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REPORT ON X-RAY MEASUREMENT ON LHC COLLIMATOR MATERIALS AT BNL

E. Quaranta

...with many thanks to:

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Outline

- Motivation
- BNL irradiation facility
- Material irradiation at BLIP and TANDEM
- X-Ray diffraction at the NSLS
- Summary of the tests
- Conclusion and Outlook

Motivation

LHC collimators are exposed to high radiation dose level during the normal operation of the machine.
It may lead to **DRAMATIC CHANGES** in the **material properties** (reduction in thermal conductivity, increase in electrical resistivity and Young's modulus, volume deformation, etc.)

Radiation hardness is a key requirement

Choice of new materials must take into account the behaviour under heavy radiation loads to:

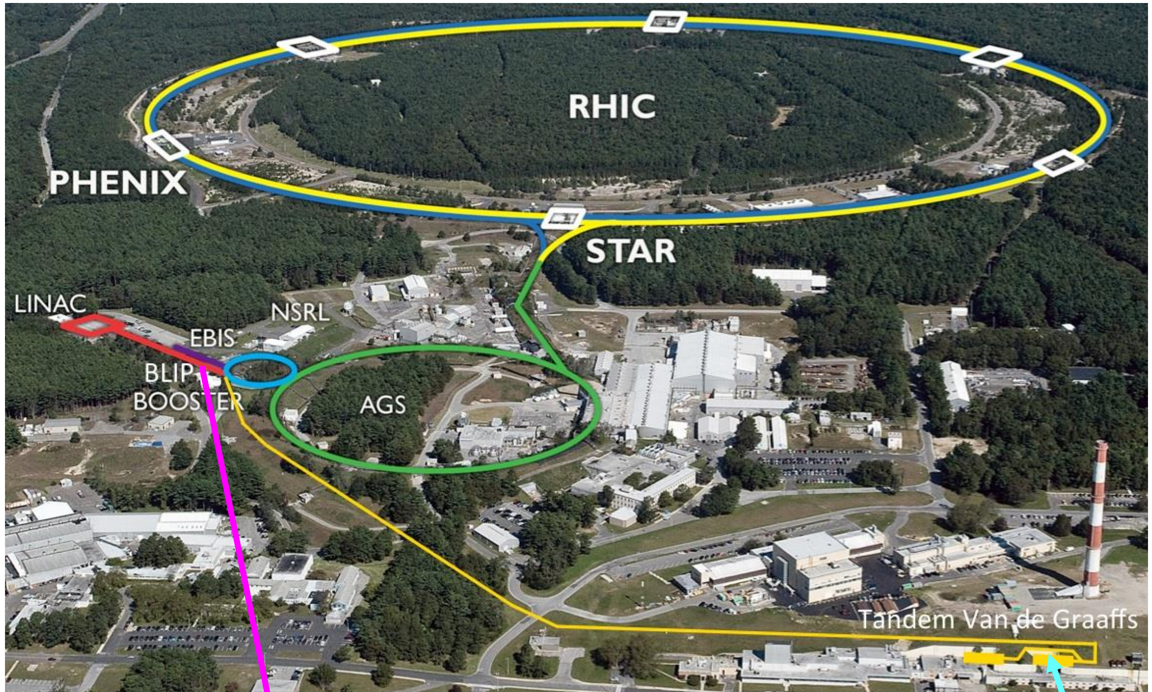
MINIMIZE the WORSENING of physical/mechanical properties due to radiation-induced effects

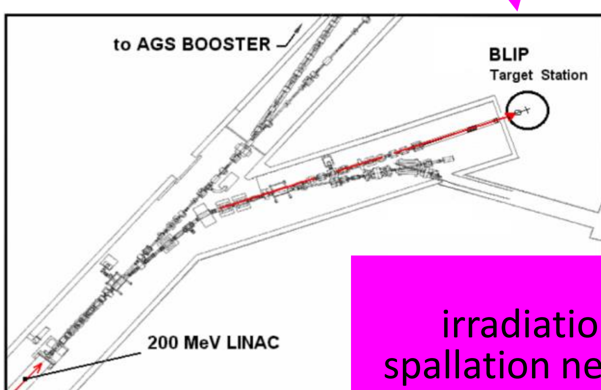
Where do we are in terms of radiation-induced damage in present and novel collimator materials?

Answer will be based on:

- Investigation of material **behaviour** in highly **irradiation environment.**
- Complementary studies in several research center (Kurchatov Institute, GSI, BNL) with different irradiation conditions and setup.

BNL irradiation facilities





Tandem van de Graaff:
Irradiation with 28 MeV proton
for very localized damage

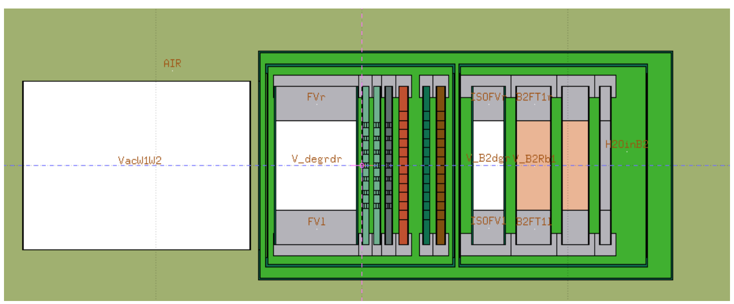
BLIP:
irradiation up to 200 MeV proton or
spallation neutrons from 112 MeV protons

Material irradiation at BLIP

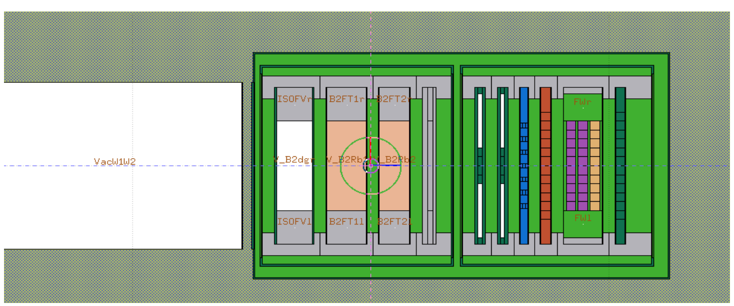
200 MeV proton irradiation (8 weeks):

- Glidcop AL-15 (*SCM Metals, USA*)
- Molybdenum (*Plansee, Austria*)
- MoGr (*Brevetti Bizz, Italy*)
- CuCD (*RHP Tech., Austria*)

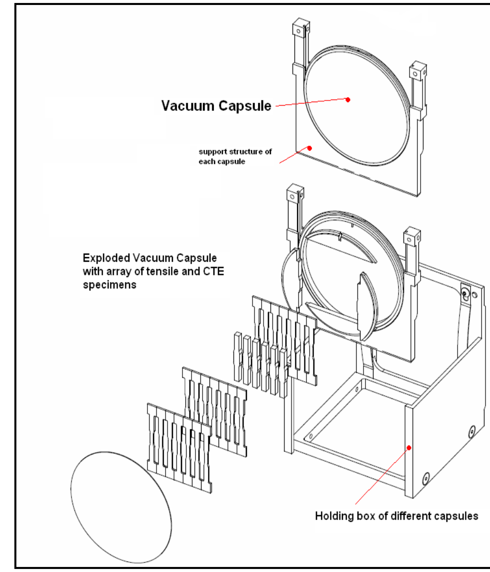
Note: 200 MeV proton irradiation performed at BLIP also on CFC and Glidcop in 2012 (US-LARP collaboration).

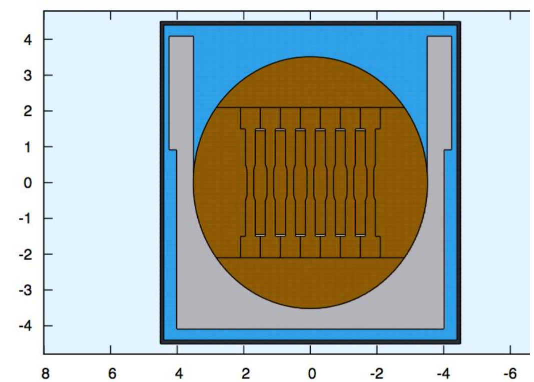


Setup for 200 MeV proton irradiation



Setup for fast spallation neutron irradiation



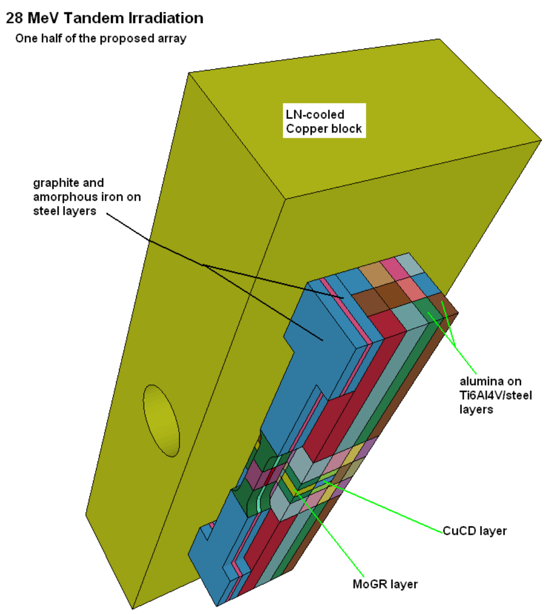


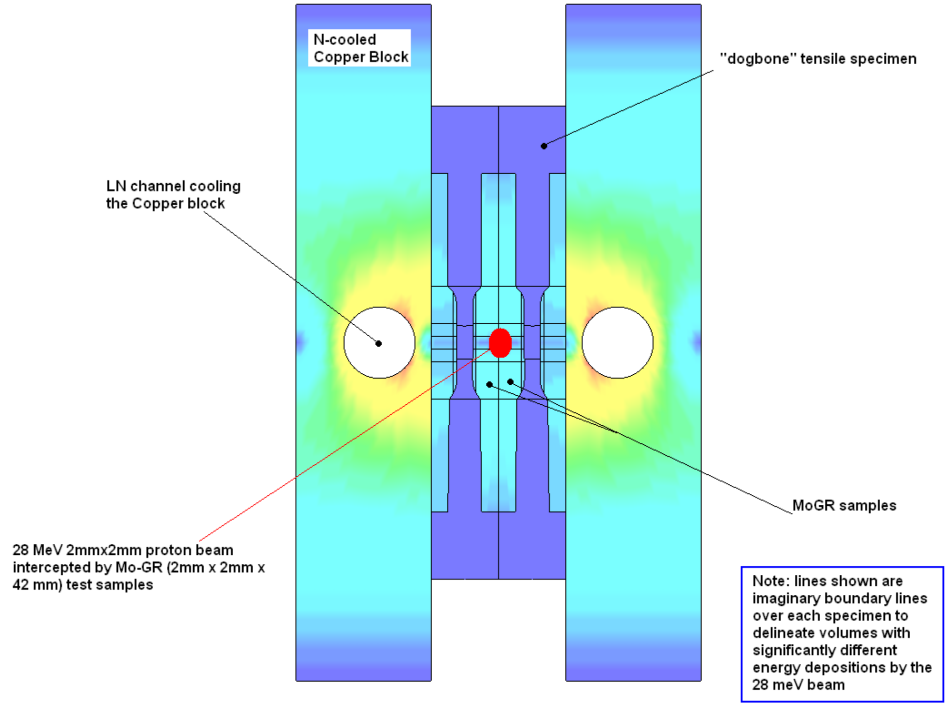
Spallation neutrons from 112 MeV protons:

- CuCD (*RHP Tech., Austria*)
- Graphite (also interesting for collimators)

…and at TANDEM

- Tightly focused 28 MeV proton beam (1.5 x 1.75 mm beam core + tail)
- Primary beam intercepted by **Mo** sample (high-Z material) to maximize secondary particle spectrum
- Spallation neutron field produced by primary protons used to irradiate **MoGr**, **CuCD** and **Glidcop** (2x2x42 mm)

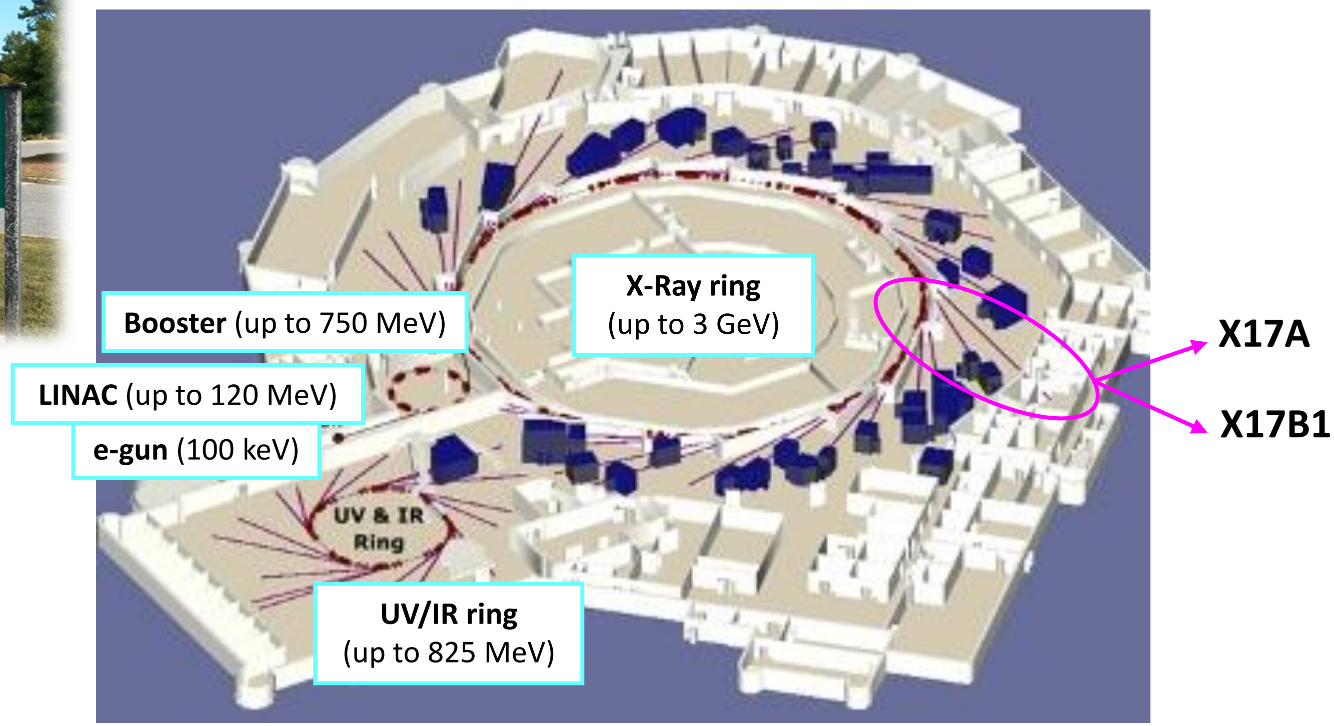




NSLS: National Synchrotron Light Source

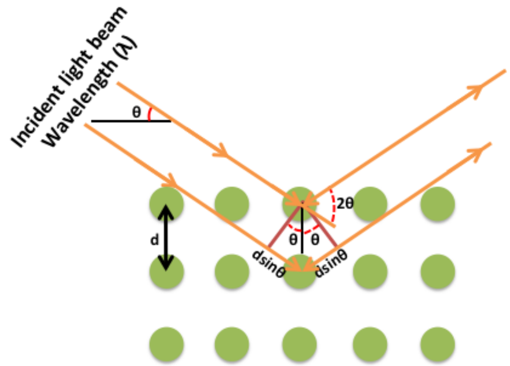
BROOKHAVEN NATIONAL LABORATORY

X-ray beam from NSLS used for **phase and strain mapping** of cold and irradiated collimator material samples.
2 runs: April and September 2014 (“last light” before NSLS shutdown).
The new beamlines in NSLS II will start the operations in mid-2015.



LHC Collimation Project CERN

X-Ray diffraction analysis

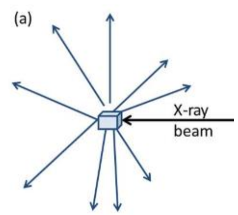


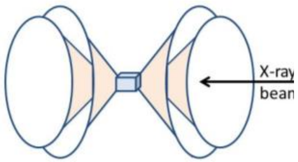
Constructive interference when:

$$\boxed{n\lambda = 2d \sin\theta}$$

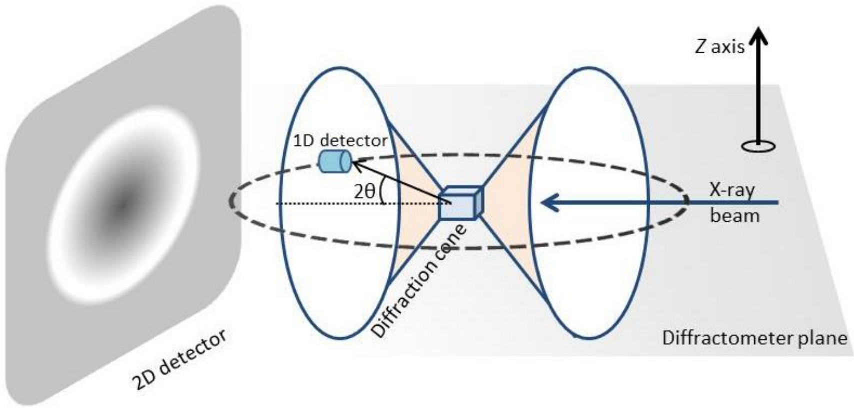
Bragg's law

Single crystal diffracts in discrete directions





Polycrystalline material creates series of diffraction cones



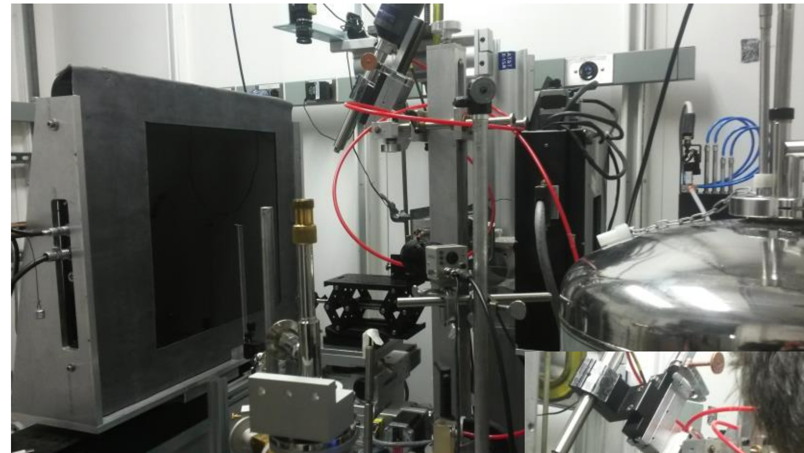
A two dimensional (2D) XRD system is a diffraction system with the capability of simultaneously collecting and analyzing the X-ray diffraction pattern in 2D.

Main advantages compare with 1D:

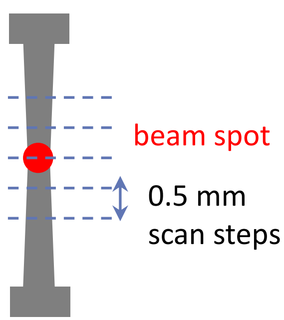
- No sample orientation dependence
- Crystalline percentage measurement more accurate

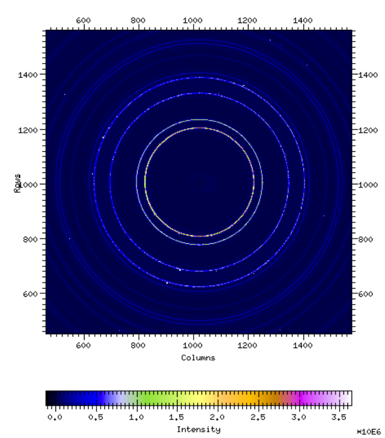
2D XRD at X17A beamline

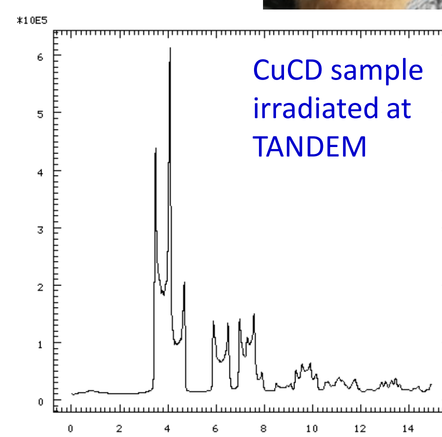
- **Monochromatic** X-Ray beam
- Energy = **60-70 keV**
- Beam spot size: 0.5 x 0.5 mm



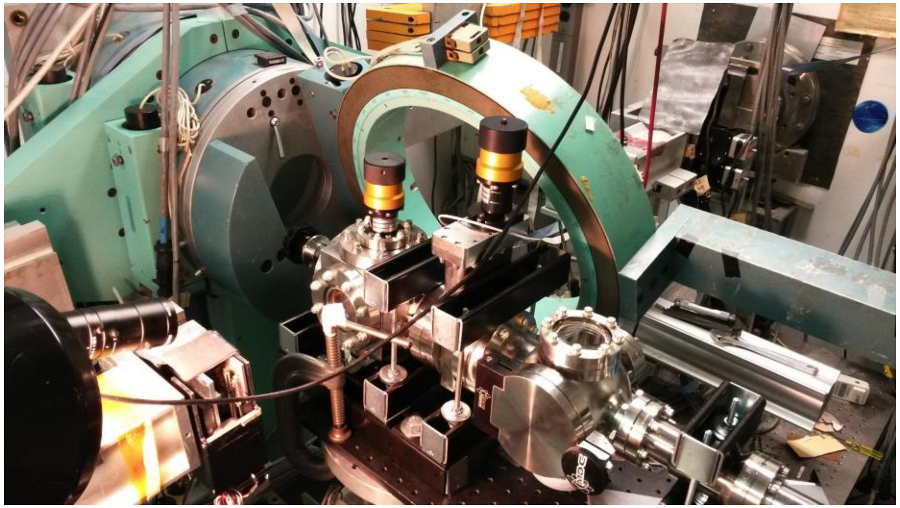
- Discretized scan along the length of each sample
- Data will be used as **benchmark** with similar measurements foreseen to be performed at NSLS II

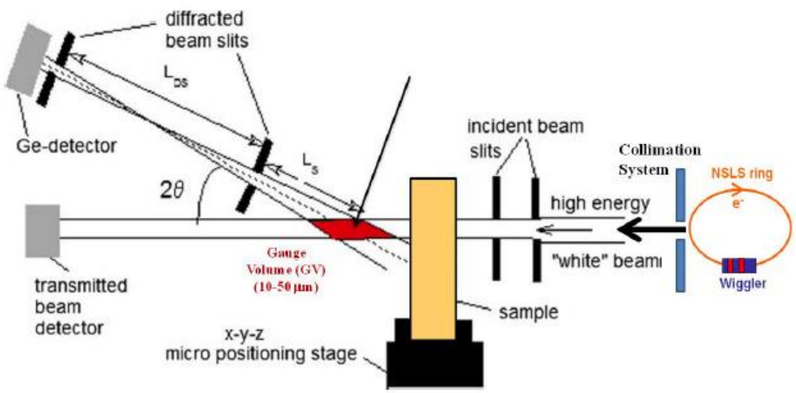






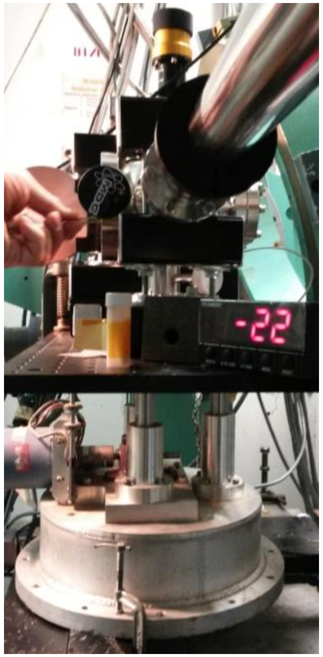
Energy Dispersive X-Ray Diffraction at X17B1 beamline

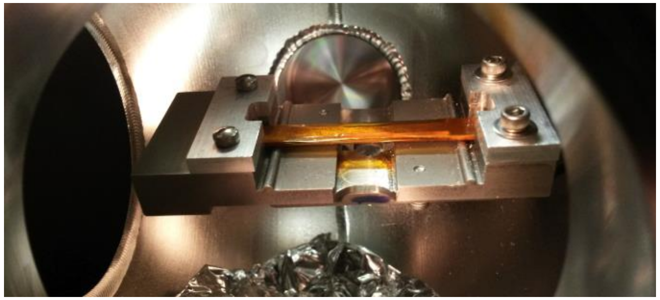




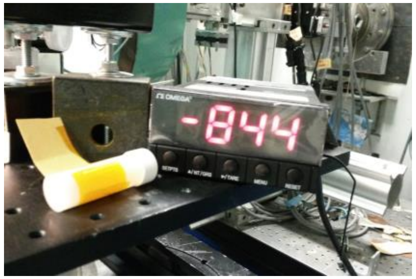
- Continuous **white** radiation
- Energy **up to 200 keV** (bulk analysis)
- **Fixed angle** 2θ (good for in-situ measurements)
- **Energy distribution** of scattered photons analyzed by a semiconductor detector
- Multichannel analyzer to determine pulse height

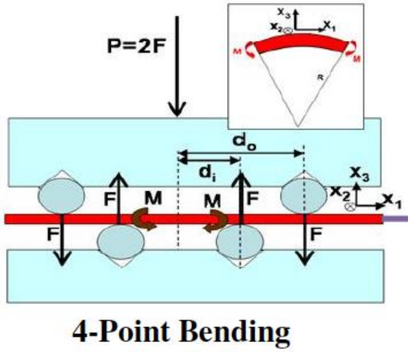
EDXRD at X17B1
for simultaneous phase and strain mapping





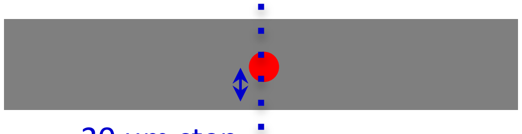
Load on sample placed in 4-points bending fixture





Discretized scan along sample thickness

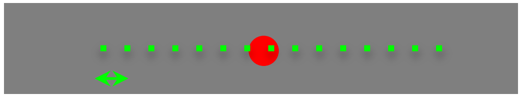
beam spot = 20 µm x 1 mm



20 µm step

Discretized scan along sample length

beam spot = 20 µm x 0.5 mm



0.5 mm step

Summary of the tests

		Irradiation	Activity and dose evaluation (at IEF)	X-Ray diffraction at X17A (NSLS)	Phase and strain map at X17B1 (NSLS)
Mo	Cold sample	-	-	✓	✗
	Protons BLIP	✓	✓	✗ *	✗ *
	Protons TANDEM	✓	✓	✓	✓ **
Glidcop	Cold sample	-	-	✓	✓ **
	Protons BLIP	✓	✓	✗ *	✗ *
	Protons TANDEM	✓	✓	✓	✓ **
MoGr	Cold sample	-	-	✓	✗
	Protons BLIP	✓	✓	✓ ***	✓ ***
	Protons TANDEM	✓	✓	✓	✓ **

* = waiting for the radioactive samples to cool down in hot cells
** = measurement performed with pure bending load applied to the sample
*** = sample exposed at only 2h of proton irradiation at BLIP

Summary of the tests (cont'd)

		Irradiation	Activity and dose evaluation (at IEF)	X-Ray diffraction at X17A (NSLS)	Phase and strain map at X17B1 (NSLS)
CuCD	Cold sample	-	-	✓	✗
	Protons BLIP	✓	✓	✗*	✗*
	Neutron BLIP	✓	✓	✓	✓
	Protons TANDEM	✓	✓	✓	✓

* = waiting for the radioactive samples to cool down in hot cells

Status and Outlook

BLIP

- 200 MeV proton irradiation (8 weeks): COMPLETED
- Neutron irradiation from 112 MeV protons (several months not continously): COMPLETED
- Cooling of highly radioactive samples in Hot Cell Lab 66: ON-GOING

TANDEM VAN DER GRAAF

- 28 MeV proton irradiation + sample cooling: COMPLETED

NSLS (National Synchrotron Light Source)

- X-Ray diffraction studies for phase and strain mapping of some cold and irradiated samples: COMPLETED (to be continued in NSLS II in late 2015)
- Data analysis: ON-GOING

CFN (BNL Center of Functional Nanomaterials)

- Annealing and Electron Microscopy analysis: NOT STARTED (foreseen for beginning 2015)

IEF (BNL Isotope Extraction Facility)

- Activity and dose measurements per sample: COMPLETED
- γ-spectra for selected samples: PARTIALLY COMPLETED

Status and Outlook (cont'd)

IEF (BNL Isotope Extraction Facility)

- Macroscopic analysis: NOT STARTED (foreseen for 2015)

Physical and mechanical properties to be measured on both reference and irradiated samples are:

- Stress-strain behaviour up to failure (tensile tests on metals, flexural tests on composites)
- Thermal conductivity
- Coefficient of Thermal Expansion (CTE)
- Swelling
- Electrical resistivity
- Damage recover after annealing

The instrumentation now available in BNL laboratories are:

- Tinius-Olsen mechanical tester + CERN fixture for flexural test
- LINSEIS dilatometer (annealing up to 1000 ^{o}C for dimensional stability recovery, electrical resistivity and thermal conductivity)
- 4-point electrical resistance apparatus
- Panametrics Ultrasound system
- Ortec Ge Detector - photon spectra analysis
- High precision scales – density measurements

The “fantastic 5” at
NSLS X17B1beamline!

Thank you for your attention