Proton Radiography: Applications in Imaging

Matthew Freeman, for the pRad collaboration

LA-UR-15-28693

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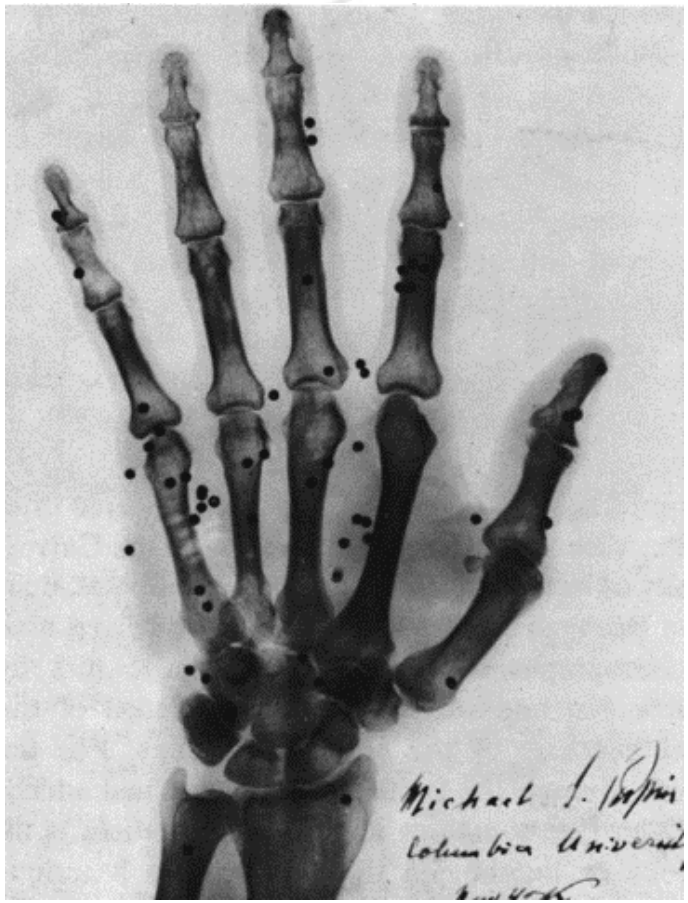
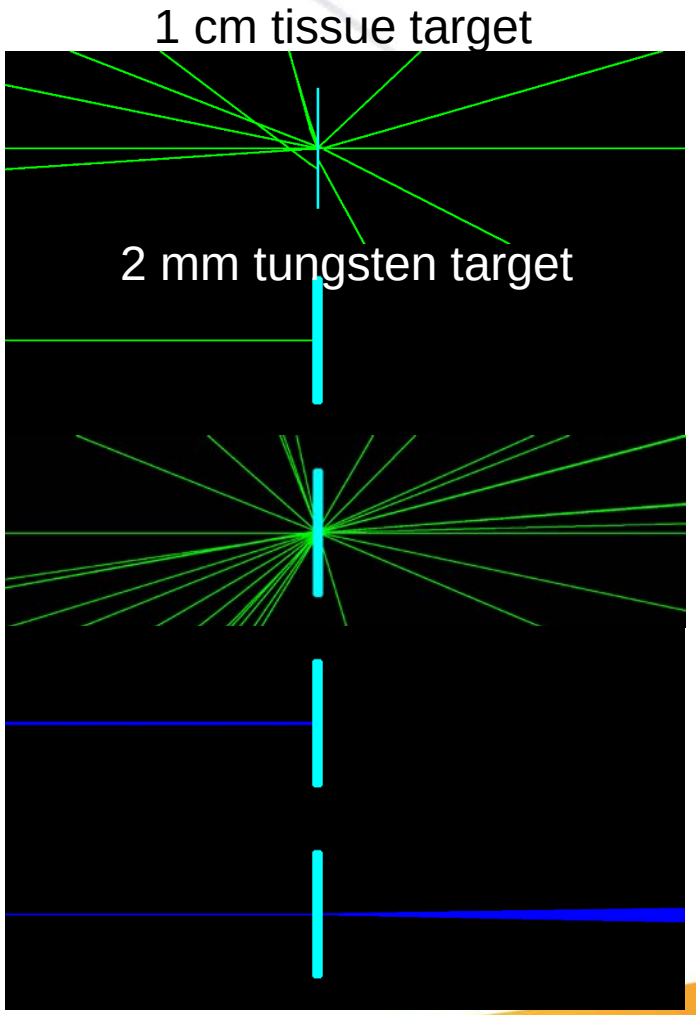
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

The Challenge: Image Dense, Rapidly Evolving Systems

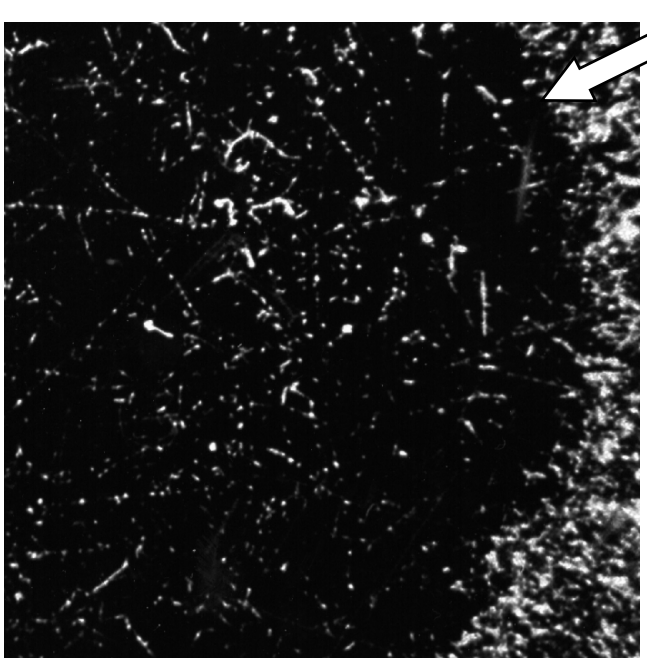


[1] W. C. Röntgen, Nature **53** (1896) 274.

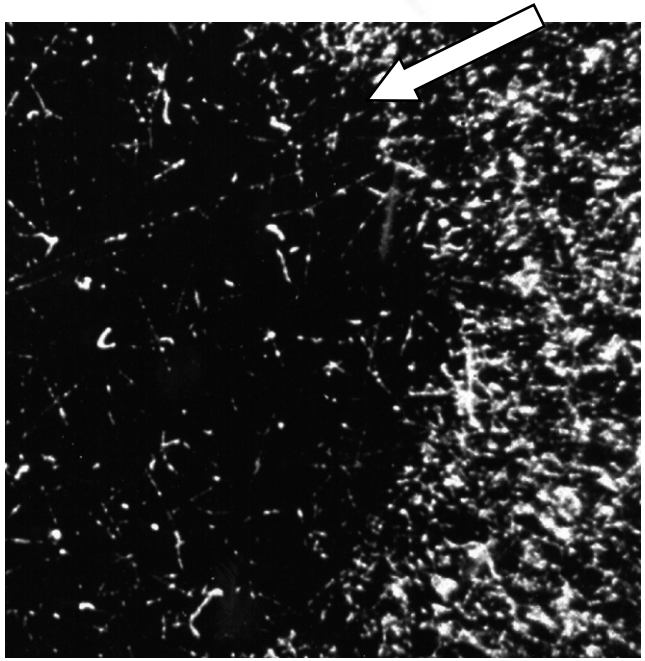


Flash radiography of hydrotest implosion (Manhattan project)

Static



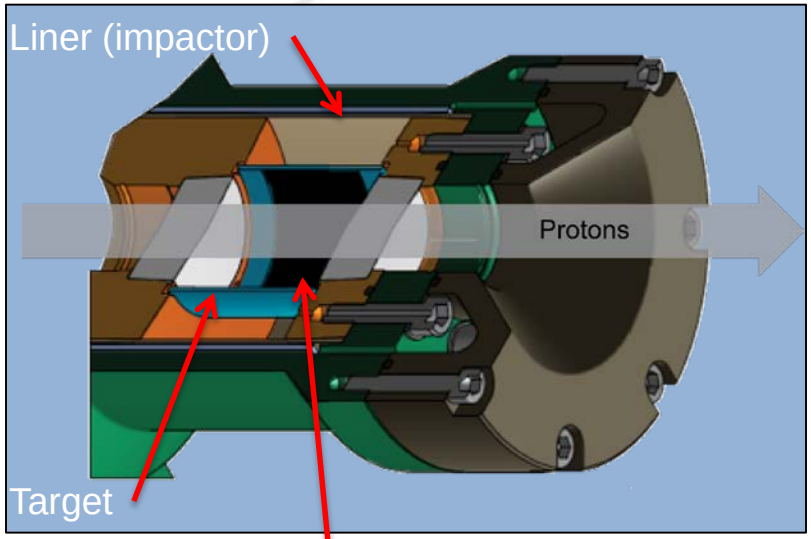
Dynamic

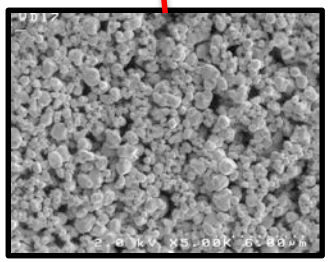


- 15 MeV betatron X-ray source
- 1 μsec long pulses
- Wilson cloud chamber detector

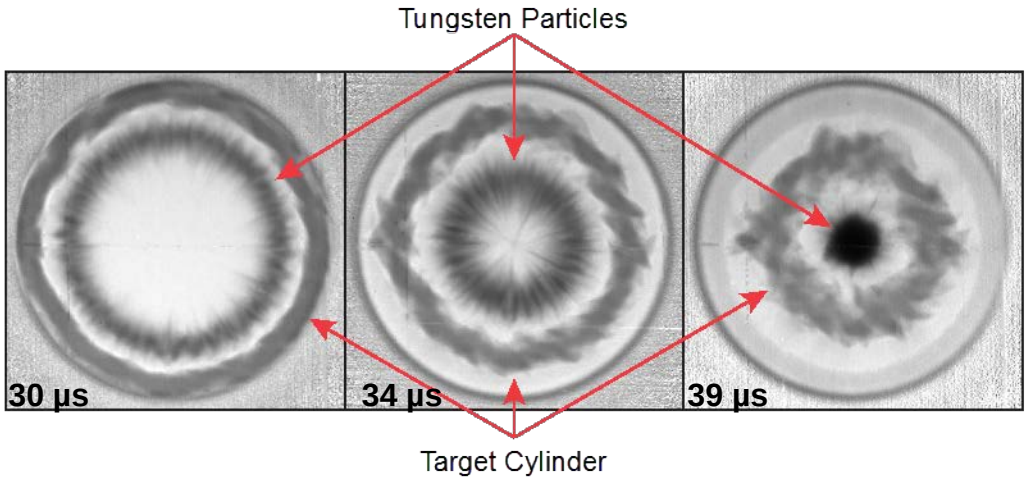
PHELIX liner implosions

(P.I.: David Oro)





Tungsten powder
0.1 -1 µm diameter



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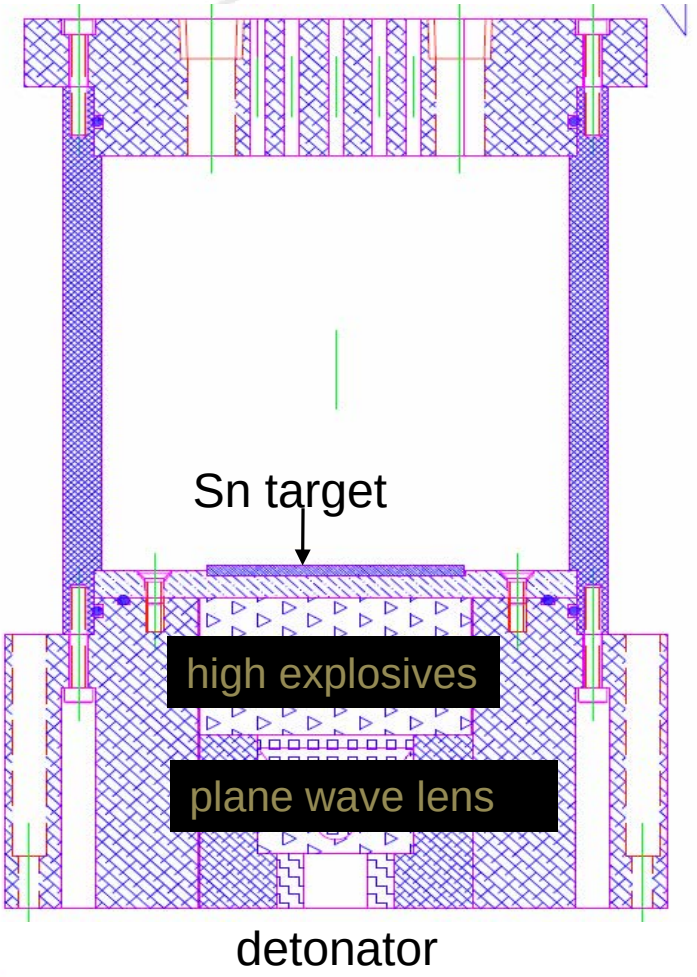
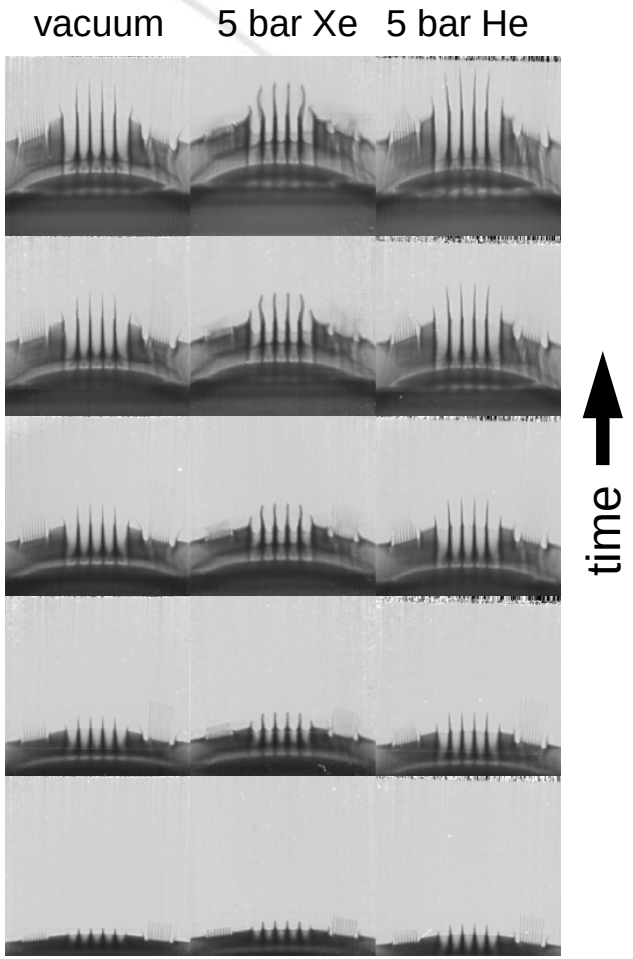
High dynamic range and temporal sensitivity visualize delicate, evolving systems

(P.I.: William Buttler)





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Spall material failure

(P.I.: David Holtkamp)

Los Alamos NATIONAL LABORATORY EST. 1943

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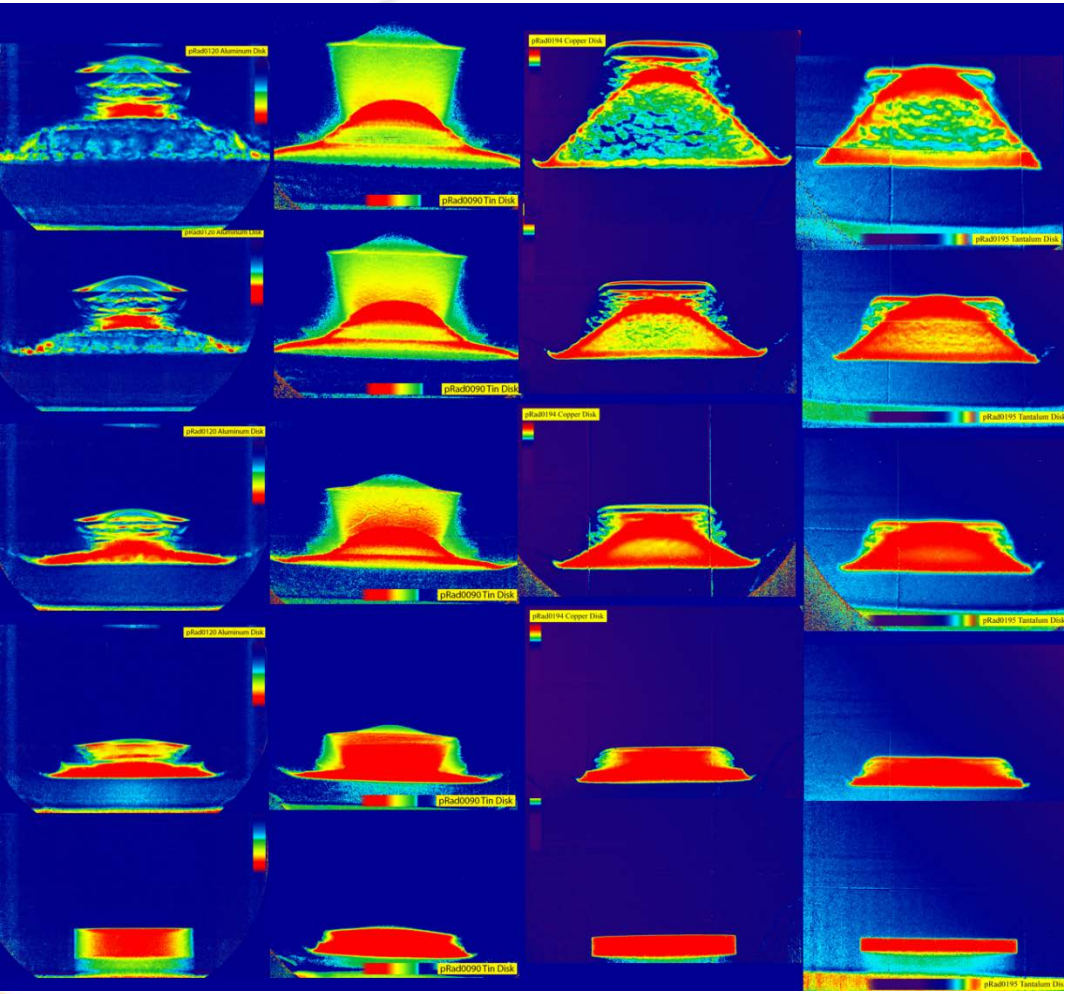
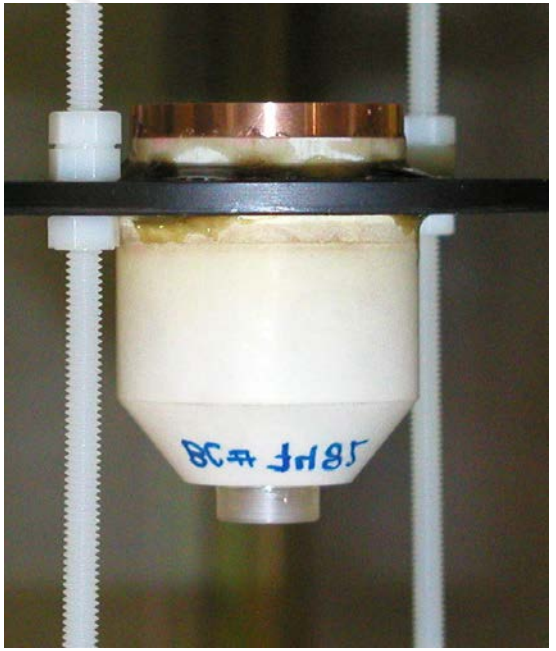
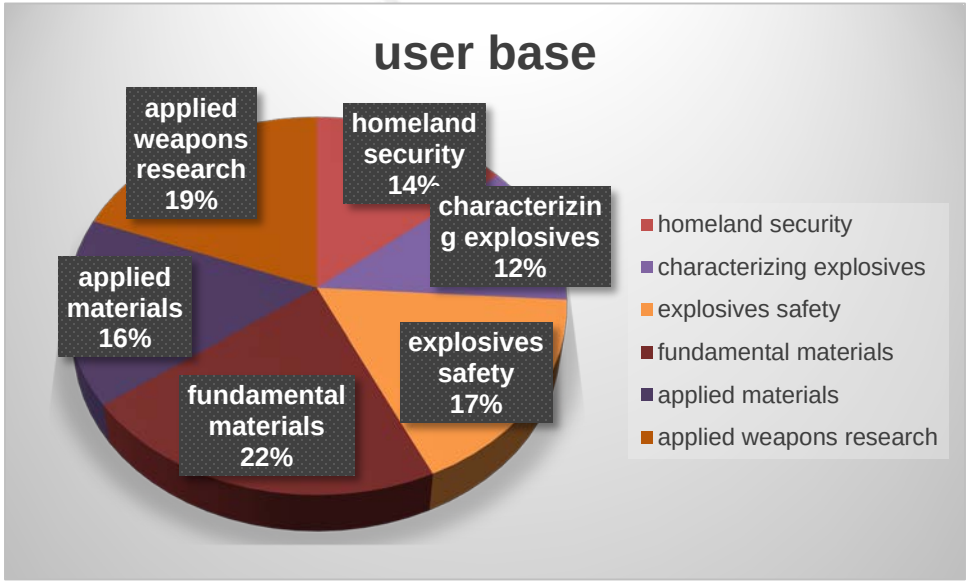




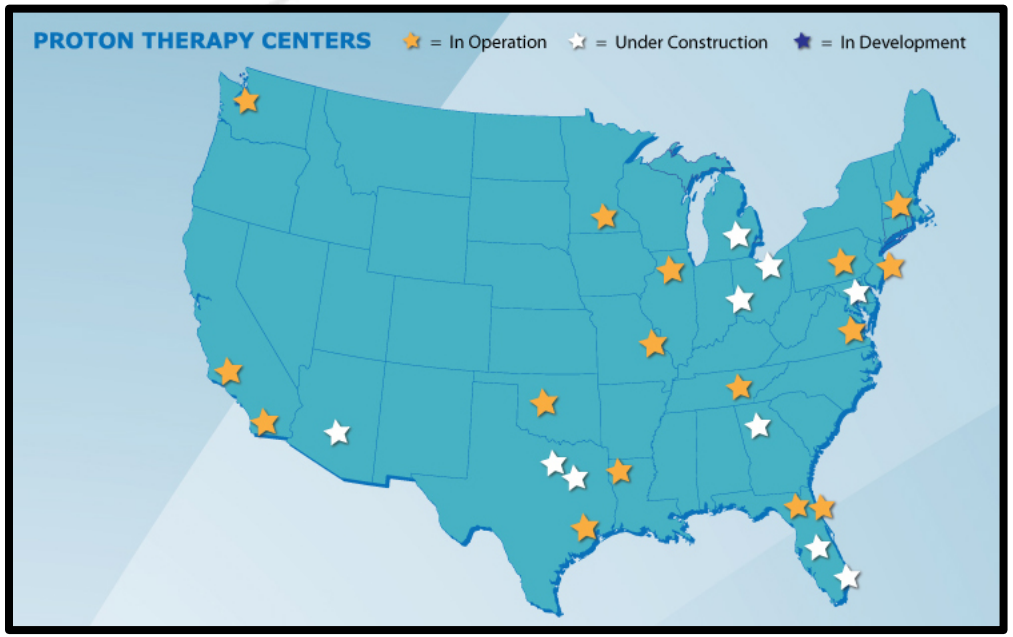
pRad can investigate fundamental properties of various metals in extreme conditions

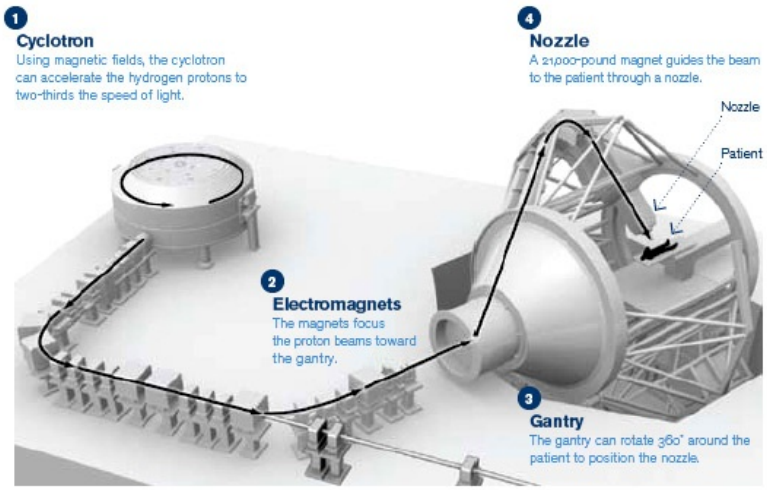
User programs reach out to new applications

- user programs provide experimenters the opportunity to work at pRad
- classified or unclassified
- yearly call for proposals
- beam time allocated based on Program Advisory Committee recommendations



Protons are gaining acceptance for cancer therapy in the U.S.





- cancer treatment techniques are evolving and improving
- currently 16 proton therapy centers in the U.S., 10 more under construction
- typical proton energy ~ 200 MeV

Protons increase dose-delivery accuracy

conventional radiotherapy

~200 MeV Protons

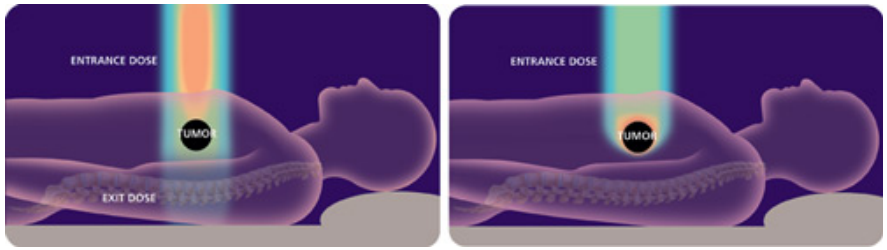
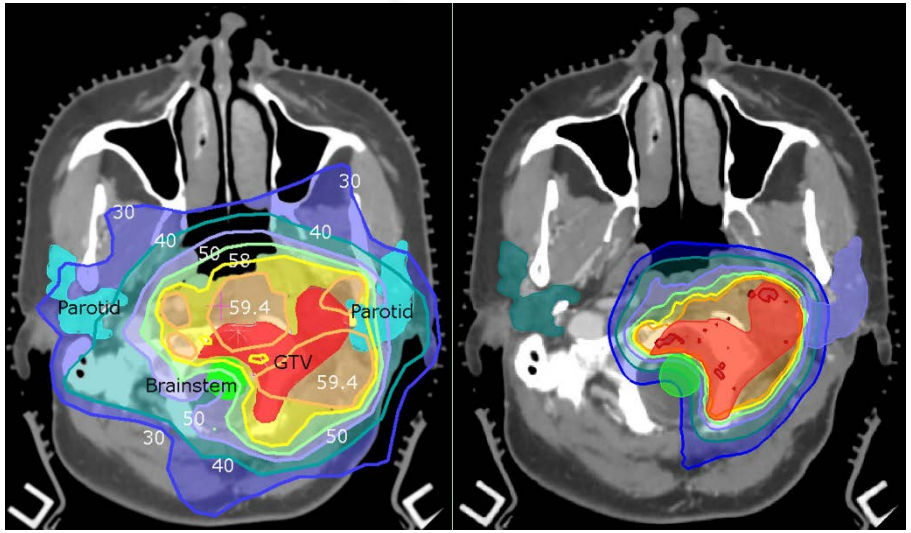


image courtesy Nancy Mendenhall,
UF Proton Therapy Institute

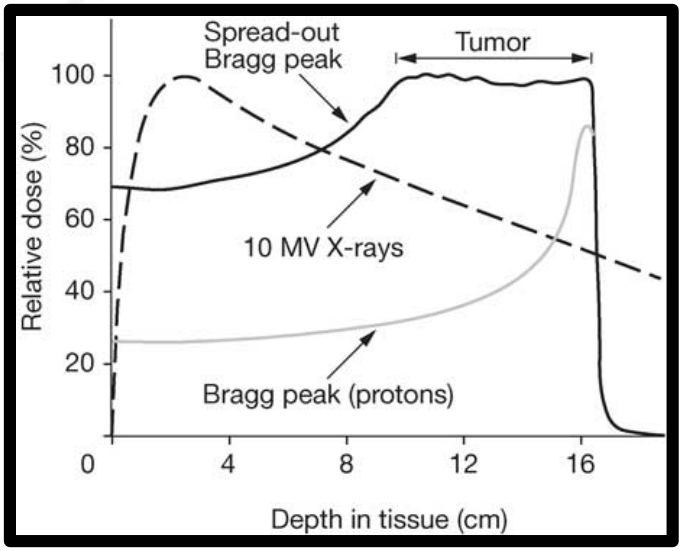
conventional radiotherapy

~200 MeV Protons

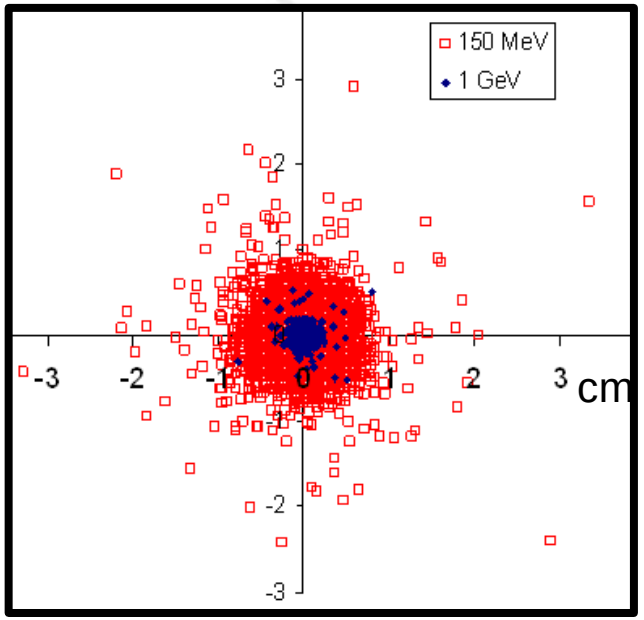


plans courtesy Francis H. Burr Proton Therapy Center, MGH, Boston:
45y/o male with benign cerebral meningioma in the petro-clival junction

New technology cuts cost and increases beam energy



Graphic from Nature Clinical Practice Oncology
http://www.nature.com/nrclinonc/journal/v1/n2/fig_tab/ncponc0090_F1.html



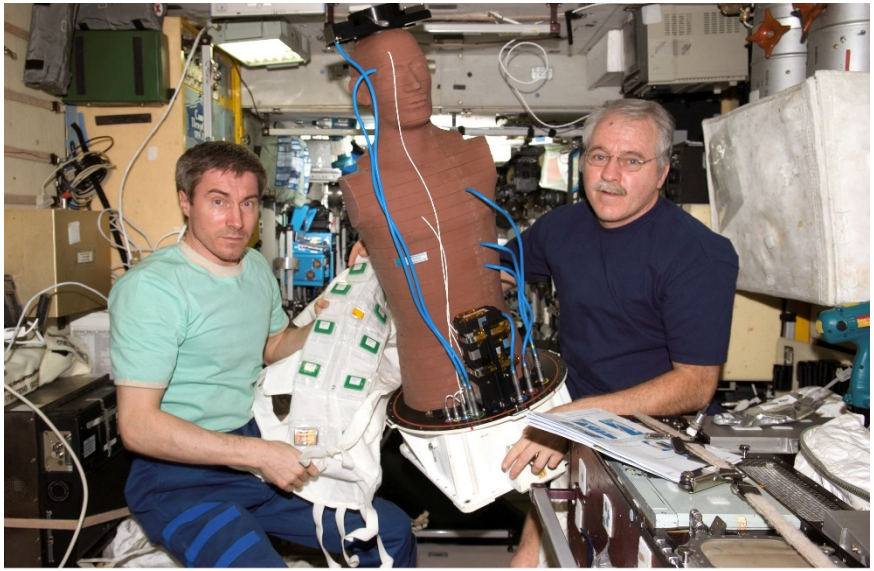
Lateral scattering of proton beams at two different energies after 15 cm in water.

Simulation by SRIM2011.

- higher energy → increased precision
- to take advantage of increased precision you need ***in situ*** imaging

Enhanced contrast delineates soft tissue w/ inverse collimator

proton radiograph of an adult zebrafish



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Astronauts Sergei Krikalev and John Philips on board the International Space Station with MATROSHKA, built by the German Space Agency (DLR) for dosimetry.

proton radiograph of the head of the anthropomorphic phantom MATROSHKA.

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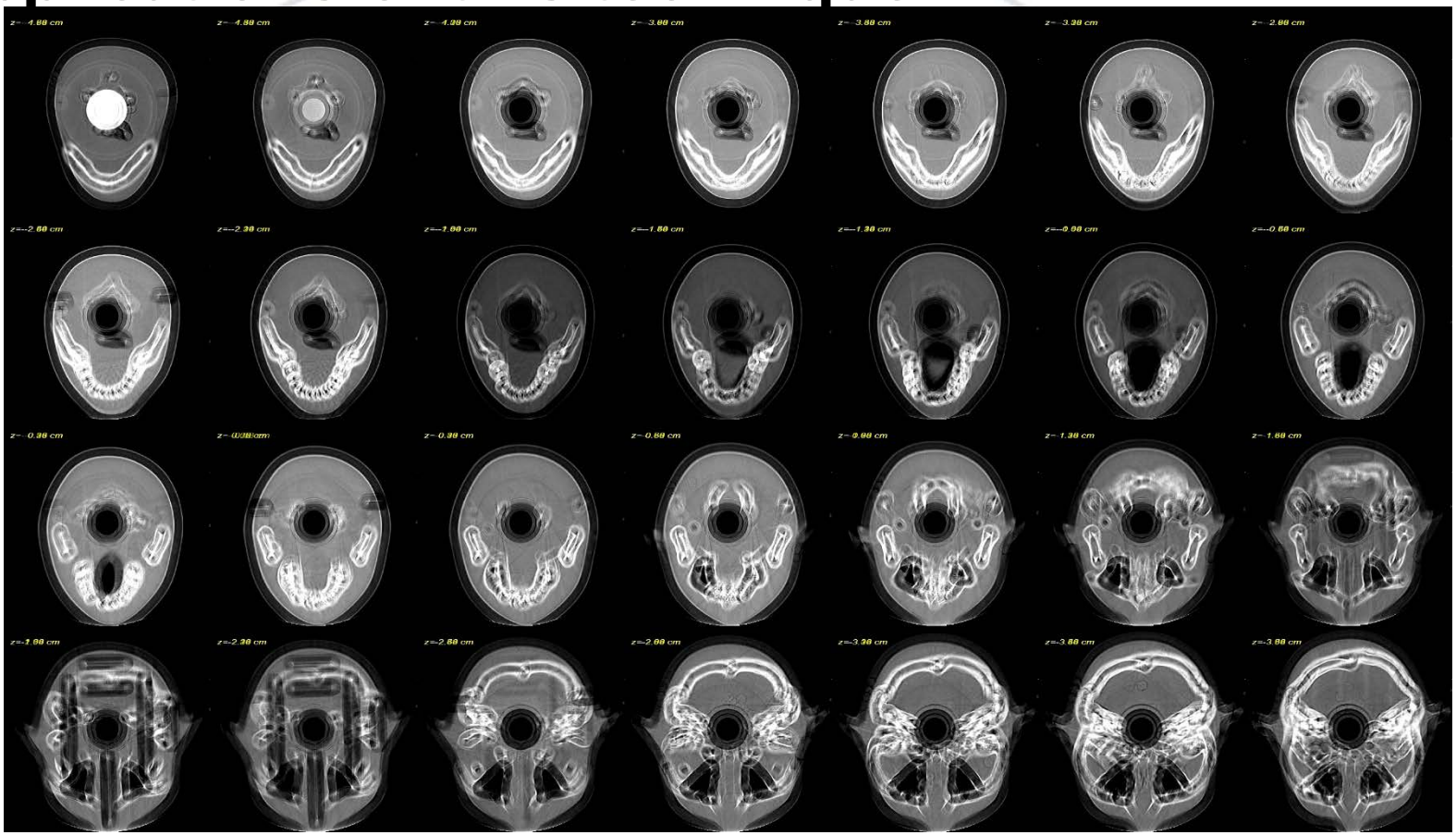
Anthropomorphic Matroshka phantom shows great promise for medical applications of this technique.



- complete 3D information rivaling the gold-standard medical CT
- 200 μm slices (every 16th shown)

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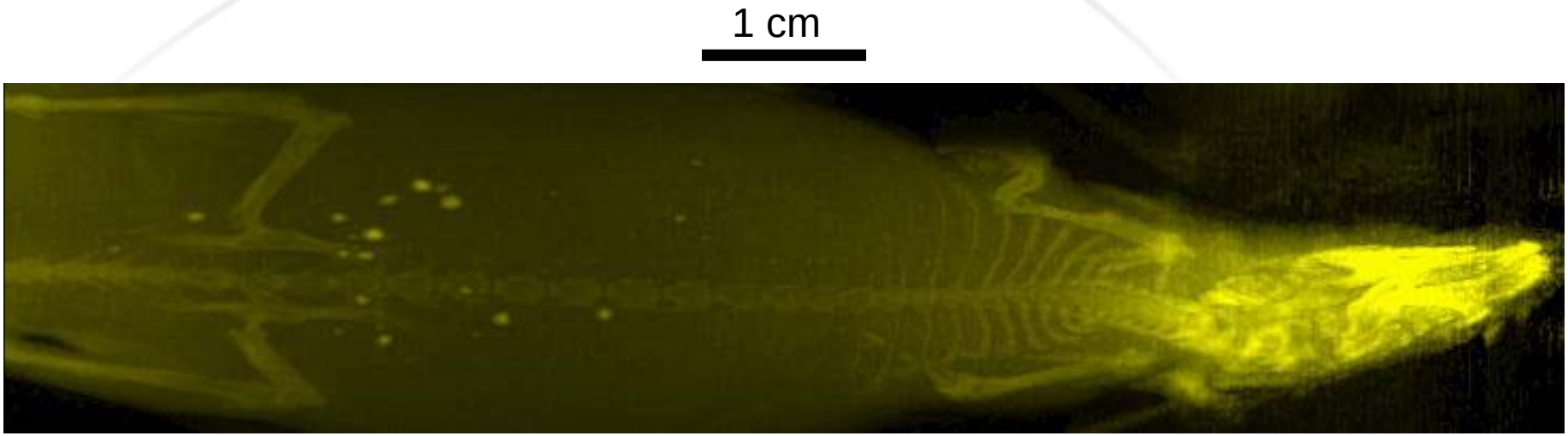
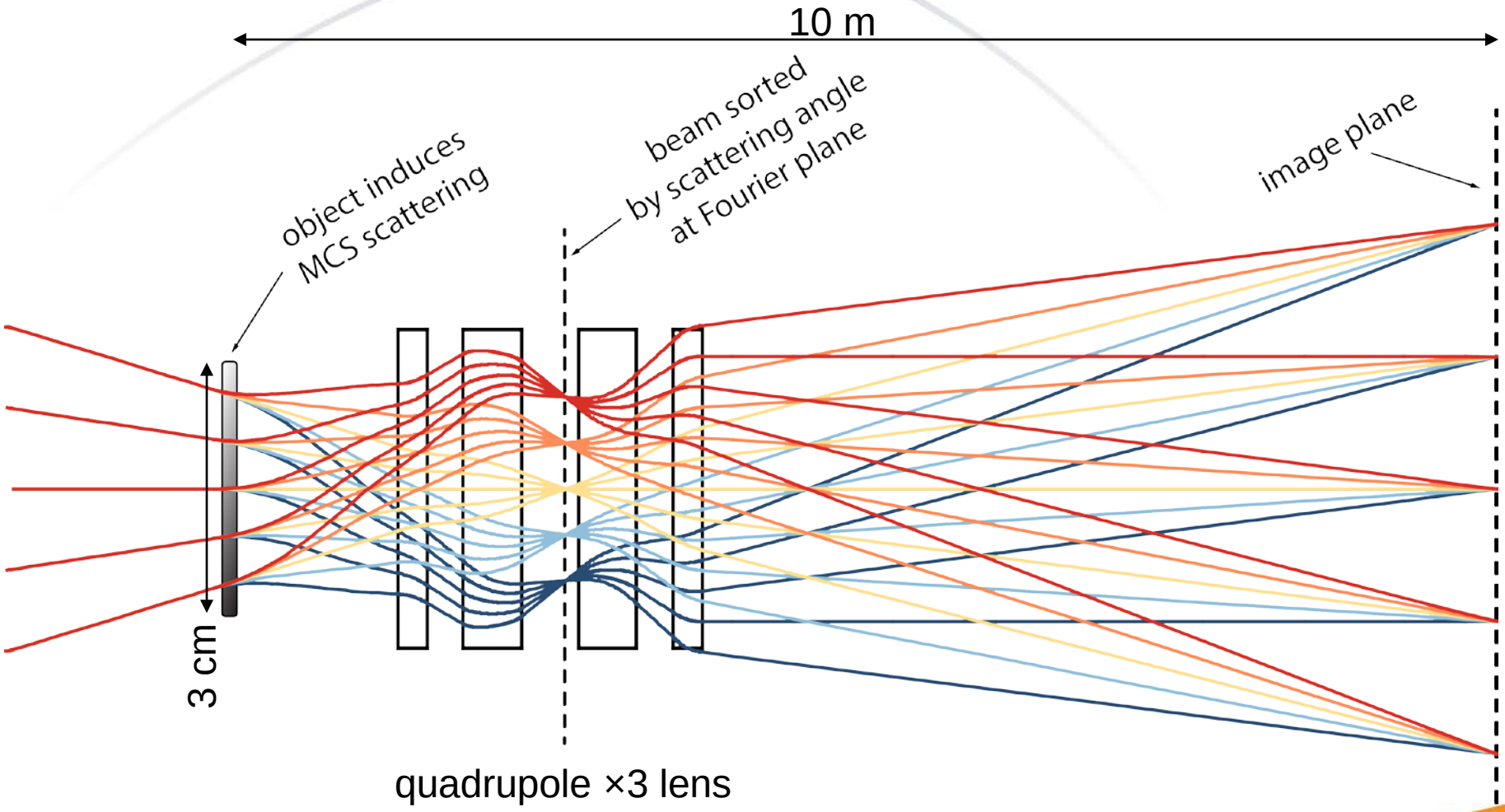
Proton radiography provides high resolution 3D information



- **Fine details visible, showing excellent resolution**
- **New collimators informed by modeling continue to enhance contrast in soft tissue, even more so with targeted gold nano-particles.**

A magnetic lens focuses the proton beam similar to glass lenses focusing light



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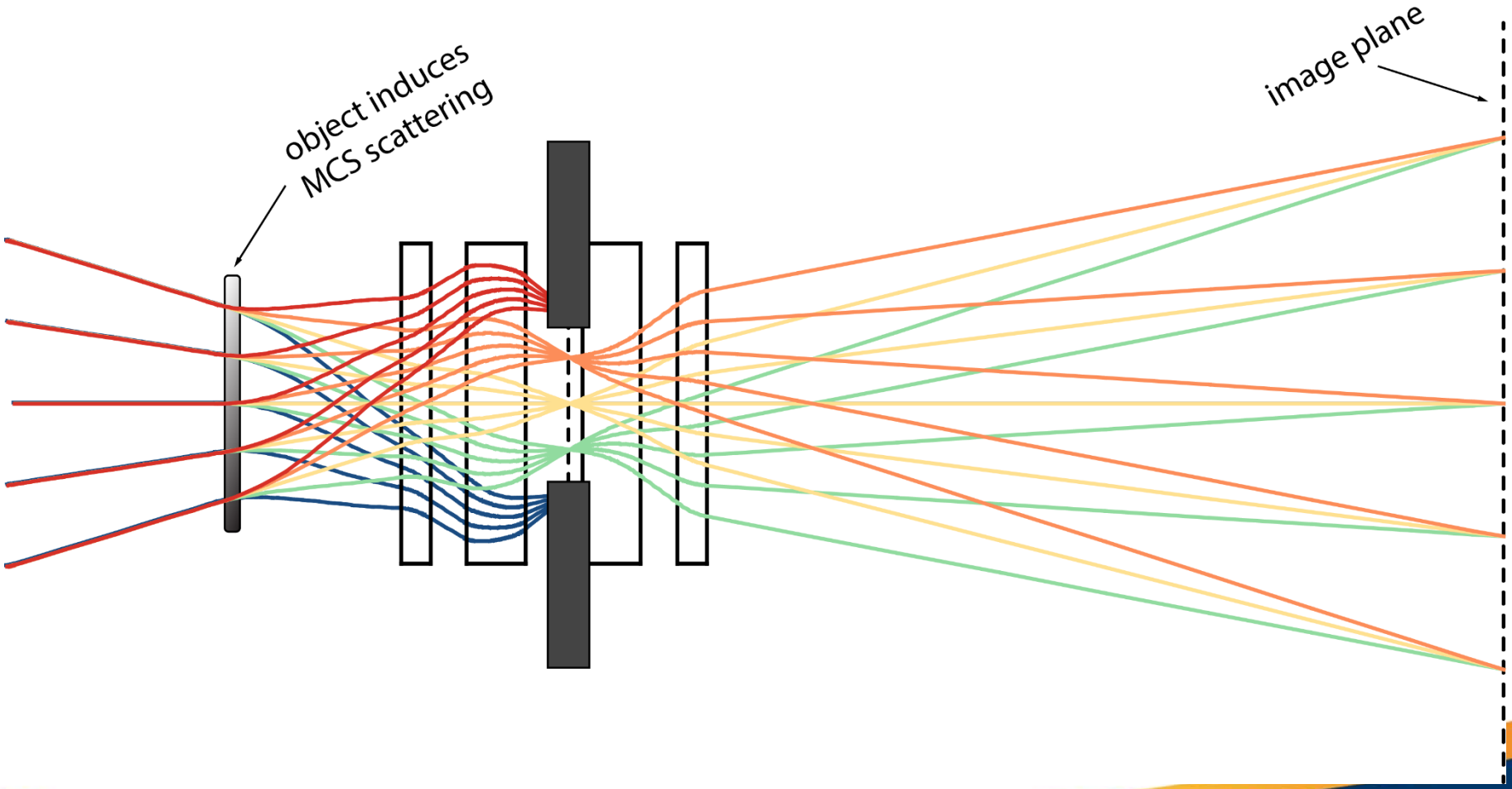

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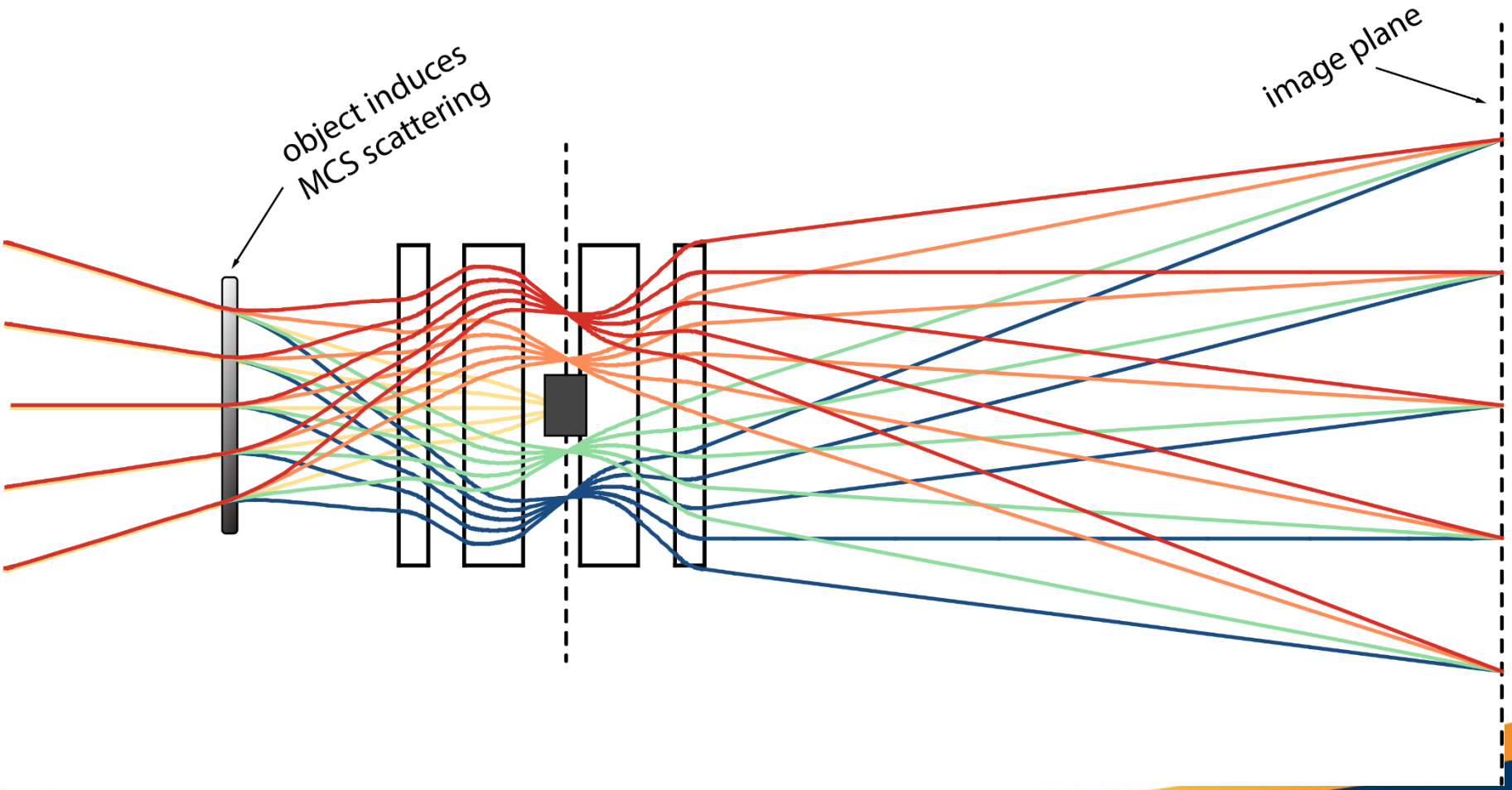

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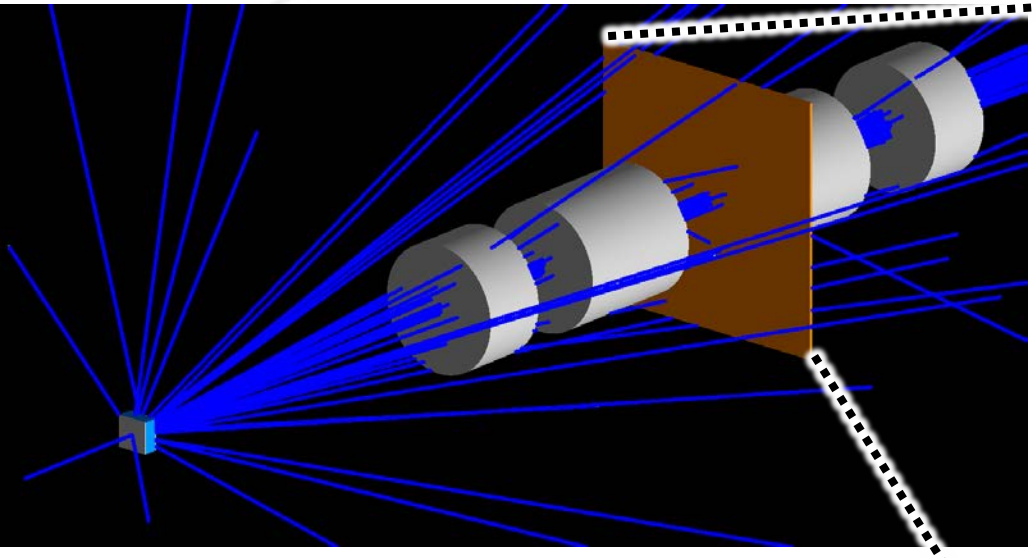
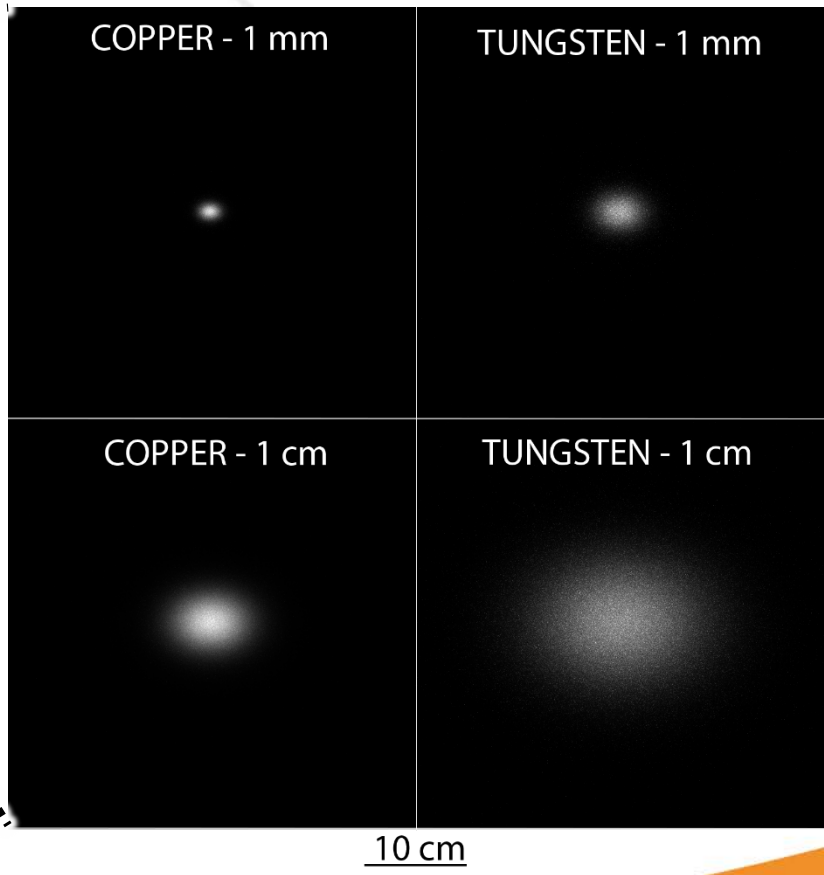
New collimator exploits known scatter to enhance contrast

detector placed at Fourier (scattering angle) plane



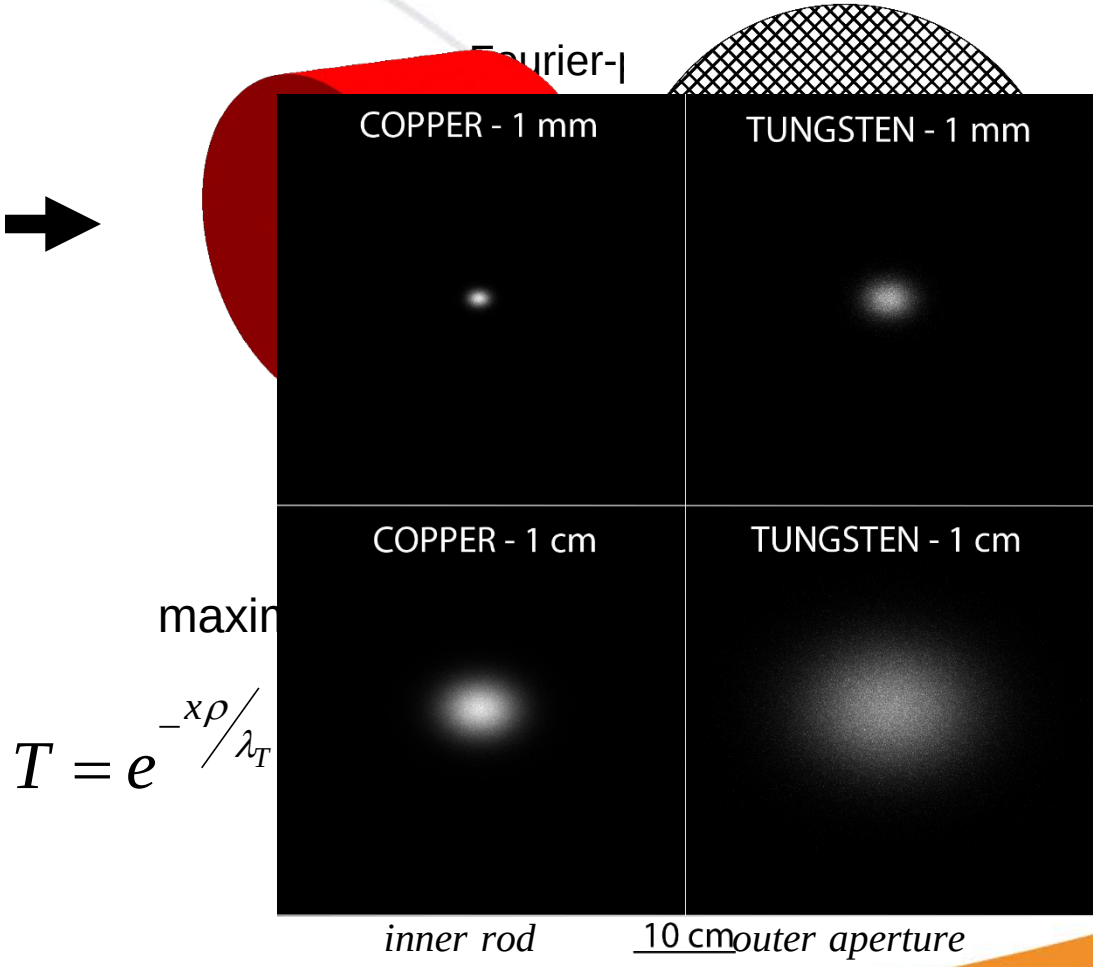
Fourier-plane images



scatter introduced by object:

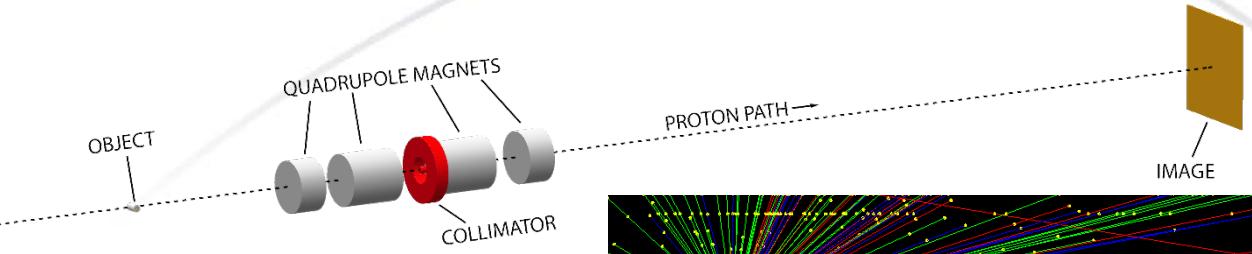
$$\theta_o = \frac{13.6MeV}{\beta p}\sqrt{x/X_o}\left[1+0.038\ln\left(x/X_o\right)\right]$$

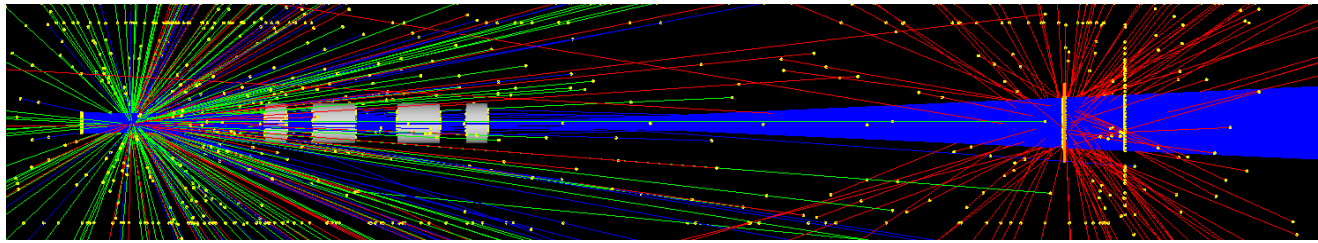
New collimator exploits known scatter to enhance contrast



$$T = e^{-x\rho/\lambda_T}$$

Modeling the proposed collimator informs design changes

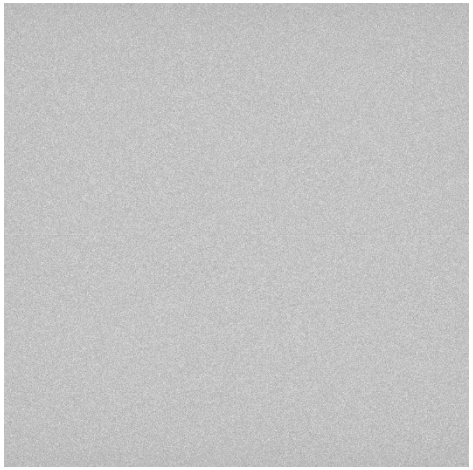




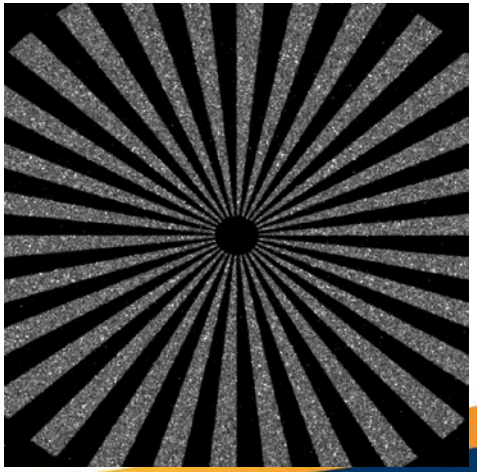
Monte-Carlo simulation

100-μm Pb target

no collimator



new collimator



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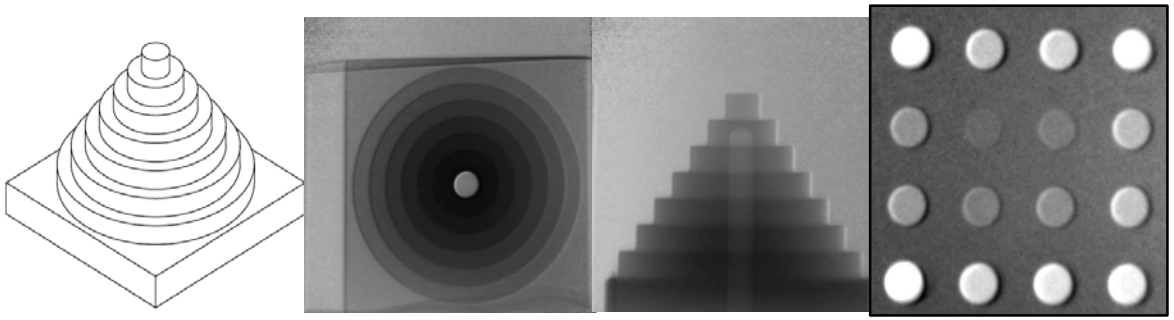
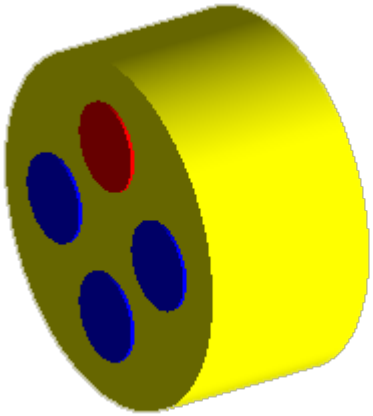
Modeling the scatter-acceptance angle for biological relevance

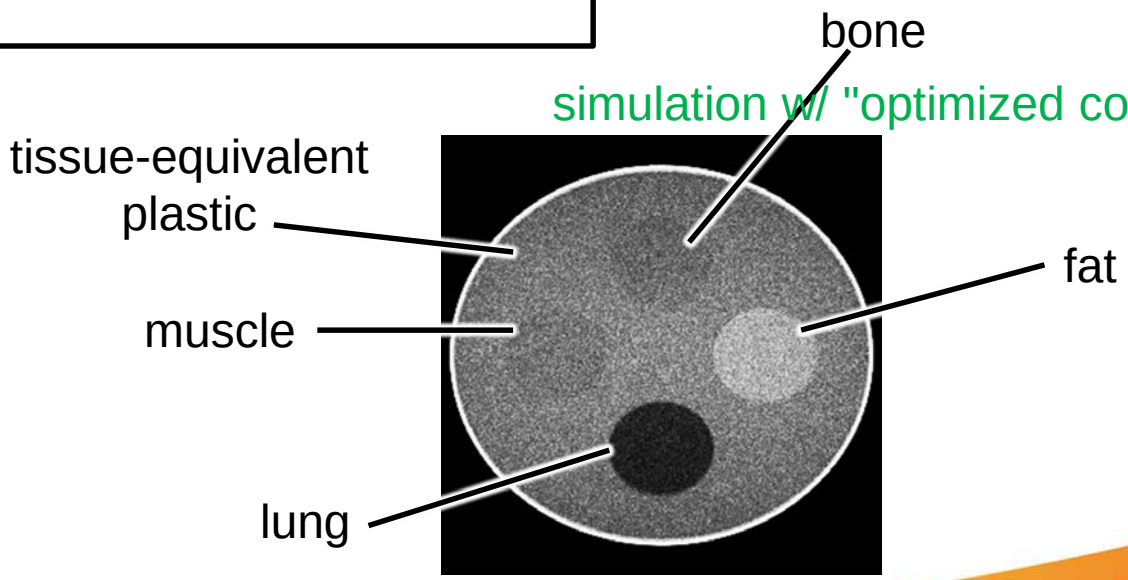


Proton radiography of tissue-equivalent PMMA calibration objects with inverse collimator

digital tissue phantom



simulation w/ "optimized collimat



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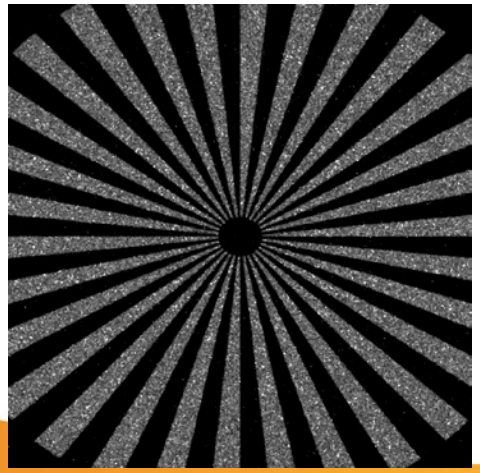
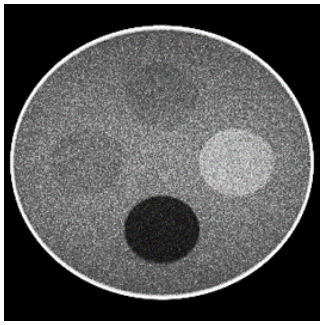
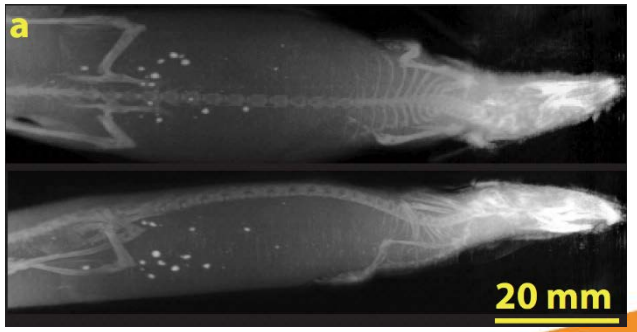
Conclusions

- 800 MeV proton radiography continues to find new applications, providing new information to measure properties of dynamic materials
- Proton radiography research for national security and medical imaging development are mutually beneficial
- Preliminary studies by an external user collaboration may enable vastly improved precision in proton cancer treatment







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