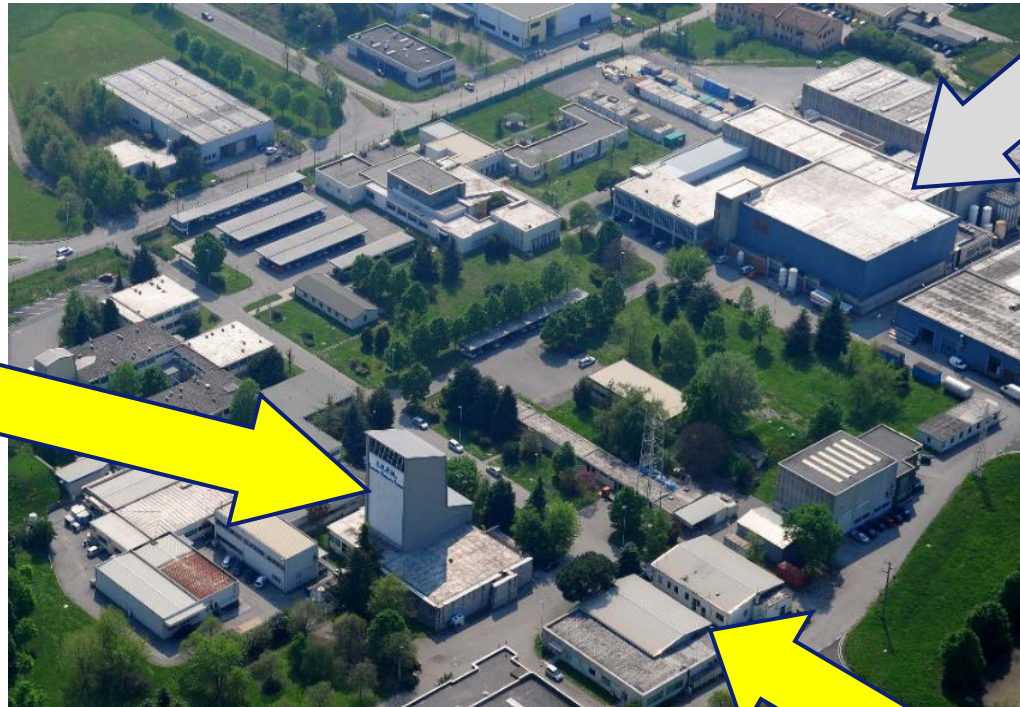


MeV ion beams in applied and fundamental research at the Laboratori Nazionali di Legnaro

Valentino Rigato

Sci. Coord. AN2000 and CN VdG Accelerators
INFN - Laboratori Nazionali di Legnaro

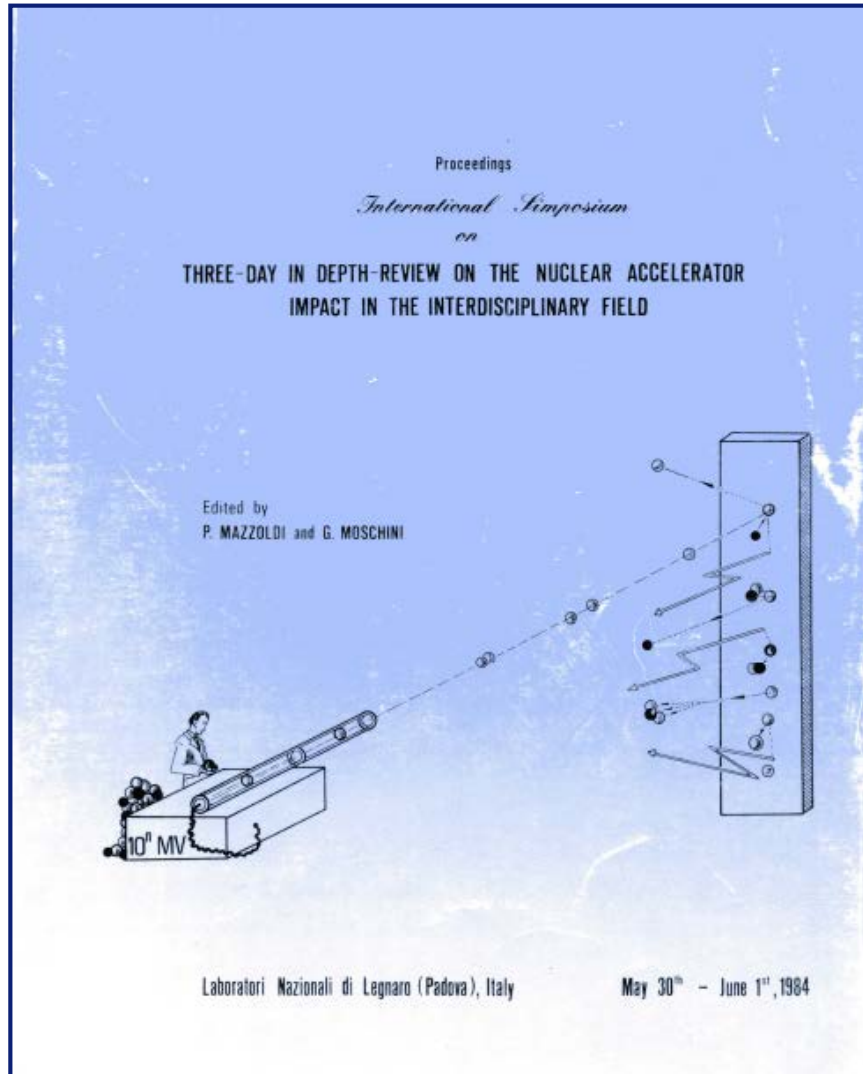


CN (Van de Graaff)

AN2000 (Van de Graaff)

Management:

- U.S.I.P. (User Selection Panel for Interdisciplinary Physics)
- Machine's operation: LNL Accelerator Division (SAFI service: 4 people **Mo-Fri -24H only authorized user**)
- Scientific Coordinator
- FACILITIES SUPPORTED by ENSAR2 UE PROJECT
- Convenzione Università Padova –INFN LNL



FOREWORD

Over the past few years there has been an increasing interest in the study and application of nuclear accelerators in the interdisciplinary field. The Symposium covered recent and novel developments in the use of nuclear accelerators, including Tandem accelerators, particularly from a basic point of view, in cross disciplinary field as Astrophysics, Geophysics, Medicine, Solid State Physics, Material Science, Surface Science, Hyperfine Interactions, Environment Pollution, Dosimetry and Radiation Biology.

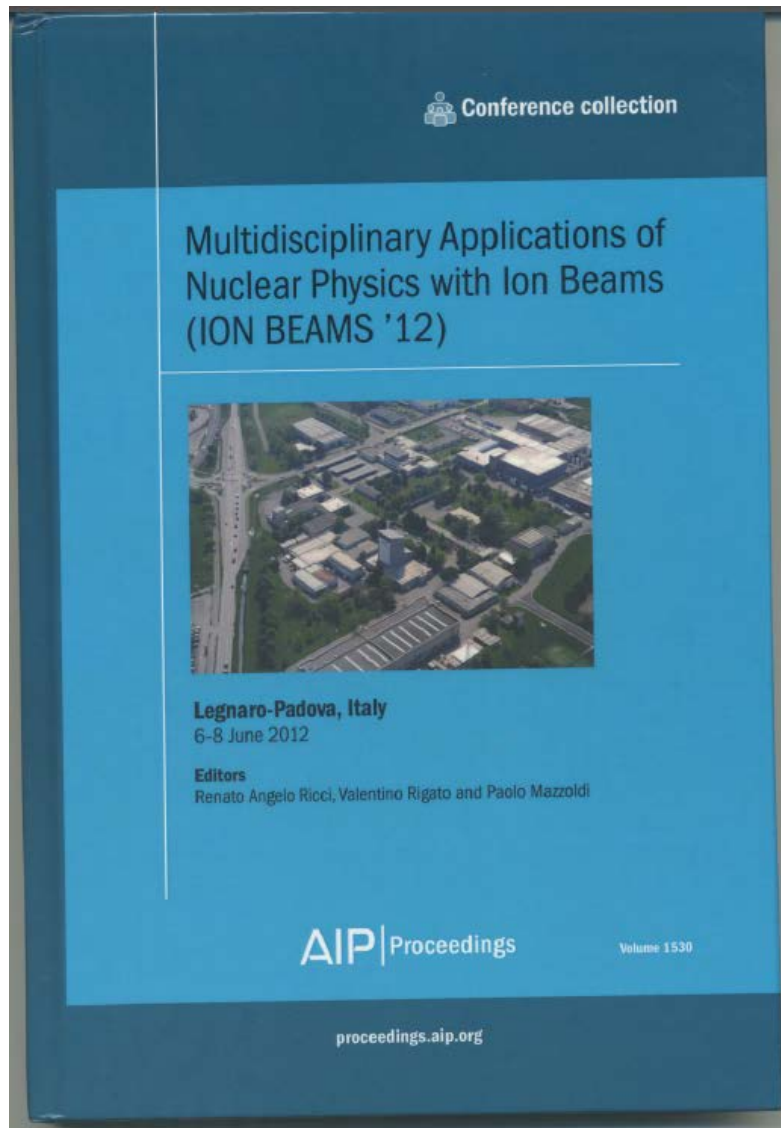
The Symposium consisted of papers of invited speakers, each giving both a review of a major topic and new ideas for further development. The introduction of each topic was followed by shorter contributed papers.

Invited talks were given by the following speakers:

J.A. Davies - Chalk River,
C. Cohen - Ecole Normale Paris,
G. Amsel - Ecole Normale Paris,
N. Hertel - University of Aarhus,
J.P. Biersak - Hahn-Meitner Institut Berlin,
R.A. Ricci - University of Padova,
J. Goldring - Weizmann Institute Rehovot,
G.W. Arnold - Sandia Laboratory New Mexico,
J.P. Thomas - Institute de Physique Nucléaire Villeurbanne,
C. Tuniz - University of Trieste,
E. Dafni - Weizmann Institute Rehovot,
G. Dearnaley - Harwell Laboratory Didcot,
H.J. Matzke - J.R.C. Karlsruhe,
O. Meyer - Kernforschungszentrum Karlsruhe,
D.E. Watt - University of St. Andrews.

A round table on "State of the art, prospect and needs in Megavolt accelerator building technology" has been organized with G. Amsel, F. Chmara (Ionex Corporation), G. Dearnaley, M. Letournel (Strasbourg), J.D. Larson (L.N.L. Legnaro), H.R. Hyder (Oxford).

The Symposium was attended by about one hundred participants with approximately 60% from Italy. New developments in nuclear techniques were also featured. The success of this Meeting suggests the utility of this kind of organizations for stimulating contacts and discussions between researchers in this developing area.



Preface: Multidisciplinary Applications of Nuclear Physics with Ion Beams

This book is a collection of papers presented at the International Conference "Multidisciplinary Applications of Nuclear Physics with Ion Beams" (ION BEAMS '12) held at the INFN Laboratori Nazionali di Legnaro (LNL), Padova, Italy, on June 6-8, 2012. It contains most of the invited talks plus other selected contributions presented during the conference in the LNL Aula Villi (Professor Claudio Villi from Padova was one of the founders of the Laboratory and President of the Istituto Nazionale di Fisica Nucleare from 1970 to 1975).

The Conference was organized as a special event in the frame of the celebration of the 50th anniversary of the Legnaro Laboratory founded by Professor Antonio Rostagni, head of the Physics Department of the University of Padova, originally named "Centro di Ricerche Nucleari della Regione Veneto", which was initially equipped with a 5.5 MV High Voltage Electrostatic Accelerator (see the Introduction of R.A. Ricci).

The Laboratori Nazionali of Legnaro is recognized as an accelerator Research Center with many active research programs in multidisciplinary fields, ranging from nuclear spectroscopy and neutron physics to materials development and analysis, radio-biology, environmental physics and surface modification by ion beams thanks to the continuously evolving accelerator equipment.

Over the last 40 years there has been an increasing interest in studies and applications of nuclear accelerators in different interdisciplinary domains. Existing infrastructures have been continuously updated and new ion beam laboratories were setup in all industrialized countries. The main aim of the Conference was therefore to outline the present status and possible future developments in the utilization of such facilities at international level through joint research programs in fields such as Biophysics, Medicine, Solid State Physics, Material Science, Environmental Pollution, Dosimetry, Radiation Biology and Geophysics.

ION BEAMS'12 was the latest of a series of meetings concerning the nuclear physics techniques and applications of ion beams to interdisciplinary fields. It was attended by about 90 participants from different countries (Croatia, France, Germany, Greece, India, Romania, Spain, Switzerland, UK, USA) with approximately 75% from Italy. The invited speakers, chosen following the recommendations of the Scientific Committee, presented a review of the various accelerator facilities in Italy (LNL, LNS-Catania, Florence, Lecce and Naples Universities) and of selected international facilities and multi-facilities programs to fix the state of the art and the perspectives of short-medium terms future developments. Shorter oral presentations were given after the introduction of each scientific topic to outline original results and perspectives of different groups in the various fields of ion beams science and technology. About 30 contributions were presented at the poster session.

The various presentations were distributed in six sessions: Cultural Heritage (chaired by J.C. Dran), Ion Beam facilities and Instrumentation (chaired by R. A. Ricci); Ion Beam Analysis and Material Modifications (chaired by P. Mazzoldi, V. Rigato, G. Della Mea, M. Berti); Radiation Physics (chaired by M. Belli and P. Colautti); Radiation Biophysics and Medicine (chaired by R. Cherubini and M. Belli), Radiation Damage (chaired by M. Carpinelli). They were preceded by the introduction

Multidisciplinary Applications of Nuclear Physics with Ion Beams (ION BEAMS '12)
AIP Conf. Proc. 1530, 1-2 (2013); doi: 10.1063/1.4812898
© 2013 AIP Publishing LLC 978-0-7354-1168-5/30.00

- **Micro and sub-micron beams :**
 - precision targeting
 - Ion microscopy
- **Single event :**
 - Single ion deterministic irradiation / doping
- **Applications with reaction products**
 - Eg.: Neutrons from Be and Li / energetic protons from D(³He)

TOPICS

Radiation Interaction and Damage
 Surface Modification
 Materials Science
 Nuclear Data Acquisition and Analysis
 Ion Beam Analysis and Channeling
 Environmental Sciences
 Art and Archaeology
 Dosimetry, Microdosimetry, Nanodosimetry
 Radiation Biophysics and Medicine.

LIST OF INVITED SPEAKERS

Preliminary list of invited speakers

- D.K. Avasthi (IUAC, New Delhi, India)
 L.C. Feldman (Institute for Advanced Materials, Devices and Nanotechnology, Rutgers University, USA)
 M. Hill (CRUK/MRC, Gray Inst. for Radiation Oncology and Biology, Oxford, UK)
 W. Möller (Helmholtz-Zentrum Dresden-Rossendorf, Germany)
 C. Pacheco (C2RMF-Centre de recherche et de restauration des musées de France, Palais du Louvre, Paris, France)
 H. Rabus (Physikalisch-Technische Bundesanstalt, Braunschweig, Germany)
 M. Toulemonde (CIMAP Laboratory, Caen, and GANIL, France)
 R. Webb (Surrey Ion Beam Centre, University of Surrey, Guildford, UK)
 A. Zucchiatti (Centro de Micro Analisis de Materiales, Universidad Autónoma de Madrid, Spain)

ION BEAMS 12

Multidisciplinary Applications of
 Nuclear Physics with Ion Beams

Legnaro (PADOVA), Italy
 6th - 8th June 2012



TOPICS

Radiation Interaction and Damage
 Surface Modification
 Materials Science
 Nuclear Data Acquisition and Analysis
 Ion Beam Analysis and Channeling
 Environmental Sciences
 Art and Archaeology
 Dosimetry, Microdosimetry, Nanodosimetry
 Radiation Biophysics and Medicine.

LIST OF INVITED SPEAKERS

Preliminary list of invited speakers

- D.K. Avasthi (IUAC, New Delhi, India)
 L.C. Feldman (Institute for Advanced Materials, Devices and Nanotechnology, Rutgers University, USA)
 M. Hill (CRUK/MRC, Gray Inst. for Radiation Oncology and Biology, Oxford, UK)
 W. Möller (Helmholtz-Zentrum Dresden-Rossendorf, Germany)
 C. Pacheco (C2RMF-Centre de recherche et de restauration des musées de France, Palais du Louvre, Paris, France)
 H. Rabus (Physikalisch-Technische Bundesanstalt, Braunschweig, Germany)
 M. Toulemonde (CIMAP Laboratory, Caen, and GANIL, France)
 R. Webb (Surrey Ion Beam Centre, University of Surrey, Guildford, UK)
 A. Zucchiatti (Centro de Micro Analisis de Materiales, Universidad Autónoma de Madrid, Spain)
- Presentations of Italian Ion Beam Facilities**
 M. Bianconi (CNR-IMM, Bologna, Italy)
 L. Calagnone (Centro Diagnostico e Diagnostico, Università del Soleim, Lecce, Italy)
 L. Cantagallo (Dipartimento di Scienze Fisiche, Università di Napoli Federico II and INFN Sez. di Napoli, Italy)
 G. Cutone (INFN Laboratori Nazionali del Sud, Catania, Italy)
 M. G. Grimaldi (Dipartimento di Fisica e Astronomia, Università di Catania, and MATIS CNR-IMM, Catania, Italy)
 F. Maroldi (Università di Firenze and INFN LABC, Firenze, Italy)
 V. Rigato (INFN Laboratori Nazionali di Legnaro, Italy)
 F. Teresi (CIRCE, INNOVA and Dept. of Environmental Sciences - Sec. Università di Napoli, Italy)
 C. Ur (INFN Padova, Italy)

Scientific Committee

- R. Broda, Institut of Nuclear Physics, Krakow, Poland
 M. Corpinelli, INFN Cogne, Italy
 A. Clement Font, CNAM and Universidad Madrid, Spain
 G. Della Mea, Trento University, Italy
 J.C. Dron, C2RMF-Centre de recherche et de restauration des musées de France, Palais du Louvre Paris, France
 D. Goodhead, Medical Research Council, Harwell, UK
 P. Mandò, Florence University and IABEC, Florence, Italy
 P. Mazzoldi, Padova University, Italy
 G. Maschini, Padova University, Italy
 G. Ottaviani, Modena and Reggio Emilia University, Italy
 R. A. Ricci, INFN Legnaro, Italy
 V. Rigato, INFN Legnaro, Italy
 E. Rimini, CNR-Istituto per la Microelettronica e Microsistemi, Catania, Italy

Organizing Committee

- R. A. Ricci (Chair), INFN Legnaro, Italy
 V. Rigato (Scientific Secretary), INFN Legnaro, Italy
 R. Chenabre, INFN Legnaro, Italy
 P. Colautti, INFN Legnaro, Italy
 A. Lombardi, INFN Legnaro, Italy
 P. Mazzoldi, Università di Padova, Italy
 C.A. Ur, INFN Padova, Italy

Conference Secretaries

- Cristina Camporese, INFN Legnaro, Italy
 Anna D'Este, INFN Legnaro, Italy
 Cristina Milesi, INFN Padova, Italy
 Daniela Zeno, INFN Legnaro, Italy

CONTACT ADDRESS
<http://ionbeams12.infn.it/>
 ionbeams@infn.it



ICNMTA 2014

14th International Conference on Nuclear Microprobe Technology and Applications

6-11 July 2014 *Palazzo del Bo and Centro Culturale San Gaetano, Padova*
Europe/Rome timezone

Overview

- Committees
- Download
- Important Deadlines (new)
- Scientific Programme and Topics
- Presentations and Proceedings
- Registration
- IAEA Cooperation
- Joint Training Course on Ion Beam Microscopy
- Venue and Travel
- Accommodation
- Social Events
- Official Invitations
- Industrial Exhibition and Sponsorship
- Related Conferences
- CONTACTS
- Author index

ICNMTA2014 Secretariat

The conference covers the aspects of nuclear microscopy regarding both the development of the micro/nano focused ion beam technology and the state of the art in the various applications of ion micro/nano probes in many scientific fields, ranging from high-tech materials to Biology, geology, art and archaeology.

We hope you found your visit to Padova stimulating and enjoyable, and we look forward to seeing you in Lanzhou - China 2016

ICNMTA 2016

Closing remarks by Istvan Rajta

Plenary session speakers

- M. Breese, Singapore - *Three dimensional silicon micromachining using a nuclear microprobe.*
- T. Calligaro, France - *The nuclear microprobe in cultural heritage studies: state of the art and challenges.*
- C. Greubel, Germany - *Radiobiological and medical research at the ion microprobe SNAKE.*
- D. Jamieson, Australia - *Cold beams and focused beams: new technology for new microprobes in the quantum era.*
- J. Meijer, Germany - *The functionalization of single atoms addressed by ion beam implantation.*
- R. Ortega, France - *Applications of nuclear microprobe imaging in neuroscience.*
- G. Vizkelethy, US - *Radiation Effects Microscopy in Microelectronic Devices Using a Heavy Ion Nuclear Microprobe.*
- F. Watt, Singapore - *Nuclear Microscopy of biological cells using MeV ions: A critical review.*
- R. Webb, UK - *Ambient Pressure Molecular Concentration Mapping Using Simultaneous MeV-SIMS and PIXE.*



Joint Training Course on Ion Beam Microscopy

3-4 July 2014 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

Overview

- General Information
- Topics, Lecturers and Timetable
- How to reach LNL
- Accommodation
- ICNMTA 2014
- Participants

Joint Training Course Secretariat

The purpose of this two-day course (held just before the ICNMTA 2014 Conference) is to review the current status of ion beam microscopy and to highlight innovative aspects of single-ion and microprobe techniques for the analysis and modification of materials at the micro and nano-scale.



2011 Interdisciplinary Physics with Ion Beams: Status and Perspectives - LNL Users Workshop

chaired by R.A. Ricci - V. Rigato

from Thursday, 16 June 2011 at 14:00 to Friday, 17 June 2011 at 14:40 (Europe/Rome)
at INFN-LNL (C. Villi (June, 16th) & Sala LNL(June, 17th))

Description The workshop will discuss the status and perspectives of the interdisciplinary physics experiments performed at LNL using the AN2000, CN and TANDEM accelerators. The spokespersons of the various disciplines will briefly present their activity and results, and most importantly, will outline the requests and perspectives for the future. Members of the User Selection Panel (USP) and of the LNL Users Board will participate to the workshop. During the workshop the details of the EU program ENSAR (<http://www.ensarf7.eu/>) will be presented and the new LNL organization concerning the PAC and USP for the evaluation of new experiments will be outlined.

Support tari@lnl.infn.it

Manage ▾

Thursday, 16 June 2011

- 14:00 - 14:10 Welcome of LNL Director 10'
Speaker: G. Fiorentini (INFN-LNL)
- 14:10 - 14:20 USP Chairman Welcome 10'
Speaker: R. A. Ricci (INFN-LNL)
- 14:20 - 14:30 Status of AN2000 and CN VdG Accelerator 10'
Speaker: V. Rigato (INFN-LNL)
- 14:30 - 14:35 Status of TANDEM-ALPI Accelerator 5'
Speaker: C. Ur (INFN-LNL)
- 14:35 - 14:52 PDSS at AN2000: a continuing activity 17'
Speaker: G. Battaglin (Ca'Foscari University Mod)
- 14:52 - 15:09 Defects and Impurities in compound III-Vs
Speaker: A. Gasparotto (Dipartimento di Fisica U)
- 15:09 - 15:26 Crystals characterization for ultra-relativistic applications 17'
Speaker: D. De Salvador (Dipartimento di Fisica U)
- 15:26 - 15:43 Synthesis and characterization of thin film applications in optics, radiation detection
Speaker: G. Maggioni (INFN - LNL)
- 15:43 - 16:00 Thin film interactions and surface modification
Speaker: G. Ottaviani (Phys. Dept. Univ. Modena)
- 16:00 - 16:20 break (LNL cafeteria)
- 16:20 - 16:37 Metal-dielectric-metal multilayers for neutron
Speaker: M. Natali (ICIS-CNR Padova)
- 16:37 - 16:54 Migration of radionuclides and colloids in beam techniques: be of help? 17'

2013 LNL Interdisciplinary Users Meeting

chaired by Valentino Rigato (INFN-LNL)

Tuesday, 9 July 2013 from 09:00 to 18:00 (Europe at INFN Laboratori Nazionali di Legnaro (Aula V

Description LNL USIP organizes a 1-day Workshop, to be held performed at the CN, AN2000 and TANDEM-ALPI experiments are invited to the workshop for a pres

MORN	
USIP Welcome and Introduction	
Presentation Order	Experiment / (proposer)
1	Dia.Fab. (F.Piccolo)
2	GEOPD (C. Mazzoli)
3	10B (A. Cacioli)
4	HeavyFe (A. Gasparotto)
5	NASPENA (E. Rosato)
6	ILITS (D. Moro)
7	PDSS (G. Battaglin)
8	CARTA (R. Menegazzo)
9	SIRAD Experiments at T
AFTERN	
10	HCCC (D. De Salvador)
11	LINBOPD (N. Argiolas)
12	PFNS (M.Cinausero / F
13	MITRA TANDEM (V.C
14	MITRA_CN (P.Colautti)
15	SID-MICROSI 1 slide (P
16	RADAR (L. Gozzellino)
17	MESH (L. Gozzellino)
18	EXCALIBUR (R.Cherubi
COFFEE I	
19	MICROARCHAEOSTUDY (B. Constatntinescu)
20	TPR-LNL (Tardocchi)
21	TNNS (G. Maggioni)

2015 LNL Interdisciplinary Users' Meeting

chaired by Valentino Rigato (LNL)

from Wednesday, 8 July 2015 at 09:00 to Thursday, 9 July 2015 at 16:00 (Europe/Rome)
at INFN Laboratori Nazionali di Legnaro (Sala Villi)
Viale dell'Università 2 35020 LEGNARO PD ITALY

Description LNL USIP organizes a 1-day Workshop, to be held at the Laboratori di Legnaro with all the spokespersons of the experiments performed at the CN, AN2000 and TANDEM-ALPI Accelerators in interdisciplinary physics. All spokespersons of USIP experiments and all interested Users of the LNL facilities are welcome. The presentation of selected running experiments and of all the new proposals will take place together with the discussion on future activity.

Meeting language: English.

v.1.4

Go to day ▾

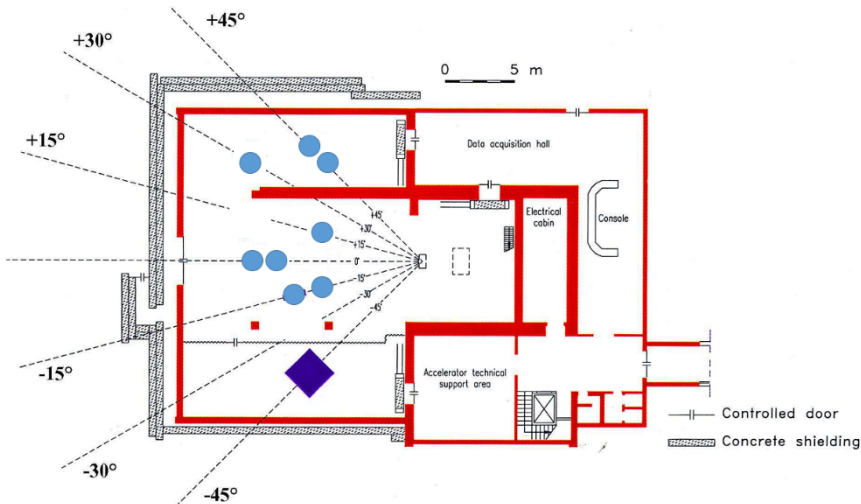
Wednesday, 8 July 2015

- 09:00 - 10:45 Morning Session I
Convener: Mauro Belli (ROMA1)
- 09:00 **Welcome 10'**
Speaker: Renato Angelo Ricci (LNL)
- 09:10 **TANDEM-ALPI-PIAVE Complex 20'**
Speaker: Marco Mazzocco (PD)
- 09:30 **AN2000 and CN Accelerators 20'**
Speaker: Valentino Rigato (LNL)
- 09:50 **Small Accelerators' Operation 20'**
Speaker: Stefania Canella (LNL)
- 10:10 **The SIRAD experiments Summary and New proposals ESA-Compliant(TANDEM-ALPI) and CHIPX65 (CN) 30'**
Speaker: Dario Bisello (PD)
- 10:45 - 11:15 Coffe Break
- 11:15 - 13:10 Morning session II
Convener: Prof. Marina Berti (Physics Department University of Padova)
- 11:15 **MITRA activity at CN and TANDEM 20'**
Speaker: Valeria Conte (LNL)
- 11:35 **RADAR and MESH experiments at TANDEM and CN 20'**
Speaker: Gianluca Ghigo (TO)
- 11:55 **LP2-B1C experiment (TANDEM) 15'**
Speaker: Dr. Massimo Emilio Angiolini (ENEA Technical Unit for Fission Technologies)
- 12:10 **BELINA and n-TOF experiments at CN 20'**
Speaker: Pierfrancesco Mastinu (LNL)
- 12:30 **DICER experiment at CN 15'**
Speaker: Dr. Gianmaria Collazuol (PD)

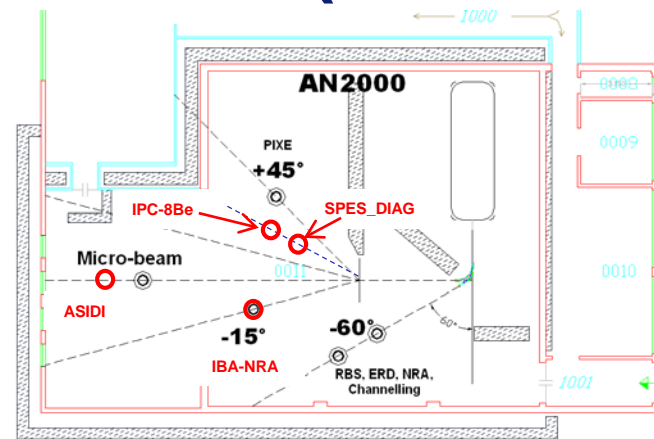
CN (oper. since 1961)

7 beam lines (1-6MV **pulsed/cont**, ^1H , ^2H , ^3He , ^4He , ^{14}N)

- Radiation-Biology (broad beam in air, single ion microbeam in air – resolution: $\sim 4\text{-}5\mu\text{m}$)
- Neutron Production (dosimetry/spectrometry):
 - $^7\text{Li}(p,n)^7\text{Be}$: $Q=-1.644\text{ MeV}$ – thin target
 - $^7\text{Li}(d,n)^8\text{Be}$: $Q=15.031\text{ MeV}$ – thin target
 - $^9\text{Be}(p,n)^9\text{B}$: $Q=-1.85\text{ MeV}$, – thick target
 - $^9\text{Be}(d,n)^{10}\text{B}$: $Q=4.361\text{ MeV}$ – thick target
- Radiation Damage
- Ion Beam Analysis (NRA, EBS, ERDA, IBIL, PIXE, PIGE)
- Nuclear cross section measurements / nuclear (astro)physics



AN2000 (oper. 1971)



5 beam-lines (0.25-2.2MV ^1H , ^3He , ^4He)

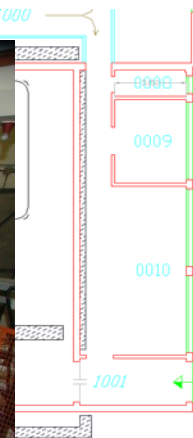
- **Micro-beam (best resolution: $\sim 2\mu\text{m}$)**
 - ✦ MicroPIXE, microIBICC, microIBIL
 - ✦ Ion Beam Writing (MEMS)
 - ✦ Single particle irradiation /doping
 - ✦ Detectors tests
- Ion Beam Analysis
 - ✦ NRA, RBS, ERD, IBIL
 - ✦ Ion Channelling
- PIXE
 - ✦ Archaeology, Cultural Heritage, Environmental
- $\text{D}(^3\text{He},p)^4\text{He}$
- Nuclear (astro)physics

CN (oper. since 1961)

AN2000 (oper. 1971)

7 beam lines (

- Radiation-B resolution:
- Neutron Pro
 - $^7\text{Li}(p,n)^7\text{Be}$: Q
 - $^7\text{Li}(d,n)^8\text{Be}$: Q
 - $^9\text{Be}(p,n)^9\text{B}$: Q
 - $^9\text{Be}(d,n)^{10}\text{B}$: C
- Radiation D
- Ion Beam A
- Nuclear cro

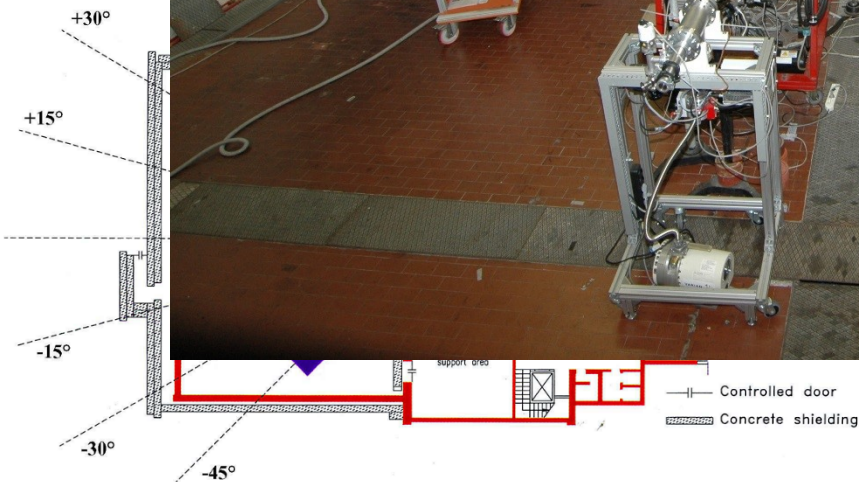


He, ^4He)

(um)

oIBIL

oping

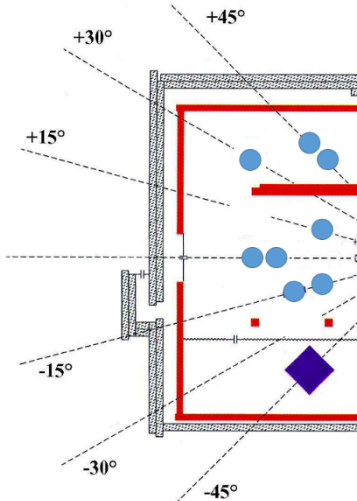
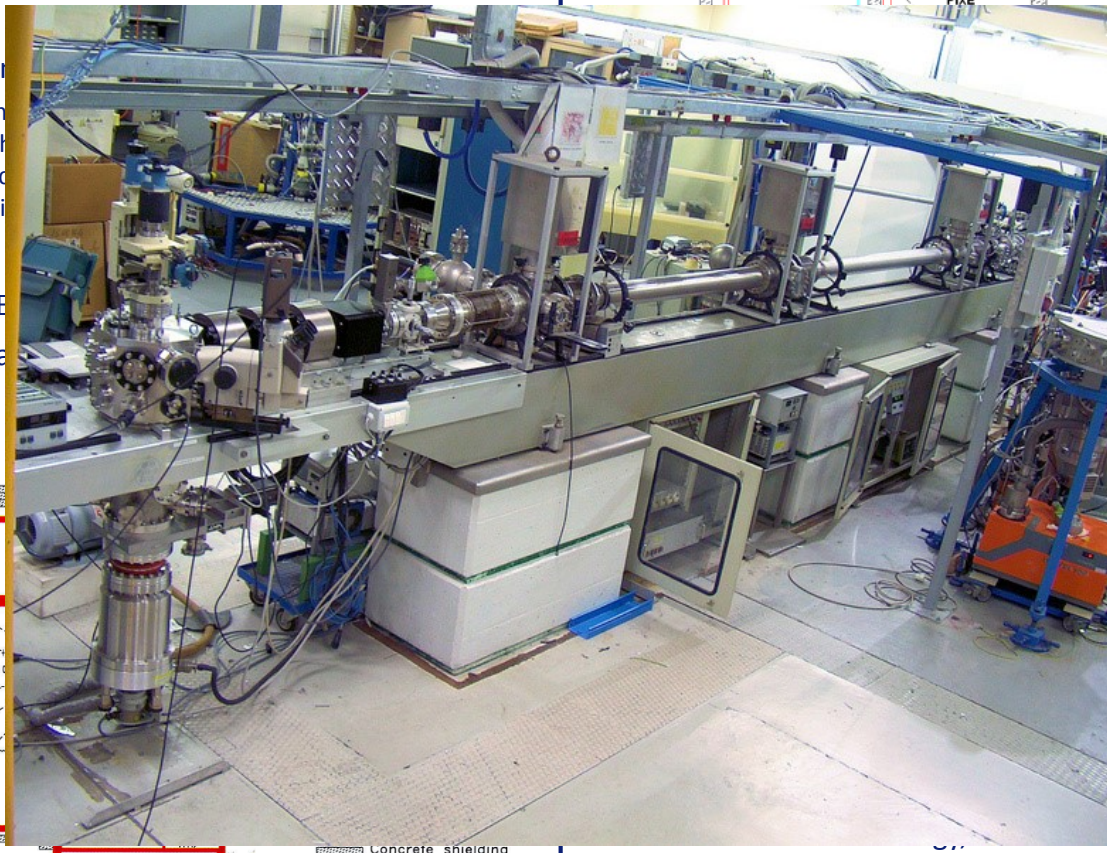


- FIXE
 - + Archaeology, Cultural Heritage, Environmental
 - D($^3\text{He},p$) ^4He
 - Nuclear (astro)physics

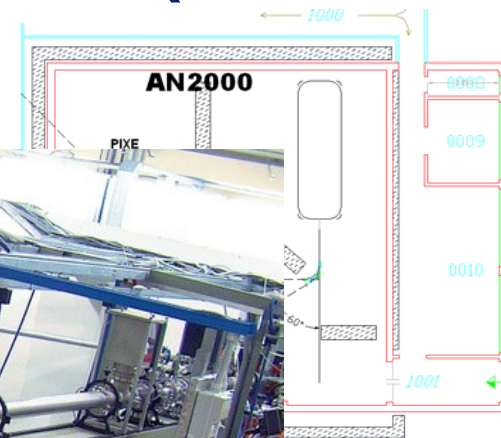
CN (oper. since 1961)

7 beam lines (1-6MV pulsed/cont, $^1\text{H}, ^2\text{H}, ^3\text{He}, ^4\text{He}, ^{14}\text{N}$)

- Radiation-Biology (broad beam in air, single ion microbeam in air – resolution: $\sim 4\text{-}5\mu\text{m}$)
- Neutron Production (dosimetry)
 - $^7\text{Li}(p,n)^7\text{Be}$: $Q=-1.644\text{ MeV}$ – thick target
 - $^7\text{Li}(d,n)^8\text{Be}$: $Q=15.031\text{ MeV}$ – thick target
 - $^9\text{Be}(p,n)^9\text{B}$: $Q=-1.85\text{ MeV}$, – thick target
 - $^9\text{Be}(d,n)^{10}\text{B}$: $Q=4.361\text{ MeV}$ – thick target
- Radiation Damage
- Ion Beam Analysis (NRA, ERDA)
- Nuclear cross section measurements



AN2000 (oper. 1971)



$^1\text{H}, ^3\text{He}, ^4\text{He}$)

$\sim 2\mu\text{m}$)

microIBIL

(S)

/doping

Heritage, Environmental

- $\text{D}(^3\text{He},p)^4\text{He}$
- Nuclear (astro)physics

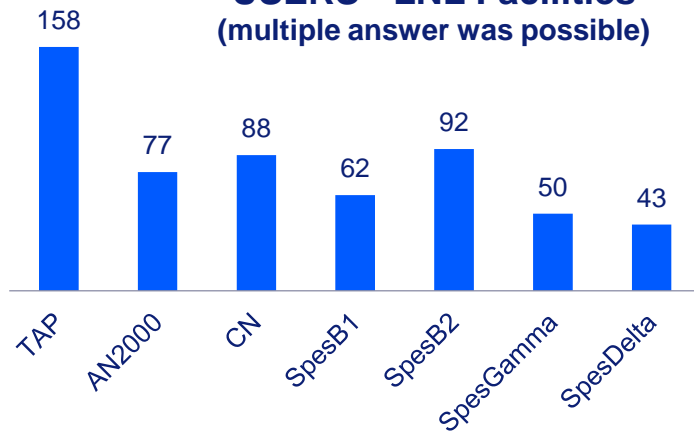
MAIN FEATURES OF AN2000 and CN

	AN2000	Notes	CN	Notes
Date	1971	HVE	1961	HVE
Accelerator Type	Van de Graaff, with charging belt	Single ended accelerator with high pressure CO ₂ /N ₂ insulation gas	Van de Graaff, with charging belt	Single ended accelerator with high pressure SF ₆ based mixture insulation gas. Originally 5MV then upgraded to 7MV
Structure	Horizontal		Vertical	
Ion Source	RF (source maximum current 250μA ¹ H ⁺ , 125μA ⁴ He ⁺)	HVE SO-173 short Emittance < 1.2 π mm mrad MeV ^{1/2}	RF (source maximum current 500μA ¹ H ⁺ , 250μA ⁴ He ⁺)	HVE SO-173 long Emittance < 1.5 π mm mrad MeV ^{1/2}
Ions	¹ H ⁺ , (³ He ⁺)*, ⁴ He ⁺	*On request	¹ H ⁺ , ² H ⁺ , (³ He ⁺)*, ⁴ He ⁺ , ⁴ He ⁺⁺ , (¹⁵ N ⁺⁺)*	*On request
Terminal Voltage	0.3-2.2 MV	0.2MV optional	1.0-6.0 MV	0.8 MV optional / (6÷7 MV not reached)
Shortening Rod	YES		YES	
Stabilization	GVM, SLIT		GVM, SLIT	⁴ He ⁺⁺ only GVM
Remote control	NO		NO	
Automatic HV conditioning	NO		NO	
Energy calibration	YES	(p,γ) reactions	Necessary every shift when changing beam and conditions	(p,γ) reactions, α-EBS
PULSED BEAM	NO		YES	3MHz with compression in the terminal: pulse duration about 2ns, beam deflection along beam-line for lower frequency.

MAIN FEATURES OF AN2000 and CN

	AN2000	Notes	CN	Notes
Analysing magnet	YES	90°/60° (NMR)	YES	90° (GaussMeter)
Switching magnet	YES	On 90° line: -15°, 0°, +15°, +30°, +45°	YES	-45°, -30°, -15°, 0°, +15°, +30°, +45°
Beam lines	5		7	
Microprobe	YES (~ 2µm size minimum)	Quadrupoles triplet "Oxford" type	NO	
Beam in air	NO	Under development D(3He,p)4He with 90µm silicon	YES	Thin membrane for radiation biology, low intensity.
Single particle	YES	1 to 1000 p/s	YES	~1000 p/s
Neutrons	NO		YES	
Ion Beam Analysis	YES	ERD, EBS, NRA, PIXE, Channelling (PIGE limited by maximum energy)	YES	EBS, PIXE, PIGE, NRA (ERD and channelling difficult)
Large area uniform irradiation	NO		NO	
Small area uniform irradiation	YES	~3x3mm ² with microprobe scan	NO	
Beam time hours (average 2010-2016)	1540	See fig. 3.2	1150	See fig. 3.4
Experimental area	~ 300 m ²	Incl. acc. footprint	~ 425 m ²	Incl. acc. footprint
Clean room	NO		NO	
RH%, Temperature close loop	NO		NO	

USERS - LNL Facilities (multiple answer was possible)



AUTORIZZAZIONI ALL'ESERCIZIO IN AUTONOMIA DELL'ACCELERATORE AN2000

#	Persona autorizzata	Ente di appartenenza	data autorizzazione	scadenza autorizzazione
1	Scian Carlo	Università Padova	26/02/2015	25/02/2017
2	Mazzoli Claudio	Università Padova	02/03/2015	01/03/2017
3	Tonini Rita	Università Modena	05/03/2015	04/03/2017
4	Battaglin Giancarlo	Università di Venezia	19/06/2015	18/06/2017
5	Battiato Alfio	Università Torino	19/06/2015	18/06/2017
6	Ceccato Daniele	Università di Padova	10/12/2015	09/12/2017
7	Maggioni Gianluigi	Università Padova	21/02/2017	20/02/2019
8	De Salvador Davide	Università Padova	17/03/2017	16/03/2019
9	Picollo Federico	Università Torino	10/04/2017	09/04/2019
10	Forneris Jacopo	INFN Torino	10/04/2017	09/04/2019
11	Re Alessandro	Università Torino	29/05/2017	28/05/2019
12	Lo Giudice Alessandro	Università Torino	29/05/2017	28/05/2019
13	Rigato Valentino	INFN LNL	27/09/2017	26/09/2019

AUTORIZZAZIONI ALL'ESERCIZIO IN AUTONOMIA DELL'ACCELERATORE CN

#	Persona autorizzata	Ente di appartenenza	data autorizzazione	scadenza autorizzazione
1	RIGATO Valentino	INFN-LNL	09/11/2015	08/11/2017
2	CACIOLLI Antonio	INFN Padova	09/11/2015	08/11/2017
3	DEPALO Rosanna	INFN Padova	09/11/2015	08/11/2017
4	GOZZELINO Laura	Politecnico di Torino	11/11/2015	10/11/2017
5	GHIGO Gianluca	Politecnico di Torino	11/11/2015	10/11/2017
6	MASTINU Piefrancesco	INFN-LNL	18/11/2015	17/11/2017
7	PANTANO Devis	Università di Padova	28/01/2016	27/01/2018
8	TESSARO Mario	INFN-Padova	28/01/2016	27/01/2018
9	DE SALVADOR Davide	Università di Padova	17/02/2016	16/02/2018
10	FAGOTTI Enrico	INFN-LNL	01/03/2016	28/02/2018
11	MARTIN HERNANDEZ Guido	CEADEN, La Habana, CUBA	08/03/2016	07/03/2018
12	FORMICOLA Alba	INFN-LNGS	18/07/2016	17/07/2018
13	MENEGAZZO Roberto	INFN-LNL	18/07/2016	17/07/2018
14	JUNKER Matthias	INFN-LNGS	18/07/2016	17/07/2018
15	CINAUSERO Marco	INFN-LNL	26/07/2016	25/07/2018
16	GRAMEGNA Fabiana	INFN-LNL	26/07/2016	25/07/2018
17	FABRIS Daniela	INFN Padova	26/07/2016	25/07/2018
18	MARCHI Tommaso	IKS - KU Leuven	26/07/2016	25/07/2018
19	GUGLIELMETTI Alessandra	INFN-Milano	04/10/2016	03/10/2018
20	AGOSTEO Stefano	Politecnico di Milano	10/04/2017	09/04/2019
21	COLAUTTI Paolo	INFN-LNL	21/04/2017	20/04/2019
22	CONTE Valeria	INFN-LNL	21/04/2017	20/04/2019
23	LONGHIN Andrea	INFN-Padova	16/06/2017	15/06/2019
24	COLLAZUOL Gianmaria	Università di Padova	16/06/2017	15/06/2019
25	CHERUBINI Roberto	INFN-LNL	05/10/2017	04/10/2019

USER BEAM TIME REQUEST - U.S.I.P. ASSIGNED BEAM-TIME

CALL	Submission dead-line	Call Period	AN2000		CN		AN+CN Assignment
			Request (days)	USIP Assignment (days)	Request (days)	USIP Assignment (days)	(days)
(I) MARZO 2011	12-feb-11	April 4- July 2011	96	73	91	62	135
(II) LUGLIO 2011	30-giu-11	October 2011-Feb 2012	130	98	78	63	161
(I) MARZO 2012	15-Feb-12	March-July 2012	117	80	105	63	143
(II) LUGLIO 2012	12-lug-12	October 12-Feb. 2013	112	84	89	76	160
(I) GENNAIO 2013	7-Dic-12	March -July 2013	79	71	79	79	150
(II) LUGLIO 2013	10-giu-13	October 13-Feb 14	105	84	79	73	157
(I) GENNAIO 2014	12-dic-13	March-July 2014	80	69	85	62	131
(I) LUGLIO 2014	10-giu-14	Oct. 14 -March 2015	62	40	94	61	101
(II) GENNAIO 2015	not performed	extended to July 2015					
(I) LUGLIO 2015	03-giu-15	Oct. 2015-Feb. 2016	68	44	87	65	93
(I) GENNAIO 2016	21-gen-16	March/April to July 2016	64	64	77	51	104
(II) LUGLIO 2016	27-giu-16	October 2016-Feb2017	71	71	47	45	116
(I) FEBBRAIO 2017	25-gen-17	March-September 2017	53	49	33	31	80
(II) OTTOBRE 2017	15 Sett. 2017	Nov2017-April2018	106	71	68	65	136

	2011-2014	Appr./Req. (%)	2011-2018	Appr./Req. (%)
Average AN2000 request / year [days]	195		165	
Average USIP assignment/year [days]	150	76.7%	130	78.8%
Average CN Request/year [days]	175		145	
Average USIP assignment/Year	135	77.0%	116	79.7%

CN

EXPERIMENTS / YEAR

14-27

External Institutions

Univ. Napoli, Modena e Reggio, Padova, Roma3, Trento, Torino; CNR-Pd, INAF-IASF Bologna, Politecnico Milano, Torino, CEADEN (Cuba), Comisión Nacional de Energía Atómica, Argentina; Univ. Seville (Spain), Belgian Nuclear Res. Centre SCK-CEN, INFN Catania

AN2000

EXPERIMENTS / YEAR

13-26

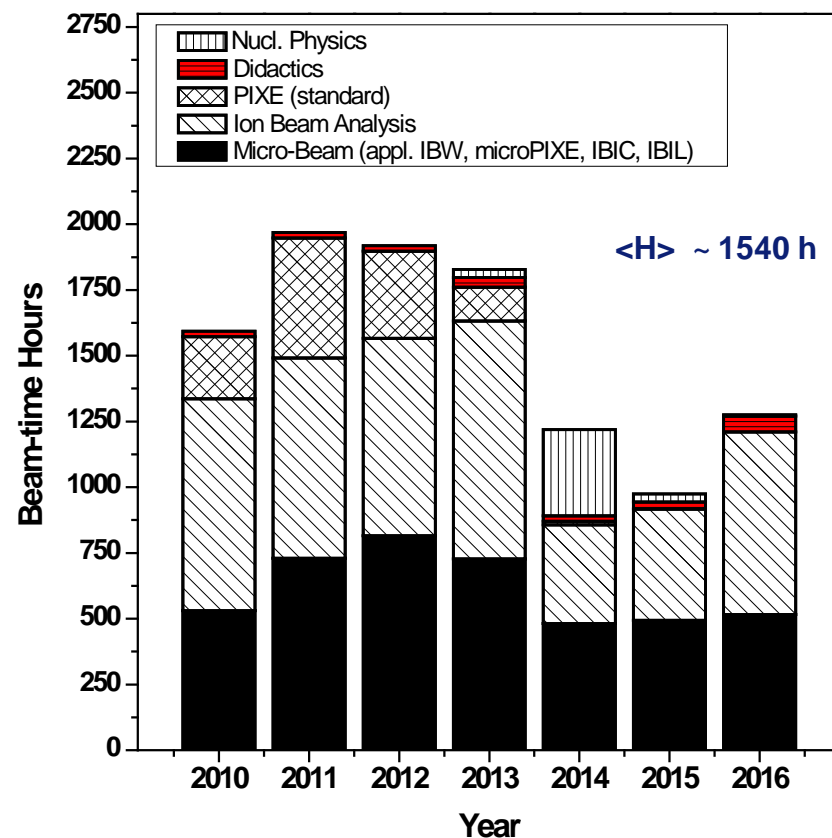
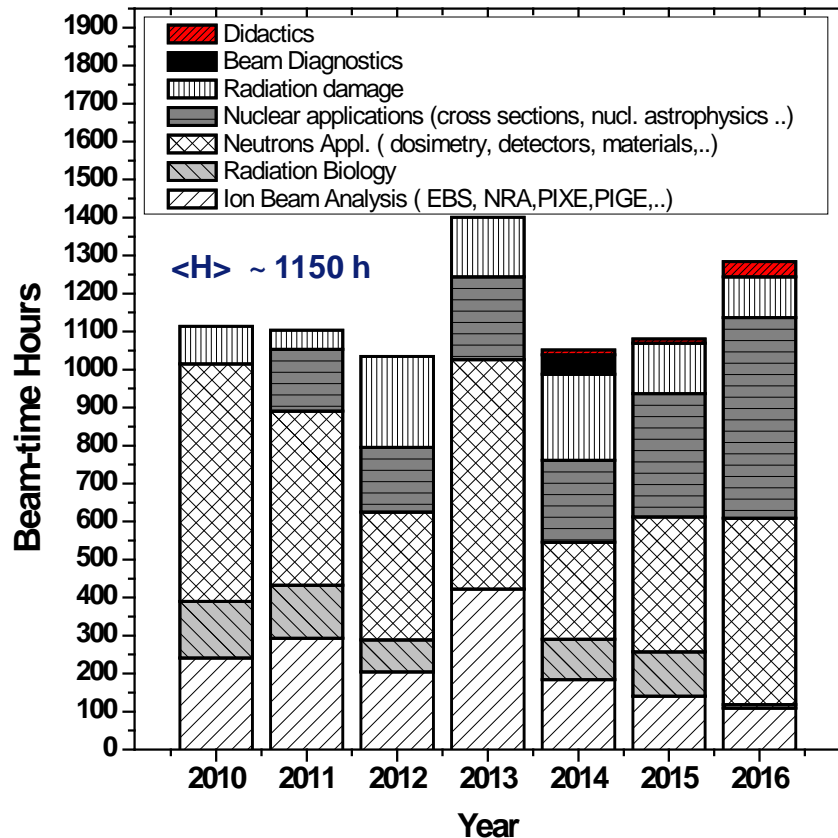
External Institutions

Univ. Bologna, Modena e Reggio, Padova, Trento, Torino, Verona; Politecnico di Torino, INRiM (Torino), CNR-IFP (Milano), CIEMAT, CNAM (Spain), Nat. Inst Nucl. Phys. Bucharest (Romania), IUAC (India), Lulea Univ. of Technology (Sweden), INFN-LASA (Milano)

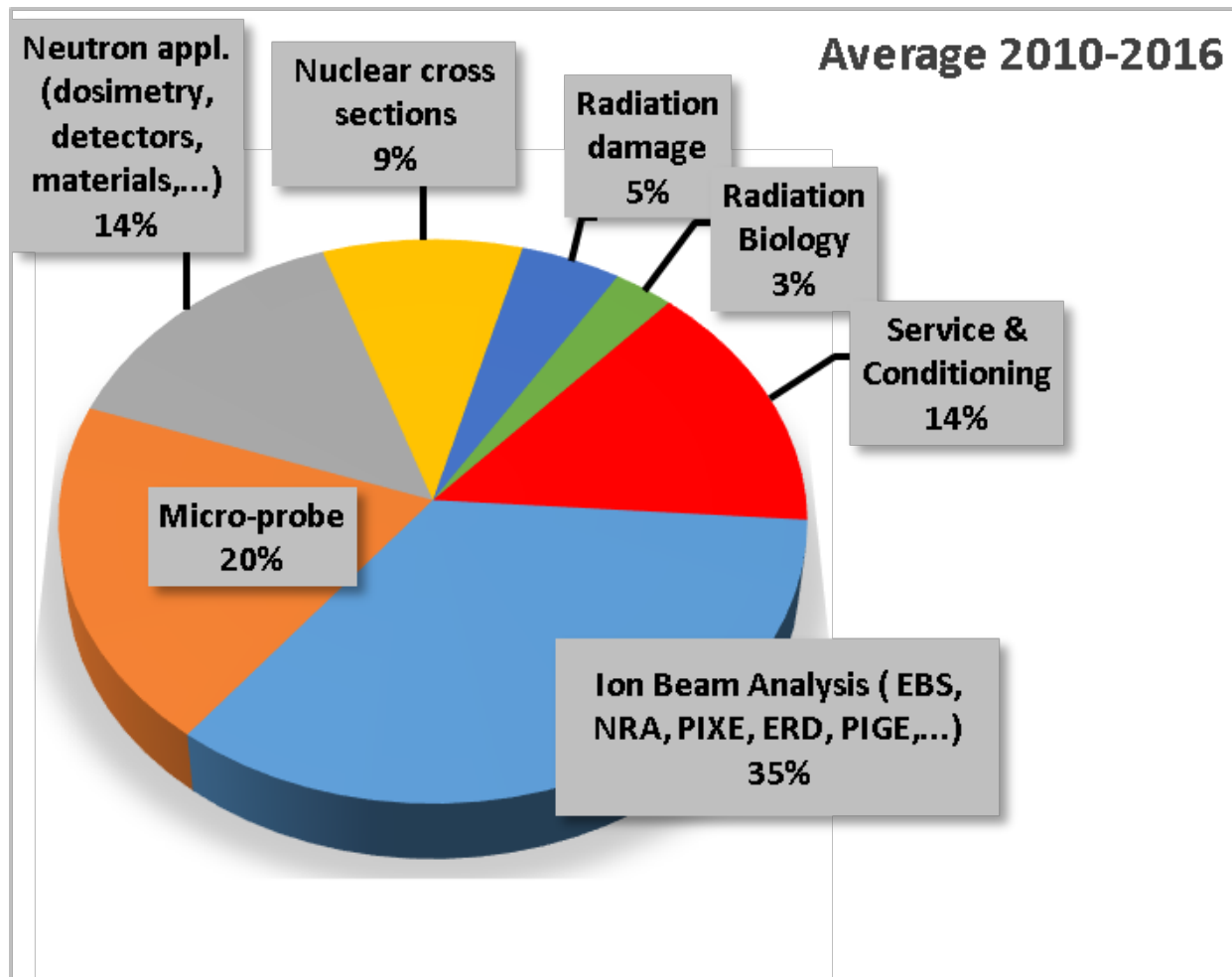
CN

ISI PUBLICATIONS rough estimate ~ 80 / year

AN2000



Average use of the AN2000 and CN accelerators in the last seven years



There are two possible upgrade options:

- a. replacing the two Van de Graaff accelerators with state of art electrostatic or cascade machines, refurbish existing old buildings and infrastructures and purchase new beamline modern experimental setups;
- b. phasing-out both the AN2000 and CN (in due time) to concentrate the efforts on a single new electrostatic accelerator facility with the necessary features to feed the foreseen applications and future developments.

Option (a) means doubling infrastructures, accelerators and some beam-lines, fighting against the lack of dedicated resources and operation staff. Furthermore each facility must be switched off completely for upgrade and infrastructure dismantling. This will interrupt the research activity for a period of order of one year (or slightly more) per machine.

Option (b) offers a unique opportunity both from an organization, technical and scientific point of view.

In fact from the technical point of view a single new accelerator with advanced unprecedented features would be sufficient for carrying out the activity as reported in previous slides and for the future developments, provided that the accelerator specifications are carefully defined.

From an organization point of view, with modern instrumentation and automated procedures, a more efficient beam-time usage is foreseen: more users may be satisfied with the same amount of beam-time hours and even a higher throughput in excess of 3000 hours/year is expected.

Concentrating the resources in a single laboratory will also mitigate the chronic personnel lack, faced in recent years, for the operation of accelerators: the few operators of the existing two Van de Graaff machines may be teamed together enlarging the time and quality of service provided.

In addition, the installation of the new accelerator and related instrumentation may be run in parallel with the activity of the other two, thus minimizing the shut-off time.

Preliminary specification

Accelerator Type	Single ended accelerator with high pressure SF ₆ insulation . Cascade type preferred.	Tandem accelerators should be ruled out for the limitations with Helium beams and lack of brilliance for extreme vacuum micro and nano probe. Electrostatic type may be current limited.
Structure	Horizontal or Vertical	Budget dependent
Terminal Voltage (TV)	0.1÷ 5.0MV	6MV optional, budget dependent
Ion Source	RF or ECR	Low emittance, high brightness prerequisites. Optimal beam transmission maintained over the entire range. RF source may limit beam species but is
Ions	¹ H ⁺ , ² H ⁺ , ³ He ⁺ , ⁴ He ⁺ , ⁴ He ⁺⁺ , ¹⁵ N ⁺⁺ , ¹⁴ N ⁺⁽⁺⁾ , C ⁺⁽⁺⁾ , O ⁺⁽⁺⁾	C beams are available only with ECR source. Noble gases Ar, Xe optional (the maximum mass should be taken into account in deflection magnet design)
Beam current (max)	50uA (¹ H, ⁴ He) 10uA (others)	on target at all energies
Beam current (min)	1000 p/s	on target at all energies
Shortening Rod	YES	necessary for lowest energy (0.1 to 0.35MV) if not differently guaranteed eg.: dedicated low energy ion optics in terminal
Stabilization	GVM // resistive divider chain //SLIT feedback loop	High dispersion magnet + SLIT mode preferred
Remote control	YES	
Automatic High Voltage conditioning	YES	
Energy Accuracy	t.b.d.	~1 keV or better
TV Ripple (V_{RMS})	2x10 ⁻⁵ x TV or 30V	Whichever is higher
Beam Energy reproducibility	1x10 ⁻⁴ x TV or 50V	Whichever is higher
Beam Energy Stability (1 hour)	1x10 ⁻⁵ x TV or 30V	Whichever is higher. Measured with <i>ad hoc</i> NRA
Pulsed beam	YES	300kHz to about 3MHz, with buncher in terminal
Beam Current Stability (1 hour)	<±5%	Without feedback of target current
Servicing Interval	>1000 hours	At maximum intensity
Annual operation capability	>7000 hours	At maximum intensity
Continuous operation	120 hours	Intervention free (for ECR source)

It is expected that the new accelerator will serve about 10 beam-lines in a new laboratory with at least 1200 m².

- 1 nano-probe in clean room (low stray EM fields, precision ion optics, high-resolution microscopy)
- 1 micro-probe in vacuum in clean room for routine micro-analyses (certified analysis, existent beamline)
- 1 total IBA microanalysis low divergence beamline / nuclear cross sections measurements (sub-mm size collimated ion beam)
- 2 high current nuclear cross section measurements beamline / neutron production
- 1 beamline for cell/tissue irradiation in clean room
- 1 large area uniform irradiation in clean room
- 1 micro-probe in air in clean room (big samples, or analysis on samples incompatible with high vacuum - optional)
- 1 beamline for SPES RIB projects in radiation shielded area (near to single charged SPES low energy beamline - optional)
- 1 spare for future use (shallow underground physics...)

CONCLUSIONS

- LNL user research infrastructure counts two MeV VdG Accelerators used for fundamental and applied physics and ion beam applications.
 - The research activity pioneered in the 80s at LNL with the small VdG Accelerators is continuing with many active projects led by national and international research teams.
 - About 3000 beam-time hours provided to users
 - The CN and AN2000 electrostatic accelerators, although well consolidated in the tradition of the Legnaro Laboratories, feel the adverse effects of aging and are becoming **less attractive for international programs** such as those in Horizon 2020 and in many other international multi-disciplinary contexts.
 - The lack of competitiveness causes the **loss of joint financed research** which is nowadays necessary to foster further improvements in innovative research.
 - To preserve and boost the national and international users attraction, **the renewal of accelerators, infrastructures and instrumentation must be carried out in short time**. This will pay back in intellectual property and financial terms through multi-partner national and international collaborative research and industrial contracts.
 - With the right building infrastructure and instrumentation the new accelerator will feed advanced research programs in fundamental and applied research in field such as:
 -) nuclear (astro)physics,
 -) nuclear target characterization and development
 -) solid state and surface physics,
 -) nanotechnology, quantum devices,
 -) certified micro-analysis and irradiation
 -) advanced microscopy and modification of materials
-at a top level in Europe.*

Thank you for the attention !