Defect-free Ultra-Rapid Polishing/Thinning of Diamond Crystal Radiator Targets for Highly Linearly Polarized Photon Beams

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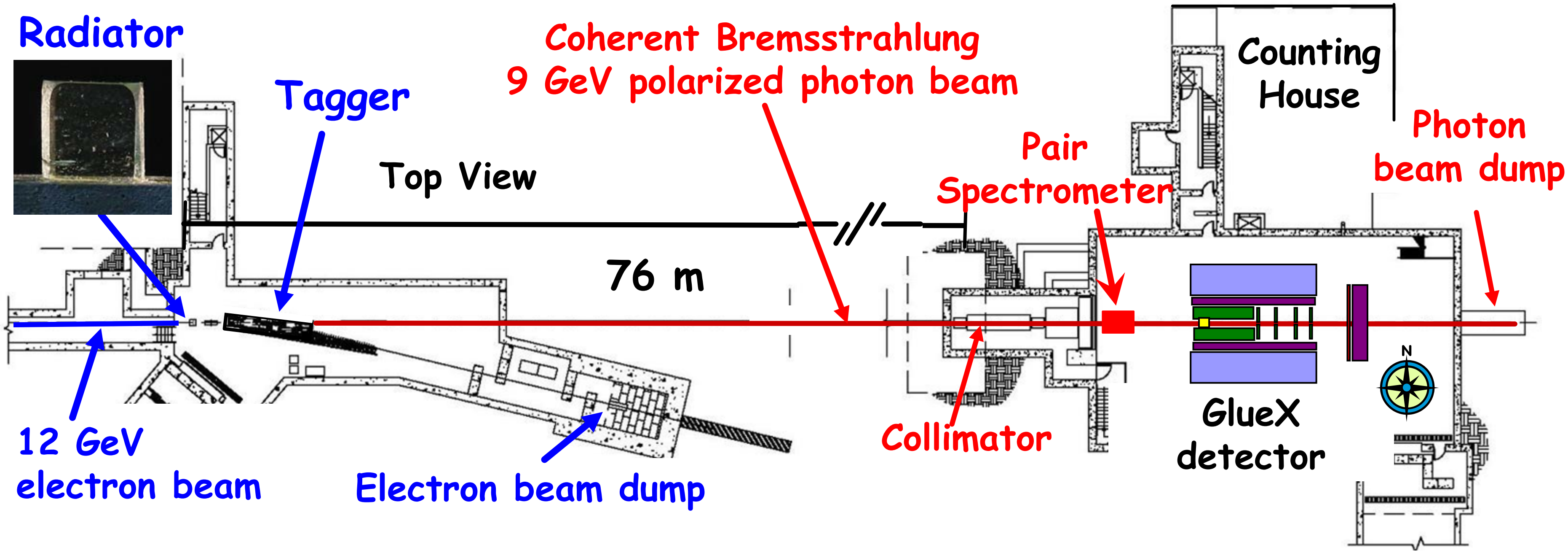
Outline

- **Application: high-energy polarized photon source**
  - uniqueness of diamond as a radiator
  - competing specifications: thickness vs. flatness
  - proposed solution: a thick frame around the radiator
- **Two approaches investigated**
  - vapor phase ion etching with mask (Sinmat)
  - milling by UV laser ablation (UConn)
- **Conclusions and Future Directions**

Diamond - a high-energy polarized photon source



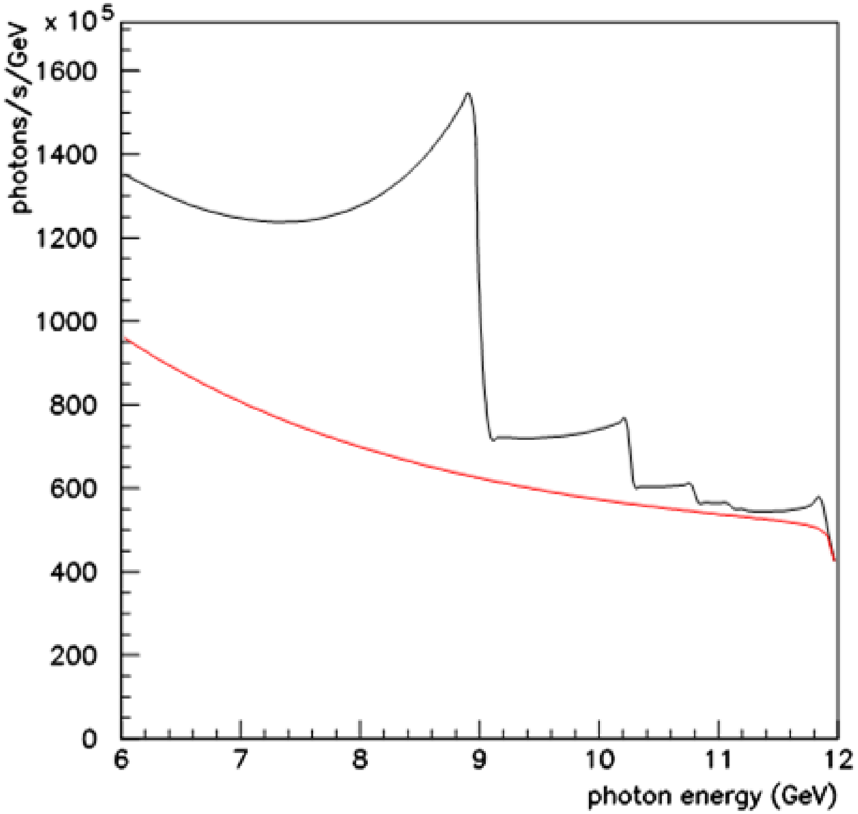
Crystalline radiator => electrons “bremsstrahlung” from entire planes of atoms at a time

1. discrete peaks in energy spectrum
2. photons are polarized within the peaks

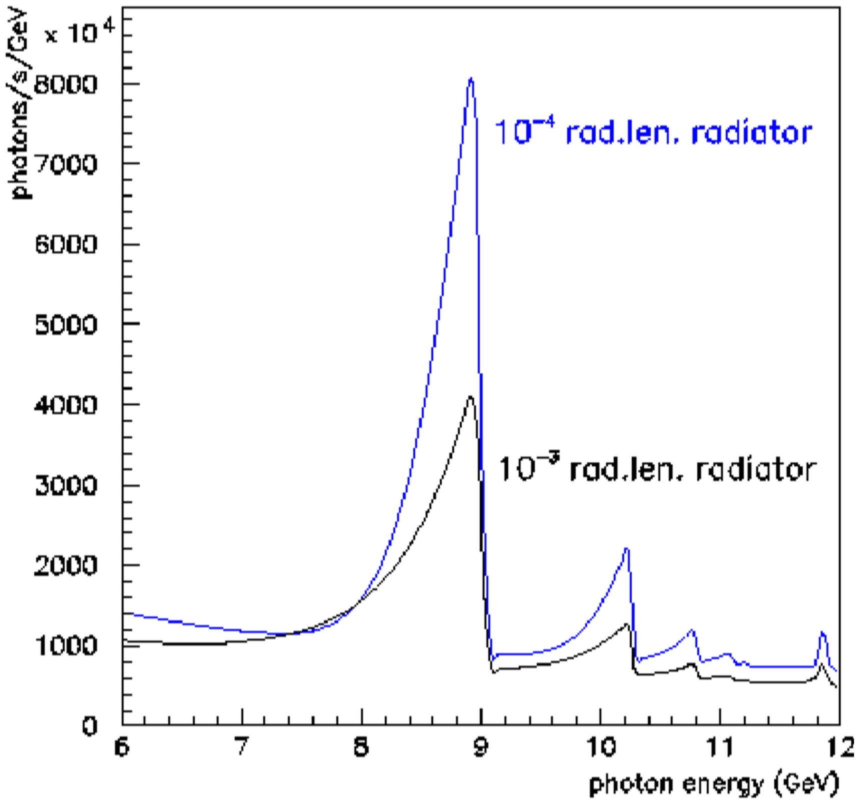
Diamond is the unique choice for crystal radiator

1. low atomic number
2. dense atomic packing
3. high thermal conductivity
4. radiation hard, mechanically robust, large-area monocrystals, ...

Coherent bremsstrahlung beam properties



Bremsstrahlung spectrum with (black) and without (red) an oriented diamond crystal radiator

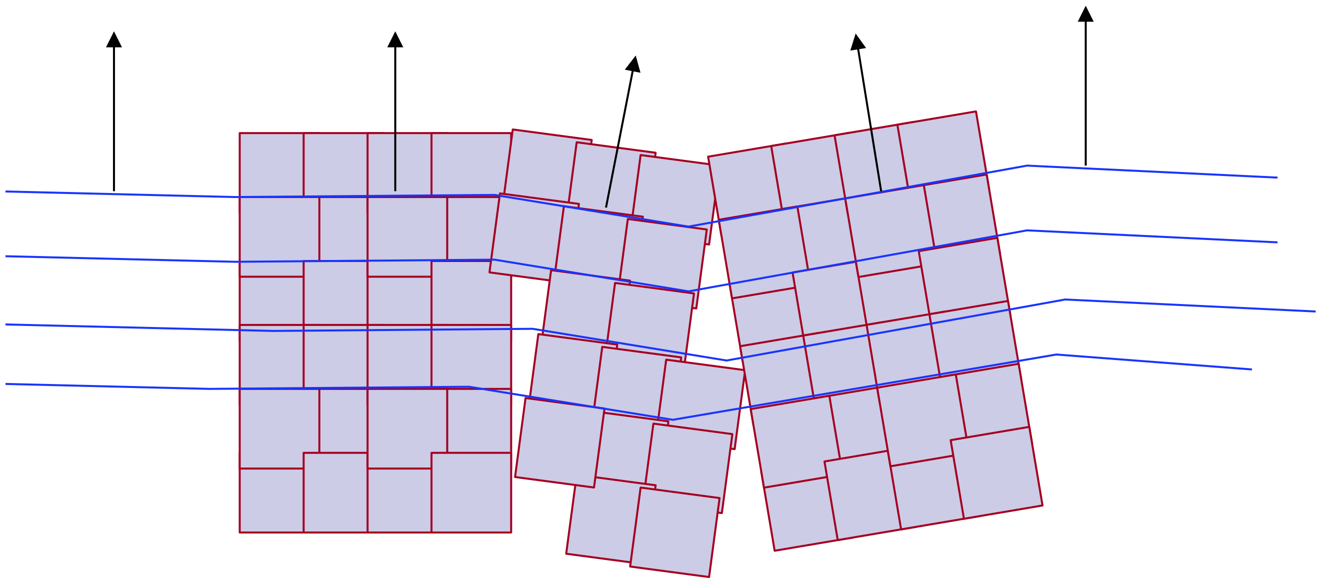


Same spectrum, after cleanup using small-angle collimation

Diamond radiator requirements

1. **thickness 10^{-4} radiation lengths ~ 20 microns**
2. **“mosaic spread” of the crystal planes ~ 20 μrad RMS**

crystal appears as a mosaic of microscopic quasi-perfect domains



- Actually includes other kinds of effects
  - distributed strain
  - plastic deformation
- **Measured directly by X-ray diffraction: “rocking curves”**

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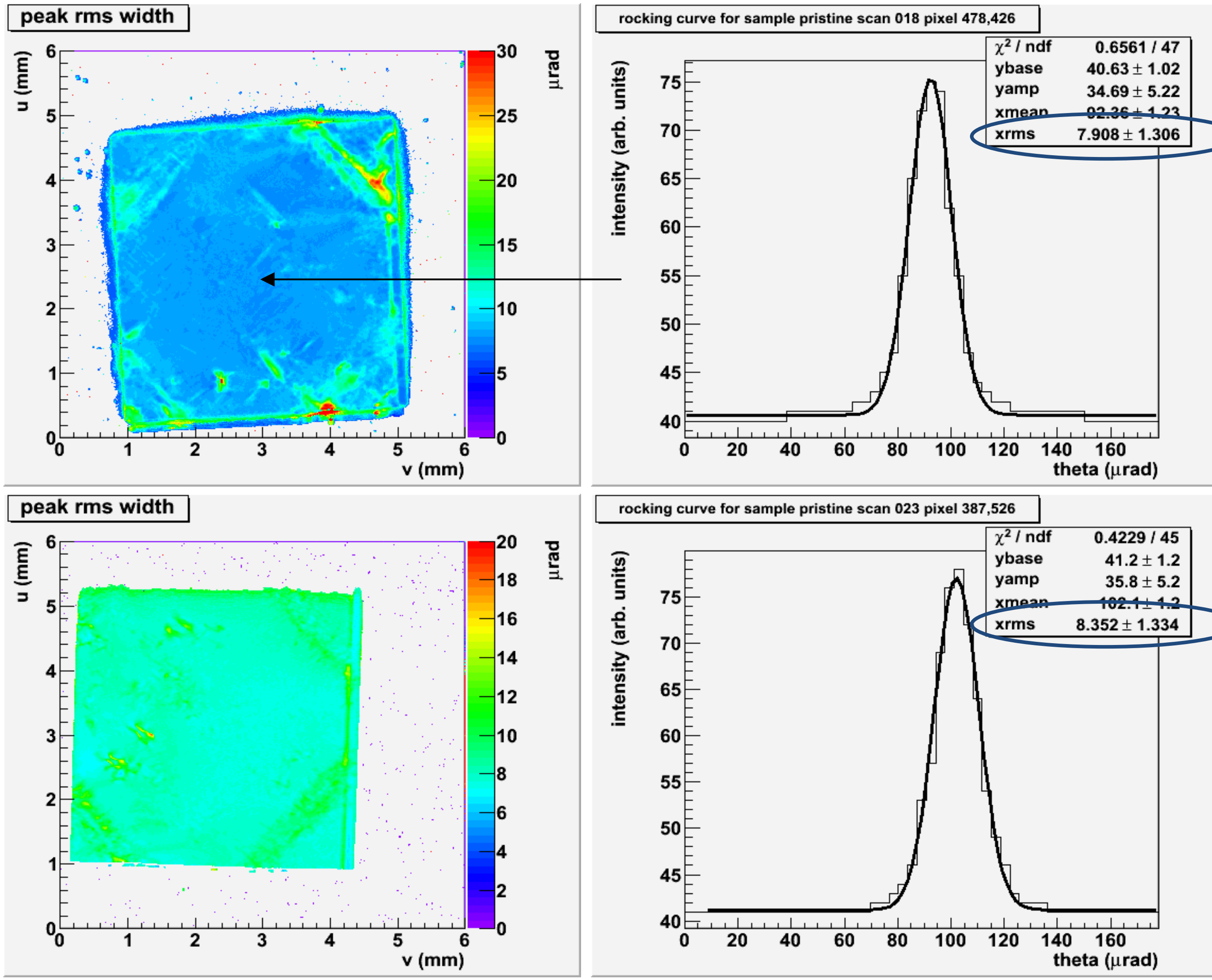
E6 single-crystal CVD(!) diamond



Very close to theoretical rocking curve RMS width for diamond !

but…

These crystals are 300 microns thick.

X-ray measurements performed at Cornell High Energy Synchrotron Source (CHESS)

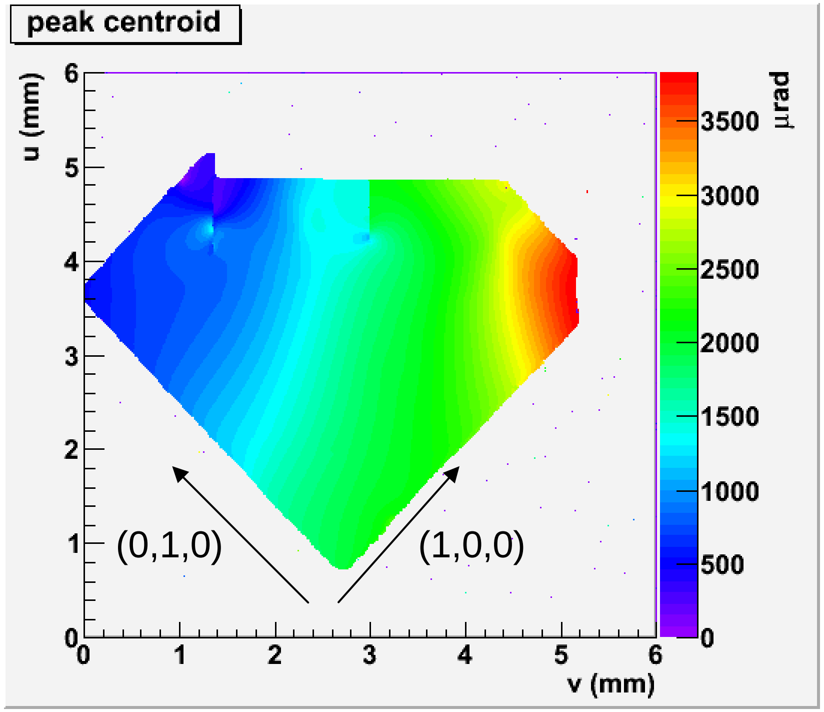
CHESS

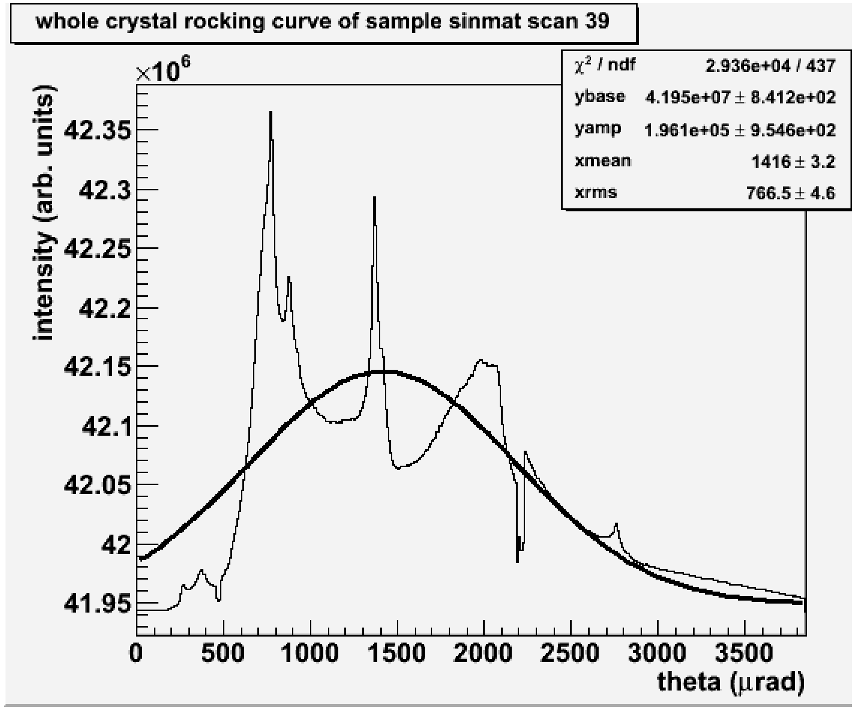
Cornell High Energy Synchrotron Source

E6 CVD diamond thinned to 15 microns

Sample was thinned using proprietary Sinmat RCMP process (presented in early talk)

- very fragile -- notice the corner broken off
- rocking curve shows very large bending deformation





X-ray measurements performed at Cornell High Energy Synchrotron Source (CHESS) - *STTR phase 1*

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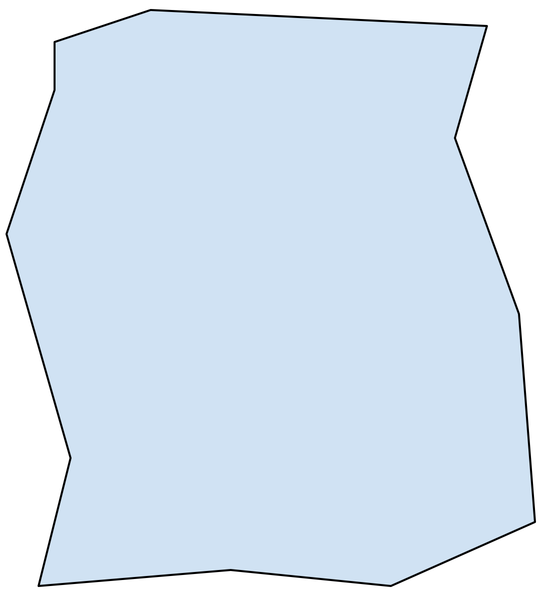
Primary R&D challenge in Phase 2

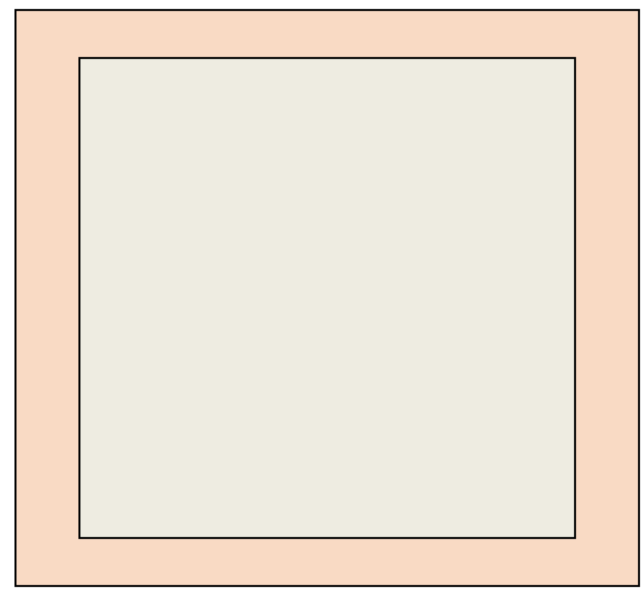
Understand and overcome the thin diamond warping problem.

Diamonds appear to warp severely when thinned to 20 microns.



Warping is from combination of mounting and internal stresses.

Try to stiffen the diamond by leaving a thick outer frame around the 20 micron region.

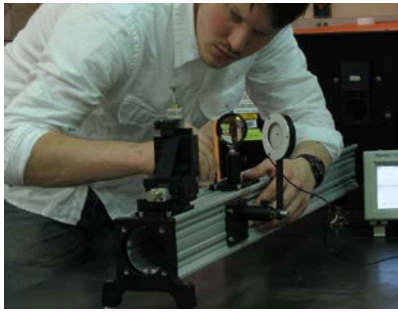


Frame around 20 micron window is still part of the single crystal, acts like a drum head.

Two-prong method of attack

1. Chemical etching using a mask - Sinmat

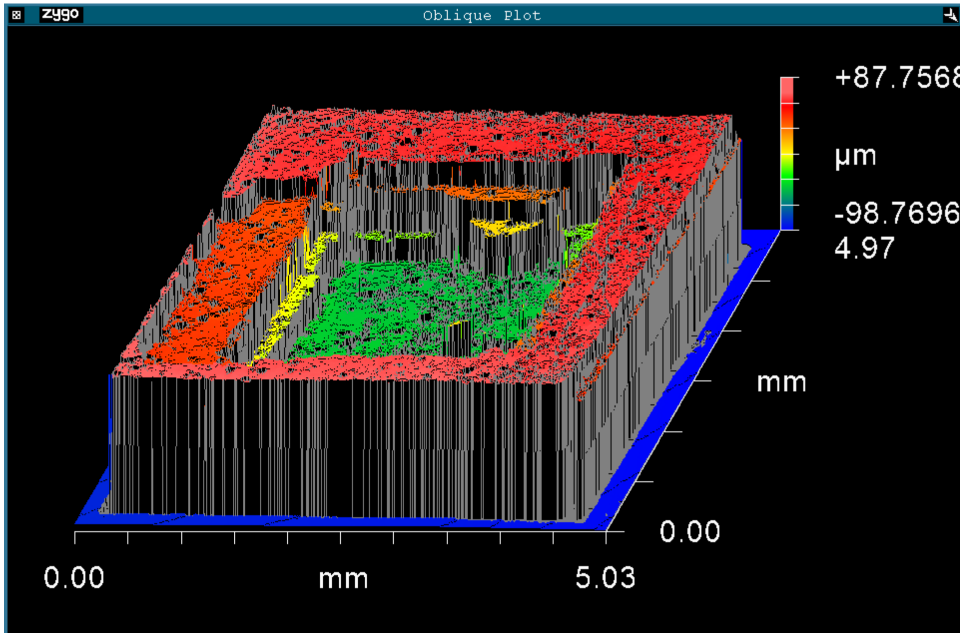
- Step 1: Deposit a metallic mask covering the outer frame region.
- Step 2: Etch masked sample using oxygen VPIE.
  - Monitor removal rates, expect >50 microns/hr
  - Watch when mask sputters away, when gone return to step 1.
- Step 3: Measure central thickness, remove residual mask when done.

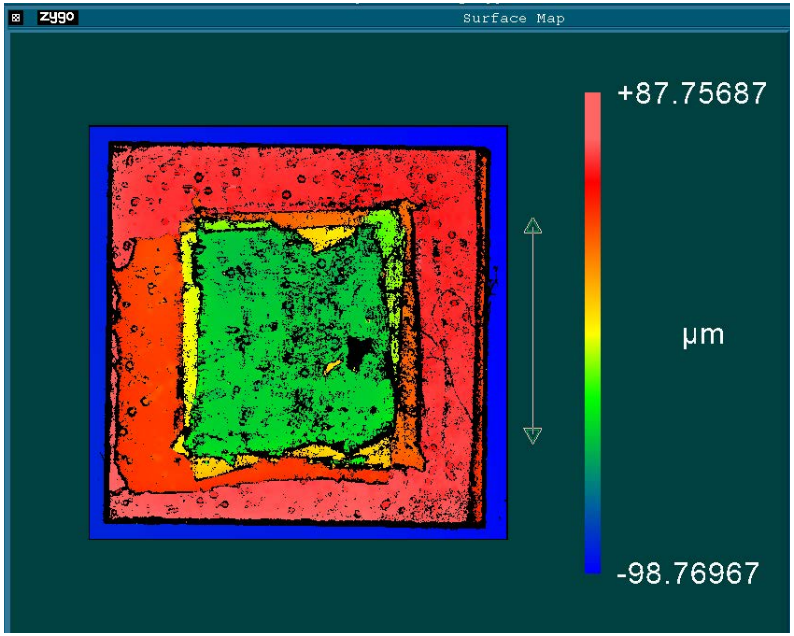


2. Precision milling with a UV laser - UConn

- New ablation facility built at UConn for this project
  - 5W pulsed excimer laser generates 5W at 193 nm
  - UV optics to expand beam, focus to 0.1mm spot
  - evacuated ablation chamber with tilted sample holder
  - 3D motion controls to raster the diamond across the beam
- Software developed to generate smooth flat ablated surface

APPROACH 1: Chemical etching

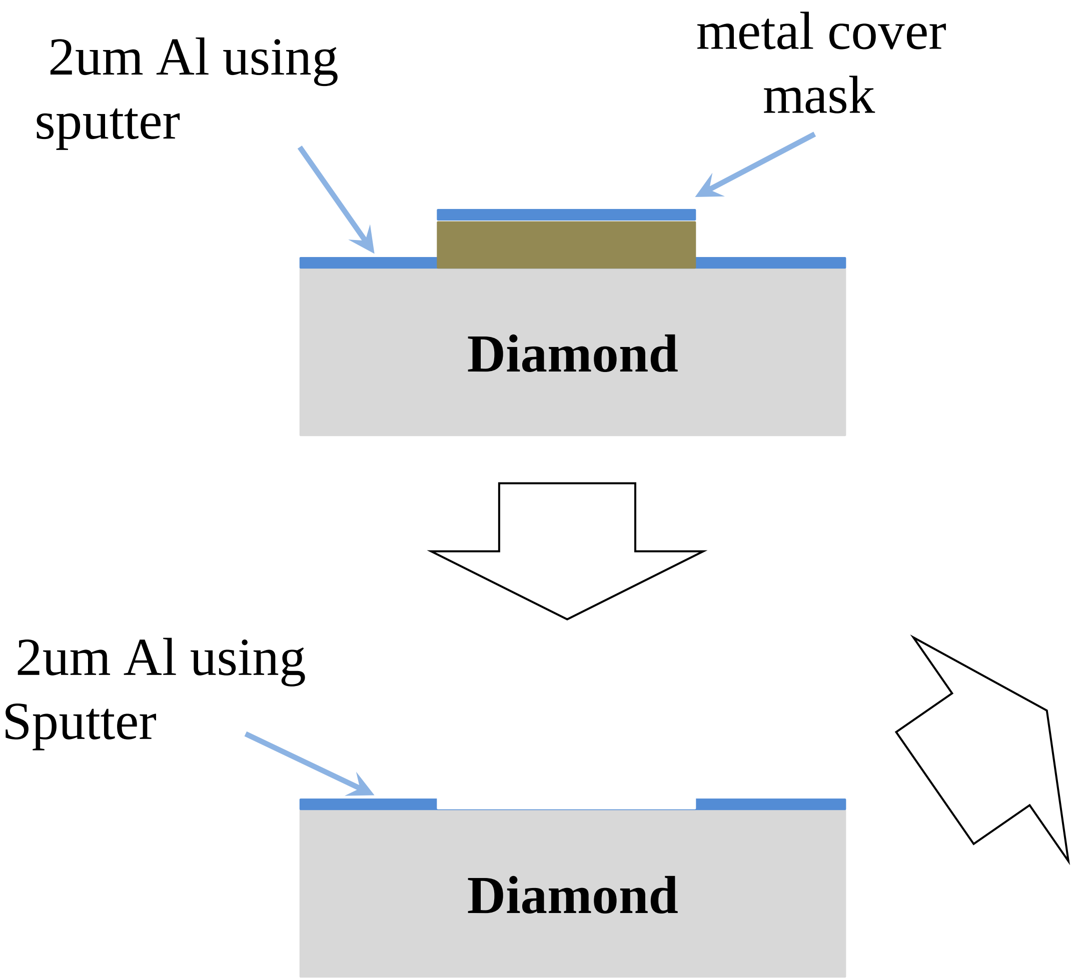




- Slight misalignment shows 4 masks were needed.
- Frame thickness is 185 microns
- Central region is 55 microns thick
- Etched surface shows significant roughness, pits 10 microns deep

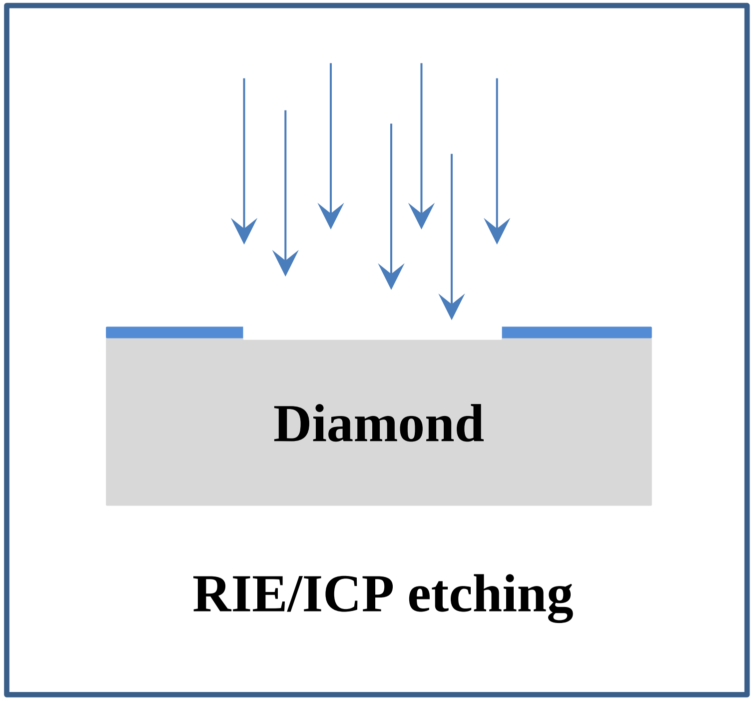
Careful monitoring needed to prevent burn-through below 50 µm

Vapor Phase Etch Process

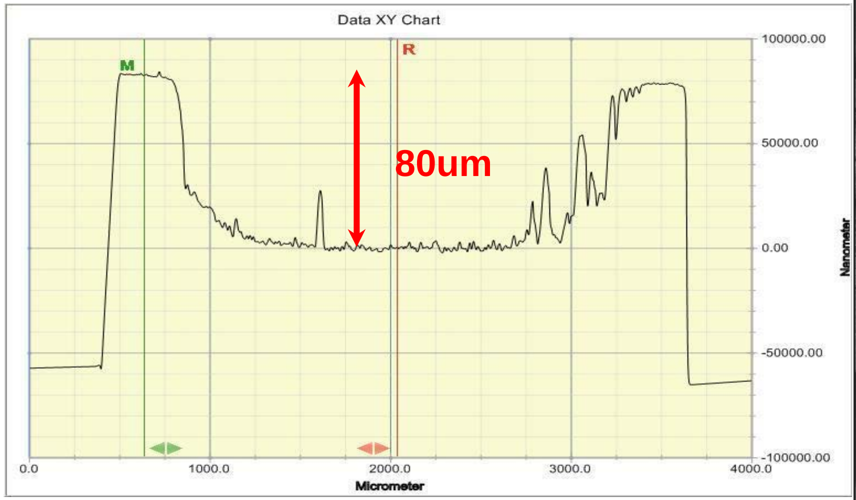


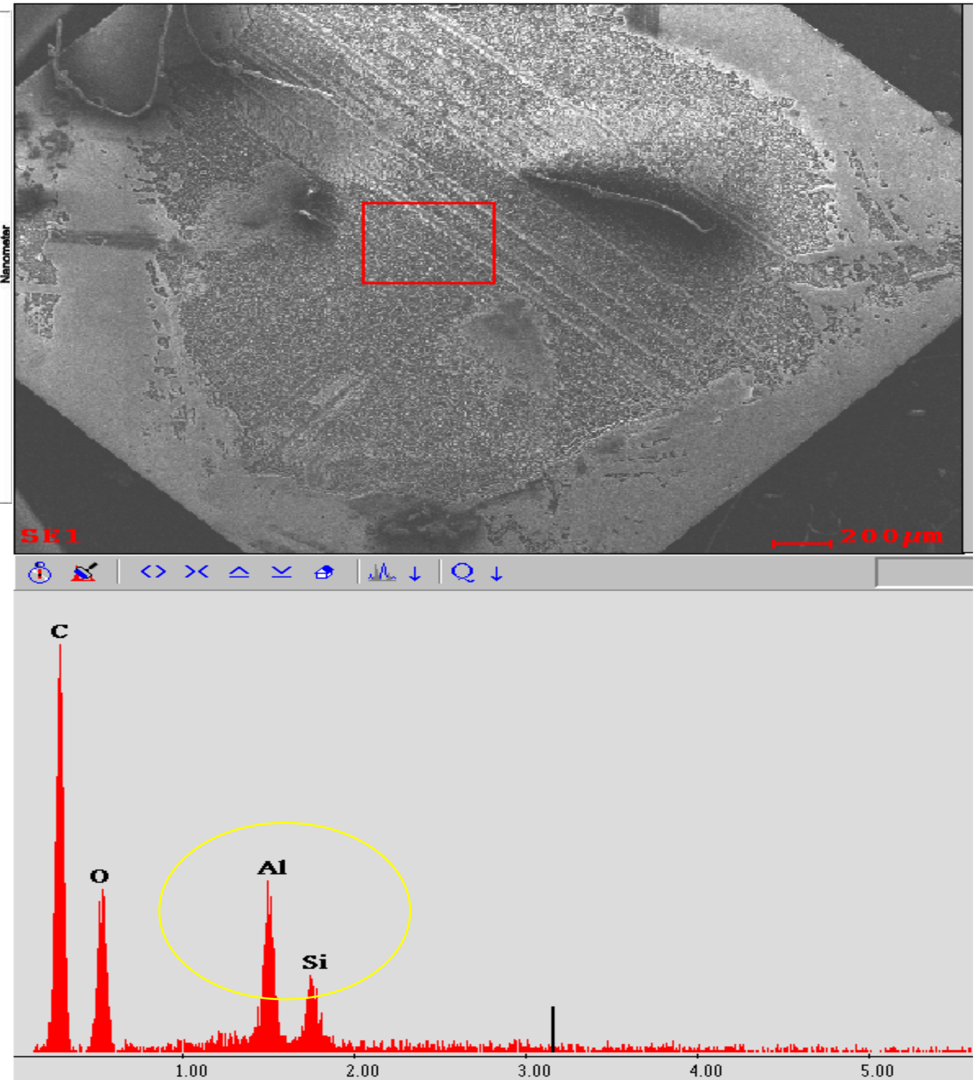
➢ **Diamond etching recipe**

Gases O2 & Ar gas
RIE/ICP= 500W / 1500W



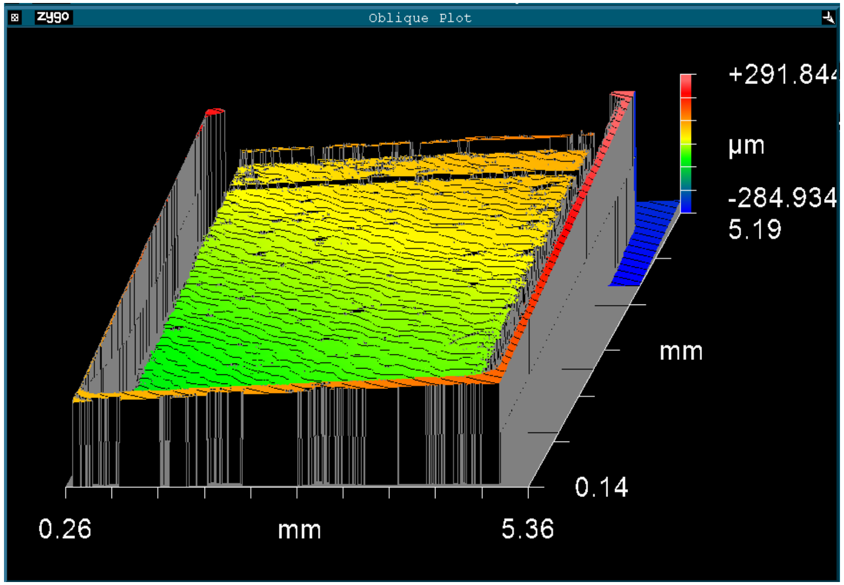
Vapor Phase Etch Process

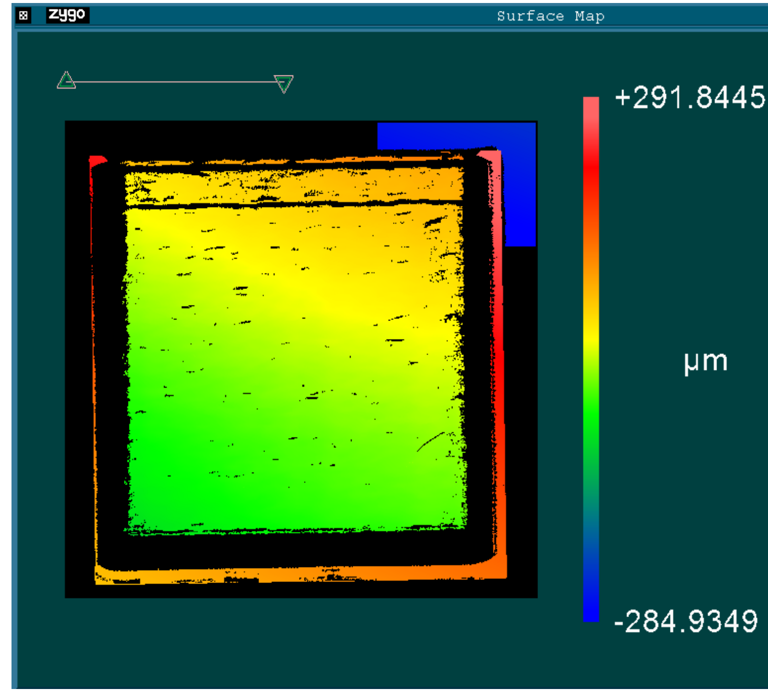


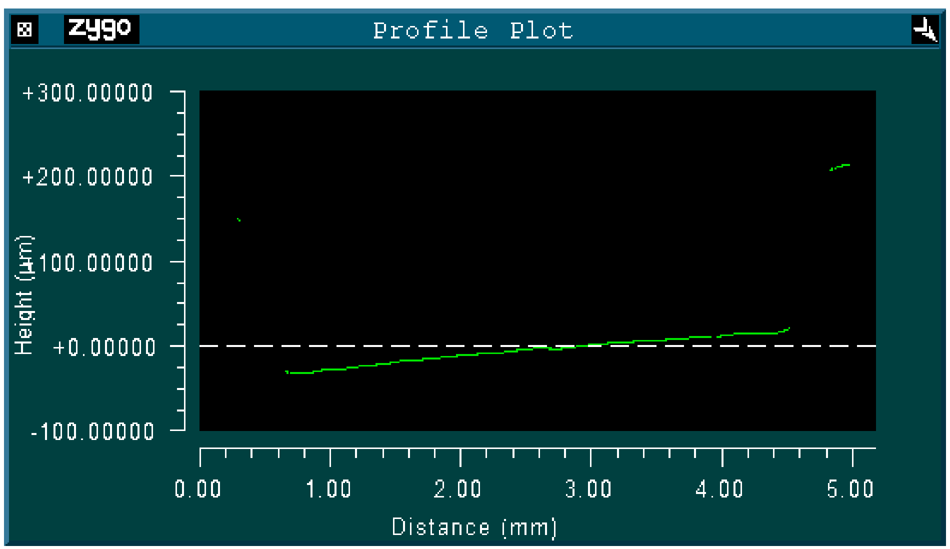


- ✓ Etch rate continuously reduced with progressive etching
- ✓ Al mask re-sputtered on the sample

APPROACH 2: Laser ablation

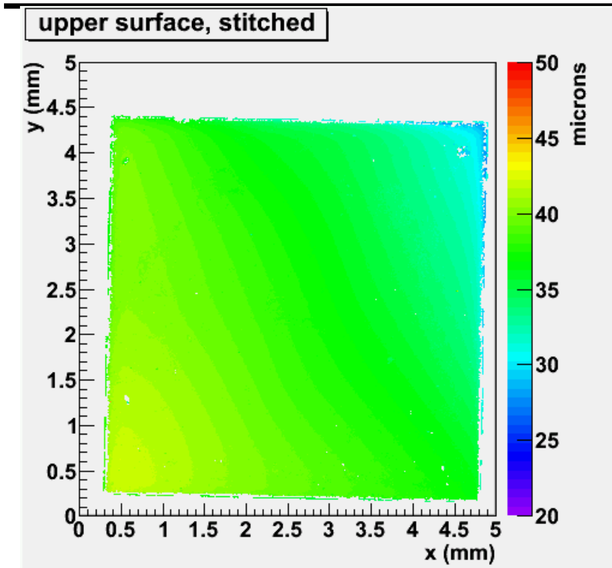


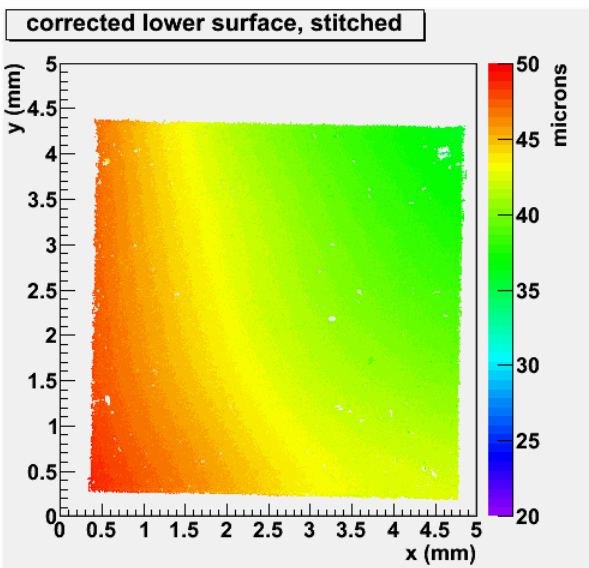




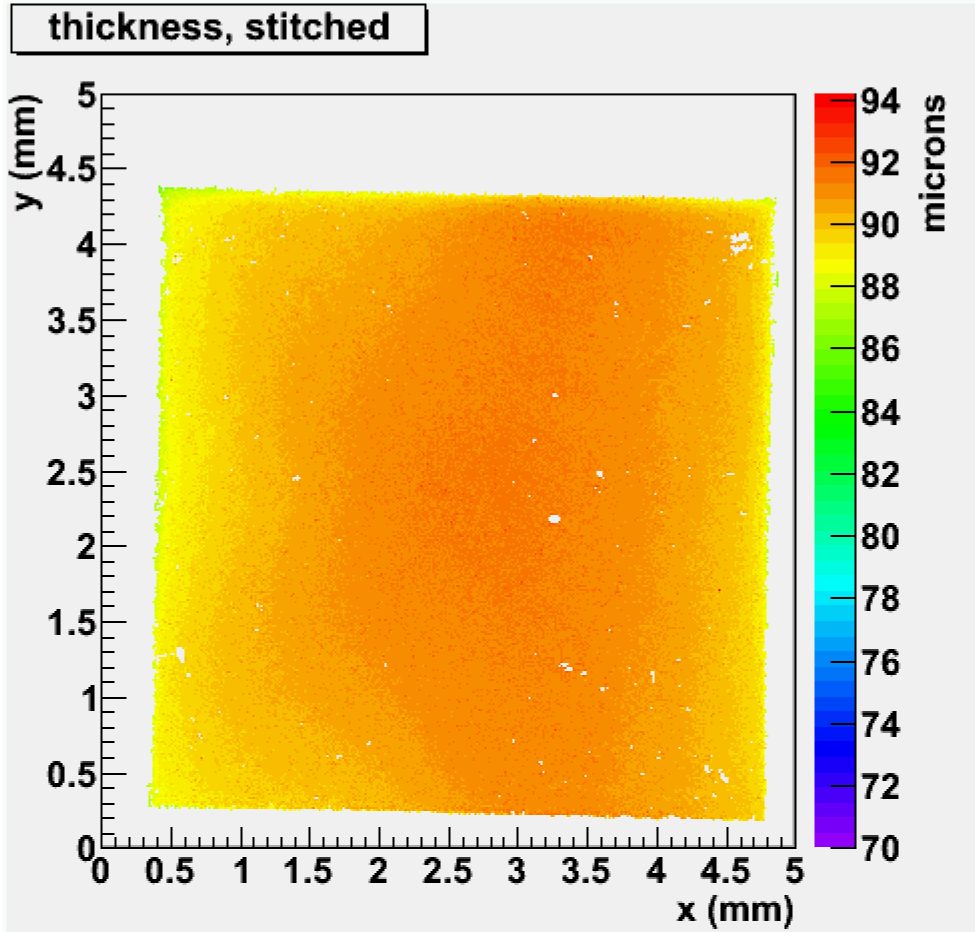
- 200 microns removed in 8hr
- surface roughness < 1 µm
- ***risk of burn-through below 50 µm thickness***

Uniform sample S90





surface and thickness profiles (Zygo 3D)



Uniform sample S30

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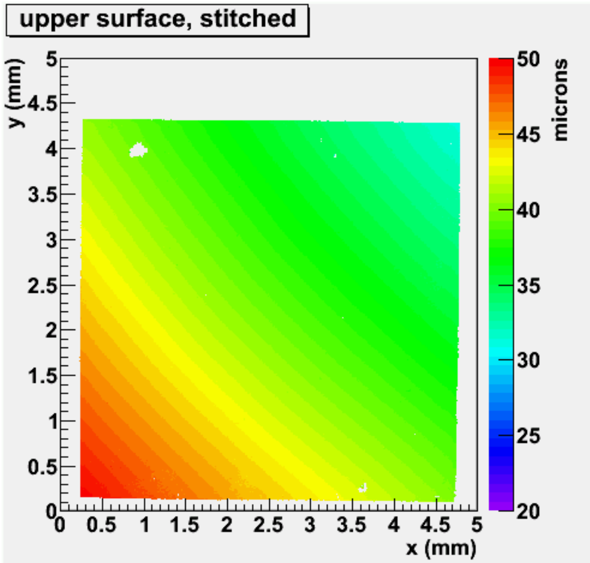
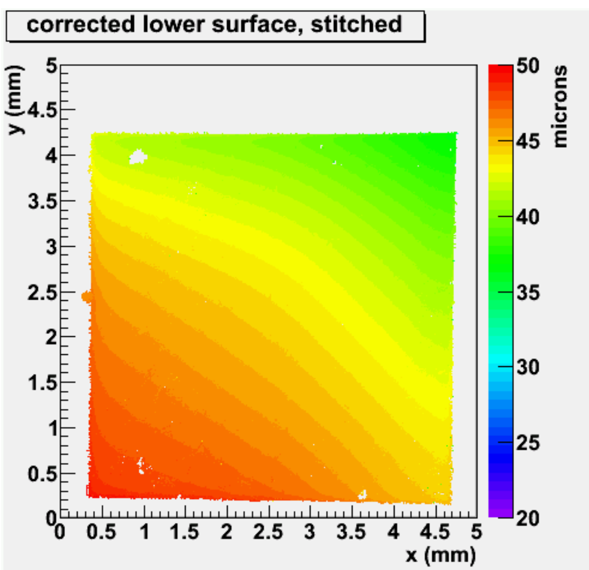
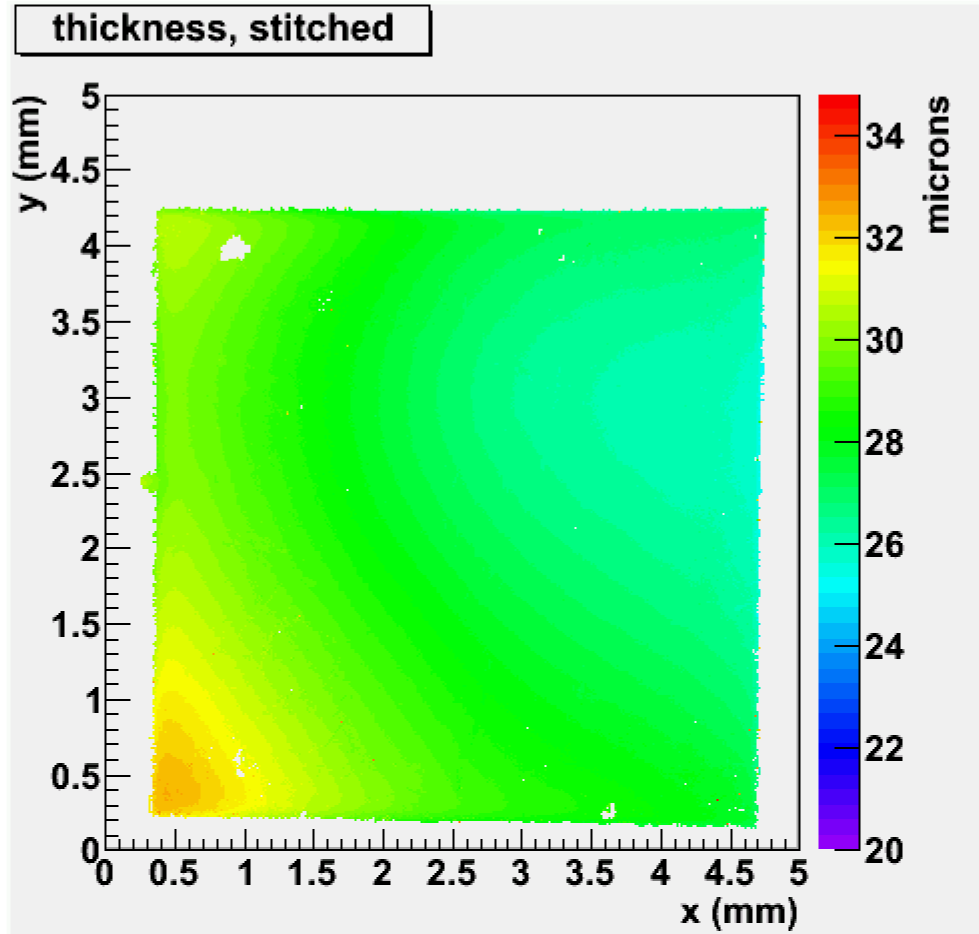




Final polish with RCMP technique



X-ray assessment: S90

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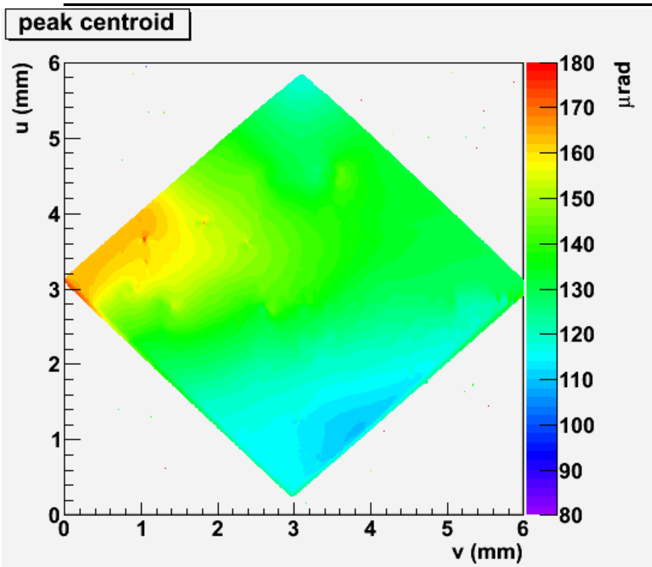
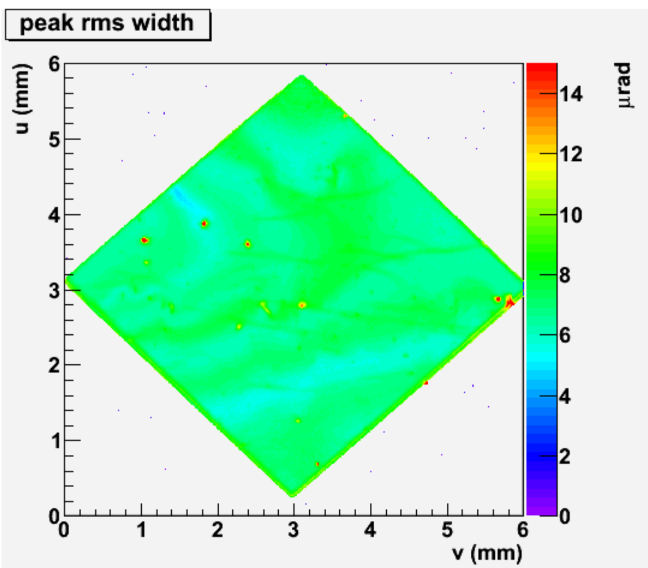
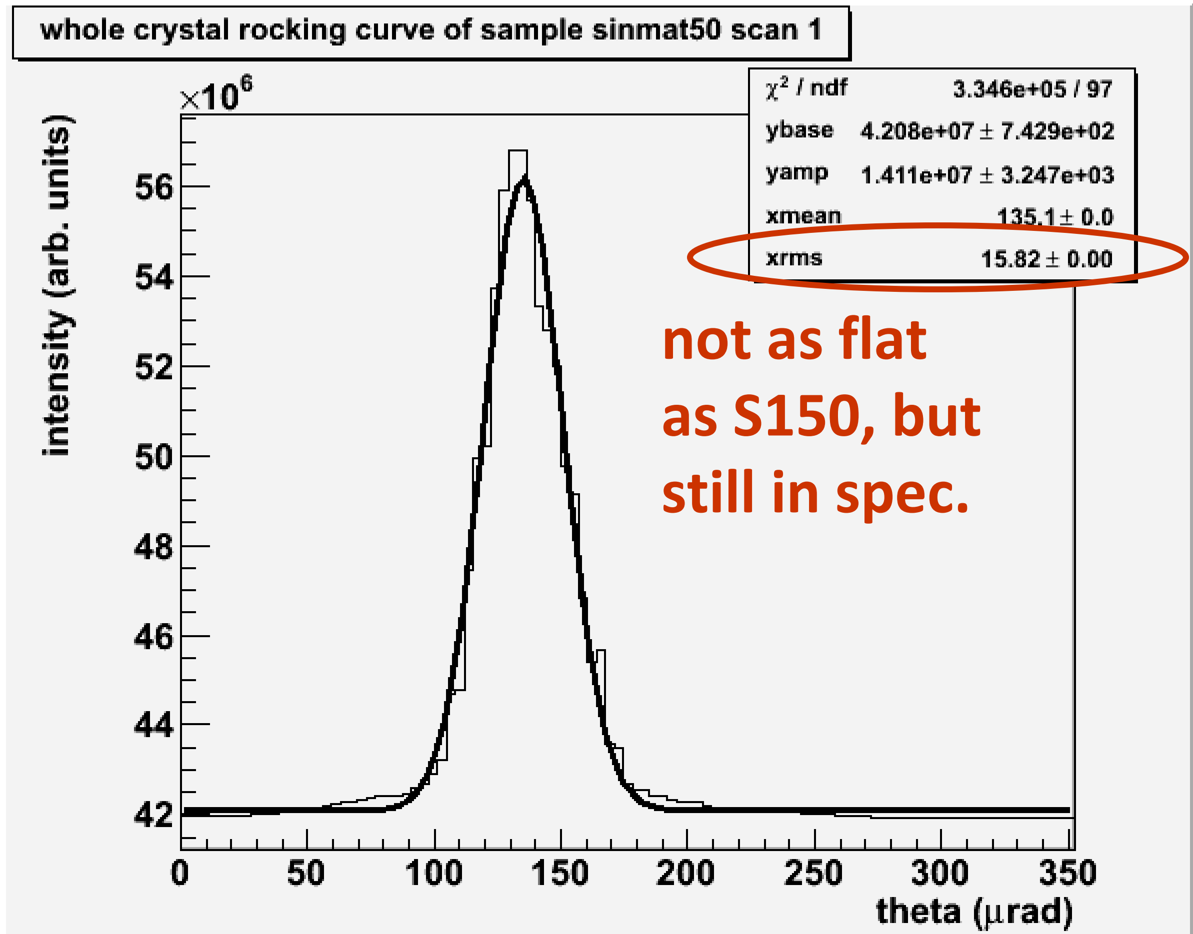




whole-crystal rocking curve (220)



not as flat as S150, but still in spec.

X-ray assessment: S30

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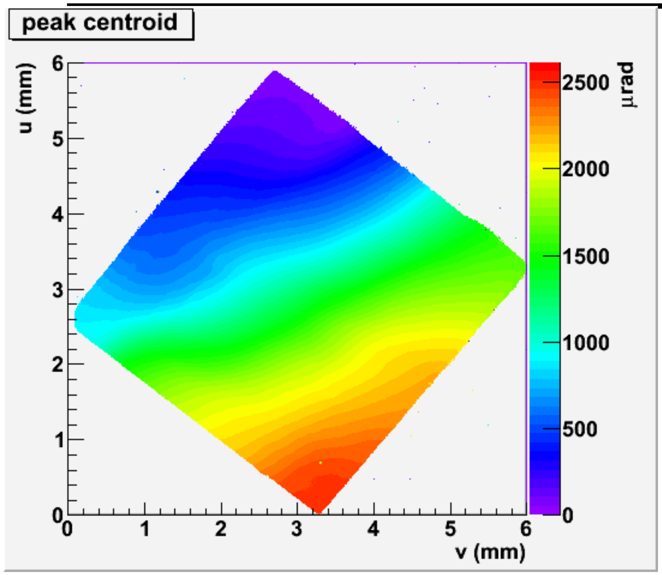
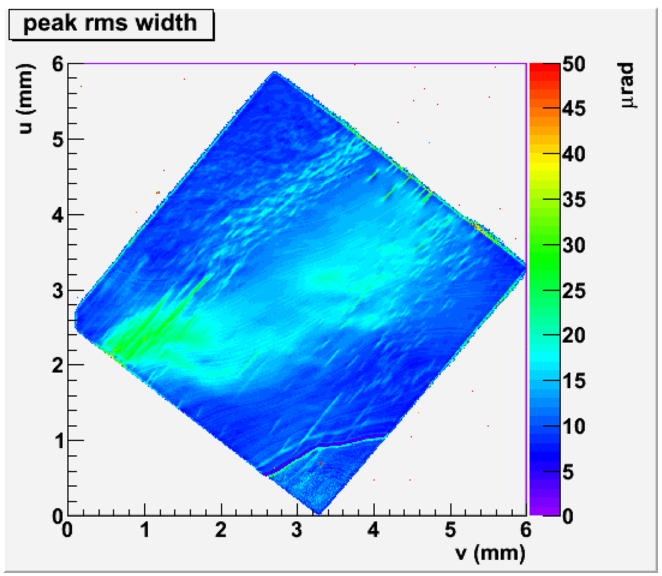
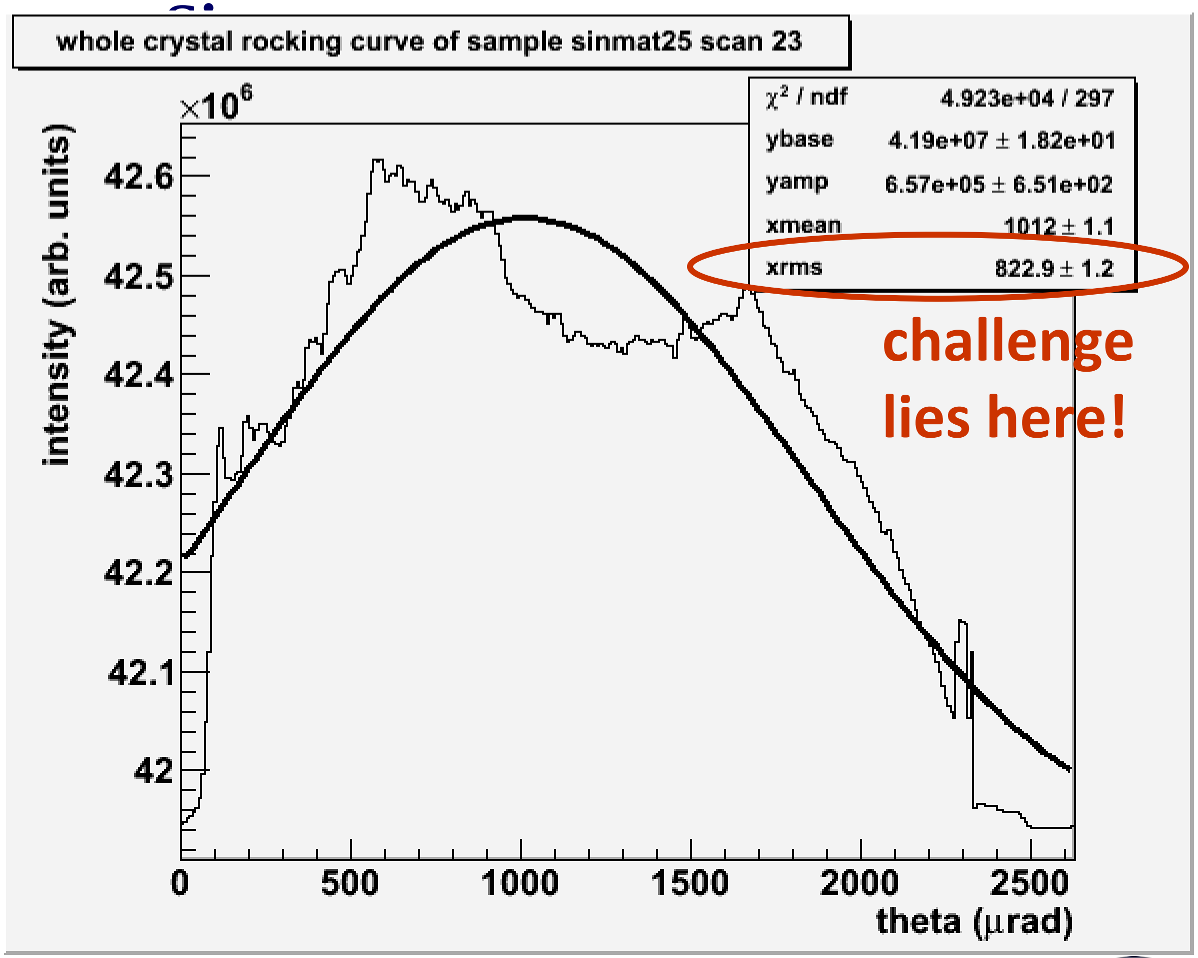
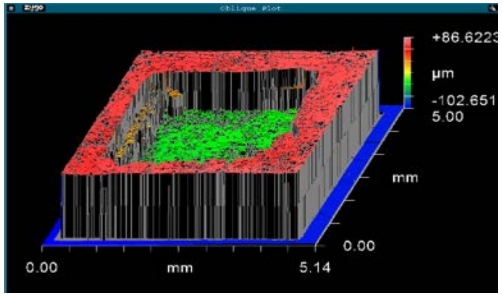


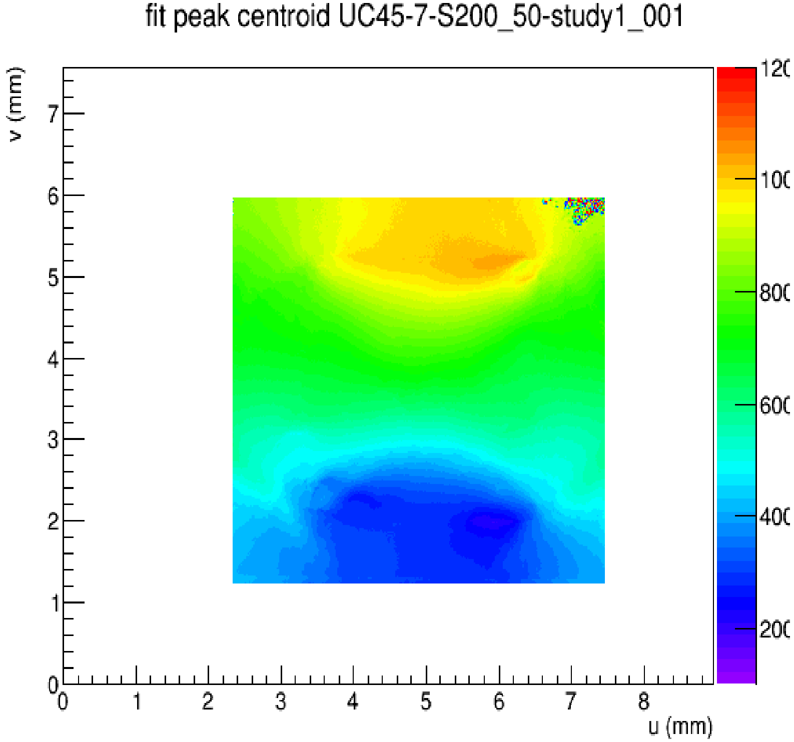


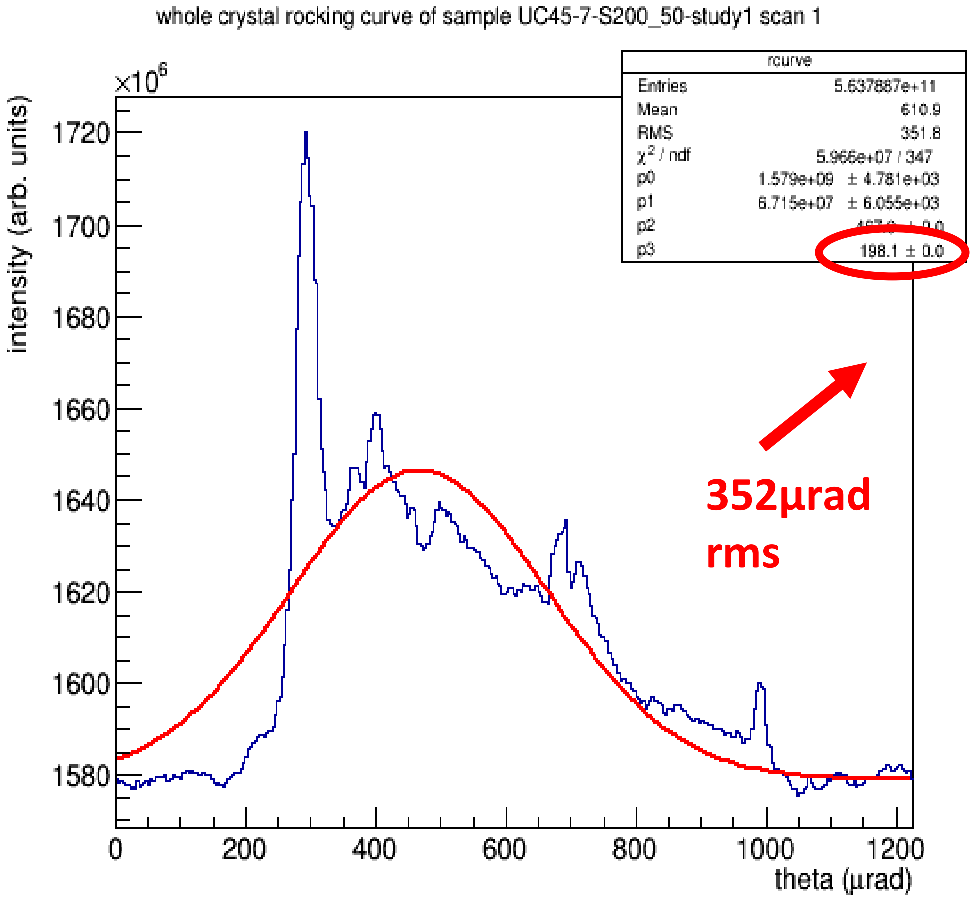
rocking curve of S30



X-ray diffraction: S200_50

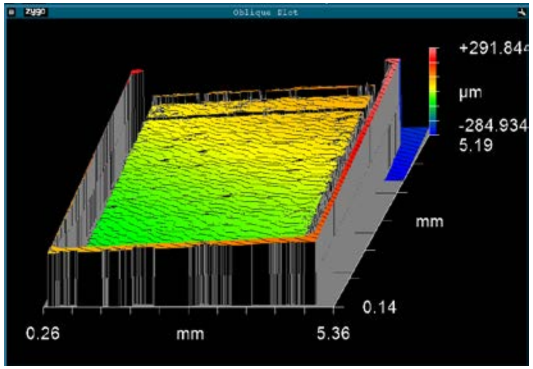


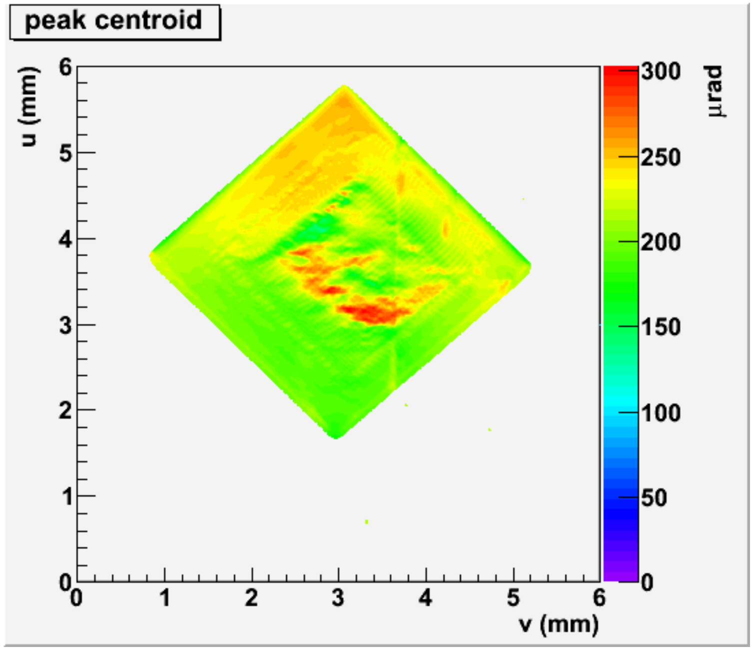




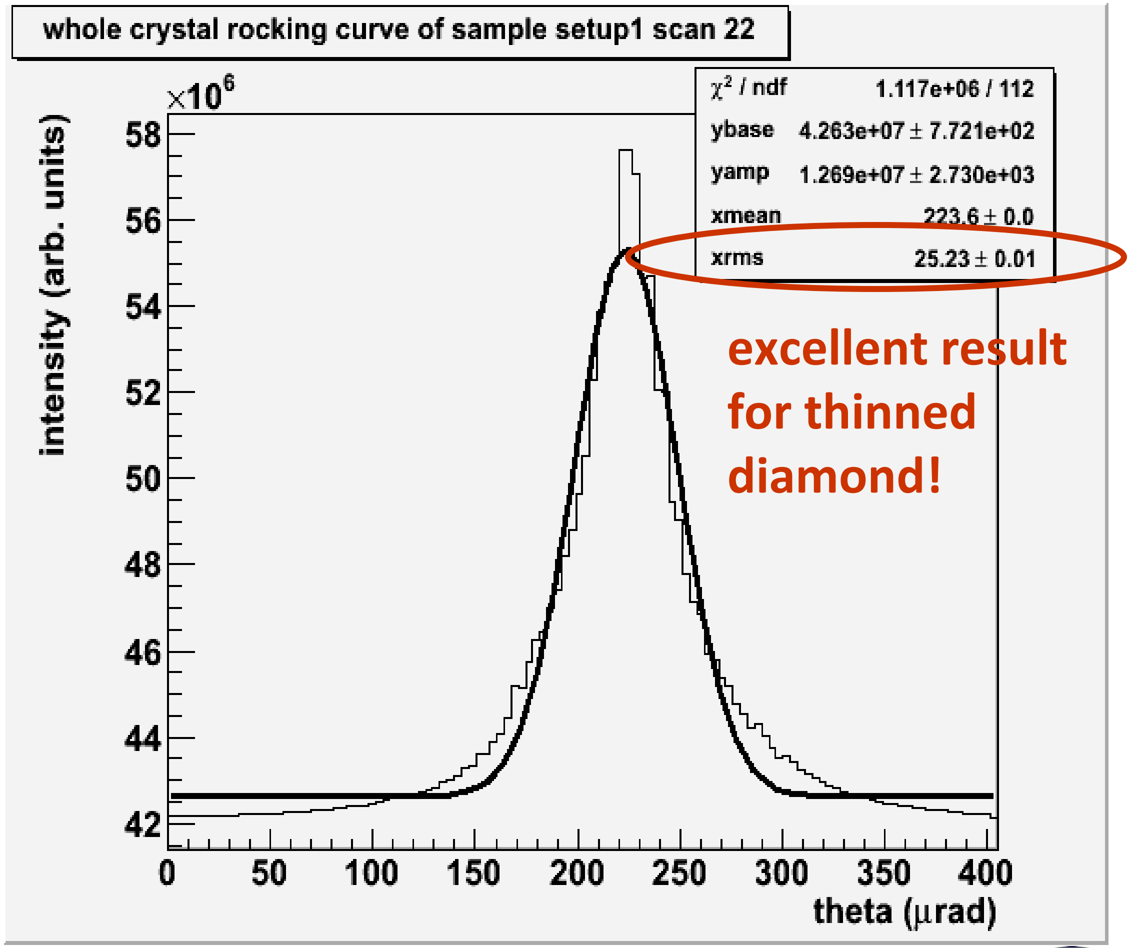
result: large bending strain across crystal

X-ray diffraction: UC300_40



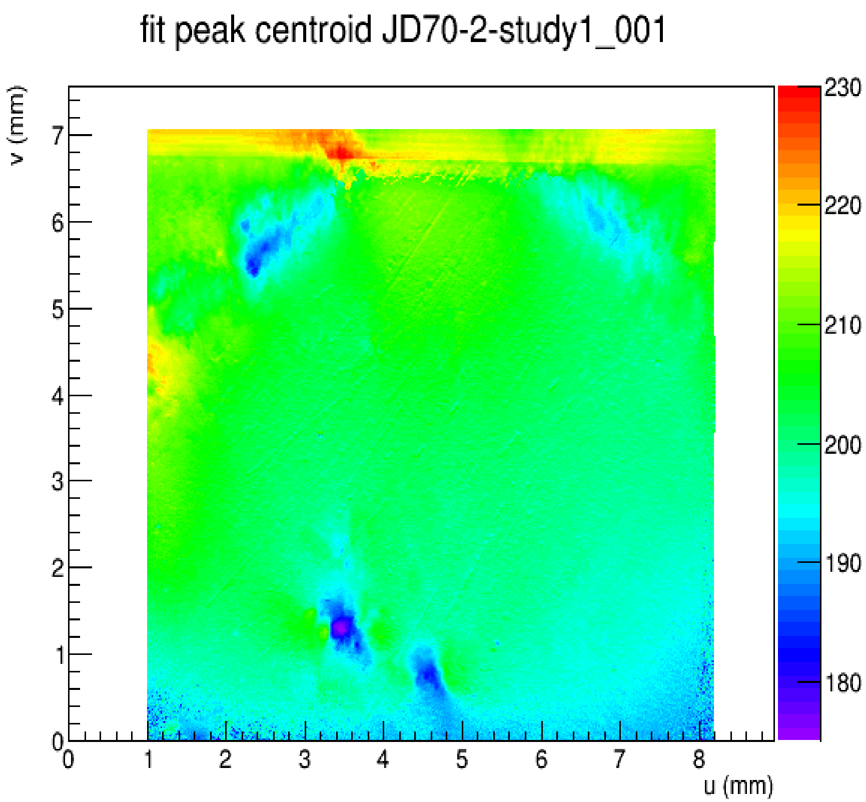


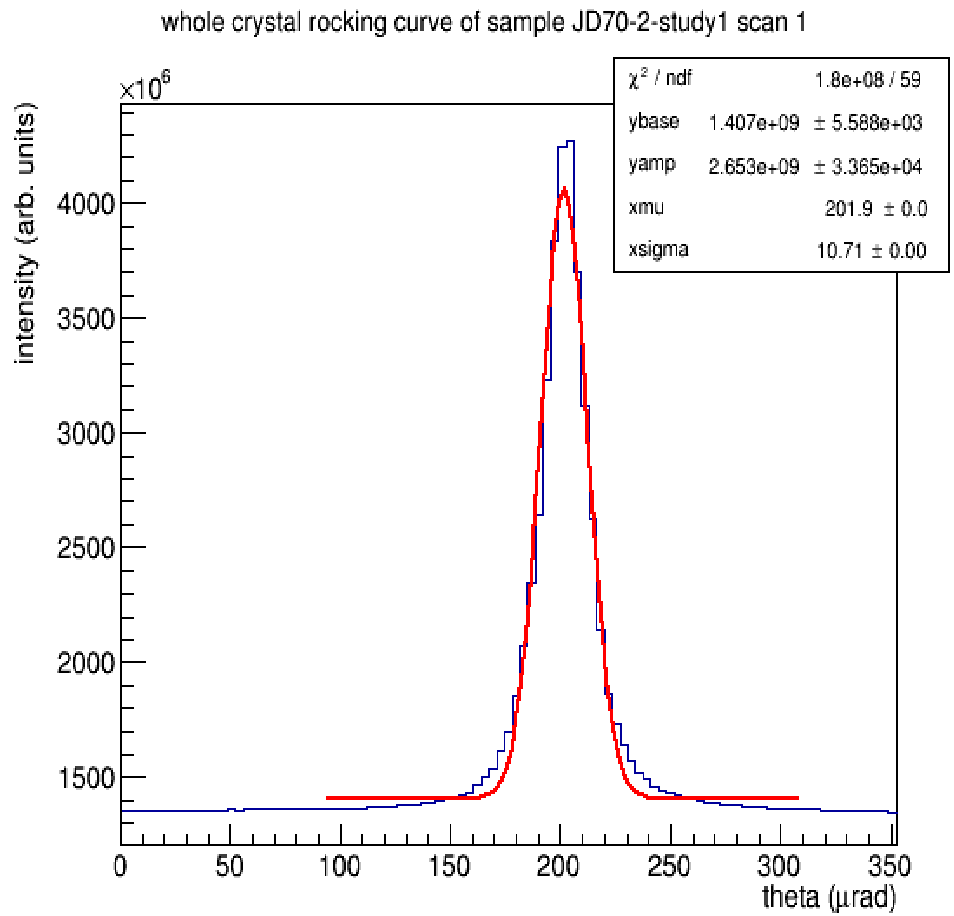
surface was not treated after ablation



Next steps: large-area 7x7 mm^2

- excellent crystal quality
- very large thickness 1.2mm





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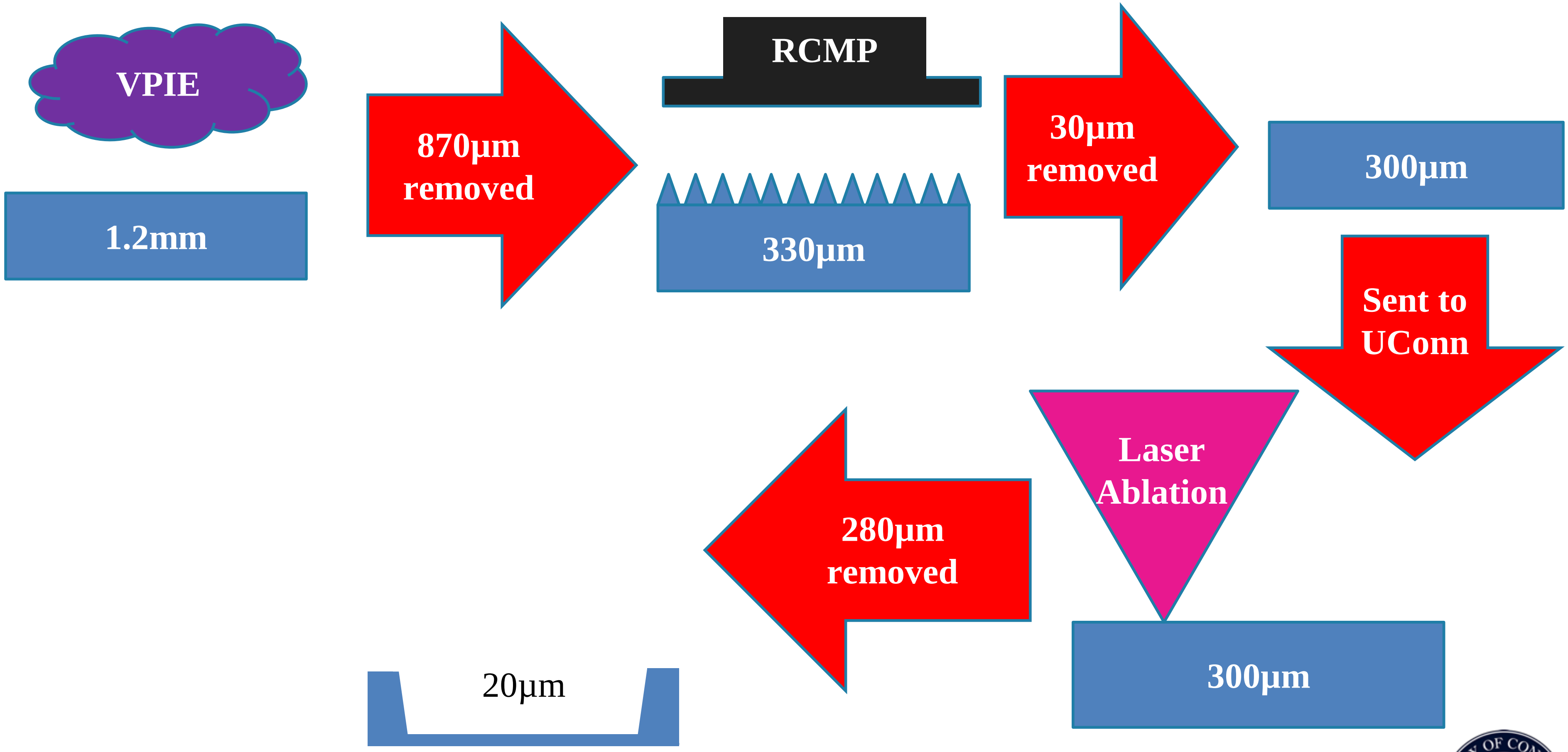
Summary of Methods

parameters → method ↓	20 µm thickness	cut rate	multiple sample	quality
Reactive CMP	✓	✓	✓	x
Vapor Phase Etch process	✓	✓	✓	x
Laser ablation	✓	x	x	✓

Plan: combine the 2 approaches



Summary

Developed a three-step process to thin diamond samples

- Step 1: Vapor phase etching process (75 micron/hr)
- Step 2: Polish surface defects with RCMP process
- Step 3: Cut thin central window using laser ablation

Validated results of all proposed steps using X-ray diffraction

- Designed a custom diamond diffraction setup at CHESS
- Optimized procedures to obtain 3 rocking curves per hour
- Developed analysis code to assess X-ray diffraction topograph
- Developed custom analysis code for 2-surface profilometry

Expected by Phase 2 completion

- 3 production-quality crystals 7x7 mm^2 with 20 micron window
- draft publication for NP instrumentation journal

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  - Fridah Mokaya (grad)
  - Alex Barnes (grad)
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