*26th US-LARP Collaboration Meeting - CM26*
*May 18th-20th, 2016*
*Standford Linear Accelerator Centre, SLAC, Menlo Park, CA, USA*

# *Irradiation studies in support of HL-LHC and other collimation topics*

*Stefano Redaelli, CERN, BE-ABP*

*on behalf of HL-WP5*

*The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.*

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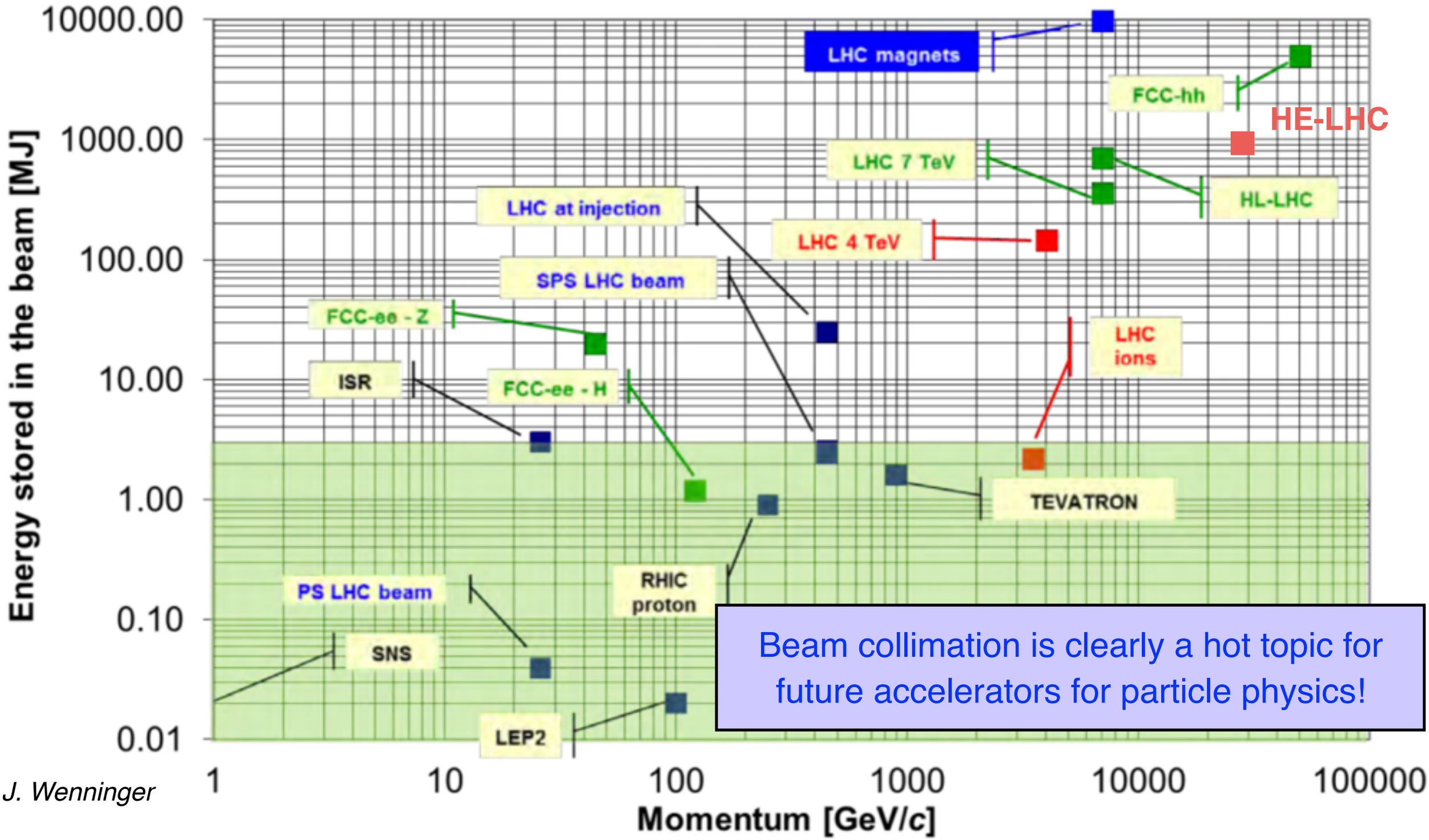
# Beam stored energy challenges




*J. Wenninger*

# Example: FCC-hh parameter table

| | LHC (Design) | HL-LHC | FCC-hh (Baseline) |
|---|---|---|---|
| **Beam energy** | 7 TeV | 7 TeV | 50 TeV |
| **Beam intensity** | $3 \times 10^{14}$ | $6 \times 10^{14}$ | $10 \times 10^{14}$ |
| **Stored energy** | 360 MJ | 690 MJ | 8500 MJ |
| **Power load ( $\tau$=0.2h)** | ~500 kW | ~960 kW | ~11800 kW |
| **Energy density** | ~1 GJ/mm$^2$ | ~1.5 GJ/mm$^2$ | ~200 GJ/mm$^2$ |

**2 order of magnitudes above the LHC:**

↓

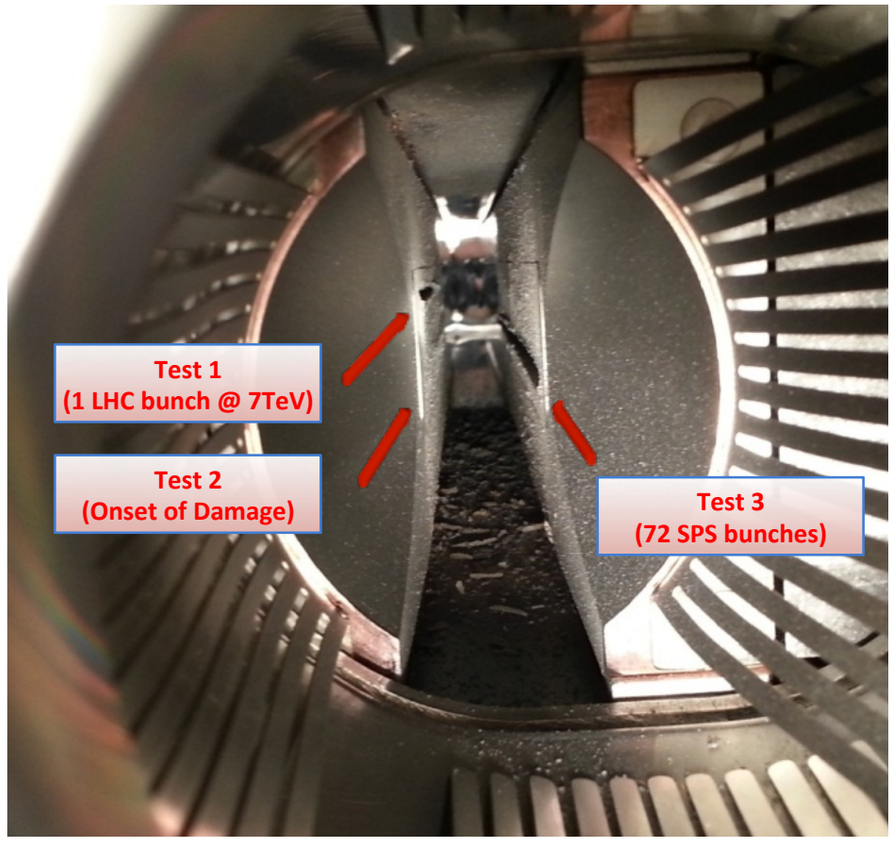
outstanding challenges for collimator materials

# Role of materials for collimation

Handling high-brightness, high-energy beams poses challenges for

- ultra-high thermal shocks;
- **high radiation doses**;
- beam impedance.

Rich and interdisciplinary domain, with synergy and impact beyond accelerators.




Contrasting requirements (robustness vs absorption vs impedance) called for **broad-spectrum R&D program**.
*Excellent results achieved in recent ~10 years, but best materials still "young". While we are confident that present baseline materials for HL-LHC (MoGr, CuCD, coatings) are ready for large productions, some open questions remain.*

# Overal context

Kurchatov

And actively working on new collaborations (with specific look at new applications beyond accelerator physics applications)

*Advertisement: detail at recent collimation workshop https://indico.cern.ch/event/508693 (organized by A. Rossi, A. Bertarelli)*

# US-LARP role

**Unique** possibility to address the behaviour of materials under high radiation doses at **BNL**:

- beam irradiation with high intensity beams at BLIB
- expertise in handling highly irradiated samples
- measurements of key micro- and macro-scopic properties
- access to facilities like NSLS and NSLSII: Xray analysis

Specialized expertise to address the required topics related to collimation material behaviour under extreme irradiation conditions.

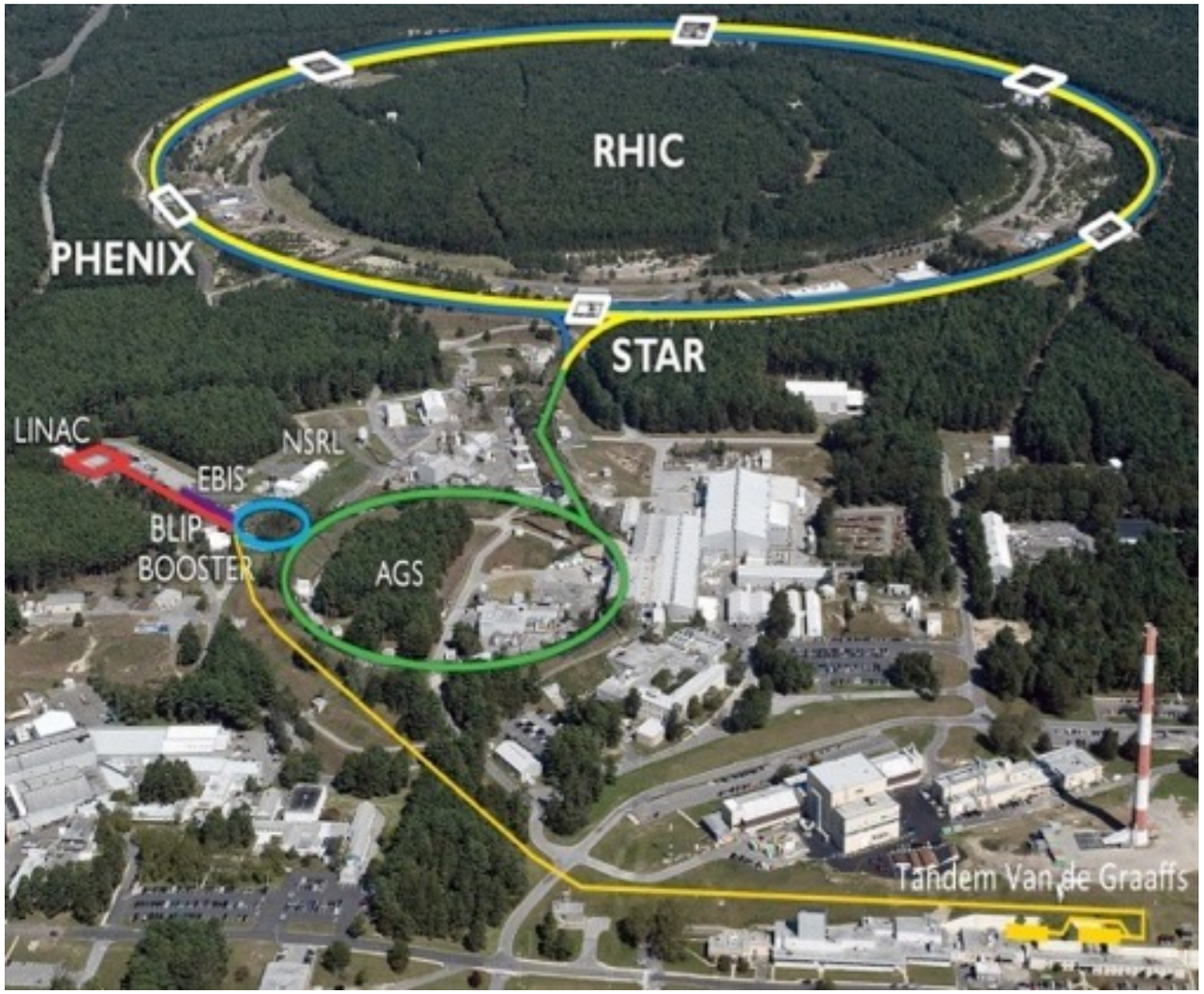
Good collaboration: exchange of CERN students (1 master, 1-2 PhD) working at BNL and participating to beam tests and data analysis.

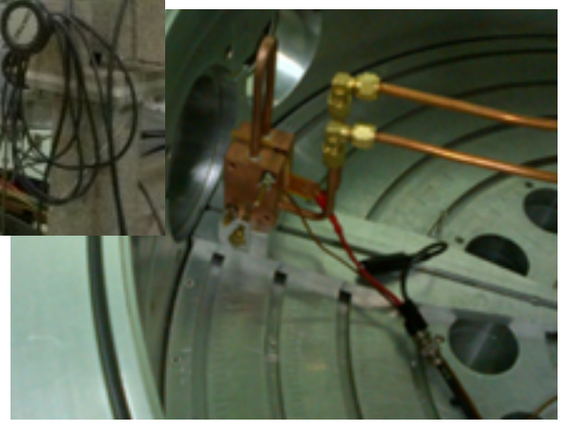
# BNL facilities

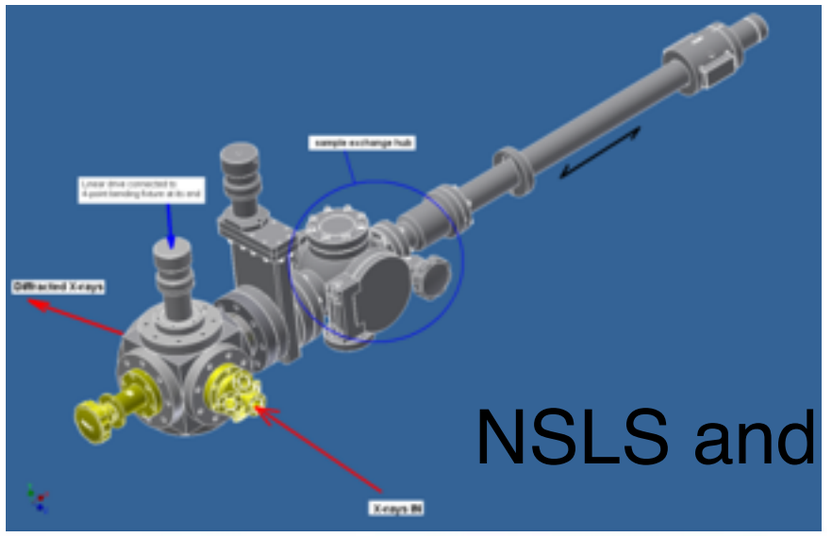
Irradiations took place at BLIP (181 MeV) and Tandem (28 MeV)

At elevated temperatures a BLIP (MoGR ~420C; Mo ~1100 C)
At sub-zero temperatures at Tandem (spallation field from 28 MeV on Mo)

MoGR also irradiated with protons + spallation neutrons to ~ (5+5) $10^{18}$

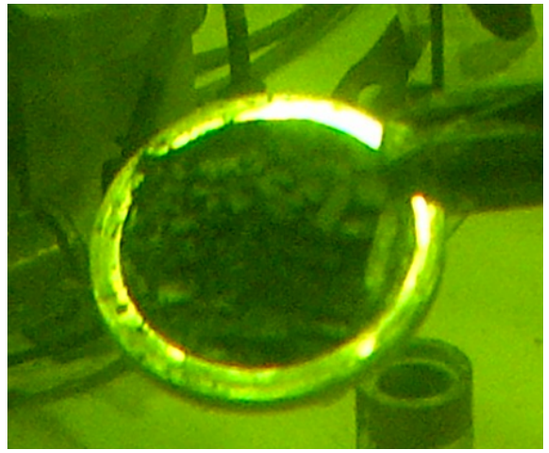




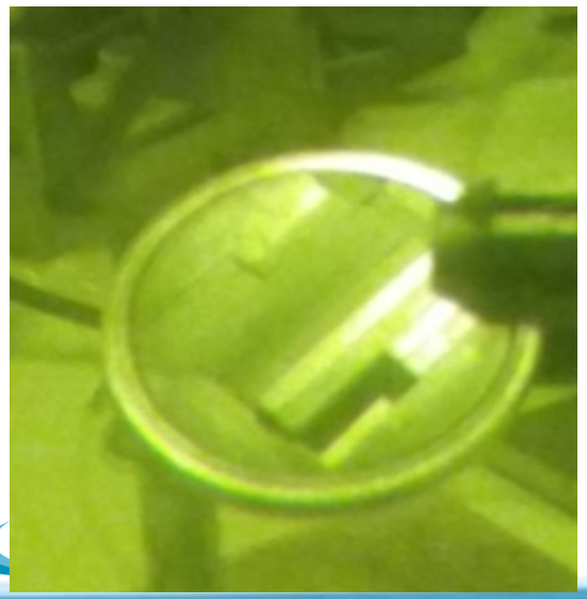

NSLS and NSLSII

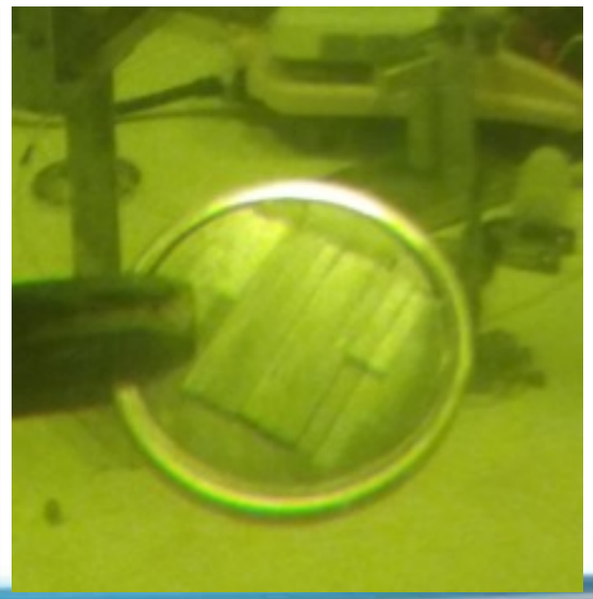
# Recent examples



State of Mo-GR after 1.1 $10^{21}$ p/cm$^2$ FLUE

Two sets of samples of latest grades (improved from the 2012 ones used in the first irradiation campaign) recently inspected after doses of **7x10$^{19}$ p/cm$^2$**





Role of these studies:
Raising awareness of possible issues: confirming (hopefully) validity of improved material MoGR grades, feeding back on production techniques (confirming initial results from GSI).
**It is clear to me that this activity must continue!**

CARBON FIBER COMPOSITES AND COMPOUNDS INTERCEPTING ENERGETIC PROTON BEAMS – IRRADIATION DAMAGE AND THERMAL SHOCK

N. Simos[1], Z. Zhong[1], H. Kirk, L-P Trung, K. McDonald[3], Z. Kotsina[5], P. Nocera[6]
[2]CERN TEAM (R. Assmann, S. Redaelli, A. Bertarelli, E. Quaranta)
[3]FERMI Lab (R. Zwaska[2], K. Amigan[2], P. Hurh[2], N. Mokhov)
[4]Princeton University, Princeton, New Jersey, USA
[5]Department of Solid State Physics, National and Kapodistrian University of Athens, Greece
[6]Department of Solid State Physics, University of Rome, Italy

*To be submitted*

**For submission to PRST-AB**
**Physical Review Special Topics – Accelerators and Beams (PRST-AB)**

# Detailed scope for new tests

In the context of the on-going effort to push forward the development and understanding of behaviour of new material under beam irradiation for future collimators, we propose

Continue irradiation campaigns of new materials, pushing forward the present limits/understanding

- ↦ Complete assessment of final grades to be adopted for HL-LHC
- ↦ Probing new candidates materials for HE-LHC and FCC-hh

Full characterization of pre- and post-irradiation samples

- ↦ Assessment of macroscopic thermo-mechanical properties a a function of radiation doses

Complete analysis (and publish results) of previous campaigns

- ↦ Big amount of data not yet fully exploited (topic for Toohig fellow?)

*Detailed break-down will follow in a proposal to be worked out with Nick.*

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# For discussion

- **Beam halos: measurement and control (if not part of AUP project)**

  *See talk by Miriam. Interest from the new teams (see talk by Themis).*
  *Important to realize that there is a fertile ground for studies beyond hollow e-lens!*

- **Explore new synergies within LARP partners on halo studies**

  *Operation aspects for halo monitoring with active halo control in place.*

- **Beam tests of CERN gun's with RHIC beams**

  *Unique chance to test with beam the hollow e-lens excitation modes planned for the HL-LHC halo control (effect on beam core from pulsed excitation).*

- **Crystal collimation**

  *Another example of benefit of previous collaborations: started crystals at SLAC following collaboration with UA9.*
  *Certainly a topics that we want to study for future accelerators.*

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 021003 (2013)

**Beam diffusion measurements using collimator scans in the LHC**

Gianluca Valentino,[1,2,*] Ralph Aßmann,[3,†] Roderik Bruce,[1] Florian Burkart,[1] Valentina Previtali,[4] Stefano Redaelli,[1] Belen Salvachua,[1] Giulio Stancari,[4,‡] and Alexander Valishev[4]

# Conclusive remarks

- **Presented ideas for future USA contributions to collimation studies for present and future accelerators**
- **Focus on irradiation tests**

  *Very important for collimation, also as crucial stepping stone for future higher-energy accelerators. Strong synergy with FCC study.*
  *BNL can provide a unique facility and specialised expertise to help us!*
- **There is room for starting new exciting activities on beam collimation, building on past collaborations**

  *Examples were given for discussion, emphasising synergy to future colliders*
- **Too early for me to provide budget estimates, as need more discussion with people involved in various labs.**

  *New topics essential involve man power. BNL irradiation: cost for facility.*
- **Looking forward to continuing our fruitful collaboration**