Diamond radiator radiation damage and quality/lifetime effects

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Outline

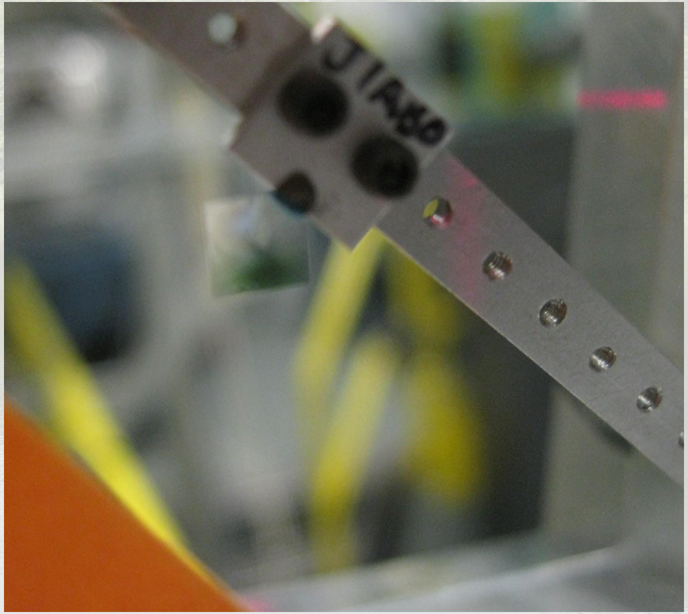
1. Radiation damage case study 1 - **J1a-50**
2. Radiation damage case study 2 - **JD70-100**
3. Outstanding questions yet to be addressed
4. Original basis for the GlueX crystal spec.
5. Proposal for a critical review of the above
    - pros
    - cons
    - what-ifs
6. Concluding recommendations

Case study: **J1a-50**

- 4mm x 4mm x 50μm
- HPHT-1a (Drukkers) from Hall B inventory (never used in Hall B)
- used in Hall D for commissioning beamline 4/2015 - 4/2016

  0.109 C total ~ 0.1 C/mm^2

- showed weird effects, later understood as beam moving off edge as the goni rotated
- showed visible “color centers” after use



Radiation damage

Very little quantitative information exists in the literature about radiation damage lifetime for diamond radiators.

a slide from a talk I gave at Cornell in 2006

Diamond Crystal Lifetime

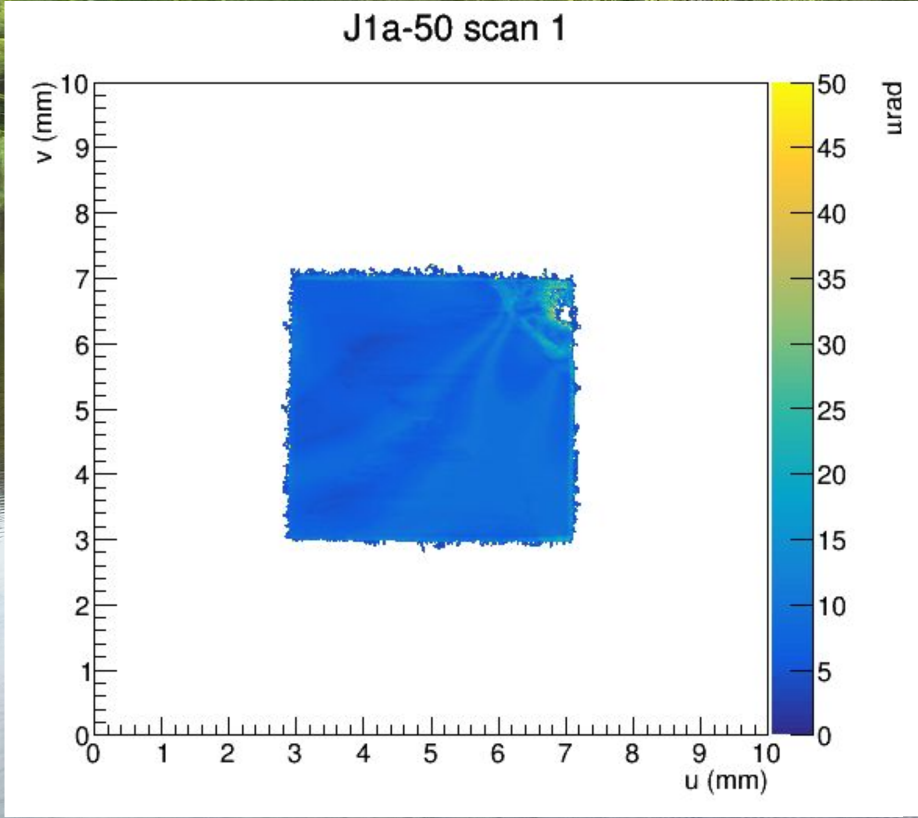
conservative estimate (SLAC) for useful lifetime (before significant degradation):

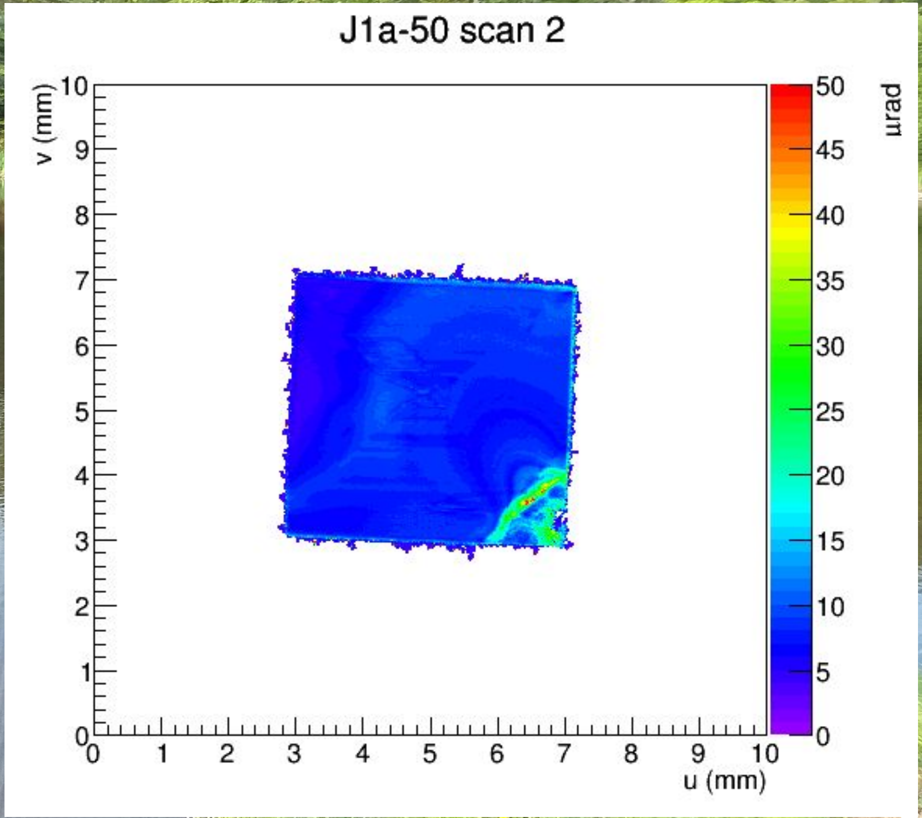
0.25 C / mm^2

during initial running at 10^7 g/s this gives 600 hrs of running before a spot move
a "good" crystal accommodates 5 spot moves

R&D is planned that will improve the precision of this estimate.

J1A50: X-ray rocking curves taken at Canadian Light Source in November, 2017





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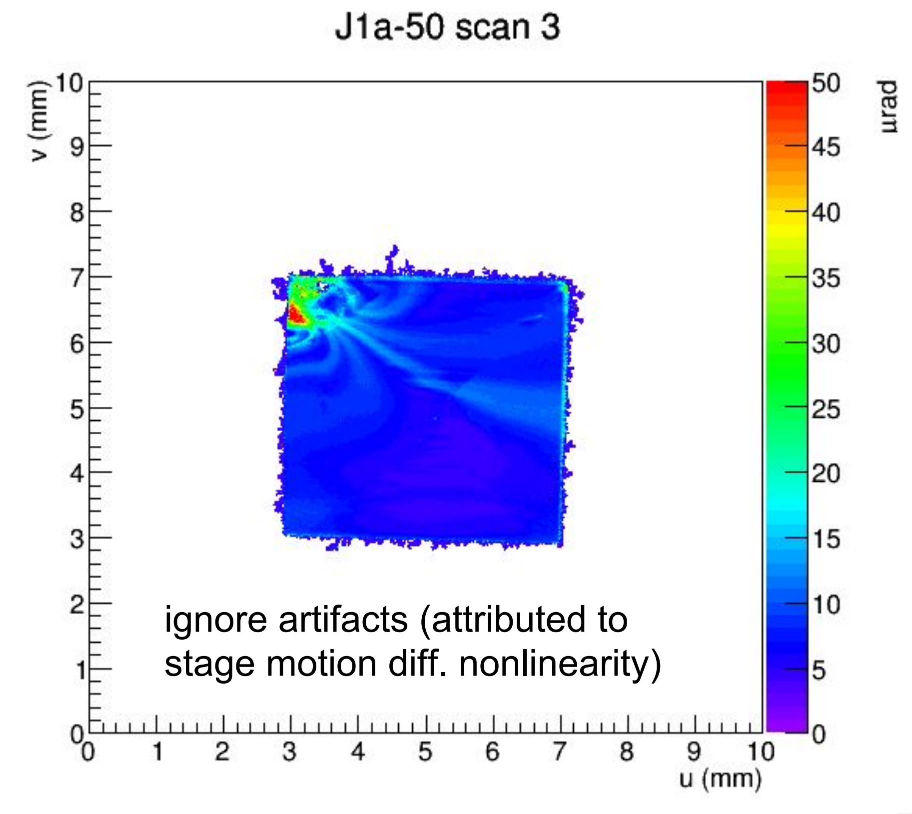

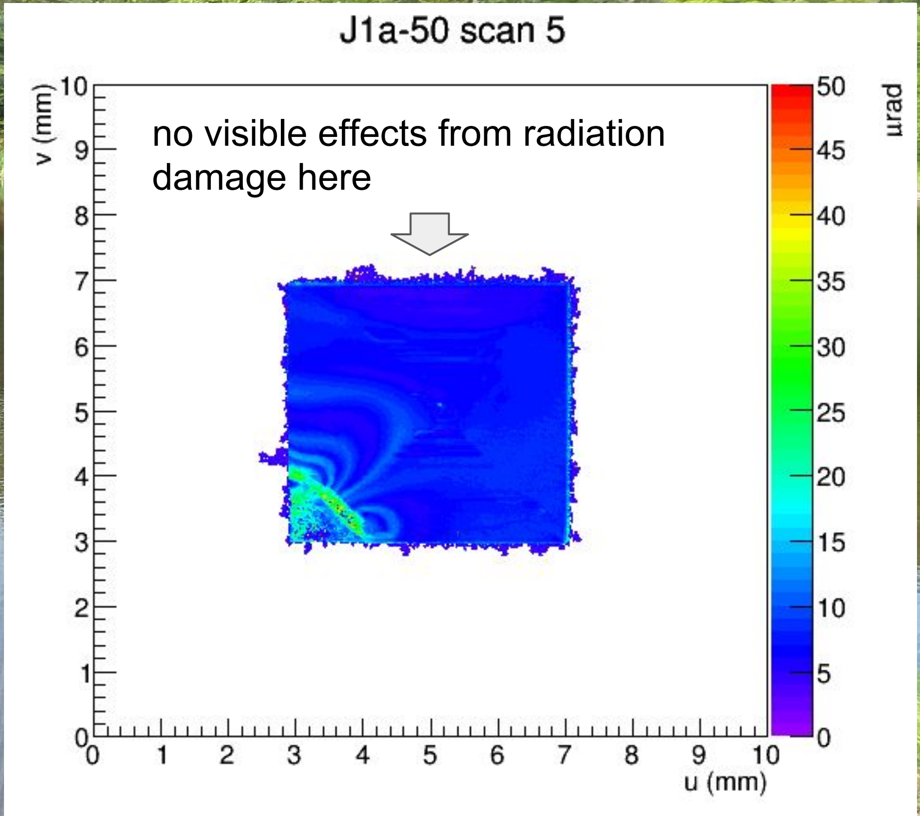

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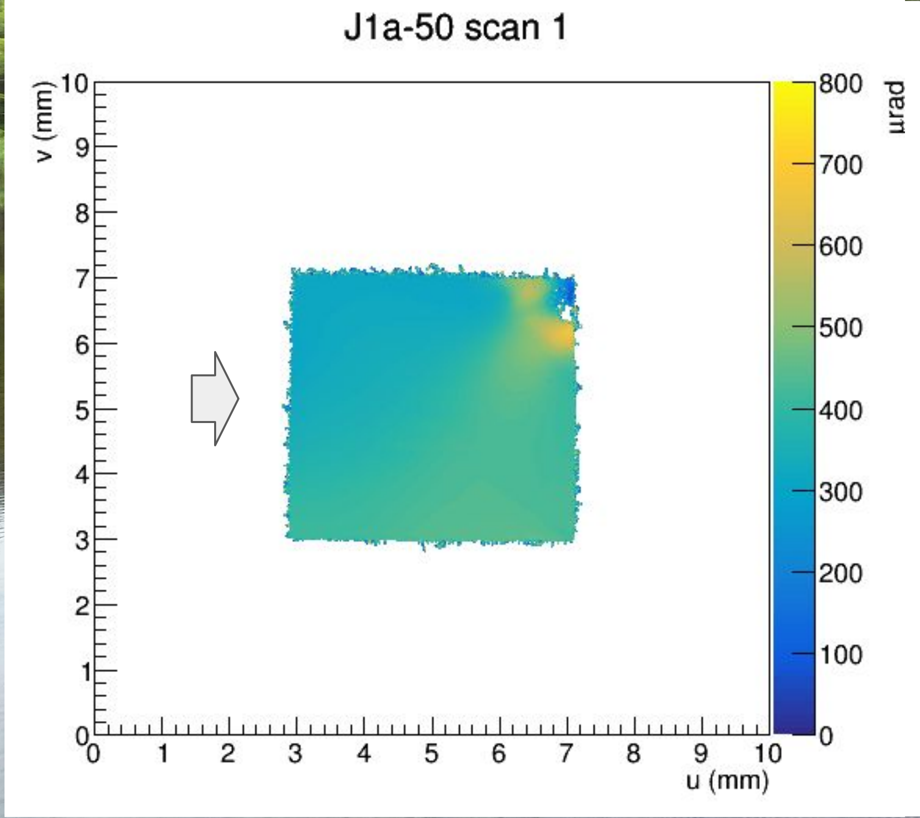

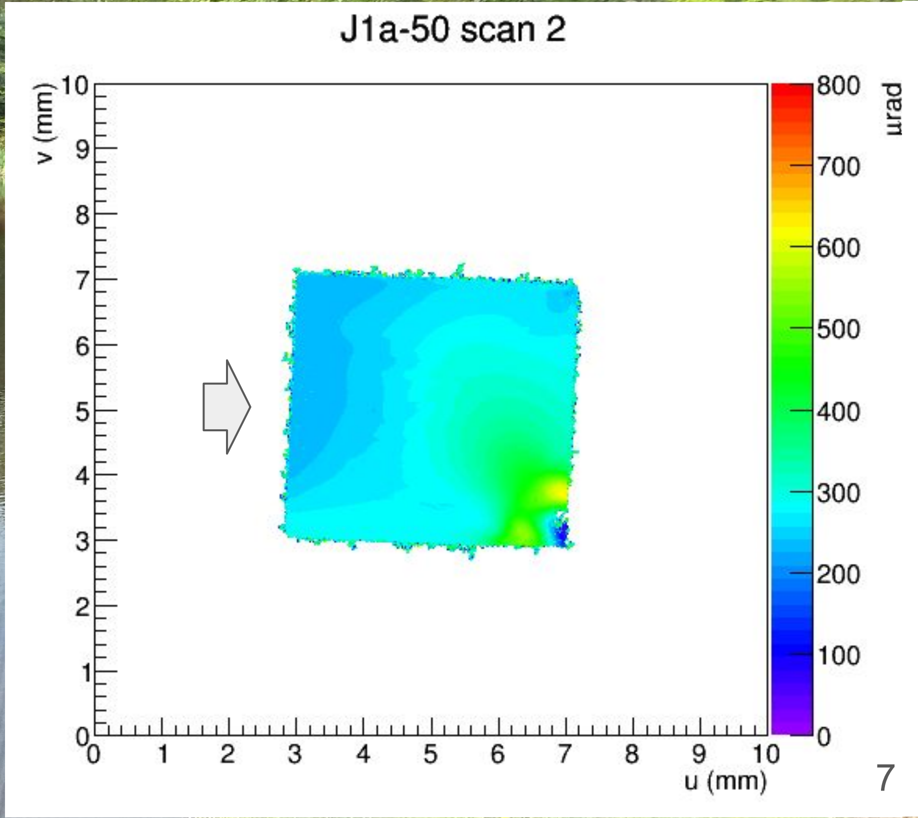

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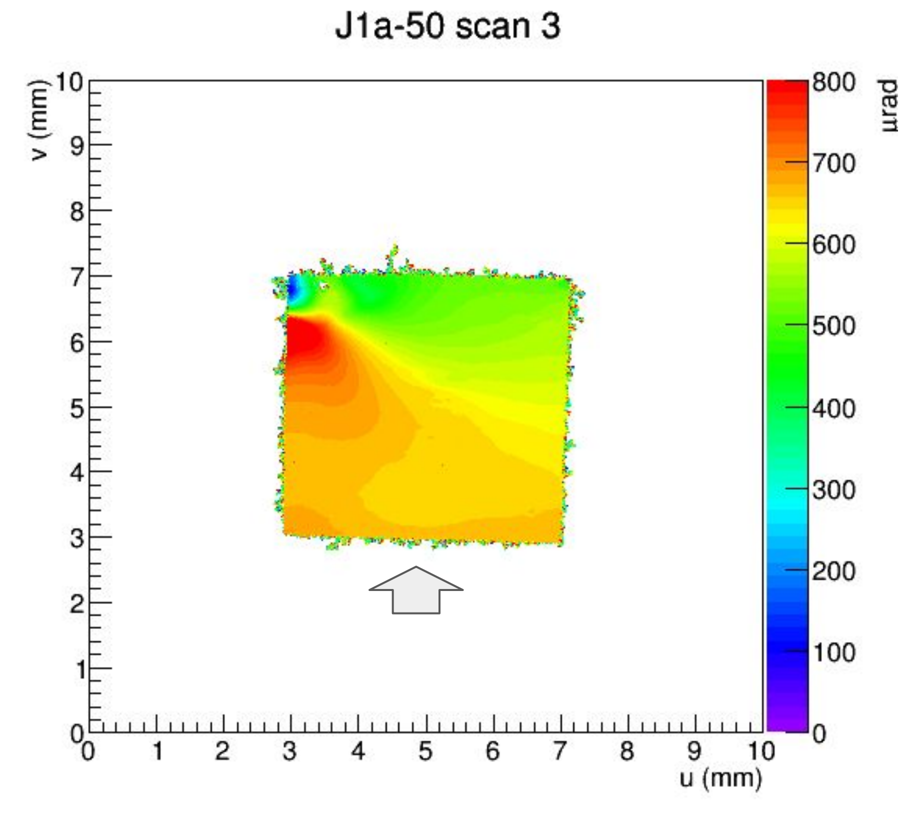

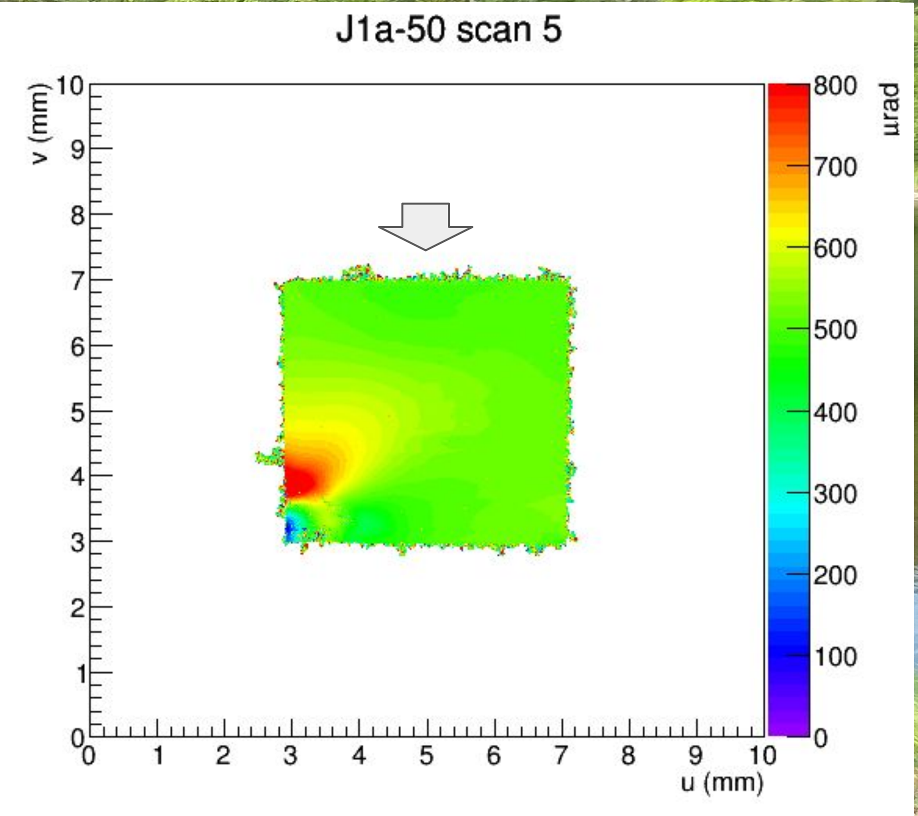

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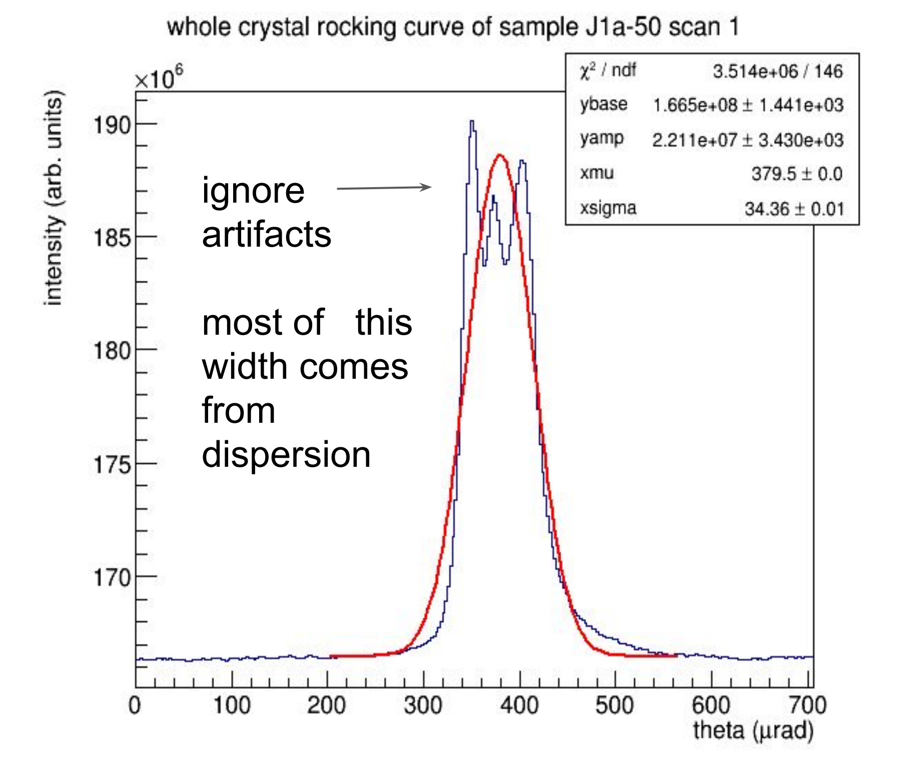
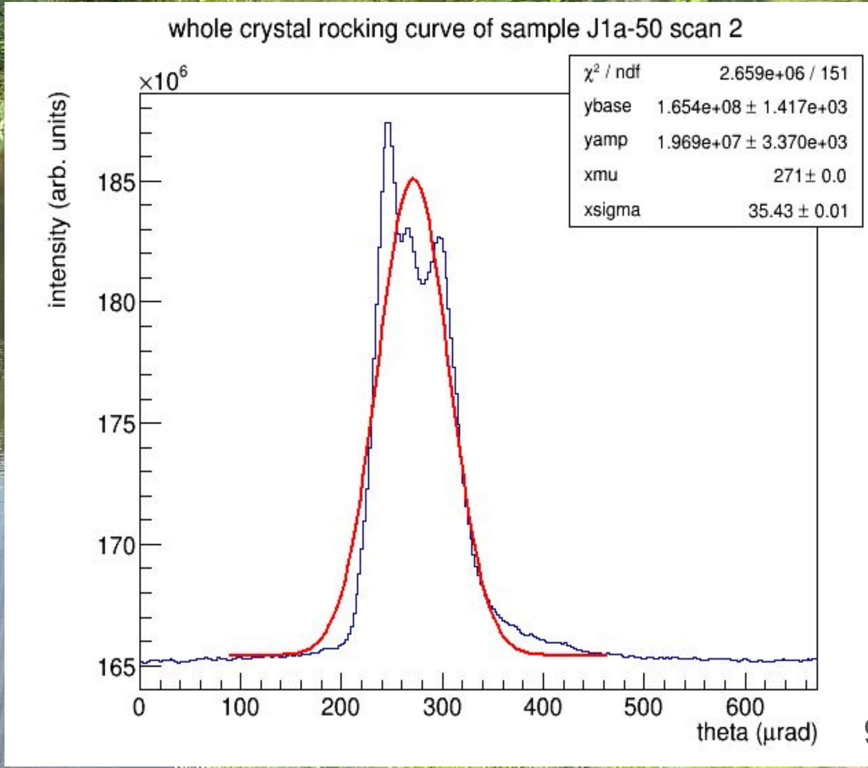


ignore artifacts

most of this width comes from dispersion



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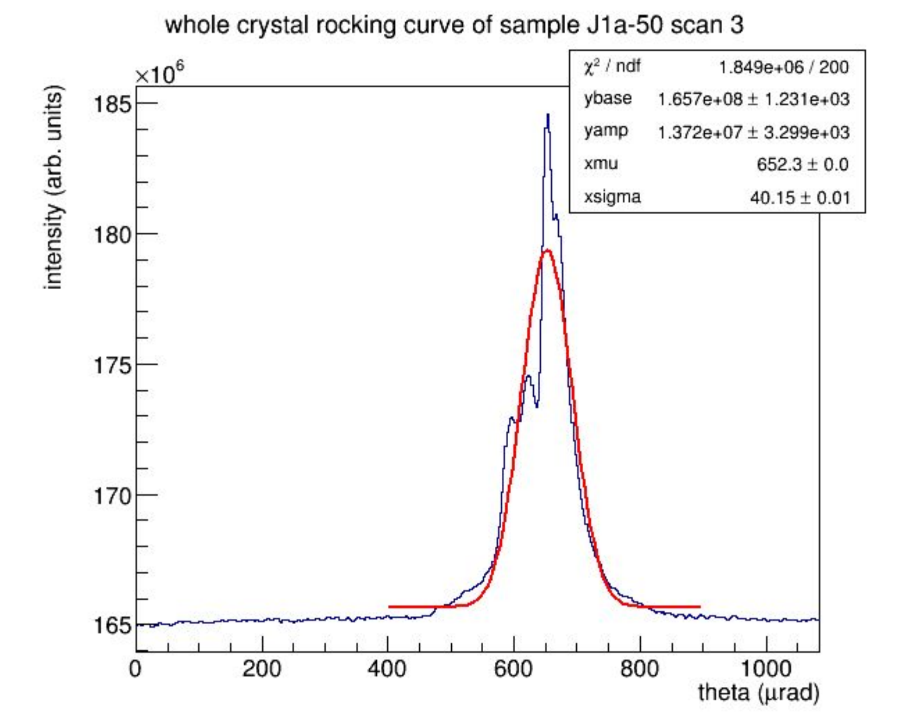

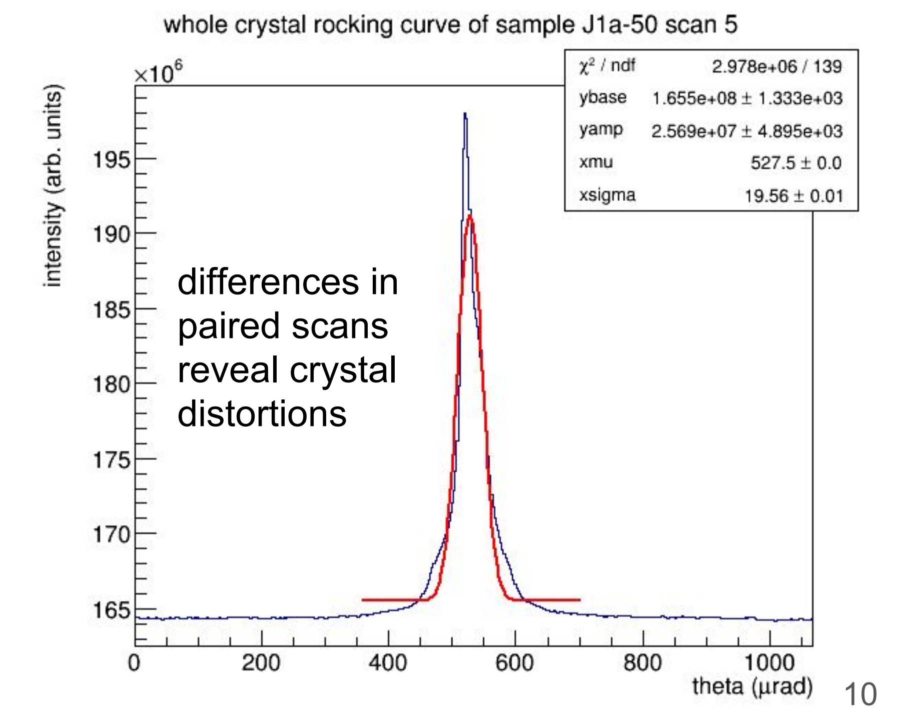

differences in paired scans reveal crystal distortions

Case study: conclusions for **J1a-50**

1. X-ray *local* rocking curves show no obvious effects from radiation damage
2. This is consistent with the threshold of 0.25 C/mm^2 from SLAC
3. J1a-50 remains one of our best diamonds in terms of RC width
4. Its future utility to GlueX is limited by its small area

remaining questions:

- What is the threshold for radiation damage that affects RC width?
- Is the growth in RC width linear with integrated charge or nonlinear?
- What is the effective lifetime of diamond radiators for GlueX?

Radiation damage: next specimen JD70-100

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- Is the growth in RC width linear with integrated charge or nonlinear?
- What is the effective lifetime of diamond radiators for GlueX?

JD70-100 radiator

- used Jan. 2017 - May 2018
- integrated time in beam: **7.2 Ms**
- integrated beam charge: **0.588 C**
- *to be tested at CLS in Fall 2018*

Radiation damage: next specimen JD70-100

Radiation damage: threshold found with JD70-100?

- average beam spot area at radiator: **1.25 mm^2**
- threshold observed March 1, 2018? **0.33 / 1.25 = 0.26 C/mm^2 (!)**
- *good agreement with the semi-qualitative value from SLAC*

JD70-100 radiator

- used Jan. 2017 - May 2018
- integrated time in beam: **7.2 Ms**
- integrated beam charge: **0.588 C**

Outstanding questions remaining

- What is the nature of the crystal radiation damage?
  - no observable effect seen in local RC width in J1a-50
  - some evidence of warping was seen in J1a-50
  - is bending of the crystal the primary cause of RC broadening?
- Is the effect linear with dose? linear above some threshold?
  - the effect seemed to take off during mid-March 2018
  - the total dose on JD70-100 *has nearly doubled since March 1, 2018*
- How much to do we care?
  - depends on how much we want to rely on CBSA for polarization
  - maybe CBSA systematics are not a driving concern...
  - we need to look at the ***polarization figure of merit***

Digression: a page from GlueX history

Radiator quality standards: *from the GlueX CDR*

- CBSA was primary polarimetry method, TPOL was secondary
  - crystal imperfections enter CBSA as model-dependent
  - together with beam optics modeling, variability, collimator alignment, ...
  - goal was to minimize polarimetry systematics from CBSA

    i. ***make sure other systematics dominate over crystal defects;***
    ii. ***start with best beam emittance we can hope for;***
    iii. ***combine that with multiple scattering from smallest crystal thickness we can practically work with;***
    iv. ***result was < 20 urad RMS for whole-crystal rocking curve***

- This requirement was based on CBSA systematics, ***not any consideration of optimizing the polarization***

Radiator quality standard: ***a critical review***

- Doesn't *crystal quality* factor into the polarization quality?
  - it does of course, but ...
  - in a weaker way than was considered in setting the GlueX specs
    1. **qualitative:** a degraded diamond is more difficult to orient;
    2. **quantitative:** at some point the polarization figure of merit starts to degrade

- **A critical review of the Gluex crystal quality spec is needed**

Radiator quality standard: ***a critical review***

Why?

1. We can meet the existing spec. with a ready supply of 50um diamonds.
2. Relaxing the spec. may extend the useful lifetime of our radiators, but *that* has not so far been a major problem for us.
3. On the other hand it introduces new questions that have not been issues under the existing spec, like how to orient the diamond with a wider edge.
4. It diverts manpower away from other things that are more pressing.

Radiator quality standard: ***a critical review***

Why?

1. It is now becoming clear that the TPOL has become *our primary means* of polarimetry, with CBSA providing an important check of those results.
2. This means that we have a potentially obsolete spec driving our resource allocations.
3. *Diamond procurement, assessment, orienting, etc. is not free in terms of cost or effort!*
4. <u>Maintaining this spec stands in the way of other beamline optimization.</u>

Radiator quality standard: ***a critical question***

- *What is the nature of the radiation damage effect that caused the broadening of the edge seen with JD70-100 (and before, at SLAC)?*

1. d-spacing changes and mosaic growth that *broadens the local RC*
2. migration of defects into clusters that localizes strain leading to warpage, *broadening the global RC* but not the local one.

⇦ Evidence from J1a-50 favors #2.

Radiator quality standard: ***a critical question***

What if?

The presence of the thick frame around the 20um diamond JD70-104 might make it essentially immune to warpage from effect #2.

- It is already so thin that it has warped as much as it can under the forces of its own internal strain, subject to the frame constraint.
- The frame remains outside the region of radiation damage, so it should be essentially unaffected by the beam.
- If effect #2 dominates, then the framed diamond ***will*** age differently.

Concluding recommendations

1. Ask the Beam Working Group to report back to the collaboration by the end of the summer with a revised spec on diamond radiator quality based on *polarization figure-of-merit* optimization and *orientability.*
2. Remove JD70-100 and have the UConn + Regina team take it to Saskatoon and measure the detailed rocking curve across the entire crystal, and provide insight into the causes for the degraded edge.
3. Run for an extended period in Fall 2018 with JD70-104 and electron beam current sufficient to reach the desired photon flux. Within a period of a few weeks it will be apparent whether framed radiators have any substantial advantage over flat in their radiation lifetime.