INFN LNS
Istituto Nazionale di Fisica Nucleare

The NUMEN Project

C. Agodi, F. Cappuzzello, M. Bondì, L. Calabretta, D. Carbone, M. Cavallaro, M. Colonna, A. Cunsolo, G. Cuttone, A. Foti, P. Finocchiaro, V. Greco, L. Pandola, D. Rifuggiato, S. Tudisco

INFN - Laboratori Nazionali del Sud, Catania, Italy; INFN - Sezione di Catania, Catania, Italy; Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy;

!

A basic question in modern Physics

Neutrinos play a fundamental role in various areas of modern physics from nuclear and particle physics to cosmology.

- *1930: W.Pauli hypothesis of existence of neutrino to explain the energetic spectrum of electrons emitted in β decay*
- *1935 : Maria Goeppert Mayer described for the first time the $2\upsilon\beta\beta$ decay*
- *1937: E.Majorana article: ”Teoria simmetrica dell’elettrone e del positrone” Il Nuovo Cimento 14 (1937) 171*

- **1986: first discovery of $2\upsilon\beta\beta$ decay predicted by Maria Goeppert Mayer in 1935**

(today found in ≈12 nuclei)

- **1998: discovery of neutrino oscillations and the non-zero mass of neutrinos, predicted by Pontecorvo in 1957**

Neutrino mass explanations: all are based on some form of new physics beyond the Standard Model. Measurement of the neutrino masses and mixing can open a window on the physics of “Unification” .

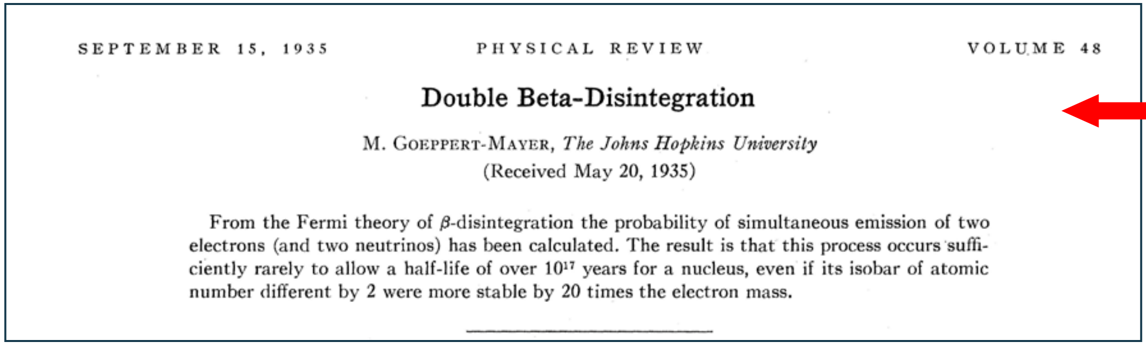
A basic question in modern Physics

Neutrinos play a fundamental role in various areas of modern physics from nuclear and particle physics to cosmology.

- *1930: W.Pauli hypothesis of existence of neutrino to explain the energetic spectrum of electrons emitted in β decay*
- *1935 : Maria Goeppert Mayer described for the first time the $2\upsilon\beta\beta$ decay*
- *1937: E.Majorana article: "Teoria simmetrica dell'elettrone e del positrone" Il Nuovo Cimento 14 (1937) 171*

- **1986: first discovery of $2\upsilon\beta\beta$ decay predicted by Maria Goeppert Mayer in 1935**

(today found in ≈12 nuclei)



SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

Double Beta-Disintegration

M. Goeppert-Mayer, *The Johns Hopkins University*
(Received May 20, 1935)

From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

Described for the first time by Maria Goeppert-Mayer (1935),

- **1998: discovery of neutrino oscillations and the non-zero mass of neutrinos, predicted by Pontecorvo in 1957**

Neutrino mass explanations: all are based on some form of new physics beyond the Standard Model. Measurement of the neutrino masses and mixing can open a window on the physics of "Unification" .

Is the neutrino a Majorana or Dirac particle?

The question if the neutrino is a Dirac or Majorana particle is equivalent to the question if the reversal of the spin of a neutrino would turn it into an antineutrino or not.

$L(\nu_e, e^-) = -1$

$L(\bar{\nu}_e, e^+) = +1$

The lepton number, as charge, is conserved

Dirac $\nu_e \neq \bar{\nu}_e$

$H(\nu_e) = -1$

$H(\bar{\nu}_e) = +1$

The ν behaviour is determined by elicity

Majorana $\nu_e = \bar{\nu}_e$

if $m_\nu = 0$ ⇒ L = H

DIRAC = MAJORANA

Is the neutrino a Majorana or Dirac particle?

The question if the neutrino is a Dirac or Majorana particle is equivalent to the question if the reversal of the spin of a neutrino would turn it into an antineutrino or not.

$L(\nu_e, e^-) = -1$
$L(\bar{\nu}_e, e^+) = +1$

The lepton number, as charge, is conserved

Dirac $\nu_e \neq \bar{\nu}_e$

$H(\nu_e) = -1$
$H(\bar{\nu}_e) = +1$

The ν behaviour is determined by elicity

Majorana $\nu_e = \bar{\nu}_e$

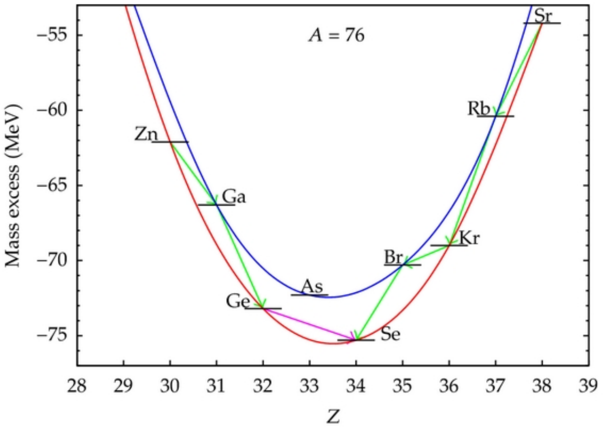
if $m_\nu = 0$ → L = H
DIRAC = MAJORANA

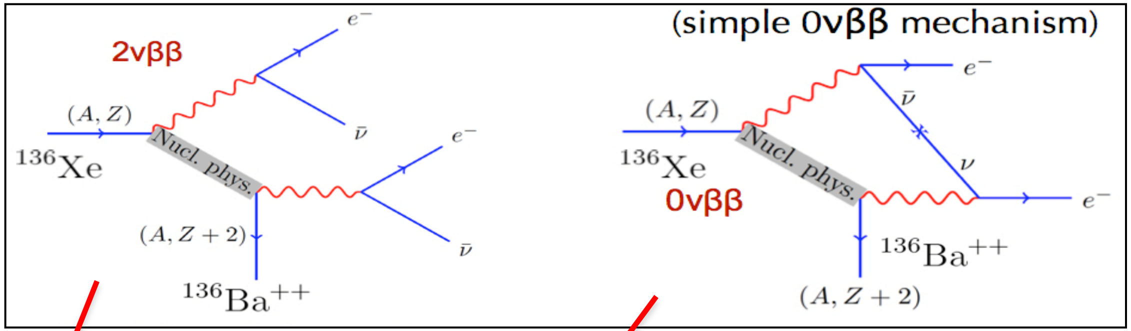
But $m_\nu \neq 0$!

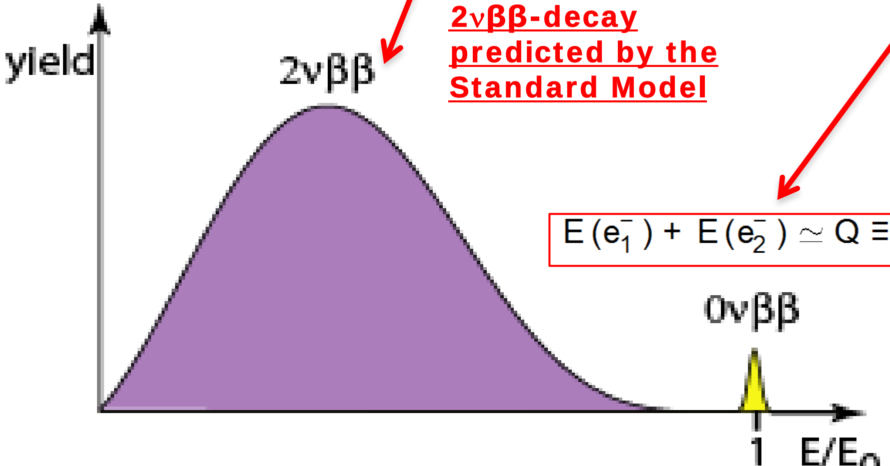
Double beta decay

Neutrinoless double beta decay is potentially the best way to probe the Majorana or Dirac nature of neutrino and to extract its effective mass.

Process mediated by the weak interaction occurring in even-even nuclei where the single β-decay is energetically forbidden







2νββ-decay predicted by the Standard Model

0νββ-decay forbidden by the Standard Model

$$E(e_1^-) + E(e_2^-) \simeq Q \equiv M_i - M_f$$

Search for 0νββ decay: a worldwide race

Experiment	Isotope	Lab	Status
GERDA	^{76}Ge	LNGS	Phase I completed Migration to Phase II
CUORE0 /CUORE	^{130}Te	LNGS	Data taking / Construction
Majorana Demonstrator	^{76}Ge	SURF	Construction
SNO+	^{130}Te	SNOLAB	R&D / Construction
SuperNEMO demonstrator	^{82}Se (or others)	LSM	R&D / Construction
Candles	^{48}Ca	Kamioka	R&D / Construction
COBRA	^{116}Cd	LNGS	R&D
Lucifer	^{82}Se	LNGS	R&D
DCBA	many	[Japan]	R&D
AMoRe	^{100}Mo	[Korea]	R&D
MOON	^{100}Mo	[Japan]	R&D

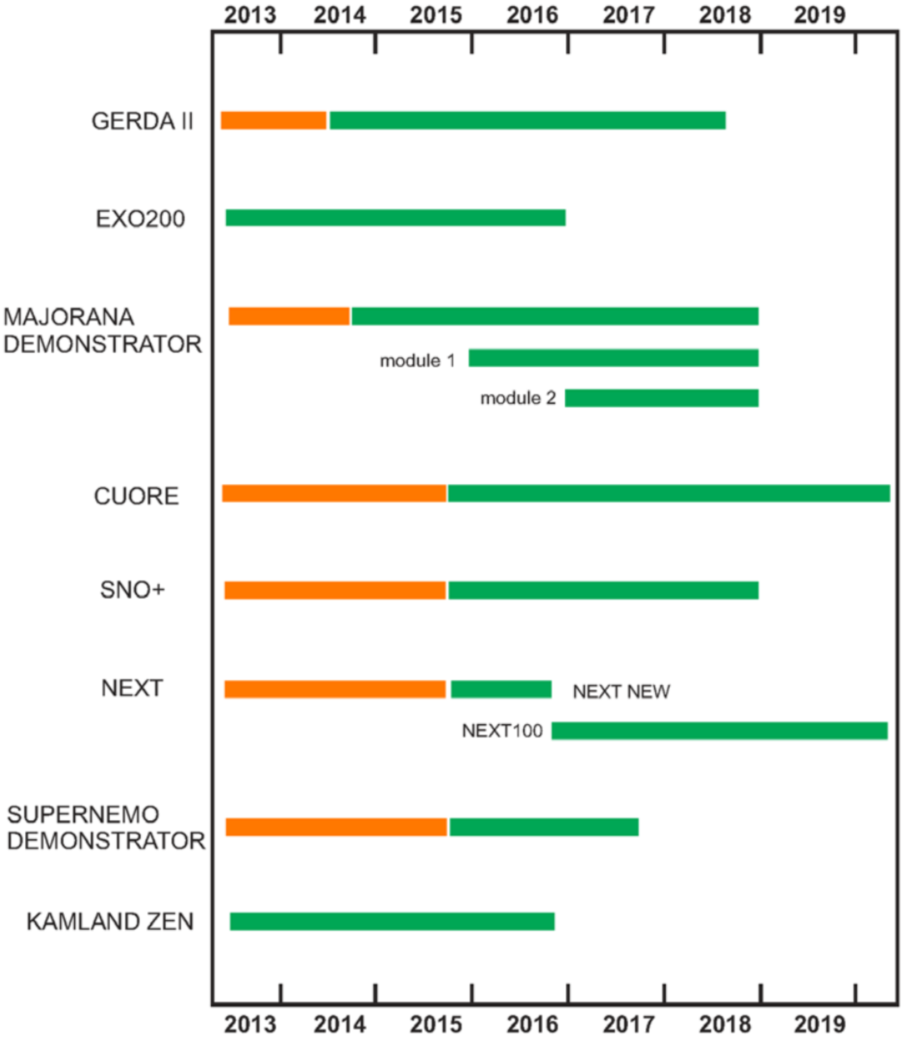


Figure 2.2. Approximate timelines for the presented projects. The orange bars represent nominal construction periods and green illustrates actual or intended running.

The role of nuclear physics

In the **$0\nu\beta\beta$** double beta decay the decay rate can be expressed as a product of independent factors, that also depends on a function containing physics beyond the Standard Model throught the masses and the mixing coefficients of the neutrinos species :

$$1/T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) = G_{01}\left|M^{\beta\beta0\nu}\right|^2 \left|\frac{\langle m_\nu\rangle}{m_e}\right|^2$$

$$\langle m_\nu\rangle = \sum_i \left|U_{ei}\right|^2 m_i e^{i\alpha_i}$$

A lot of new physics inside !

$$\left|M_\varepsilon^{\beta\beta0\nu}\right|^2 = \left|\left\langle 0_f \left\| \hat{O}_\varepsilon^{\beta\beta0\nu} \right\| 0_i \right\rangle\right|^2$$

The role of nuclear physics

In the $0\nu\beta\beta$ double beta decay the decay rate can be expressed as a product of independent factors, that also depends on a function containing physics beyond the Standard Model throught the masses and the mixing coefficients of the neutrinos species :

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

$$\langle m_\nu \rangle = \sum_i \left|U_{ei}\right|^2 m_i e^{i\alpha_i}$$

A lot of new physics inside !

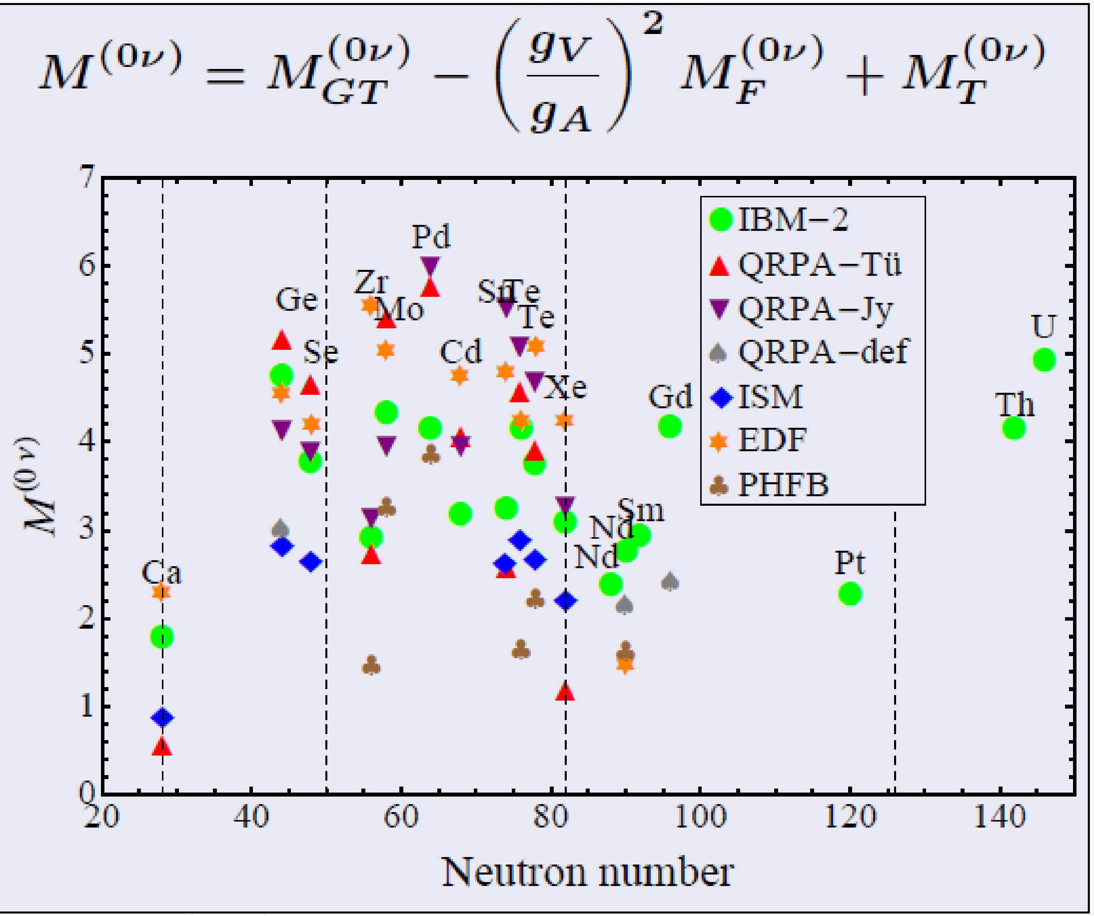
$$\Downarrow$$

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

Thus, if the $M^{0\nu\beta\beta}$ nuclear matrix elements were known with sufficient precision, the neutrino mass could be established from $0\nu\beta\beta$ decay rate measurements.

The state of the art

Evaluation of $$\left|M_{\varepsilon}^{\beta\beta 0\nu}\right|^2 = \left|\left\langle 0_f \left\| \hat{O}_{\varepsilon}^{\beta\beta 0\nu} \right\| 0_i \right\rangle\right|^2$$



$$M^{(0\nu)} = M_{GT}^{(0\nu)} - \left(\frac{g_V}{g_A}\right)^2 M_F^{(0\nu)} + M_T^{(0\nu)}$$

Courtesy of Prof. F.Iachello

✓**Calculations** **(still sizeable uncertainties)**: QRPA, Large scale shell model, IBM …..

E. Caurier, et al., PRL 100 (2008) 052503
N. L. Vaquero, et al., PRL 111 (2013) 142501
J. Barea, PRC 87 (2013) 014315
T. R. Rodriguez, PLB 719 (2013) 174
F.Simkovic, PRC 77 (2008) 045503.
F.Iachello et al. NPB 237-238 (2013) 21 - 23

✓**Measurements** (still not conclusive for 0νββ):

(π^+, π^-)
single charge exchange (^{3}He,t)
electron capture
transfer reactions…

N. Auerbach, Ann. Of Phys. 192 (1989) 77
S.J. Freeman and J.P. Schiffer JPG 39 (2012) 124004
D.Frekers, Prog. Part. Nucl. Phys. 64 (2010) 281
J.P. Schiffer, et al., PRL 100 (2008) 112501
D.Frekers et al. NPA 916 (2013)219 - 240

A new esperimental tool: DCE

0νββ vs DCE

1. **Initial and final states:** Parent/daughter states of the *0νββ* are the same as those of the target/residual nuclei in the DCE;

2. **Spin-Isospin mathematical structure** of the transition operator: Fermi, Gamow-Teller and rank-2 tensor together with higher L components are present in both cases;

3. **Large momentum transfer:** A linear momentum transfer as high as 100 MeV/c or so is characteristic of both processes;

4. **Non-locality**: both processes are characterized by two vertices localized in two valence nucleons.

5. **In-medium** processes: both processes happen in the same nuclear medium, thus **quenching** phenomena are expected to be similar;

6. Relevant **off-shell propagation** in the intermediate channel: both processes proceed via the same intermediate nuclei off-energy-shell even up to 100 MeV.

Factorization of the charge exchange cross-section

for single CEX:

β-decay transition strengths
(reduced matrix elements)

α= Fermi (F)
or Gamow Teller (GT)

$$\frac{d\sigma}{d\Omega}(q,\omega) = \hat{\sigma}_\alpha\left(E_p,A\right)F_\alpha(q,\omega)B_T(\alpha)B_P(\alpha)$$

$$|M_j(\alpha)|^2 = |B(\alpha)|$$

C.J Guess,et al, PRC 83 064318 (2011)

unit cross-section

$$\hat{\sigma}\left(E_p,A\right) = K(E_p,0)|J_\alpha|^2 N_\alpha^D$$

T.N.Taddeucci, et al, Nucl. Phys. A 469 (1987) 125

The factor $F_\alpha(q,\omega)$ describes the shape of the cross-section distribution as a function of the linear momentum transfer and the excitation energy.

In the hypothesis of a surface localized process (for direct quasi elastic processes):

generalization to DCE:

In analogy to the single charge-exchange, the dependence of the cross-section from q is represented by a Bessel function.

$$\frac{d\sigma^{DCE}}{d\Omega}(q,\omega) = \hat{\sigma}_\alpha^{DCE}\left(E_p,A\right)F_\alpha^{DCE}(q,\omega)B_T^{DCE}(\alpha)B_P^{DCE}(\alpha)$$

unit cross-section $\hat{\sigma}_\alpha^{DCE}\left(E_p,A\right) = K(E_p,0)|J_\alpha^{DCE}|^2 N_\alpha^D$

The unit cross section

In the σ(E_p,A) the specificity of the single or double charge exchange is express through the volume integrals of the potentials: the other factors are general features of the scattering.

Single charge-exchange

J_{ST} Volume integral of the V_{ST} potential

Double charge-exchange

J'_{ST} Volume integral of the $V_{ST}GV_{ST}$ potential, where $G=\sum_{n} |n\rangle\langle n| / E_n -(E_i+ E_f)/2$ is the intermediate channel propagator (including off-shell)

If known it would allow to determine the NME from DCE cross section measurement, whatever is the strenght fragmentation

↓

This is what happens in single charge exchange :

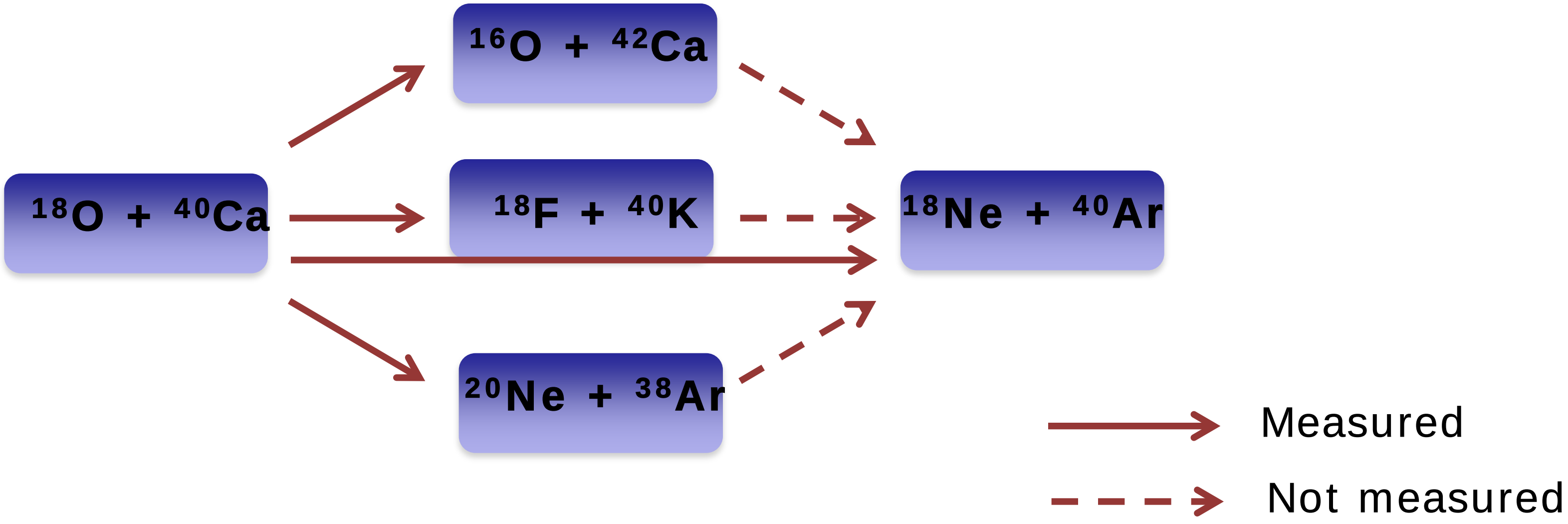
B(GT;CEX)/B(GT;β-decay) ~ 1 within a few % especially for the strongest transitions

In a simple model one can assume that the DCE process is just a second order charge exchange, where projectile and target exchange two incorrelated isovector virtual mesons.

DCE @ LNS

The pilot experiment: ^{40}Ca(^{18}O,^{18}Ne)^{40}Ar@LNS

- $^{18}O^{7+}$ beam from LNS Cyclotron at 270 MeV (10 pnA)
- ^{40}Ca solid target of 300 μg/cm^2
- Ejectiles detected by the MAGNEX spectrometer
- Angular setting $\theta_{opt} = 4^\circ$ $\longrightarrow$ $\boxed{-2^\circ < \theta_{lab} < 10^\circ}$



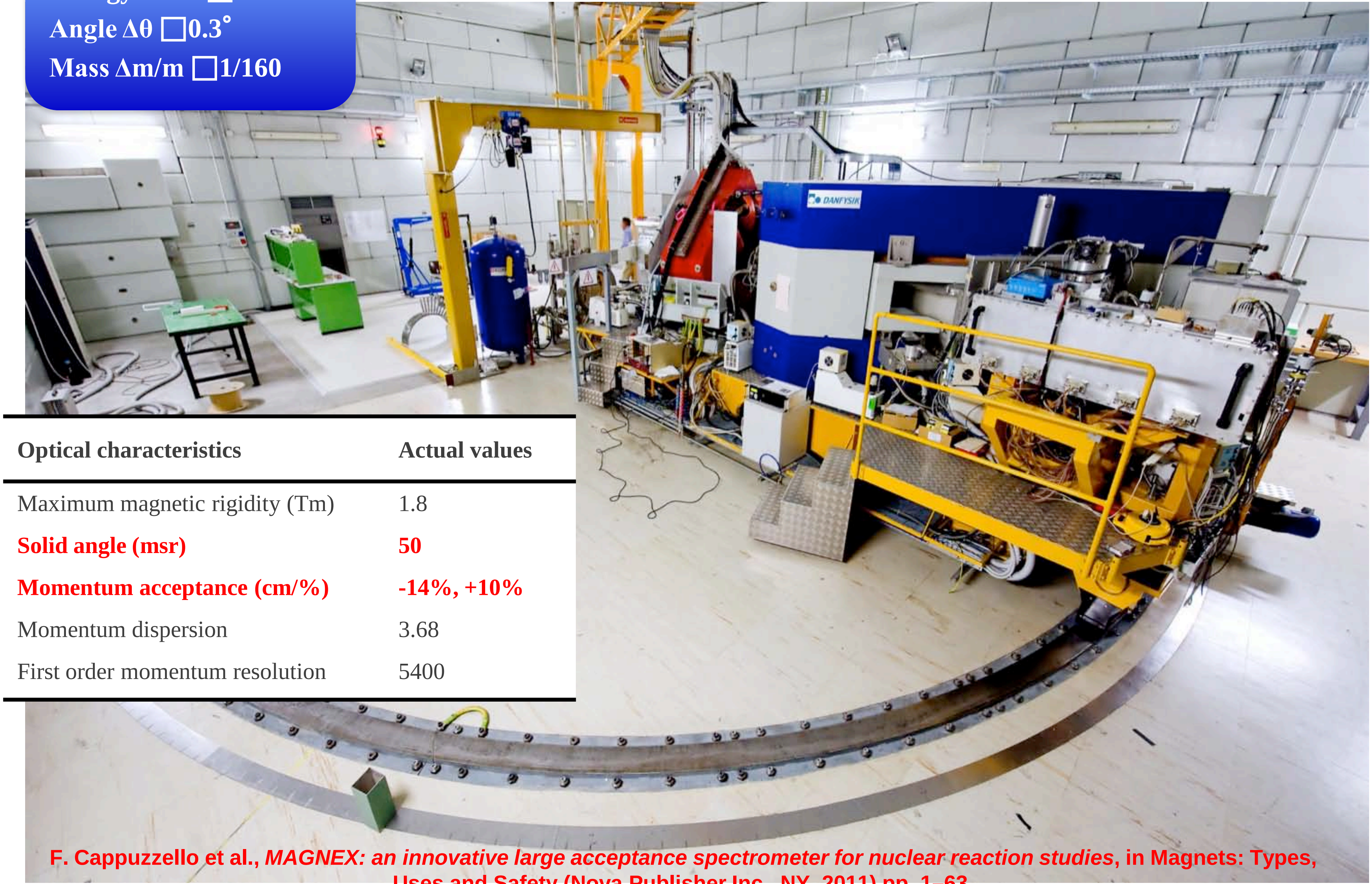
The experimental SET-UP@ LNS: MAGNEX

Measured Resolution:

Energy ΔE/E □1/1000

Angle Δθ □0.3°

Mass Δm/m □1/160

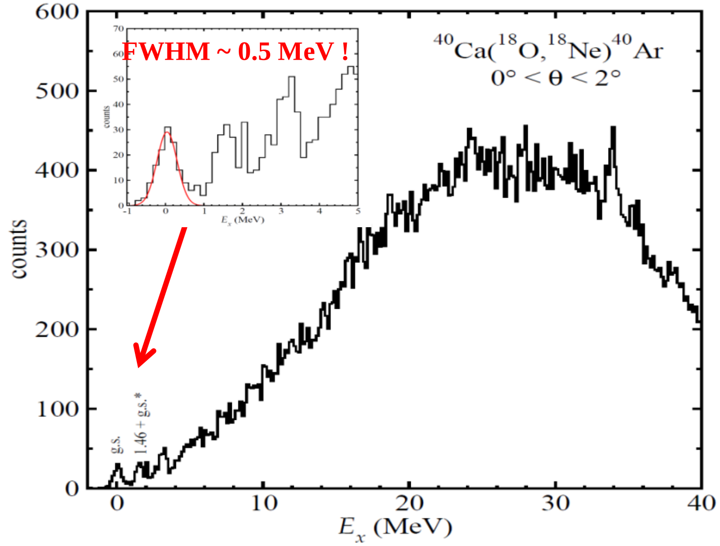


Optical characteristics	Actual values
Maximum magnetic rigidity (Tm)	1.8
Solid angle (msr)	**50**
Momentum acceptance (cm/%)	**-14%, +10%**
Momentum dispersion	3.68
First order momentum resolution	5400

F. Cappuzzello et al., *MAGNEX: an innovative large acceptance spectrometer for nuclear reaction studies*, in Magnets: Types, Uses and Safety (Nova Publisher Inc., NY, 2011) pp. 1–63.

Preliminary results

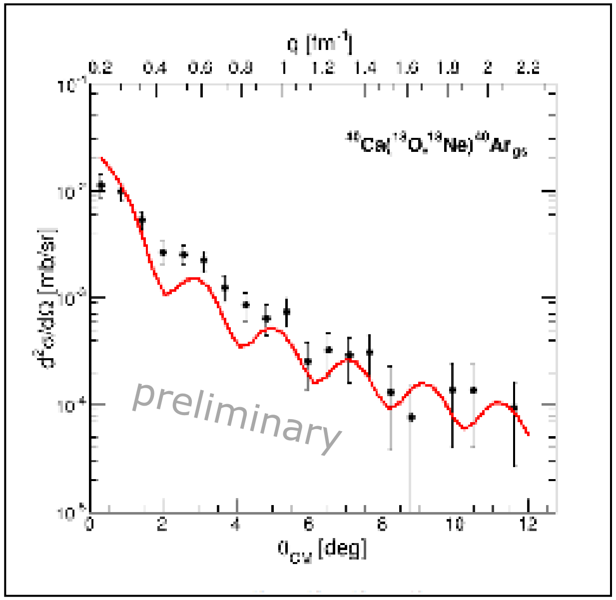
Measured energy spectrum of ^{40}Ar at very forward angles with an energy resolution of FWHM ~ 0.5 MeV .



The ^{40}Ar 0^+ ground state is well separated from both the first excited state ^{40}Ar 2^+ at 1.46 MeV and the ^{18}Ne excited state at 1.887 MeV

Differential cross-section of the transition

$^{40}Ca_{g.s.}(^{18}O,^{18}Ne)^{40}Ar_{g.s.}$ @ 270 Mev



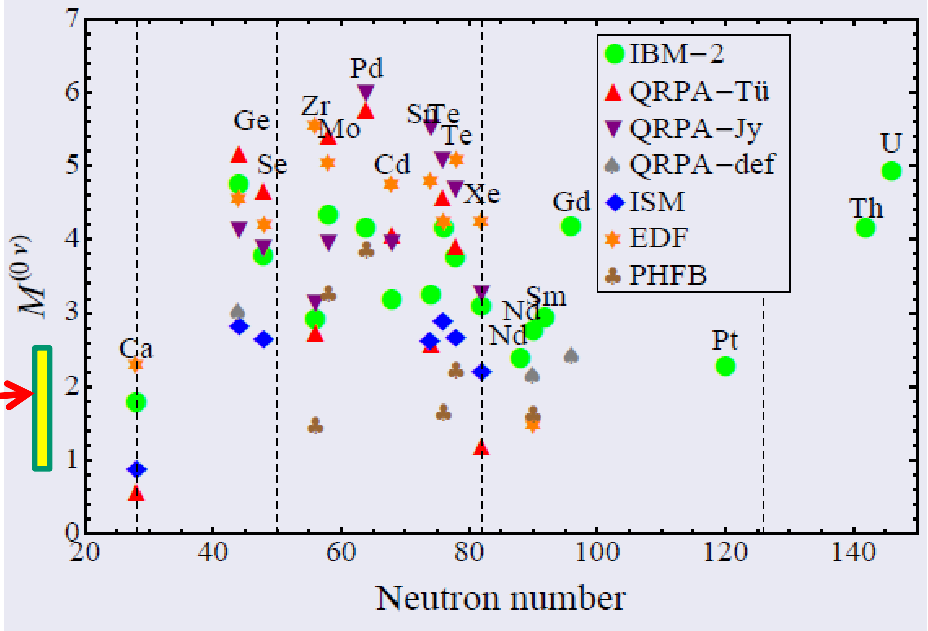
The position of the minima is well described by a Bessel function : such an oscillation pattern is not expectd in complex multistep transfer reactions.

$d\sigma^{DCE}/d\Omega$=11μb/sr at $\theta_{cm}=0^0$

Very preliminary matrix elements

Pure GT ⇒ $$\left|M^{DCE}_{40Ca\rightarrow 40Ar}(GT)\right|^2 = 0.22 \pm 0.11$$

Pauli blocking about 1/7



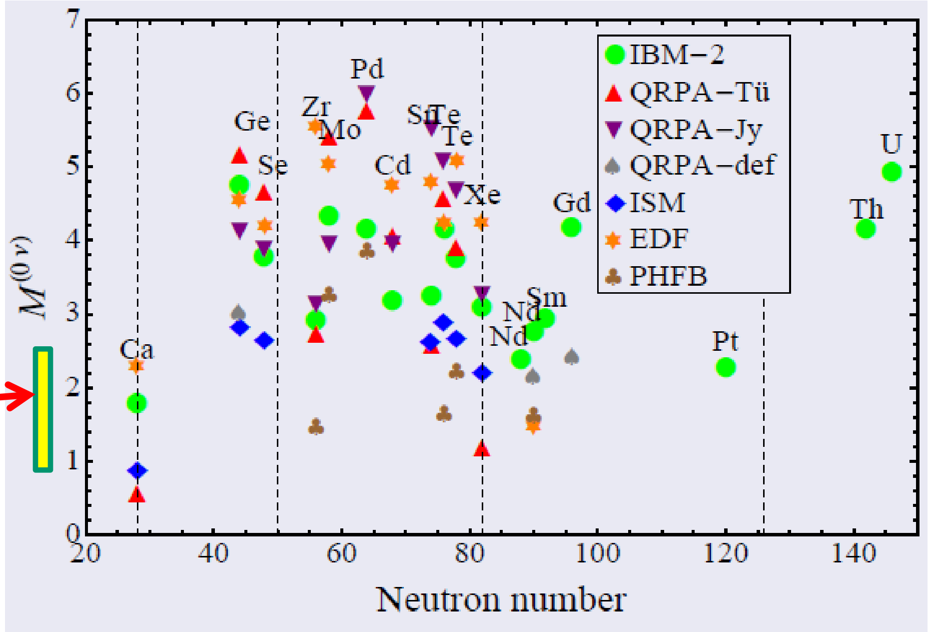
Just to speculate: our preliminary Pauli blocking corrected result

Pure F ⇒ $$\left|M^{DCE}_{40Ca\rightarrow 40Ar}(F)\right|^2 = 0.30 \pm 0.15$$

Very preliminary matrix elements

Pure GT

$$\left|M^{DCE}_{40Ca\to 40Ar}(GT)\right|^2 = 0.22 \pm 0.11$$



Pauli blocking about 1/7

Just to speculate: our preliminary Pauli blocking corrected result

Pure F

$$\left|M^{DCE}_{40Ca\to 40Ar}(F)\right|^2 = 0.30 \pm 0.15$$

Despite the approximations used and the simplified scheme considered these results indicate that the DCE unit cross section is at our reach!

…experimental limits

Determination of nuclear matrix elements seems to be at our reach…

BUT :

1. **About one order of magnitude more yield would have been necessary for the reaction studied.**
2. **(^{18}O,^{18}Ne) reaction particularly advantageous due to the large value of both the strengths and to the concentration of the GT strength in the ground state. But it is of $\beta^+\beta^+$ kind, while most of the research on $0\nu\beta\beta$ is on the opposite side;**
3. **Some of the reactions of $\beta^-\beta^-$ kind have a smaller *B(GT)*, so a sensible reduction of the yield is foreseen in these cases;**
4. **Gas target will be necessary, e.g. ^{136}Xe or ^{130}Xe, which are normally much thinner than solid state ones, with a consequent reduction of the collected yield.**
5. **In some cases the energy resolution (about half MeV) to separate the ground state form the excited states in the final nucleus. So coincident detection of γ-rays from the de-excitation of the populated states is necessary.**
6. **A strong fragmentation of the double GT strength is known in the nuclei of interest**

An upgraded set-up, able to work with two orders of magnitude more current than the present, is thus necessary!

This goal can be achieved by a substantial change in the technologies used in the beam extraction and in the detection of the ejectiles

…experimental limits

Determination of nuclear matrix elements seems to be at our reach…

BUT :

1. **About one order of magnitude more yield would have been necessary for the reaction studied.**
2. **(^{18}O,^{18}Ne) reaction particularly advantageous due to the large value of both the strengths and to the concentration of the GT strength in the ground state. But it is of $\beta^+\beta^+$ kind, while most of the research on $0\nu\beta\beta$ is on the opposite side;**
3. **Some of the reactions of $\beta^-\beta^-$ kind have a smaller *B(GT)*, so a sensible reduction of the yield is foreseen in these cases;**
4. **Gas target will be necessary, e.g. ^{136}Xe or ^{130}Xe, which are normally much thinner than solid state ones, with a consequent reduction of the collected yield.**
5. **In some cases the energy resolution (about half MeV) to separate the ground state form the excited states in the final nucleus. So coincident detection of γ-rays from the de-excitation of the populated states is necessary.**
6. **A strong fragmentation of the double GT strength is known in the nuclei of interest**

An upgraded set-up, able to work with two orders of magnitude more current than the present, is thus necessary!

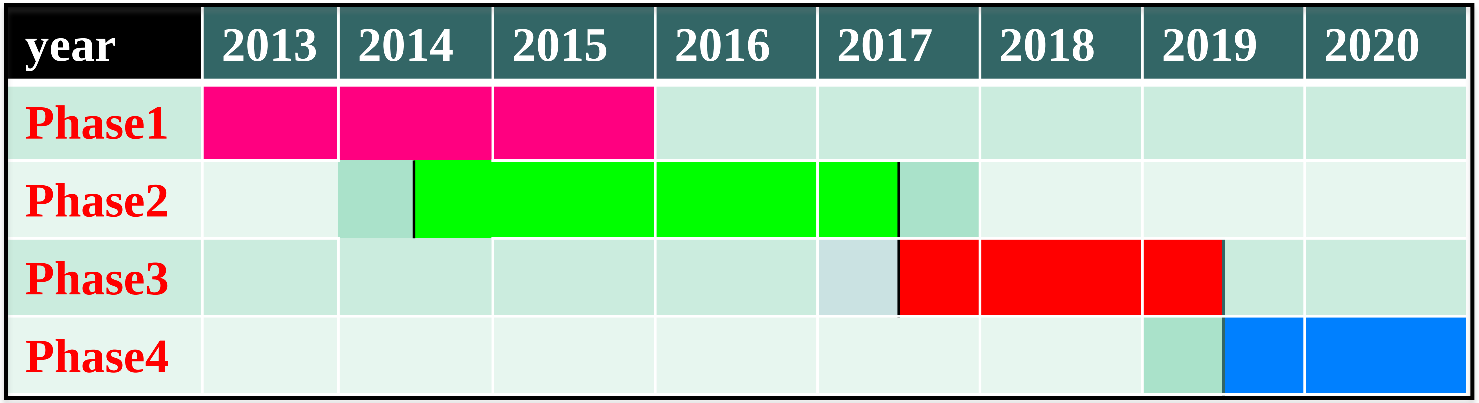
This goal can be achieved by a substantial change in the technologies used in the beam extraction and in the detection of the ejectiles

From the pilot experiment towords the “hot cases”

The Phases of NUMEN project

- **Phase1**: The experimental feasibility : the pilot experiment
- **Phase2**: “hot” cases optimizing the experimental conditions and getting first results
- **Phase3**: The facilities Upgrade:
- **Phase4** : The systematic experimental campaign

Preliminary time table



year	2013	2014	2015	2016	2017	2018	2019	2020
Phase1	🟪	🟪	🟪					
Phase2		🟩	🟩	🟩	🟩			
Phase3					🟥	🟥	🟥	
Phase4							🟦	🟦

Phase2: “hot” cases
optimizing the experimental conditions and getting first results

We propose to study the $(^{18}O,^{18}Ne)$ reaction as a probe for the $\beta^+\beta^+$ transitions and the $(^{20}Ne,^{20}O)$, or alternatively the $(^{12}C,^{12}Be)$, for the $\beta^-\beta^-$, with the aim

1.to explore the DCE mechanism in both directions, to assure that the extracted NME for the ground-to-ground transitions are compatible;

2.to find the best compromise between energy resolution and count rate for the selected nuclei;

3.to map different combination of scalar and vector nucleon-nucleon interaction by changing the beam energy.

4.To look for the best kinematical conditions in which the direct DCE cross section is dominant respect to the competing multi-step channels cross sections;

5.to probe the dependence of the cross section on the linear momentum transfer;

6.to check the predicted difference among the nuclei in which protons and neutrons occupy the same major shells and those in which they occupy different ones.

7.R & D : on the detector FPD , gas tracker and gamma detector

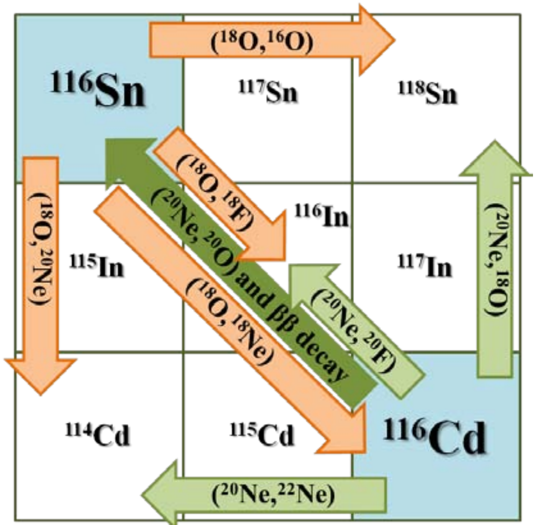
8.Theoretical models development

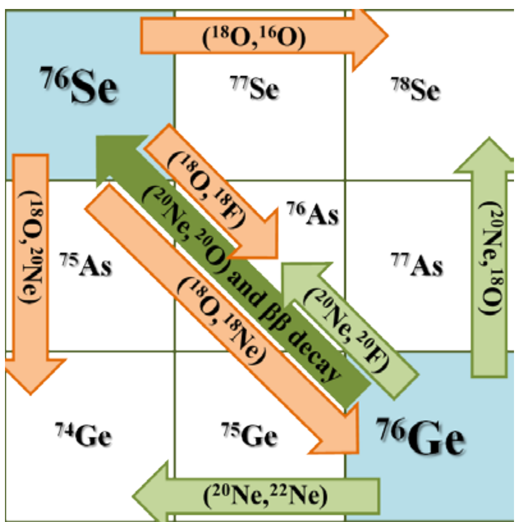
Phase2: experimental activity

We propose to perform the experiments here listed during NUMEN Phase 2, with the aim to investigate the best working conditions for the experimental campaign.

		2015				2016				2017			
Reaction	**Energy (MeV/u)**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
^{116}Sn (^{18}O,^{18}Ne) ^{116}Cd	15-30	🟥	🟥										
^{116}Cd (^{20}Ne,^{20}O) ^{116}Sn	15-25			🟦	🟦								
^{130}Te (^{20}Ne,^{20}O) ^{130}Xe	15-25					🟩	🟩						
^{76}Ge (^{20}Ne,^{20}O) ^{76}Se	15-25							🟪	🟪				
^{76}Se (^{18}O,^{18}Ne) ^{76}Ge	15-30									🟦	🟦		
^{106}Cd(^{18}O,^{18}Ne) ^{106}Pd	15-30											🟨	🟨

For each of them, the complete net of reactions involving the multi-step transfer processes, characterized by the same initial and final nuclei will be studied under the same experimental conditions.





Phase2: R&D and MAGNEX upgrade

For the spectrometer the main foreseen upgrades are:

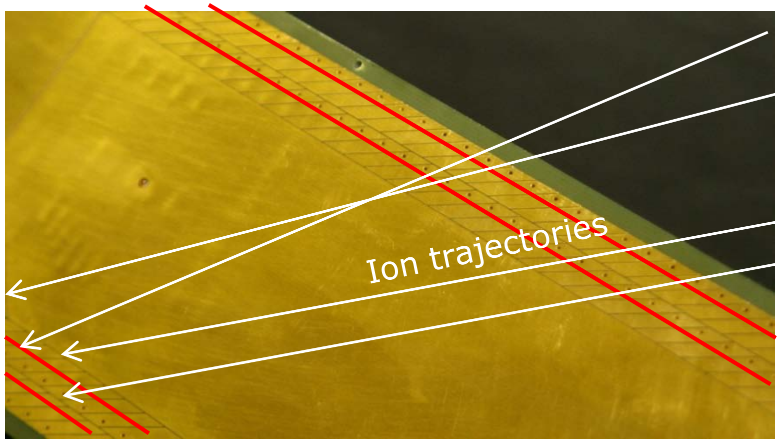
1. **The substitution of the present FPD gas tracker with a GEM tracker system;**
2. **The substitution of the wall of silicon pad stopping detectors with SiC detectors or similar;**
3. **The enhancement of the maximum magnetic rigidity;**
4. **The introduction of an array of detectors for measuring the coincident γ-rays.**

R&D: a new gas tracker

A major upgrading is required preserving the good tracking and particle identification.
A GEM-based tracker, working at low pressure and wide dynamic range, will be a key issue of the R&D activity.

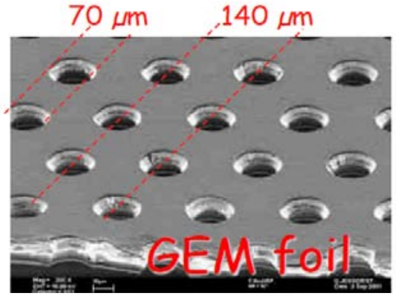
From

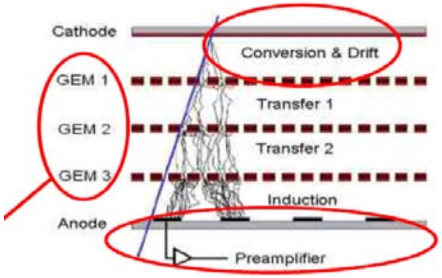
Multiwire gas tracker limited to about 1 kHz



To

GEM gas tracker to go to 100 kHz





Initial tests, with INFN-LNF , of existing 3-foils GEM prototypes will be at the basis of the construction of a prototype detector, which includes the initial versions of the read-out electronics. Forthcoming tests of the prototype with radioactive sources and heavy-ion beams will be performed afterward at the LNS.

R&D: ion identification

INFN LNS
Istituto Nazionale di Fisica Nucleare

NUMEN Phase 2 will also investigate promising technologies for stopping detectors, which need also to be upgraded in view of the high detection rate.

From standard technologies, based on silicon pad detectors → **To SiC crystals**

- **We propose an R&D to explore, characterize and build, after the GEM tracker, a wall of telescopes based on thin epitaxial SiC (100 µm thickness) for energy loss followed by thick (about 1 cm) CsI detectors for residual energy.**
- **This solution looks like to be promising because it decouples the GEM tracker from particle identification (PID) function and it is based on existing SiC technology, even if not yet implemented in commercial large area detectors.**
- **Test of characterization of epitaxial SiC under heavy ion beams will be proposed to be scheduled next months at the LNS in collaboration with colleagues from CNR.**

R&D : exclusive measurements

- **An array of scintillators will also be studied within NUMEN Phase2.**
- **These detectors are intended for detecting γ-rays from the de-excitation of the residual nucleus (and ejectile) in coincidence with the spectrometer, thus improving the resolution in the energy spectra.**
- **The challenge here is to work in a very intense flux of γ-rays and neutrons produced also by the interaction of the beam with the target. This implies a good energy resolution in order to optimize the signal-to-noise ratio and reduce the probability of spurious coincidences.**
- **Interesting options as the HPGe, $LaBr_3$(Ce) or CsI will be studied in detail.**
- **Members of the Italian-Brasilian (see INFN-IFUSP-IFUFF collaboration MoU) collaboration are interested to collaborate on this topics with possible in-kind contribution in the future development of NUMEN.**
- **During Phase2 the strategy is to build small prototypes for different detector materials and, after a characterization with radioactive sources, use them under realistic experimental conditions (intense beams, coincidence with MAGNEX, study of DCE) at the LNS.**

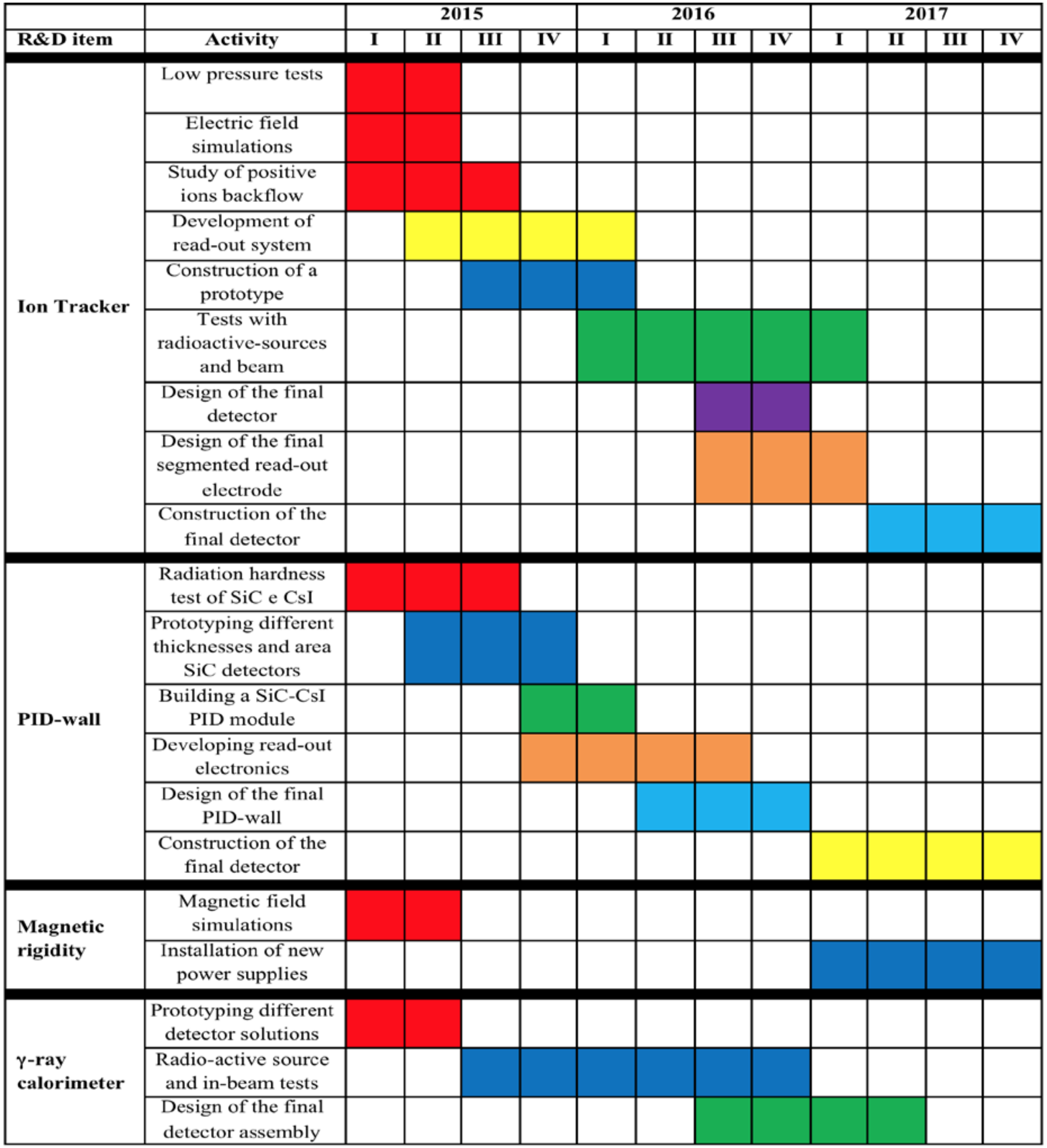
R&D : increase the magnetic rigididy

- **MAGNEX maximum magnetic rigidity is limited to about 1.8 Tm, which corresponds to about 50 MeV/u for $^{20}Ne^{10+}$, but less than 30 MeV/u for $^{20}O^{8+}$.**

- **This limit should be reasonably increased in order to explore DCE reactions in the convenient dynamical conditions around 50 MeV/u, where the Gamow-Teller-like modes prevail over the Fermi-like ones.**

- **A conservative approach is to work in a slight saturated field with the existing magnets, which allows to reach about 2.1-2.2 Tm, i.e. about 65 MeV/u for $^{20}Ne^{10+}$, 40 MeV/u for $^{20}O^{8+}$. This implies the upgrade of the existing power supplies.**

Time table for NUMEN Phase 2: R&D activity



		2015				2016				2017			
R&D item	**Activity**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
Ion Tracker	Low pressure tests	🟥	🟥										
	Electric field simulations	🟥	🟥										
	Study of positive ions backflow	🟥	🟥	🟥									
	Development of read-out system		🟨	🟨	🟨	🟨							
	Construction of a prototype			🟦	🟦	🟦							
	Tests with radioactive-sources and beam					🟩	🟩	🟩	🟩	🟩			
	Design of the final detector							🟪	🟪				
	Design of the final segmented read-out electrode							🟧	🟧	🟧			
	Construction of the final detector										🟦	🟦	🟦
PID-wall	Radiation hardness test of SiC e CsI	🟥	🟥	🟥									
	Prototyping different thicknesses and area SiC detectors		🟦	🟦	🟦								
	Building a SiC-CsI PID module				🟩	🟩							
	Developing read-out electronics				🟧	🟧	🟧	🟧					
	Design of the final PID-wall						🟦	🟦	🟦				
	Construction of the final detector									🟨	🟨	🟨	🟨
Magnetic rigidity	Magnetic field simulations	🟥	🟥										
	Installation of new power supplies									🟦	🟦	🟦	🟦
γ-ray calorimeter	Prototyping different detector solutions	🟥	🟥										
	Radio-active source and in-beam tests			🟦	🟦	🟦	🟦	🟦	🟦				
	Design of the final detector assembly							🟩	🟩	🟩	🟩		

PHASE3:
Facility Upgrade

1. Disassembling of the old set-up and re-assembling of the new ones (about 18-24 months).

2. Data analyses, to the preparation of the next experiments.

3. Test of the new detectors with Tandem beam.

4. Experiments on single charge exchange or transfer reactions will be performed in other laboratories in order to provide possible pieces of information still lacking, e.g. measurements of *B*(GT) or transfer amplitudes.

LNS

PHASE4 :
systematic experimental campaign

To reach our "holy Graal"

⬇

A series of experimental campaigns at high beam intensities and long experimental runs in order to reach in each experiment integrated charge of hundreds of mC up to C, for the experiments in coincidences, spanning all the variety of *0νββ decay* candidate isotopes, like:

^{48}Ca,^{82}Se,^{96}Zr,^{100}Mo,^{110}Pd,^{124}Sn,^{128}Te,^{136}Xe,^{148}Nd,^{150}Nd,^{154}Sm,^{160}Gd,^{198}Pt

NUMEN
International Referee

The Evaluation Committee composed of **Francesco Iachello**, Yale University, U.S.A. (Chair), **Muhsin Harakeh**, University of Groningen, The Netherlands, **Dieter Frekers**, University of Münster, Germany, met at the **Laboratori Nazionali del Sud (LNS) in Catania, Italy, May 19 and 20, 2014.**

The Committee finds that this is an interesting proposal worth exploring and strongly supports the exploratory phases 1-2 of the project.

Presidenza INFN 22 July 2014

The Committee therefore recommends that Phases 1-2 with the upgrade of the detector system be approved with highest priority and…

NUMEN
National CSN3 Referee

September 2014

The CSN3 Committee is composed of **Andrea Vitturi**, Padova University, **Silvia Leoni**, Milano University, **Enrico Fioretto**, LNL.

INFN CVI Report 2014
LNS - CVI Meeting on 20 - 22 October 2014

- …"LNS is carving a niche in nuclear physics with plans to upgrade the SC cyclotron "…
- "The SC Cyclotron is the workhorse of the lab, supporting programs in hadron therapy, nuclear physics, and looking forward to supporting programs being highlighted in the 'What's Next' exercise. The SC Cyclotron upgrade is intriguing and seems of appropriate size "….

INFN Piano Triennale – Trento 8-9 novembre 2014

- Talk A.Masiero

LNS

INFN Istituto Nazionale di Fisica Nucleare

The NUMEN Holy Graal: the unit cross section

Studying if the σ^{DCE} is a smooth function of E_p and A

is the most ambitious goal of our project

This requires that a systematic set of appropriate data is built, facing the relative experimental challanges connected with the low cross sections and resolution requests

Goal N.1 for NUMEN

A new generation of DCE constrained 0νββ NME theoretical calculations can emerge

The measured DCE cross sections provide a powerful tool for theory in order to give very stringent onstraints in the NME estimation The DCE processes can be artificially generated in the lab! (Few labs. as the LNS)

Goal N.2 for NUMEN

Providing relative NME information on hot cases of 0νββ is strongly required by the community in order to compare the sensitivity of different half-life experiments

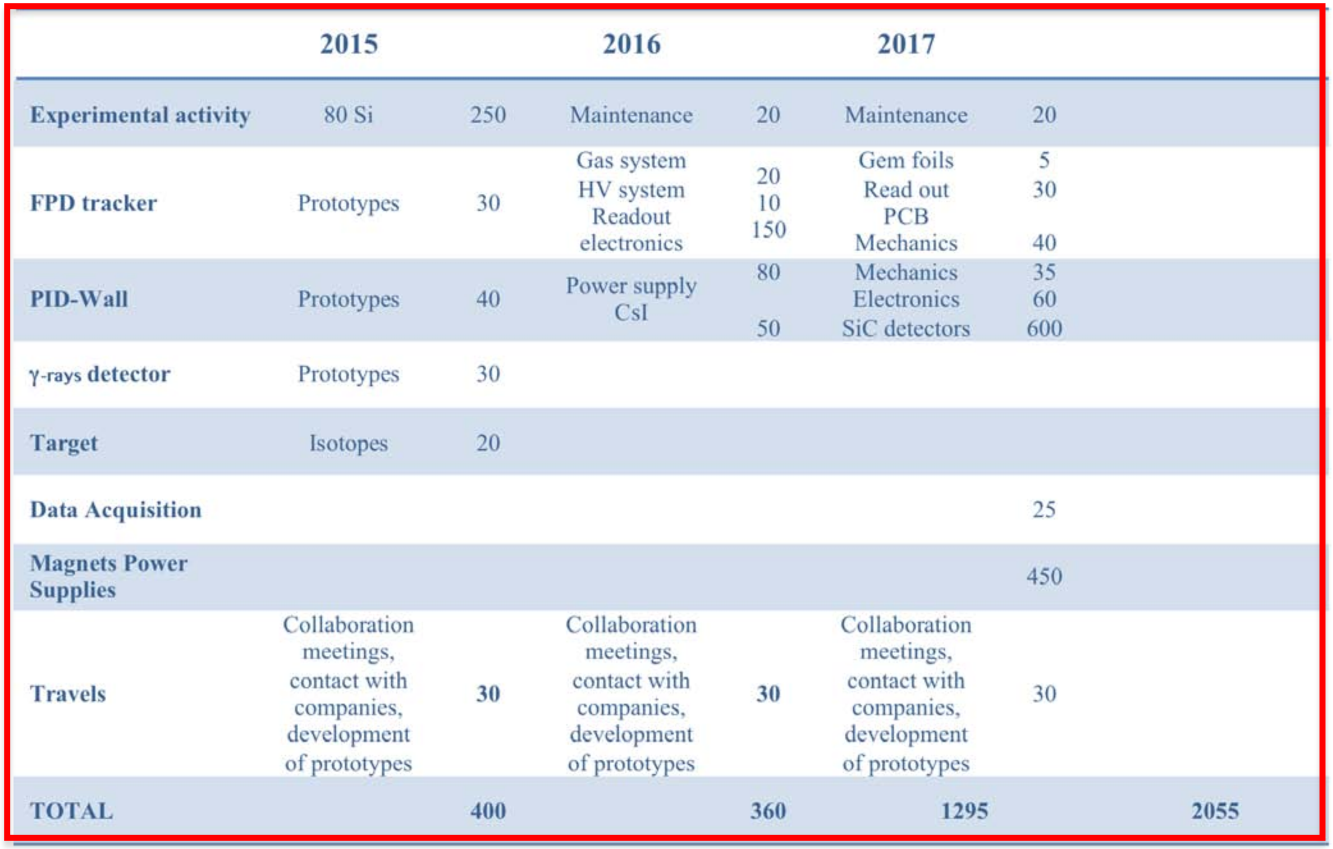
This could impact in future development of the field.

Goal N.3 for NUMEN

Conclusions and Outlook

- **The factorization of DCE cross sections is potentially a major source of information about NME for *0*$\nu\beta\beta$**
- **At LNS we show that the (^{18}O,^{18}Ne) cross section can be suitably measured**
- **Magnetic spectrometers are essential, especially with large acceptance**
- **Severe limitation from present available beam current**
- **High beam intensity is the new frontier for these studies**
- **Strong synergy between heavy-ion and neutrino community**

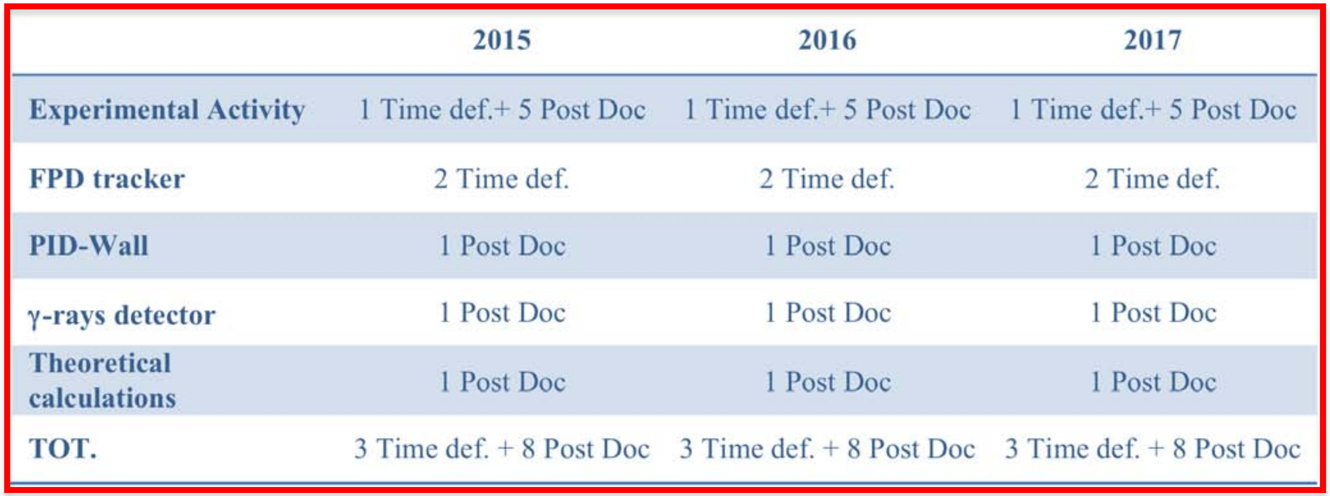
Phase2 estimated cost



	2015		2016		2017		
Experimental activity	80 Si	250	Maintenance	20	Maintenance	20	
FPD tracker	Prototypes	30	Gas system HV system Readout electronics	20 10 150	Gem foils Read out PCB Mechanics	5 30 40	
PID-Wall	Prototypes	40	Power supply CsI	80 50	Mechanics Electronics SiC detectors	35 60 600	
γ-rays detector	Prototypes	30					
Target	Isotopes	20					
Data Acquisition						25	
Magnets Power Supplies						450	
Travels	Collaboration meetings, contact with companies, development of prototypes	**30**	Collaboration meetings, contact with companies, development of prototypes	**30**	Collaboration meetings, contact with companies, development of prototypes	30	
TOTAL		**400**		**360**		**1295**	**2055**

Summary of the budget request for Phase2: the costs are in k€

Manpower request for the NUMEN Phase 2



	2015	2016	2017
Experimental Activity	1 Time def.+ 5 Post Doc	1 Time def.+ 5 Post Doc	1 Time def.+ 5 Post Doc
FPD tracker	2 Time def.	2 Time def.	2 Time def.
PID-Wall	1 Post Doc	1 Post Doc	1 Post Doc
γ-rays detector	1 Post Doc	1 Post Doc	1 Post Doc
Theoretical calculations	1 Post Doc	1 Post Doc	1 Post Doc
TOT.	3 Time def. + 8 Post Doc	3 Time def. + 8 Post Doc	3 Time def. + 8 Post Doc