

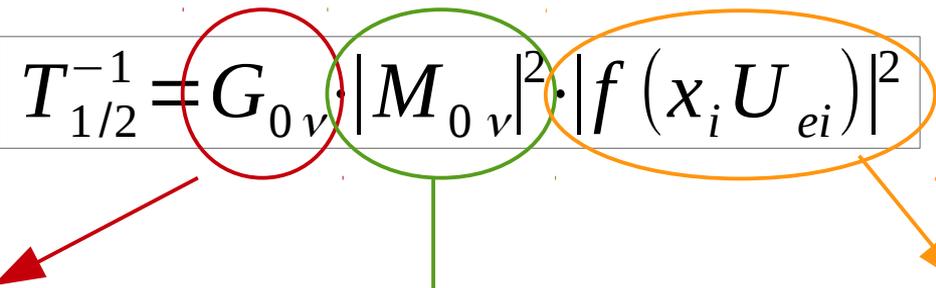
NUMEN: Status and perspectives

Domenico Torresi
for the NUMEN collaboration

LNS Users' Committee Tuesday, 11 December 2018

Main goal

The neutrinoless double beta decay lifetime:

$$T_{1/2}^{-1} = G_{0\nu} \cdot |M_{0\nu}|^2 \cdot |f(x_i U_{ei})|^2$$


Phase Space Factor

Nuclear Matrix Elements

function containing masses m_i the mixing coefficients U_{ei} and Majorana phases ξ_i

Main goal

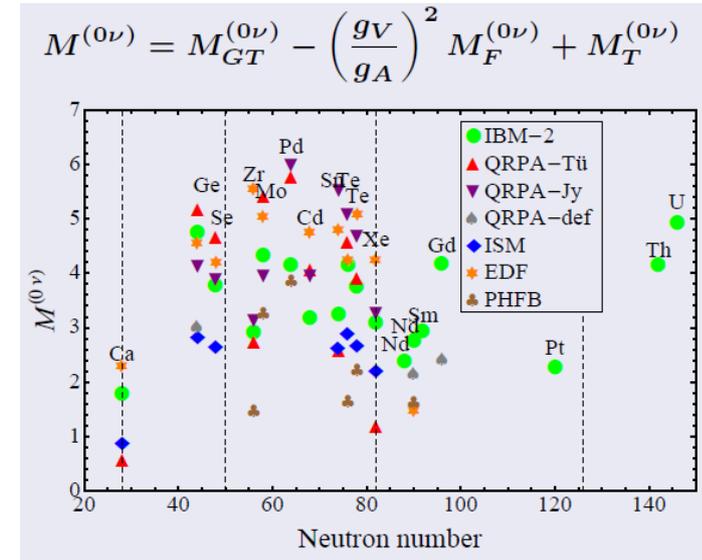
The nuclear matrix elements evaluation up to date are based on:

Calculations: QRPA, Interacting Boson Model, Large scale shell model...

Measurements: early measurements not conclusive for $0\nu\beta\beta$

- π -induced DCE reaction
- Heavy-ion induced DCE reaction
- Single charge exchange

A new experimental approach to extract the NMEs for $0\nu\beta\beta$ decay is based on the study of the heavy-ion double charge exchange reaction using **large-acceptance high-resolution spectrometer**.





The NUMEN project

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

Proponents: C. Agodi, J. I. Bellone, D. Bonanno, V. Branchina, S. Brasolin, G. Brischetto, O. Brunasso, S. Burrello, S. Calabrese, L. Calabretta, D. Calvo, V. Caprossi, F. Cappuzzello, D. Carbone, M. Cavallaro, I. Ciraldo, M. Colonna, G. D'Agostino, F. Delaunay, C. Ferraresi, J. Ferretti, P. Finocchiaro, M. Fisichella, A. Foti, G. Gallo, H. Garcia-Tecocoatz, A. Hacisalihoglu, F. Iazzi, G. Lanzalone, F. La Via, J.A. Lay, F. Longhitano, D. Lo Presti, P. Mereu, L. Pandola, F. Pinna, S. Reito, D. Rifuggiato, A. D. Russo, G. Russo, E. Santopinto, O. Sgouros, V. Soukeras, A. Spatafora, D. Torresi, S. Tudisco, R.I.M. Vsevolodovna

1 Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud , Italy

2 Dipartimento di Fisica e Astronomia, Università di Catania, Italy

3 Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy

4 Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Italy

5 DISAT, Politecnico di Torino, Italy

6 DIMEAS, Politecnico di Torino, Italy

7 Istituto Nazionale di Fisica Nucleare, Sezione di Genova, Italy

8 Dipartimento di Fisica, Università di Genova, Italy

9 Università degli Studi di Enna "Kore", Italy

10 CNR-IMM, Sezione di Catania, Italy

11 LPC Caen, Normandie Université, ENSICAEN, UNICAEN, CNRS/INP3, France

12 Department of Physics, Yale University, USA

13 Institute of Natural Sciences, Karadeniz Teknik University, Turkey

14 Departamento de FAMN, University of Seville, Spain

T. Borello-Lewin, P.N. de Faria, J.L. Ferreira, R. Linares, J. Lubian, N. H. Medina, D.R. Mendes, M. Morales, J. R. B. Oliveira, M.R.D. Rodrigues, R.B.B. Santos, M.A.G. da Silveira , V.A.B. Zagatto

15 Universidade de Sao Paulo, Brazil

16 Universidade Federal Fluminense, Brazil

17 Instituto de Pesquisas Energeticas e Nucleares IPEN/CNEN, Brazil

18 Centro Universitario FEI Sao Bernardo do Campo, Brazil

A. Pakou, G. Souliotis

19 Department of Physics and HINP, University of Ioannina, Greece

20 Department of Chemistry, National and Kapodistrian University of Athens, Greece

L. Acosta, P. Amador, R. Bijker, D. Belmont, E.R. Chávez Lomelí, R. Espejel, A. Flores, B. Góngora, A. Huerta, D. Marín-Lámbarrí, S. Martínez, J. Mas, C. Ordoñez, G. Reza, S. Sandoval, H. Vargas, G. Vega

21 Instituto de Fisica, Universidad Nacional Autónoma de México, Mexico

22 Instituto Nacional de Investigaciones Nucleares, Mexico

23 Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico

H. Lenske

24. Department of Physics, University of Giessen, Germany

I. Boztosun, H. Djapo, S. Firat, S. Hazar, Y. Kucuk, S.O. Solakci, A. Yildirin

25. Department of Physics, Akdeniz University, Turkey

N. Auerbach

26. School of Physics and Astronomy, Tel Aviv University, Israel

H. Petrascu

27. IFIN-HH, Romania

N. Deshmukh

28. Nuclear Physics Division, Saha Institute of Nuclear Physics, India

J. Kotila

29. University of Jyväskylä, Finland

G. De Geronimo

30. Stony Brook University, USA

N. Pietralla, P. Ries, V. Werner

31. Institut für Kernphysik, Technische Universität Darmstadt, Germany

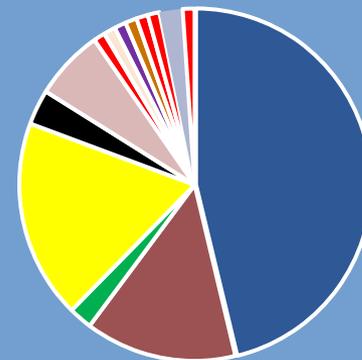
R. Chen, J. Ma, J.S. Wang, Y.Y. Yang

32. Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

J. Barea

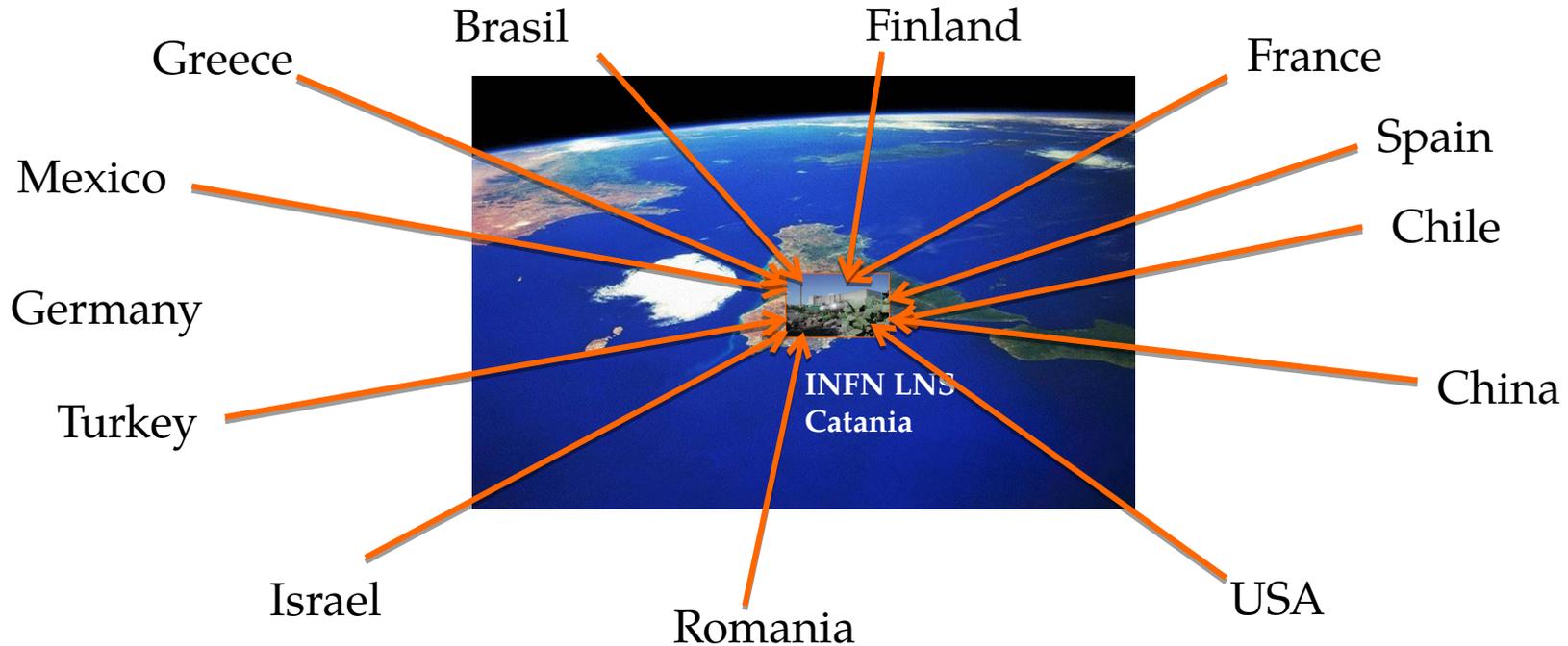
33. Departamento de Fisica, Universidad de Concepcion, Chile

100 Researchers
33 Institutions
14 countries





NUMEN: the international collaboration



A growing *in-kind* contribution

- ✓ **Manpower:** post-doc and fellowships on external funding;
- ✓ **Tools and devices for the development of detector prototypes.**

NUMEN: In-kind maturato

In-kind su attrezzature

Institution	In-kind	Cost
University of Akdeniz	3 LaBr3(Ce) 2x2 inches	~ 30 k€
UNAM	Thermal camera + mechanics for target stress tests	10 k€
UNAM	TeBe detector chamber	11 k€
UNICT	Electronic development	10.5k€
Total		62..5k€

TOTAL in kind

equipments 2018 ~ 62.5 k€

manpower 2018 ~ 164 k€

**TOTAL NURE ERC
2018 ~ 245 k€**



TOTAL 471.5 K€

In-kind su manpower

Collaborator name	Gained Fellow	Duration	Cost of the collaborator*
Dr. Vinicius Bocaline Zagatto	Post-Doctoral Fellowship for Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). Program: "Ciencia Sem Fronteira". Modality: Pos-doutorado no Exterior Process number: 205864/2014-7	Apr 2015 - Apr 2016	~ 40 k€
J.R.B. Oliveira, N.H. Medina, M. Morales, L.R. Gasques	SPRINT Grant 01/2017	Feb. 2018-Feb. 2020	~ 20 k€
Dr. Aylin Hacisalihoglu	Scientific and Technological Research Council of Turkey (TUBITAK) 2214/A International Doctoral Research Fellowship Programme	Nov 2016 – Nov 2017 + rinnovo Nov. 2017-May 2018	~ 30 k€ + 15 k€
Dr. Aydin Yildirim	Scientific and Technological Research Council of Turkey (TUBITAK) International Doctoral Research Fellowship Programme	Sept.2018 – Aug.2019	~ 30 k€
Dr. Oktay Selcuk	Scientific and Technological Research Council of Turkey (TUBITAK) International Doctoral Research Fellowship Programme	Sept.2018 – Aug.2019	~ 30 k€
Drs. Suna Firat	Scientific and Technological Research Council of Turkey (TUBITAK) International Doctoral Research Fellowship Programme	Sept.2018–Feb.2019	~ 15 k€
Dr. Sinan Hazar	ERASMUS+: Learning Agreement Student Mobility for Traineeships	Jun 2018 - Aug 2018	~ 3 k€
Dr. Jonas Leonardo Ferreira	Programa Doutorado Sanduiche no Exterior (PDSE), Portaria n° 60/2015/CAPEs	Apr 2017 - Set 2017	~ 10 k€
Dr. Onofrios Sgouros	ERASMUS+: Lifelong Learning Program/ ERASMUS University of Ioannina, Greece	May 2013 - Jul 2013	~ 3 k€
Dr. Vasileios Soukeras	ERASMUS+: Lifelong Learning Program/ ERASMUS University of Ioannina, Greece	May 2013 - Jul 2013	~ 3 k€
Dr. Onofrios Sgouros	ERASMUS+: Learning Agreement Student Mobility for Traineeships	Jun 2017 - Sep 2017	~ 6 k€
Dr. Vasileios Soukeras	ERASMUS+: Learning Agreement Student Mobility for Traineeships	Jun 2017 - Sep 2017	~ 6 k€
Prof. A. Pakou	ERASMUS+: Learning Agreement Student Mobility for Traineeships	Feb 2017	~ 1 k€
Prof. F. Delaunay	LPC Caen University 5 months sabbatical supported for activity at INFN -To	Oct 2017- Mar 2018	~ 30 k€
Prof. F. Delaunay	Politecnico di Torino 9 months Invited Professor (50% NUMEN)	Oct 2018- Jun 2019	~ 35 k€
		Total fellowships 6 years + 10 months	Total fellowship ~ 192 k€ +
		Total academic 14 months	Total academic ~ 65 k€ +
			Total mobility 20 k€
			TOTAL in kindmanpower ~ 277 k€





NUMEN: the project phases

- ✓ **Phase1: the experiment feasibility**
 - $^{40}\text{Ca}(^{18}\text{O},^{18}\text{Ne})^{40}\text{Ar}$ @ 270 MeV already done: the results demonstrate the technique feasibility.
- ✓ **Phase2: toward "hot" cases optimizing experimental conditions and getting first result**
 - Few experiments on selected isotopes candidate for $0\nu\beta\beta$ decay (integrated charge of tens of mC)
 - R&D on CS and MAGNEX, preserving the access to the present facility
 - Theoretical model developments.
- ✓ **Phase3: the facility upgrade**
 - Disassembling of the old set-up and re-assembling of the new ones will start (18-24 months)
 - Tests of new detectors (Tandem @ LNS and other Laboratories)
- ✓ **Phase4: the systematic experimental campaign**
 - Systematic experimental campaign with high beam intensities (some più; integrated charge of hundreds of mC up to C) on all the isotopes candidates for $0\nu\beta\beta$ decay

Tentative time table

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

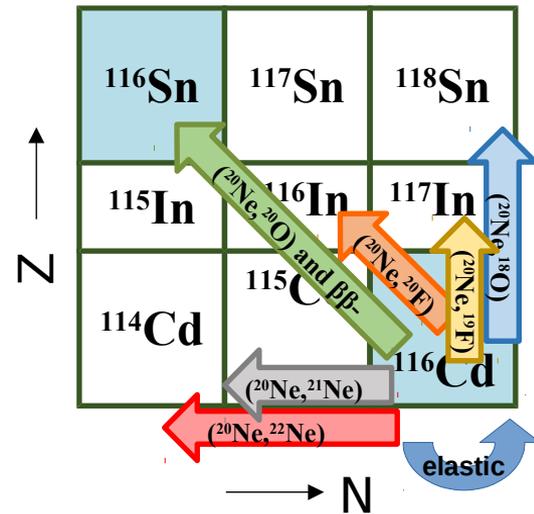
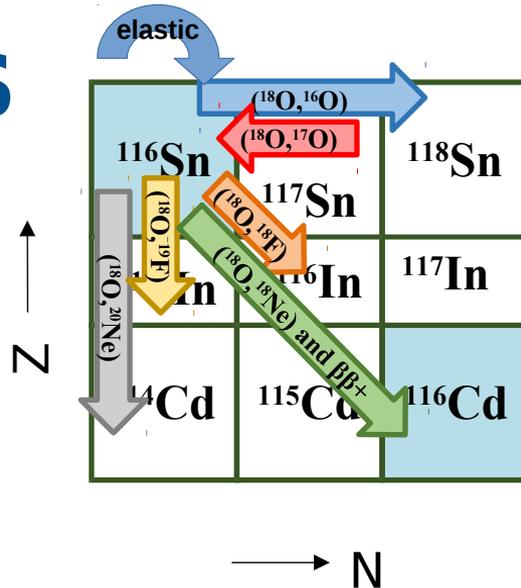




Program at LNS

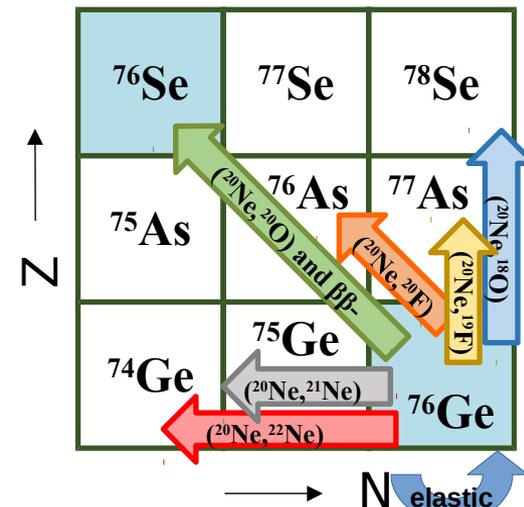
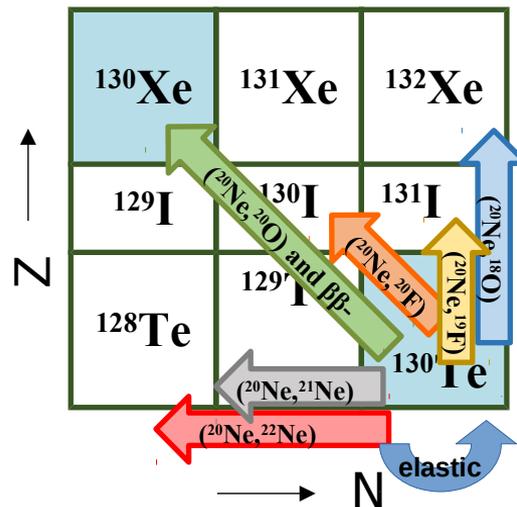
$^{116}\text{Cd} - ^{116}\text{Sn}$ case

- ✓ Two experiments @ 15 AMeV
- ✓ $^{18}\text{O} + ^{116}\text{Sn}$
- ✓ $^{20}\text{Ne} + ^{116}\text{Cd}$



$^{130}\text{Te} - ^{130}\text{Xe}$ case

- ✓ One experiment @ 15 AMeV
- ✓ $^{20}\text{Ne} + ^{130}\text{Te}$



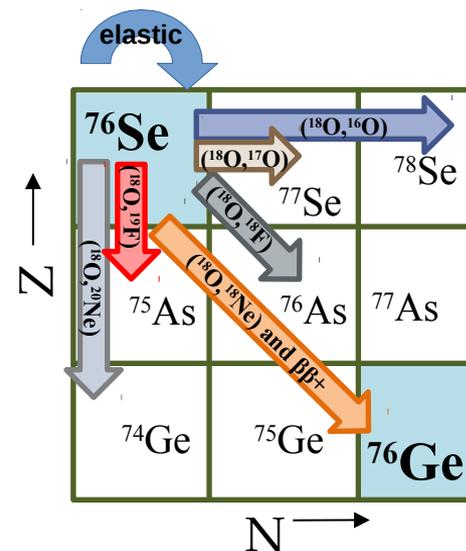
$^{76}\text{Ge} - ^{76}\text{Se}$ case

- ✓ One experiment @ 15 AMeV
- ✓ $^{20}\text{Ne} + ^{76}\text{Ge}$

NUMEN: phase 2 experimental run 2018

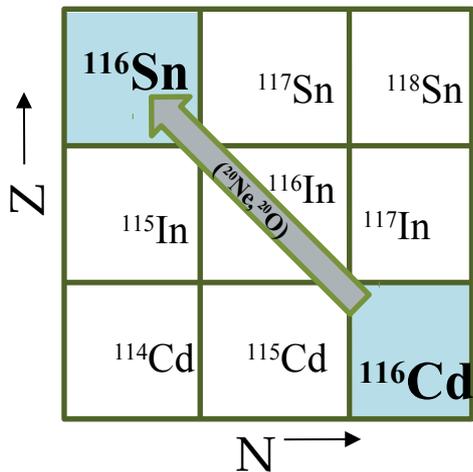
Nov-Dec 2018: $^{18}\text{O} + ^{76}\text{Se}$ @ 15 MeV/u (90 BTU)

- DCE reaction $^{76}\text{Se}(^{18}\text{O}, ^{18}\text{Ne})^{76}\text{Ge}$
 - CEX reaction $^{76}\text{Se}(^{18}\text{O}, ^{18}\text{F})^{76}\text{As}$
 - 2p-transfer $^{76}\text{Se}(^{18}\text{O}, ^{20}\text{Ne})^{74}\text{Ge}$
 - 1p-transfer $^{76}\text{Se}(^{18}\text{O}, ^{19}\text{F})^{75}\text{As}$
 - 1n-transfer $^{76}\text{Se}(^{18}\text{O}, ^{17}\text{O})^{77}\text{Se}$
 - 2n-transfer $^{76}\text{Se}(^{18}\text{O}, ^{16}\text{O})^{78}\text{S}$
 - Elastic scattering
- $0^\circ \leq \theta_{\text{lab}} \leq 9^\circ$
 $3^\circ \leq \theta_{\text{lab}} \leq 14^\circ$

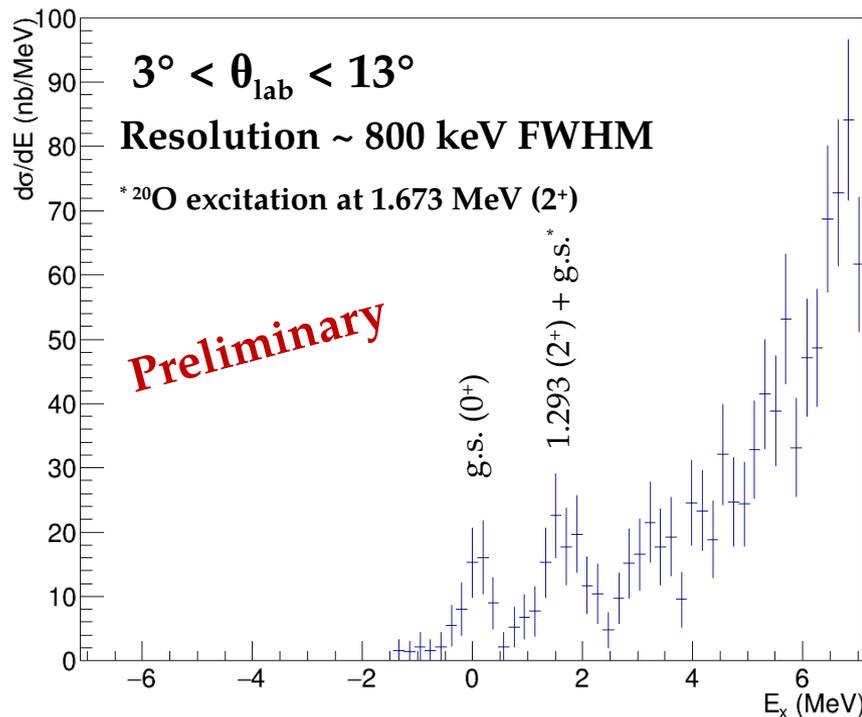




NUMEN: $^{20}\text{Ne} + ^{116}\text{Cd}$ double charge exchange



$^{116}\text{Cd}(^{20}\text{Ne}, ^{20}\text{O})^{116}\text{Sn}$



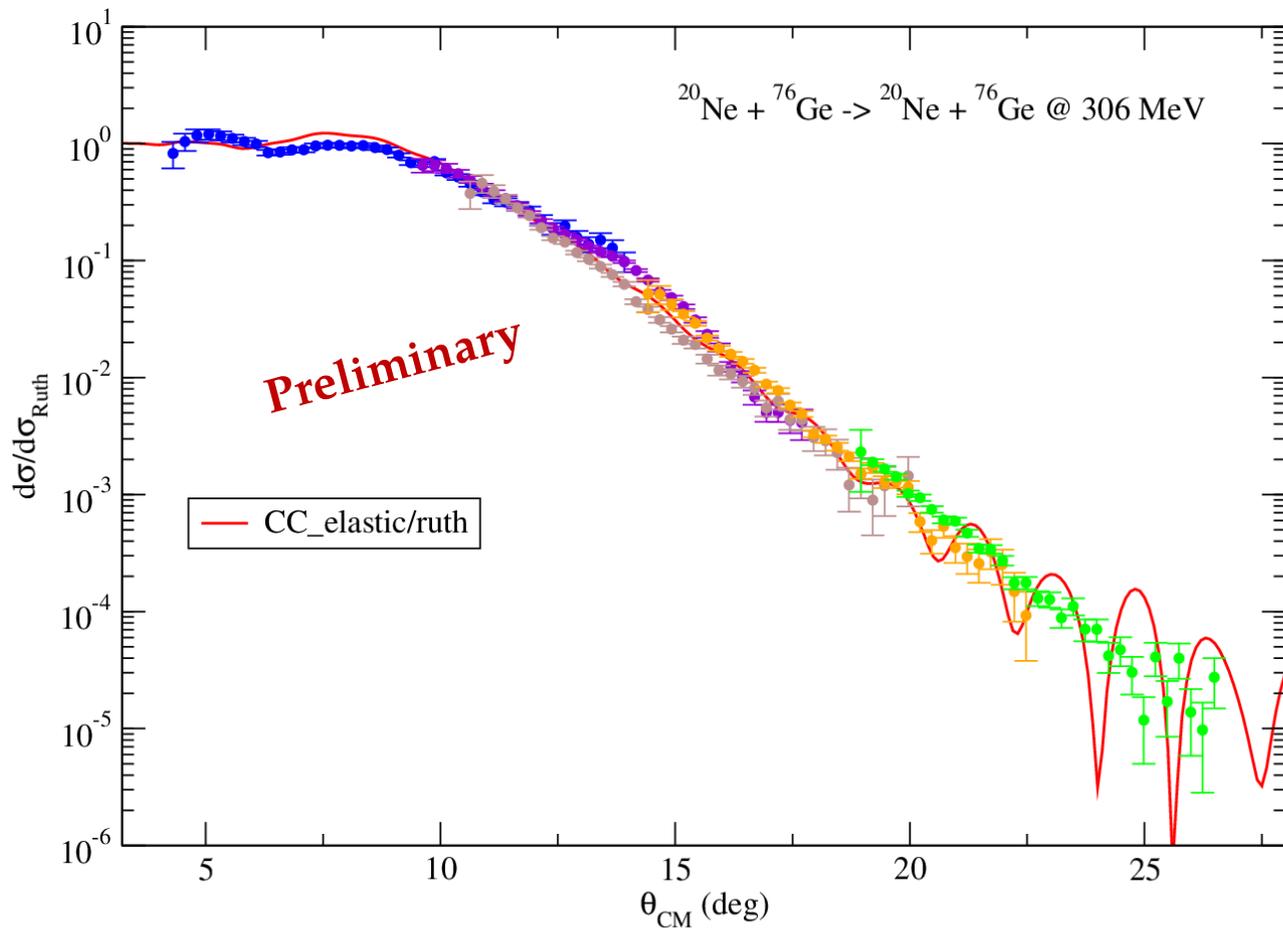
State (MeV)	Counts	Absolute cross section (nb)
g.s. (0 ⁺)	34	12 ± 2
$^{116}\text{Sn}_{1.293} (2^+) + ^{20}\text{O}_{\text{gs}} (0^+)$	67	24 ± 3
$^{116}\text{Sn}_{\text{gs}} (0^+) + ^{20}\text{O}_{1.673} (2^+)$		

Analysis on the cross-section sensitivity

Cross section sensitivity better than 1 nb



NUMEN: $^{76}\text{Ge}(^{20}\text{Ne},^{20}\text{Ne})^{76}\text{Ge}$ Elastic scattering

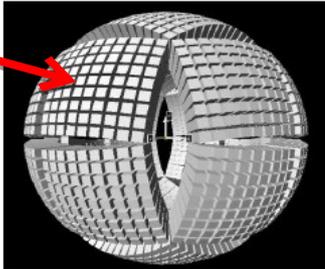




NUMEN: upgrade of the experimental set-up



The upgraded magnetic system for MAGNEX	
The new beam dump	
Design of the targets	
NUMEN focal plane detector tracker	
Particle identification	
The gamma calorimeter for NUMEN	
Front-end and read-out electronics	
Data handling and data processing	



R&D

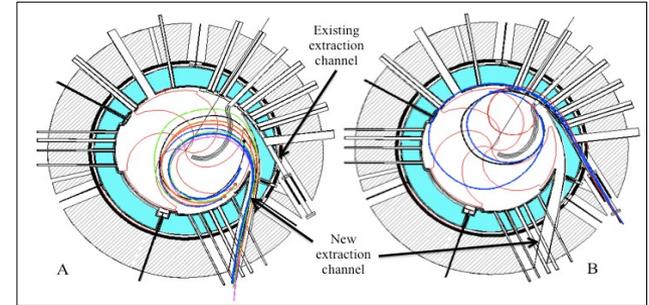


Technical Design Report (TDR)

NUMEN: upgrade of the experimental set-up

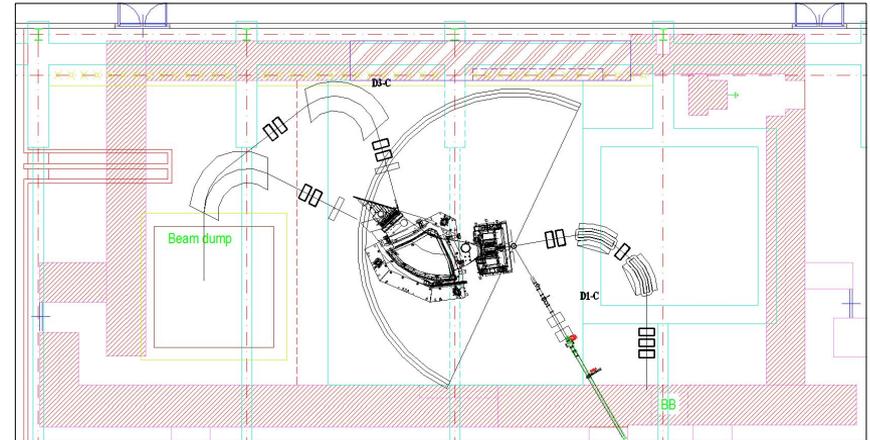
✓ Upgrade of the LNS accelerator and beam lines

- ✓ **CS** accelerator current (from 100 W to 5-10 kW); from electrostatic to extraction by stripping.
- ✓ **beam transport line** transmission efficiency to nearly 100%. The new beam transport line corresponds with the FRAGment Ion Separation line.



✓ Beam dump for the MAGNEX hall

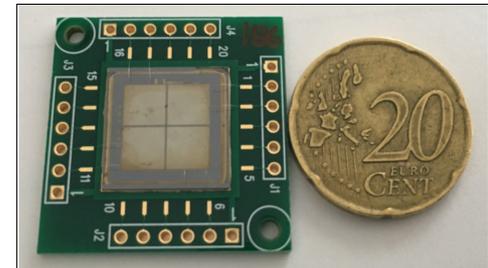
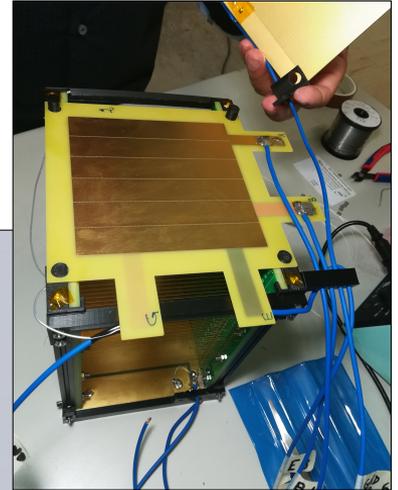
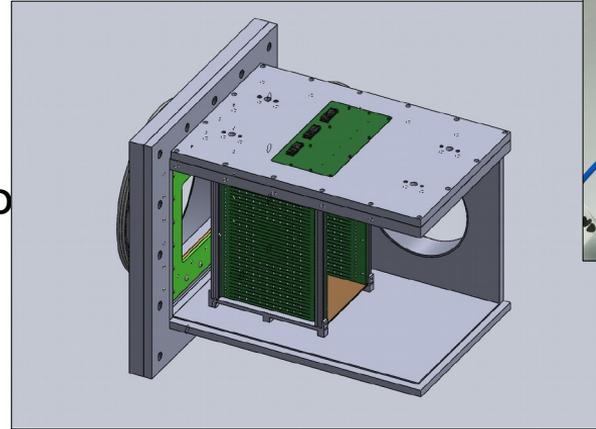
- ✓ **Shielding and power up to 10 kW**
- ✓ Borated concrete cube of 5x5x5 m³
- ✓ New entrance beam line.



NUMEN: upgrade of the experimental set-up

- ✓ **Gas tracker based on ThGEM technology**
 - ✓ Very **fast** detector.
 - ✓ High multiplication factor.
 - ✓ Tracking properties equal or better resp the present wire-based tracker.

- ✓ **SiC stopping wall**
 - ✓ Very high **radiation hardness**.
 - ✓ **Energy resolution** and **timing properties** comparable to silicon detector.
 - ✓ High granularity.

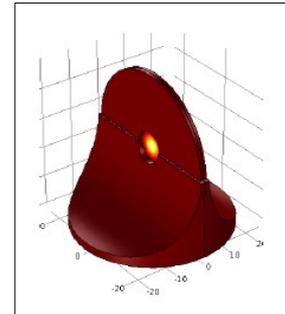
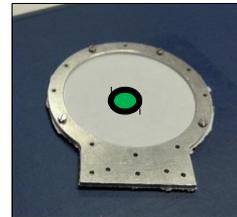




NUMEN: upgrade of the experimental set-up

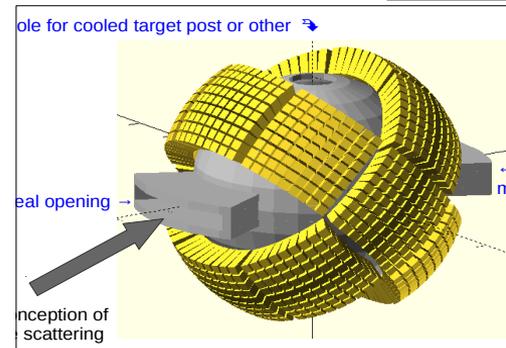
✓ Target assembly

- ✓ Pyrolytic graphite substrate.
- ✓ Cryogenic cooling system.



✓ Gamma calorimeter

- ✓ Large solid angle gamma-detector
- ✓ Good energy resolution: LaBr or Lyso



✓ Front-end and read-out electronics

- ✓ ASIC front-end based on VMM3 chip
- ✓ Read-out FPGA based



✓ Magnet upgrade

- ✓ Magnetic rigidity from 1.8 to 2.4 Tm

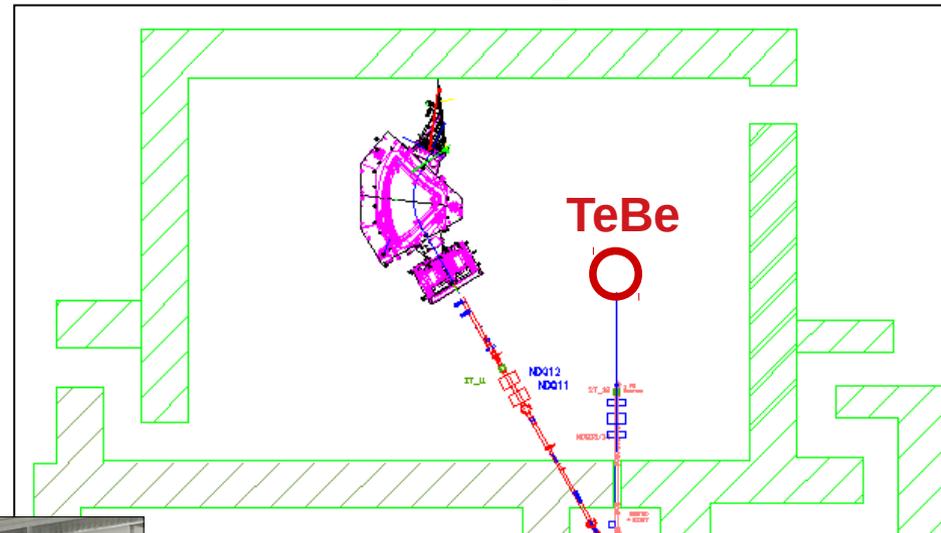
The TeBe beam line: FARE-MIUR grant

Beam line



Scattering chamber

Gas chamber



Beam line

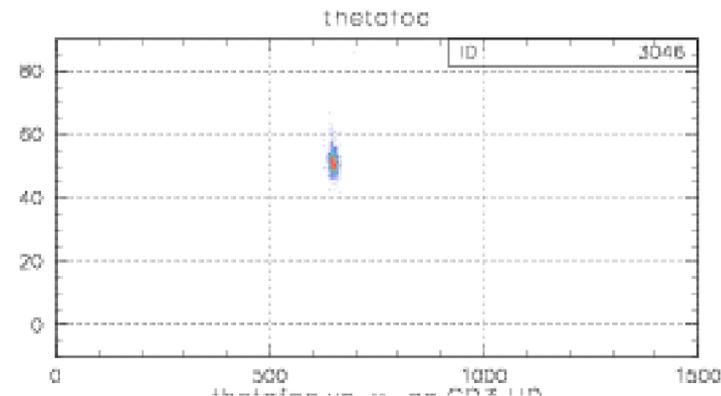
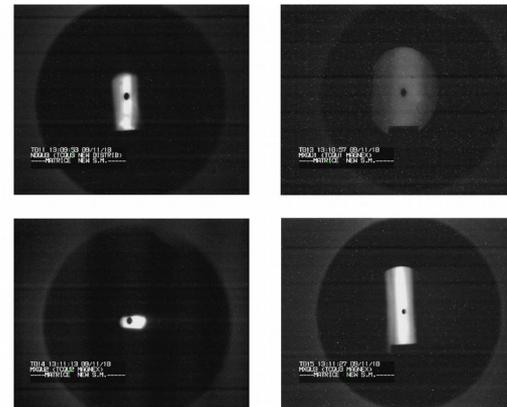
Thanks to the
LNS services

Beam tuning

Beam tuning is critical for 0° measurements!

A beam profile and its angular divergence have been obtained in two independent ways:

- ✓ At the target position, by means of shot of several scintillators along the beam line.
- ✓ At the focal plane position, by means of a highly attenuated beam, directly sent on the Focal Plane.



Thanks to the accelerator division



Timing

For future experiments a **better timing** is required (2 ns).

During the last run the need of a better timing arose for two independent reasons.

- Gamma coincidence test, performed using EDEN detector show that the gamma coincidence peak is broad. In order to better distinguish gamma from the neutron background a narrower bunch is required.
- Charge identification can be performed by using the RF. This is able to solve some ambiguities that can be present in same case (when m/q is the same for two different combination of isotopes/charge-states)

For next experiments **buncher** and/or **chopper** will be required.

Tank you
for your attention!