Los Alamos NATIONAL LABORATORY

Development of Achromatic Imaging Capabilities for pRad at LANSCE

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08/09/2022

LA-UR-22-28021

Contents

Part I – Motivation

- Proton radiography basics
- Present limitations of 800 MeV pRad at LANSCE

Part II – Focus Stacking (Semi-Achromat)

- Focus stacking concept & limitations
- First experimental results (July/August 2022)

Part III – Achromatic Lens System

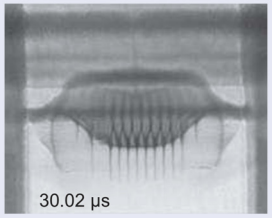
- Prototype design for 21.5 MeV electrons

Why Proton Radiography?

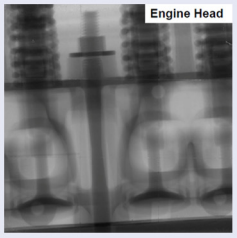
High energy protons have:

- Good range in matter
- Low amount of scattering
- Low dose deposition
- Excellent accelerator timing capabilities

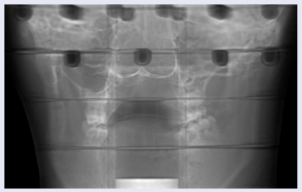
Suitable diagnostics for:



materials in extremes



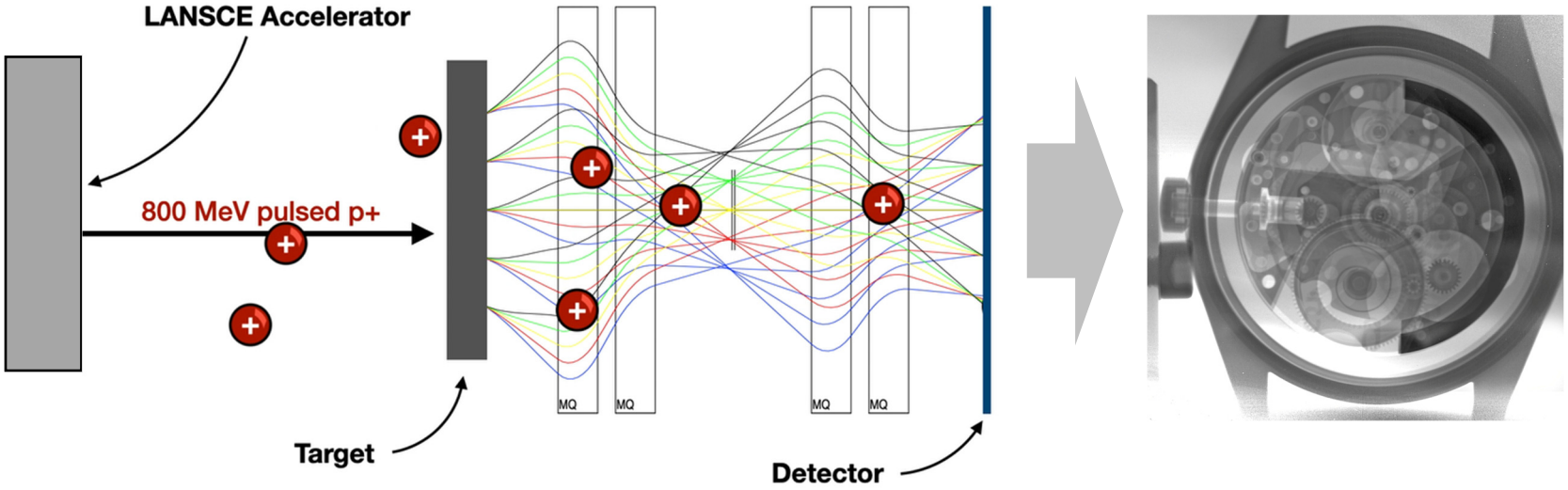
industrial applications



biophysics / medical applications

Proton Radiography – Theory

Lens based radiography



Proton transport through lens system:

$$\begin{pmatrix} x_i \\ a_i \end{pmatrix} = \begin{pmatrix} R_{11}^I & R_{12}^I \\ R_{21}^I & R_{22}^I \end{pmatrix} \begin{pmatrix} x_o \\ a_o \end{pmatrix}$$

Expression at the image plane:

$$x_i = R_{11}^I x_o + \cancel{R_{12}^I a_o}$$

=0 (imaging)

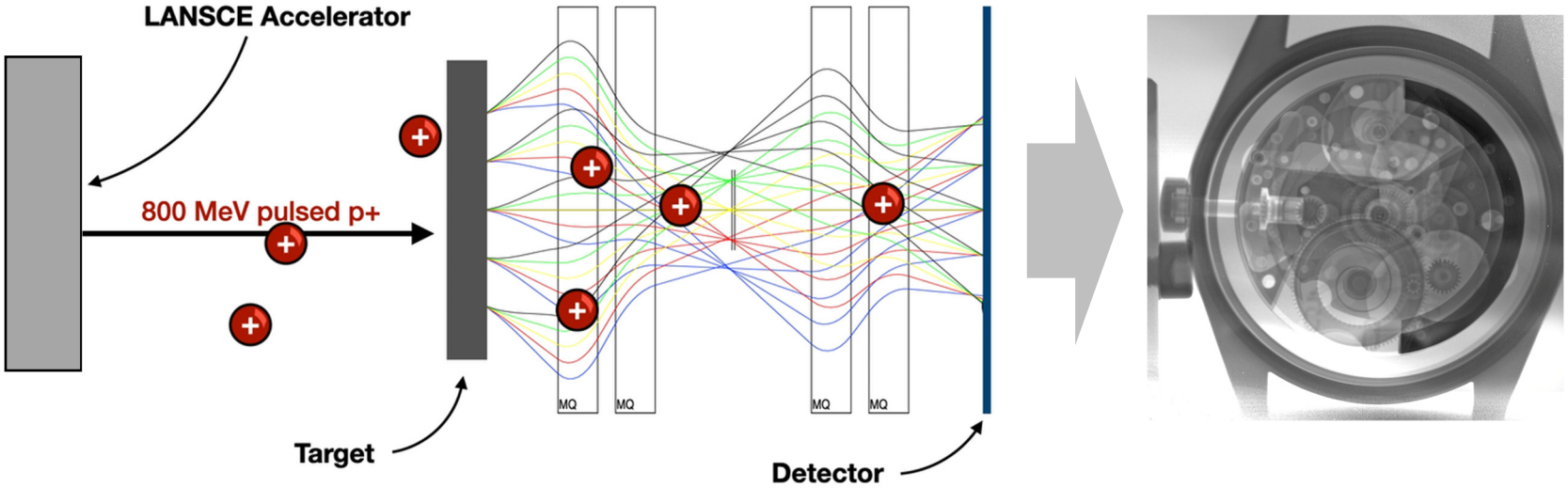
Adding 2nd order terms:

$$x_i = m\,x_o + \cancel{T_{116} x_o \delta} + T_{126} a_o \delta$$

=0 (matching)

Proton Radiography – Theory

Lens based radiography



Proton transport through lens system:

$$\begin{pmatrix} x_i \\ a_i \end{pmatrix} = \begin{pmatrix} R_{11}^I & R_{12}^I \\ R_{21}^I & R_{22}^I \end{pmatrix} \begin{pmatrix} x_o \\ a_o \end{pmatrix}$$

Expression at the image plane:

$$x_i = R_{11}^I x_o + R_{12}^I a_o$$

=0 (imaging)

Adding 2nd order terms:

$$x_i = m\,x_o + T_{116} x_o \delta + T_{126} a_o \delta$$

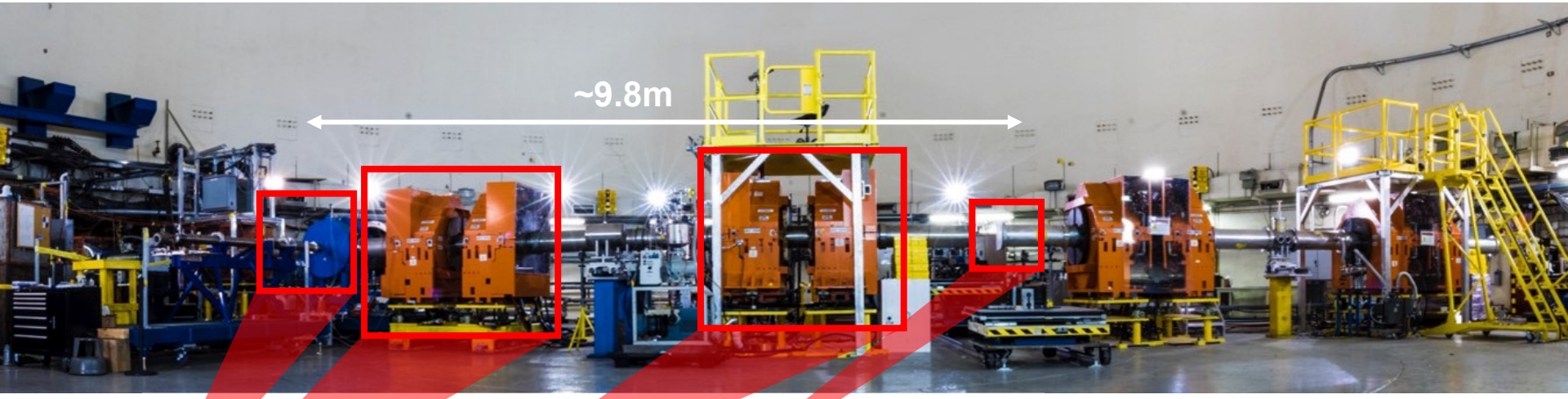
=0 (matching)

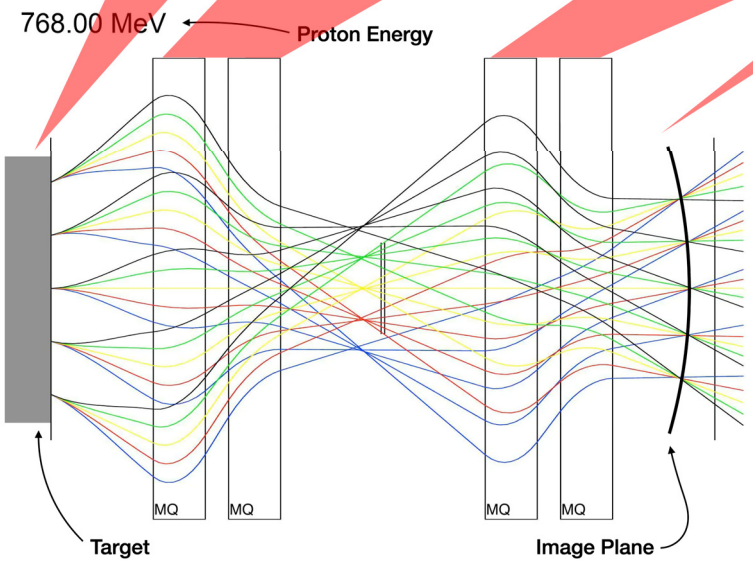
Final expression for the image plane:

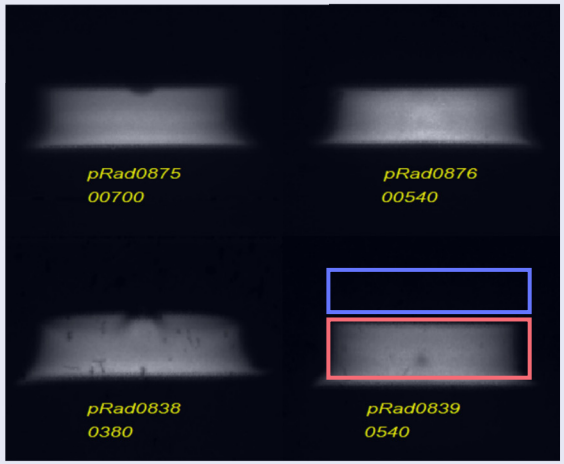
$$x_i = -\,m\,x_o + T_{126}\theta\delta$$

Proton Radiography – Limitations

Monochromaticity & depth of field limitation





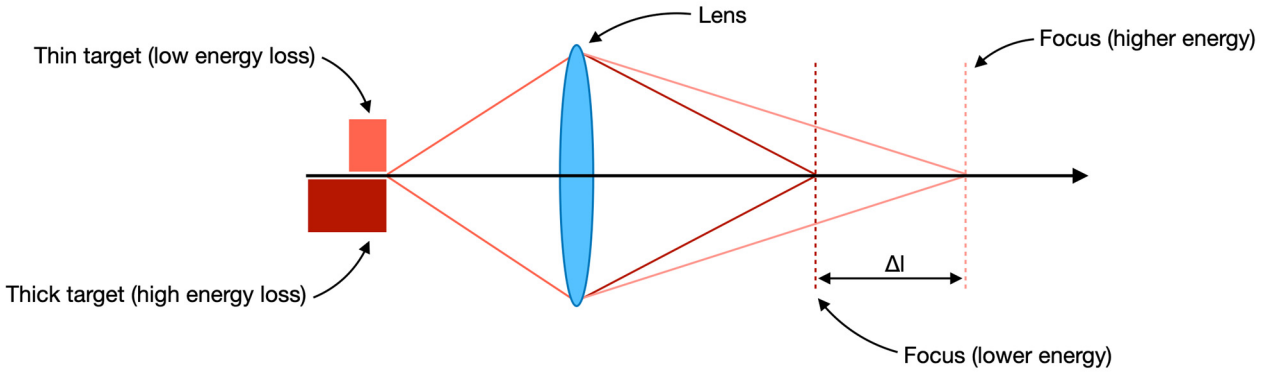


Focus either on **ejecta** (thin part)
or on **sock wave** (thick part)
–
but never on both!

Focus Stacking Concept

or ”the poor man’s achromat”

general concept



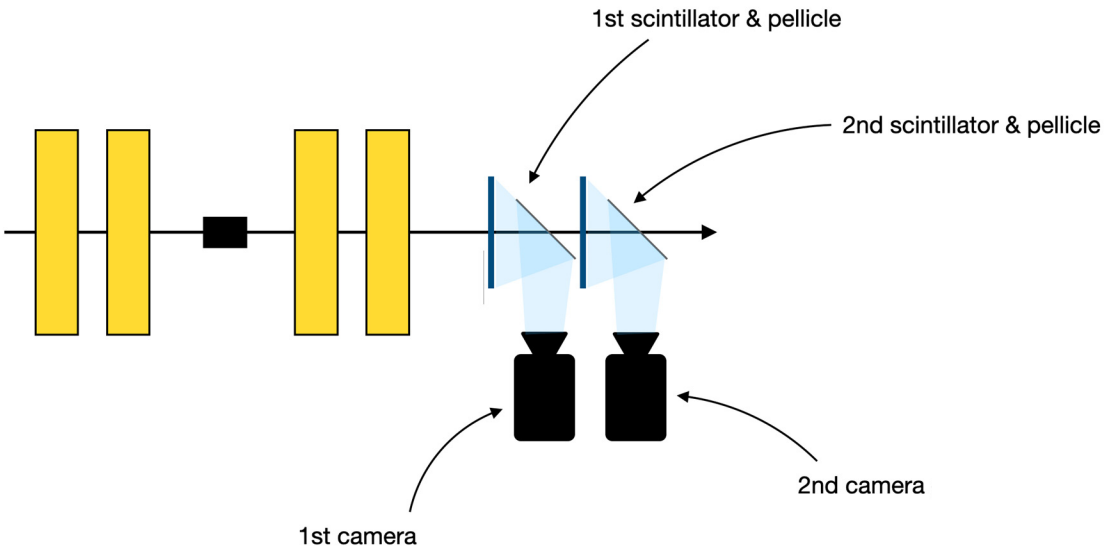
implementation for pRad

Focus Stacking Concept

or ”the poor man’s achromat”

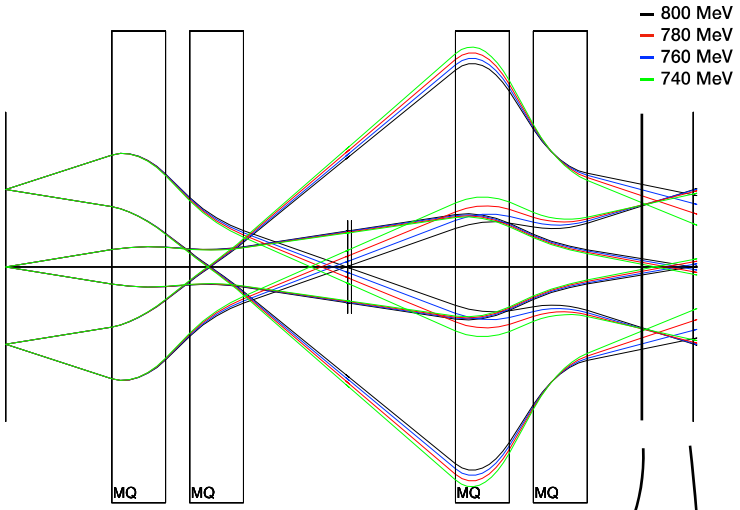
general concept

implementation for pRad



Focus Stacking Concept

Suitability for different pRad lens systems

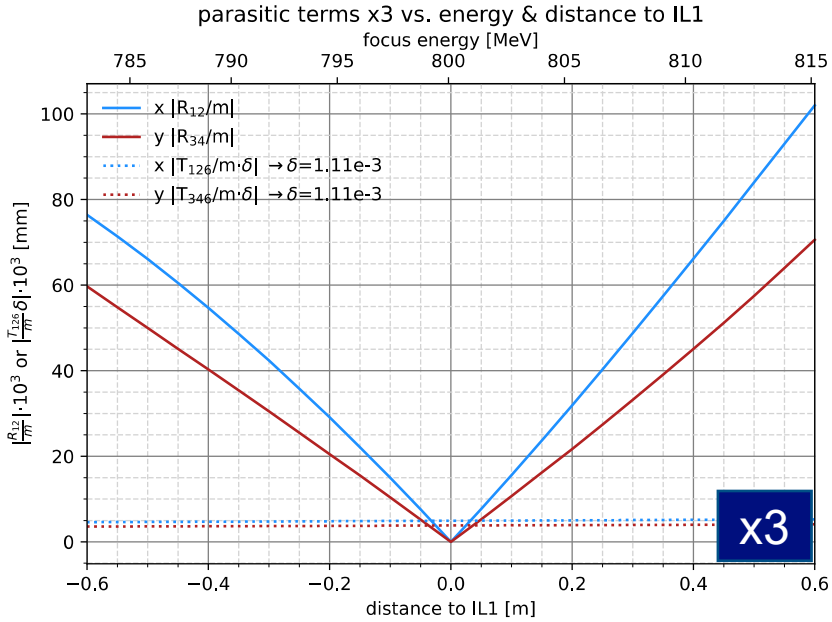


1st detector / image plane:

$$x_i = -m\,x_o + T_{126}\theta\delta$$

2nd detector / image plane:

$$x_i = -m\,x_o + \boxed{R_{12}a_0} + T_{126}\theta\delta$$

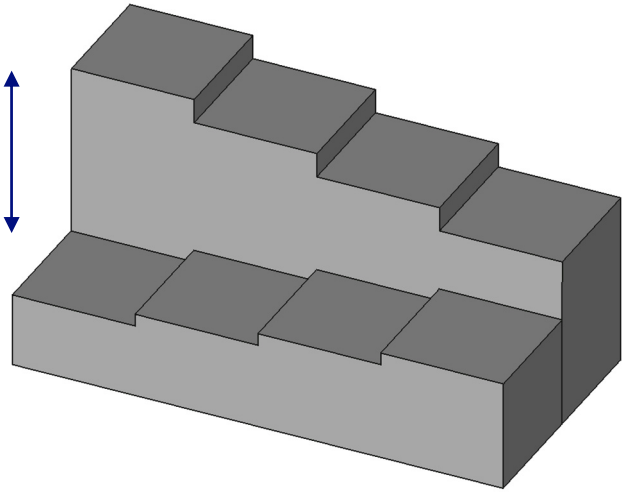


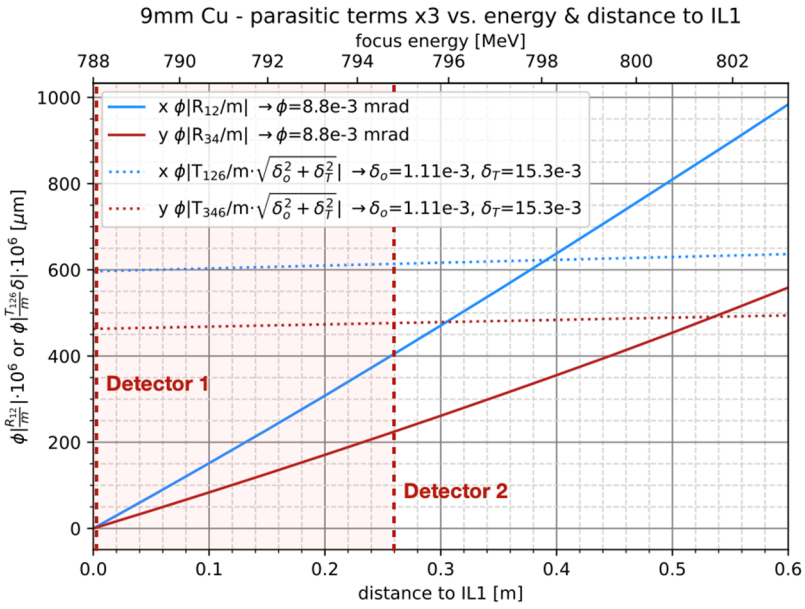
Focus Stacking Experiments

Target design & initial considerations

- Target geometry specifically designed to match a typical x3 focus stacking scenario
- Energy separation of ΔE = 6.8 MeV which corresponds to a detector z-shift of ~0.26 m

ΔE energy loss separation = 6.8 MeV

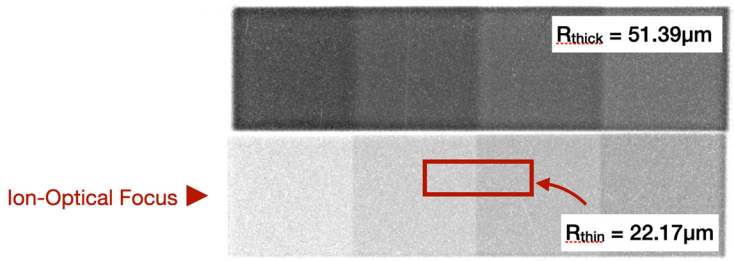




Focus Stacking Results

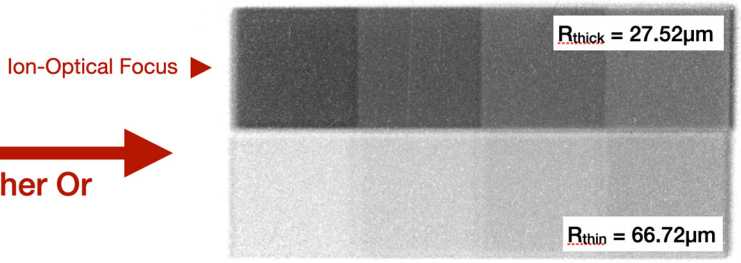
x3 magnifier / 10 mrad collimation

pRad



Regular pRad - 0mm Offset
Lens Focus @ -5MeV

Either Or



Regular pRad - 0mm Offset
Lens Focus @ -12MeV

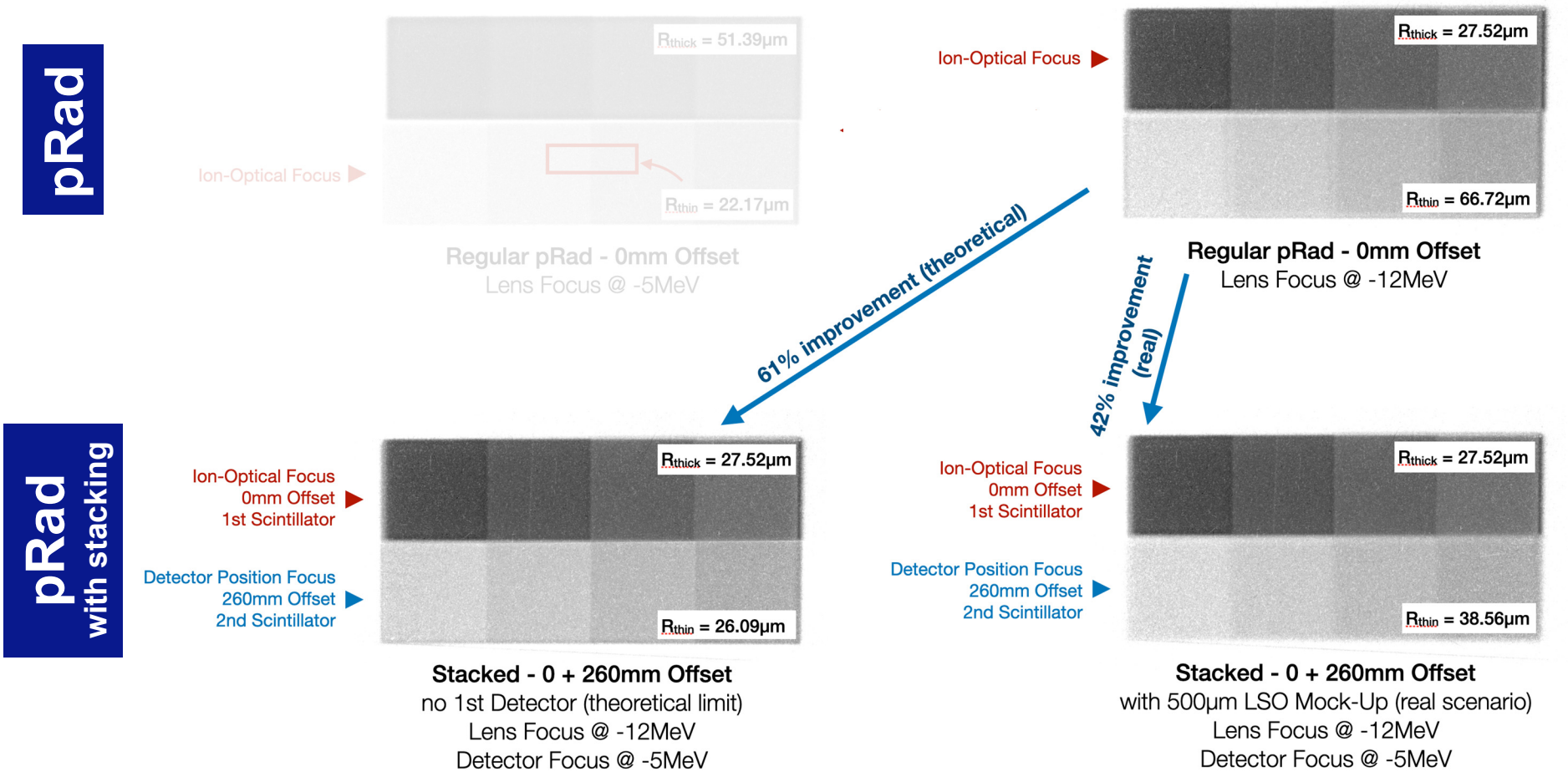
pRad with stacking

Stacked - 0 + 260mm Offset
no 1st Detector (theoretical limit)
Lens Focus @ -12MeV
Detector Focus @ -5MeV

Stacked - 0 + 260mm Offset
with 500μm LSO Mock-Up (real scenario)
Lens Focus @ -12MeV
Detector Focus @ -5MeV

Focus Stacking Results

x3 magnifier / 10 mrad collimation



Achromatic Lens - Theory

(Dis-)advantages of an achromatic lens system

Chromatic lens system (pRad):

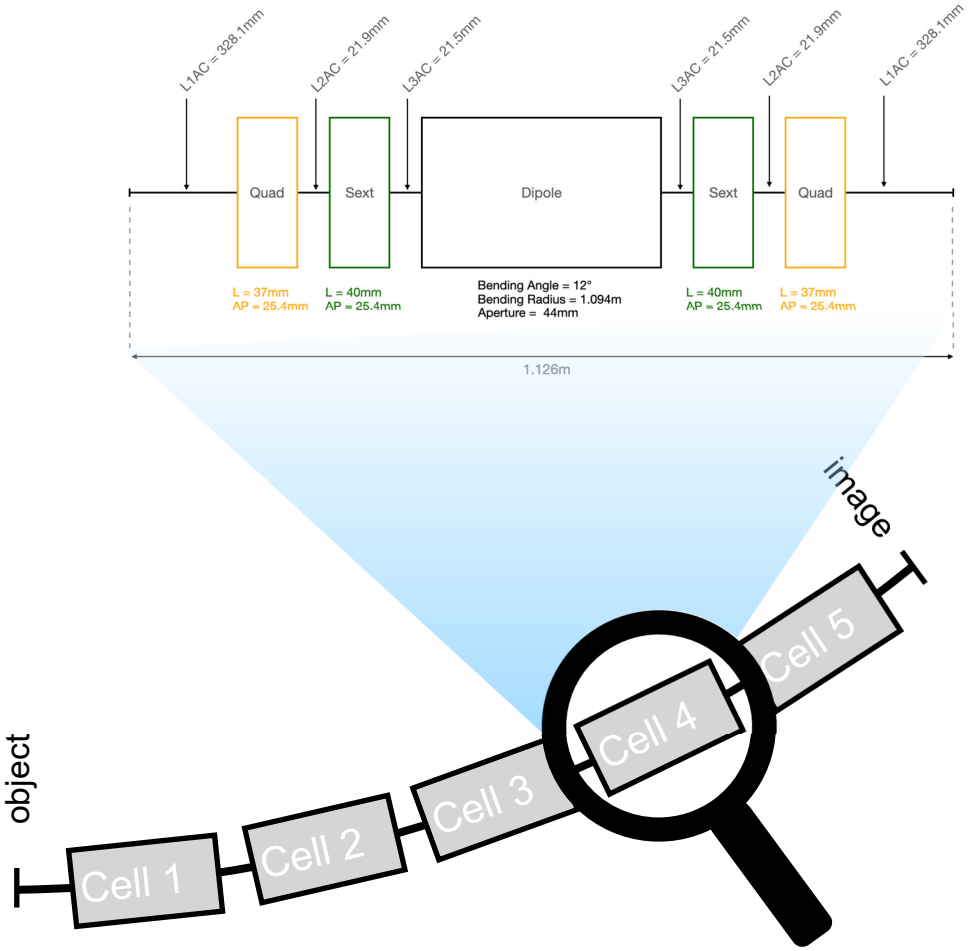
$$x_i = R_{11}x_o + R_{12}a_o + T_{126}\theta\delta + higher\ orders$$

=0 (imaging) parasitic

Achromatic lens system:

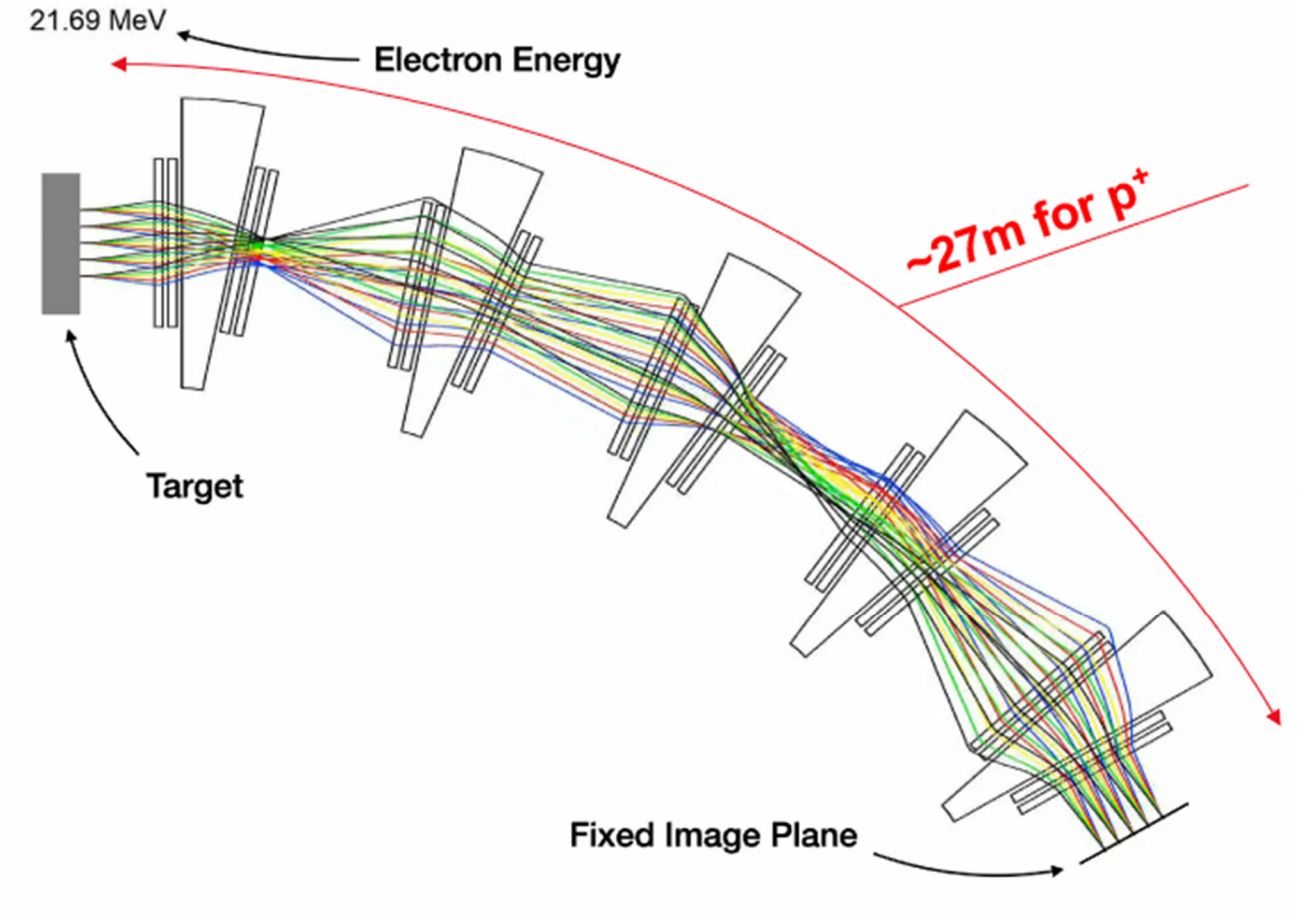
$$x_i = R_{11}x_o + R_{12}a_o + T_{126}\theta\delta + higher\ orders$$

=0 (imaging) lens suppression parasitic



Achromatic Lens

Ion-optical prototype design for 21.5MeV electrons



Summary

Part I

- pRad is a powerful user facility to diagnose materials at extremes

Part II – Focus Stacking

- Focus stacking for the x3 lens can improve the spatial resolution performance by more than 40% for low depth-of-field experiments
- The performance is mostly determined by scattering in the 1st scintillator
- -I lens results are expected to yield an even better performance

Part III – Achromatic Imager

- The pRad team is designing and building a prototype electron achromat
- First tests and results are expected in 2024
- Area A at LANSCE would provide enough space to build a full-scale proton achromat