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Title: Proton Radiography at the AGS

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Explaining pRad possibilities at AGS to wide audience

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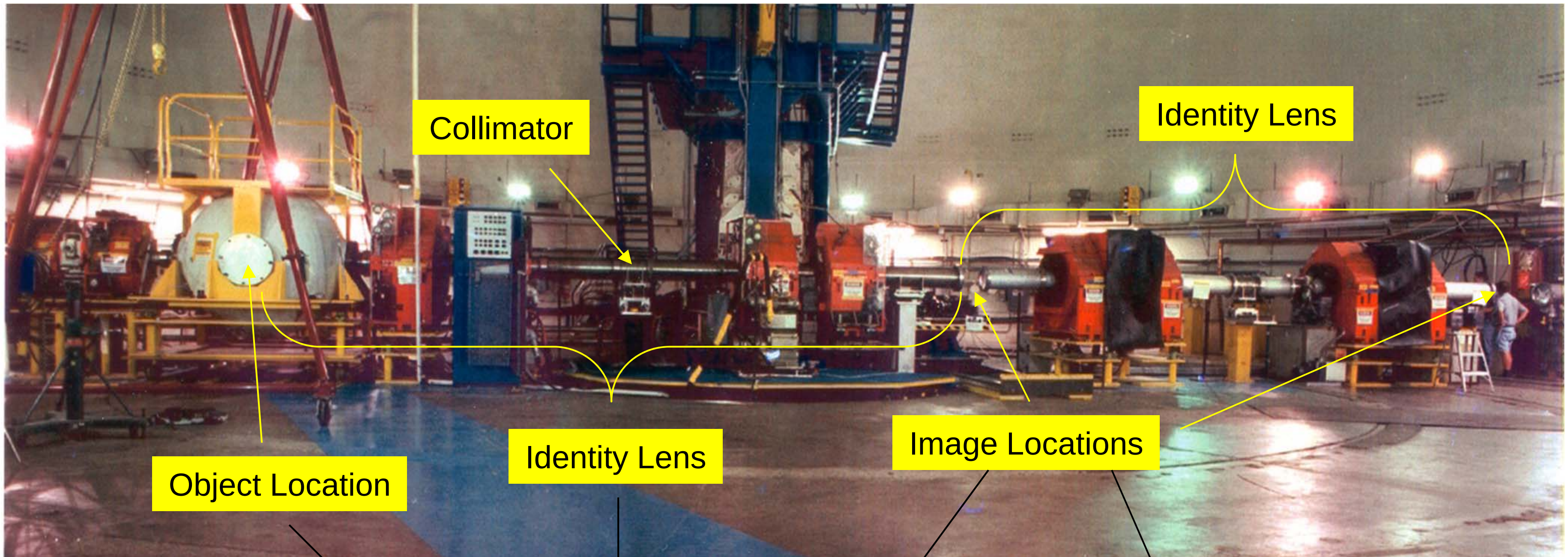
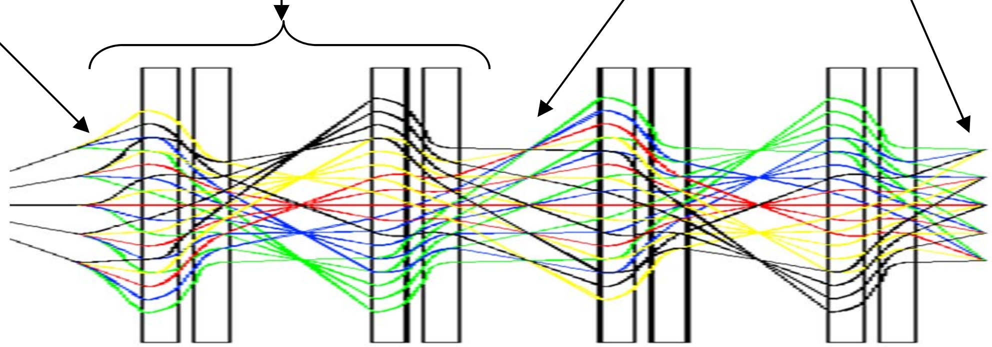
BNL Transformative Hadron Beam
Workshop July 2014

Proton Radiography at the AGS

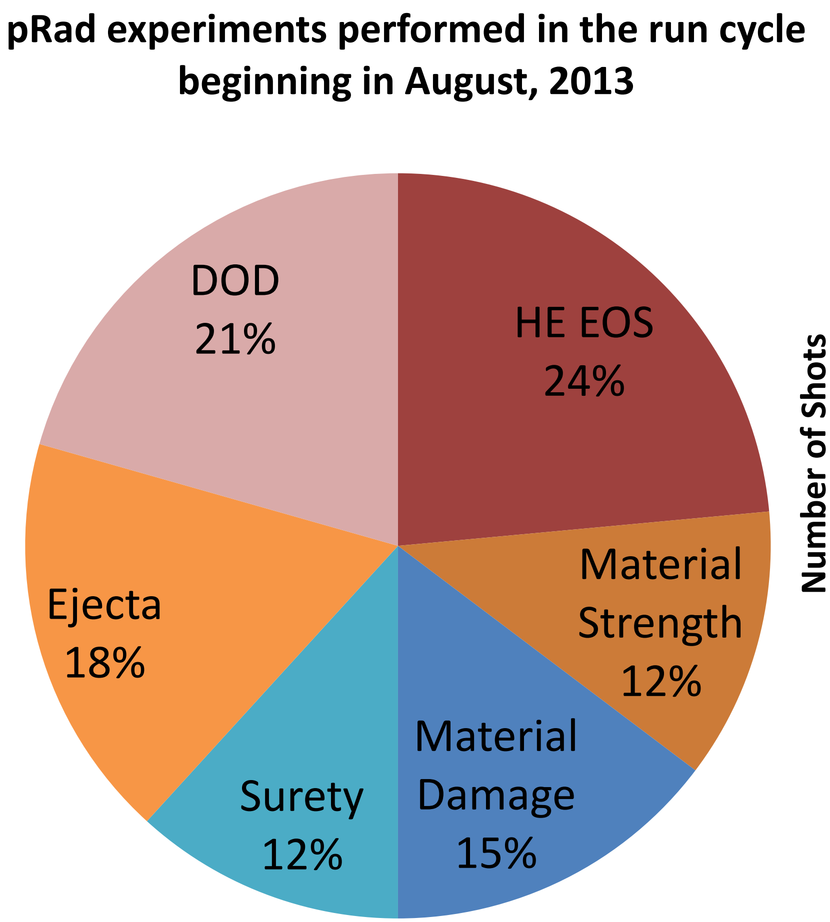
Alexander Saunders
for the LANL pRad collaboration

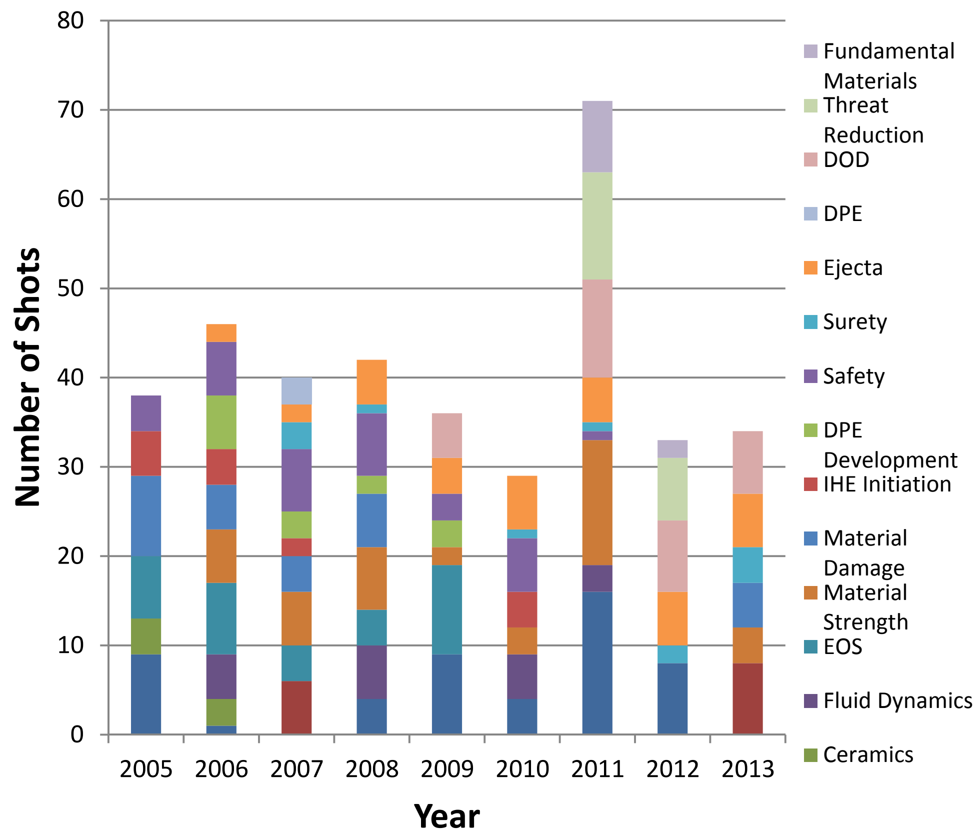
800 MeV pRad Facility at LANSCE





A diverse set of pRad experiments have been performed in the run cycle beginning in August, 2013: NNSA funded



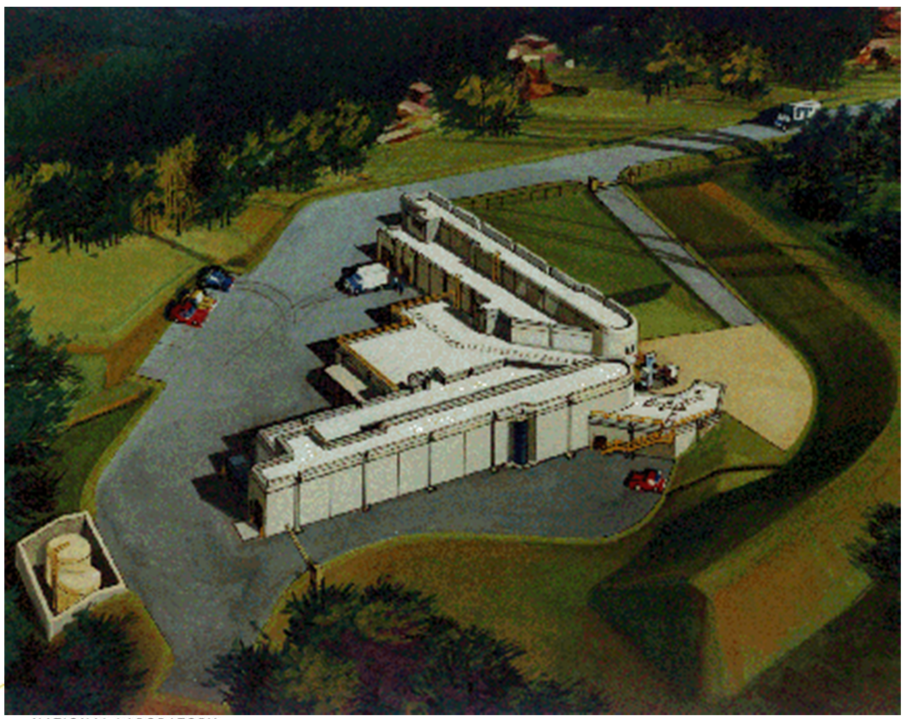


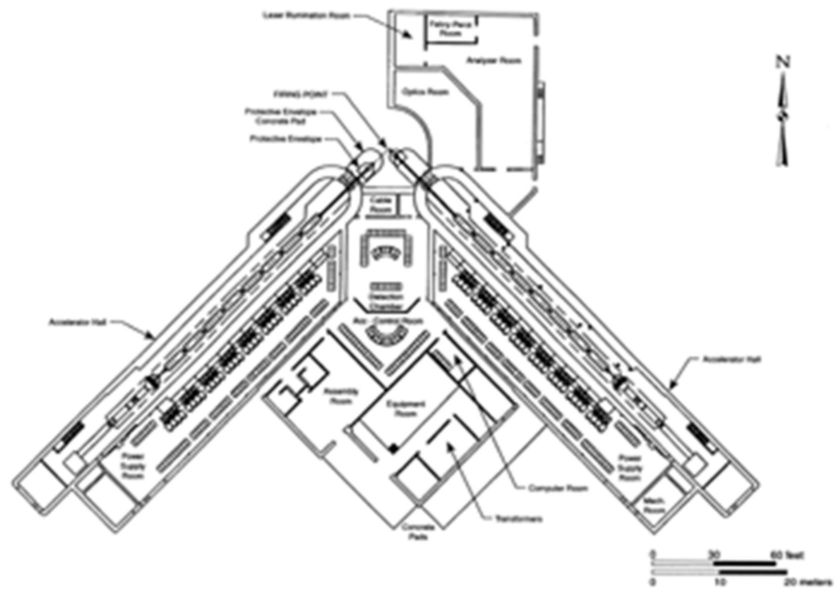
Dual Axis Radiographic Hydrodynamic Test facility (DARHT)

- Cold war stockpile
  - Remanufacture?
  - Science based stewardship?
  - Redesign?
  - Negotiated reductions?

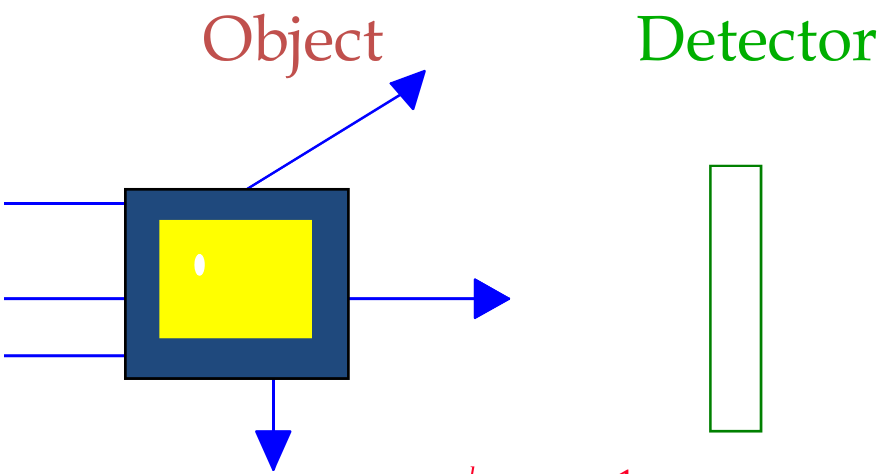
Implosions with surrogate materials (Hydrotest) coupled with modeling and simulation.

Hydrotest goal is to infer hydrodynamic performance by measuring locations and sizes of features through full thickness of imploding object





Radiography-mean free path



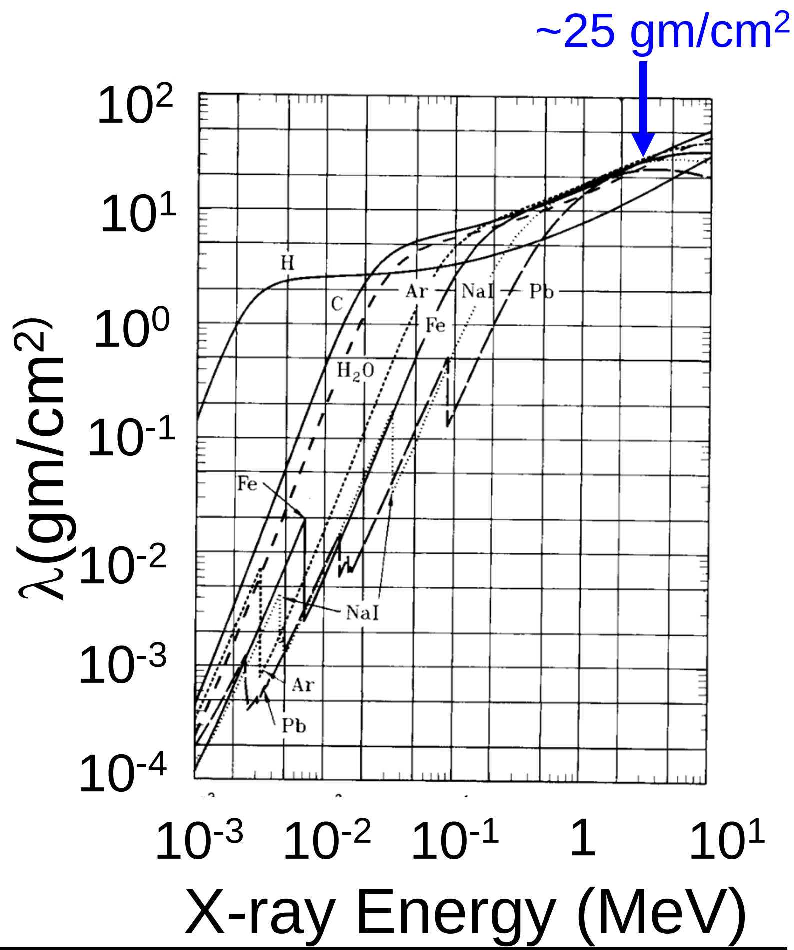
$$N = N_0 e^{-\frac{l}{\lambda}}, \ \lambda = \frac{1}{\rho\sigma}$$

$$l = -\lambda \ln\left(\frac{N}{N_0}\right)$$

$$\Delta l = \frac{\Delta N}{N}\lambda = \sqrt{\frac{1}{N}}\lambda$$

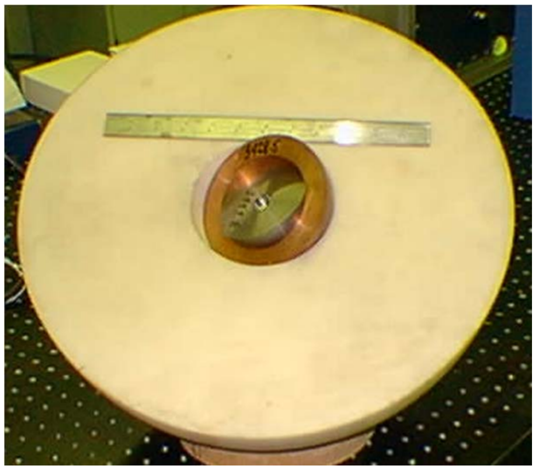
$$\text{solving } \frac{d(\Delta l)}{d\lambda} = 0 \text{ gives :}$$

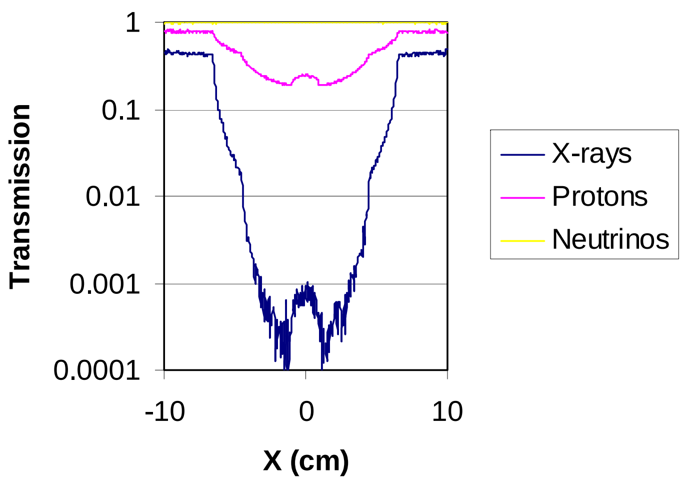
$$\lambda = \frac{l}{2}, \text{ the "best" mean free path.}$$



Different probes-1.$\times 10^9$ incident particles.

French test object (FTO)





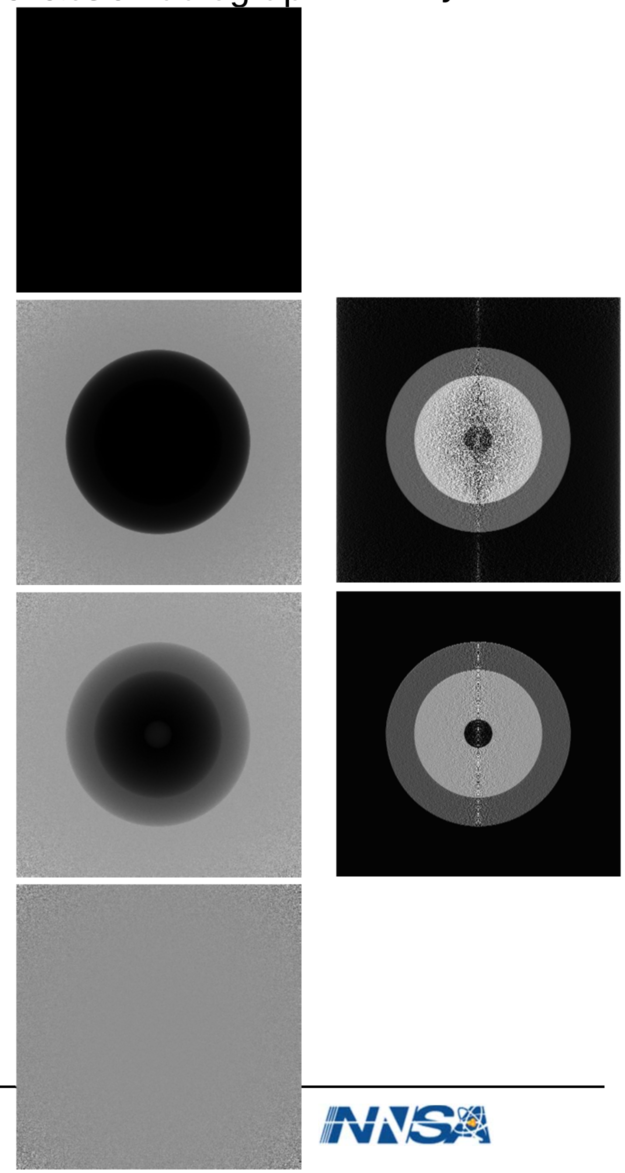
Simulated radiograph Density reconstruction

bb's
$\lambda = 0.$ g/cm^2

X-rays
$\lambda = 25.$ g/cm^2

Protons
$\lambda \approx 185.$ g/cm^2

Neutrinos
$\lambda = \infty$ g/cm^2

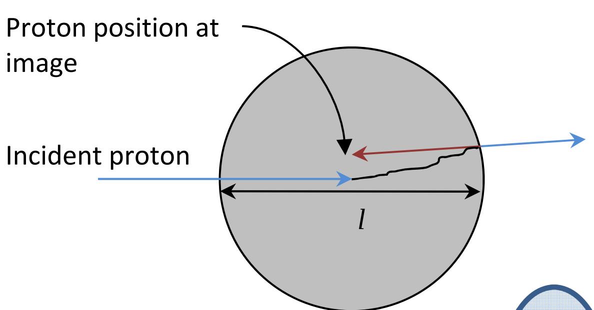


Resolution of Proton Radiography

1. **Object scattering** - introduced as the protons are scattered while traversing the object.
2. **Chromatic aberrations**- introduced as the protons pass through the magnetic lens imaging system.
3. **Detector blur**- introduced as the proton interacts with the proton-to-light converter and as the light is gated and collected with a camera system.

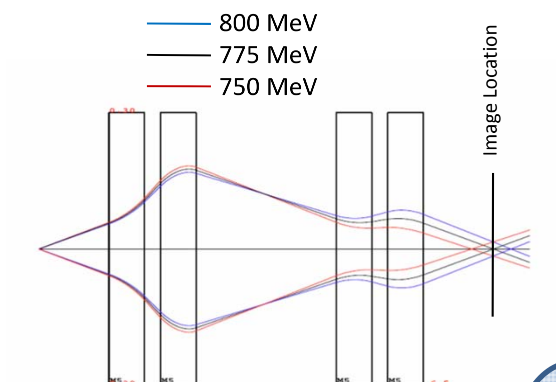
Assume detector development can keep up

Object Scattering



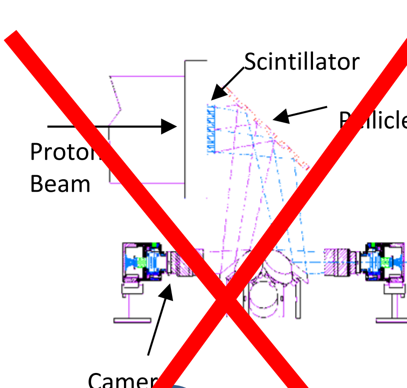
$$\sigma_o = \frac{1}{\sqrt{3}}\theta\frac{l}{2} = \frac{14.1}{\sqrt{6}}\frac{1}{P\beta}\sqrt{\frac{l^3}{x_o}} \propto \frac{l^{\frac{3}{2}}}{P}$$

Chromatic Aberrations



$$\sigma_c = l_c\theta\frac{\delta P}{P} = c\sqrt{P}\frac{\delta P}{P^2}\frac{14.1}{\beta}\sqrt{\frac{l}{x_o}} \propto \sqrt{\frac{l}{P^3}}$$

Detector Blur



Scintillator

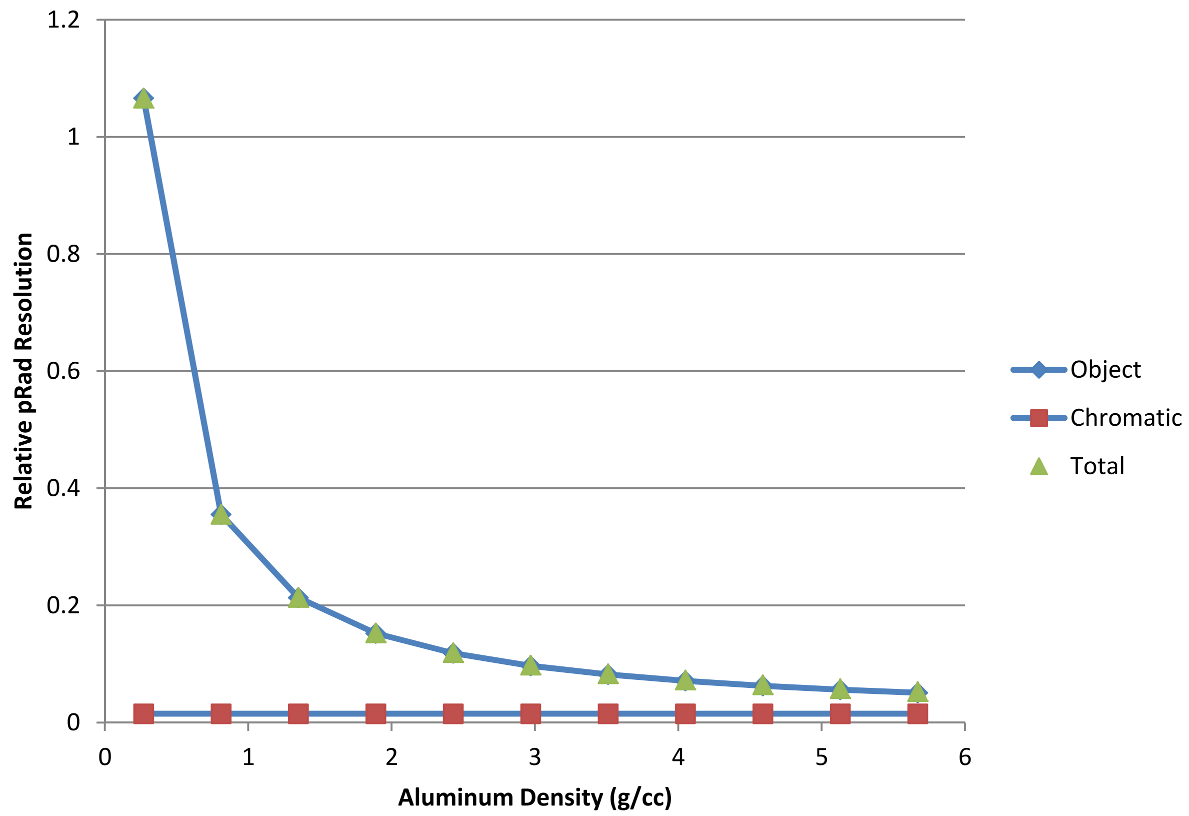
$$\sigma_s = \theta l_s \propto \frac{l_s\sqrt{l}}{P}$$

Camera

Resolution is independent of proton energy

BNL pRad achieves <100 μm resolution on FTO-like objects

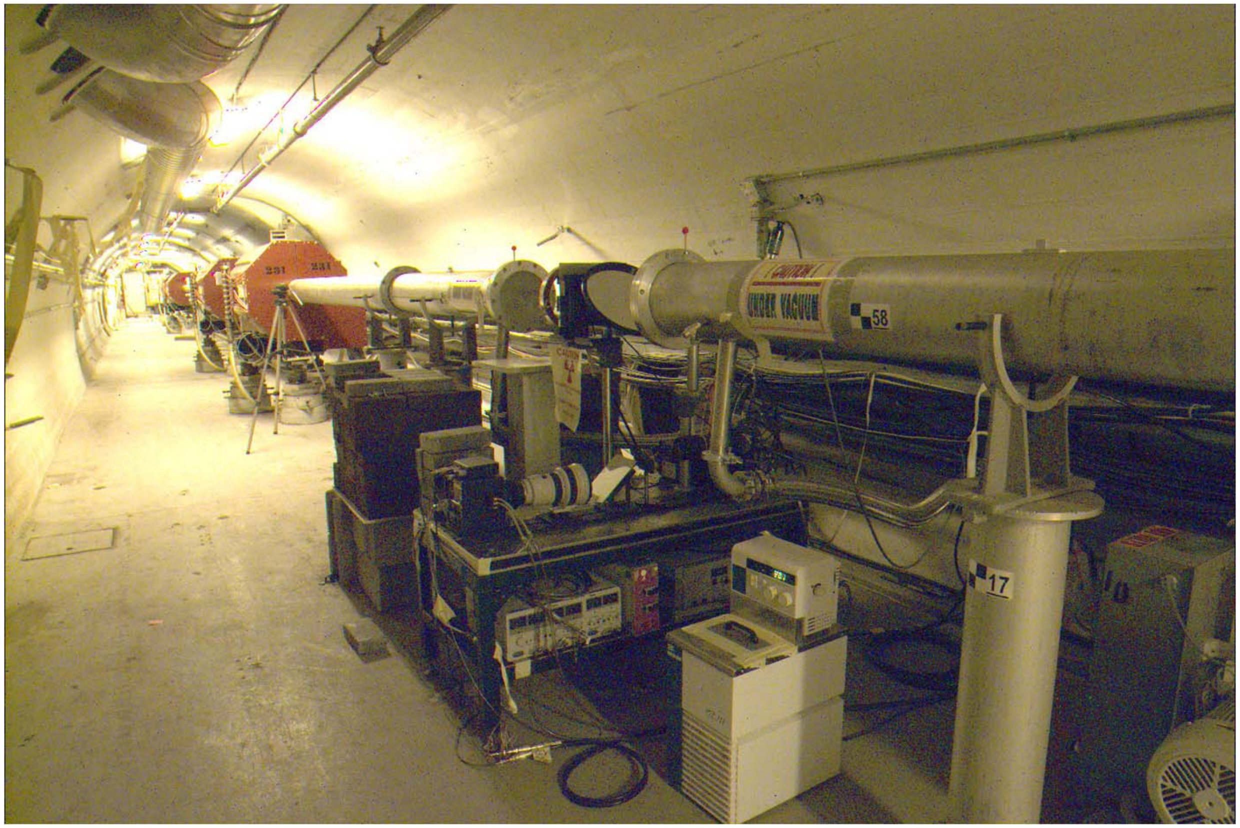
- Object blur dominates on static FTO
- But is much smaller on dynamic object due to higher density
- AGS can produce and kick single pulse at 24 GeV or four pulses (stored simultaneously) at 7.5 GeV



Lens system and camera station for 24 GeV radiography at the AGS (Experiment 933)

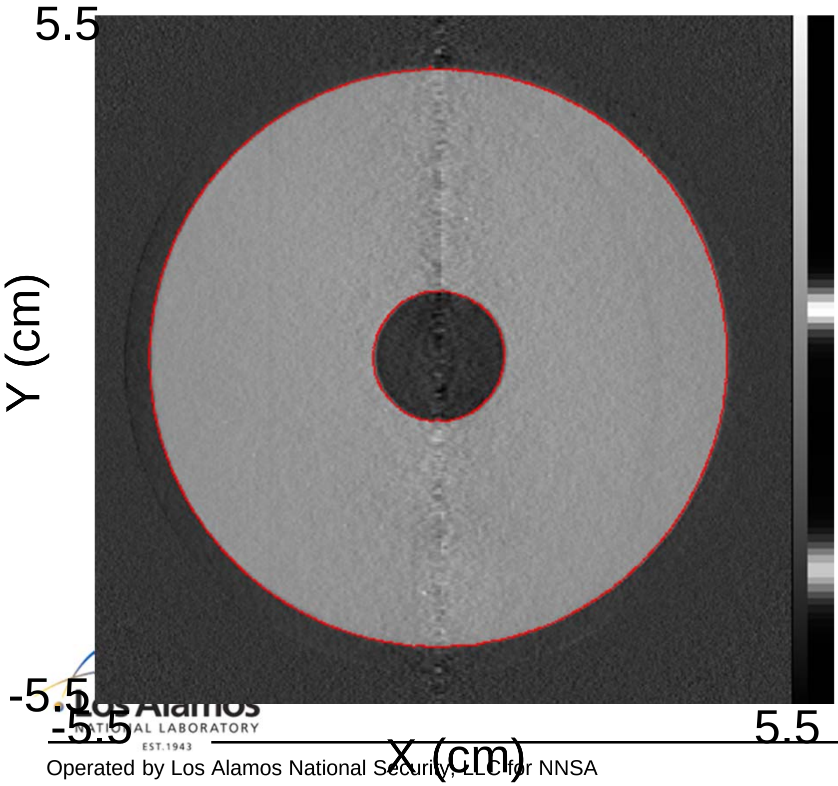
24 GeV
~30 ns pulses
$<1\times10^{11}$ protons/pulse

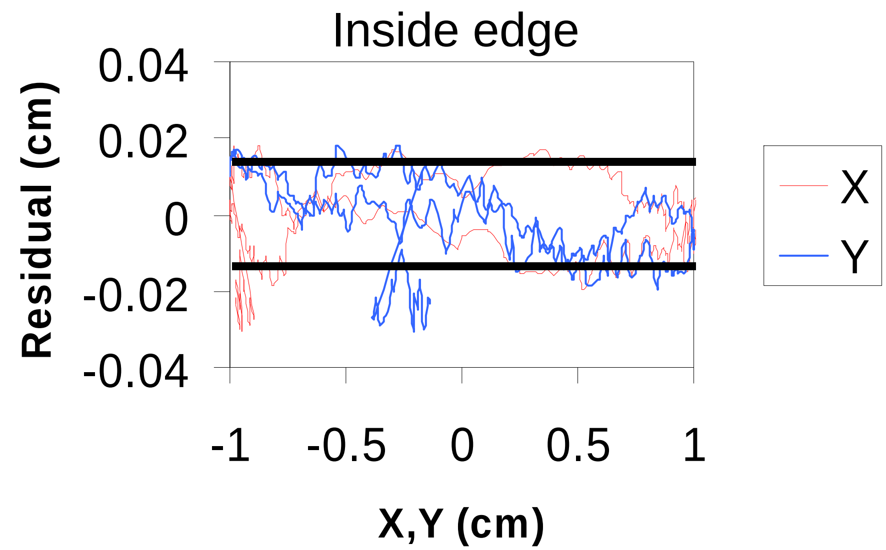
pRad lens in U-Line
at AGS

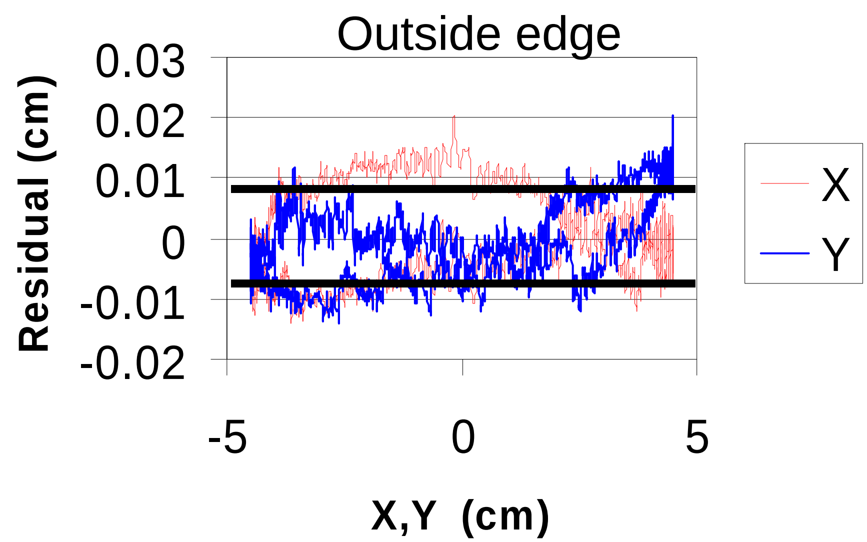


FTO edge determination

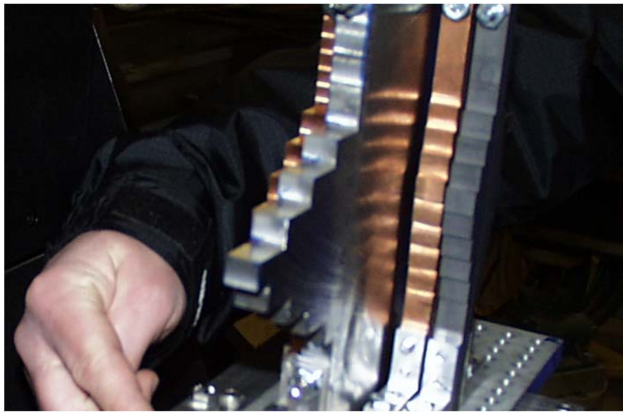
	Radius	s
	cm	xm
Outside	4.4895	0.0072
Inside	1.0090	0.0106

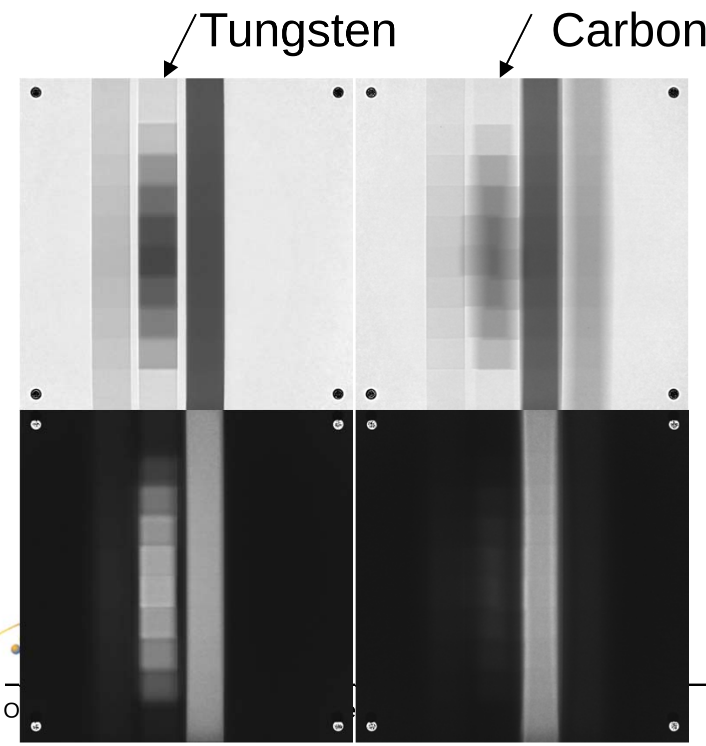


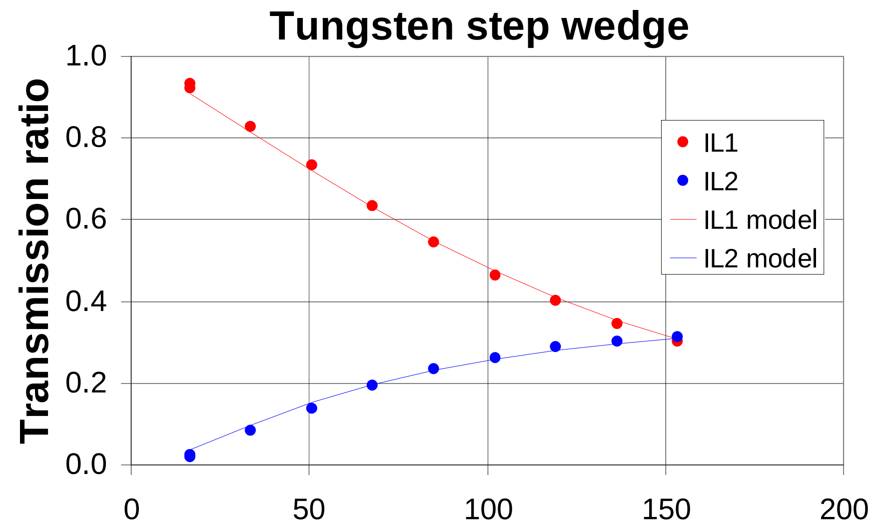


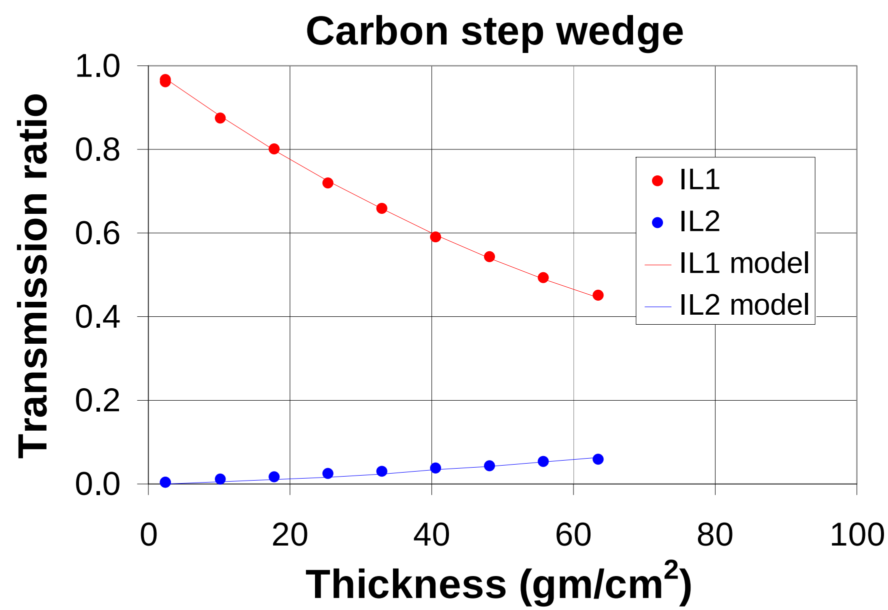


Model fits to step wedge data; a demonstration of material identification (AGS Exp 955)

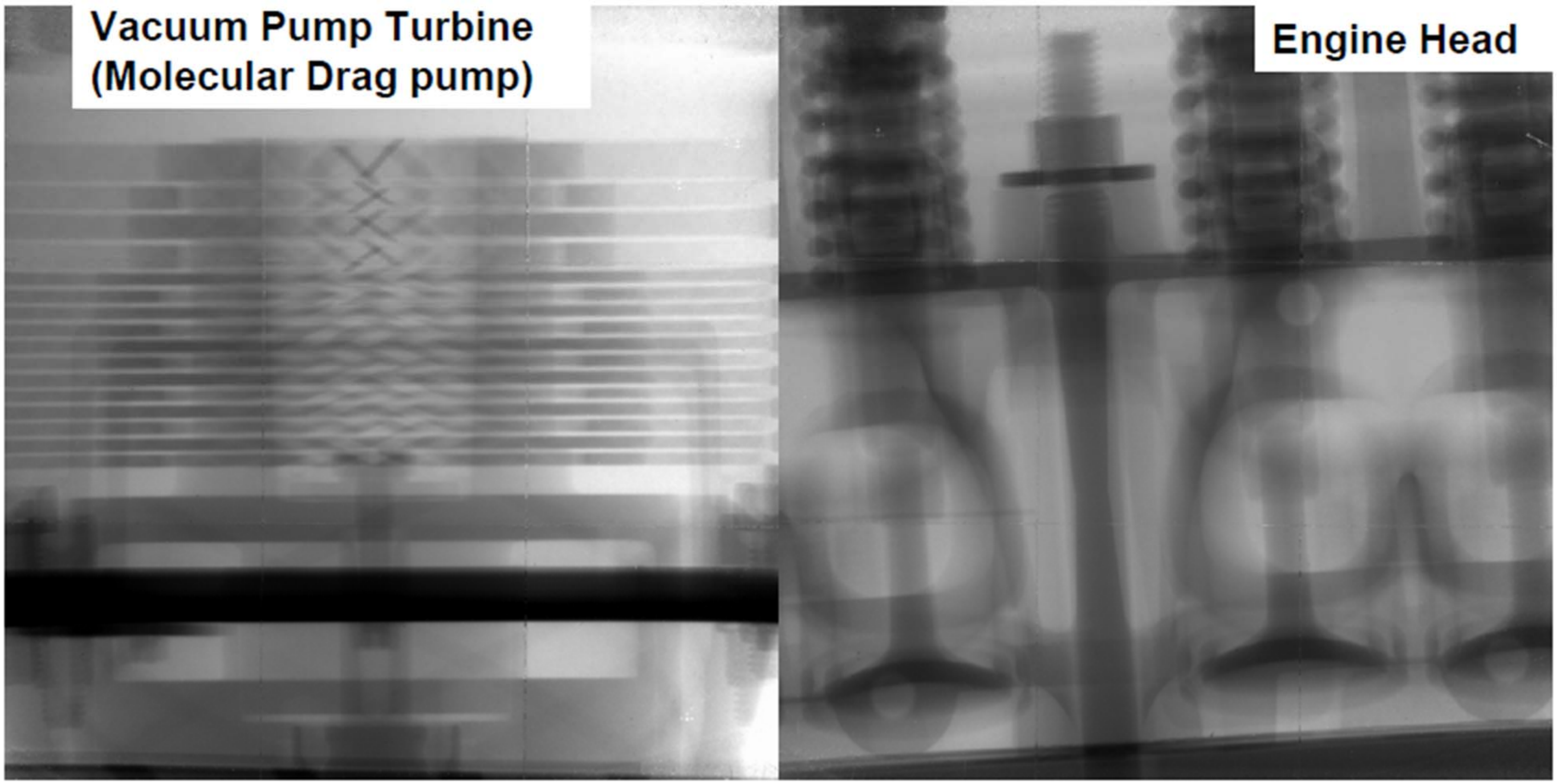






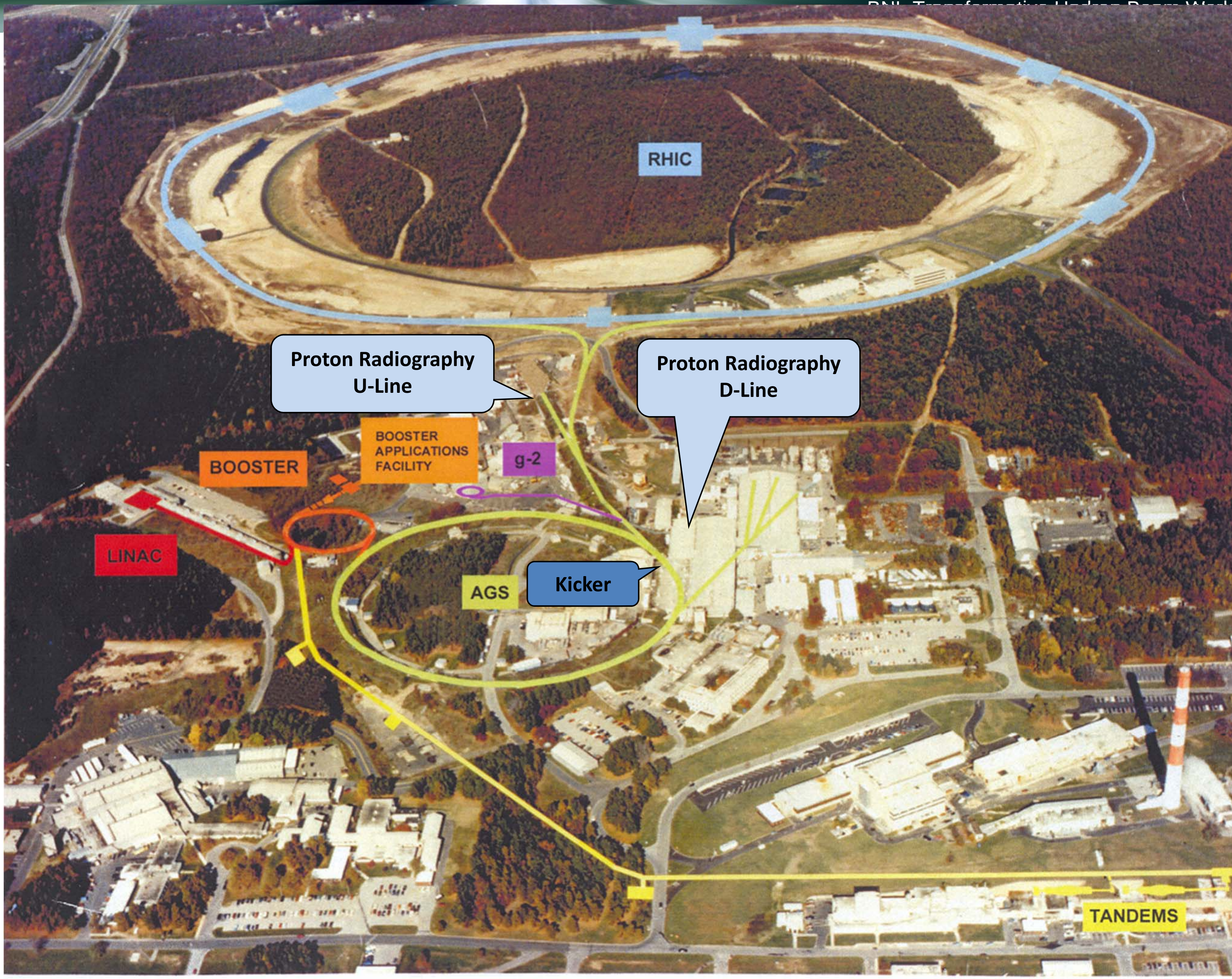


Industrial Applications could take advantage of NNSA-funded pRad facility



AGS would be a perfect source for high energy pRad facility

- Could perform single pulse or multiple pulse experiments
  - Kicker limits to one pulse at 24 GeV or four at 7.5 GeV
  - AGS limits to 12 pulses at 24 GeV
- 7-24 GeV protons
  - But only one pulse per five minutes
  - So can run in parallel with high current applications
- Static and dynamic experiments
- Requires dedicated beam line
  - Building 912 (D-Line) is ideal location
  - But U-Line reconstructed is also possible


RHIC
Proton Radiography
U-Line
Proton Radiography
D-Line
BOOSTER APPLICATIONS FACILITY
BOOSTER
g-2
LINAC
AGS
Kicker
TANDEMS

Summary

- pRad at LANSCE (LANL) is a mature program in support of NNSA goals, but limited to 800 MeV
- A pRad facility at BNL would represent a dramatic improvement in the nation's flash radiographic capability
- Building 912 or U-Line would be possible locations; pRad would use a tiny fraction of the AGS's duty factor
- Industrial users could be expected to take advantage of this new capability