A high-resolution VUV beamline @ SPARC

A. Marcelli

INFN – LNF

E. Pace

INFN, Università di Firenze

M. Coreno

CNR-IMIP

L. Poletto

CNR-IFN, Laboratorio LUXOR

Consiglio Nazionale delle Ricerche

Source FEL VUV

- first seeding results confirm the possibility to work with high harmonics in the UV domain: 250-90(~40?)nm@ 155 MeV
- repetition rate: 1-10 Hz
- radiation spectrum slightly tunable
- higher harmonics linearly polarized sources of high temporal and spatial coherence
- pulse duration: 100 fs

Consiglio Nazionale delle Ricerche ENEA INFN SPARC

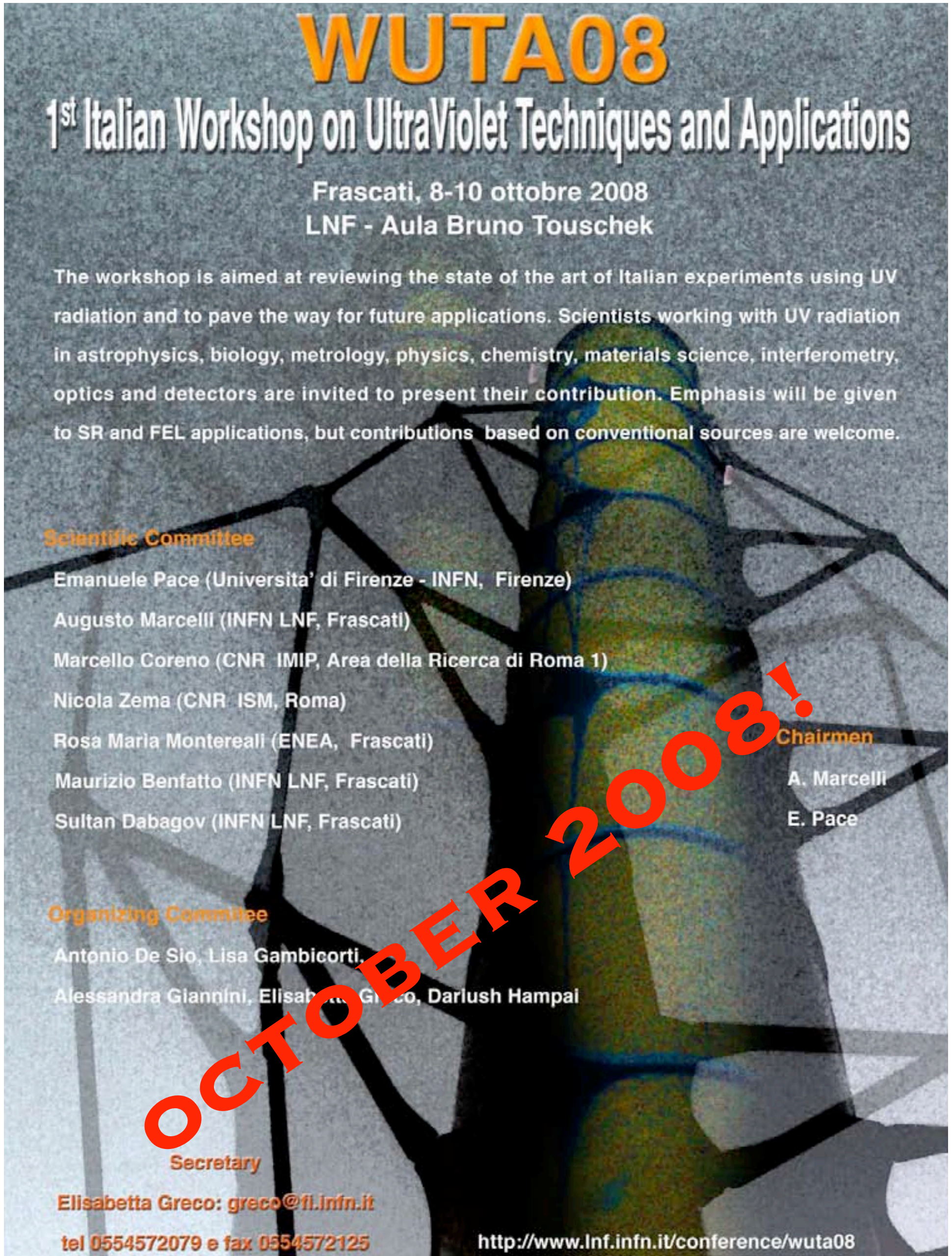
VUV monochromators@SPARC

Two possible uses of monochromators:

- As monochromators for SPARC to monochromatize the beam before the experimental chamber: increase the spectral purity of the fundamental (i.e. increase the FEL resolution), select high-order FEL harmonics and suppress the fundamental, filter out the background
- As spectrometers for the analysis of the radiation after the interaction FEL/sample

Le caratteristiche della radiazione SPARC in saturazione (emissione alla fondamentale)

Lunghezza d'onda (nm)	Dimensioni sorgente (μm rms)	Divergenza (mrad rms)	Energia per impulso (μJ)	Fotoni per impulso
400	400	0.3	5.5	
266	400	0.2	5	
160	400	0.1	2.5	
114	400	0.06	1.5	
60 (H3 di 180 nm)	400	0.06	$1 \cdot 10^{-3}$	
40 (H3 di 120 nm)	400	0.04	$1 \cdot 10^{-5}$	



WUTA08 meeting

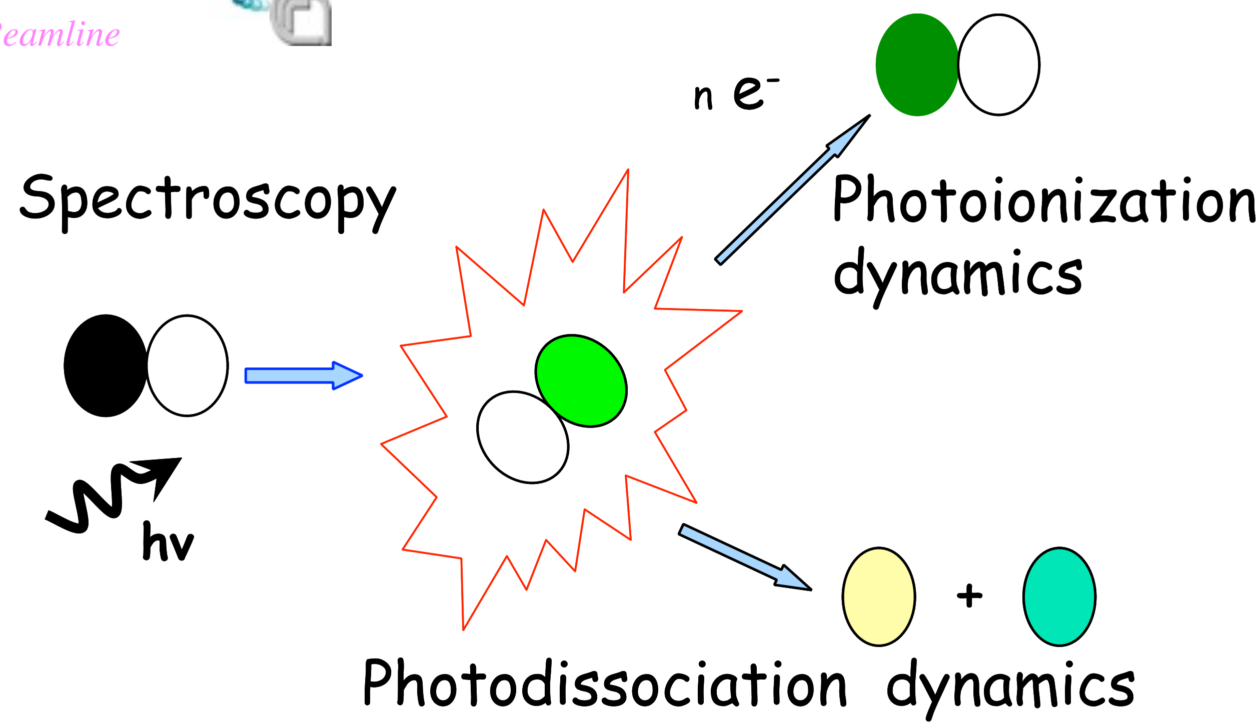
- Atomic and molecular physics
- Astronomy
- Raman
- Instrumentation
- Nanostructure
- Anelastic scattering
- Biology and astrobiology
- UV induced damaging
- Photochemistry
- Quantum coherence and entanglement

Existing scientific case

- *Atomic and molecular physics*
- *Free clusters*
- *Time resolved experiments*
- *Imaging*

Gas Phase Photoemission Beamline

Why investigate isolated species in the gas phase?



Basic phenomena: atoms, molecules, clusters, ions and radicals in a specific enviroment

Spectroscopy: a better understanding of atomic and molecular electronic structure

Dynamics: new ways to characterize many-body interactions

Even in the simplest systems many phenomena are not yet explained by existing quantum-mechanical models. **Advanced experimental techniques** allow to establish a more accurate framework of the many-body interactions in real systems.

Detailed knowledge of the electronic structure of surfaces and solids must be built via the understanding of spectroscopy and dynamics in isolated systems. Many diagnostic and spectroscopic techniques have been developed first in the gas phase and then transferred to other fields such as material and biomedical sciences, energy and sensor technology.

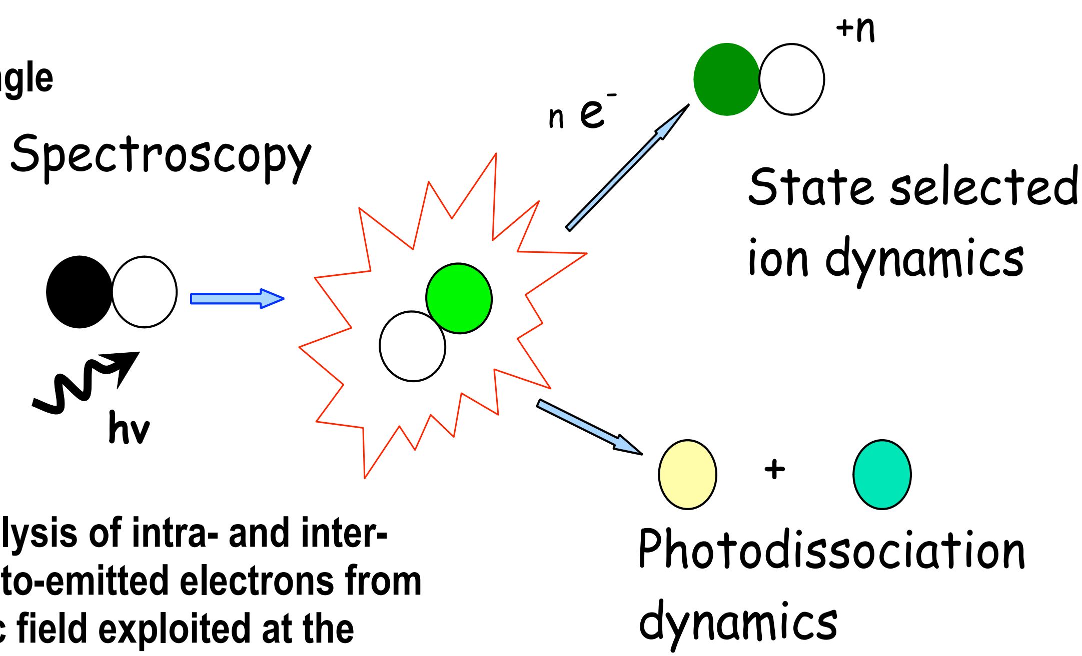
FEL & Atomic and Molecular Physics

SPECTROSCOPY OF "EXOTIC SPECIES"

High flux and Resolution allow the investigations of the electronic structure of low density matter: metastable and reactive species. High temperature species, atmospheric chemistry, combustion chemistry, isolated Molecules and Clusters in Supersonic Molecular Beam (condensation and nucleation studies, coupling to laser techniques for state selected excitation and photoemission studies).

MULTIPHOTON PROCESSES

Access to electronic states, transparent to single photon techniques ruled by dipole interaction



EXPERIMENTAL ADVANTAGES

Easier scenario for TOF and time-correlation techniques, "Pump & Probe" techniques for excited states dynamics with laser photons

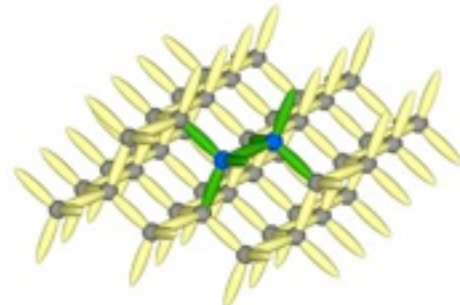
Direct measurement of lifetime; accurate analysis of intra- and inter-molecular energy transfer; interaction of photo-emitted electrons from gaseous samples with laser; electromagnetic field exploited at the same time as a diagnostic for FEL pulses ("side bands experiments") and for the investigation of photo-ionization dynamics

Clusters

Studies of free clusters and of thin solid films obtained from their deposition aim at following the evolution of the properties of the matter starting from a single isolated particle toward surface and bulk condensed phase, passing through steps of atomic and molecular aggregates of increasing complexity. Given the extremely low number of target particles in cluster experiments, great advances are expected at 4th generation synchrotron radiation sources such as FELs.

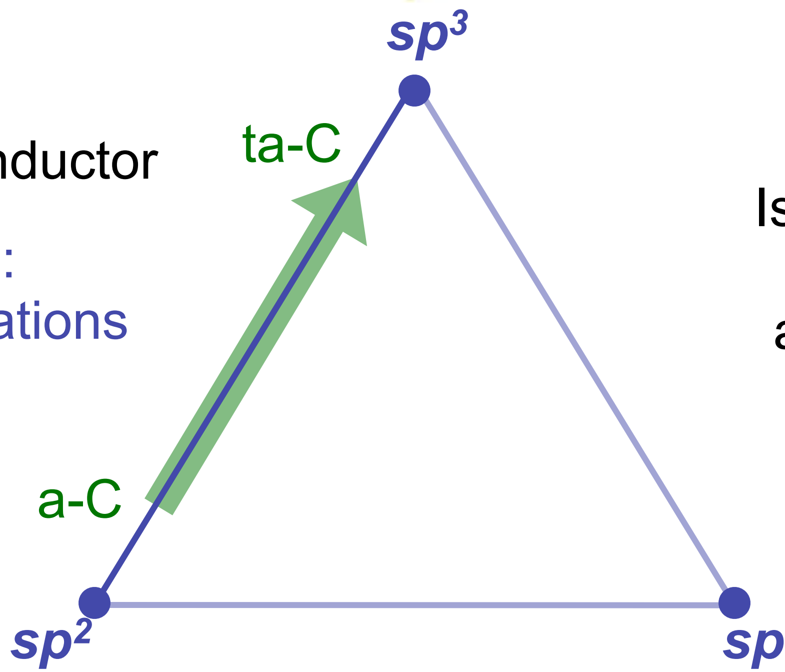
Carbon

Crystal structures



Diamond

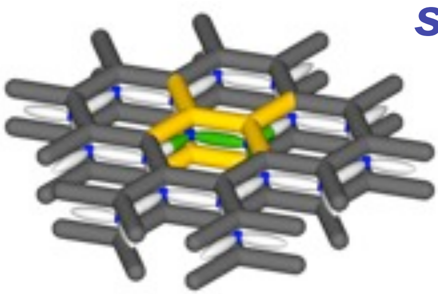
- Hard
- Semiconductor



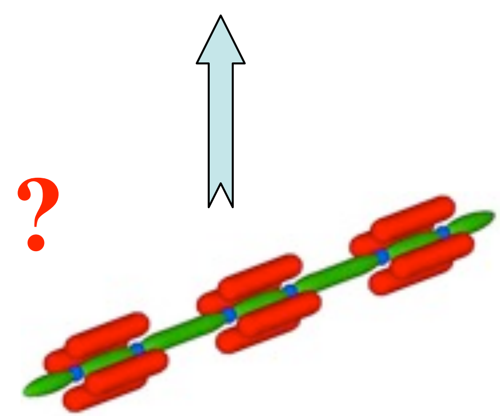
Disordered phases: mixture of hybridizations

- Soft
- Conductive

Isolated carbon cluster with less than 30 atoms exist as purely *sp* carbon chains (**carbynes**)



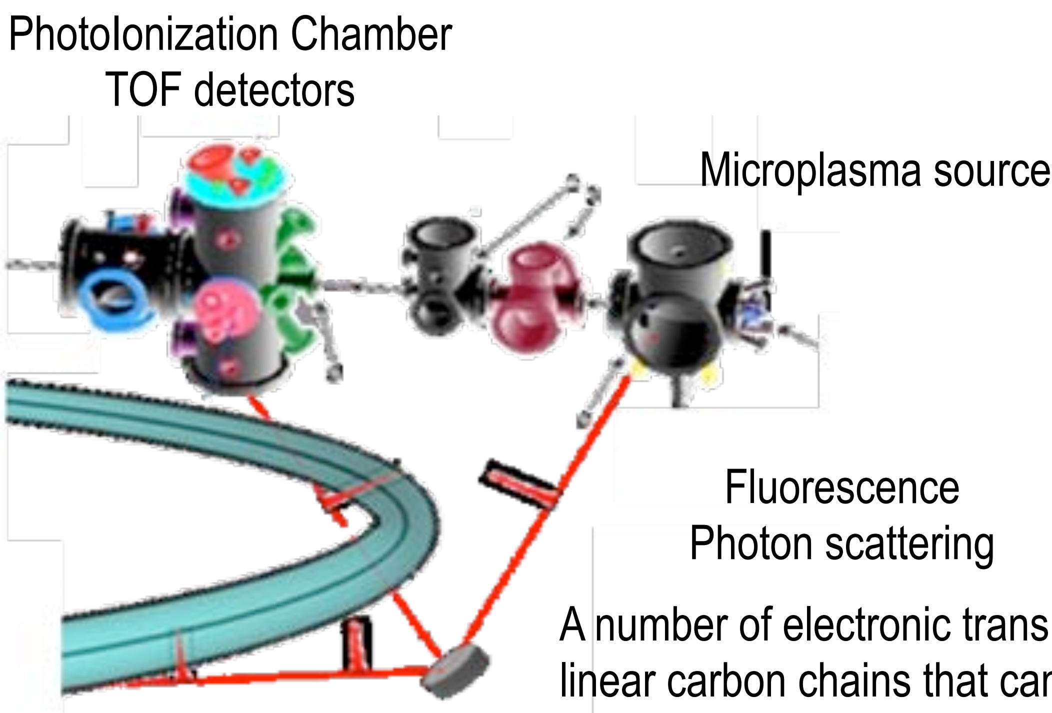
Graphene



R.O. Jones, J. Chem. Phys. **110**, 5189 (1999)

CESyRA @ Elettra

Applications FEL VUV

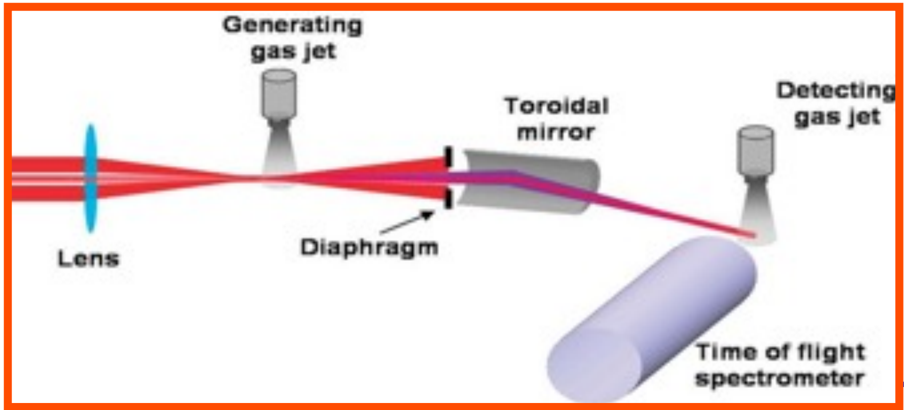


Is possible to investigate in collaboration with CIMAINA & University of Milan the electronic structure of clusters and nano-particles by means of different spectroscopic technique.

A number of electronic transitions < @ 220 nm exist for variable size linear carbon chains that can be investigated by means of Photoionization Mass Spectrometry, Resonant Photo-Ionization, Photon Induced Fluorescence, Resonant Raman Scattering and Photoemission Spectrometry.

The access to intense FEL radiation at SPARC allows to extend this schemes to experiments on mass selected clusters and nano-particles with a narrow distribution of dimensions.

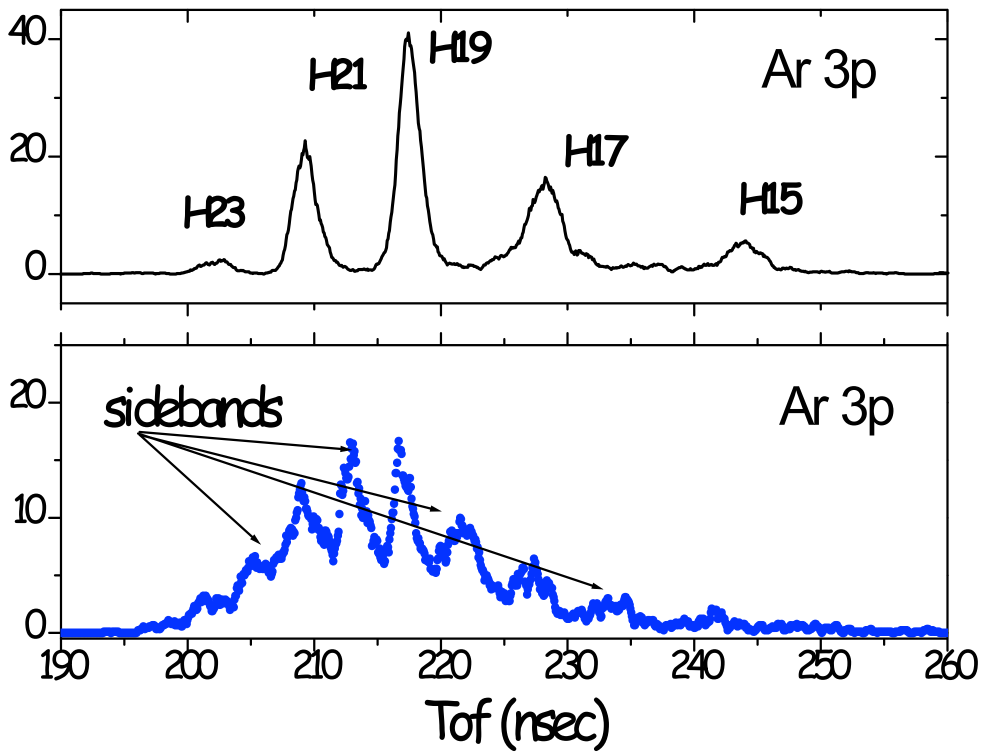
IMIP Group experience

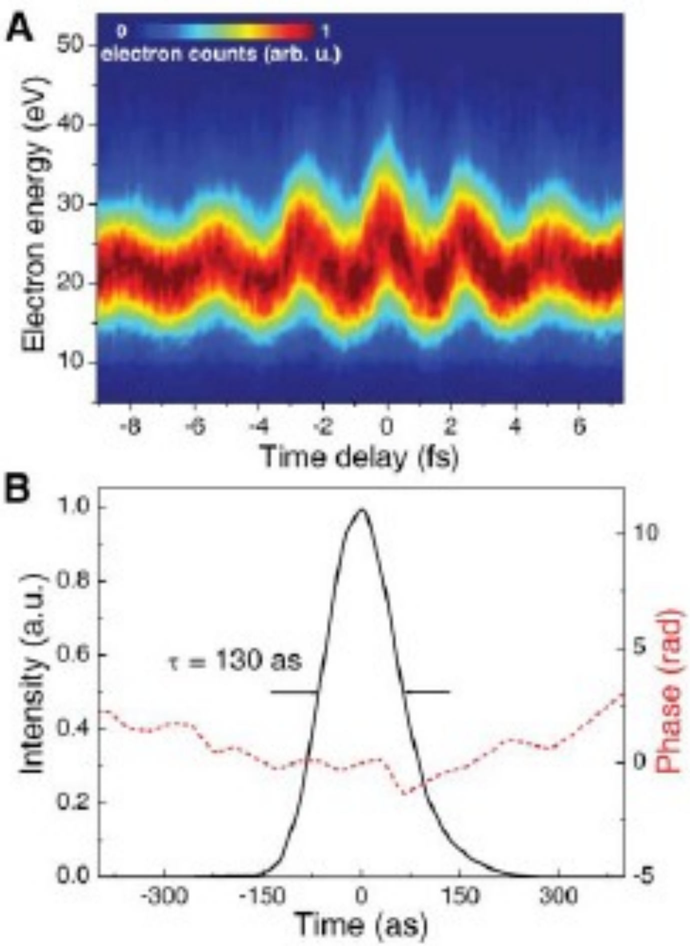


SPARC Project

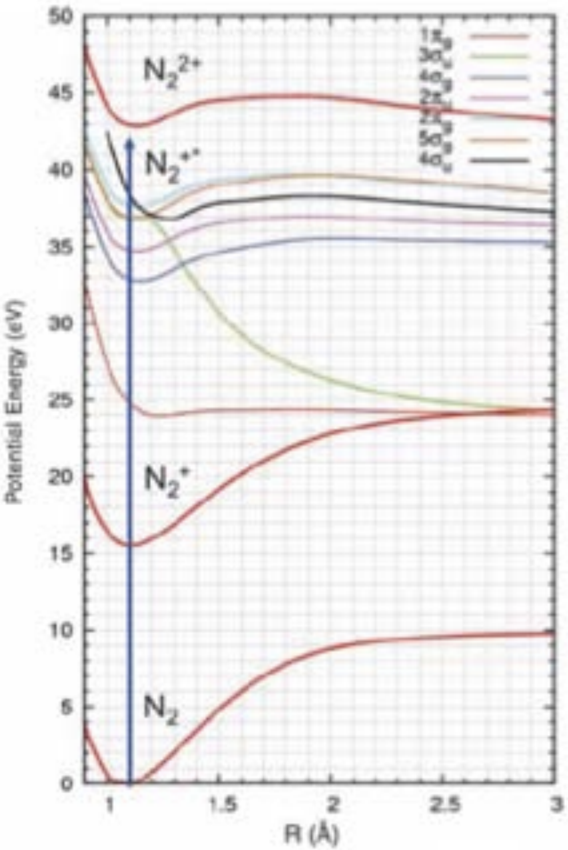
CNR-IMIP, Poli MI, UniNa,UniPd

Science 314(2006)443

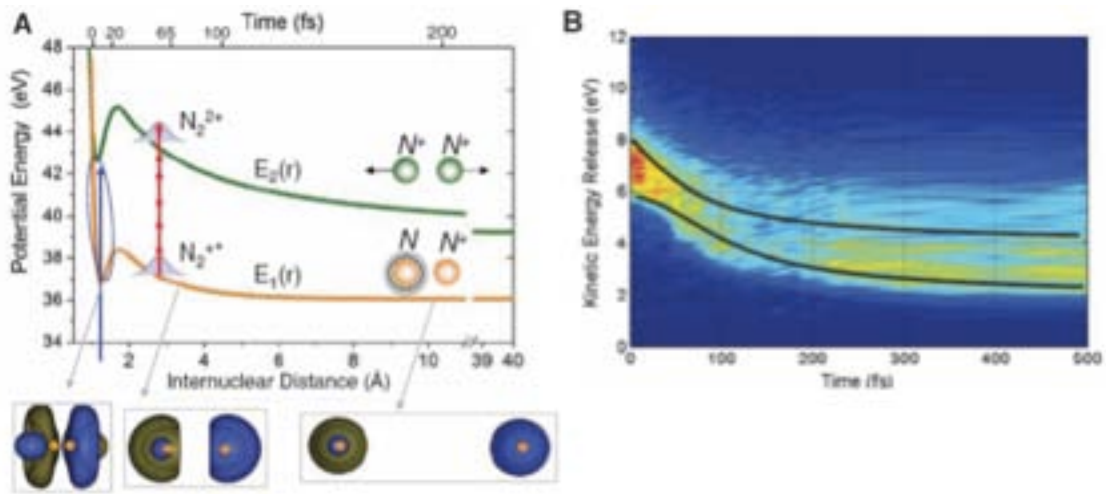


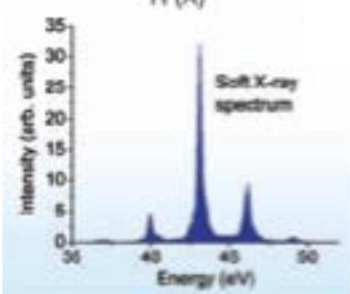


Dynamics of Excited Ionic States



State of the art of gas phase pump-probe:
Soft X-ray–Driven Femtosecond Molecular Dynamics
Murnane and Kapteyn and coworkers:
Science **317**, 1374 (2007);





	HHG	Seeded SPARC
Photons /pulse	~10^6	10^6 - 10^7

Electronic properties of biomolecules and their clusters

Solvent-free environment :

→ easier modeling of different intermolecular forces

→ results comparable with theoretical calculations

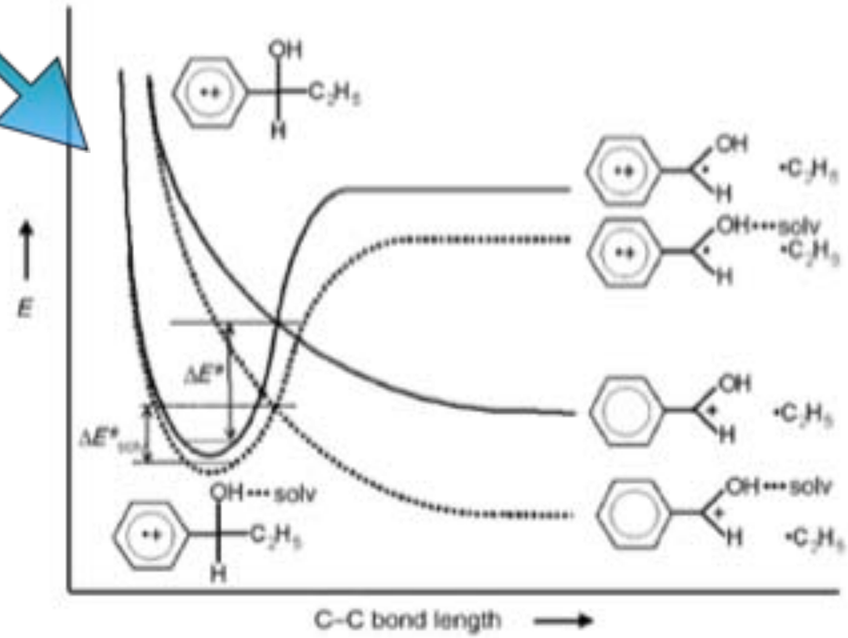
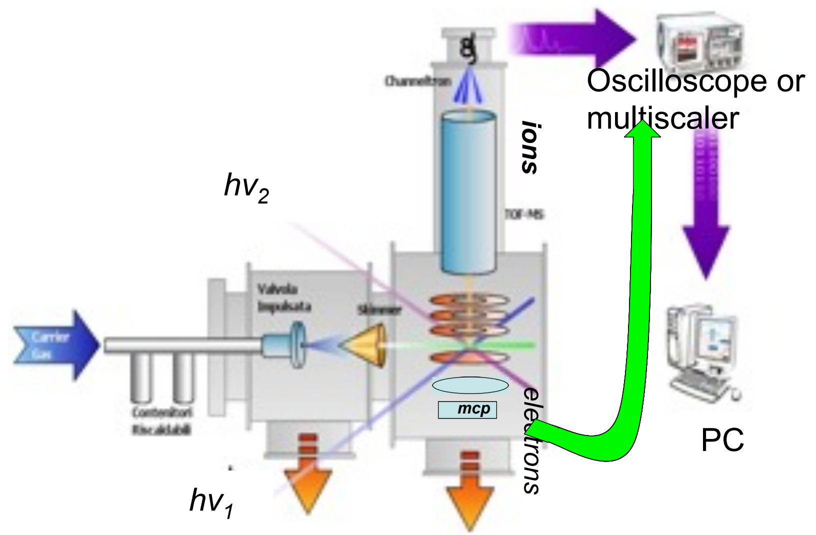
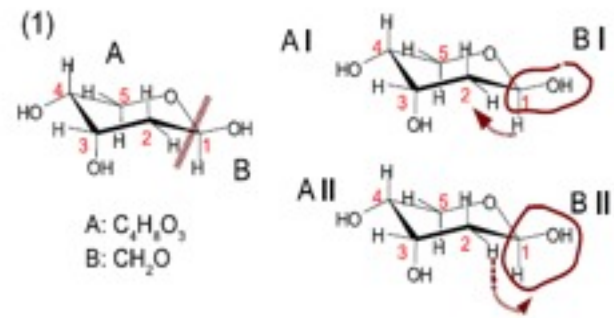


Figure 1. Pictorial crossing between the two lowest-energy electronic states of $[(BZC_2H_5)_n]^+$ (full lines) and $[(BZC_2H_5)_n\cdot solv]^+$ (broken lines).

TOF set-up @ CNR-IMIP & Unversity Tor Vergata





Variable polarization and λ < 150 nm from SPARC may extend investigation to σ-bonded systems like sugars and non aromatic aminoacids and implement valence photoemission techniques for the study of chiral recognition.

Consiglio Nazionale delle Ricerche

ENEA

INFN

SPARC

Pulsed Laser Deposition

Although much experimental effort has been addressed towards studies of rare gas and molecular clusters, studies on aggregates of elements with high vaporization temperatures are still at their infancy. At the Gas Phase beamline (Elettra, Trieste) a test project recently started for studies of free and deposited cluster produced and encouraging results have been obtained on deposition of or nano-carbon and transition metals. Pulsed-Laser Deposition (PLD) is simple and versatile technique that constitutes an approach to produce samples of refractory materials transferred from a laser-ablated target to a substrate where it is deposited. Previous work done at CNR-IMIP has investigated the ablation mechanisms and established the conditions for ablation that favor the formation of free clusters of varied chemical nature.

Consiglio Nazionale delle Ricerche ENEA INFN SPARC

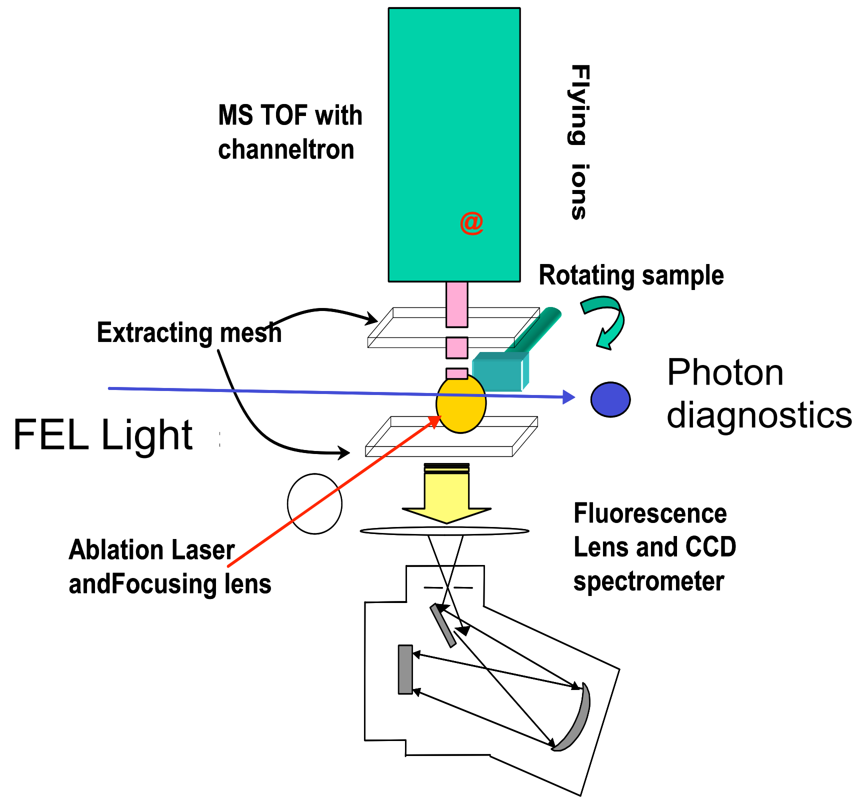
Applications FEL VUV

Surface modification and ablation studies

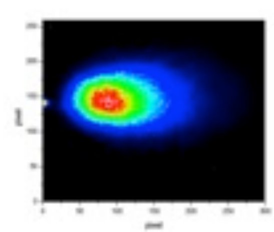
Many **important elementary processes** such as electron/hole recombination, excitation relaxation, etc., often **occur** on a much **shorter time scale and only a time resolved spectroscopy is able to elucidate the dynamics of charge and energy transfer processes.**

Ultra-short laser pulses limit the secondary ionization and photo-fragmentation, and exclude the laser/plume interaction. Therefore, only within such excitation regime, time- and space-resolved optical spectroscopy of the generated plasma provides a direct investigation of laser-target interaction and ultimately of particle emission.

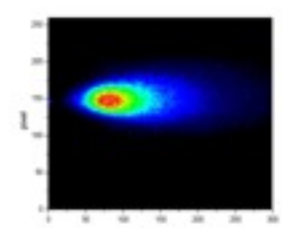
Photoemission and diffraction studies of the ablated species condensed on a substrate as a function of the laser pulses will be used for the analysis of the ablation products and optimization of the process with a view to application to thin film deposition.



1.2 ps laser pulses



200 fs laser pulses



Astrophysical sources / plasmas

VUV spectroscopy is also extremely important in the field of astrophysical sources and plasmas. High resolution spectra simulated in laboratory gives opportunity to study the emission or the absorption spectra of specific atomic or ionic species. These data may provide also fundamental information on the main parameters of plasma models and be a reference for spectra from celestial bodies.

The photon energy range (and the pulse structure) of SPARC access also the photoionization thresholds of many atmospheric constituents from troposphere, up to ionosphere, to the dynamics induced by light in such complex media.

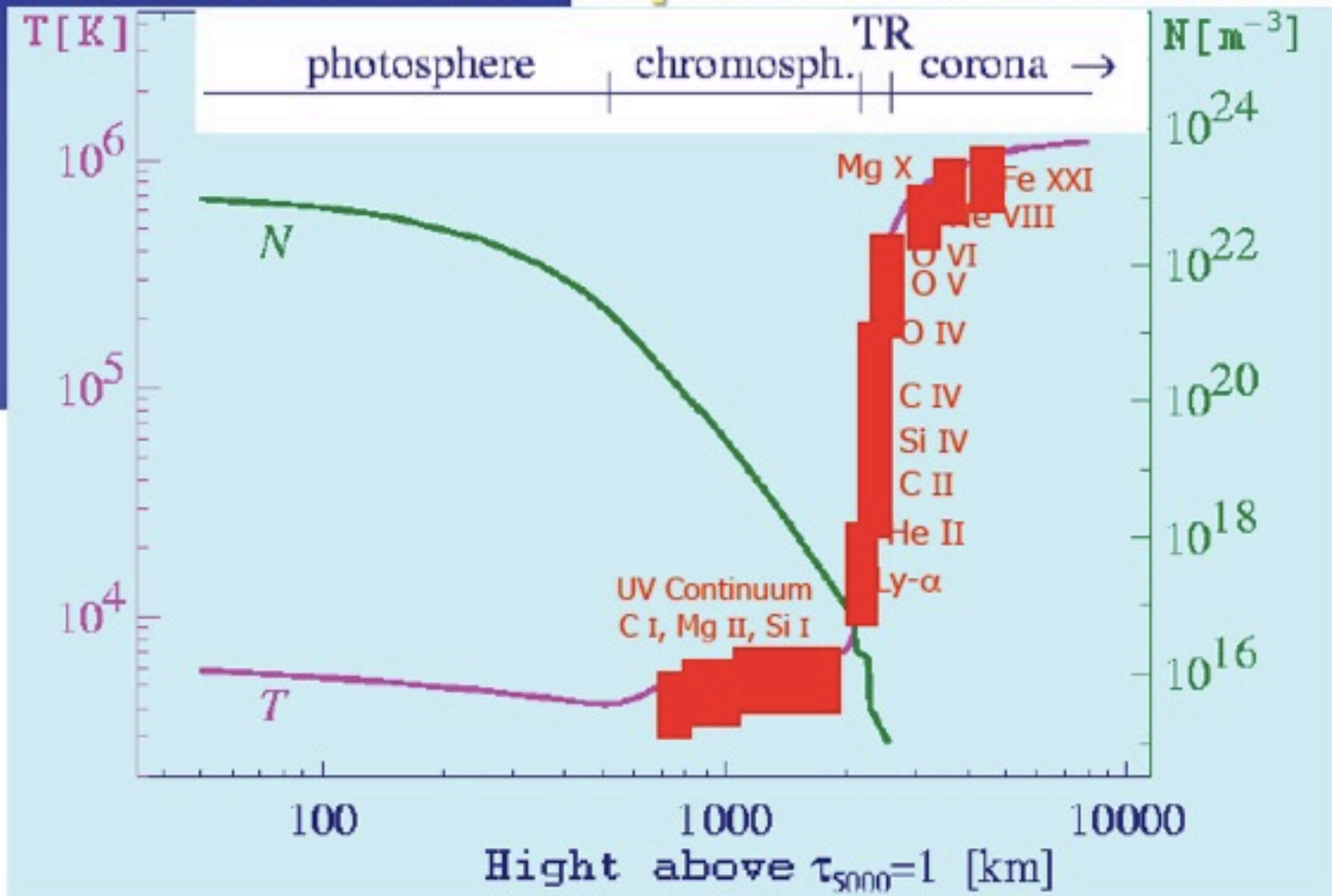
The same consideration applies to biosphere constituents, where circular polarization will make possible to add information correlating chirality and natural dichroism in biotic media to the electronic structure of its basic constituents.

A sort of philosophical statement

The current push into the infrared to study galactic and cosmic evolution at early epochs in the history of the universe is essentially calibrated on the "local Ground Truth" of the interstellar medium and stellar populations of the Galaxy for which absolute parameters can be determined. Any effort to understand, for instance, the properties of objects seen at large redshifts (early times) will ultimately require a detailed knowledge of the UV in those objects in their rest frame. As in laboratory studies where *benchmark* cases provide fundamental calibrations for sequences, the same is true for cosmic objects.

Steve Shore WUTA08

UV lines and continuum as diagnostic of the outer atmospheres of cool stars



T, N from Vernazza et al. (1981) ApJS 45, 635

Exploring the role of UV-radiation on formamide prebiotic chemistry

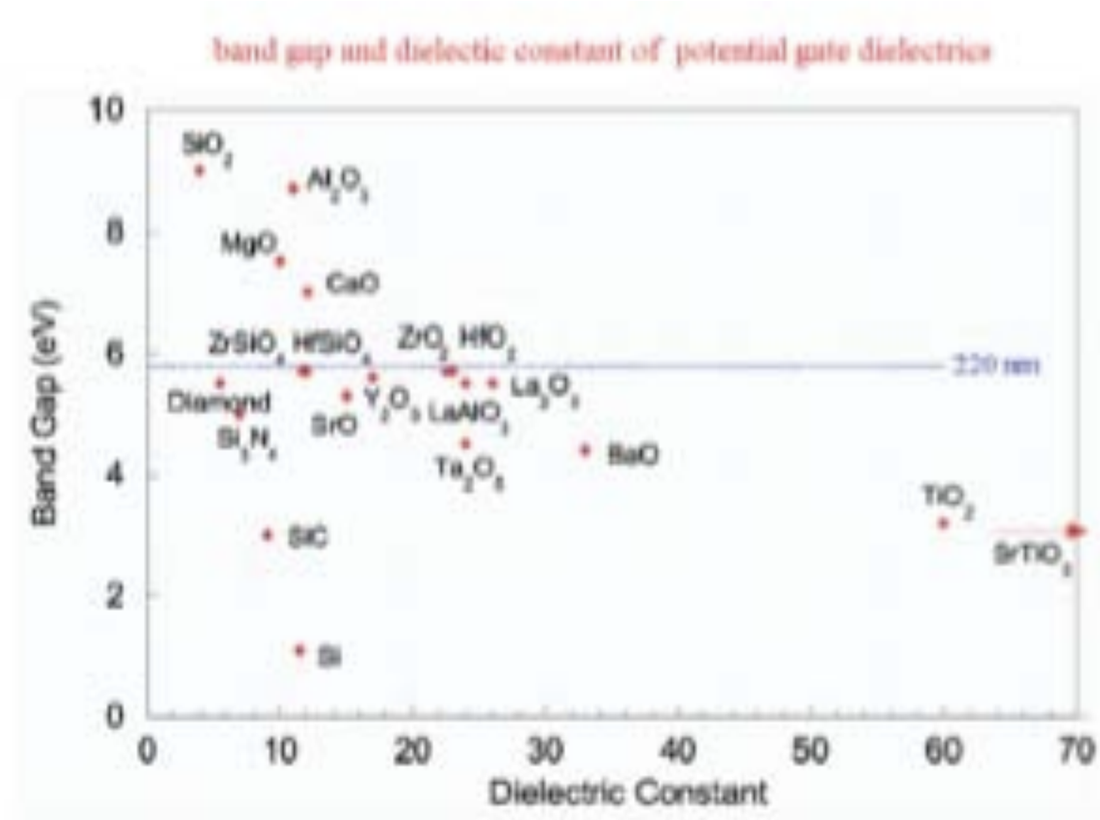
Our interest is to develop novel prebiotic chemistry of nucleic acids based on formamide under UV irradiation in the presence of minerals or selected organic compounds that can act as photocatalysts.

intense UV SR sources can be used for this novel approach to esobiology

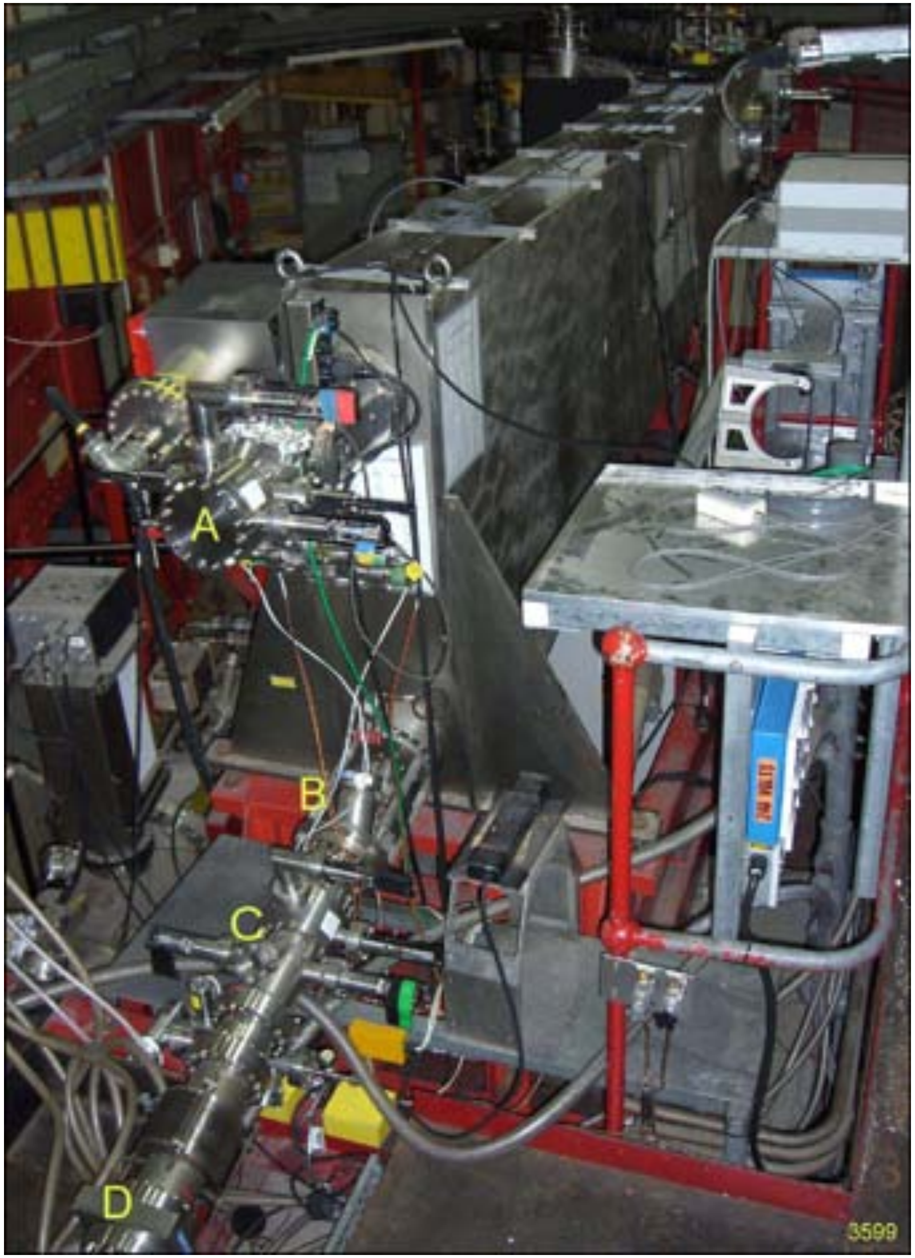
Applications FEL VUV

Raman spectroscopy on isolated building blocks of nanostructured films

Raman spectroscopy is among most popular methods for characterization of nano-structured systems. The ability of the VUV-FEL to shift the wavelength of scattered light from visible into deep UV will allow to probe new electronic transitions well within the **7-10 eV** range for classes of cluster materials such as nano-carbons and potential gap dielectrics from metal oxides



Raman Imaging…!



Monochromator

High-resolution

High-spectral purity

5m McPherson

Normal Incidence

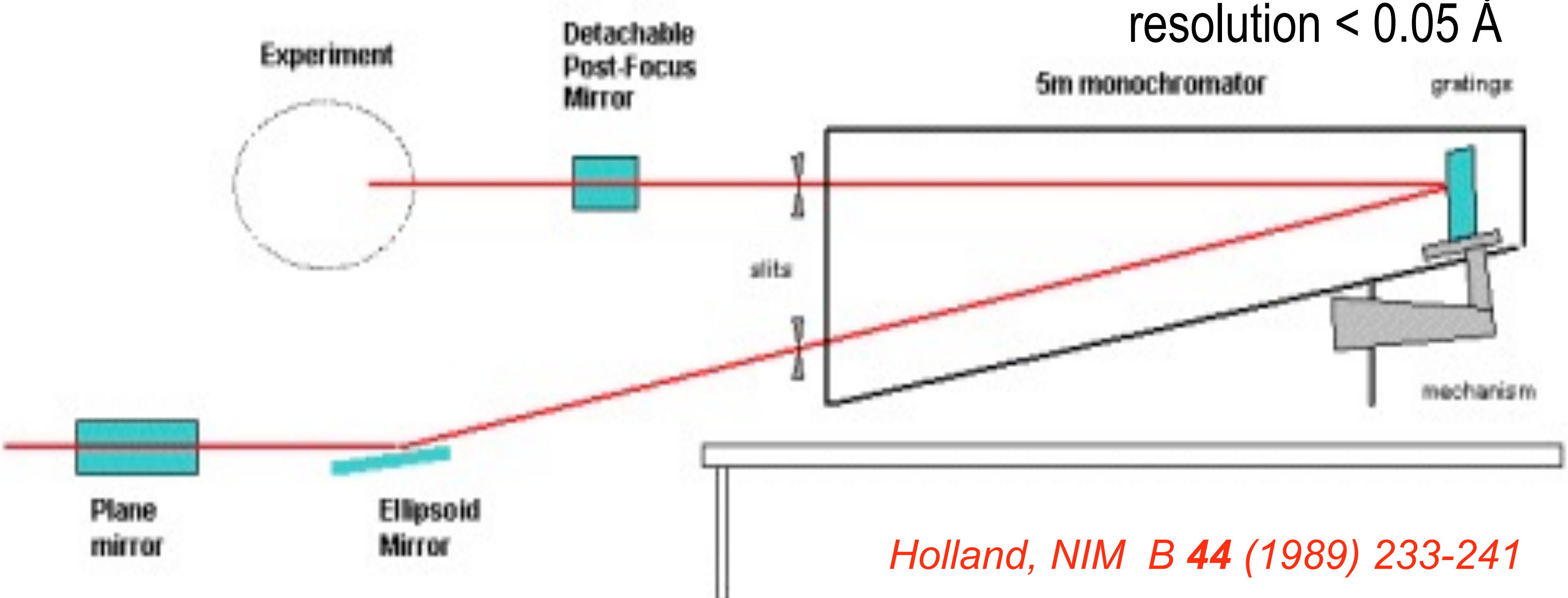
UV-VUV monochromator

from SRS-Daresbury,
beamline 3.2

Consiglio Nazionale delle Ricerche ENEA INFN SPARC

FEL VUV Monochromator

2 concave gratings
Spectral range 300 - 2500 Å (30-250 nm)
resolution < 0.05 Å



*Holland, NIM B **44** (1989) 233-241*

This normal incidence monochromator with 2 gratings that may cover the photon energy range 5–35 eV (250 - 35 nm) with a best achievable resolution of 2 meV (0.005 nm) may open unique opportunities in many fields and in particular in spectroscopy. It fits quite well the energy range available at SPARC.

5 m monochromator

- 1200 gr/mm grating
- 0.17 nm/mm dispersion

- Only high resolution
- Long pulse at the output (ps range above 100 nm)

	slit aperture (mm)		
	0.4	0.2	
wave (nm)	resolution	resolution	FWHM DT (ps)
250	3750	7500	10
150	2250	4500	3
100	1500	3000	1.2
75	1120	2250	0.7
50	750	1500	0.3
30	450	900	0.1

FEL resolution

Laboratory for UV and X-ray Optical Research

- SASE FEL: 0.5% ($\lambda/\Delta\lambda$ = 200)
- SEEDED FEL: 100 fs, 1.5 above Fourier limit

5 meter monochromator

Mirror demagı 5 (demagnification before entrance slit)

Source on slit 0.16 mm FWHM

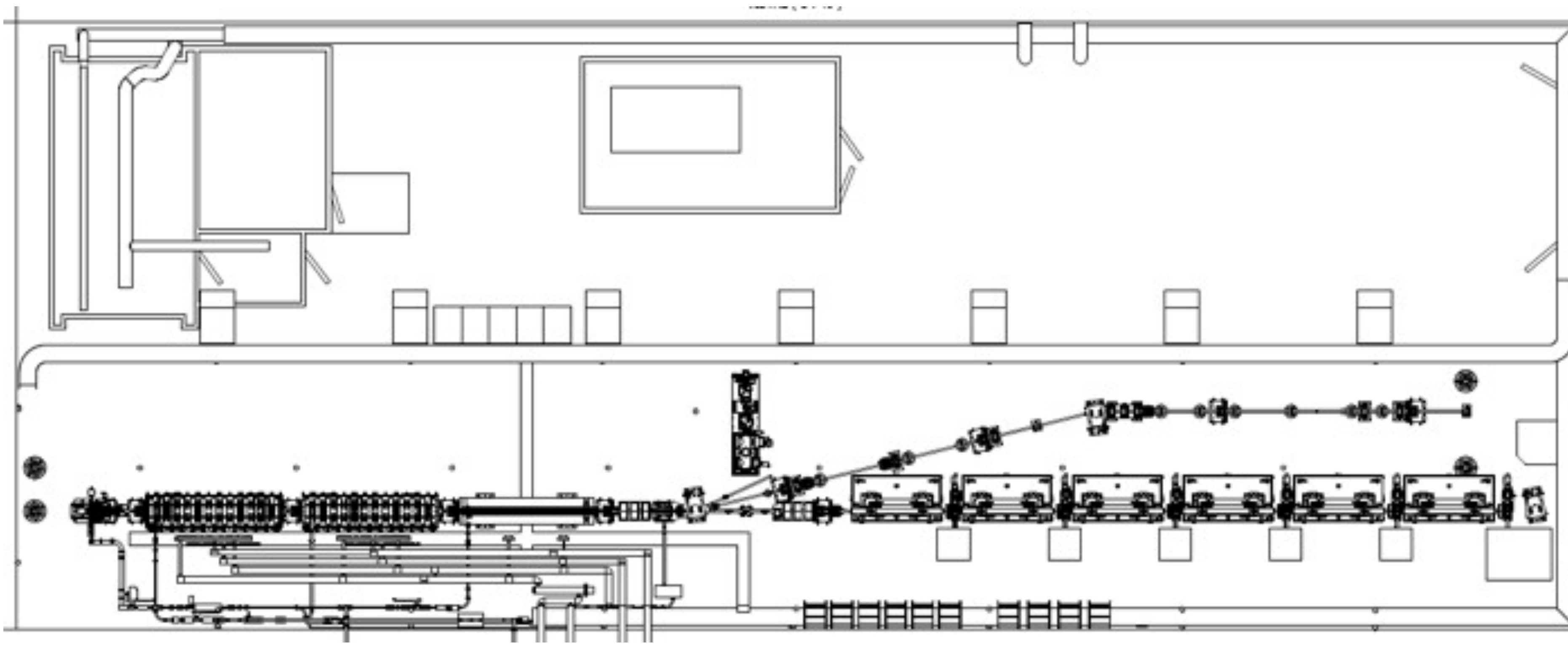
Arm 5000 mm

Grating 1 1200 gr/mm

Plate factor 0.17 nm/mm

	SEEDED	SASE	slit aperture (mm)			
			0.4	0.2		
wave (nm)	FEL resolution	FEL resolution	resolution	resolution	FWHM DT (ps)	max resolution
250	180	200	3750	7500	10.0	12000
150	300	200	2250	4500	3.0	6000
100	450	200	1500	3000	1.2	3600
75	600	200	1120	2250	0.7	2700
50	910	200	750	1500	0.3	1800
30	1510	200	450	900	0.1	1080

Consiglio Nazionale delle Ricerche

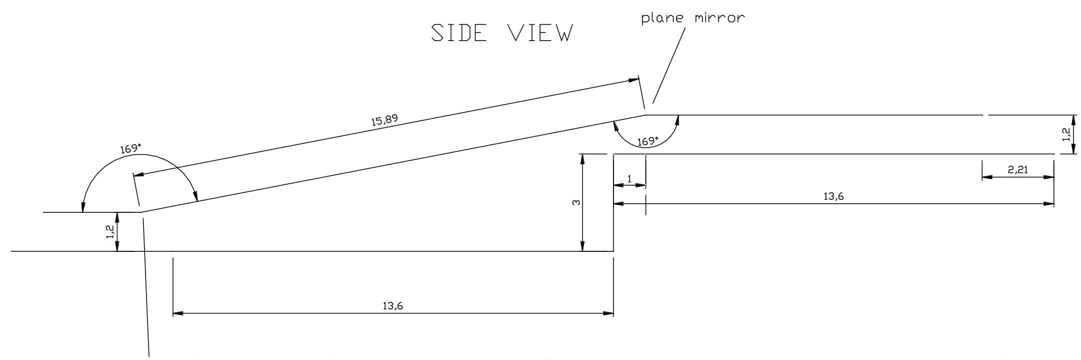


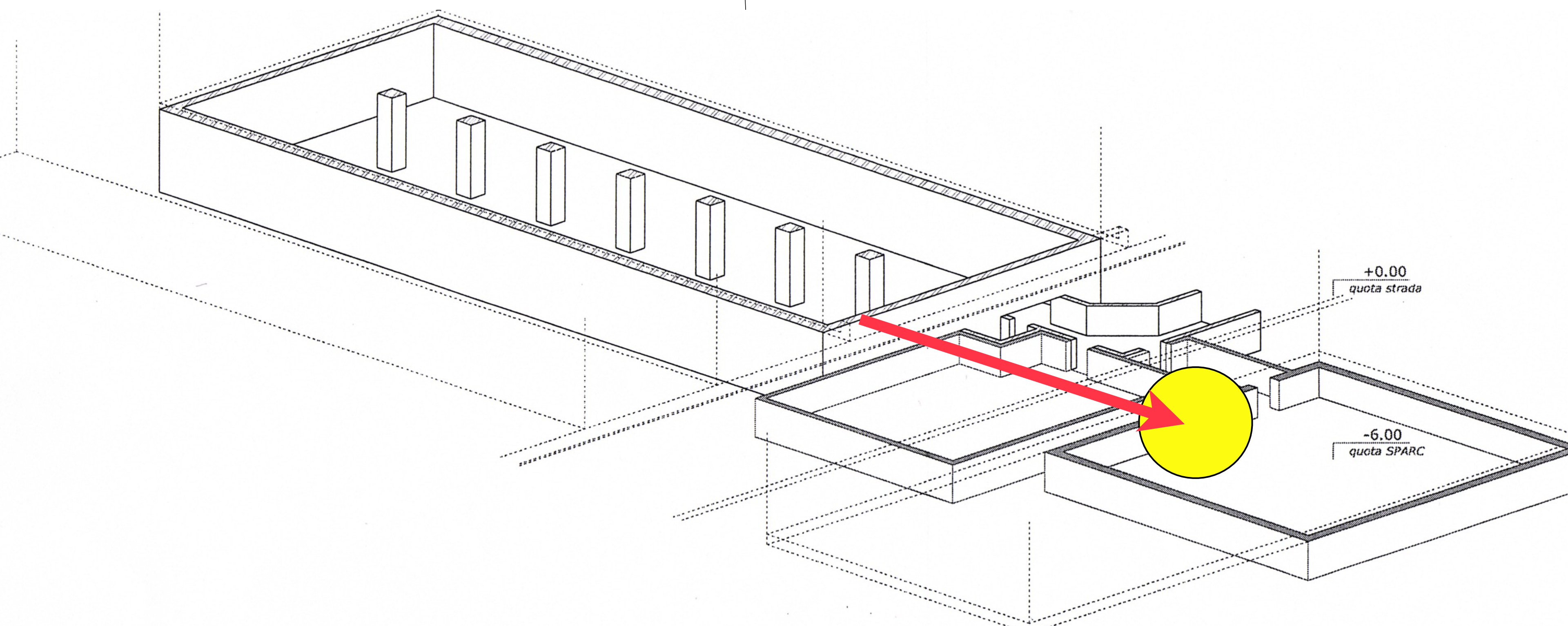
Consiglio Nazionale delle Ricerche

ENEA

INFN Istituto Nazionale di Fisica Nucleare

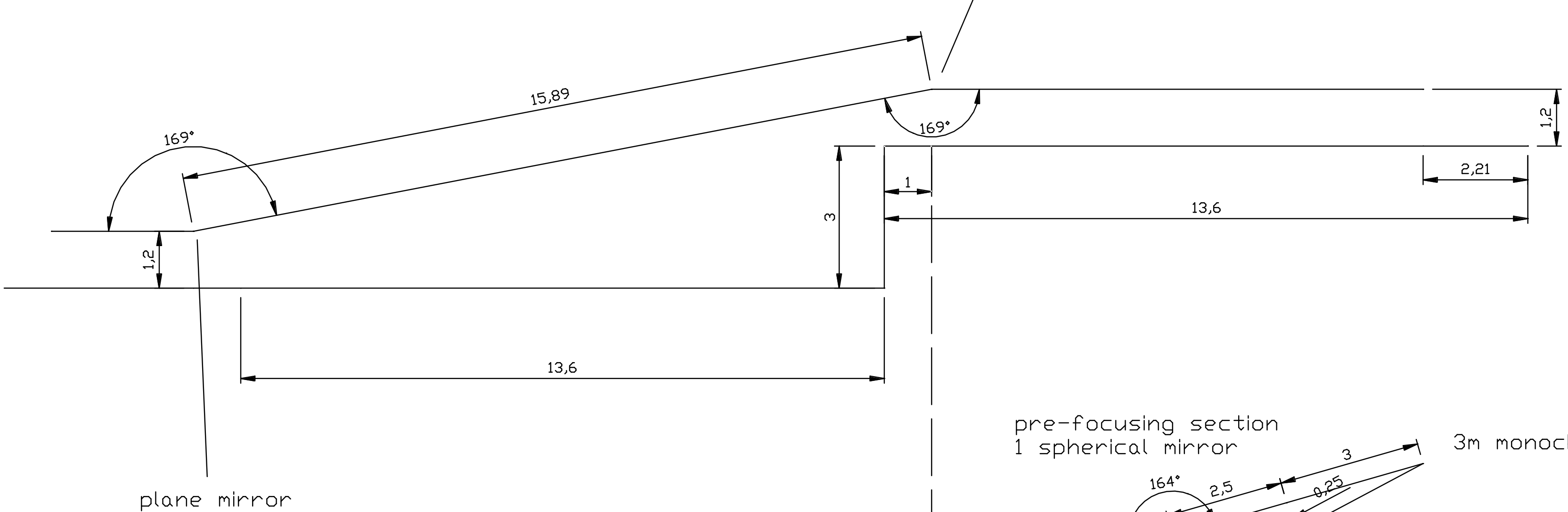
SPARC



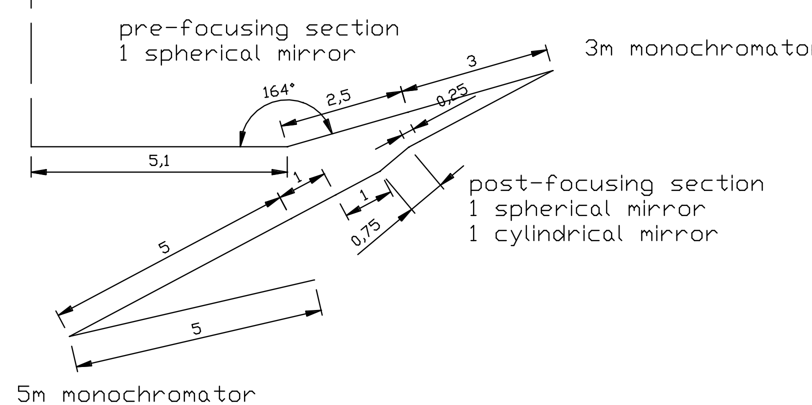


Consiglio Nazionale delle Ricerche

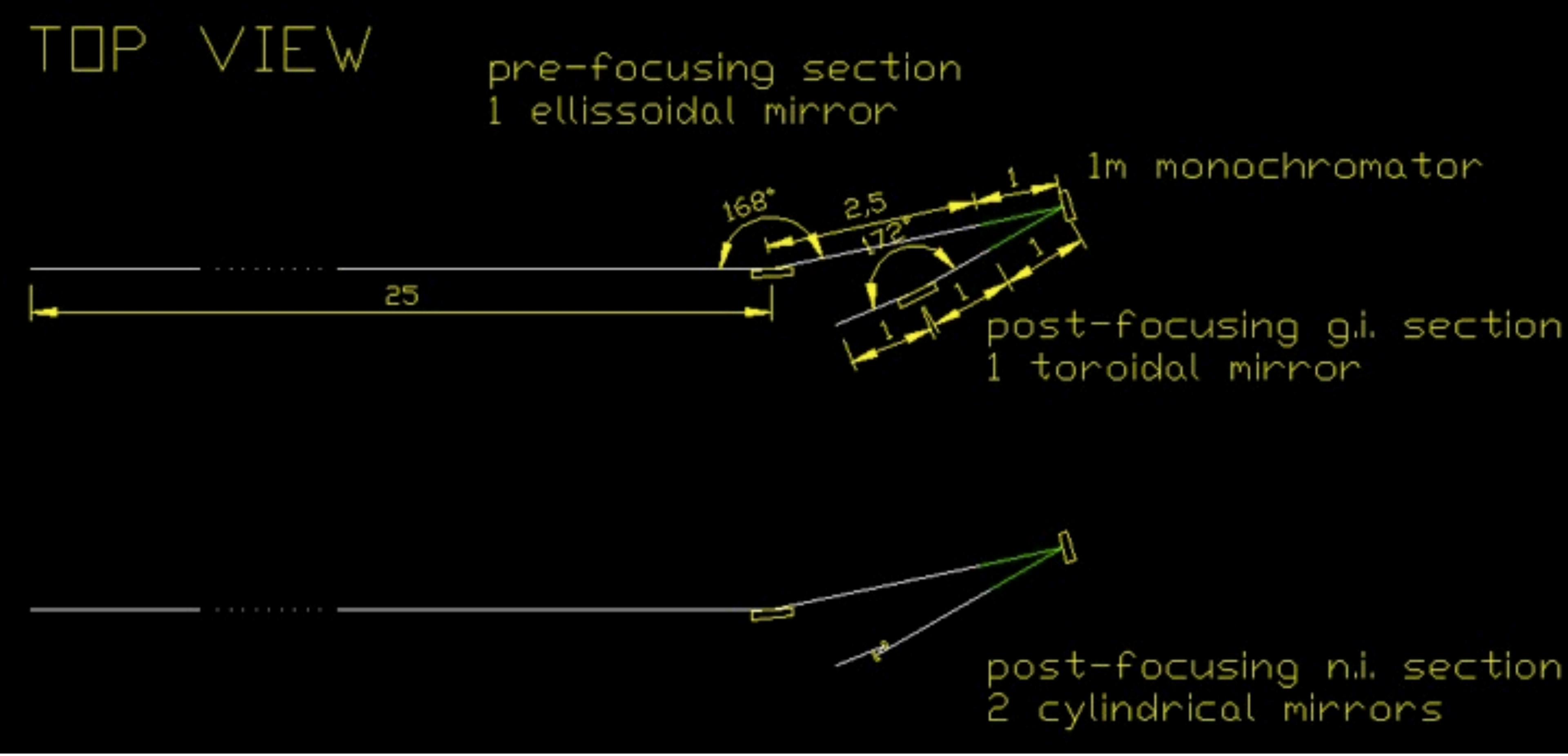
TOP VIEW



La parte iniziale della beamline è costituita da 2 specchi piani in incidenza radente e riflessione in polarizzazione s che permettono di trasportare la radiazione dal laboratorio SPARC al laboratorio LIFE, superando il dislivello di 3 m tra i due pavimenti. Questa soluzione evita di abbassare il livello del laboratorio LIFE fino al livello SPARC e di richiedere come unico collegamento tra i due laboratori un tubo in vuoto per il trasporto della radiazione FEL. Inoltre, anche i requisiti per la sicurezza sono soddisfatti, in quanto la presenza degli specchi di deviazione evita di dover lavorare nella linea diretta del fascio FEL così come esce dagli ondulatori. Si potrebbero utilizzare specchi con ricoprimento in platino, che garantisce all'angolo di incidenza utilizzato (84.5°) una riflettivita' tra 0.85 (a 40 nm) e 0.95 (a 400 nm).



SIDE VIEW

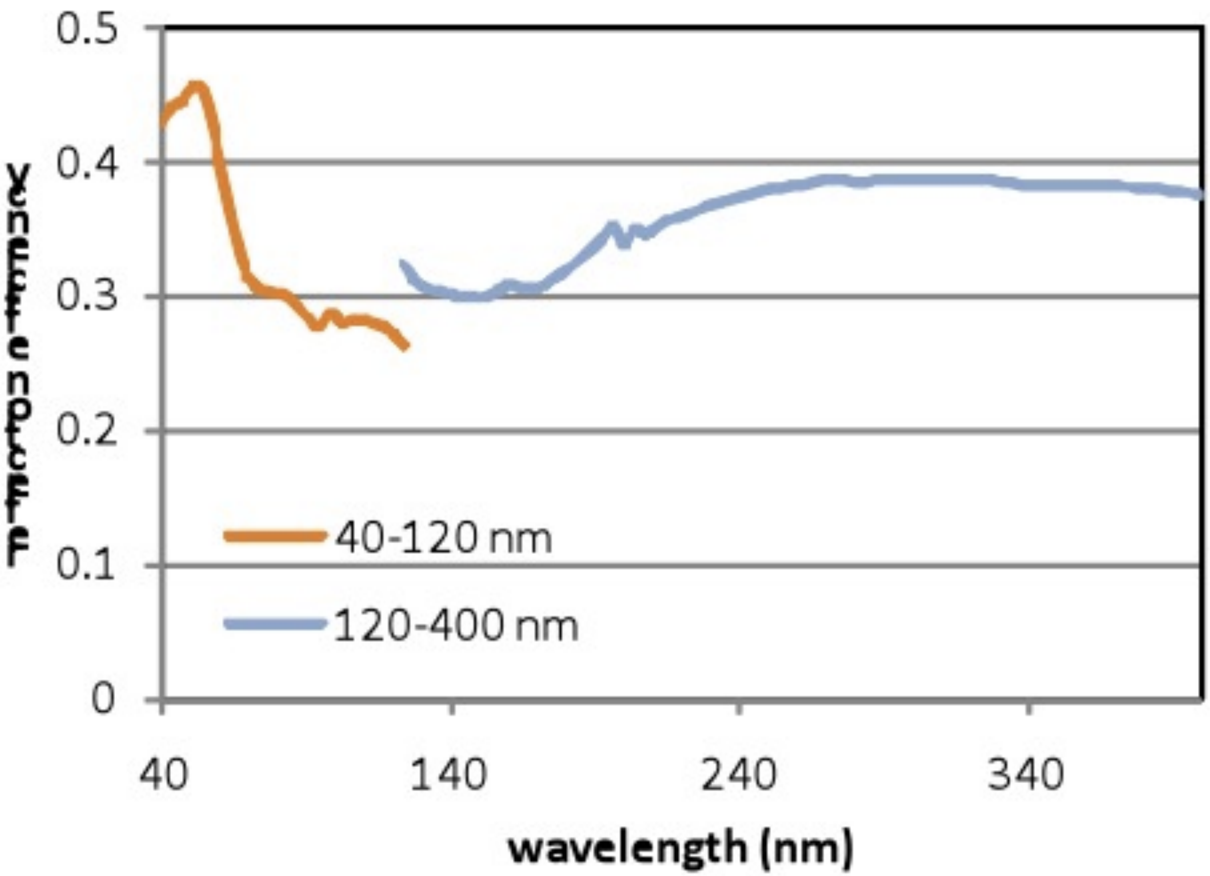


La beamline con le ottiche di focalizzazione ha un primo specchio (ellissoide) in incidenza radente illuminato in polarizzazione *p* che focalizza la radiazione sulla fenditura di ingresso del monocromatore. Una demagnificazione di un fattore 10 è necessaria per diminuire la dimensione della sorgente (da 400 μm rms a 40 μm rms) e per aumentarne la divergenza, in modo da illuminare un'area sufficientemente estesa sul reticolo di diffrazione.

Il pre-monocromatore potrebbe essere un Hilger da 1 m (600 gr/mm o 1440 gr/mm e 18° di angolo). Il monocromatore può essere utilizzato come filtro della radiazione FEL, e.g., 3ª armonica <100 nm e filtrare la fondamentale, oppure come sezione di relay ottico sostituendo uno dei reticoli con uno specchio sferico. Con una demagnificazione di 10, le fenditure di ingresso ed uscita per trasmettere tutta la radiazione focalizzata sono di 200 μm con un allungamento temporale dell'impulso.

Consiglio Nazionale delle Ricerche ENEA INFN SPARC

Efficiency beamline

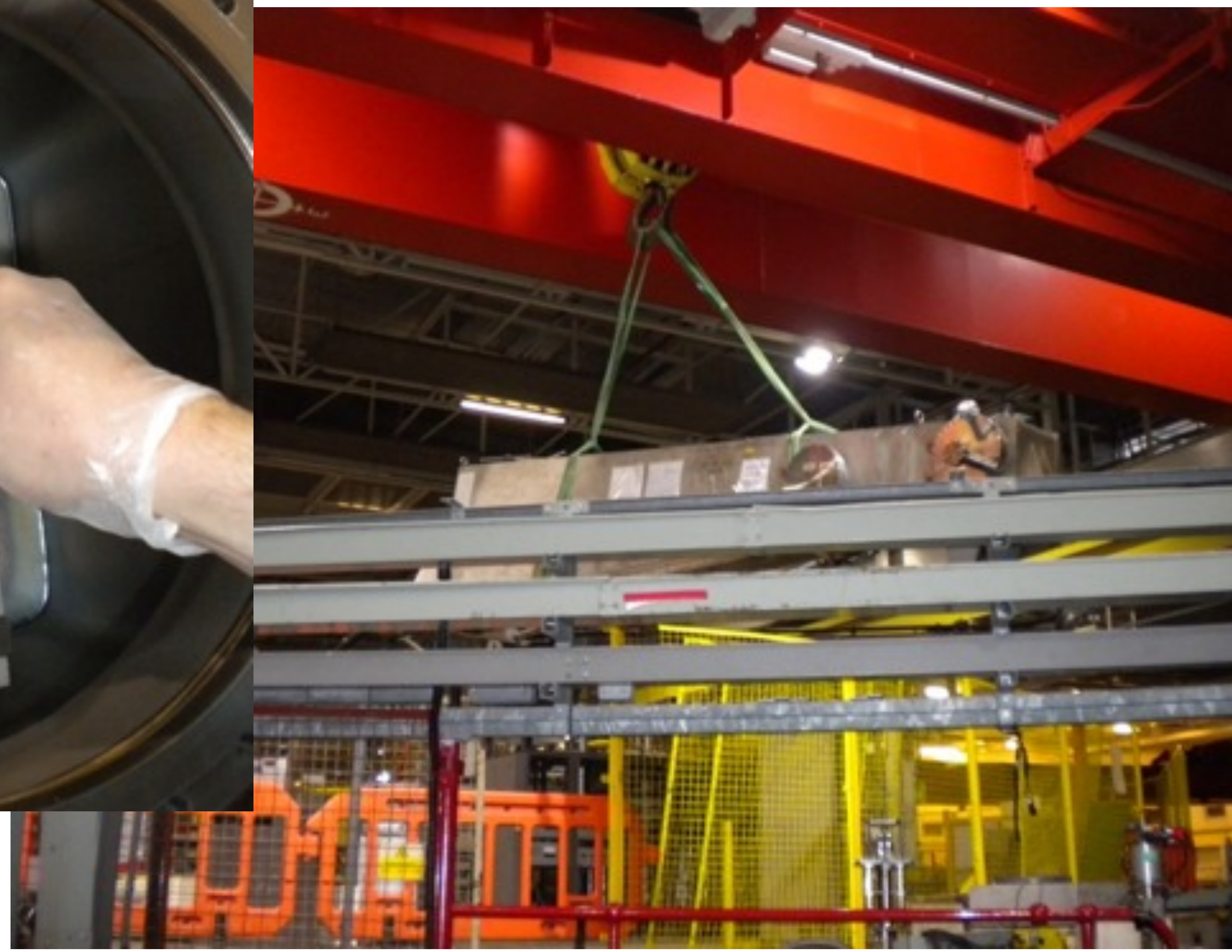


Consiglio Nazionale delle Ricerche

5m monochromator@Daresbury

Consiglio Nazionale delle Ricerche ENEA INFN SPARC

Antonio Battisti
Angelo Mazzenga
Paolo Chimenti



Consiglio Nazionale delle Ricerche ENEA INFN SPARC

Consiglio Nazionale delle Ricerche

ENEA

INFN Istituto Nazionale di Fisica Nucleare

SPARC

Conclusioni

- *5m NIM compatibile con la sorgente SPARC*
- *Case scientifico esistente*
- *Necessità di un TDR della beamline*
- *Installazione compatibile solo con una nuova area sperimentale*
- *Ampia comunità (italiana) interdisciplinare interessata a ricerche UV ad alta risoluzione*
- *Interesse INFN e consolidata in house expertise*
- *……....*

Consiglio Nazionale delle Ricerche
ENEA
INFN
SPARC

Gruppi coinvolti

FEL VUV

- *A. Marcelli, M. Benfatto, M. Ferrario* (INFN/LNF)
- *M. Coreno, L. Avaldi, P. O'Keeffe ….* (CNR-IMIP)
- *E. Pace …..* (Università di Firenze)
- *L. Giannessi* (ENEA Frascati)
- *P. Innocenzi, L. Malfatti* (Università di Sassari)
- *P. Milani, P. Piseri ...* (CIMAINA, Università di Milano)
- *M.R.F. Siggel-King* … (CCLRC Daresbury Laboratory)
- *V. Rossi Albertini, N. Zema …..* (CNR-ISM)
- *L. Poletto* (CNR-IFN)

Consiglio Nazionale delle Ricerche

Acknowledgments

- CCLRC Daresbury Laboratory
- M.R.F. Siggel-King
- Ray Jones

- M. Ferrario
- L. Palumbo
- A. Gallo/G. Di Pirro