

XlabF an X-ray Facility @LNF

Dariusz Hampai
on behalf of XlabF team

Frascati - 25 Ottobre 2023

XlabF Team

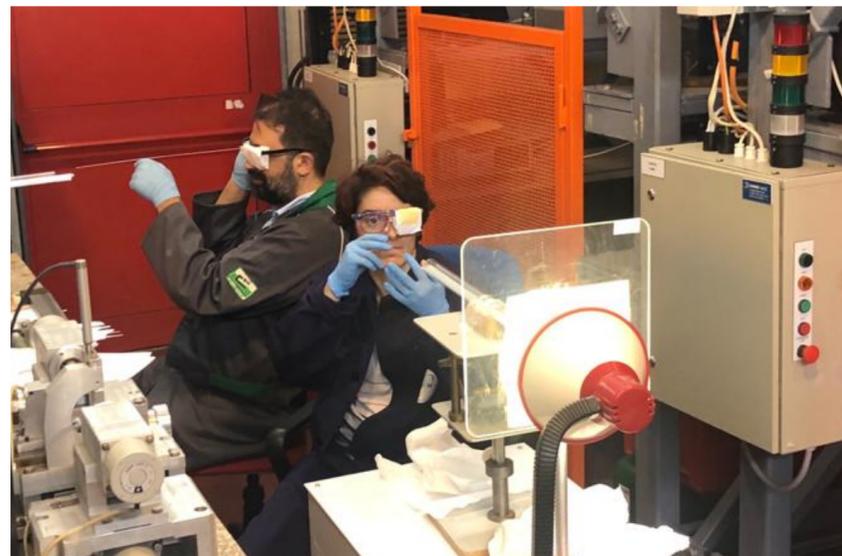
X-ray Facilities @ LNF



Prof S.B. Dabagov - Resp. XlabF



Dr. D. Hampai



Dr.ssa V. Guglielmotti



E. Capitolo



Long time ago at Frascati...

Alla fine del XX secolo, è iniziata una lunga collaborazione

Una idea è diventata un piccolissimo laboratorio. Come una "rolling stone", dopo 20 anni ci sono 4 Facilities operanti aperte ad utenti esterni e altre 2 in fase di realizzazione

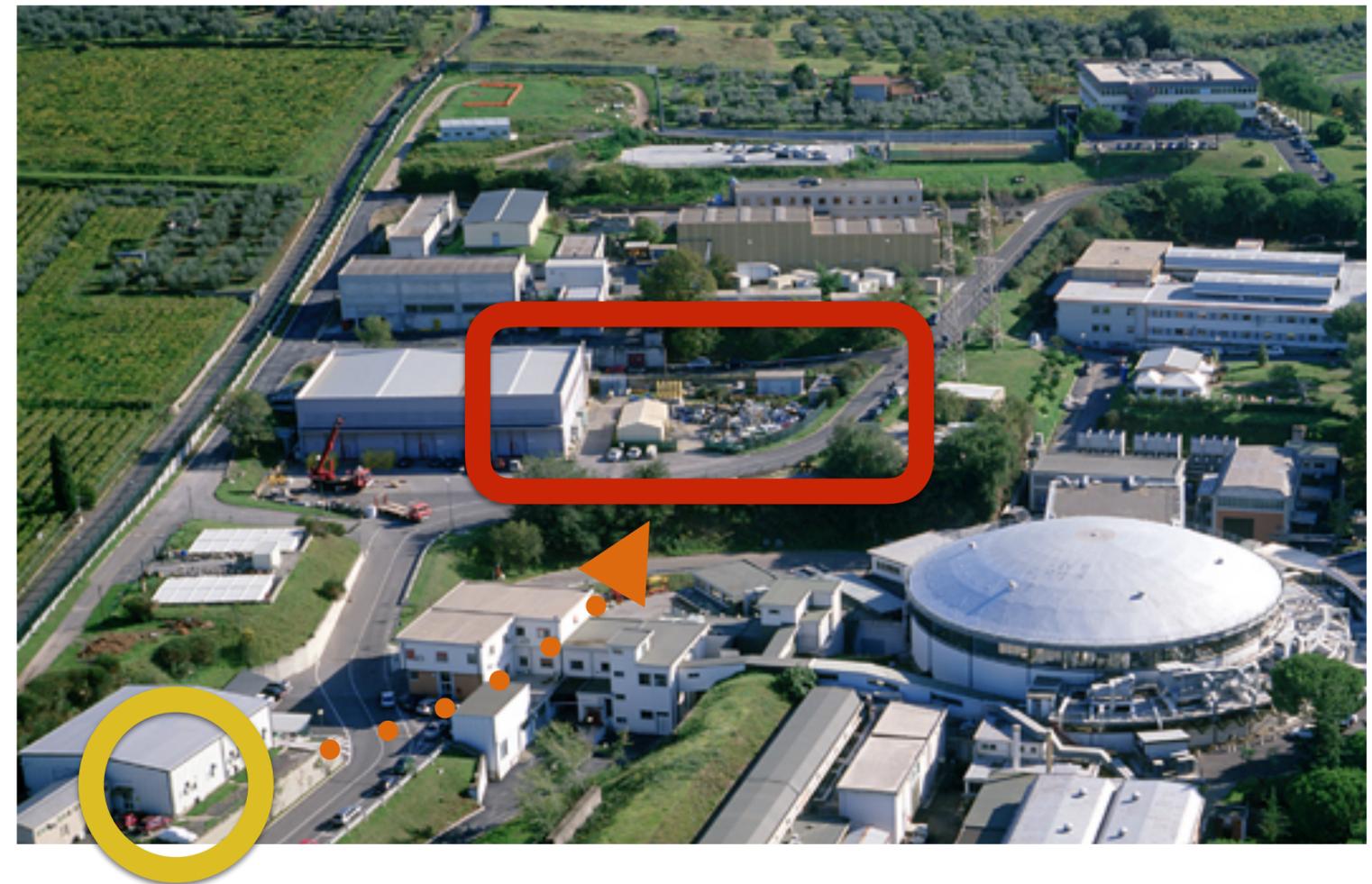
X-ray Facilities @ LNF



Ma come è iniziato XlabF?



Channeling 2004



X-ray Fac

FRASCATI

ti

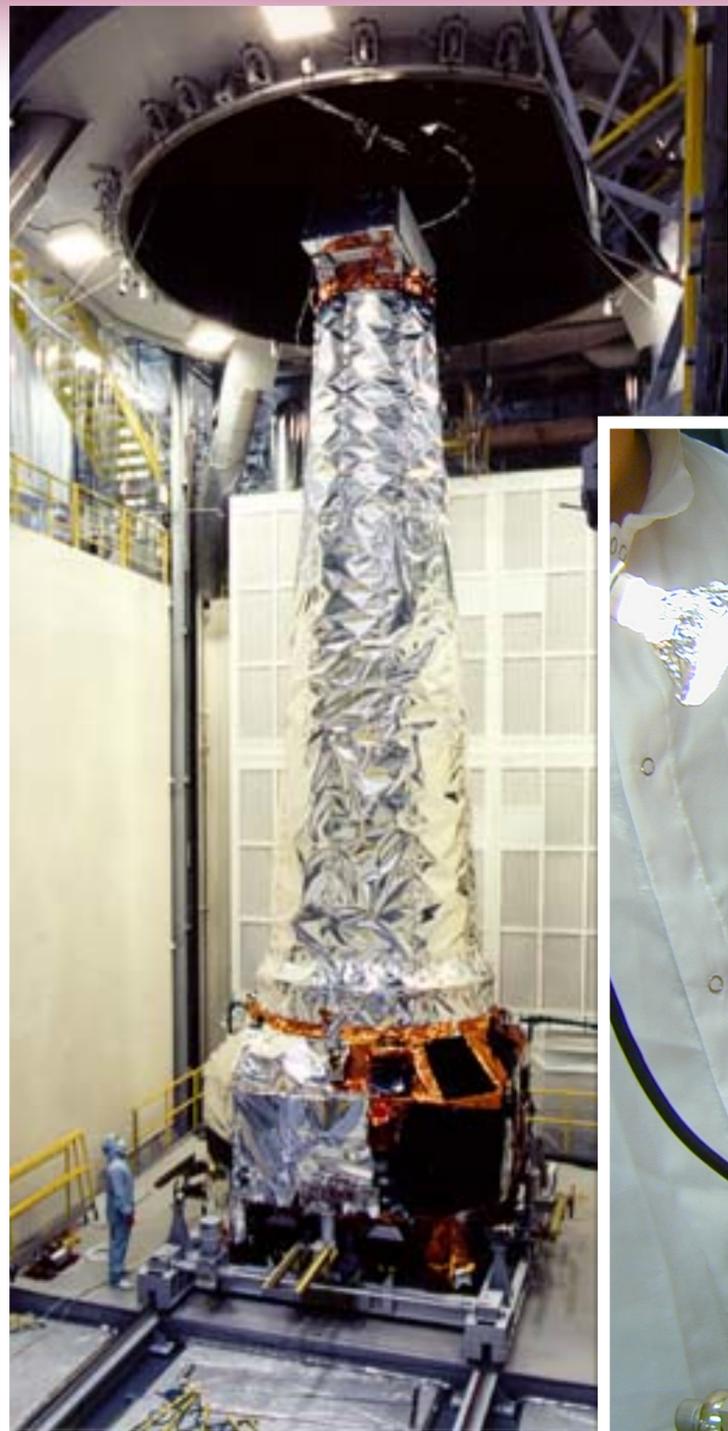


@XLabF1

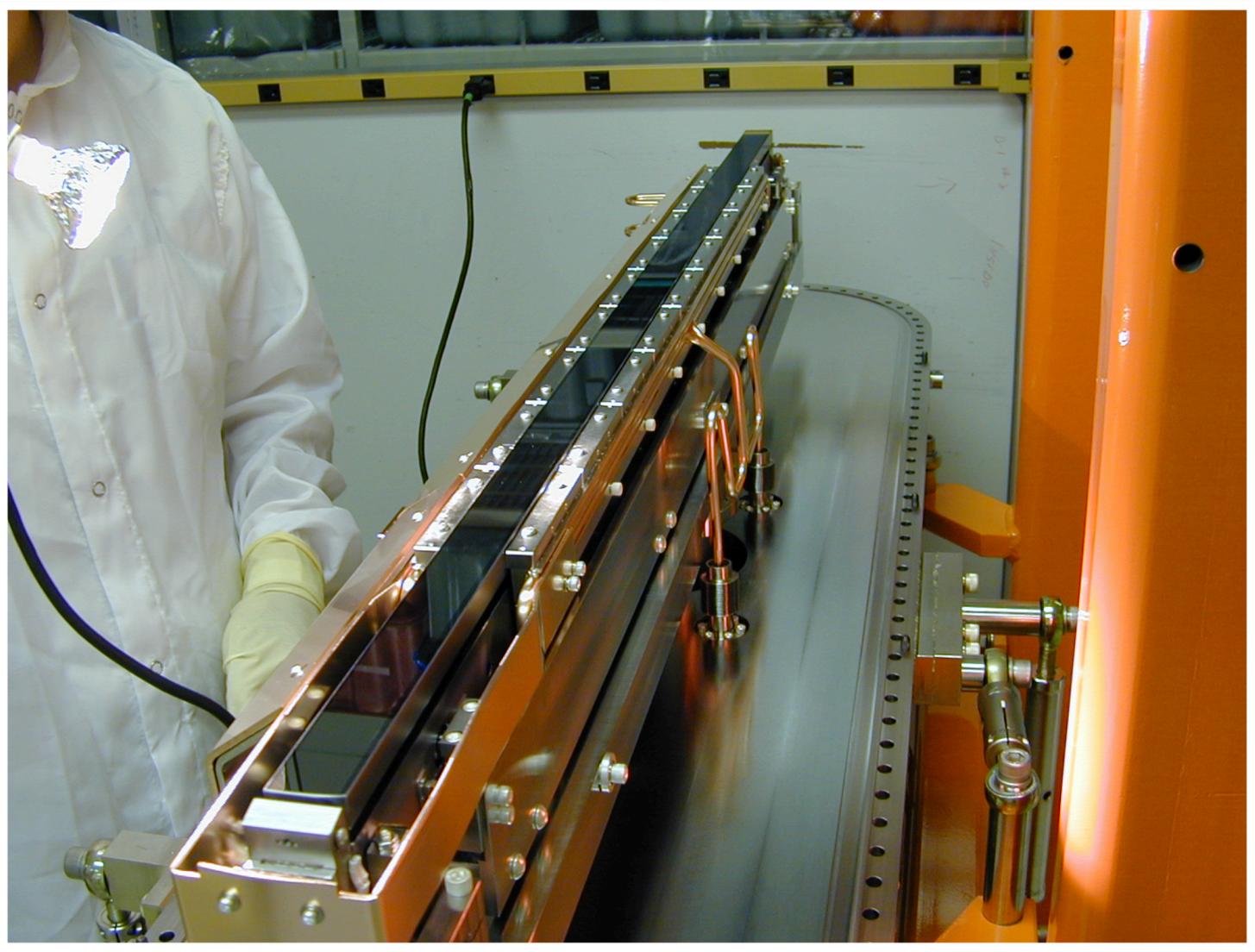


... e quale era questa attività...

X-ray Facilities @ LNF

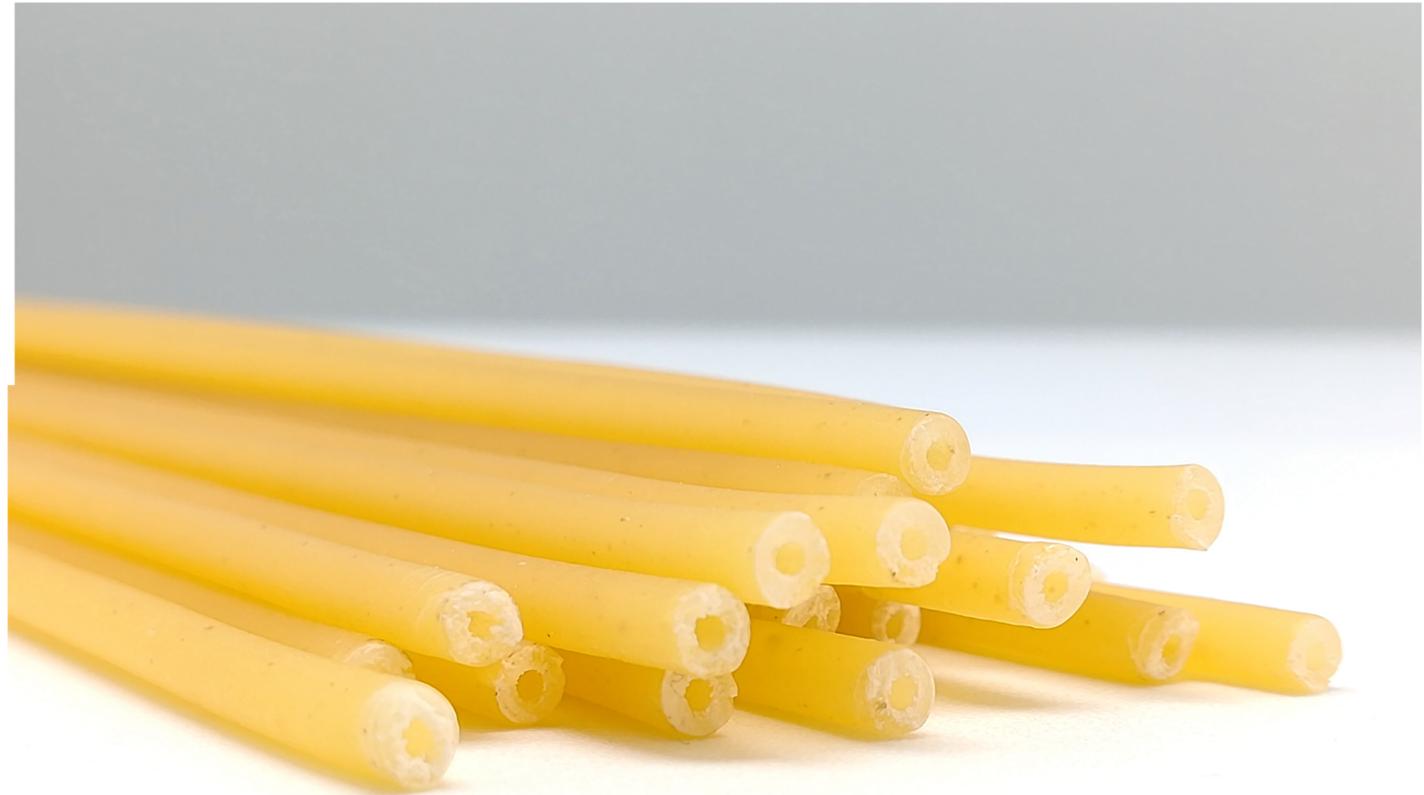
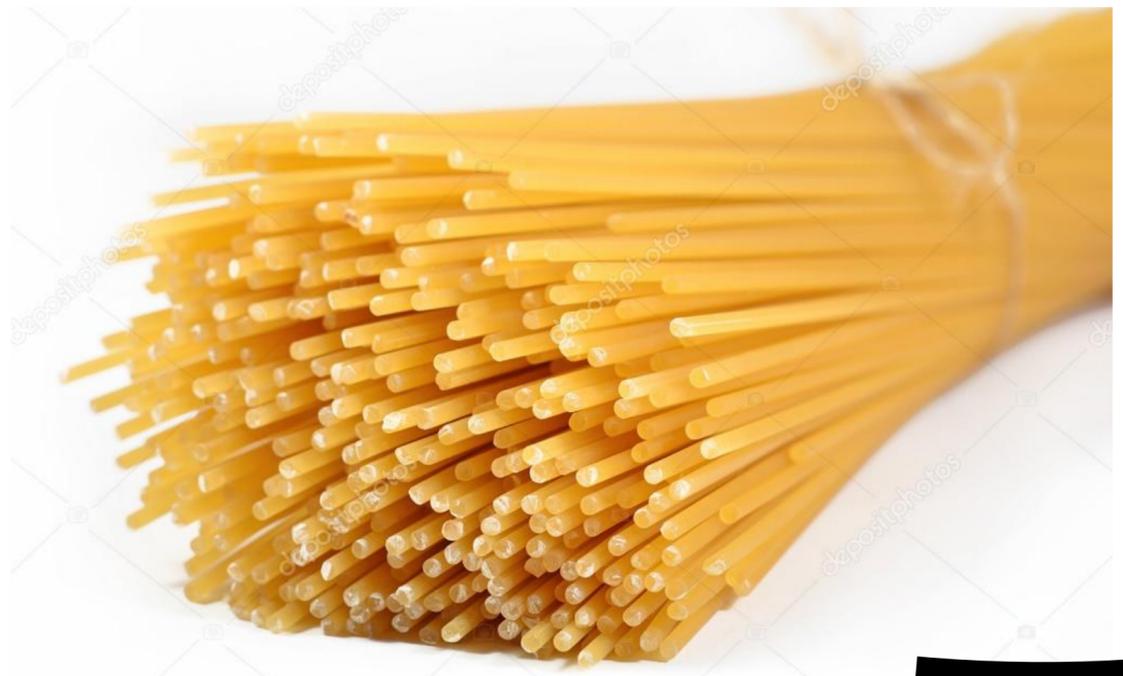
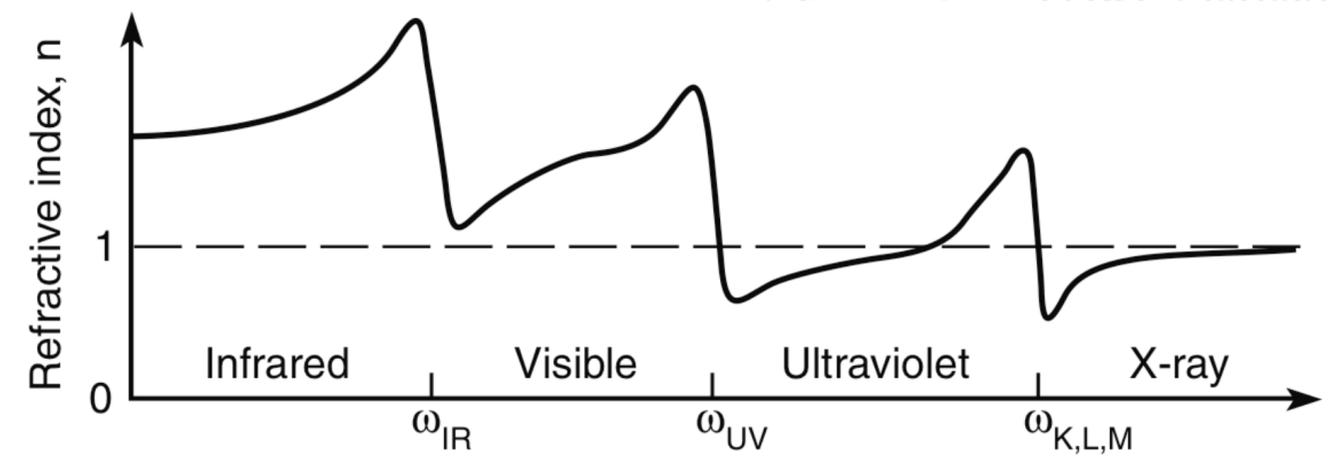


Si voleva compattare le ottiche per raggi X in qualcosa di più maneggiabile

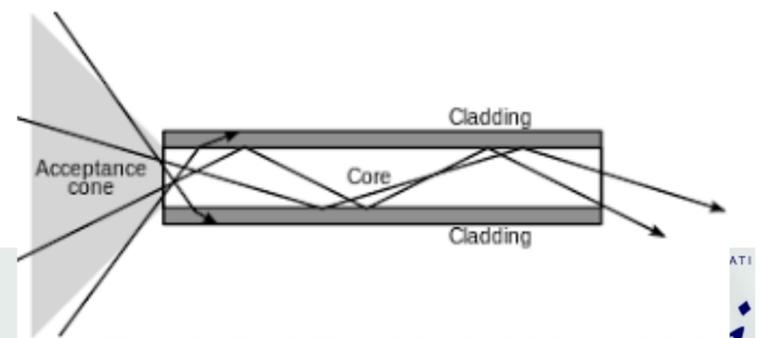
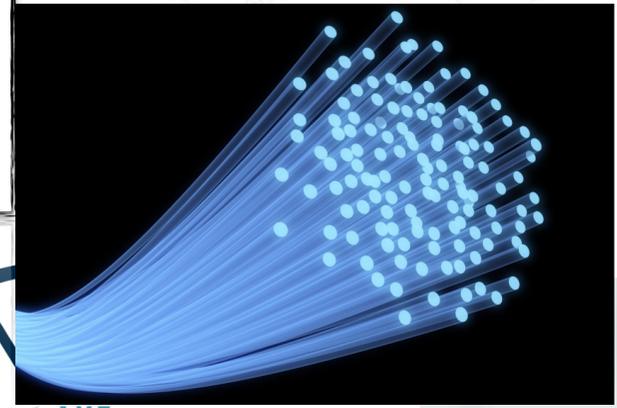


... si parte da un principio

X-ray Facilities @ LNF



cit. S.B. Dabagov



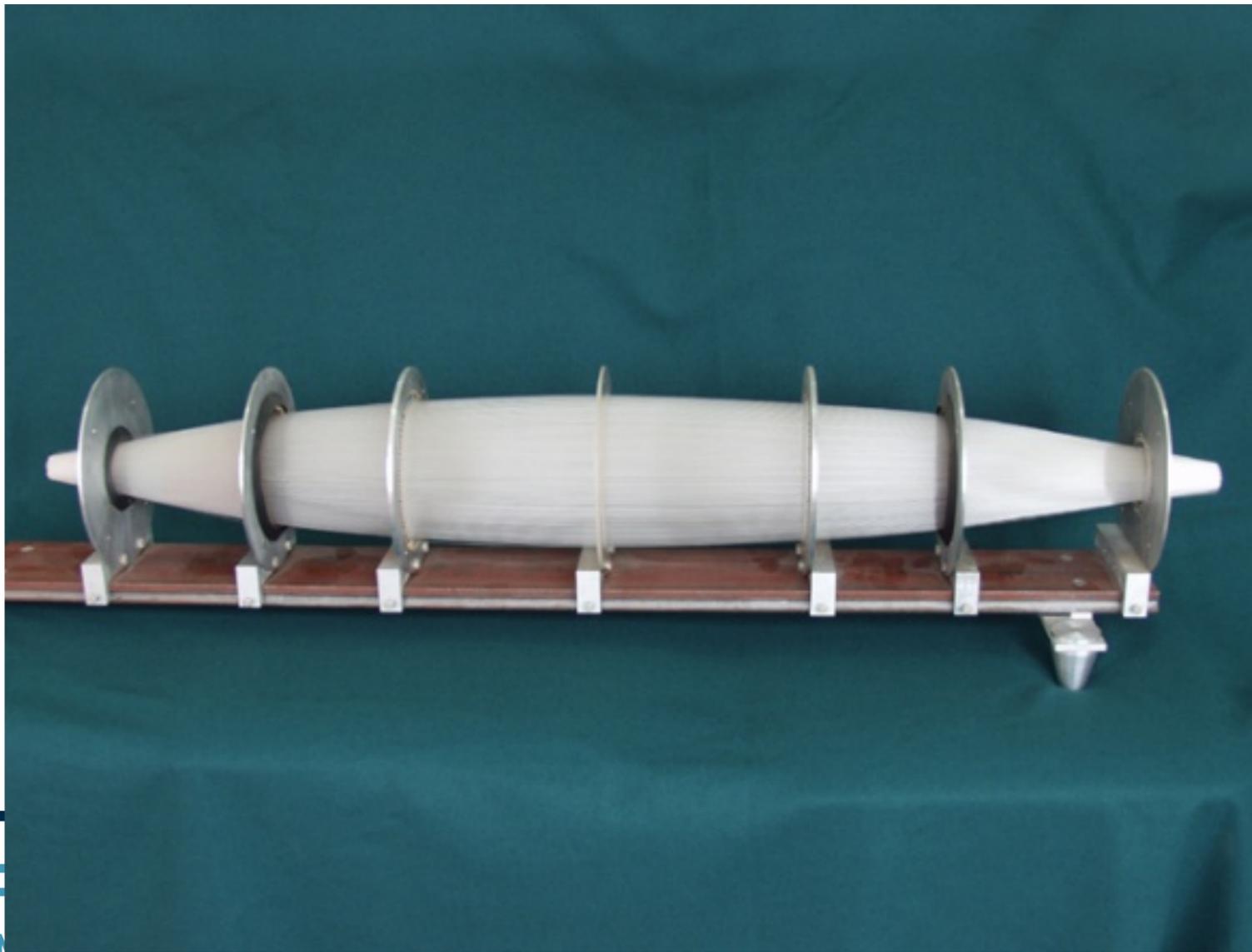
 @XLabF1

XChannel
x-ray technologies

... e allora bucatini siano! (1986)

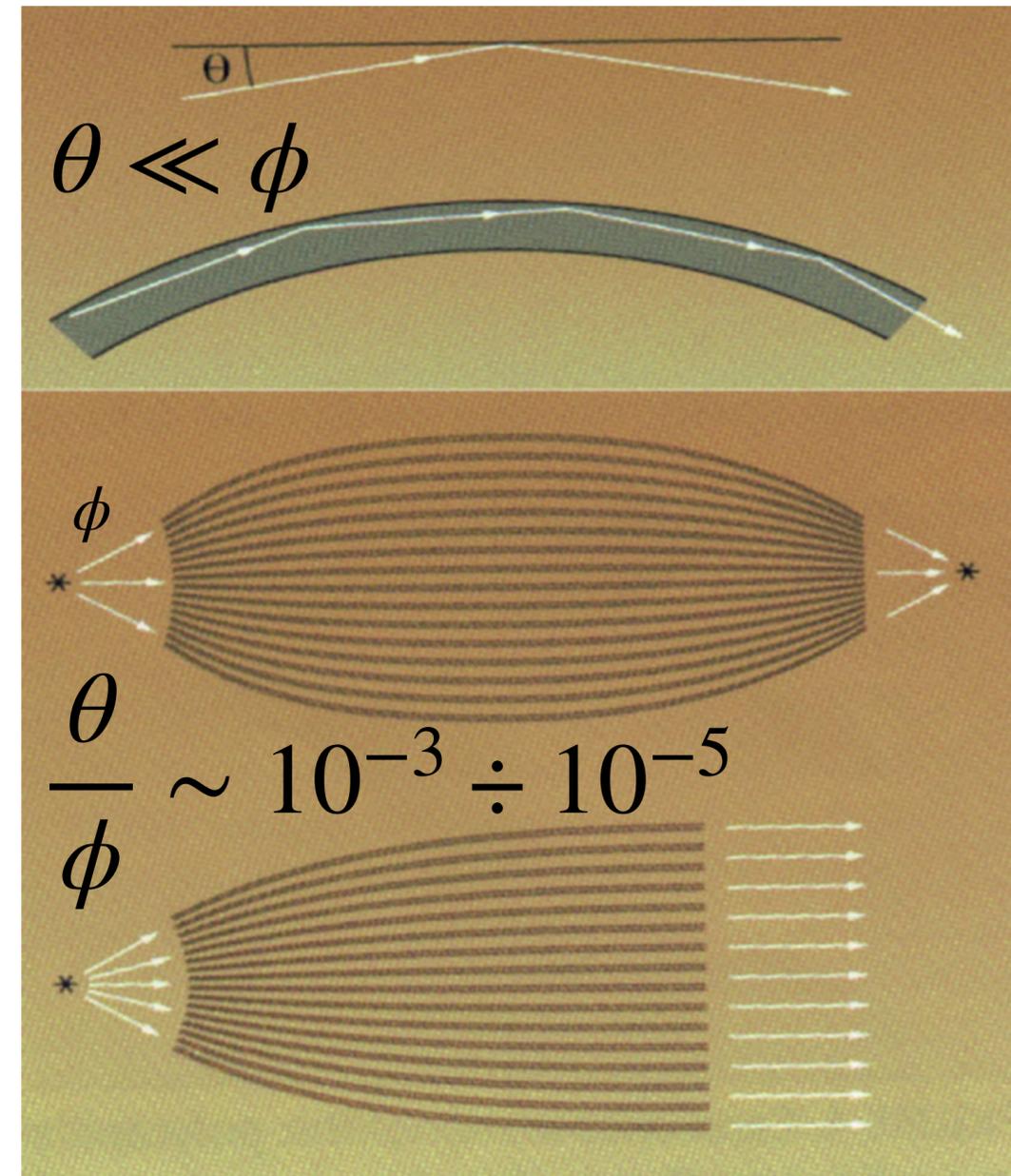
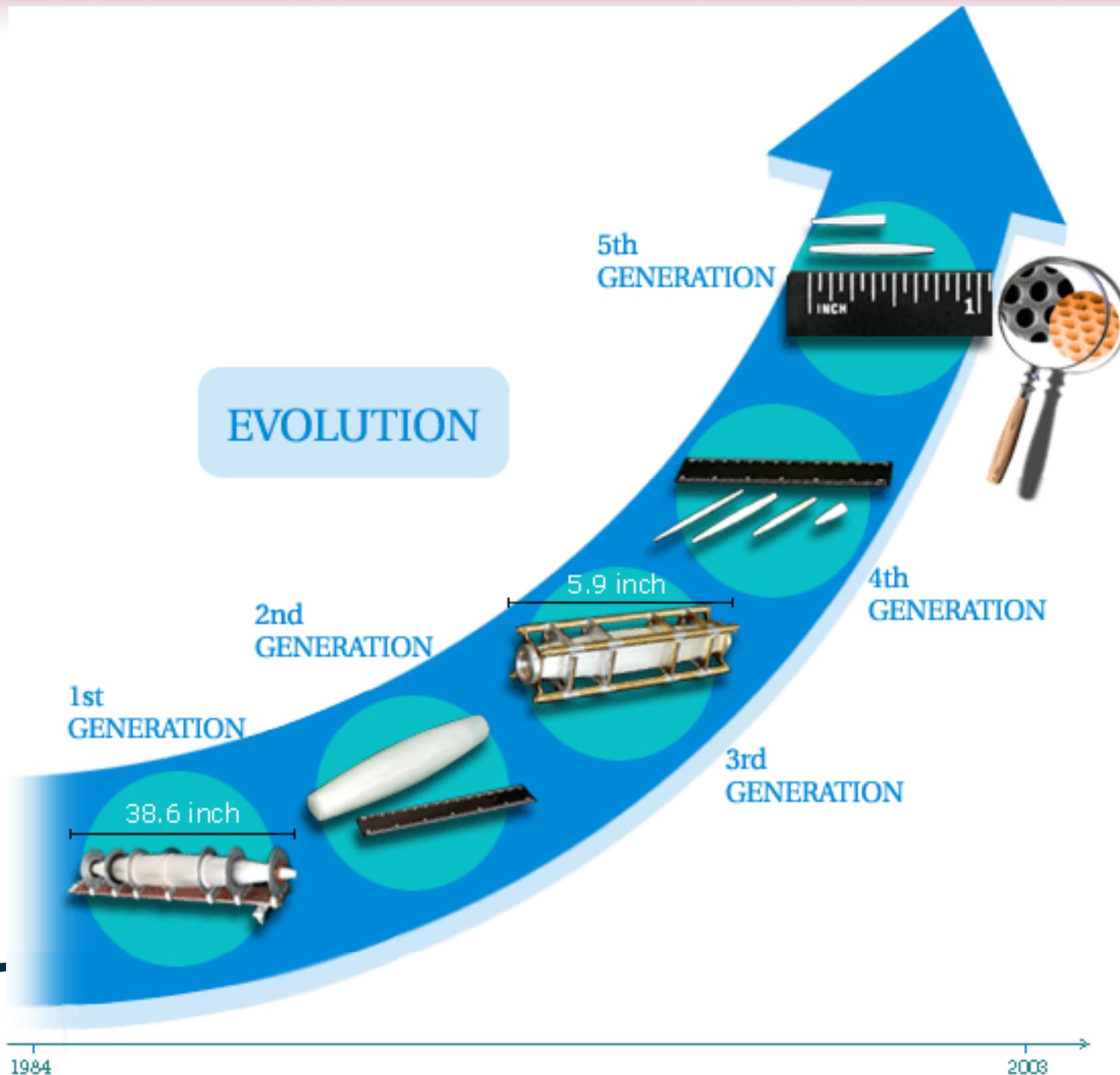
Prof. Muradin A. Kumakhov
Institute for Roentgen Optics - Mosca

X-ray Facilities @ LNFI



... ma sempre più piccoli!

X-ray Facilities @ LNF



Perché sempre più piccoli?

X-ray Facilities @ LNF

- Luce Visibile - 300-700 nm (circa)
- X-rays - 0.1-10 Å



Attività XlabF

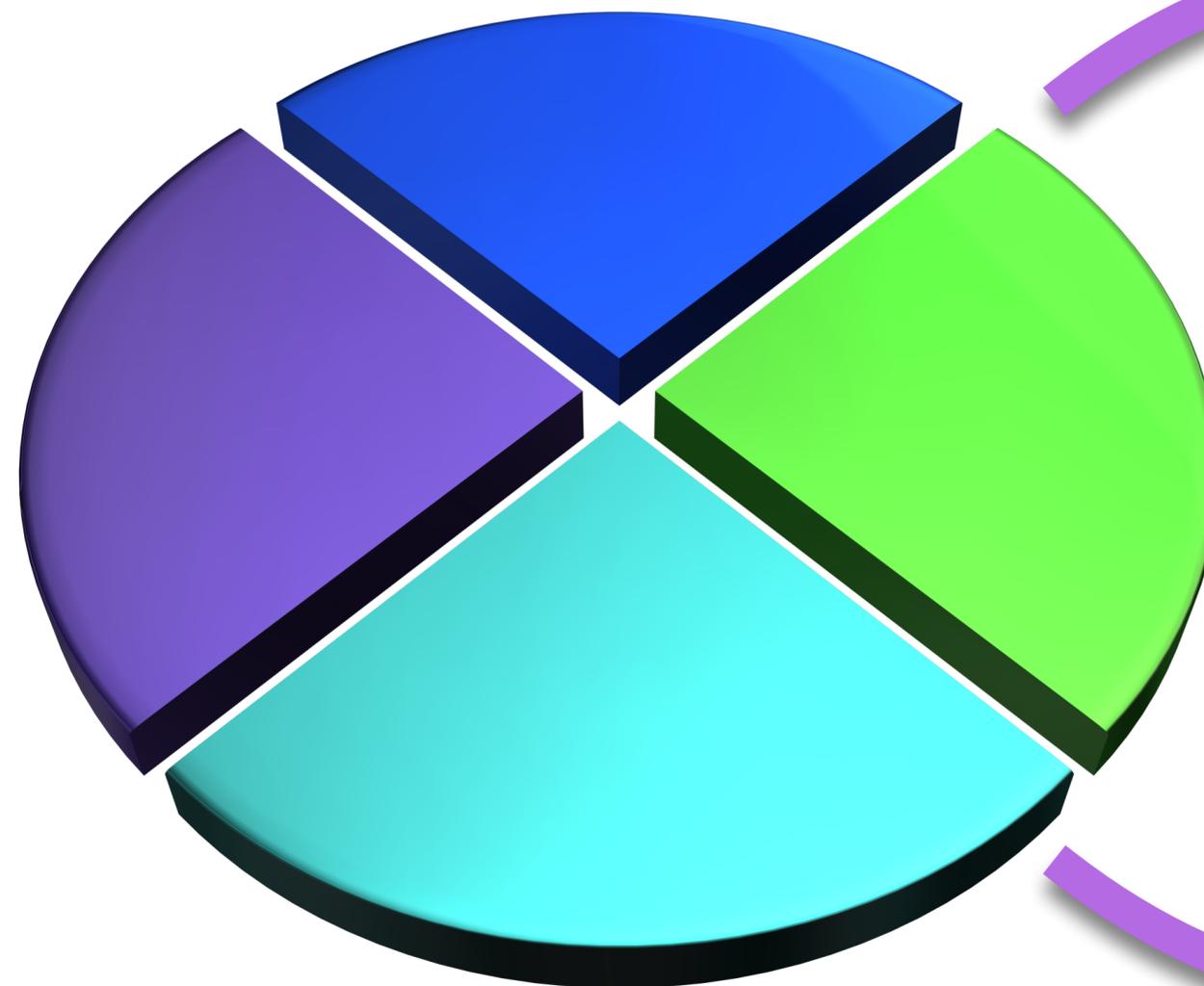
X-ray Facilities @ LNF

Fisica Teorica Interazione
Radiazione Materia

Attività INFN:
•Premiale
•Gr. V
•Gr. II

R&D Strumenti
Di Analisi mediante
Raggi X

Applicazioni
Sperimentali



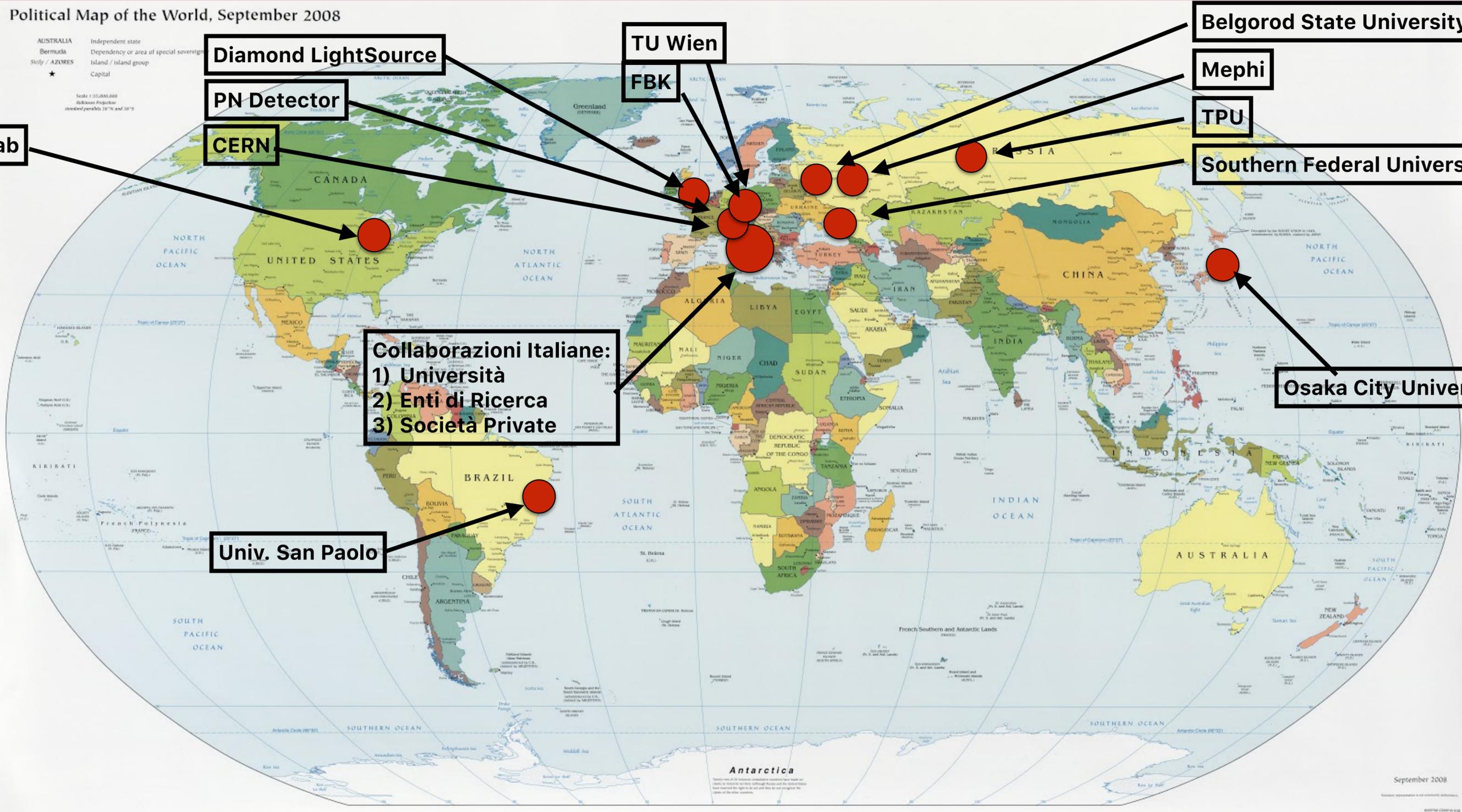
Produzione Ottiche Policapillari

Collaborazioni
Internazionali
•FermiLab
•LiteBird
•Diamond LightSource

- **Articoli Teorici: circa 150**
- **Articoli Sperimentali: circa 90 ad esclusione delle attività "extra-facility" (vedi UA9/CERN, g-2/Fermilab, ecc...)**
- **2010 - Miglior Progetto Europeo su progetti "nano" (NANORAY)**
- **2017 - Progetto Premiale (Volume Photography)**
- **Conferenze Organizzate: circa 20 tra "workshop" e "congress", sia in Italia che all'estero**
 - Channeling (2004-2023)
 - ICXOM (2005)
 - Advanced Accelerator & Radiation Physics - AARP (2011-2023)
 - ecc...
- **Partecipazione Conferenze: più di 100...**
- **Dottorati: 2 Italiani - 7 Stranieri**
- **Circa 10 lauree in Università Italiane - circa 15 Università Straniere**

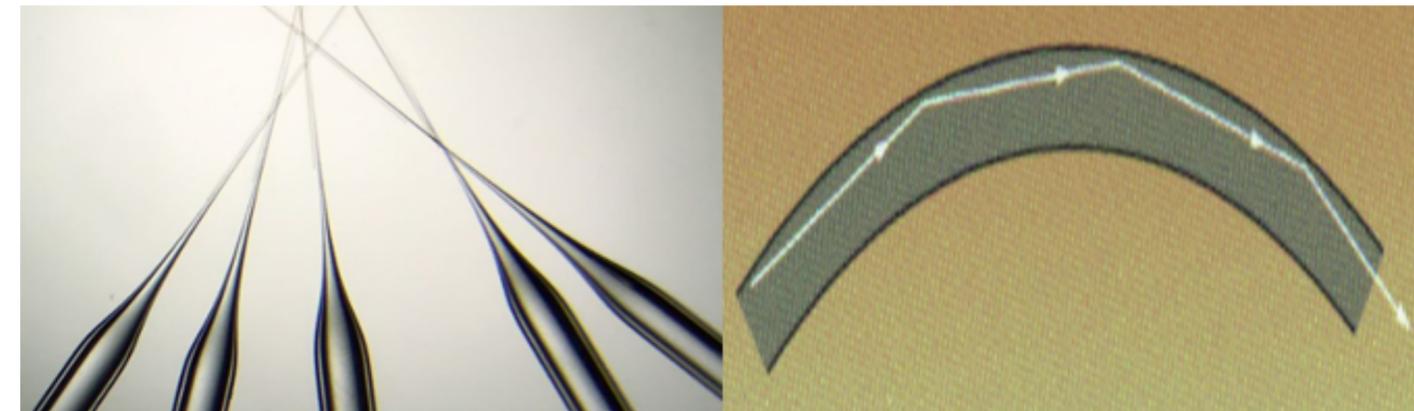
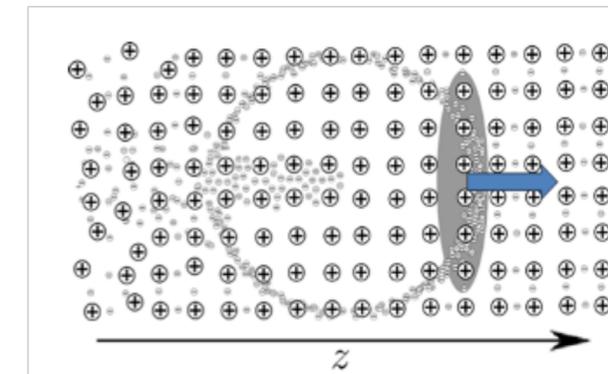
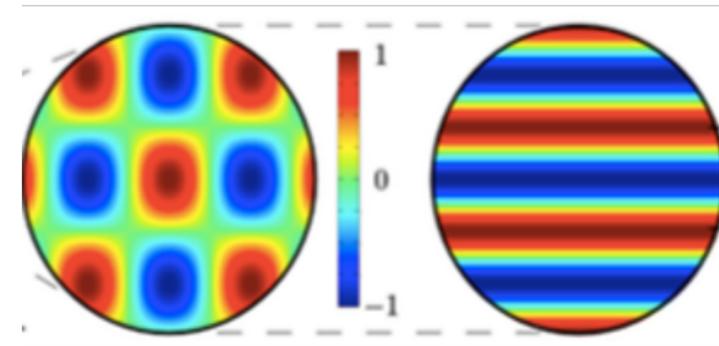
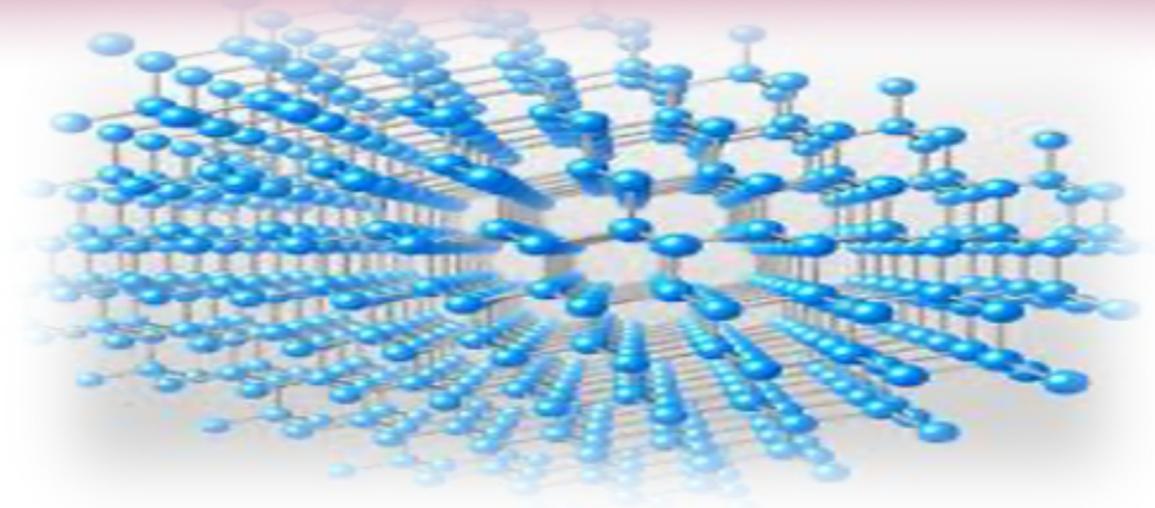
Collaborazioni

X-ray Facilities @ INFN



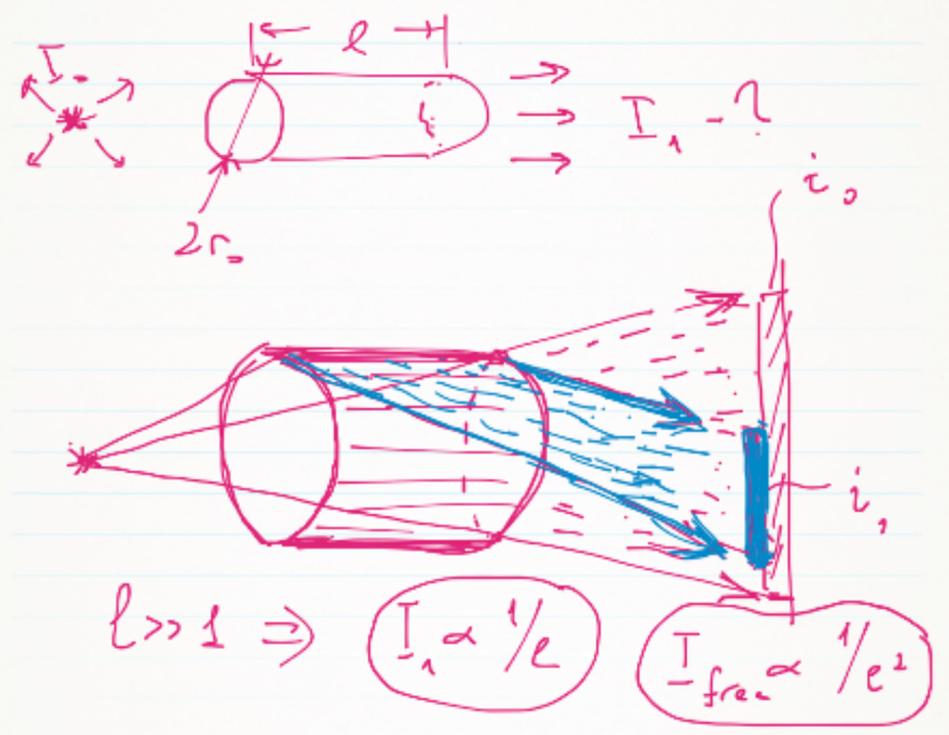
- **Fisica Teorica**
- Attività Sperimentali
- R&D Strumenti
- Produzione Ottiche

- **Crystal Channeling**
 - Beam shaping;
 - Micro-undulator;
 - Positron source
- **Laser & Plasma Channels**
 - Beam profiling for high current/luminosity;
 - Dynamics for wake field acceleration;
- **Capillary Micro- & NanoChannels**
 - capillary guides for charged beams
 - capillary guides for X & n beams

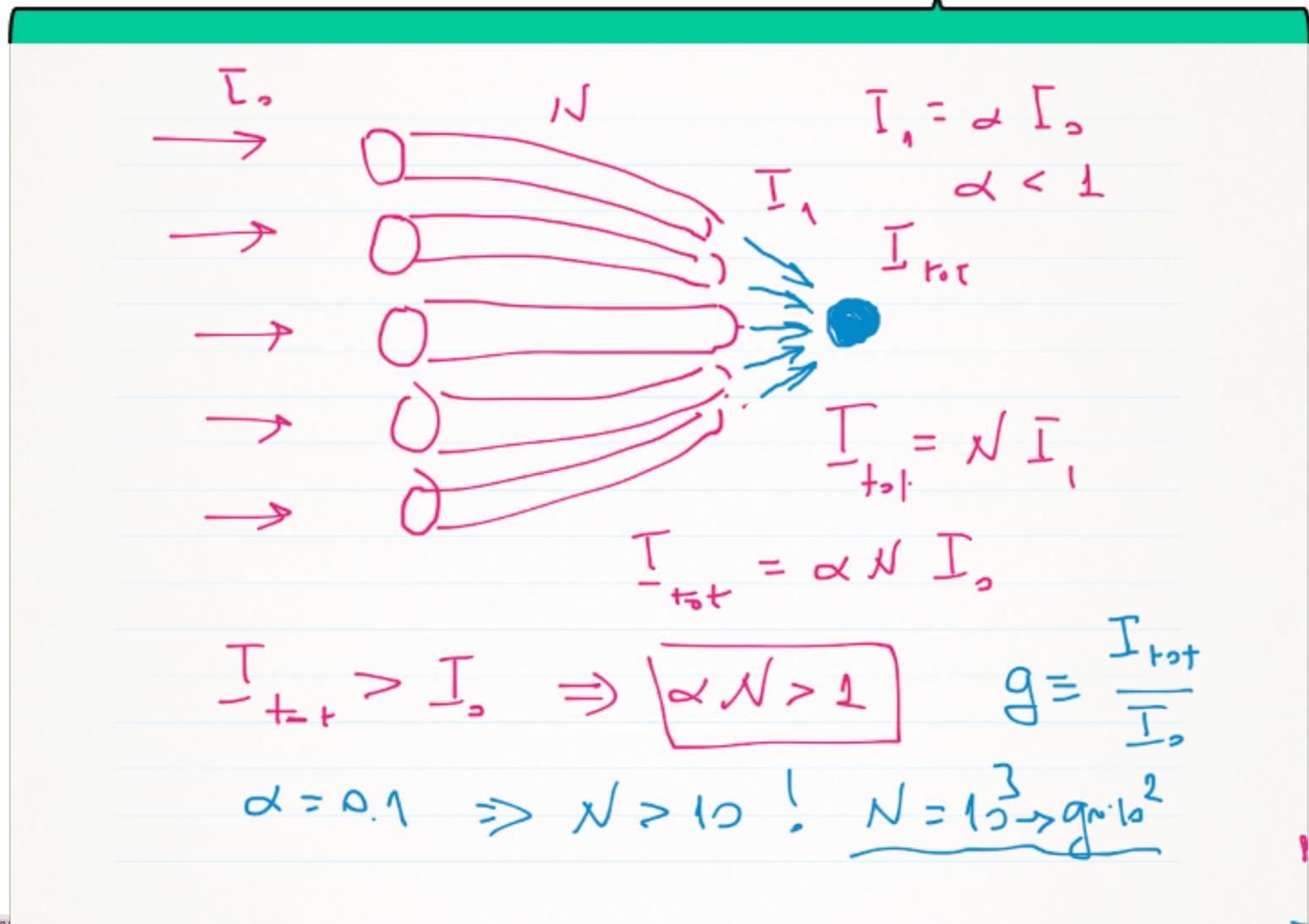


Nel caso dei Raggi X

X-ray Facilities @ Frascati

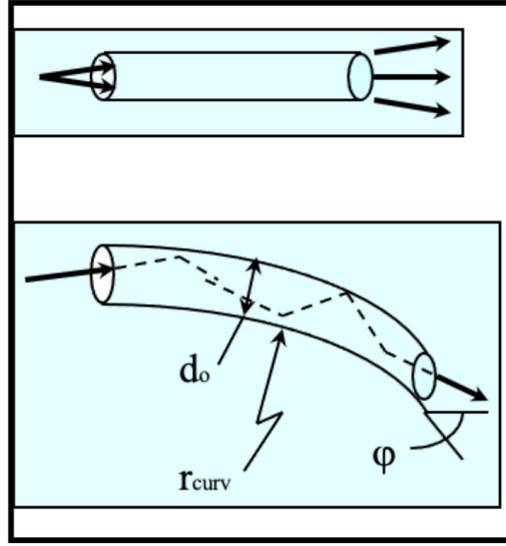


Kumakhov's task (Minsk school, 1984):
a night work for the feasibility of mono/multichannel optics



Nel caso dei Raggi X

INFN @ Frascati



$\Delta\theta \approx 2\theta_c$

free space propagation $\rightarrow L^{-2}$

$I \propto \int_{\theta_{\min}}^{\theta_c} R(x) \sin(x) dx \propto L^{-1}$

$\theta_i \leq \theta_c$ - multiple TER

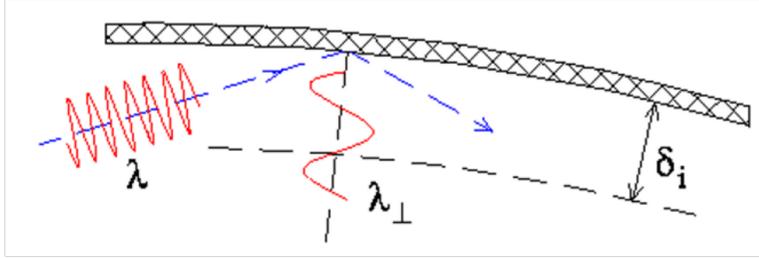
$\frac{r_{\text{curv}} \theta_c^2}{2d_0} \geq 1$ - effective guide

$I(\varphi) \propto \int [R_0(x)]^{N(x,\varphi)} dx$

$\vec{k} = (k_{\perp}, k_{\parallel})$

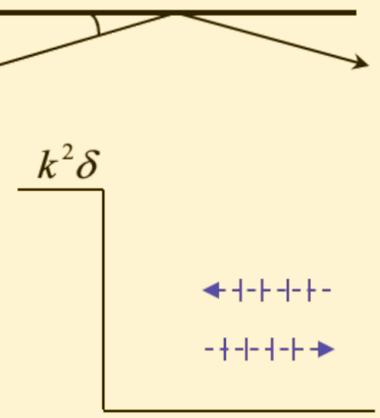
$k_{\perp} \simeq k\theta \ (\theta < \theta_c)$

$\lambda_{\perp} = \lambda/\theta \gg \lambda$



Effective guide channel $\delta_i(\theta) \simeq \lambda_{\perp}(\theta)$

plane surface



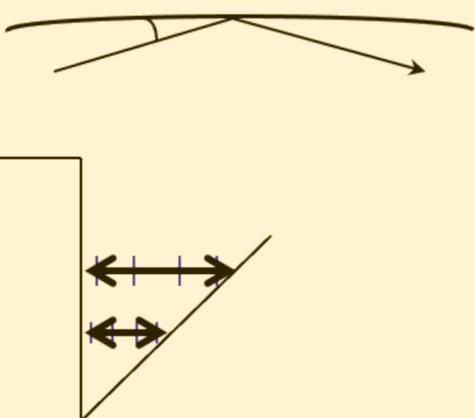
$k^2 \delta$

$k^2(\delta(r_{\perp}) - \theta^2) =$

$= \begin{cases} -k^2 \theta^2, & r_{\perp} < r_1 \\ k^2(\delta_0 - \theta^2), & r_{\perp} \geq r_1 \end{cases}$

$V_{\text{eff}} \equiv 0 \Rightarrow \theta_c \equiv \theta \approx \sqrt{\delta_0}$ **TER**

curved surface



$2 \frac{-k^2 r_{\perp}}{r_{\text{curv}}}$

potential energy due to angular momentum $kr_{\text{curv}}\varphi$

$V_{\text{eff}} = k^2 \left(\delta(r_{\perp}) - \theta^2 - 2 \frac{r_{\perp}}{r_{\text{curv}}} \right)$ **CHANNELING**

$(r_{\text{curv}})_i \theta^3 \sim \lambda$

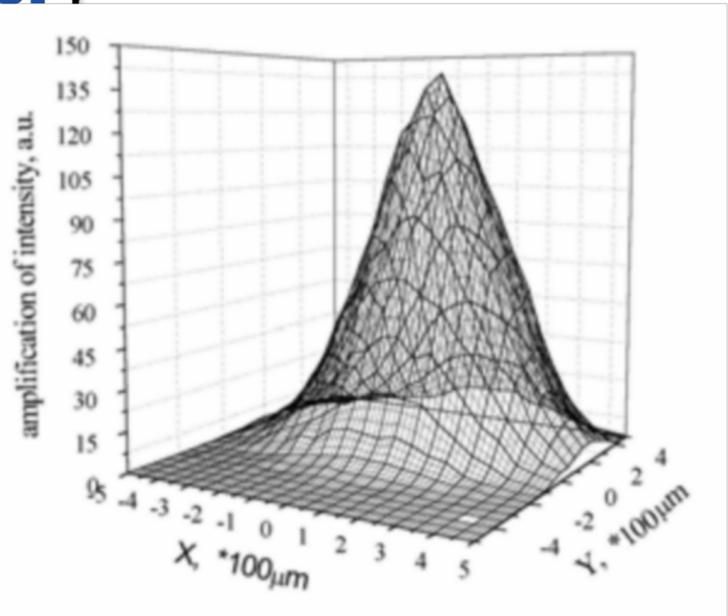
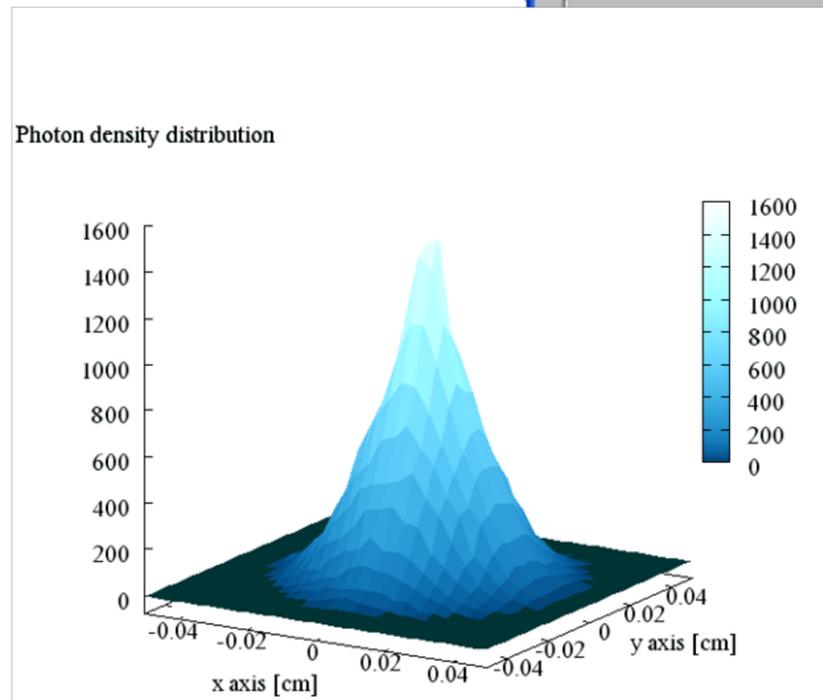
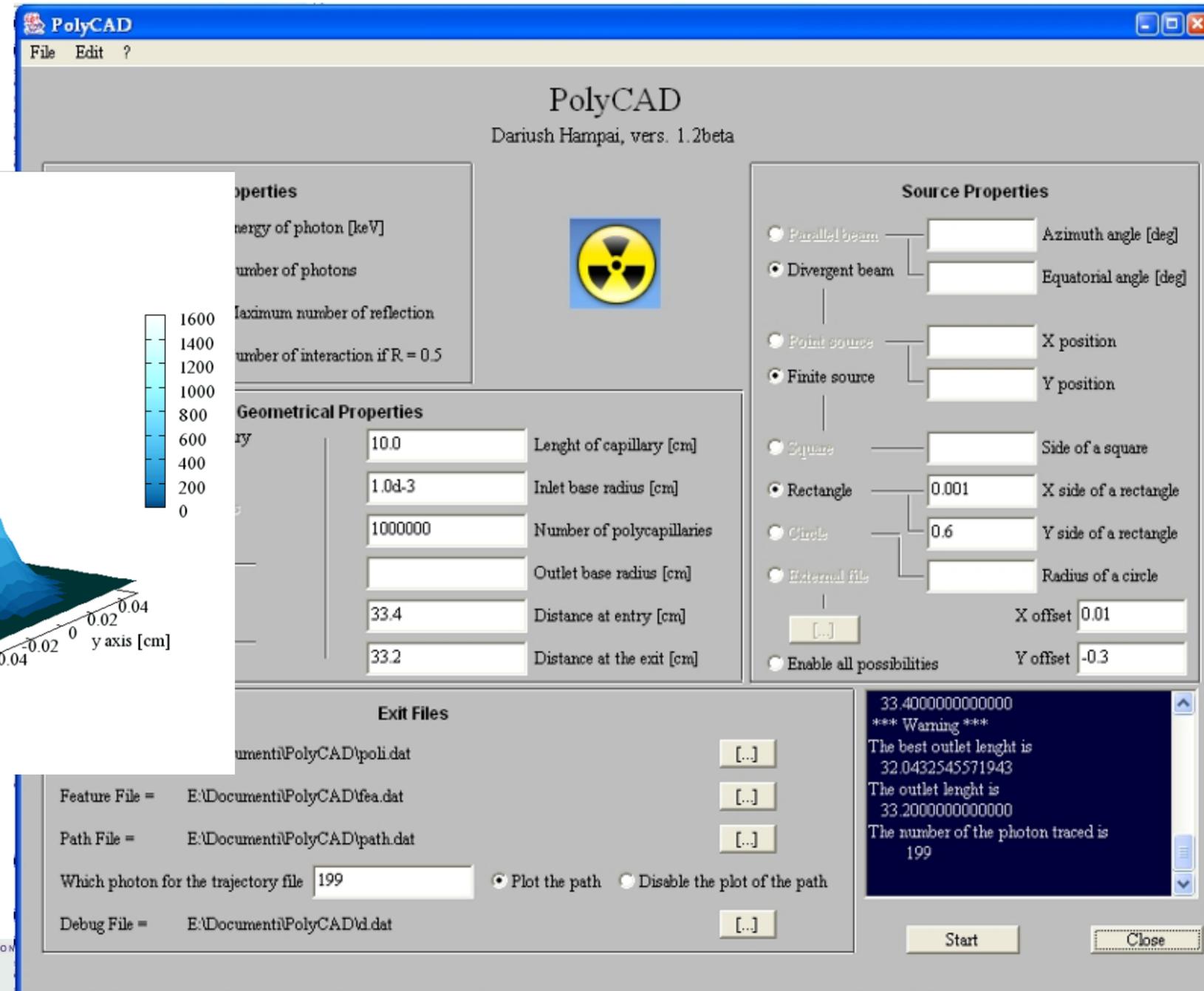
@XLabF1

Nel tempo sono stati realizzati due simulatori per ottiche policapillari, uno "classico" (PolyCAD) ed uno "ondulatorio"

S @ UNF

X-r

X-r

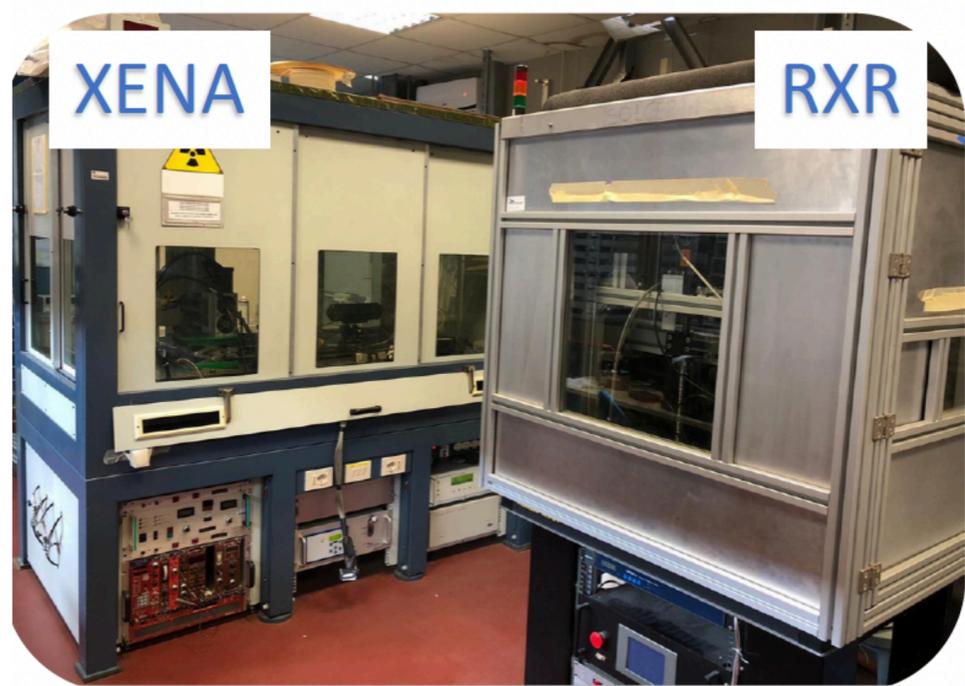


D. Hampai et al., Nucl. Instr. Meth. B 244, 481-488 (2006).

- Fisica Teorica
- **Attività Sperimentali**
- R&D Strumenti
- Produzione Ottiche

- **XENA: Facility con grande hutch sperimentale**
- **RXR: Facility per analisi 2D/3D μ XRF**
- **PXRD: Facility per analisi di Diffrazione X**
- **CTS: Facility per Imaging e Tomografia ad alta risoluzione**
- **SoX: Facility per XRF di elementi leggeri (in fase di realizzazione)**
- **μ Spex: prototipo di μ XRD e μ XRF (da ultimare)**

Facilities @ XlabF



XENA

RXR



PolyCOs



Xlab-Frascati



NEW ARRIVAL

High Resolution CT

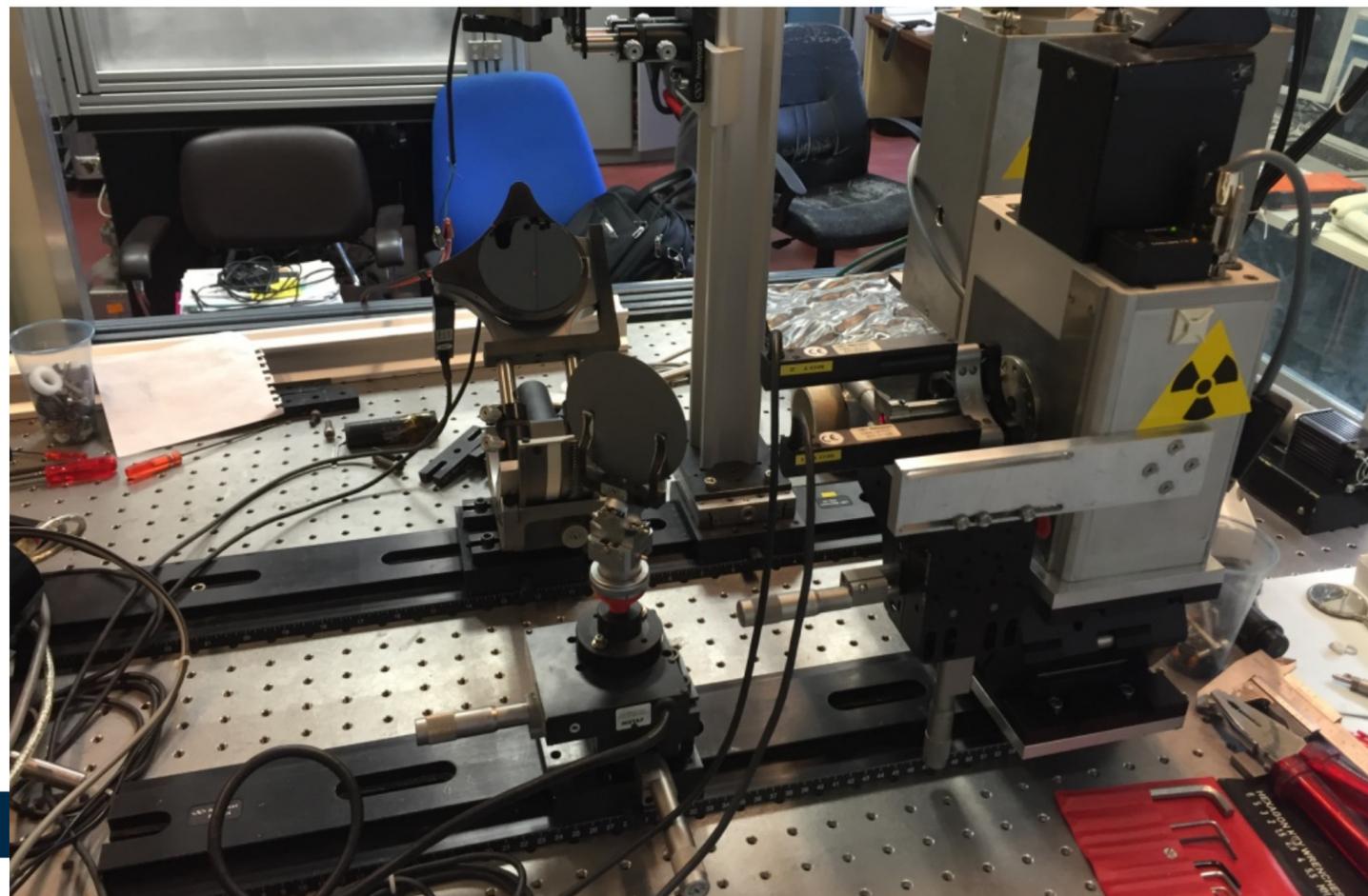


PXRD

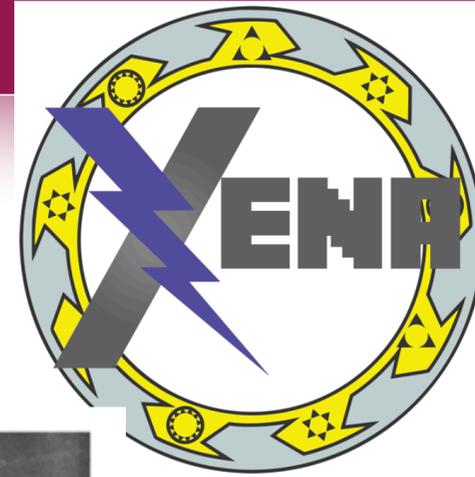
- Sorgenti raggi X - range energetico: 1 - 90 keV
 - Rame,
 - Molibdeno,
 - Tungsteno (sia $K\alpha$ che $K\beta$)
- Rivelatori: SDD (anche per basse energie), CCD (max 14x10 mm²), Scintillatore
- Componenti optomeccanici e movimentazioni lineari/rotativi da remoto
- Diverse lenti policapillari (full-lens, semi-lens e cilindriche)



- Facility for multipurpose X-ray experiments
- HR Imaging - μ CT
- Novel Source/Optics/Detectors
- first experimental table... since 2005 @ XlabF



	XENA
Station	X-ray Elemental station for Non-destructive Analysis
Analysis	(1) High resolution imaging (2) μ CT (3) X-ray optics characterization (4) Detector characterization (5) Novel sources
Resolution	(1) $< 1 \mu\text{m}$ (with LiF detector) (2) $< 17 \times 17 \times 17 \mu\text{m}^3$ (CT with spatial resolution CCD camera of $10.4 \times 10.4 \mu\text{m}^2$)

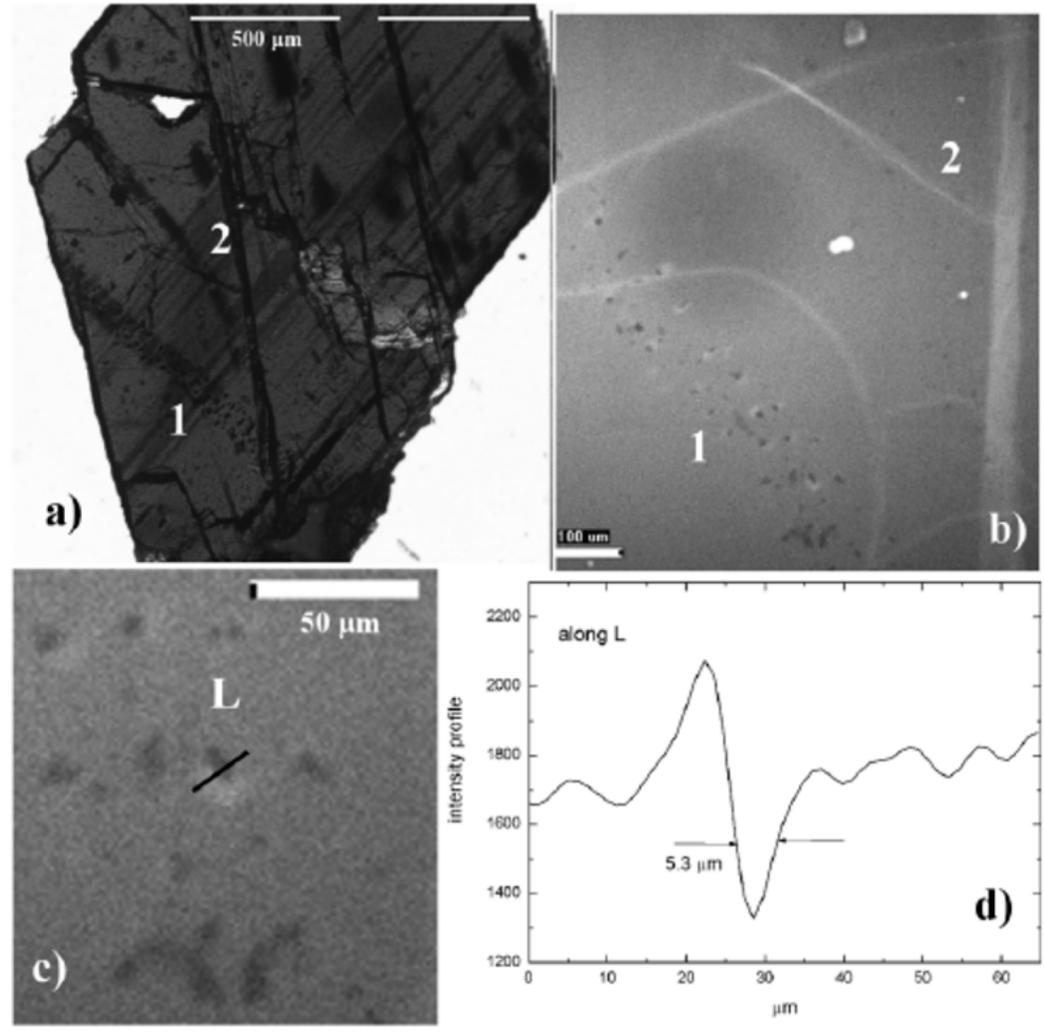
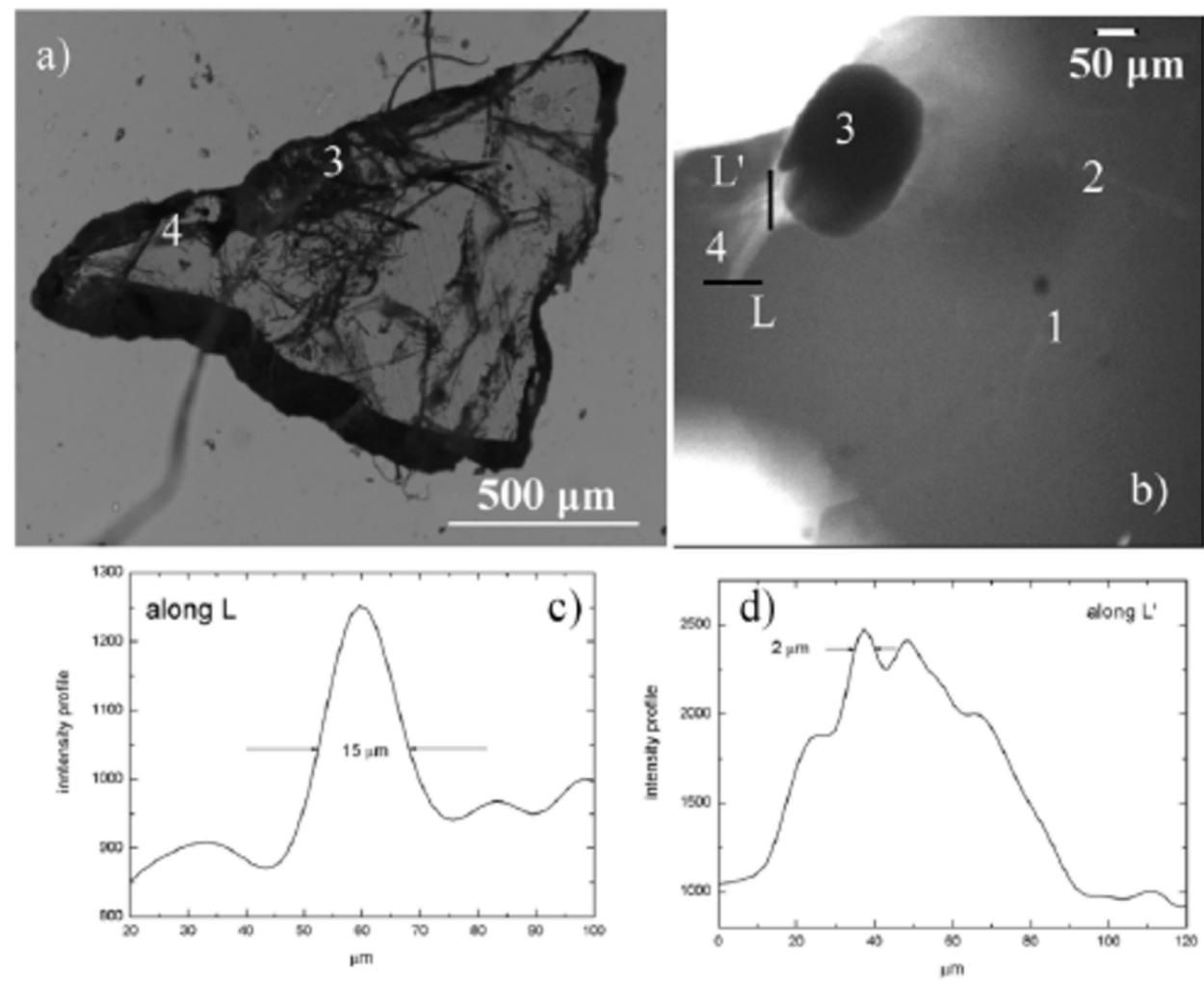


X-ray Facilities @ LNF

Geological samples

On Left: doubly-polished (010) section of cordierite

On Right: doubly-polished fragment of a magnesium-hastingsite amphibole

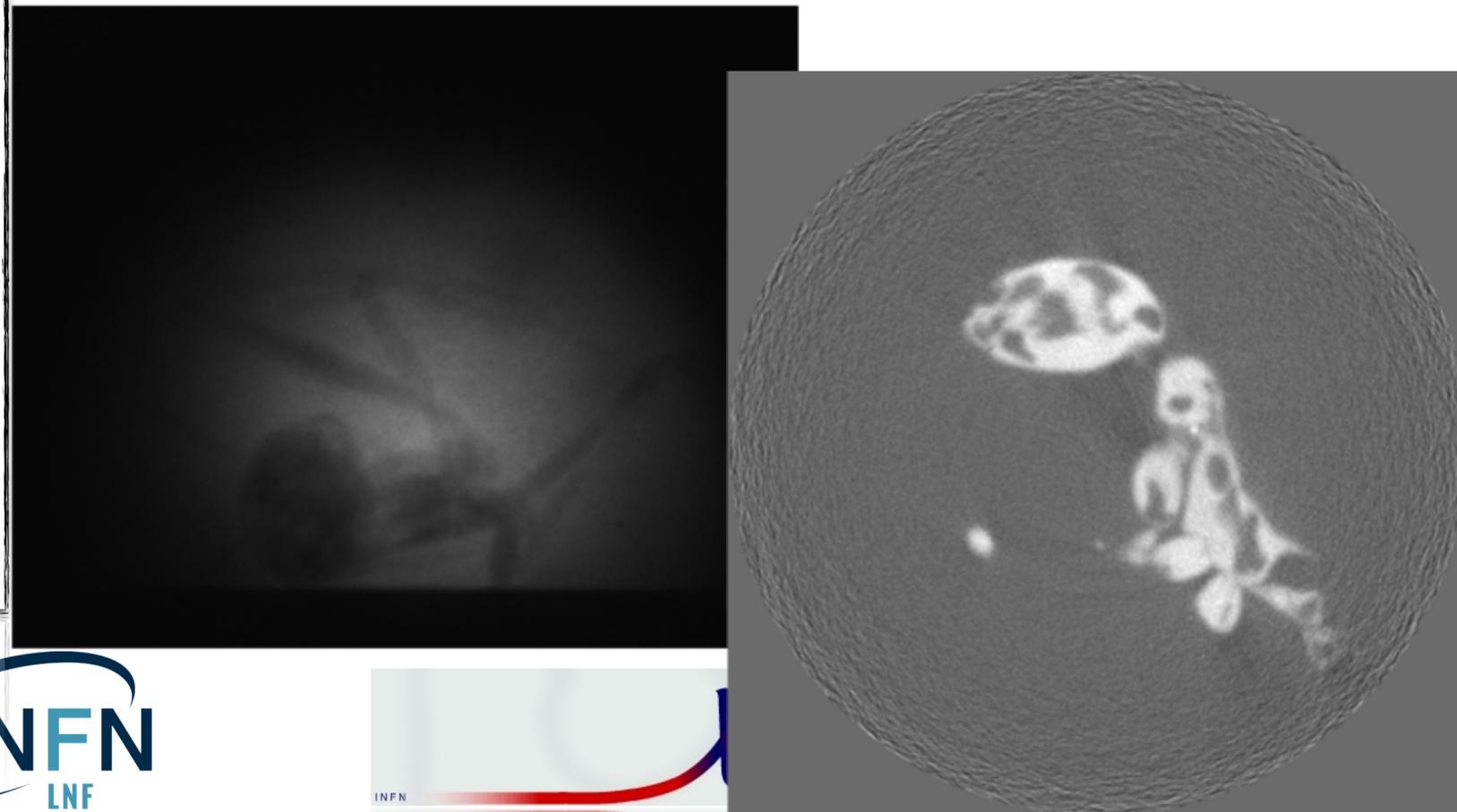


D. Hampai et al., EPL 96, 60010 (2011)

In collaborazione con ENEA - CR Frascati



- X-ray Tomography of an ant
- Polycapillary Semi-lens with 1.4 mrad res. div.
- Max Power Source 50W;
- Tension: 22 kV;
- Current: 800 μ A;
- Exp. Time: 250 ms;
- n° acq.: 720 frames for 360°
- "Octopus" (inCT) and "Amira" Softwares

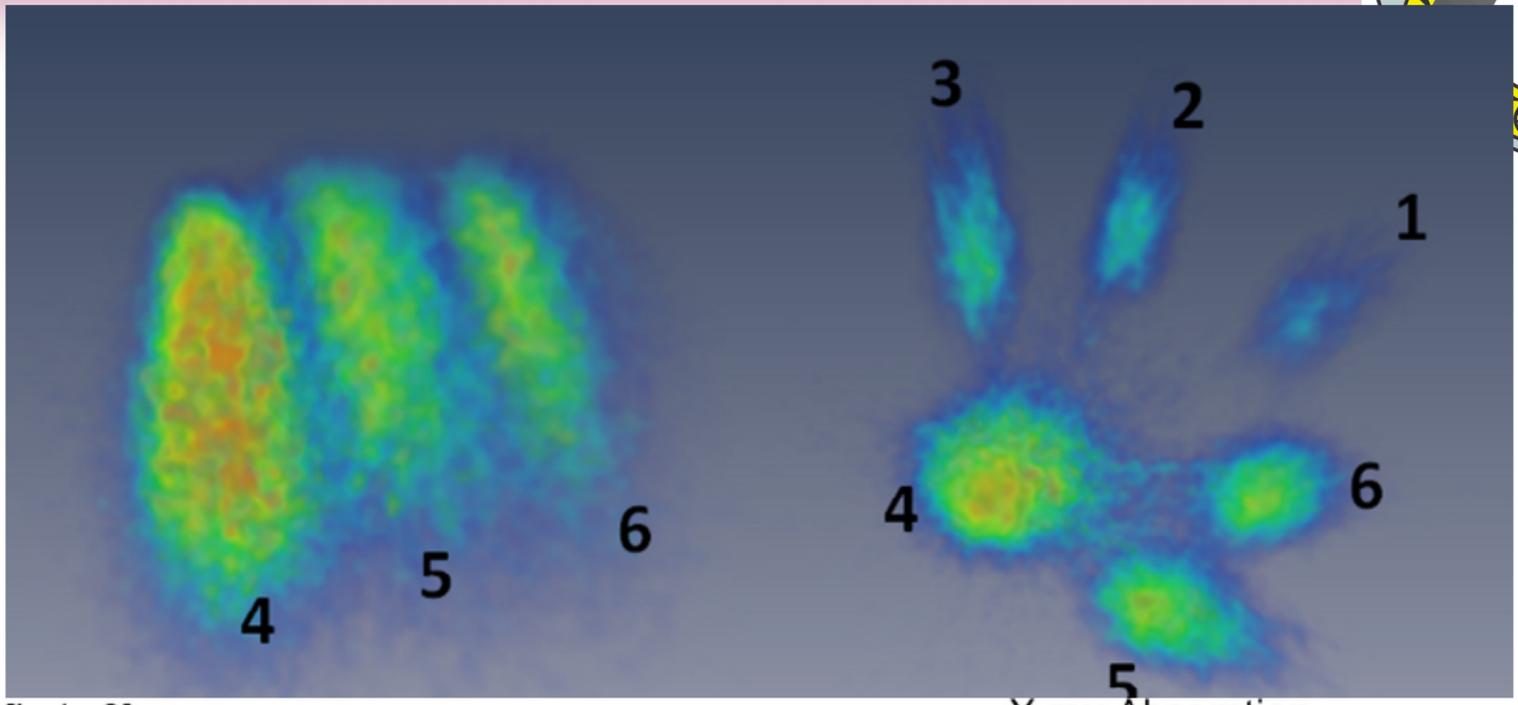
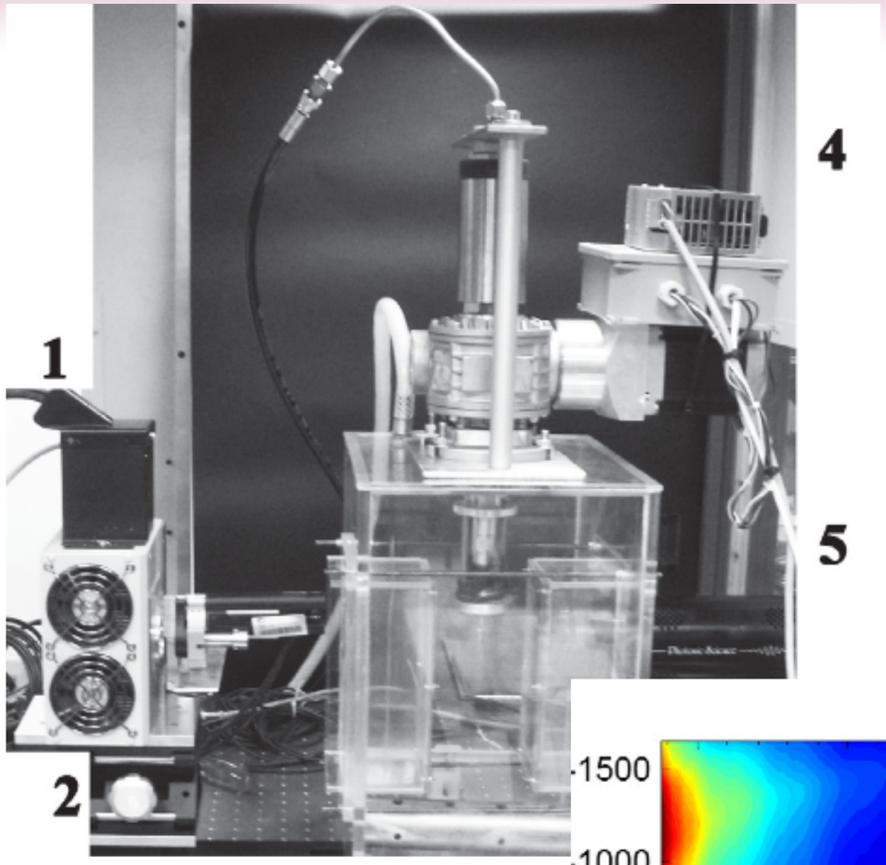


In collaborazione con IM - CNR

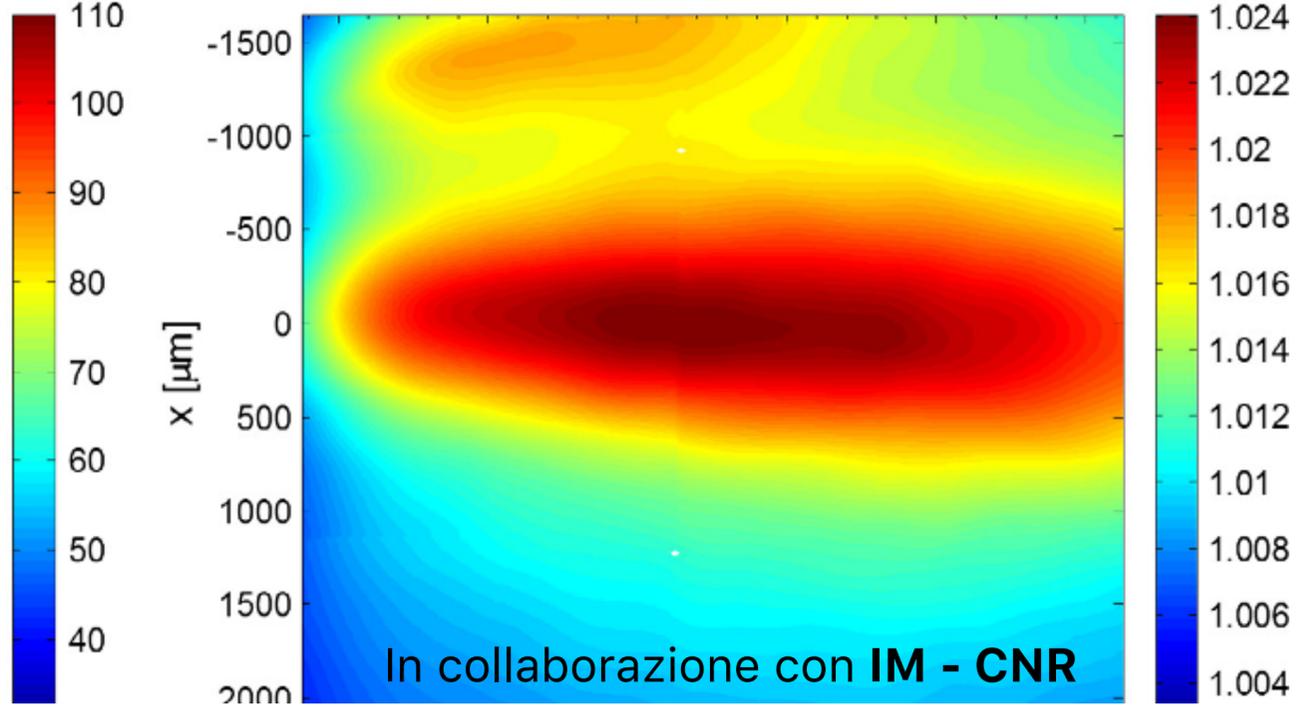
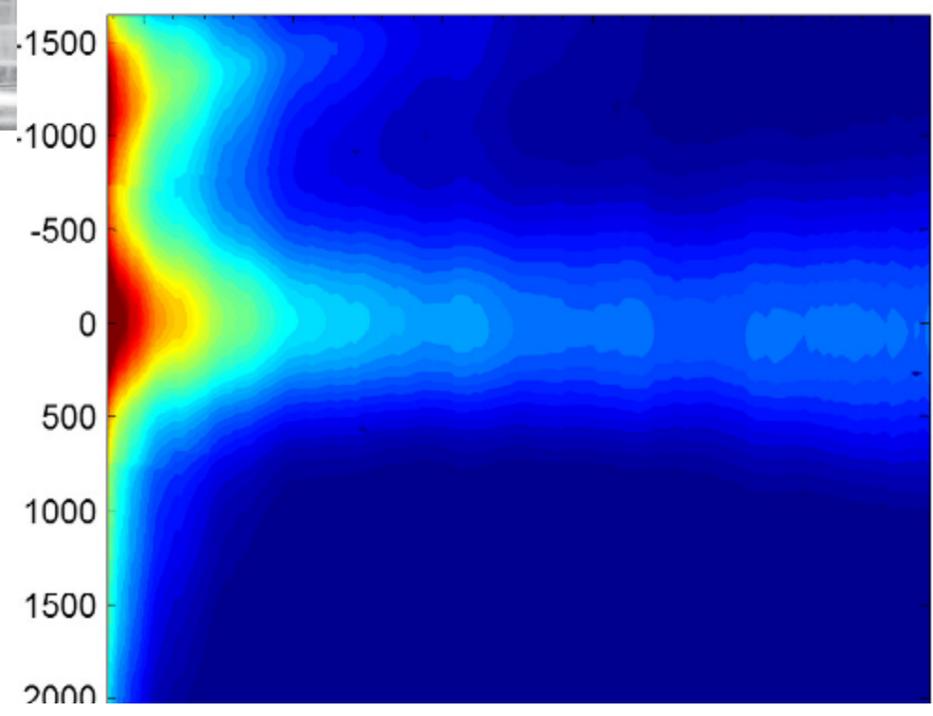




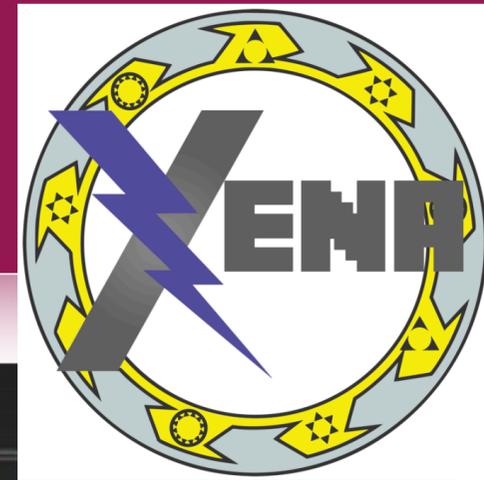
X-ray Facilities @ LNF



Questo strumento ha ricevuto un encomio come miglior strumento di analisi rilasciato da IM-CNR (2015)

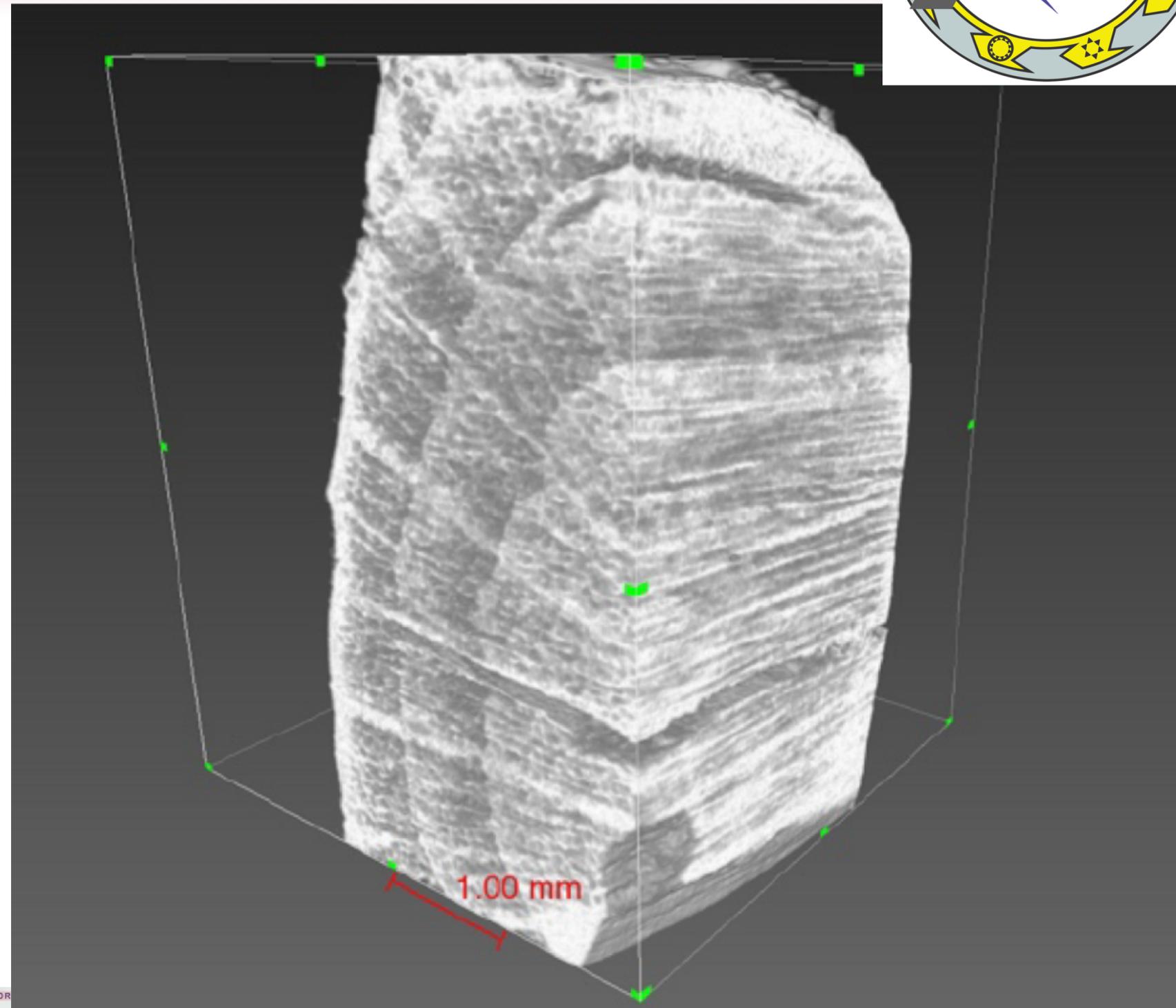


In collaborazione con IM - CNR



- Preliminary Results on a section of tree drilled sample
 - Rotation: 180°
 - Step: 0.1°
 - Acq. time = 90 msec / step
 - 40 kV
 - 0.1 mA

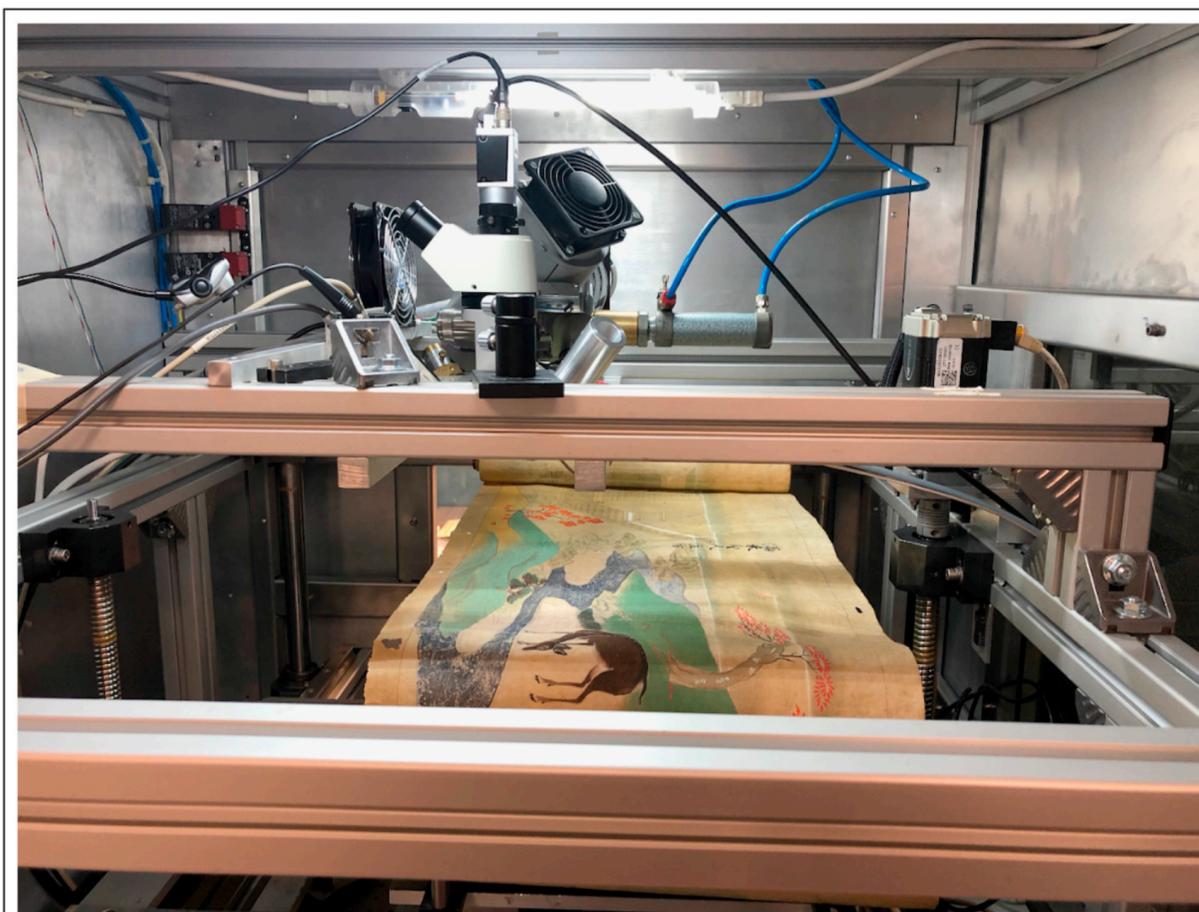
In collaborazione con **UniTuscia**





X-ray Facilities @ LNF

- Facility for (confocal) μ XRF Spectroscopy
- 2D-3D mapping
- Possibility to make Color Tomography
- Presented in 2014 @ EXRS

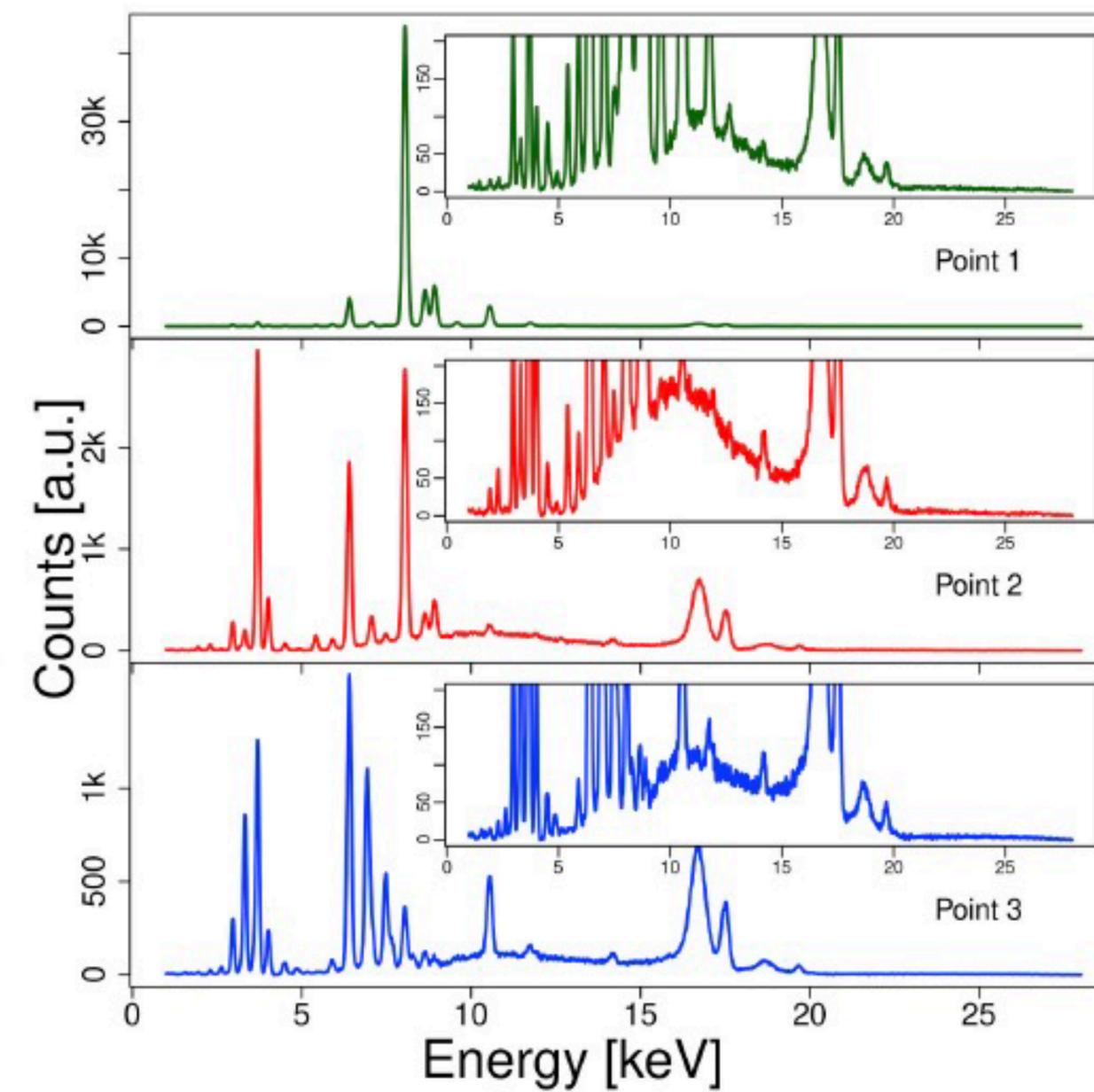
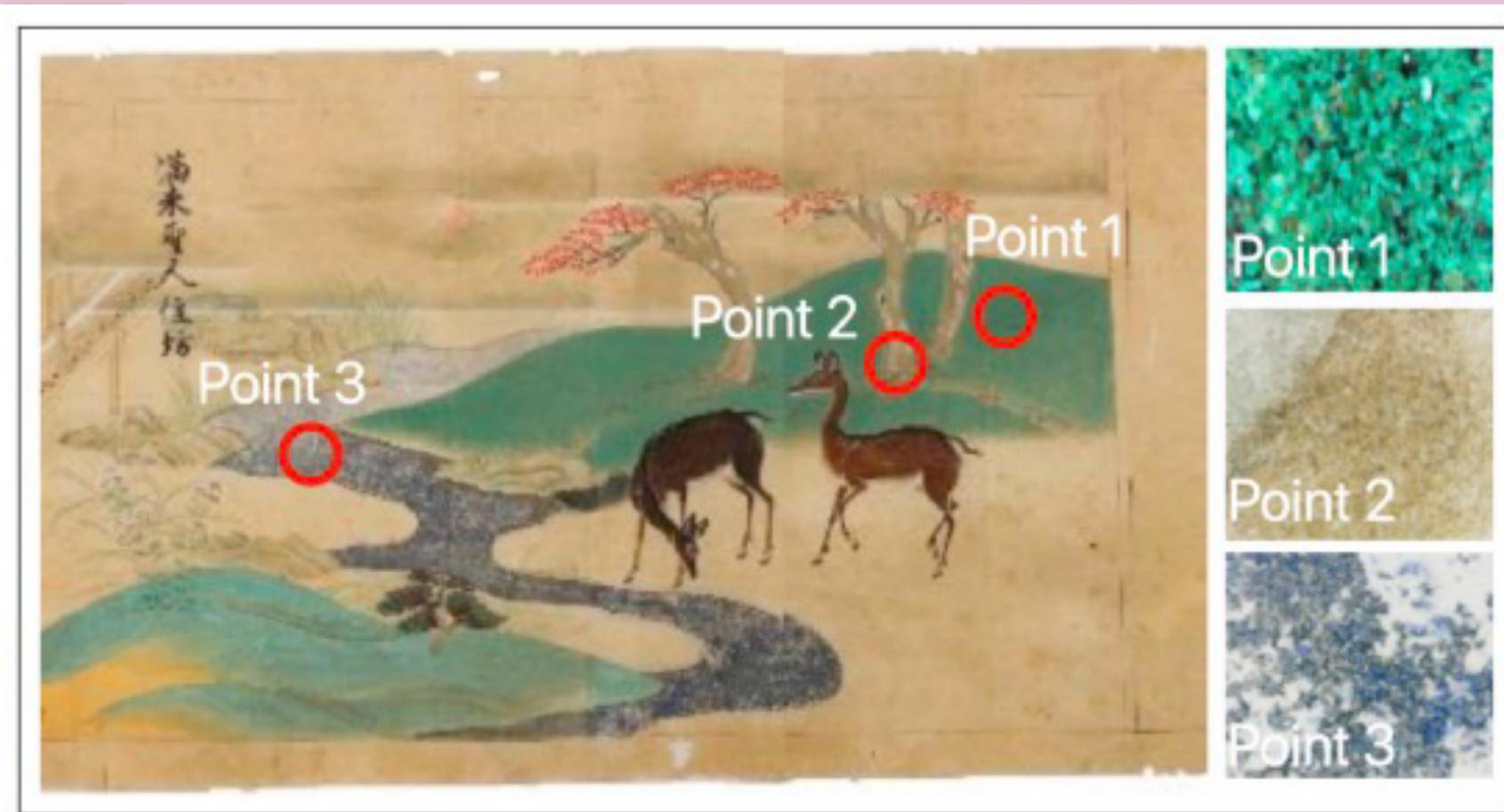


Analysis	μ XRF (2D & 3D mapping) TXRF
X-ray Source	Mo K α - 50 W source spot $\sim 50 \mu\text{m}$
primary optics	<u>polycapillary</u> optics 90 μm spot size <u>Transm.:</u> 22% @ Mo-K α
secondary optics @ high en.	<u>polycapillary</u> semi-lens div. res.: 2.2 <u>mrad</u> <u>Transm.:</u> 58 @ Cu-K α
secondary optics @ low en.	<u>polycapillary</u> semi-lens div. res.: ~ 5 <u>mrad</u> <u>Transm.:</u> ~ 30 @ Cu-K α
Detectors	SSD detectors active area: 25 mm ² En. res.: <135eV @ <u>Mn-Kα</u>
Probe size in the plane <u>xy</u> -axis (wire 40 μm)	$\leq 77 \mu\text{m}$
Probe size in the plane <u>xy</u> -axis (wire 40 μm)	$\leq 77 \mu\text{m}$
Probe size in z-axis (sheet 5 μm)	$\leq 98 \mu\text{m}$
Min. Detectable Concentration	$\sim 25 \pm 1.25 \mu\text{g/g}$

 @XLabF1



The Bhuddist Scrolls: study of emakimono pigments



Overall chemical elements found for the 3 points analysed:
Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr

S. Ceccarelli et al., Scires-IT, 12(2), 109-118 (2022).

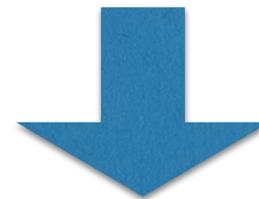
In collaborazione con Univ. Tor Vergata

Ferret-X

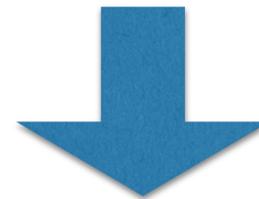


Quantitative analysis in μ -XRF: the FPM approach

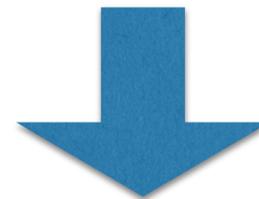
Key issue: how to carry out (a correct) quantitative analysis



Several software are now available for doing quantitative XRF analysis by conventional setup: PyMCA, AMPTEK, etc.



Few articles are reported in literature on quantitative XRF analysis with PolyCO and confocal layout but **no any software** is available for quantitative analysis with PolyCO/confocal layout



Fundamental Parameter Method (FPM)

There is a theoretical relation between the net-line intensities and the elemental concentrations:

$$I_{K,\alpha} = I_0 G w_i Q_{i,K\alpha} \rho T A_{corr} \quad \text{where} \quad Q_{i,K\alpha} = p_{i,K} f_{K,L_{2,3}} \omega_K$$

- the cross section related to the photo-ionization process, p_i , that is the probability that the electron is excited;
- the transition probability, f , related to the electrons moving from each atomic level above the vacant state;
- the probability of the radiative emission ω_K , that is the probability that the de-excitation transition determines the emission of a fluorescence photon (FY).
- weight fraction of element i , w_i
- geometry factor, G (*beam angles, distances, etc...*)
- density and thickness sample, T and ρ
- absorption correction term, representing the influence of the matrix effects, A_{corr}

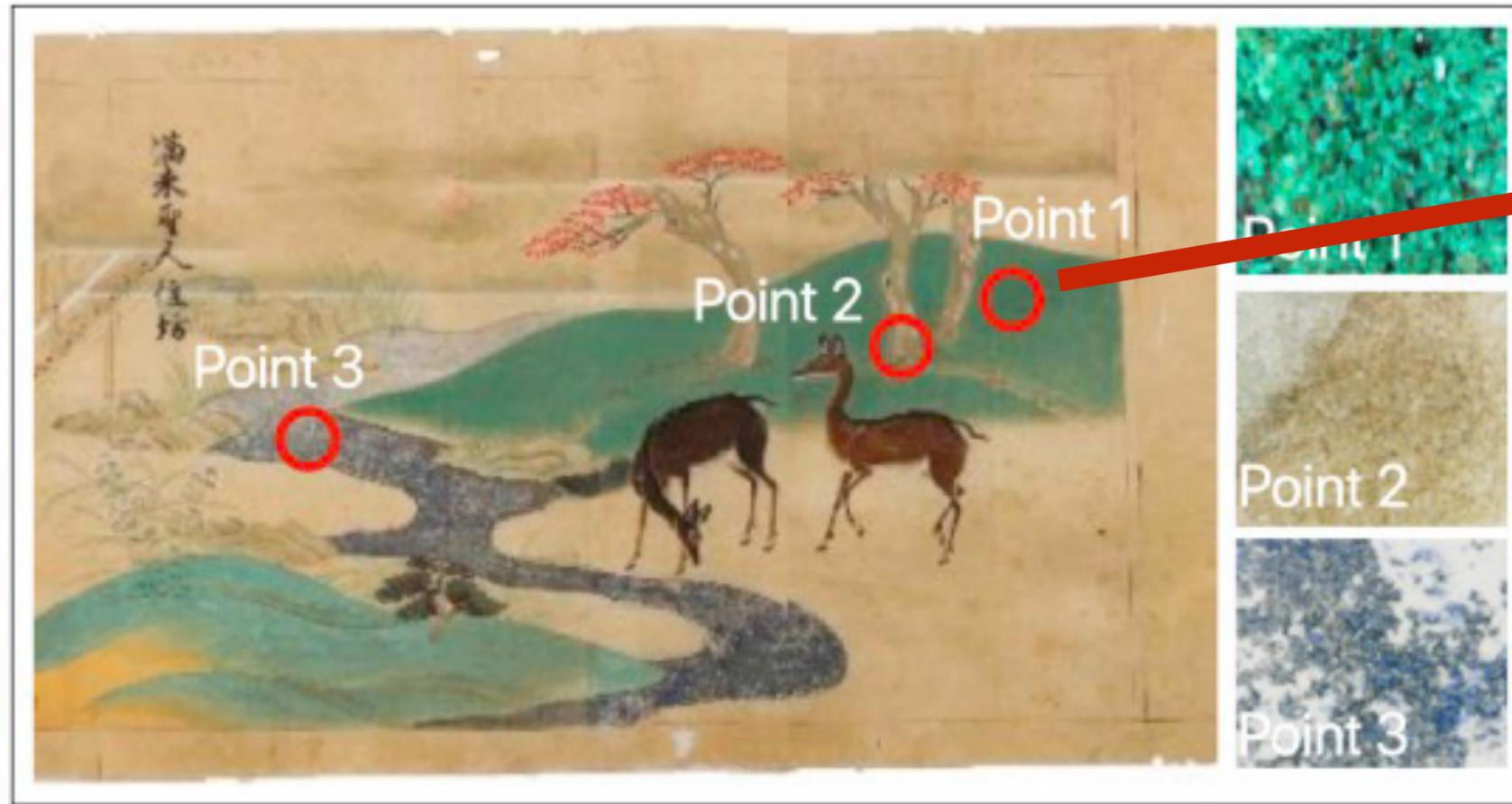


X-ray Facilities @ LNf

FPM Methods

$$I_{K,\alpha} = I_0 G w_i Q_{i,K\alpha} \rho T A_{corr}$$

$$Q_{i,K\alpha} = P_{i,K} f_{K,L_{2,3}} \omega_K$$



Element	Concentration [%]	ΔConcentration [%]
Al	4,93	0.31
S	1,62	0.18
K	17,79	0.46
Ca	26,91	0.61
Ti	0,61	0.10
Cr	0,45	0.08
Mn	0.67	0.09
Fe	6.16	0.30
Ni	0.41	0.07
Cu	38.05	0.68
Zn	2.41	0.18

**Malachite [Cu₂CO₃(OH)₂]
known also as "rokusho ink"**

@XLabF1



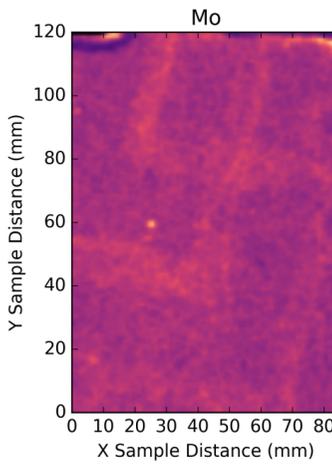
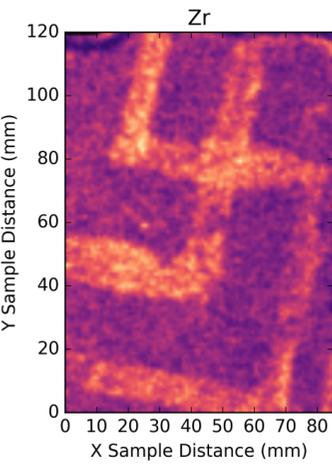
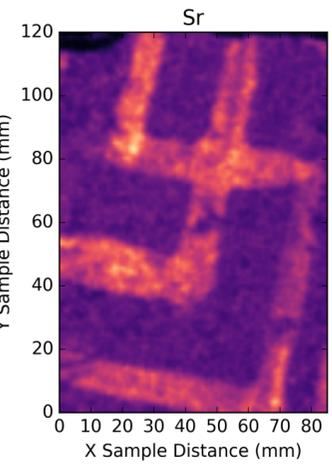
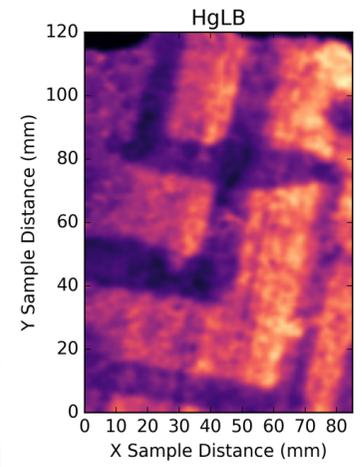
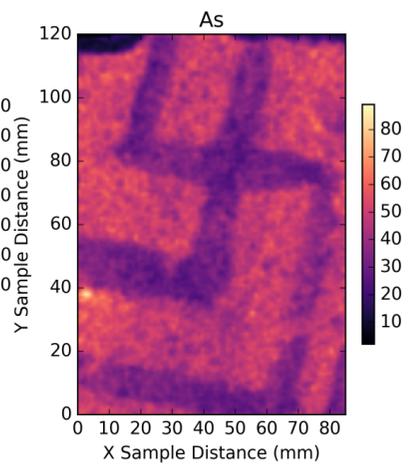
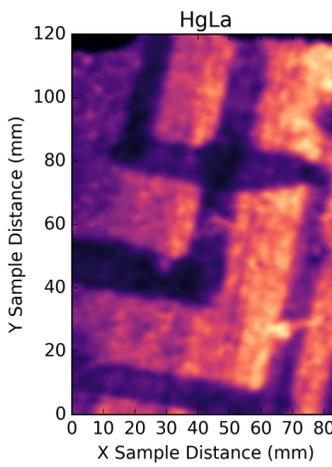
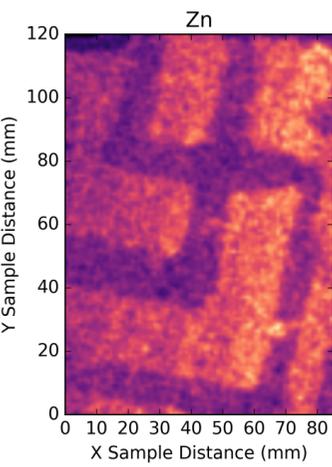
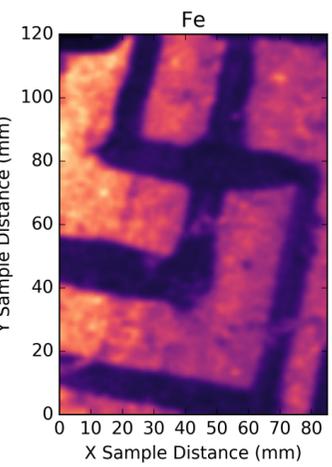
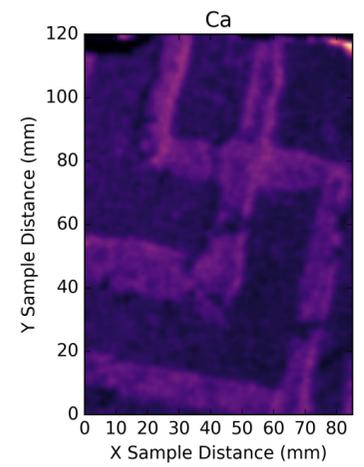
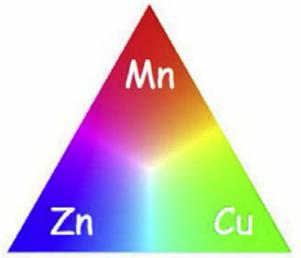
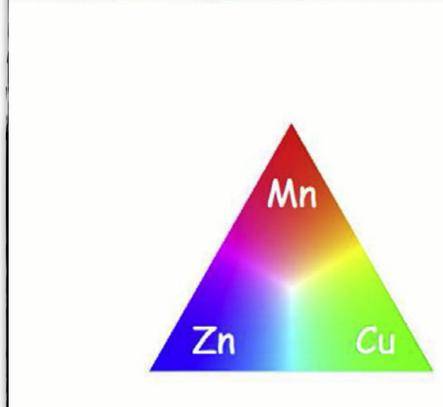
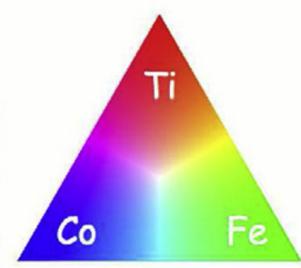
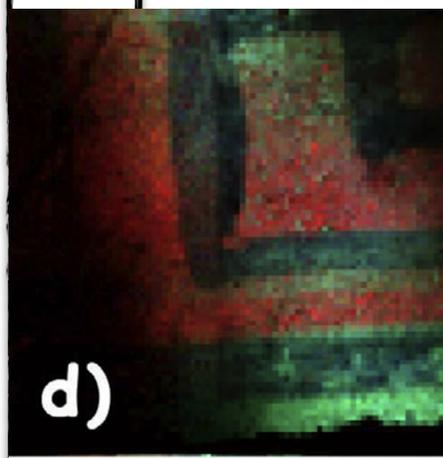
Altri Risultati



LNF



PN Detector

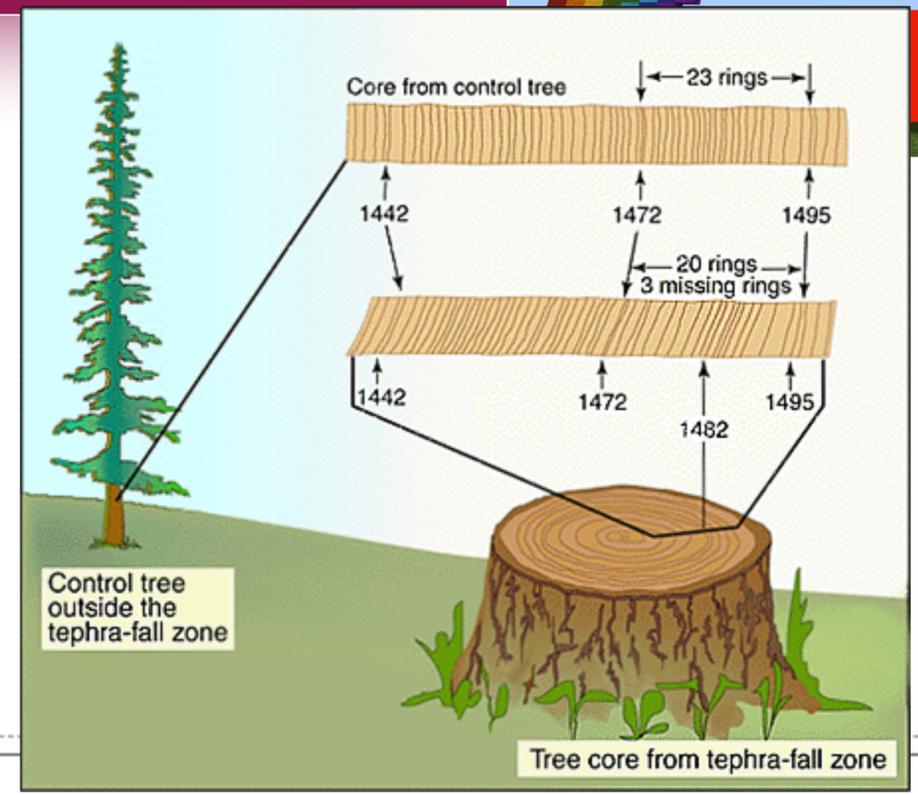




X-ray Facilities @ INFN

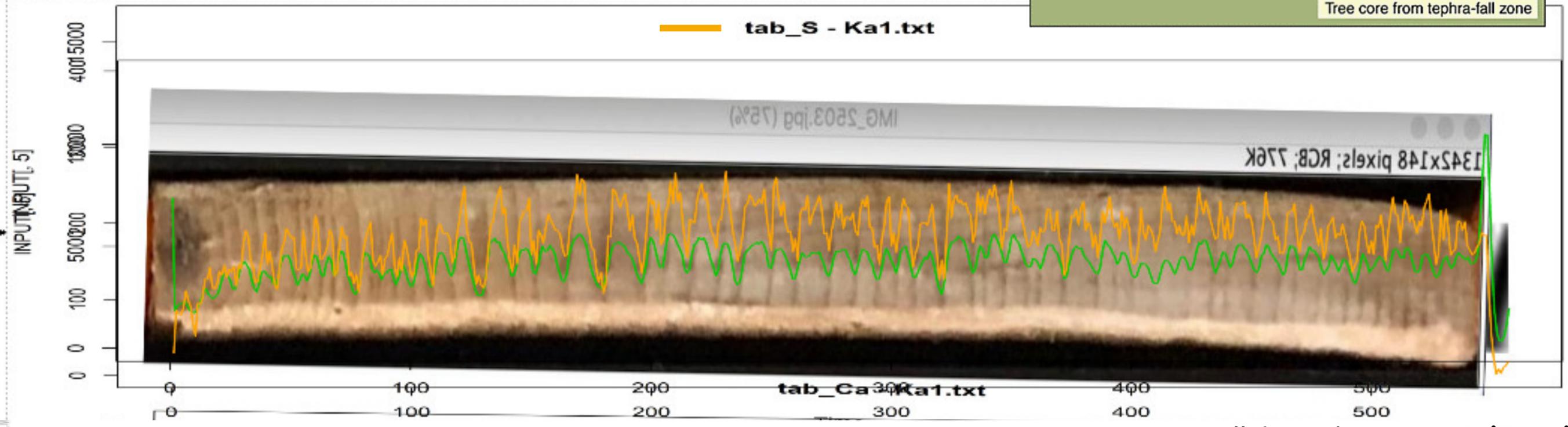
Studio degli Inquinanti nei carotaggi lignei in collaborazione e in supporto all'Università di Viterbo UniTuscia, gruppo Dafne.

Possibile, nel prossimo futuro, entrare nella collaborazione UniTuscia-National Geographic



Carotaggio di Un Faggio presso il Gargano

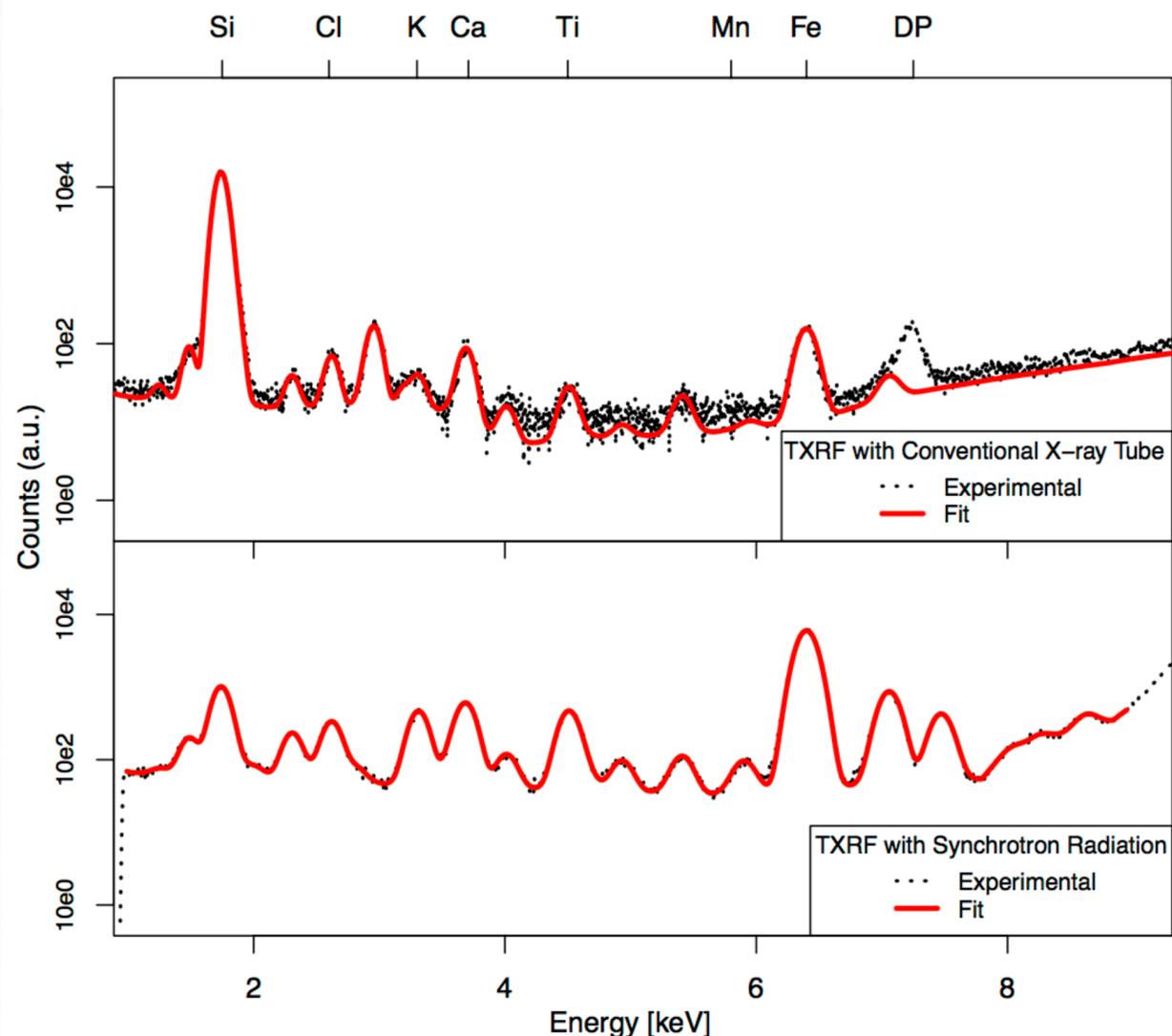
— tab_Ca - Ka1.txt
— tab_S - Ka1.txt



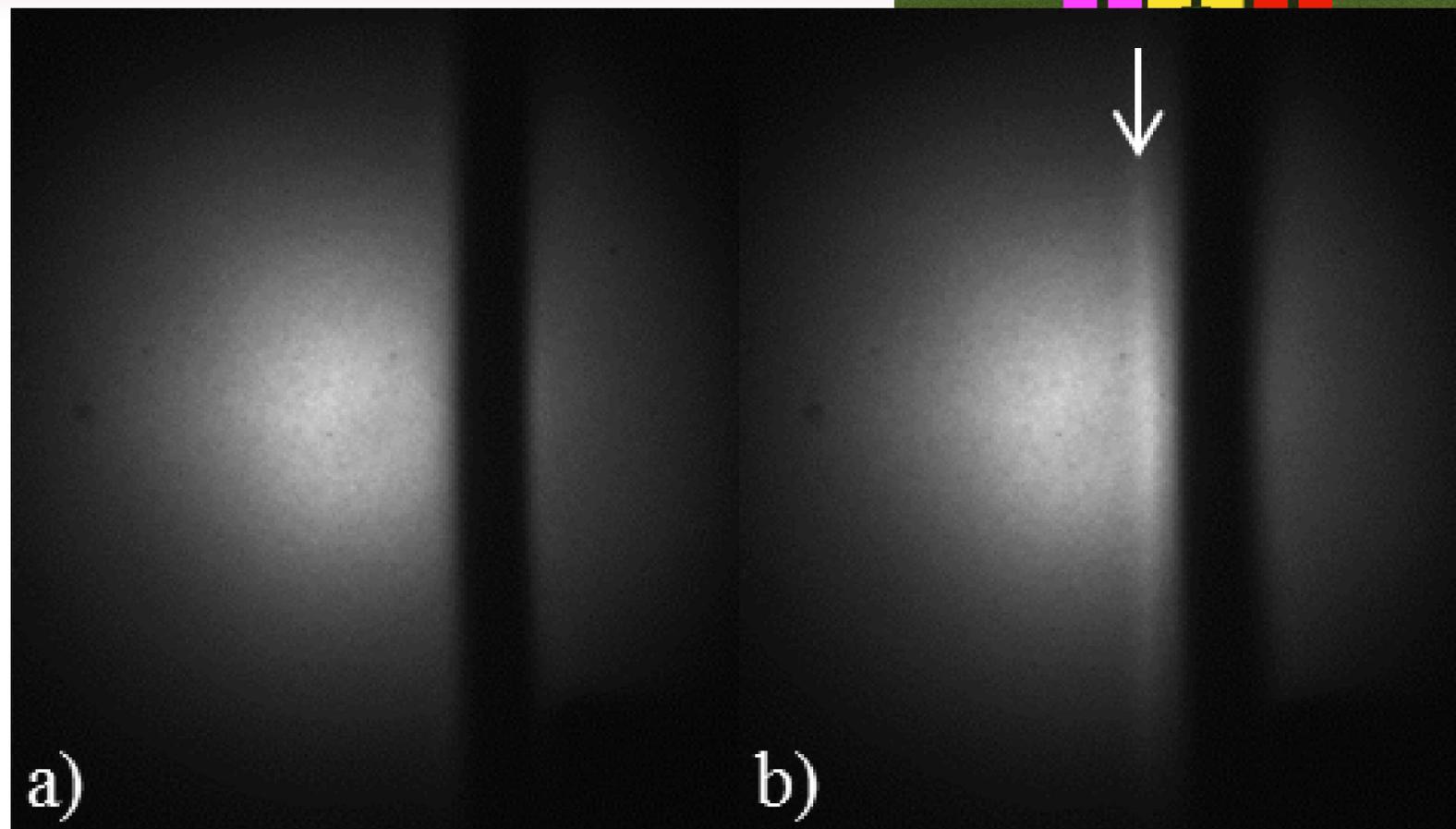
In collaborazione con UniTuscia



X-ray Facilities @ LNF



In collaborazione con
Univ. Bicocca e Diamond LightSources

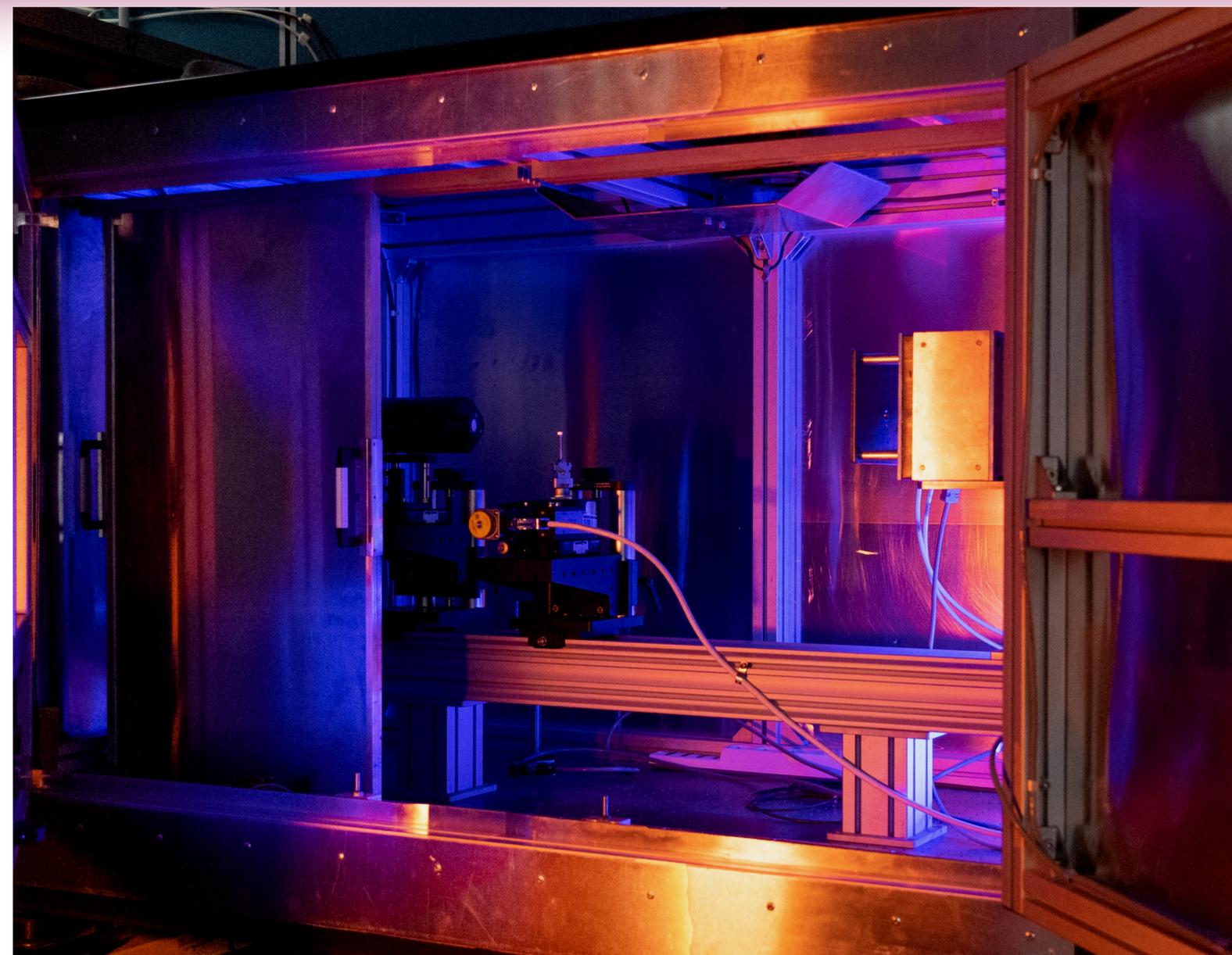


Studio del Particolato Insolubile nei Ghiacci come Archivio Naturale
Lavoro sui Ghiacci che ha portato una serie di articoli, l'ultimo su **Nature**

G. Baccolo et al., Nature Communications 12, 436 (2021).

CTS

- Facility for μ CT
- μ X-ray Source (5 μ m anode size - W- K_{α} 90kV - 200 μ A)
- Commissioning of the Control System Soft.
- Presented in 2021 @ SPIE



Durante la Pandemia
Abbiamo avuto il tempo di
realizzare **CTS**



@XLabF1

Phase Shift Propagation

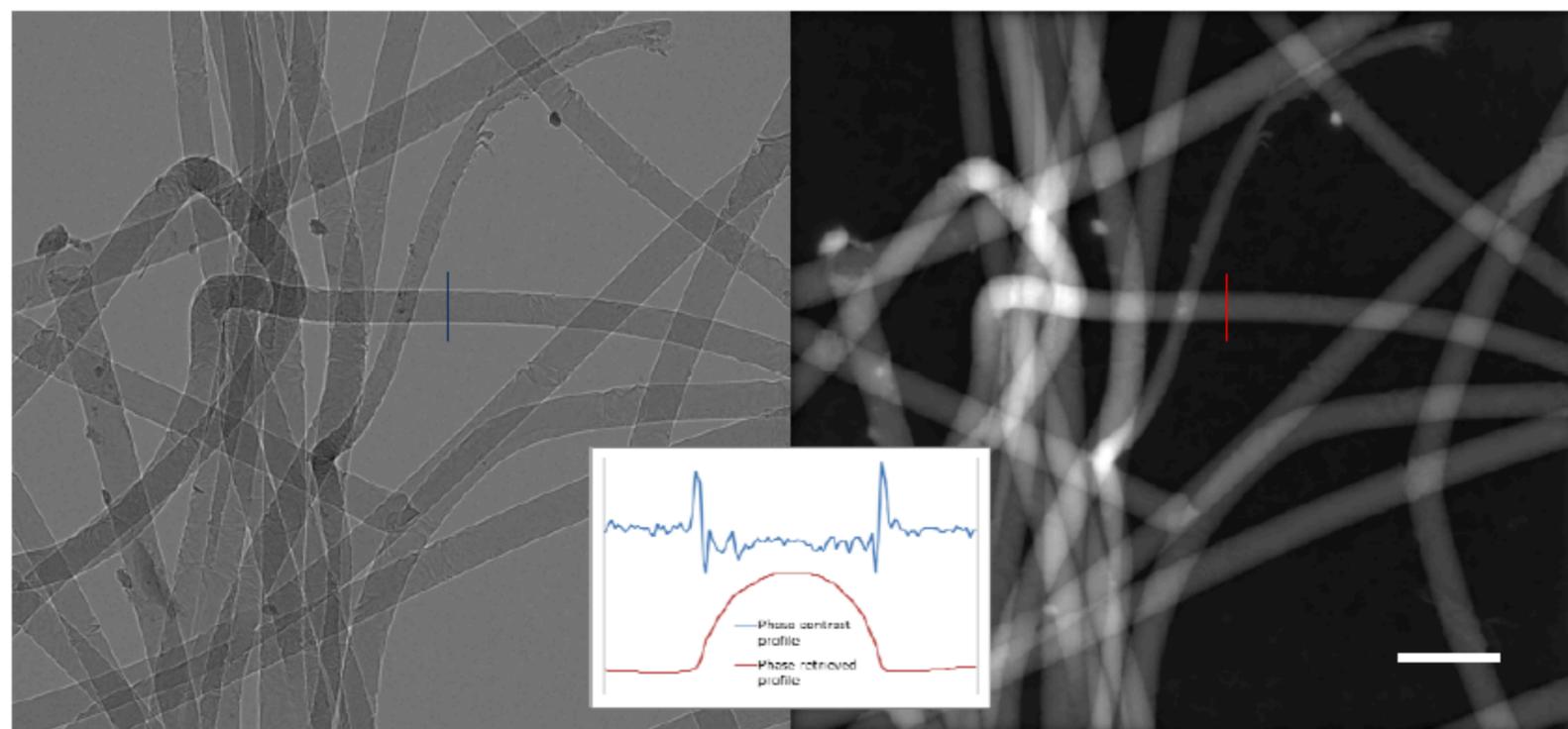
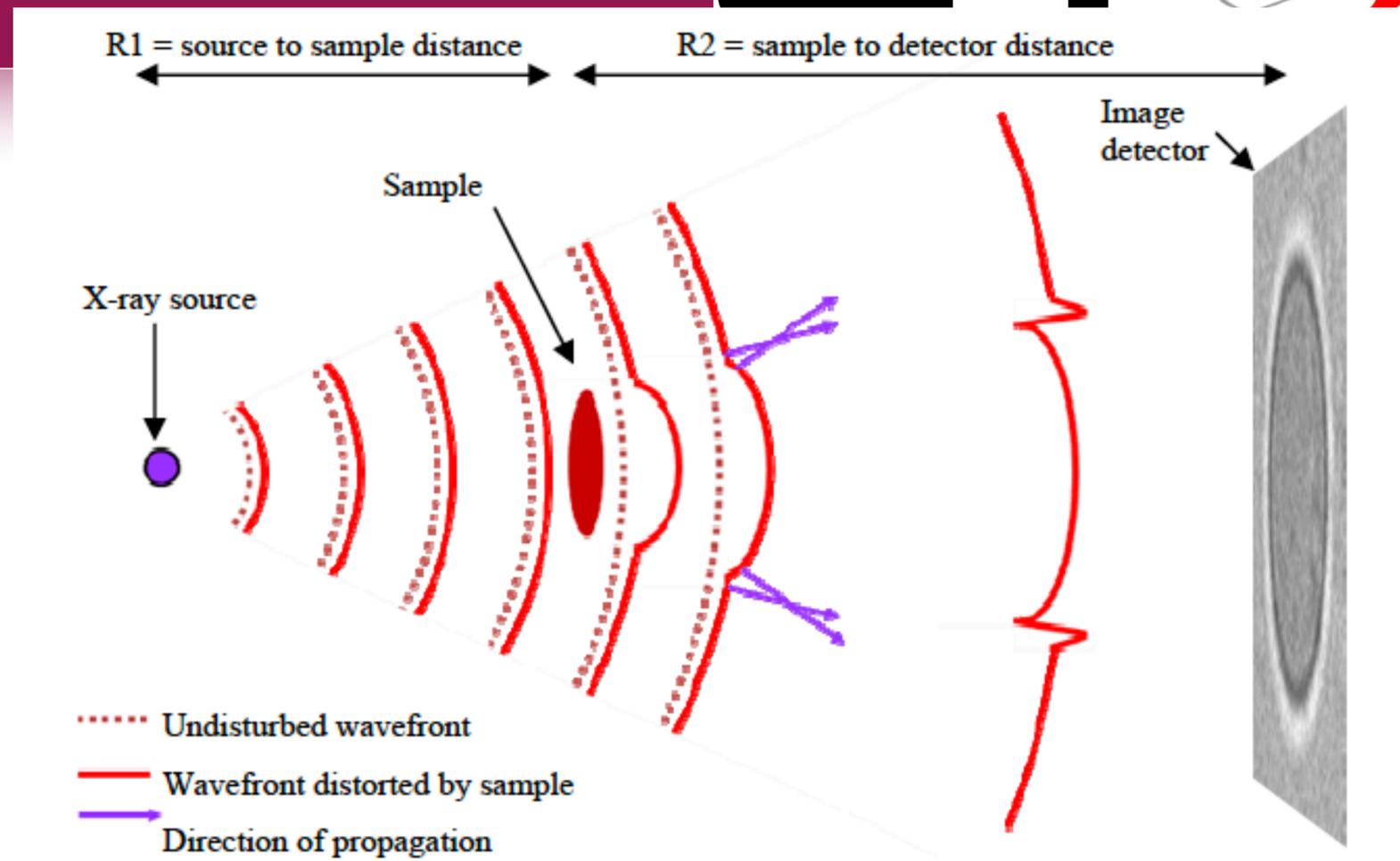
$$M = \frac{R_1 + R_2}{R_1}$$

Spacing of the phase-contrast fringes

$$S_F = \sqrt{R'\lambda} \rightarrow M\sqrt{R'\lambda} \begin{cases} \geq \frac{\text{source} \cdot R_2}{R_1} \\ \geq R_{det} \end{cases}$$

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2}$$

S. Mayo et al., Materials 5, 937-965 (2012)



Phase propagation

Phase Retrieval

R'=11

Campione Organico in Ambra

40 kV - 50 μ A

R₁ = 30 mm

R₂ = 750 mm

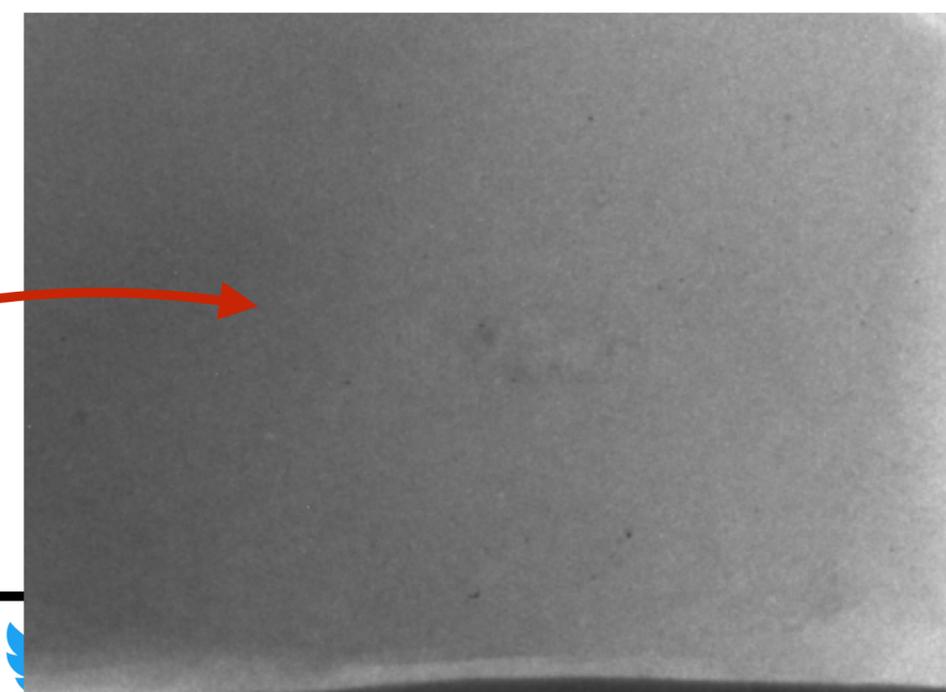
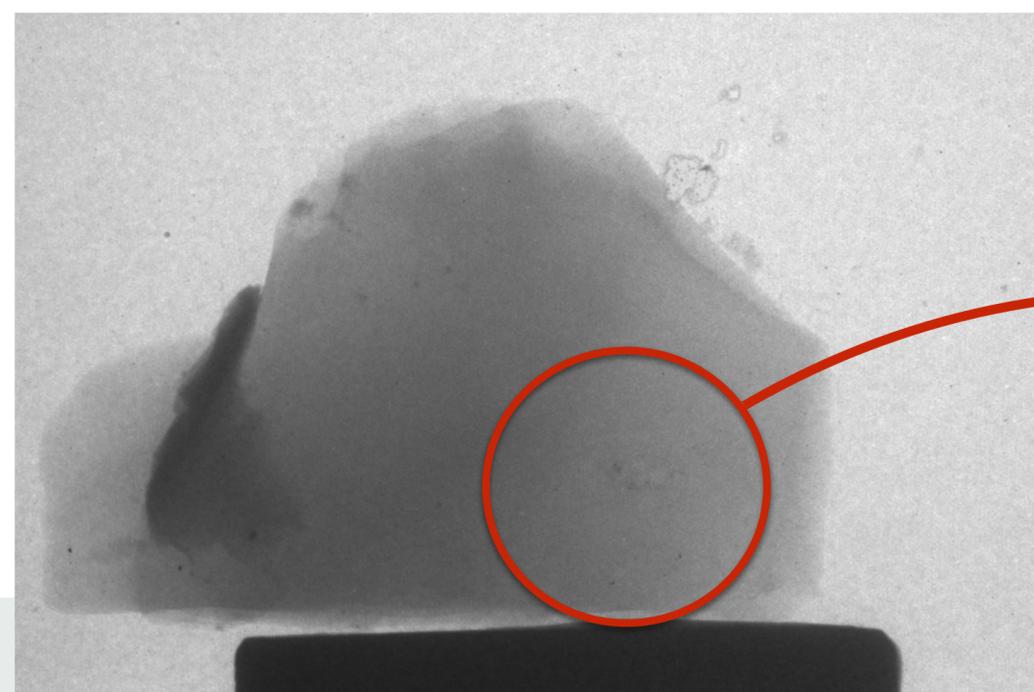
T_{acq} = 1min 30 sec

Det. size = 14x10 mm²

Pixel Size = 10.4 μ m



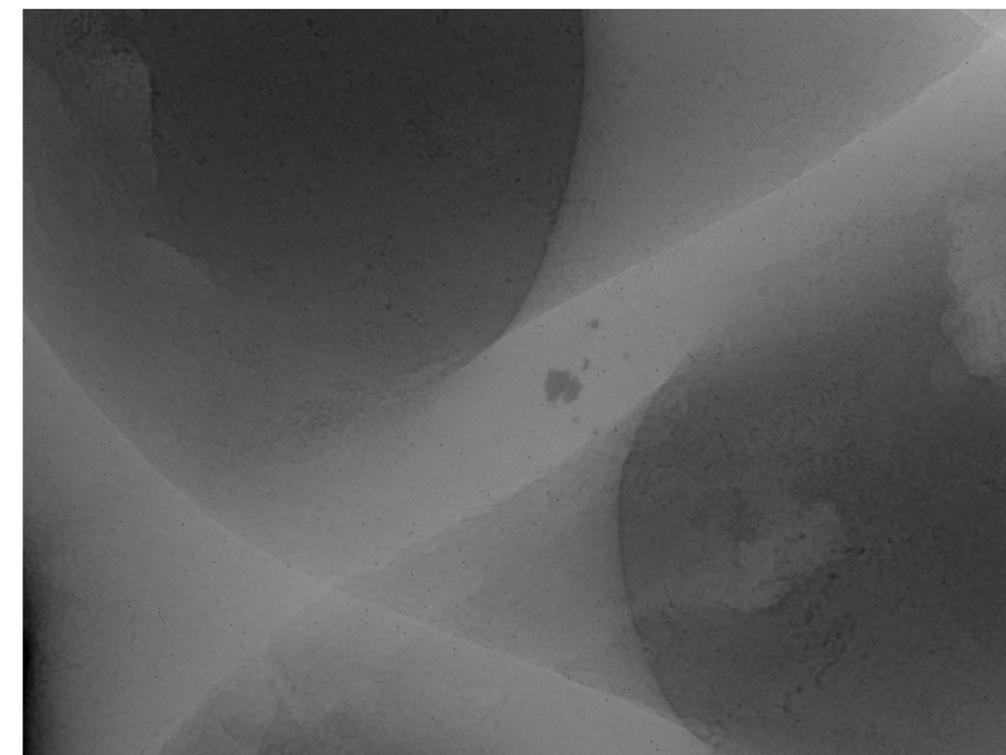
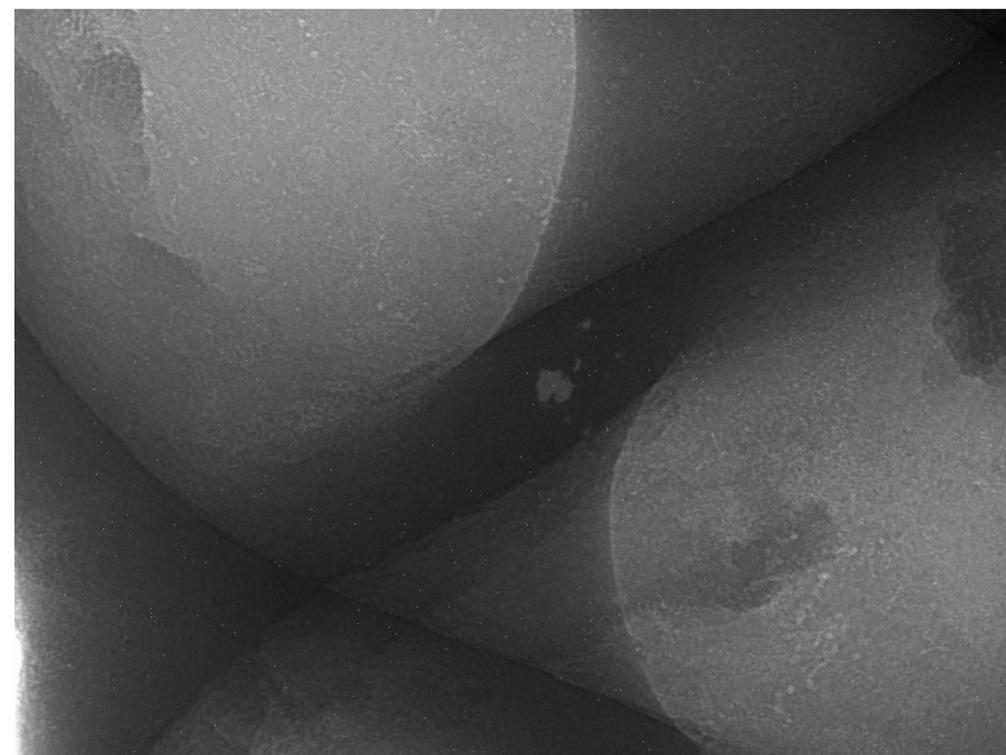
R'=2



Phase propagation

Phase Retrieval

$R'=11$



Conchiglia

40 kV - 50 μ A

$R_1 = 30$ mm

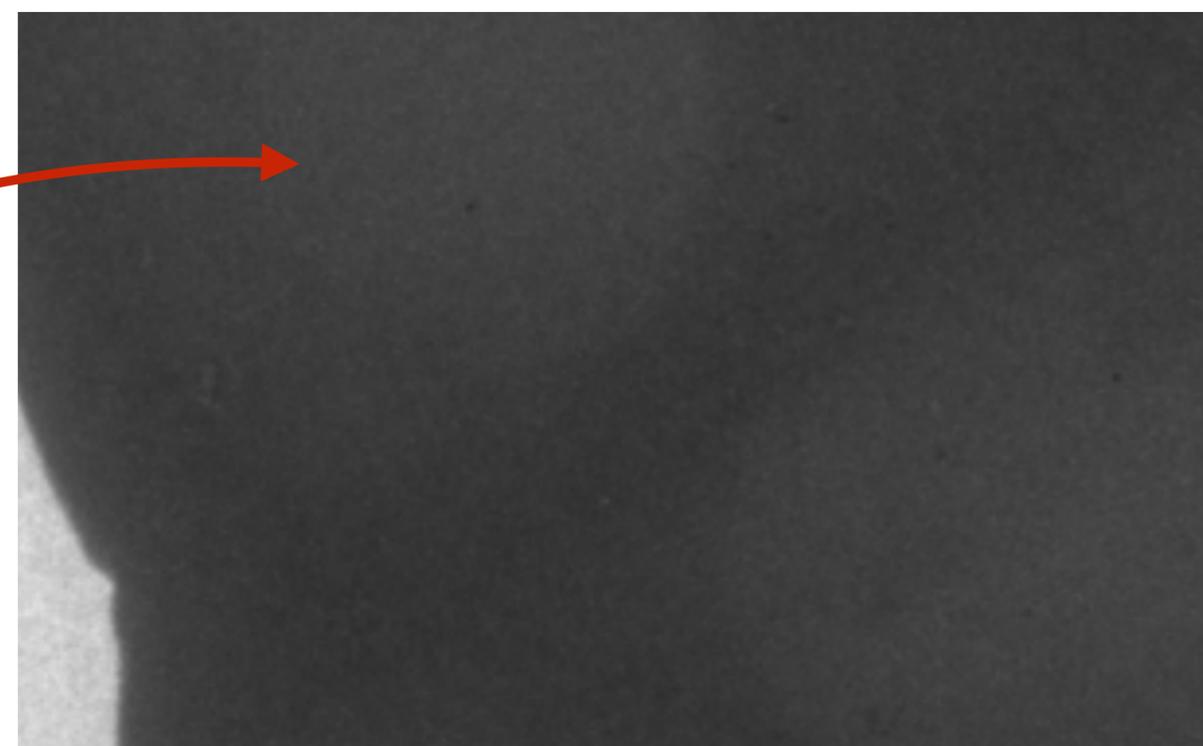
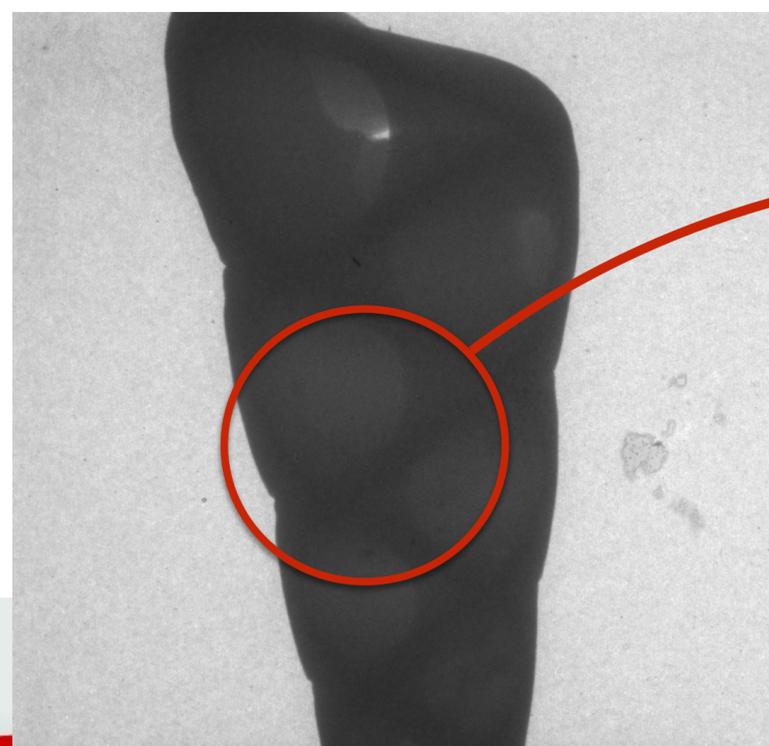
$R_2 = 750$ mm

$T_{acq} = 1$ min 30 sec

Det. size = 14x10 mm²

Pixel Size = 10.4 μ m

$R'=2$



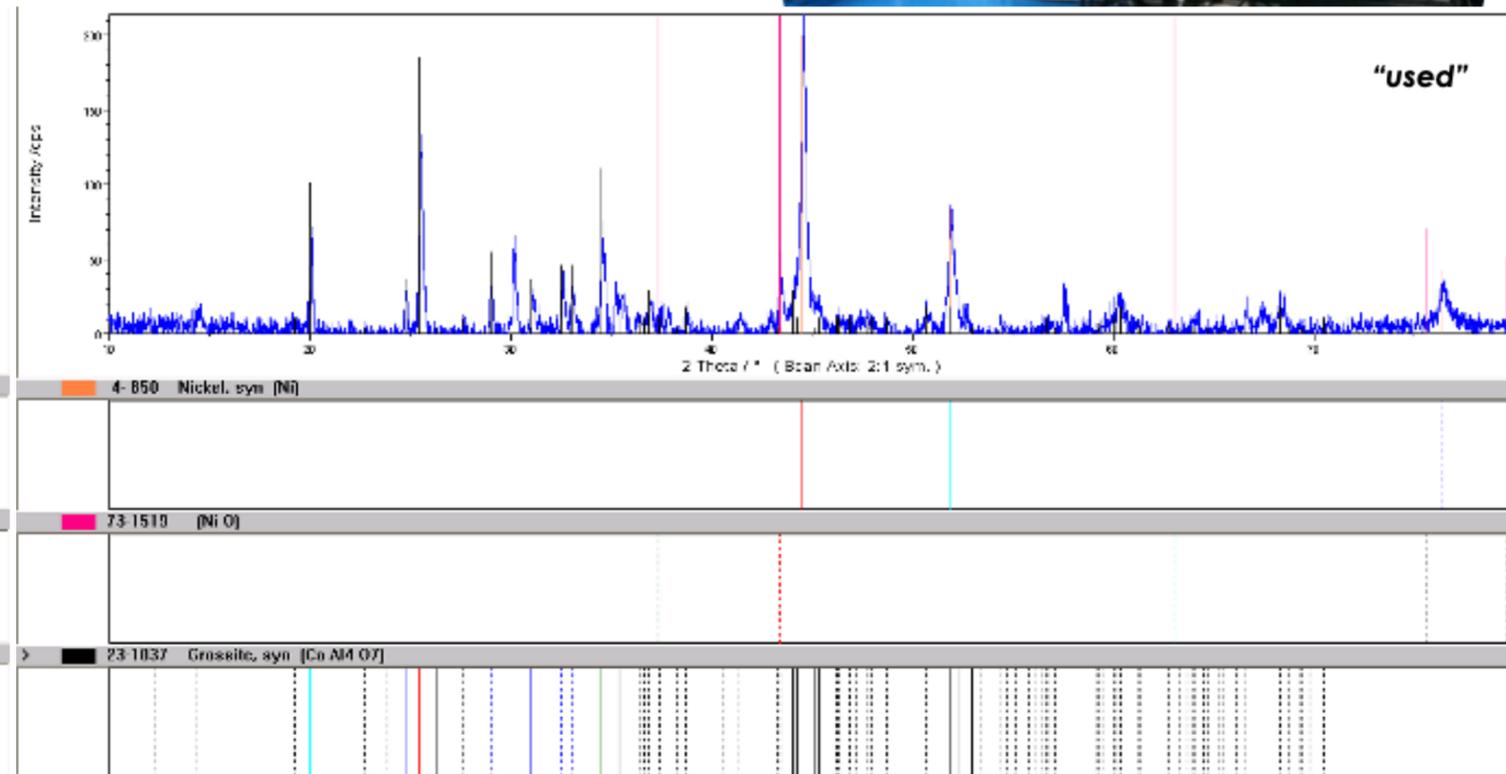
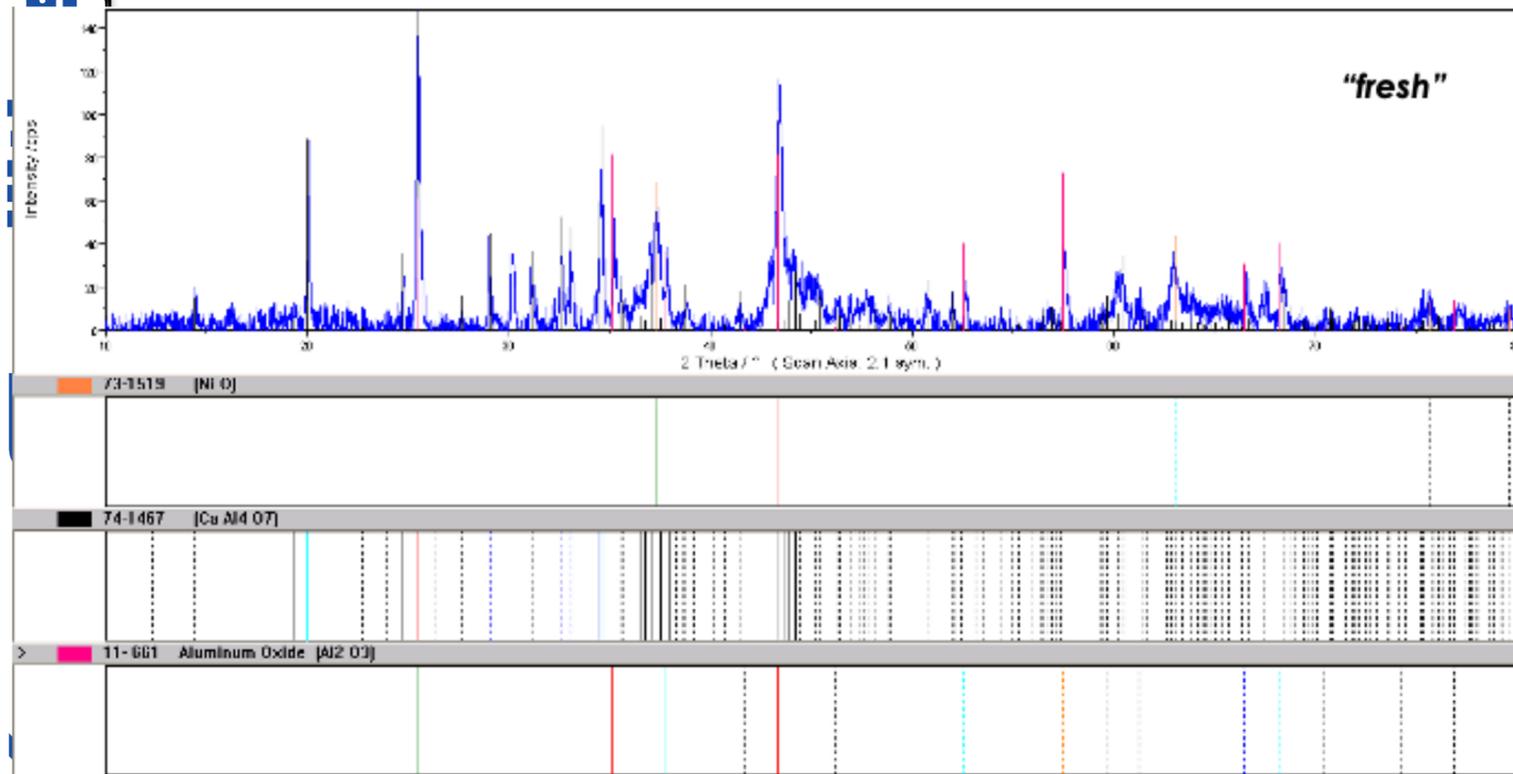
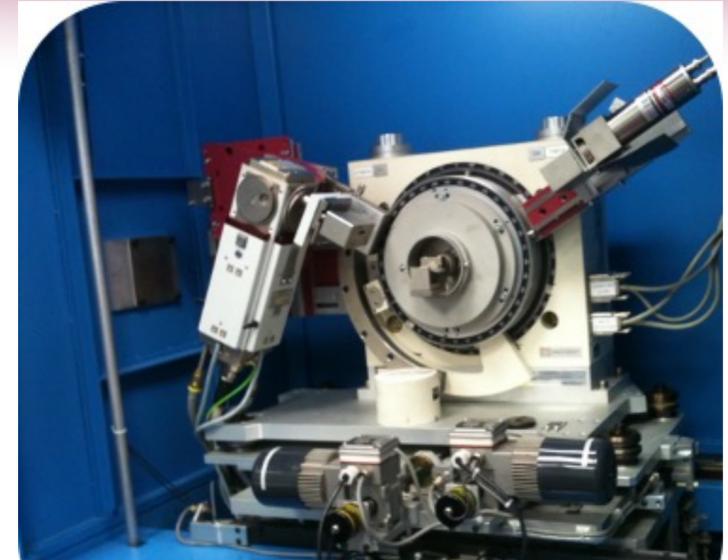
INFN

PXRD

- Diffrattometro raggi X Seifert 3003
- Target Cu - 2000 W (max) - 1200 W (normal)

Progetto Zephyrus - Lazio Innova
In collaborazione con **Univ. Marconi**

Analisi XRD: catalizzatore C1

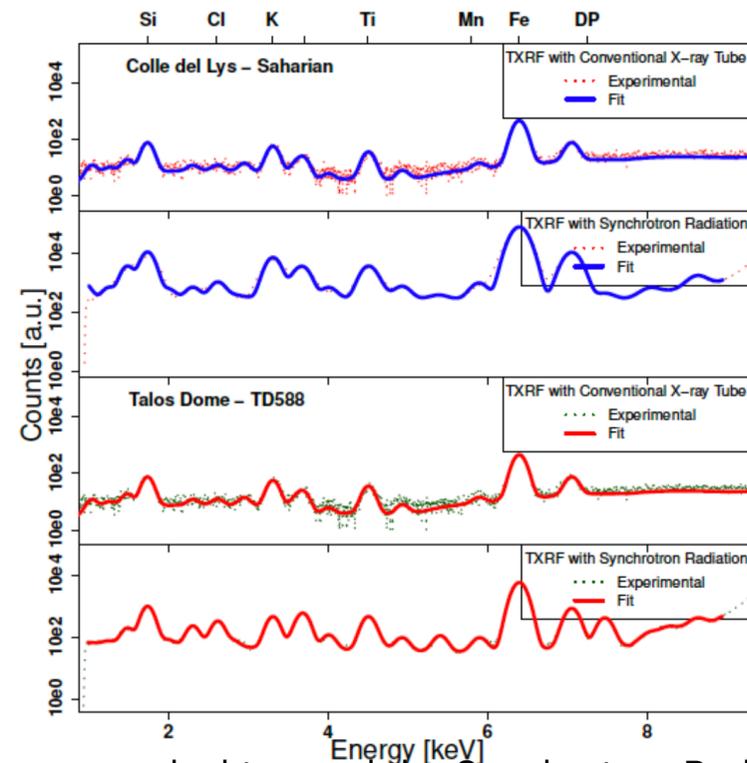


Segnali principali di: NiO, Al₂O₃, CaAl₄O₇ (come da datasheet)

Segnali principali di: NiO, Ni, CaAl₄O₇ -> possibile riduzione del NiO a Ni metallico per effetto di H₂S (riducente)

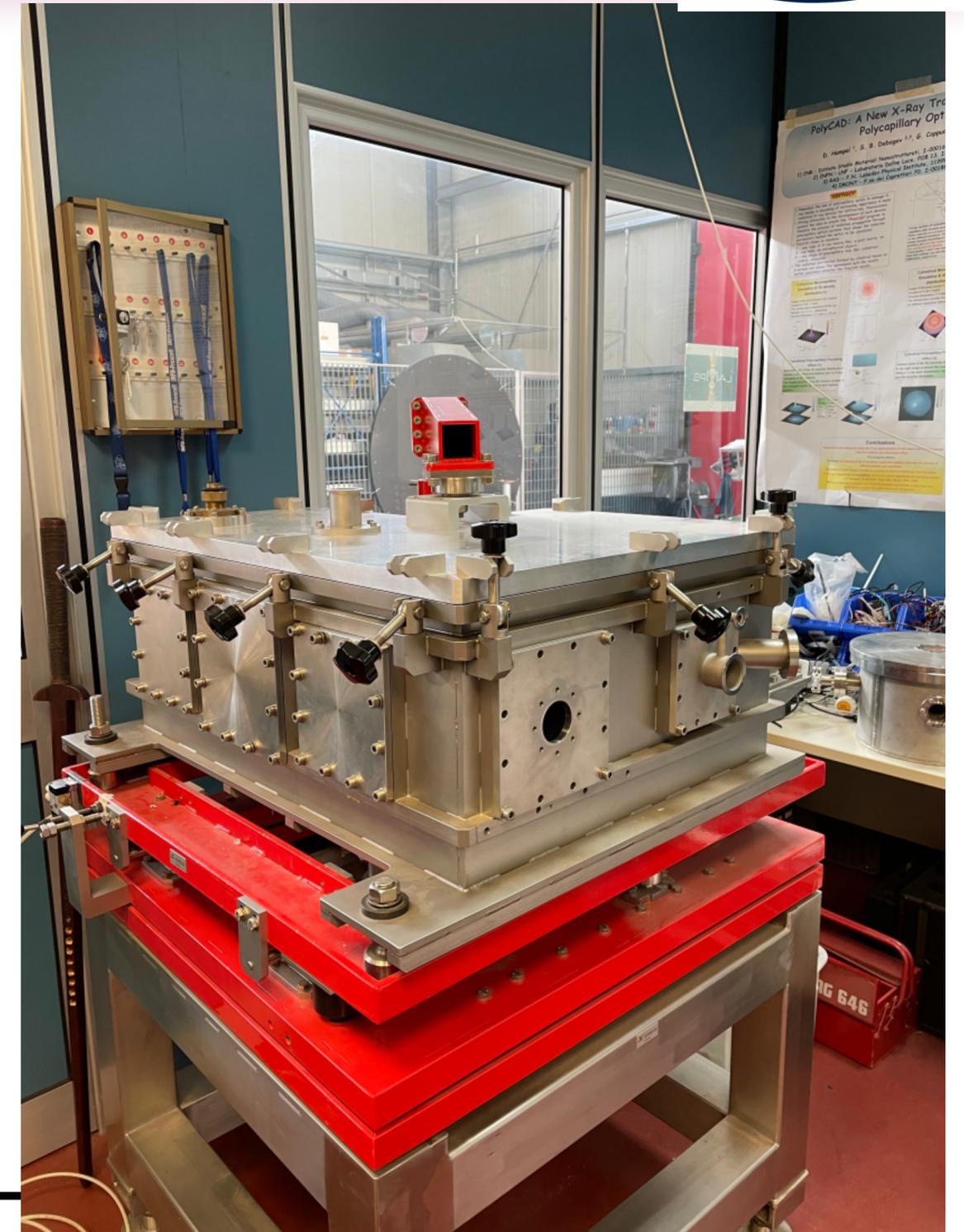
SoX

- Facility for Soft X-ray fluorescence
- High vacuum chamber for atomic numbers elements
- under development



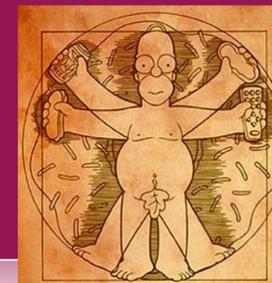
TXRF comparison between our desktop and the Synchrotron Radiation (SR) setup for XRF (first set—Alps sample) and for TXRF (second set—Antarctica sample) measurements.

G. Cappuccio et al., *Condens. Matter* 3, 33 (2018)



@XLabF1

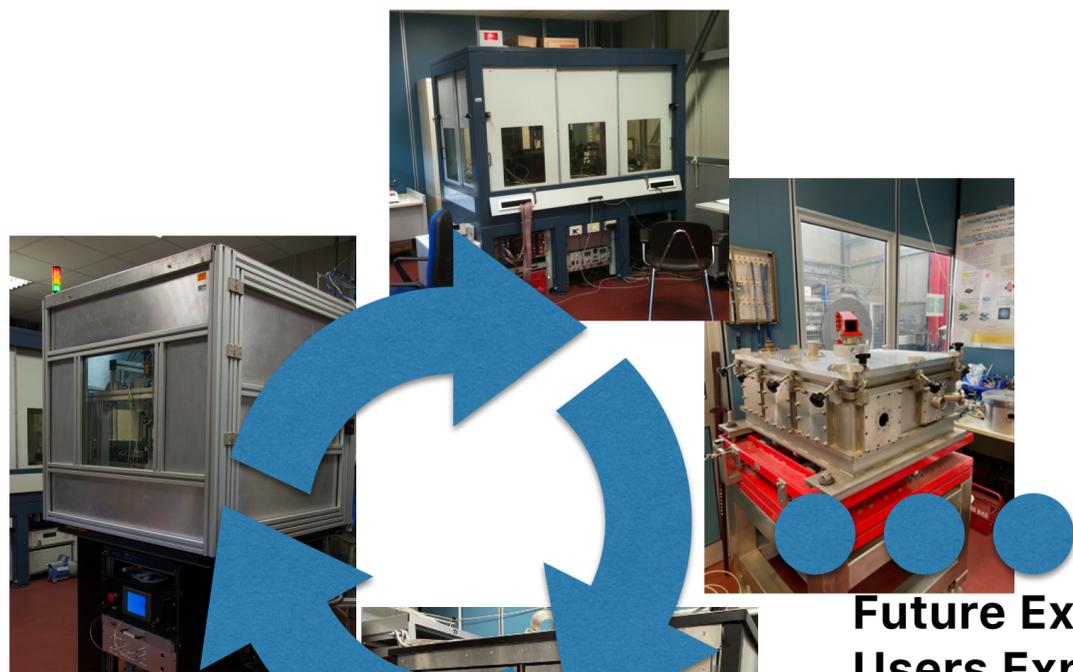
Channel x-ray technologies



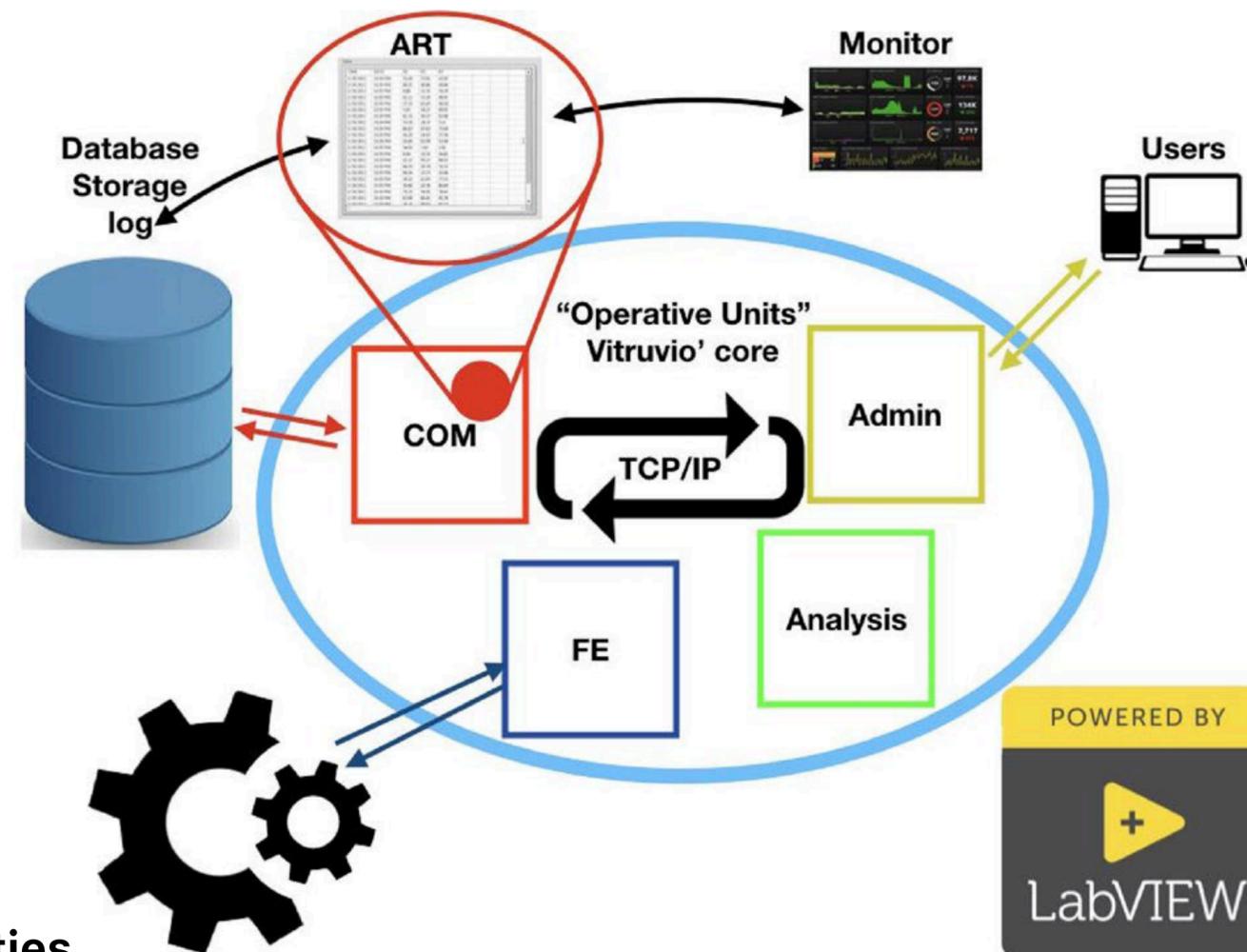
X-ray Facilities @ LNF

LabOS - Vitruvio

- Management Framework Platform (LabVIEW based)
- Scalable Framework
- The final version is under development / beta version



Future Experimental Facilities
Users Experiments

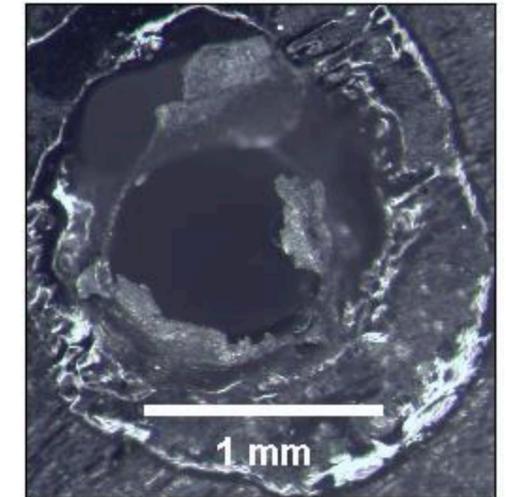
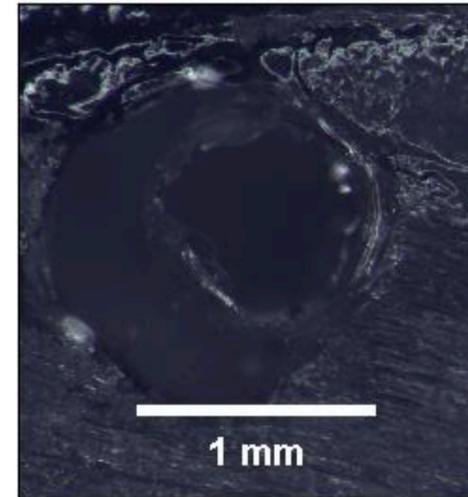


Per SPARC_LAB

Produzione e realizzazione di capillari singoli dotati di foro trasverso per immissione di gas (idrogeno), per esperimenti su tecniche di accelerazione di Plasmi mediante fasci laser ad alta potenza.



Before its use



After 1k shots

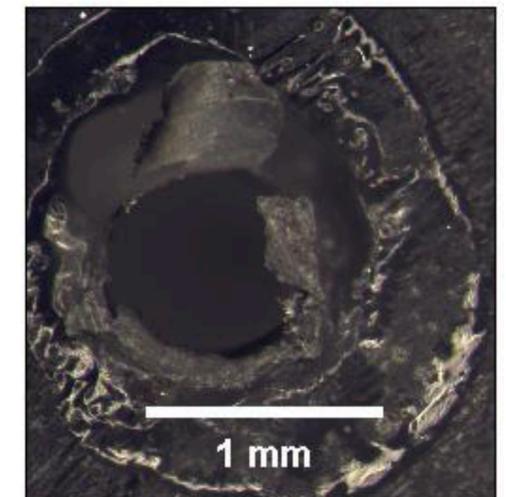
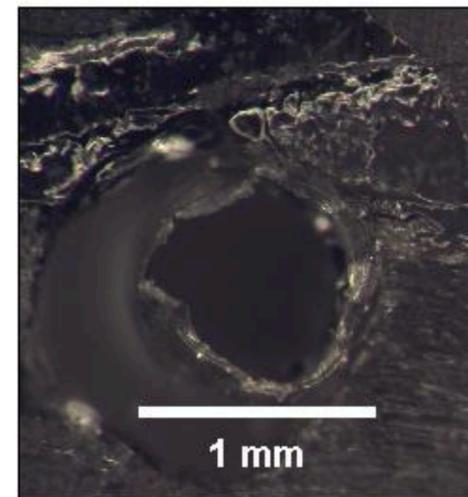
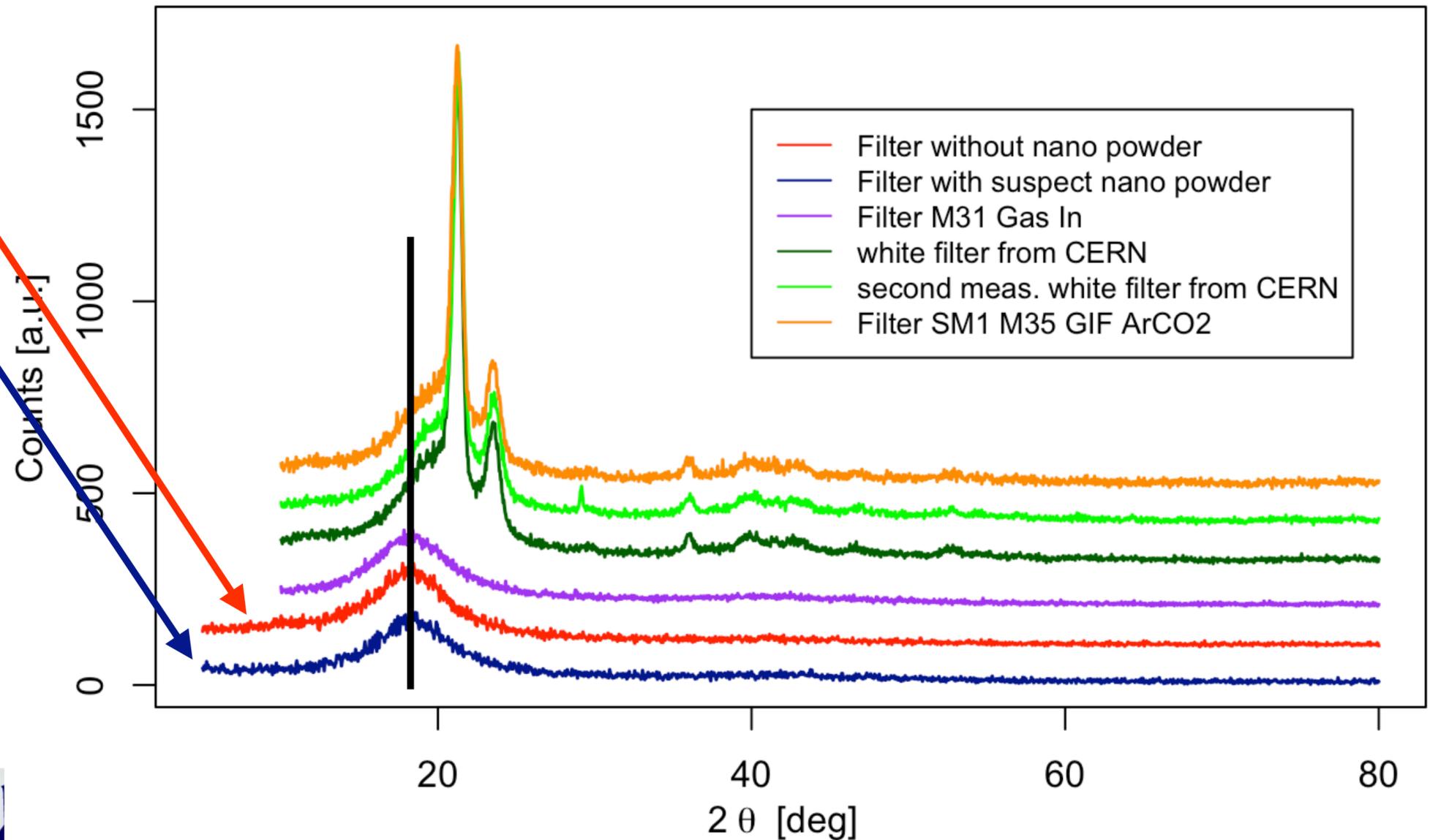


Figure 2: Capillary edges before and after one thousand shots.

Analisi di impurità nei filtri micromegas per ATLAS -CERN

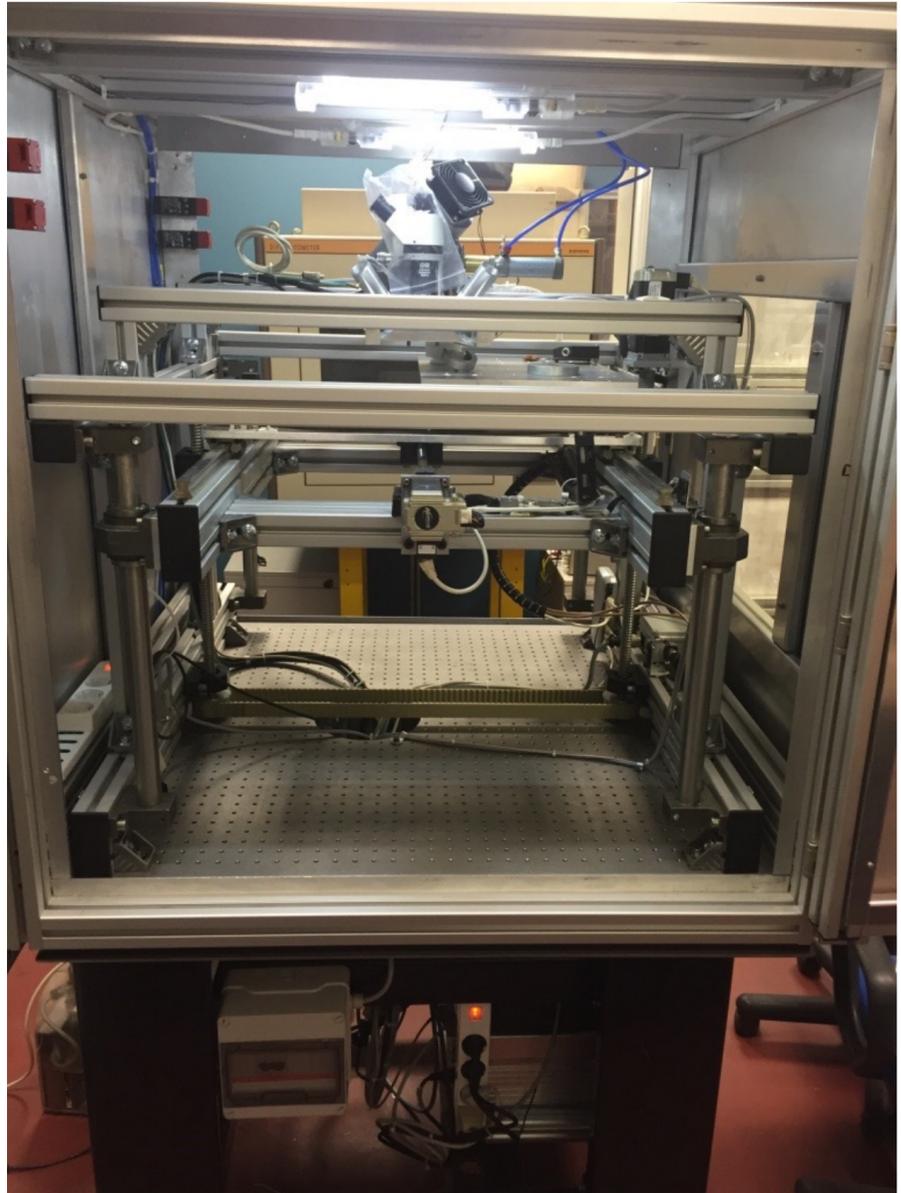
- Filtri Bianchi
- Filtri con impurità "nere" (visibili ad occhio)



- Fisica Teorica
- Attività Sperimentali
- **R&D Strumenti**
- Produzione Ottiche



X-ray Facilities @ LNF



NC TECHNOLOGIES
Innovative Elemental μ -Analysis





- Sigla: μ Spex
- Durata proposta: 3 anni
- Area di ricerca: Fisica interdisciplinare
- Responsabile nazionale: Dr. Dariush Hampai
- Unità partecipanti: INFN-LNF
- Enti esterni: Museo Civico Etrusco-Romano di Cerveteri, Fondazione "la Sapienza", Soc. Coop. Matrix s.r.l., NC Technologies s.r.l.

- Il progetto μ Spex è finalizzato allo studio, catalogazione e comprensione dei manufatti archeologici provenienti da aree di scavo:
 - mediante strumentazione già presente in XlabF (XRD e RXR)
 - lo sviluppo di un sistema da banco innovativo "all-in-one" in grado di effettuare simultaneamente analisi di micro-diffrattometria (μ -XRD) e di micro-fluorescenza di raggi X (μ -XRF).

Peltuinum

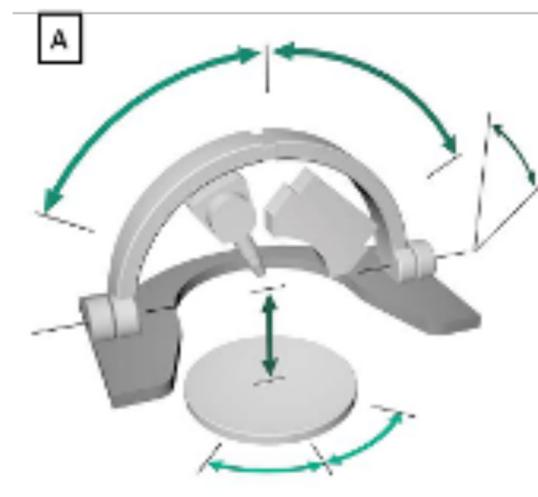
Lo studio verterà su campioni stratigrafici. La cronologia dei contesti di scavo in cui sono stati rilevati effetti sismici è stata documentata dai dati stratigrafici, ma le analisi dei materiali possono confermare e precisare l'identificazione dei terremoti storici, con una positiva ricaduta ai fini delle ipotesi sulla scansione temporale sismica in area appenninica centro-meridionale

Museo Civico di Cerveteri

Lo studio delle fibre tessili, riguardo la tipologia del materiale e la pigmentazione presente consentirà, mediante ricostruzione degli abbigliamento, lo studio dei gruppi sociali rinvenuti nelle necropoli, permettendo una maggiore comprensione delle comunità etrusche del lacus sabatinus.

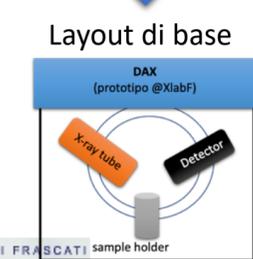
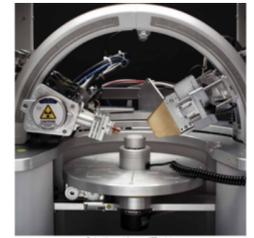
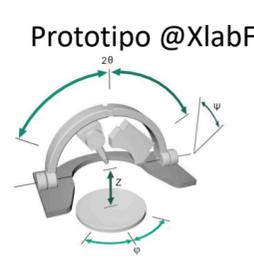


- **Prima Fase: utilizzo in parte della strumentazione già presente in XlabF**
 - Tubi a raggi X: Oxford Apogee 5000 ed Unisantis Scorpion 3.0
 - Rivelatore: scintillatore allo NaI; spettrometro XRF di XGLab; Telecamera Photonic Science.
 - Elettronica di controllo: C-RIO National Instruments per la gestione dei motori
- **Seconda Fase:**
 - Acquisto Strumentazione mancante
 - Sviluppo software basato su LabVIEW
 - Test in laboratorio
 - Validazione in situ
 - Analisi e Catalogazione dei reperti @Peltuinum / Museo Civico Etrusco di Trevignano
- **Terza Fase: Trasferimento Tecnologico**



μSpeX – micro Spettrometro

Caratteristiche	μXRD	μXRF
Anodo	Cu	Cu
Spot focale (μm)	100	100
HV (kV)	50	50
Corrente (mA)	1	1
Range 2theta (°)	1 - 130	1 - 130
Step 2theta (°)	0.01	0.01



Produzione industriale e commercializzazione



- Fisica Teorica
- Attività Sperimentali
- R&D Strumenti
- **Produzione Ottiche**

The "power" of XlabF

X-ray Facilities @ LNF

Typologies

- Full PolyCO Lens
- Semilens PolyCO
- Straight PolyCO
- Full-Semi MonoCO lens
- Single Capillary (shaped - full, semi - straight)

Focal Data

Focal distance	30- 80 mm
Focal spot (Full Lens)	60-90 μm

Dimensions single channel

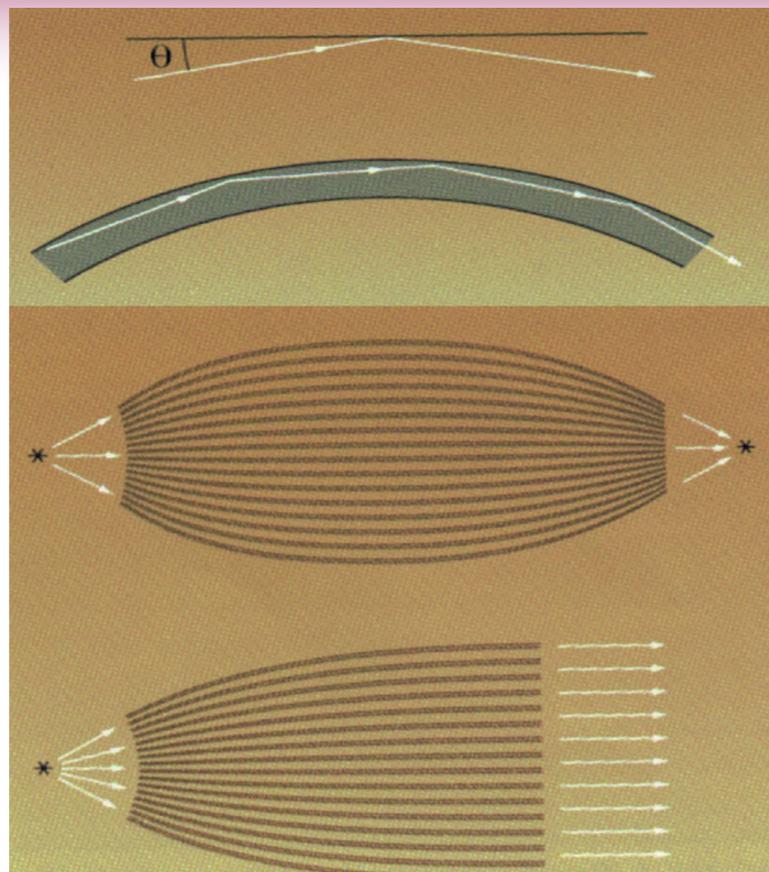
- 3-10 μm (PolyCO IV Gen.)
- >20 μm (MolyCO)

Energy range

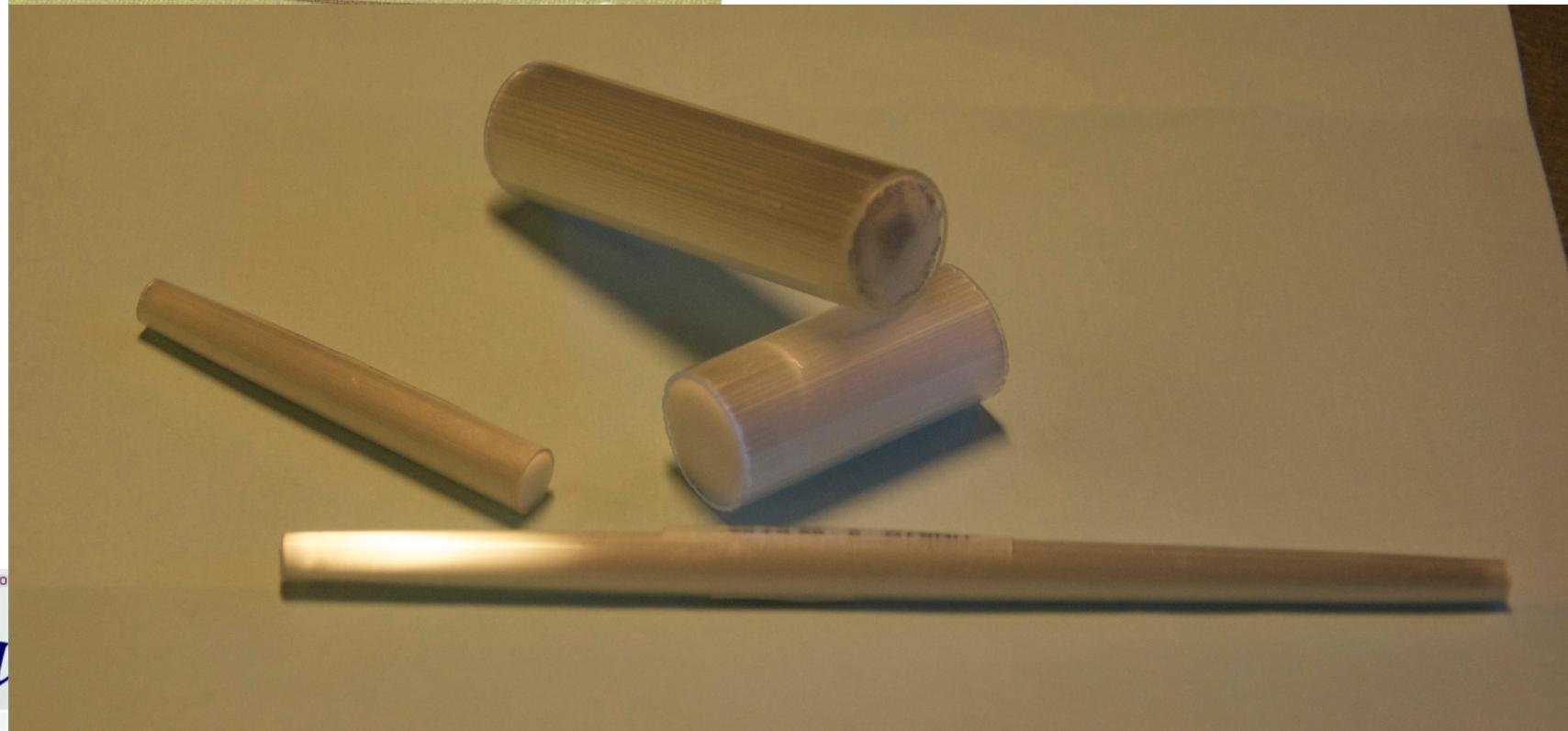
- PolyCO IV Gen. -> 3-40 keV
- MonoCO -> 1-5 keV

Transmission

- 40-70% 8 keV (PolyCO IV Gen.)
- 20-40% 17 keV (PolyCO IV Gen.)



1. beam bending through large angles
2. divergent beam to convergent one
3. divergent to quasiparallel & vv
4. Number of applications
 - scientific instrumentation (XRF, XRD)
 - elemental/structural analysis
 - medicine (diagnostics, therapy)
 - astrophysics



The "power" of XlabF

X-ray Facilities @ LNF



I nostri "clienti"

X-ray Facilities @ LNF



PN▶Detector



Typologies

- Full PolyCO Lens
- Semilens PolyCO
- Straight PolyCO
- Full-Semi MonoCO lens
- Single Capillary (shaped - full, semi - straight)

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Energy range

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follow us...

@XLabF1

X-ray Facilities @ LNF

Grazie per l'Attenzione