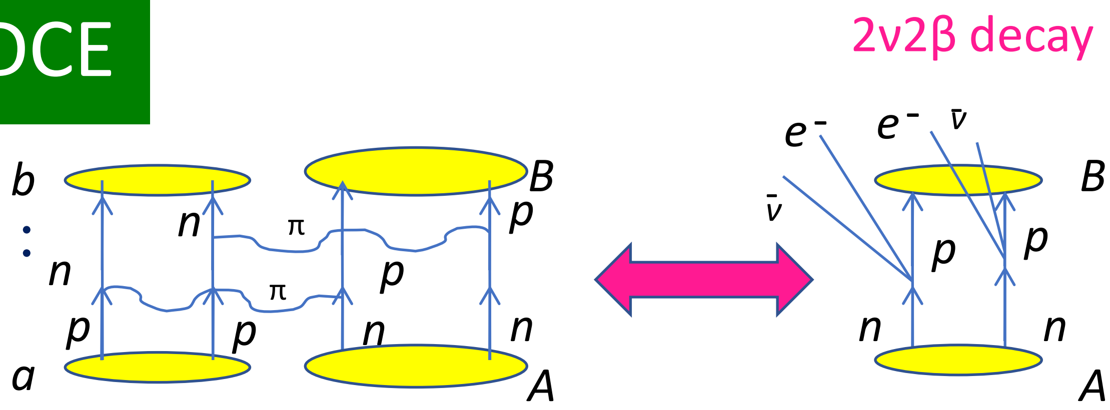
Bellone, Colonna, Lenske et al, to be submitted to PRC



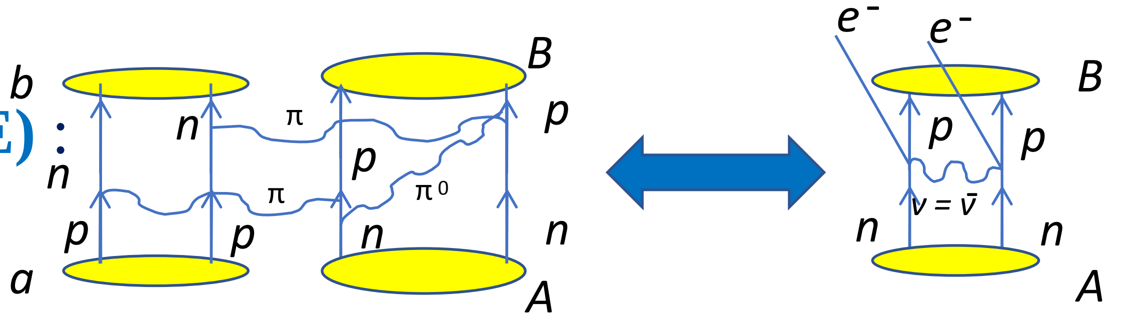
f_{BD} as a function of target mass

Theoretical description of DCE

➢ **Two-step (uncorrelated) process (1bDCE)** :
two consecutive SCE
-- Analogies with **2ν2β decay**



➢ **One-step (correlated) process (2bDCE)** :
-- Analogies with **0ν2β decay**



$nn \rightarrow pp\pi^-\pi^-$ reaction.
in the target

2ν2β decay

➢ Study of competitive processes:
-- Multinucleon **transfer**

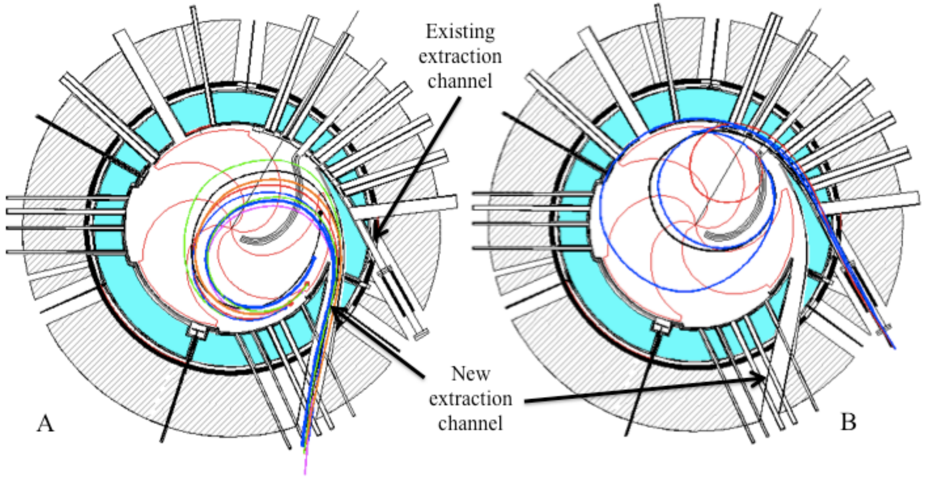
Main collaborations:

• ***H.Lenske***	Giessen Univ. – Germany
• ***N.Auerbach***	Tel Aviv Univ. – Israel
• ***J.Ferreira, J.Lubian***	Niteroi – Rio de Janeiro – Brazil
• ***J.A. Lay Valera***	University of Sevilla – Spain
• ***E. Santopinto and coll.***	Genoa Univ. and INFN - Italy

Major upgrade of LNS facilities: The CS accelerator

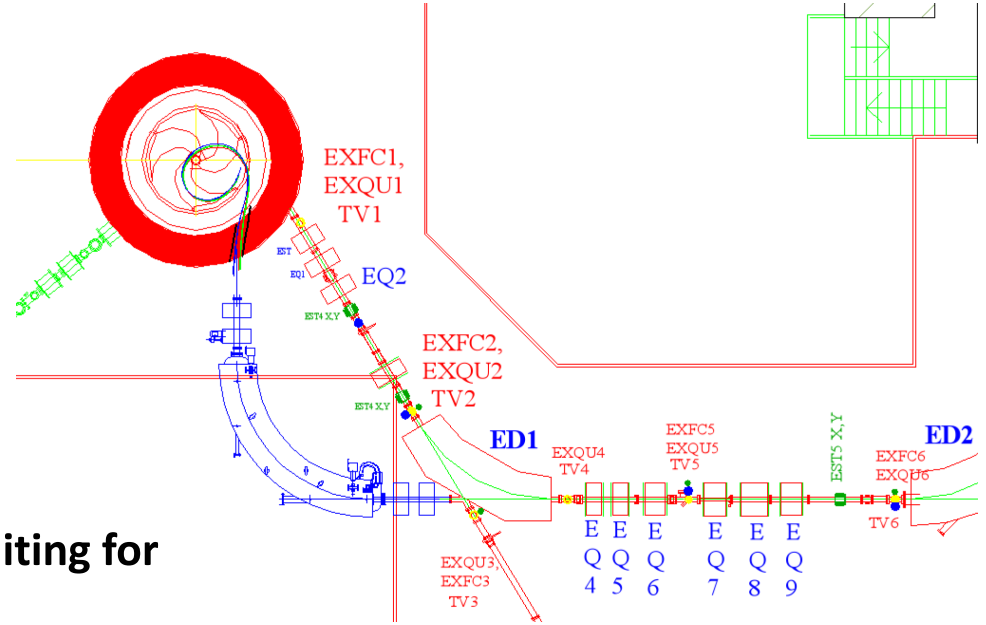
- The CS accelerator current (from 100 W to 5-10 kW);

Cost: 10.5 M€



Extraction by stripping

- The beam transport line transmission efficiency to nearly 100% (*Cost including FRIBs and Magnex beam line Upgrading 5.5 M€*)



The tender for the New Cryostat is running. Still waiting for the PON IR. Total Cost 16 M€

The Phases of NUMEN project

- **Phase1**: The experimental feasibility
- **Phase2**: "hot" cases optimizing the experimental conditions and getting first results (approved)
- **Phase3**: The facility Upgrade (Cyclotron, MAGNEX, beam lines, …..)
- **Phase4** : The systematic experimental campaign

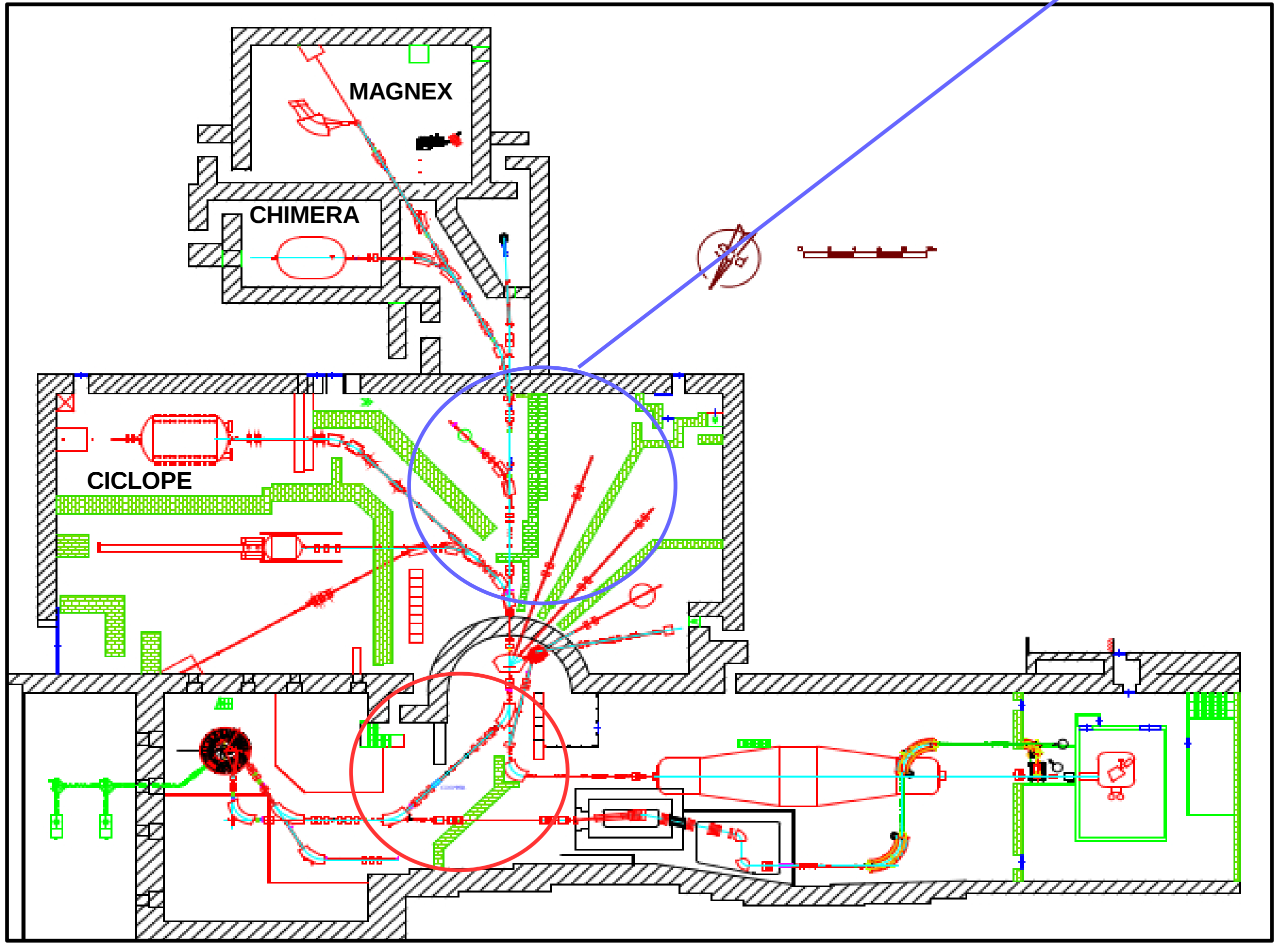
Timetable

year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Phase1	done									
Phase2				Approved						
Phase3										
Phase4										

CS UPGRADE → FRIBs - UPGRADE

Actual LNS Layout

- The proposed new FRIBs area con and pro:



- **PRO**
- It is outside from the accelerators room/vault;
- It is easier to shield this area;
- It is a completely new beam line (the pro is that the performance are optimized by the new design;
- The construction will proceed in parallel with the upgrade of the cyclotron;

- **CON**
- Loss of 2 of the present experimental tandem areas, even if one of them could be partially recovered.
- The cost.

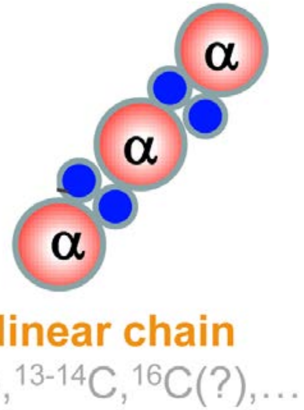
Beams with the new fragment separator

BEAM	primary beam / energy (AMeV)	thickness be target (μm)	thick wedge (μm)	optimistic YIELD FRIBS 100 W (kHz)	purity %	prymary beam intensity (kW)	YIELD new separator (kHz)	purity %	beam energy after tagging (AMeV)
14Be	18O/55	1500	0	0,06	1	2	2,6	2	46
14Be	18O/55	1500	1000	0,04	95	2	2,2	70	43
13N	16O/40	700	600	14	58	2	1230	54	4
14O	16O/40	700	600	10	41	2	807	36	4
18Ne	20Ne/60	1000	0	330	20	2	16700	16	43
18Ne	20Ne/60	1000	1000	34	58	2	3120	47	24
17F	20Ne/60	1000	1000	24	41	2	3300	49	23
34Si	36S/40	500	500	20	90	2	980	81	11
38S	40Ar/40	500	300	63	90	2	1840	66	17
34Ar	36Ar/50	250	0	141	10	2	2800	4	41
34Ar	36Ar/50	250	500	22	44	2	426	12	41
68Ni	70Zn/40	250	200	53	80	1	490	50	18

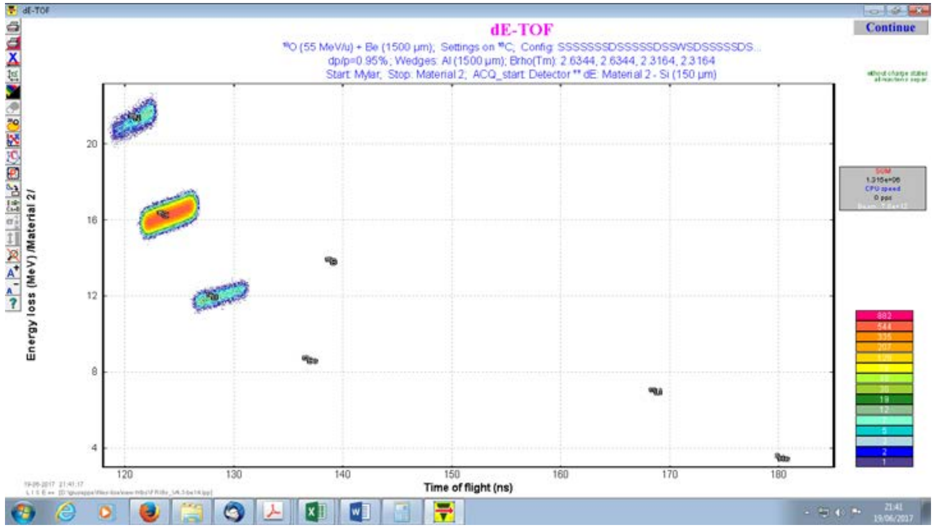
CHIMERA – FRIBS upgraded

Most of the themes studied up to now will be further developed using radioactive beams

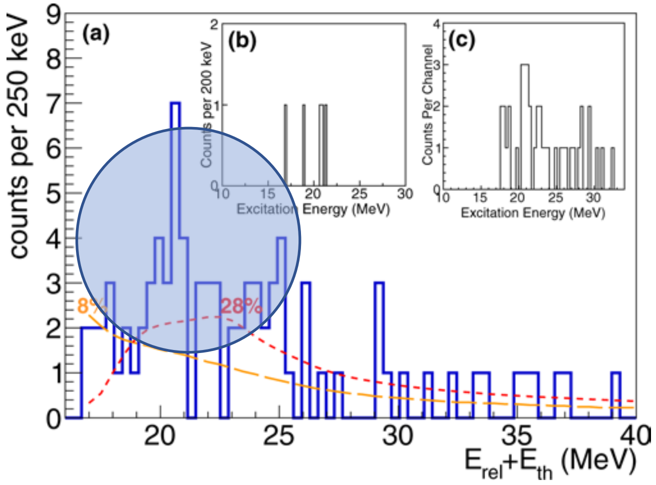
Very important for NEWCHIM experiment, the possibility to improve intensity for light-medium fragmentation beams in order to study exotic clustering



On the same topic of the **exotic clustering phenomena** explored in ^{10}Be, primary beams with higher intensities can be used to produce ^{16,18}C using FRIBS searching for channel ^{6}He + ^{10}Be



Predicted intensity ^{16}C @ 34*A* MeV: 2x10^{6} pps
Contaminant: 2%

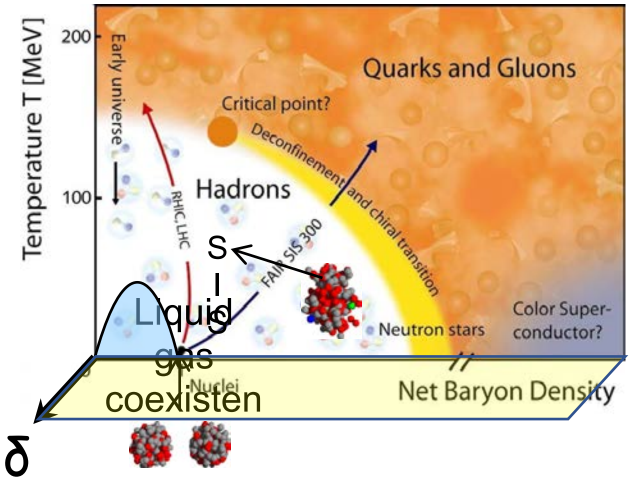


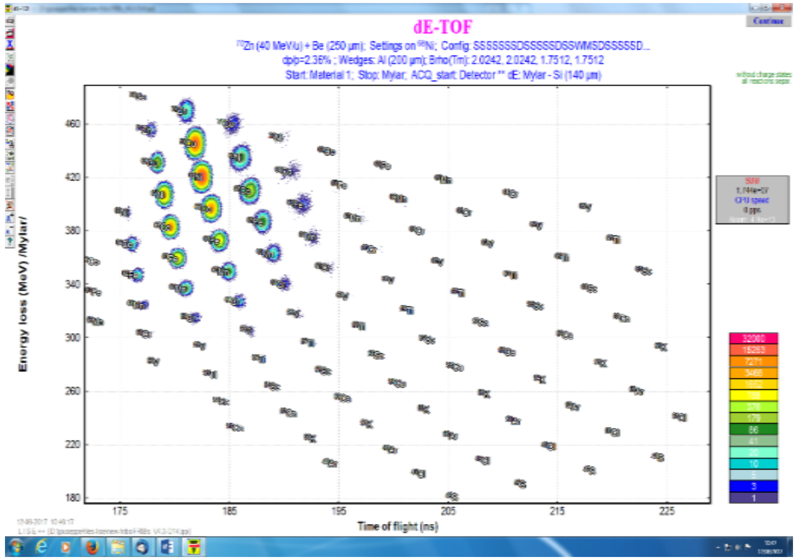
Indication of the presence such kind of resonances in ^{16}C was already observed but higher statistics is needed

CHIMERA – FRIBS upgraded

Most of the themes studied up to now will be further developed using radioactive beams

Nuclear matter phase diagram (schematic)

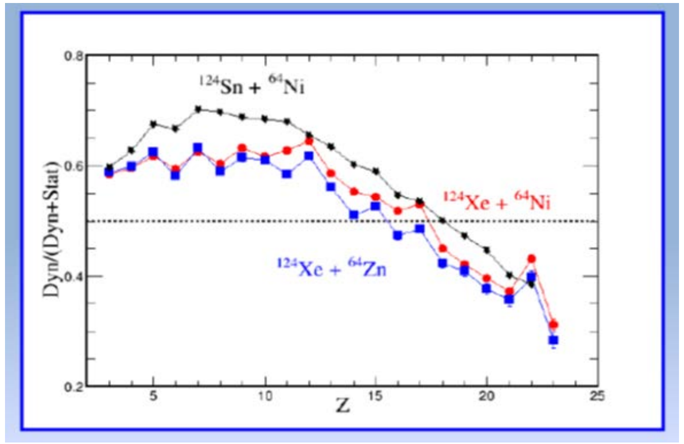




Predicted intensity of ^{68}Ni 3x10^{5} part/s

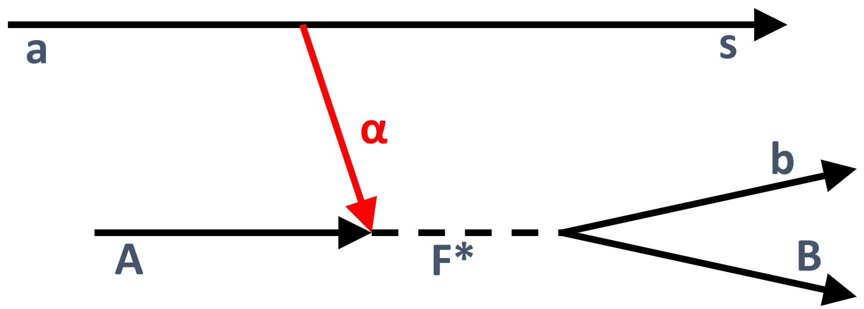
EOS study using ^{68}Ni around Fermi Energy

Use of ^{68}Ni beam could allow to extend previous measurement performed with stable beams enhancing **the effects due to isospin asymmetry** (as found in dynamical fission and pygmy resonances)



By G.Cardella and S.Pirrone

Nuclear astrophysics @ FRIBS upgraded



Using **^{6}Li** or **^{20}Ne** we can transfer a α particle and induce the reaction of astrophysical importance at the <u>relevant energies</u>

^{14}O(α,p)^{17}F → **breakout from the hot CNO cycle**: in explosive hydrogen burning, this reaction determined the permanent loss of catalysts leading to the production of heavy (A>100) proton-rich nuclei

^{13}N(α,p)^{16}O → In **asymptotic giant branch (AGB) stars**, the ^{13}C(α,n)^{16}O reaction is the n-source for heavy element production. However, the ^{13}C supply might be reduced if ^{13}N is burnt to ^{16}O before it decays → **influence on the s-process** in massive AGB stars

^{34}Ar(α,p)^{37}K → ^{34}Ar is a waiting point in **x-ray bursts**: if the (α,p) reaction rate is weak OR if the temperature is too low to overcome the Coulomb barrier, nuclear flow must await β decay before continuing on → **influence on nucleosynthesis and luminosity**

^{18}Ne(α,p)^{21}Na → it influences X-ray burst light curves as well as nucleosynthesis, in particular the abundance of ^{15}N, ^{18}F, ^{21}Ne and ^{33}S in the ashes of the thermonuclear runaway

Complementary to SPES

https://web.infn.it/spes/images/NEW_SITE/PDF/SPES_Beam_Tables/4_beam_spes_all.pdf

The PANDORA collaboration

INFN
Istituto Nazionale di Fisica Nucleare

INFN-LNS
Plasma studies

INFN-LNL
Beam-Plasma interaction

CSN-V

INFN-LNS
Nucl. Exp. aspects

INFN-Pg
Theory

INFN-other section interested (Bo, Ts, Ge)

CSN-III

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

University of Michigan
University of Cambridge

Collaborations

Official declaration of interest

MTA atomki DEBRECEN

GANIL
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS
LABORATOIRE COMMUN DSM/CEA-IN2P3/CNRS

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

PAUL SCHERRER INSTITUT
PSI

PANDORA's team – feasibility study (CSN-V)

Around 30 members, including researches (physicist, astrophysicist especially) and engineers (RF, mechanics, electronics) are involved, with a **total number of about 13 FTE**.

International cooperation already started. Partners:
Hungarian Academy of Sciences (an official Letter of Interest has been signed by the ATOMKI - Institute of Nuclear Physics Director); the **Laboratoire de Physique Subatomique & Cosmologie** of Grenoble - France (joint experimental activity will start in november 2017); the Laboratories of **GANIL - Caen**, France; the **University of Cambridge - UK** and the **University of Michigan (USA)** for the synergies relying to Astrophysics.

PANDORA – *feasibility study (CSN-V)*

The **feasibility study 2017-2018**. **BUDGET: around 150 k€** **(units: LNS+LNL)**; it is supported by the 5th Nat. Comm. of INFN including ***two milestones***:

1. Feasibility of **space-resolved measurements of the in-plasma Charge State Distribution** of ions in the magnetoplasmas

2. Handling and optimizing the **injection** efficiency **inside the magnetoplasma of the different radionuclides, such as ^{7}Be**

3. For the late 2018 (deadline: December 31, 2018) a release of a TDR for the "full-scale" plasma trap and the system of RIBs injection into the magnetoplasma is expected.

MEMORANDUM OF UNDERSTANDING

TRA

ISTITUTO NAZIONALE DI ASTROFISICA,
OSSERVATORIO ASTRONOMICO DI CATANIA

E

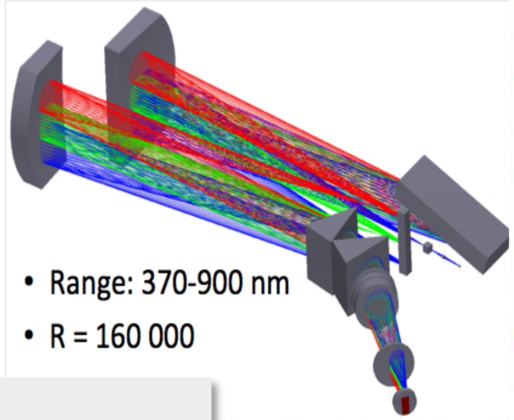
ISTITUTO NAZIONALE DI FISICA NUCLEARE,
LABORATORI NAZIONALI DEL SUD

RIGUARDANTE

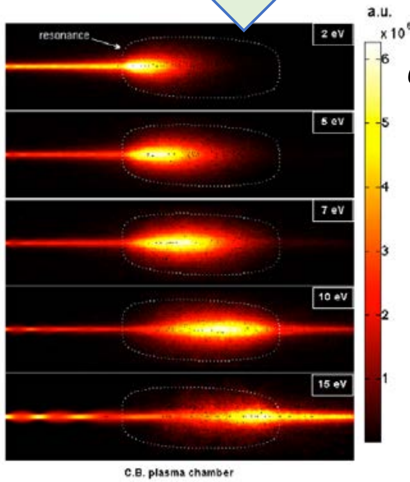
Un'intensa sinergia su obiettivi comuni della ricerca scientifica al fine di incentivare le attività interdisciplinari basate sulla fisica e temperatura, di interesse per la produzione di fasci io l'astrofisica osservativa, e segnatamente nel camp microonde in plasmi magnetizzati, della spettrosc spettropolarimetria, e dell'analisi dell'emiss

INAF-INFN
Agreement signed on August 7th, 2017!!

Spettrografo Alta Risoluzione Galileo



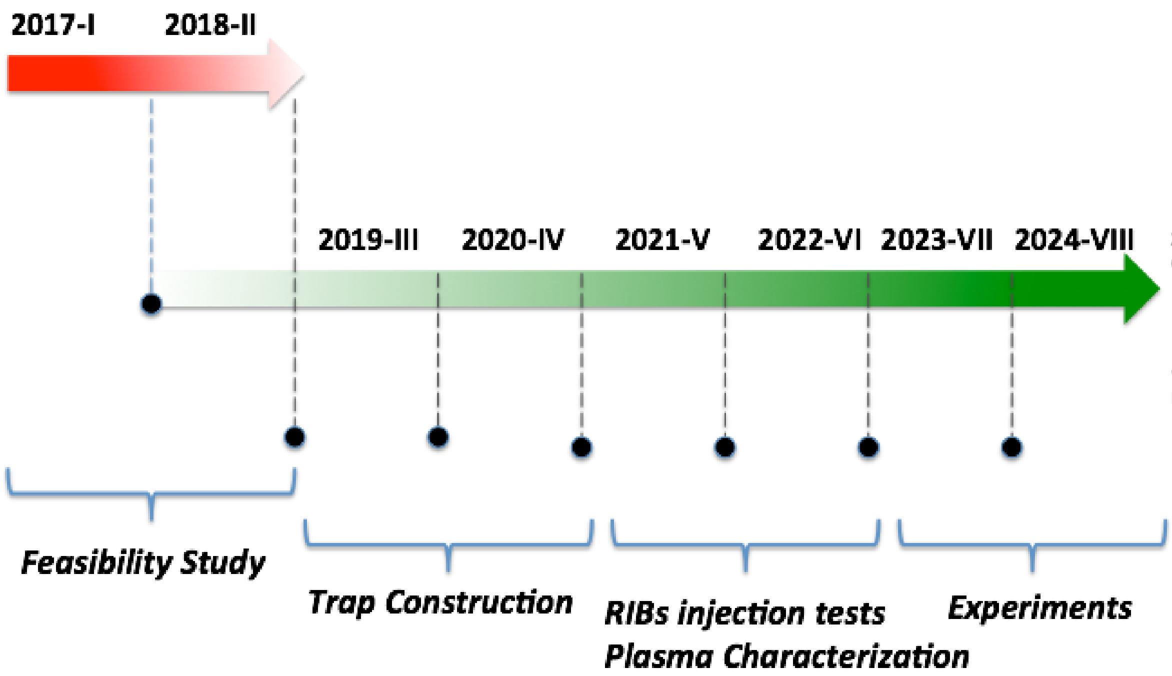
- Range: 370-900 nm
- R = 160 000

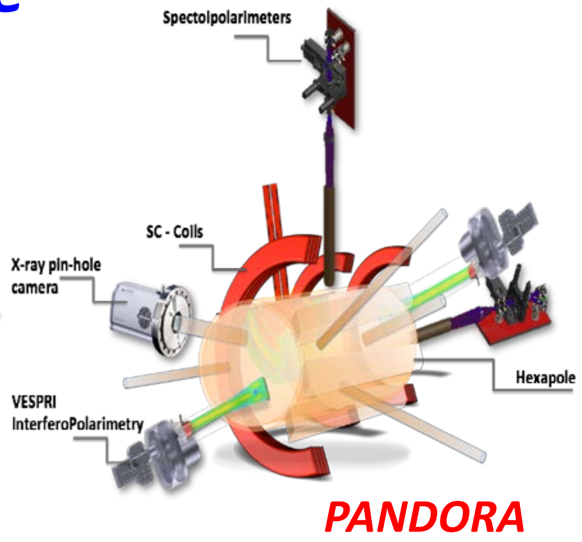


Simulations and experiments about charge breeding of light elements in high-density/high-temperature ECR plasmas

An Experiment is already Scheduled at LSPC-Grenoble for ^{7}Li charge breeding: 1-12 November, 2017

Towards PANDORA – fullscale

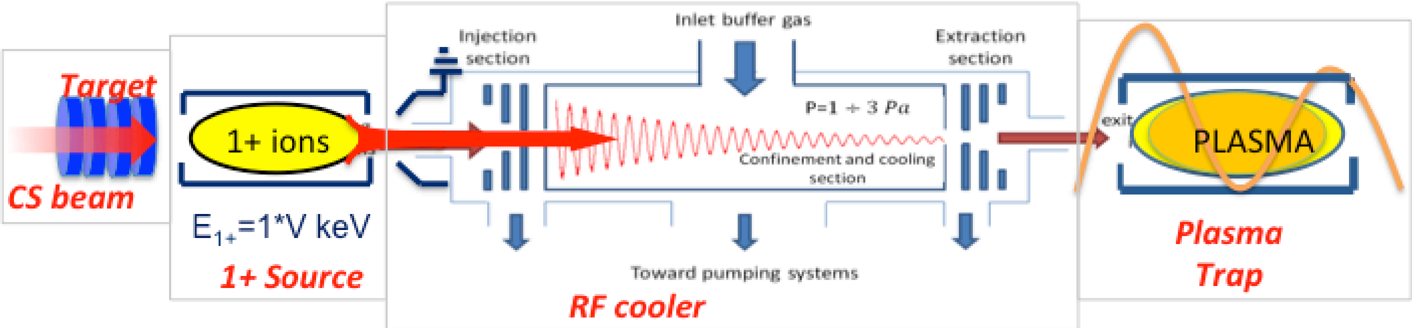




The total Budget can be subdivided according to the main subsystems:

PLASMA TRAP (superconducting magnets, RF system, diagnostics): ***2.25 M€***

Production of Radionuclides via LNS-CS + 1$^+$ source + RF-cooler: ***750 k€***



Other than the first physics case of ^{7}Be, other radionuclides to be produced on-line include:

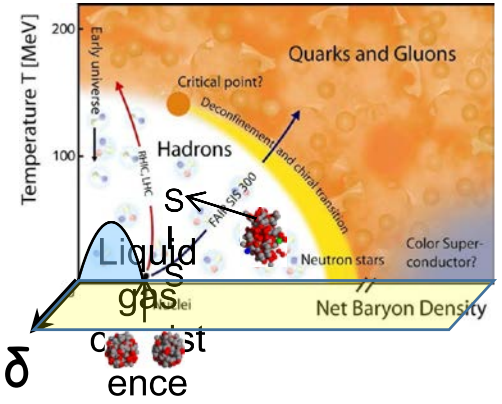
- ^{8}B (for investigating the $\beta^+2\alpha$ decay – *solar neutrino problem*)
- CNO cycle, ^{13}N, ^{15}O and ^{17}F decaying β^+

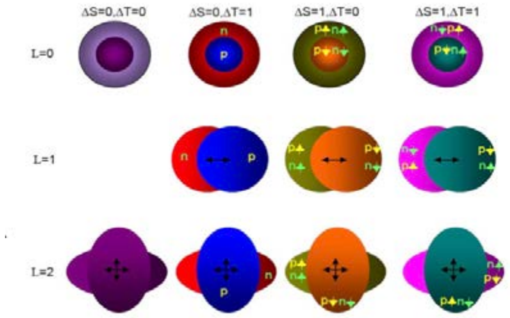
Targets of BN and/or C will be designed and irradiated by high intensity C, O and Ne beams

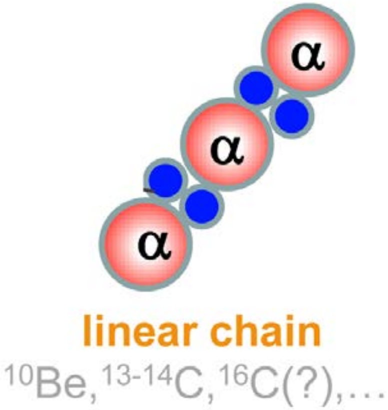
Outlook

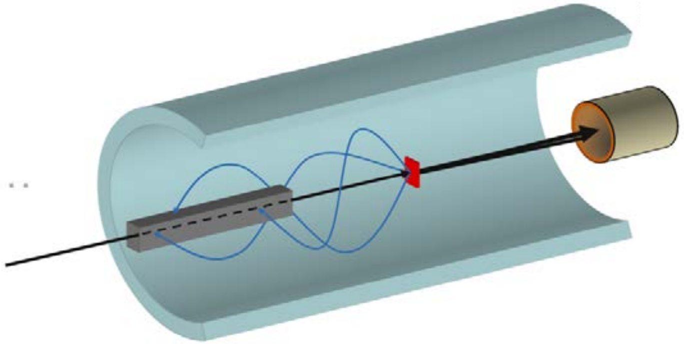
NUMEN

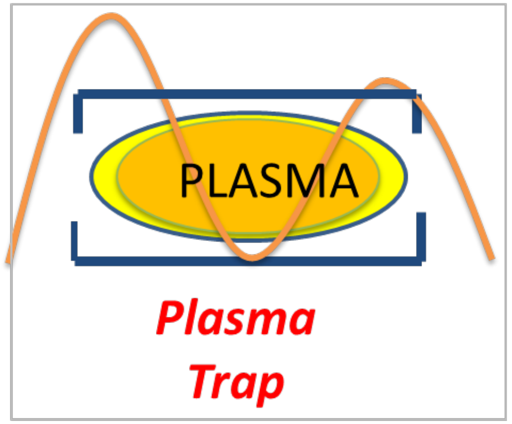
Nuclear matter phase diagram
(schematic)

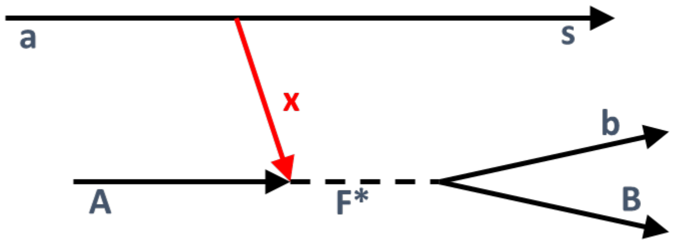








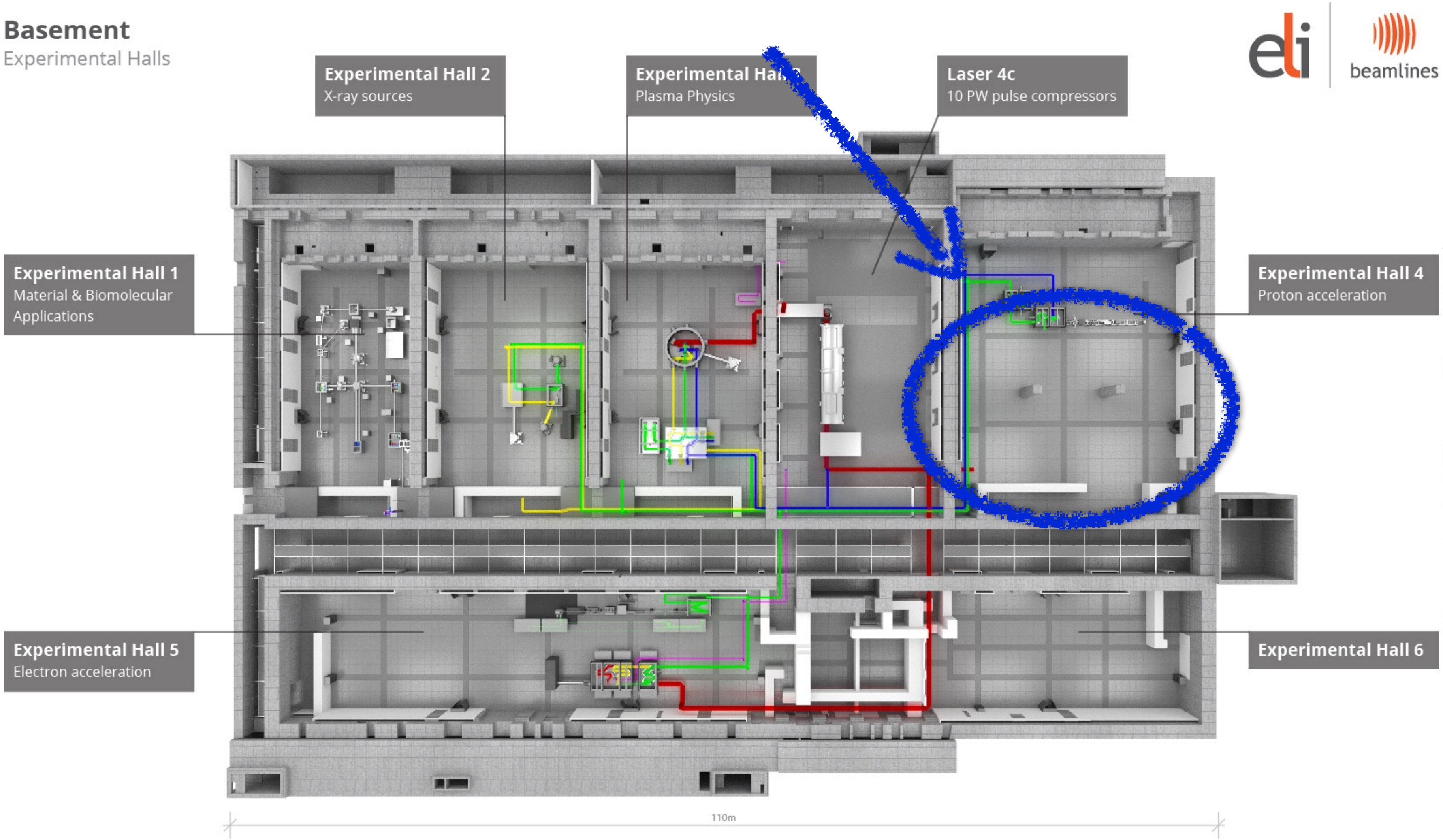


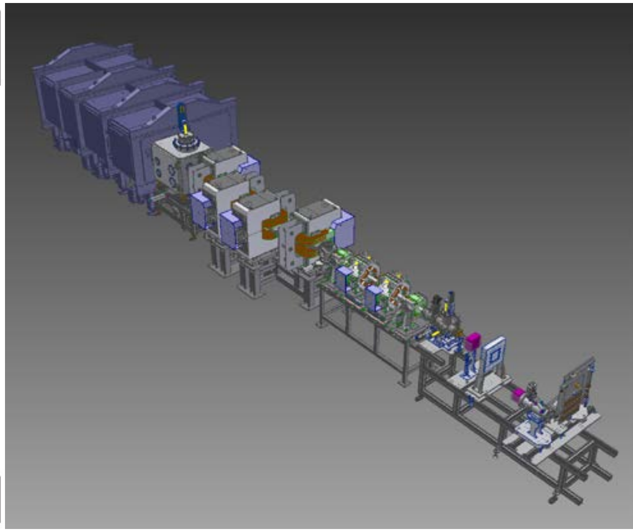


ELIMED:
ELI-Beamlines MEDical and multidisciplinary applications

- Design and development of a transport beamline for the next generation of laser-driven beams
- Design and development of diagnostic and dosimetric devices to measure the absolute and relative dose and the characteristics of laser-driven beams
- The final beamline will be installed at the ELI-Beamlines facility (Prague, CZ) within March 2018

ELIMED beamline at the ELI facility





Actual status

Status ELIMED

WP1 (Ion Beam Collection and Diagnostics)
- *permanent magnet quadrupole set*
- *TOF detector (SiC/Diamond/SEM)*
- *beam emittance diagnostics*

READY → It will be delivery to ELIMAIA at the end of October

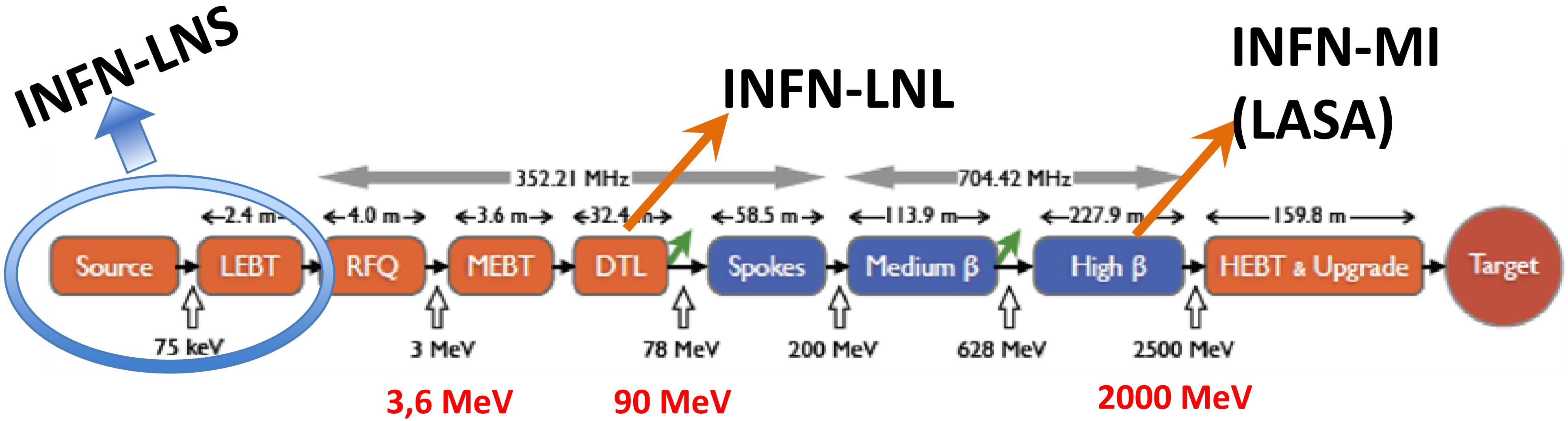
WP2 (in-Vacuum ion Beam Selection, Transport and Diagnostics)
- *Energy Selector*
- *Resistive quadrupole & steering magnet set*
- *TOF detector (SiC/Diamond/SEM) (READY)*

PARTIALLY IN LATE → It will be delivery to ELIMAIA at the end of January

WP3 (Dosimetry and sample Irradiation systems)
- *SEM detector*
- *Ionization Chamber*
- *RCF set*
- *Faraday Cup*
- *Sample irradiation system*

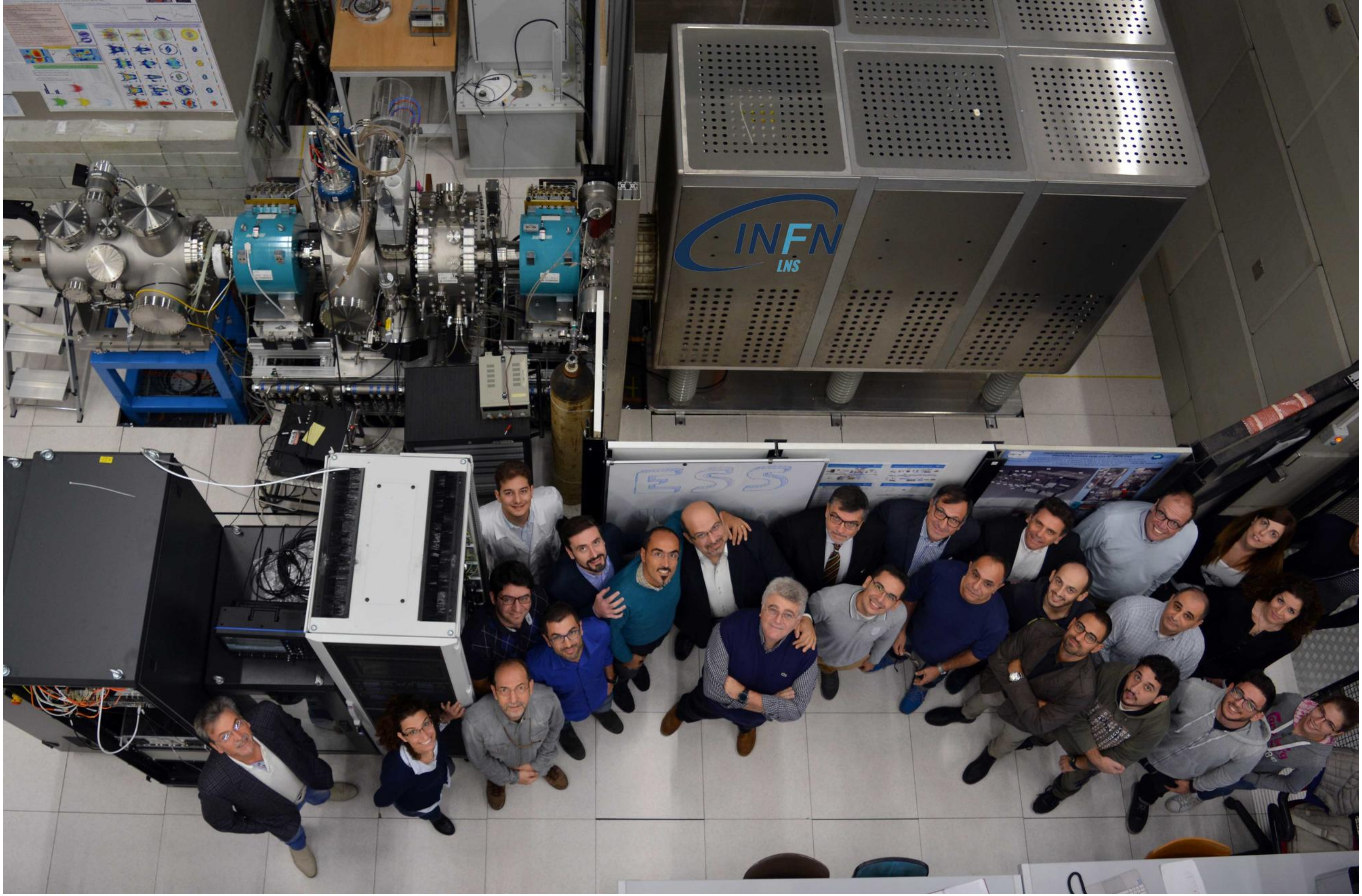
READY → It will be delivery to ELIMAIA at the end of October

ESS - The INFN contribution



INFN has been involved in the Design Update phase (2011-12), for several components of the LINAC, and it is involved in the next phase, aimed to the construction of prototypes :

- The Proton source (ready and moving from LNS to Lund)
- The LEBT (ready and moving from LNS to Lund)
- The Drift Tube Linac
- The Superconducting elliptical cavity @ high energy section


INFN
LNS
ESS


www.pi4.it
www.mtab.se
Finland

New Km3NeT Management Structure

- The Management Team meets fortnightly

Spokeperson: ***M. Taiuti***
Deputy spokesperson: A. Heijboer
Technical Project Manager: E. Koffeman
Physics & Software Manager: P. Coyle

Project Management Team

Installation Site Manager KM3NeT-Fr
P.Lamare

Installation Site Manager KM3NeT-It
N. Randazzo

Installation Site Manager KM3NeT-Gr
S. Harissopulos

- The Steering Committee meets monthly

Data Management
Off-line Software & Computing: K. Graf
On-line DAQ/Readout: ***T. Chiarusi***

Detector Construction
Qualification: S. Henry
Mechanics: E. Berbee
Electronics: D. Real
PMT: ***P. Migliozzi***
DOM integration. ***D. Vivolo***
DU integration: ***I. Sgura***
Power system: ***R. Cocimano***
Optical system: G. Kieft
Calibration: ***G. Riccobene***

Project Steering Committee

KM3NeT-INFRADEV

Start January 2017

Budget from EC 3.8 M€ (0.7 M€ for INFN)

Coordination NIKHEF
    (P. Piattelli for INFN)

Main Goal:

Preparation of legal entity
- sustainable organisation for envisaged live time
    - ERIC brings along support at ministerial level

Value added services
- Science
    - multi-messenger astronomy
    - cooperation with other science communities
- Openness
    - open data access
    - access to the infrastructure via user ports
- Society
    - outreach
    - human capacity building
    - technology transfer
    - green operation

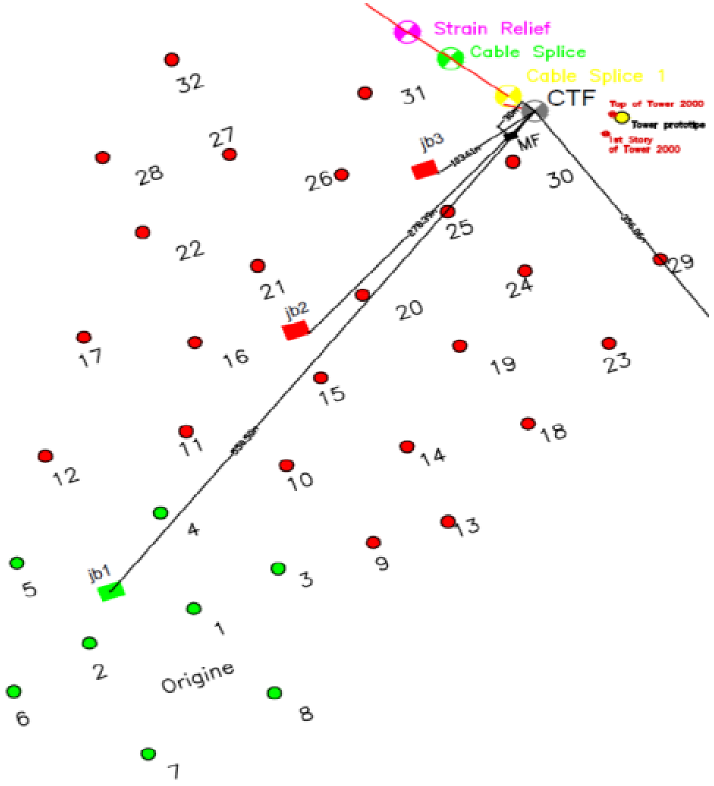
H2020 - ERIC working group

chair: Hans Chang		
Country	**Representative**	**Science delegate**
The Netherlands	Jeanette Ridder-Numan	Maarten de Jong
France	Jean-Pierre Caminade	Marine Moguen-Toursel
Germany	n.a.	n.a.
Spain	Inmaculada Figueroa	Juan Jose Hernandez Rey
Italy	Salvatore La Rosa	Piera Sapienza
Greece	Maria Koutrokoi	Christos Markou

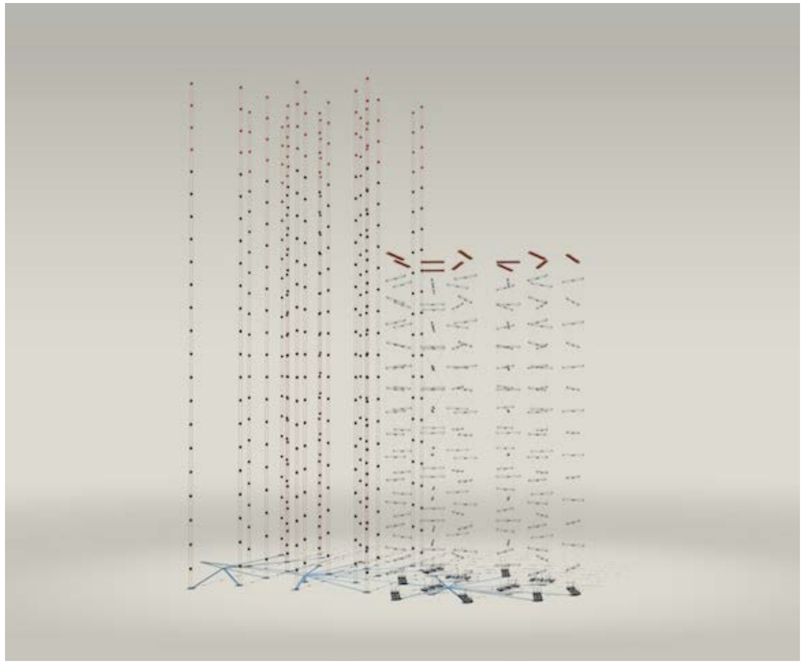
First explorative meeting of the ERIC working group held on 30 June 2017 in The Hague, The Netherlands. Last Meeting 11-12 oct 2017.

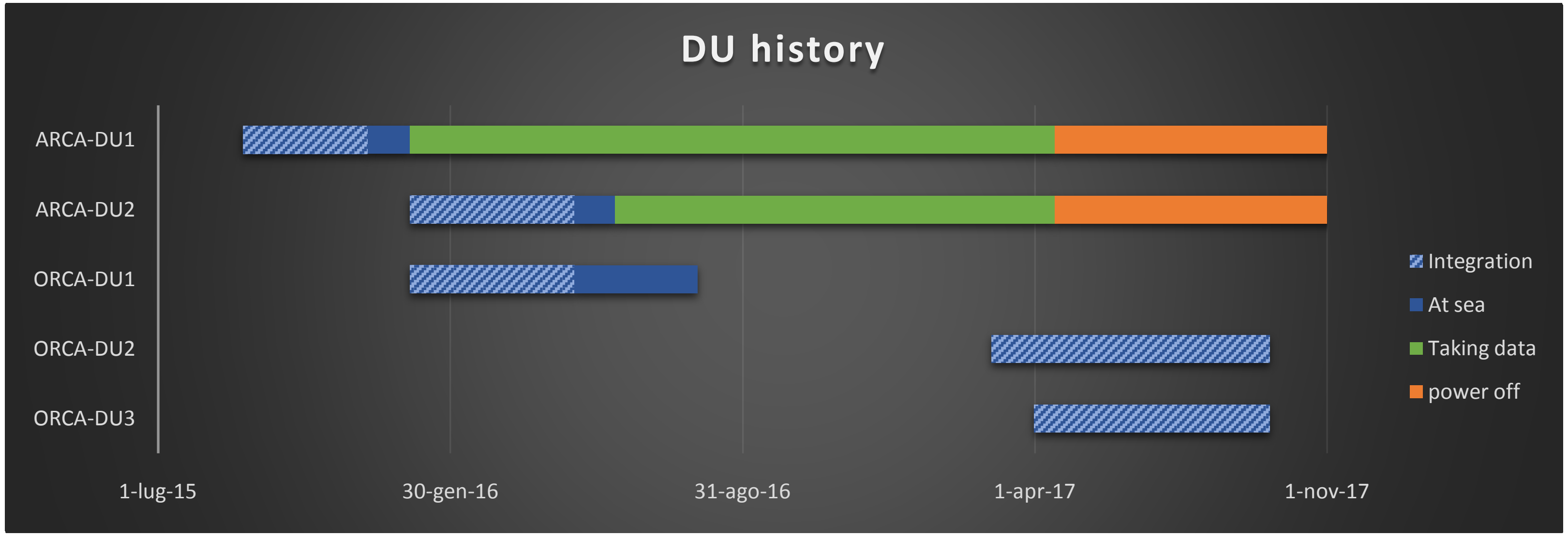
Phase 1 History

- Foreseen
  - 24 ARCA DUs
  - 6 ORCA DUs
- Realized so far
  - 3 ARCA DUs
  - 2 ORCA Dus (1 realized from INFN Successfully in operation)

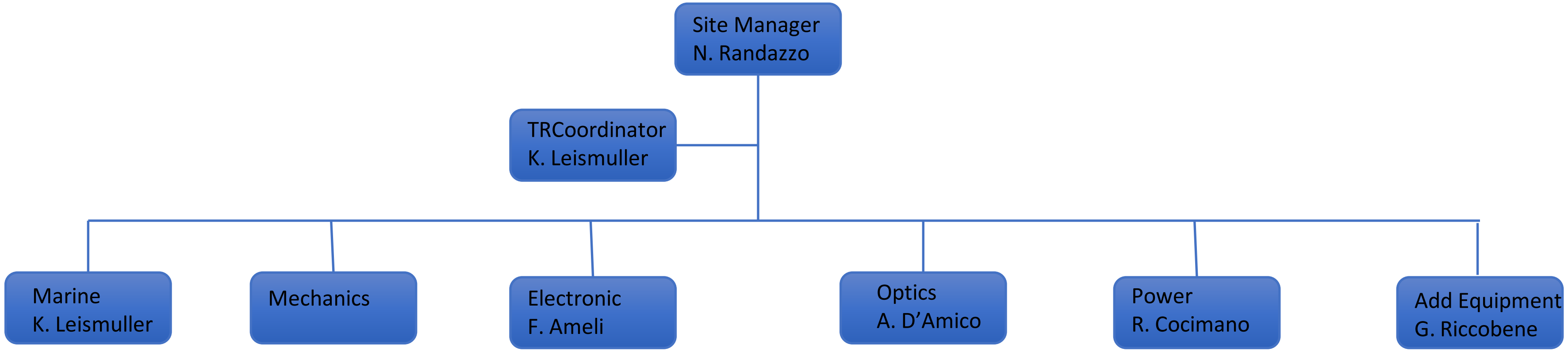


CTF: Cable Termination (Frame)
: Secondary Junction boxes
: Tower DU
: String DU
: PPM-DU





Technical Review Organization



T
E
A
M

Mechanics
- Carmelo D'Amato
- A. Grmek
- M. Sedita
- A. Miraglia

EXTERNAL
- Gene Massion

Electronic
- C. Nicolau
- F. Simeone
- A. Lonardo
- G. Riccobene

Optics
- J-W Scmelling
- G Kieft
- S. Pulvirenti

Power
- F. Amelli
- C.A. Nicolau
- A. Orlando

EXTERNAL:
- R. Masullo

Add Equipment
- F. Simeone
- S. Viola
- C.A. Nicolau
- Elio Poma

Review focus:

- Junction Boxes
- Subsea Cables
- Inventory and Management
- Project Organization
- Quality Management System
- Towers (<u>assembling & installation NOW stopped according CVI rec</u>.)
- Onshore Interface

Technical Review - Outcome

KM3NeT - High level observations

Overall the core areas of the project are in good shape. The technical requirements to perform the outlined task by the science community according to the Technical Design Report (TDR) are in place (REFERENCE to LOI, J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001 (130pp)_Letter of intent for KM3NeT 2.0)

Good solutions have been found and are incorporated in the technical implementation of the project.
The **basic infrastructure is in place**. Over and above the project infrastructure can provide support to additional applications for the science community.
The **main lesson learned** is that: due to the extreme complexity of KM3NeT, challenging ambient conditions and an expected **20 year-long operation** time, it is fundamental that **none of the steps** in the design, qualification, integration and test phases that ensure the high reliability of all detector components and of the overall system, are **bypassed**.
The stringent time frame imposed by some funding agents and stakeholders had a strong impact regarding reliability, and overall quality control and quality assurance of the project.

- **Manufacturing Engineering and System Engineering** has been neglected or not been incorporated due to lack of in-house experience.

- The design is too **complicated and complex**. This is reflected in using several pressure vessels and a manifold to manage the system in the Junction Boxes. This results in an abundance of connectors and connections, as well as having more parts than necessary and different technologies.

- The issue of **components in oil under pressure over a 20-year lifetime** has not been fully assessed (in particular optical connectors internal to the manifold structure).

- **This complexity and design philosophy in combination with the insufficient testing and qualification process cannot result in a system with 20 years lifetime.**

Technical Review - Recommendations

Change of philosophy required - Subsea Engineering

- **Restructure** the project and adopt a similar organizational chart as for the TR.
- **Hire an external Project Manager** who has substantial knowledge in manufacturing engineering, system engineering and qualification and testing standards.
- **Mechanics,** also due to organizational changes, should have **a new team leader** in an adjusted role. The position should cover the gap between scientific necessities and best practice engineering, through a liaison function with industrial and external scientific partners.

- A clear **standard for all testing activities** and a corresponding testing and qualification plan has to be established, implemented and executed
- A **quality workshop** should be held in Catania to highlight the relevance of qualification in the subsea environment to all persons working on the project.

- The **manufacturing and assembly** of basic subsea components should be **outsourced** to an industrial company with the relevant experience. The same applies to the electronic boards.
- The production of JB3 (current design) should be put on halt and a **new JB design** based on the new CTF philosophy should be developed by a third party. The goal of the new design must be:

- Introduce 'best practice' in subsea engineering

- Reduce complexity

- Adaptation to subsea campaign requirements at 3500m

- Longevity of all components and materials

Phase 1 (the bad)

- Main failures occurred in the last year
  - ARCA DU 3
  - ARCA Junction Box Phase-1
- Investigation of failures allowed to find and solve several problems
- But last failure still without solution (money and vessel unavailability to survey the site and to try to recover bypass the failure and recover the system)

Phase 1 (the goods)

ARCA DU3

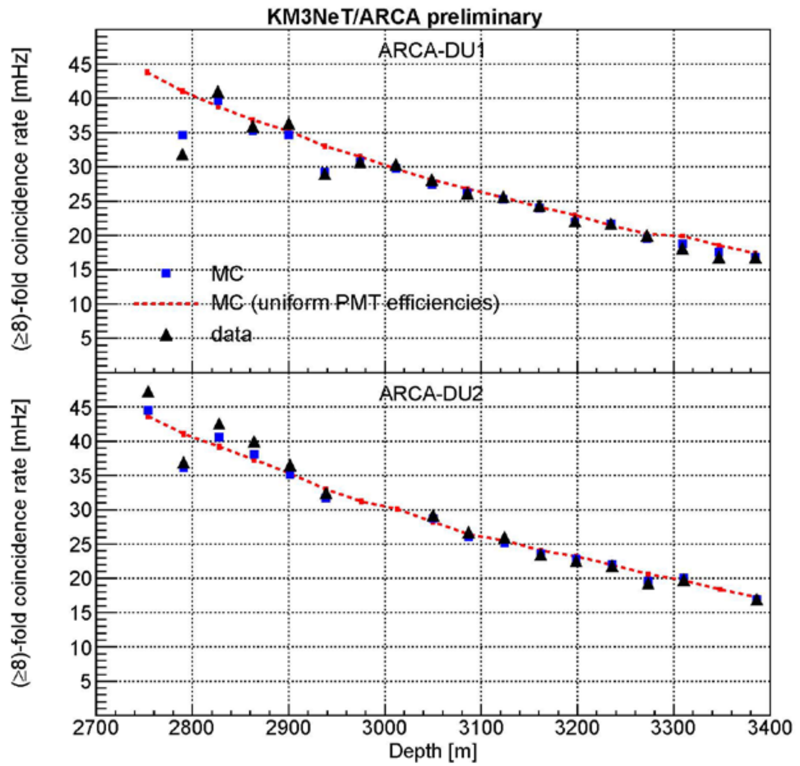
Modified grounding scheme inside the DOM

Improved design of the VEOC (dedicated assembly tools realized by NIKHEF+LNS)

JB Phase-1: Problems understood and solved with MacArteney (tender starting)

Phase 1 Summary

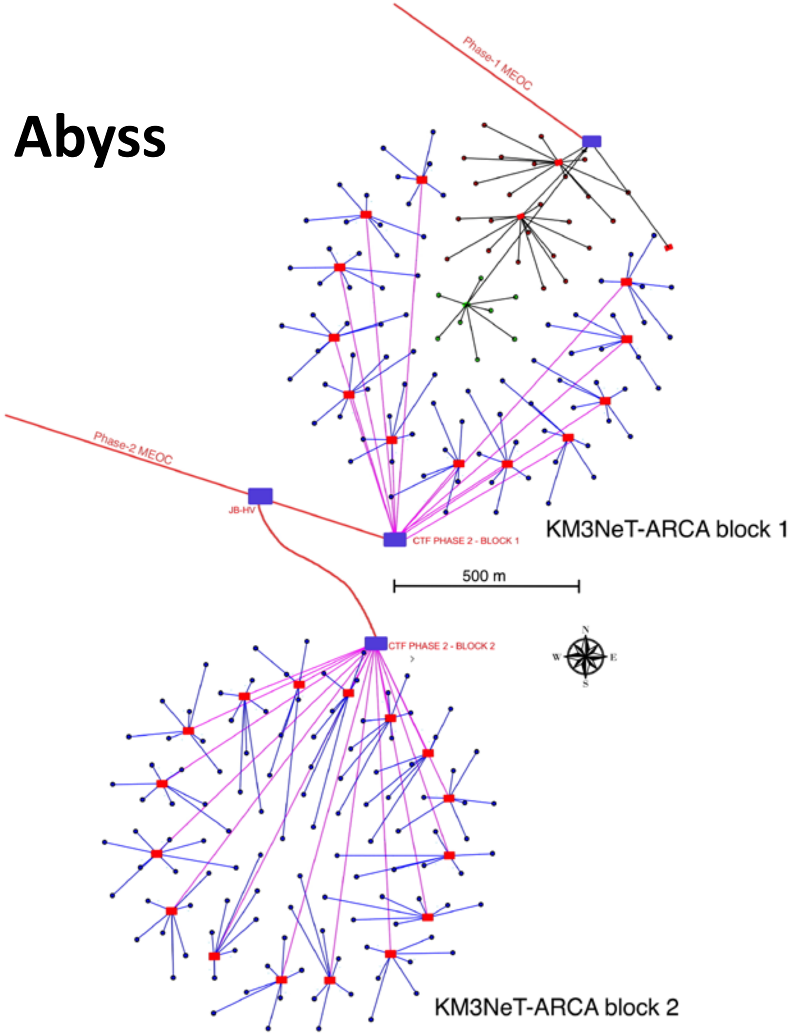
- Early «infant mortality» intrinsic of any starting project (obviously we cannot exaggerate!)
- Several lessons learned
- Quality of DUs highly improved
- Quality Assurance generally improved
- The detectors performances are well under control
- Project manager coming from industry has been just appointed



ARCA-DU1 and ARCA-DU2
Deployed December 2015 and May 2016 at Capo Passero, Sicily
Worked till April 2017
Data analysis of atmospheric muons shows excellent agreeement between data and MC

Phase 2

ARCA: Astronomy Research with Cosmics in the Abyss



To be installed in the Italian site of the KM3NeT infrastructure

115 detection units per building block

18 DOM per DU

Vertical DOM spacing 36 m

Inter-DU spacing 90 m

2 building blocks

Total volume ≈1 km^3

Budget

France: 8 M€ secured, new request for 20 M€ ongoing

Italy: POR Sicilia 34.5M€ secured (50% INFN co-funded with MIUR ESFRI Money for Km3NeT)

The Netherlands: new request for 12.7 M€. Decision in 2018. ARCA & ORCA contribution to be defined.

Italy: PON IR 16 M€ ongoing

New Cable:	14	M€
JB (phae 1 & 2)	4.5	M€
Marine Operations	4.0	M€
LOM x 8	0.4	M€
25 Strings	7.0	M€
Completion phase1	1.5	M€
Buildings and plants	2.0	M€
Other Costs	1.5	M€

Goal: In 2022 72 strings e 8 Towers (Budget from PON 2007-13, POR Sicilia, PON IR 2014-2020) in operation. At least 24 strings already in operation late spring 2019.

Dutch, French, other countries contribution to be understood!!!

Time schedule

Spring 2018: site review and installations of 3 strings.

Fall 2018: Installation of new JBs and 3 strings

Spring-summer 2019: 3 marine operations for the installations of 18 strings.

Start Integrazions strings phase 2

Autumn 2019: Installation of new cable with MVC e JBs

Spring 2020: 3 marine operations for the installations of 22 strings

…. We are still waiting the new PON (expected Nov 2017)

Km3NeT is going to be ready for Multimessanger Astronomy

LNS is going to be ready for Multimessanger Astronomy with Km3NeT, Nuclear Astrophysics and Pandora, even thanks to the upgraded Superconducting Cyclotron