THE CATHOLIC UNIVERSITY of AMERICA

Jefferson Lab

Crystals
Status and Testing

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on behalf of NPS Collaboration

Experimental requirements and conditions

Parameter	DVCS (unpol. LH2)	DVCS (pol. 3He)	WACS	DES π^0	SIDIS π^0
Photon angl. res. (mrad)			1–2	0.5 – 0.75	0.5 – 0. 75
Energy res. (%)	(5 – 6)/√E		~5	(2 – 3)/√E	(2 – 3)/√E
Distance from target	1.5 – 3.0			4.0	4.0
Sweeping magnet (Tm)	0.3	0.3	0.3	0.3	0.3
Second arm spectr.	HMS	HMS	HMS	HMS	HMS
Photon angl. (degrees)	12.4 – 23.0		33 – 69	10.1—23.4	16.3—19.2
Photon energies (GeV)	2.7 — 7.6		1.1– 3.4	3.1—5.7	0.5—5.7
Luminosity ($cm^{-2}cm^{-1}$)	~10^{38}	~10^{37}	~10^{39}	~3×10^{37}	~3×10^{37}
Acceptance	~10 msr			60%/25 msr	10—60%/25 msr
Beam current (μA)	2.5 — 25	~ 60	~ 40, +6%Cu	1—2 (*)	1—2 (*)
Targets	LH2	30 cm 3He	15 cm LH2	10 cm LH2	10 cm LH2
Beam time (hours)	~2000		~1000	894	604

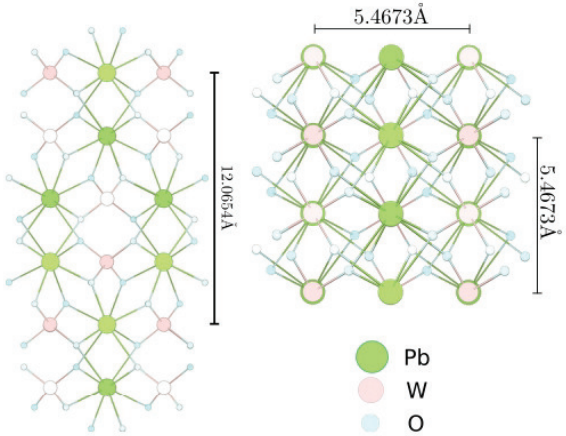
(*) 1-2 μA is a minimum requirement and background dependent. If background acceptable, then will use higher currents!

- Energy resolution → high light yield, best achievable crystals
- Coordinate resolution → fine granularity, small Moller radius, best 2x2 cm^2 or 3x3 cm^2
- Angular resolution → combine fine granularity with distance from the target
- Good Timing → Fast signal with short tail to minimize pile-up at high rates

[*] Hamlet Mkrtchyan talk for HallC meeting 24-25 January 2013

Heavy crystals like $PbWO_4$ are optimal because of excellent resolution and fast response

Overview of PbWO4 Crystal Properties



(a) Crystal Structure of PWO along the long crystal axis. (b) Cross section of PWO crystal structure perpendicular to the long crystal axis.

Material	PbWO4
Dimensions (cm)	64×74
Crystal size (cm)	2.05×2.05×18.0
Number of crystals	1116
Distance from target (m)	4.0
Position resolution (mm)	2—3
Solid angle/crystal (mrad)	0.044 (dist. 3 m) 0.025 (dist. 4 m)
Energy resolution (σ_E/E, %)	2.3/√E
Timing resolution , σ(ns)	
Radiation hardness (Gy)	10^4 –10^5 (*)

Parameter	Lead Tungsten ($PbWO_4$)
Density (g/cm3)	8.28
Radiation length Xo (cm)	0.89
Refraction index	2.36 (λ = 420 nm) 2.24 (λ = 600 nm)
Transmission range (nm)	340-1000
Moliere radius (cm)	2.19
Radiation type Sensitivity to low en. bckgr.	Scintillation (~13% Čerenkov) Sensitive
Timing property (slow/fast) τ_{sc}, ns (%)	≈30 ns / 10 ns 5 (73%) 14 (23%) 110 (4%)
Lead content (% by weight)	> 85
Hydroscopicity	No
Energy resolution σ_E/E (%)	~2.4/√E
Position resolution σ (mm)	~2.5/√E
Photon yields per 1 MeV	~140-200
Temperature dependence of Light Yield	~ -2%/°C at room temperature
Critical Energy (MeV)	--

PbWO is optimal because of small Moliere radius, high density, excellent resolution and fast response

What was planned for crystals in 2017

Finalize crystal testing facility setups at Orsay and CUA including chemical analysis

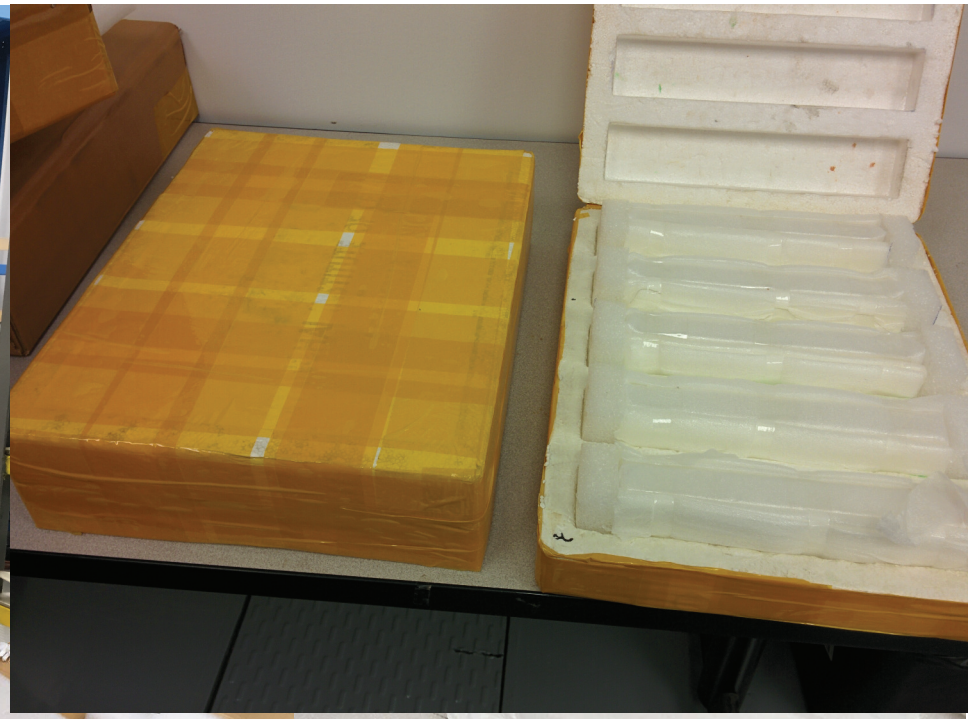
- Dimension measurements, setup data acquisition, prototype
- Optical measurements: transmittance, decay kinetic, light yield
- Radiation resistance
- Surface and chemical composition

Define and document quality assurance methods, procedures and specifications for crystals

- Setup a database to record information for each crystal
- Wiki, document draft

Characterize (some of ~100) the PbWO4 crystals purchased from SICCAS in 2017

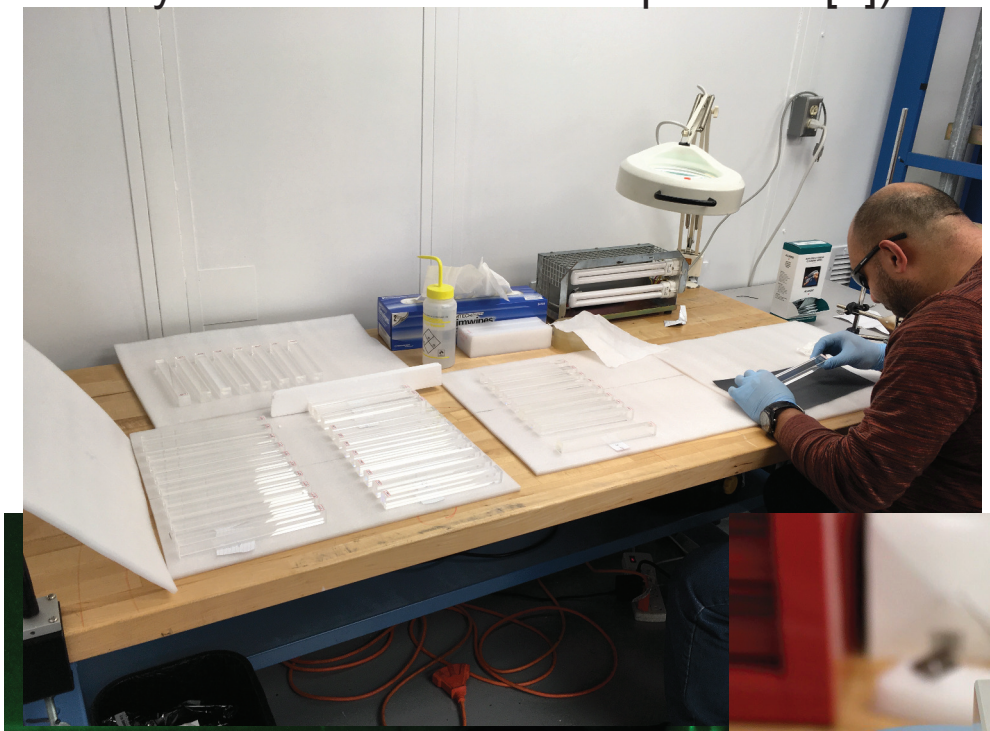
Typical shipment of PbWO4 crystals from SICCAS

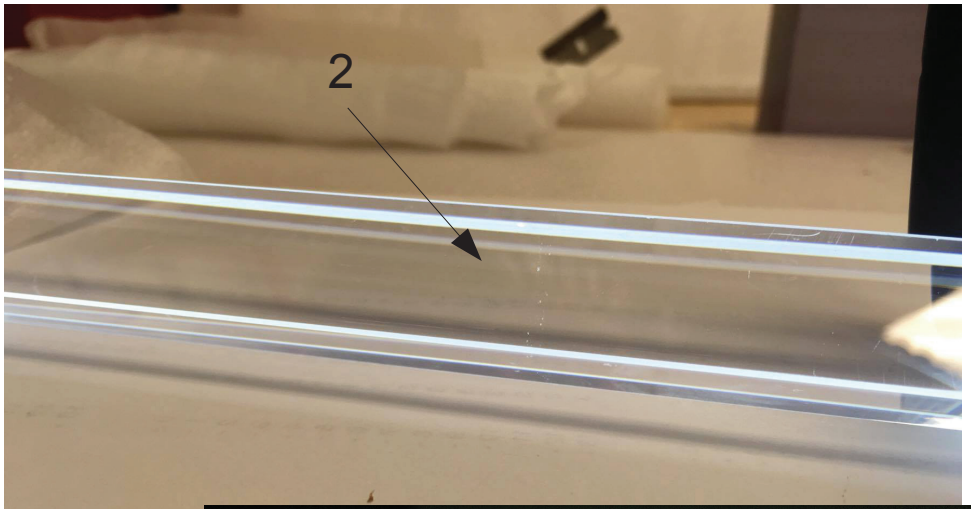


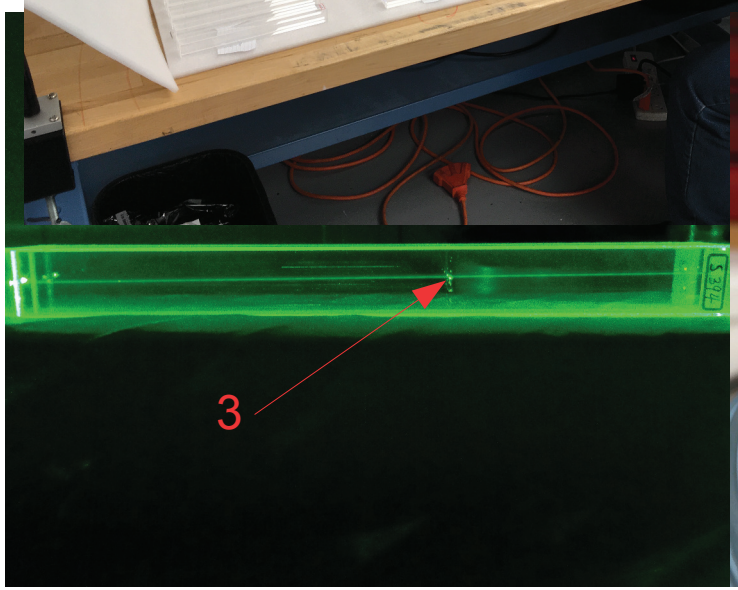
- 3 packages delivered from SICCAS in 2017 (September - 160, October - 160 and 140)
- 460 crystals in total

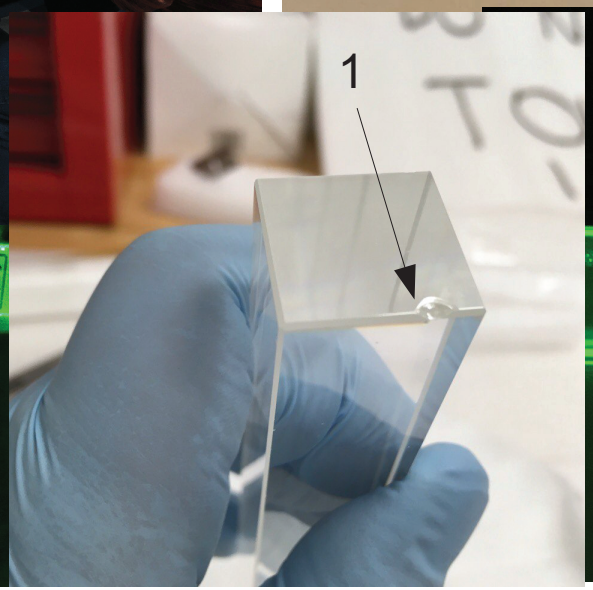
Visual inspection – method

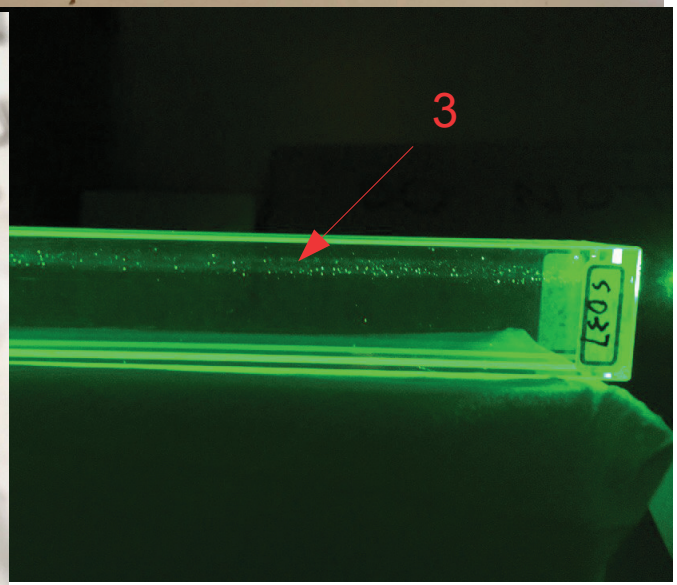
- Each crystal pass through two steps of visual inspection
- At first step each crystal inspected for cracks [1], chips, bubbles[2]
- Second step is inspection in the dark with laser pointers (some crystals defects visible only in the dark with laser pointers [3])





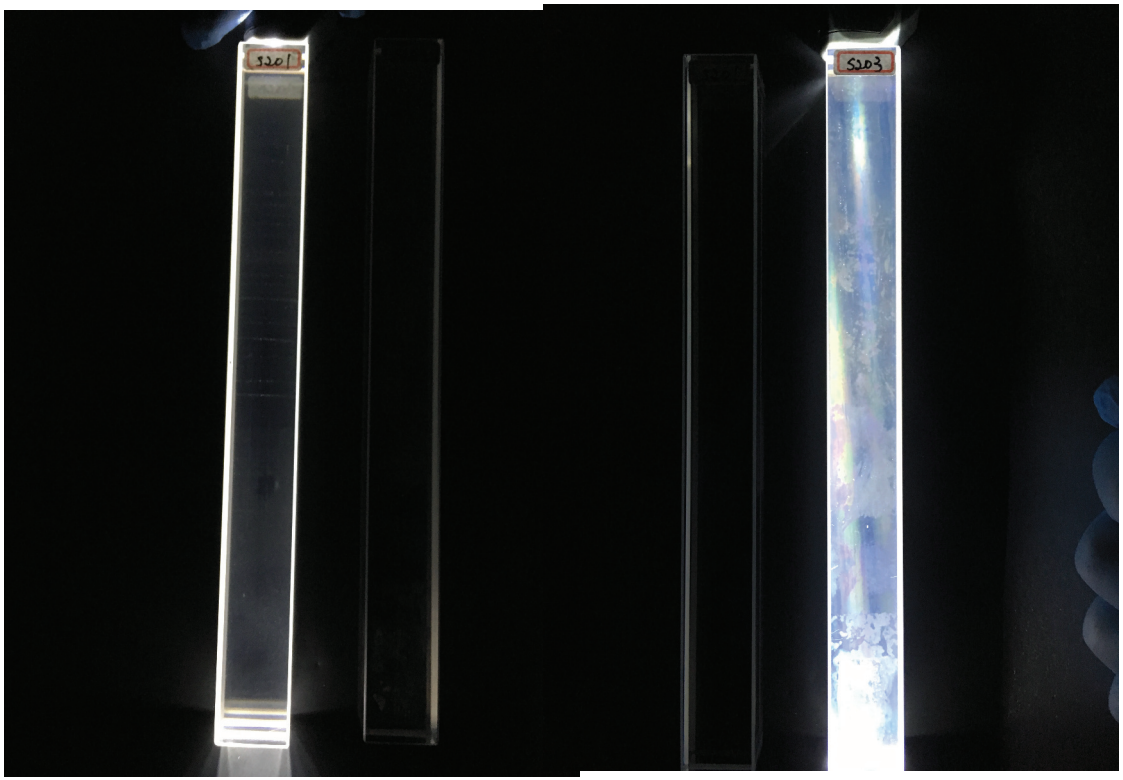


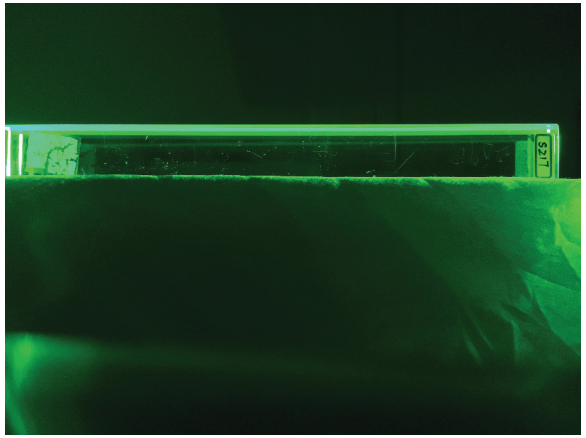


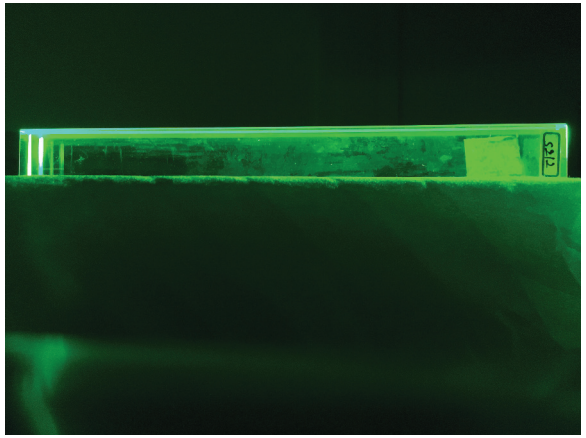


Visual inspections – interesting results

- In second package of crystals more than 10 crystals with completely different look have been observed
- The surfaces of that crystals covered with chemical film
- Scratched labels and glue prints of old labels
- Chemical film can not be clean with isopropyl alcohol
- Crystals with chemical film observed in box numbers (B2-5), (B2-6)

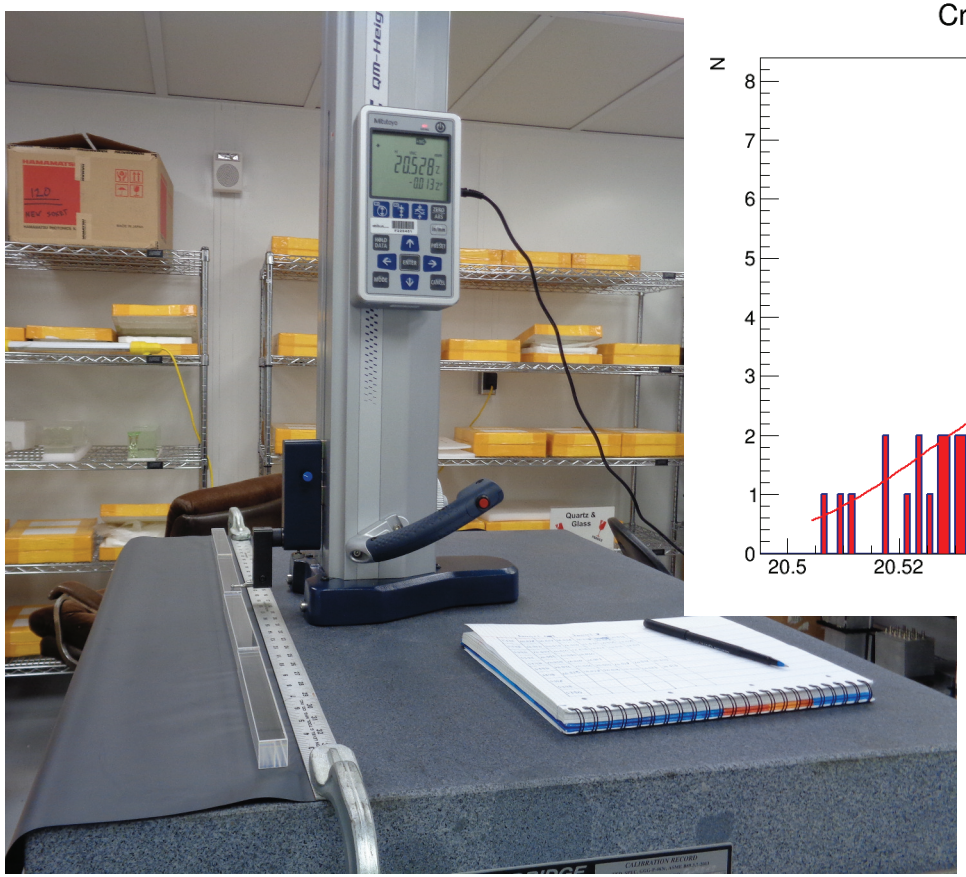


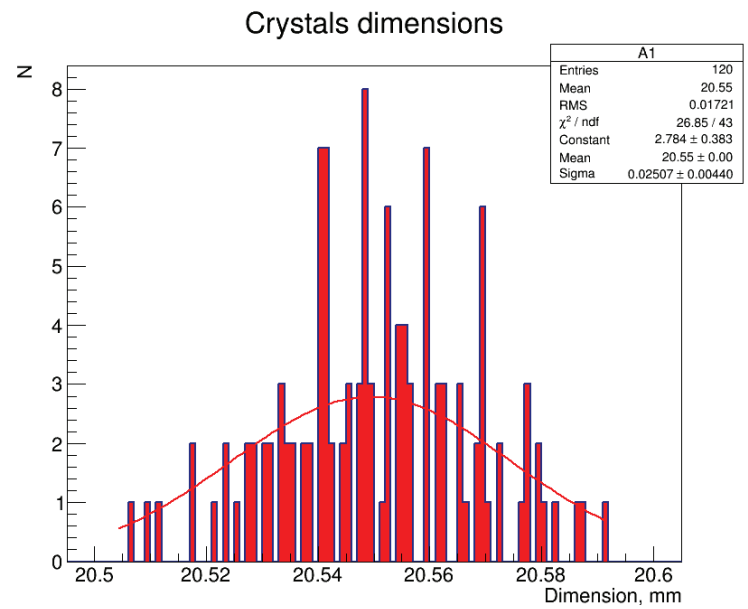




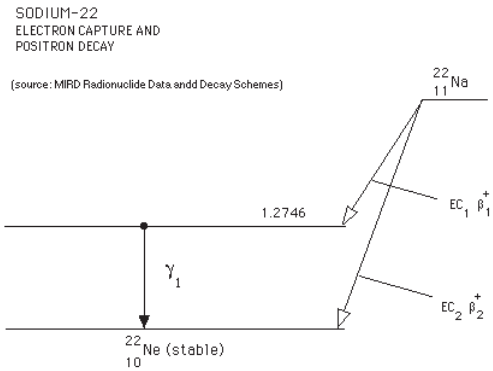
Dimension measurements

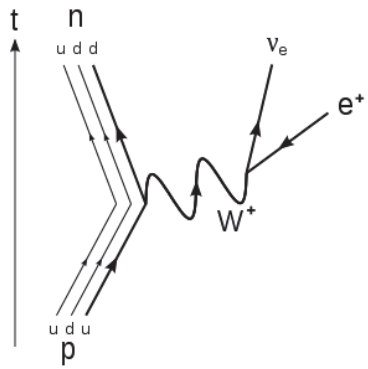
- Mitutoyo hight gage tool (accuracy ~1um)
- Granite table (flatness accuracy ~ 6 um)
- <u>Safe and more precise compare to other methods</u>
- <u>Six measurements per one crystal</u>

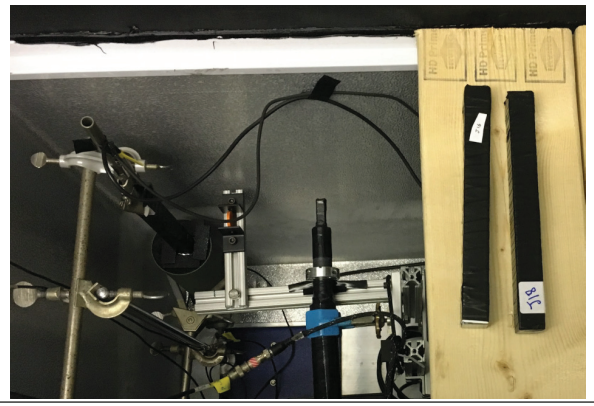


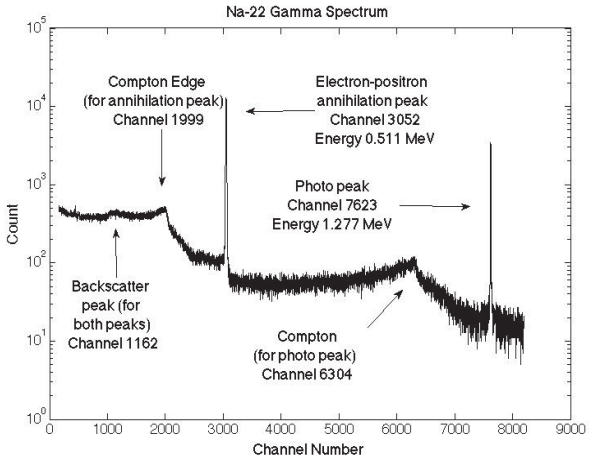


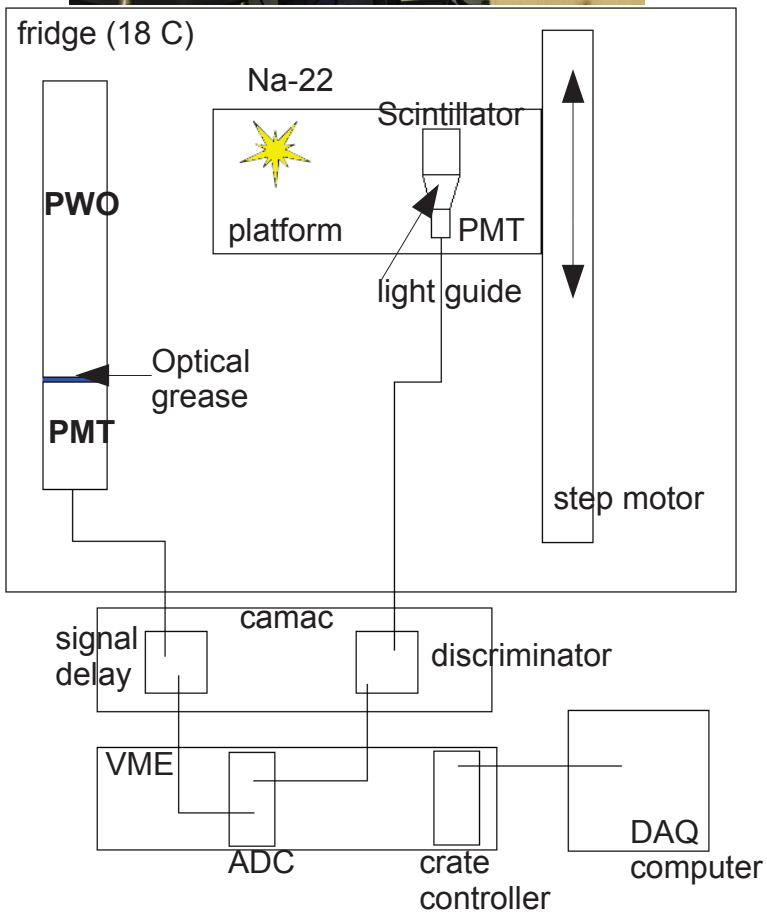
Light yield measurements

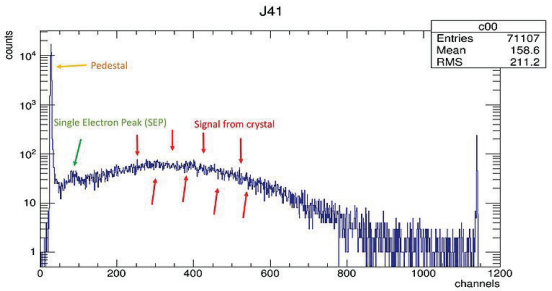


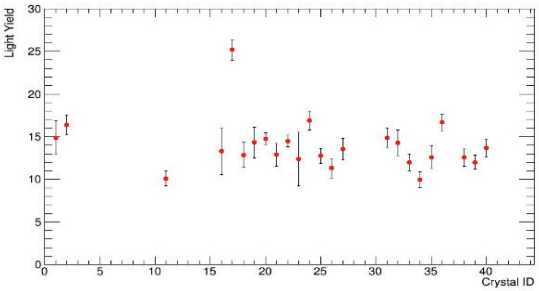




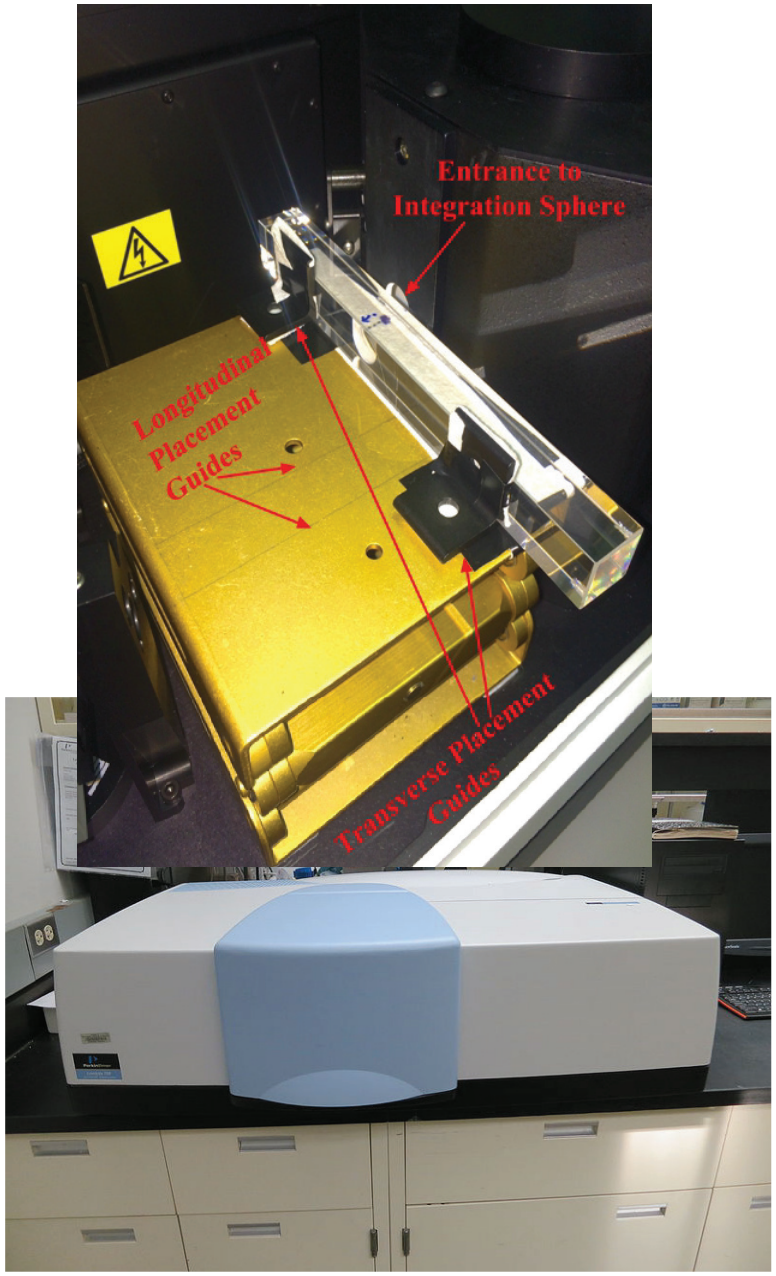


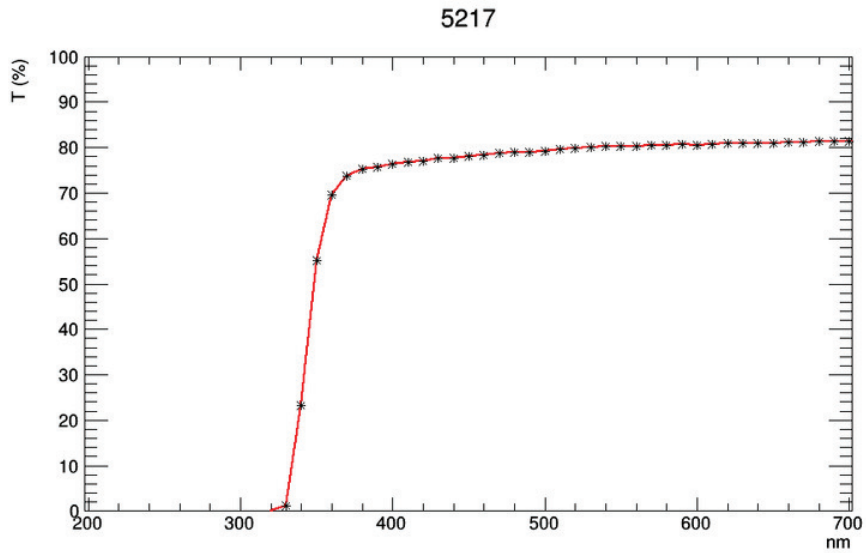


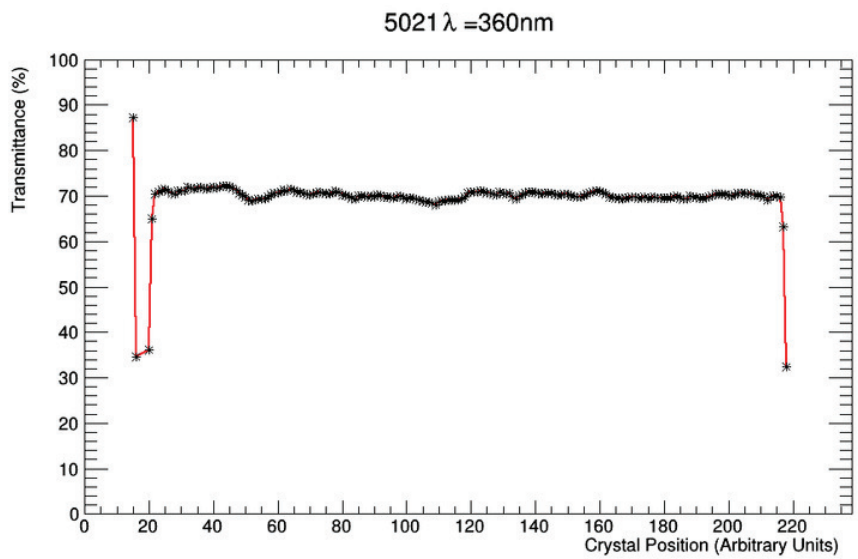




Transmittance measurements - Setup

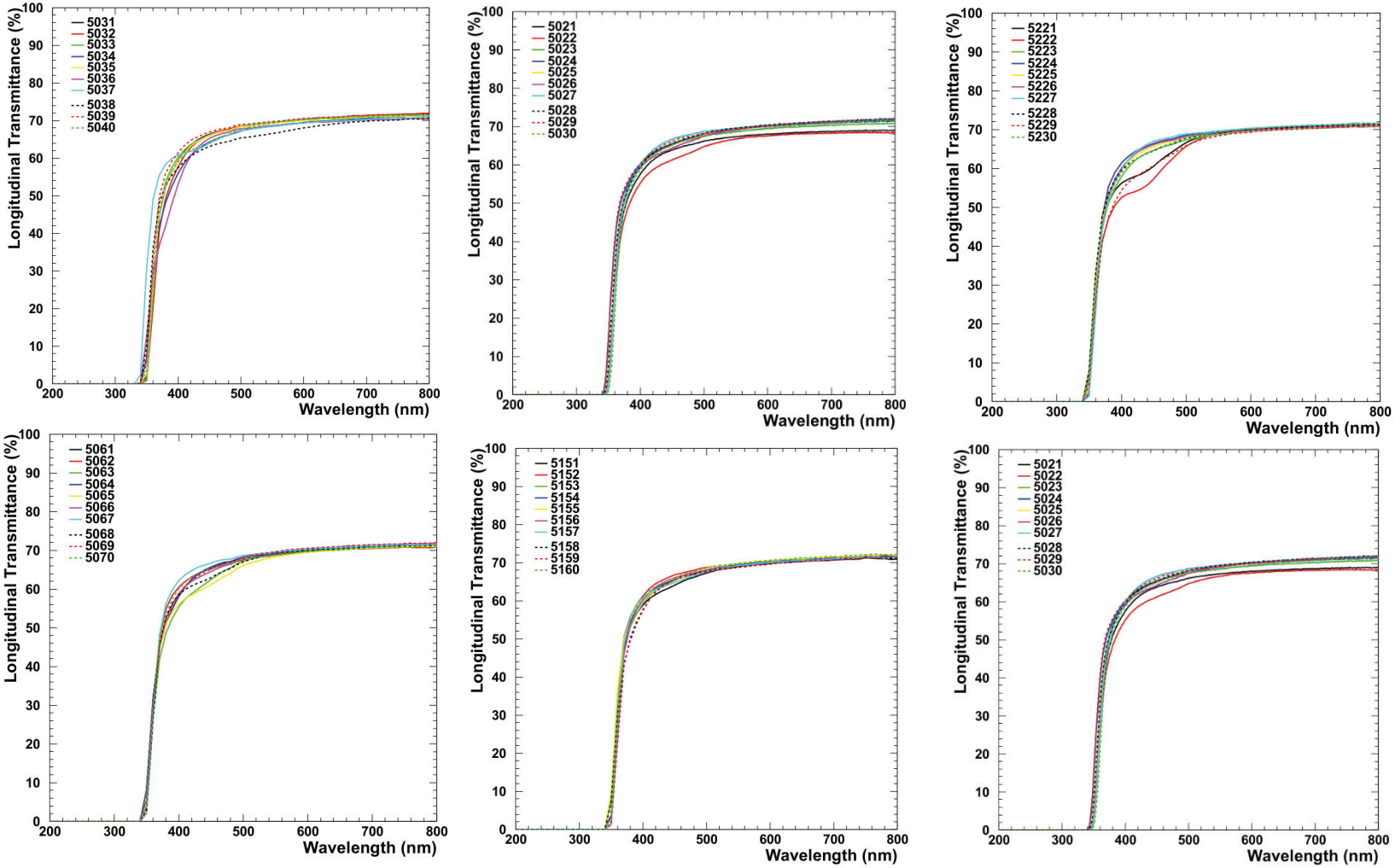






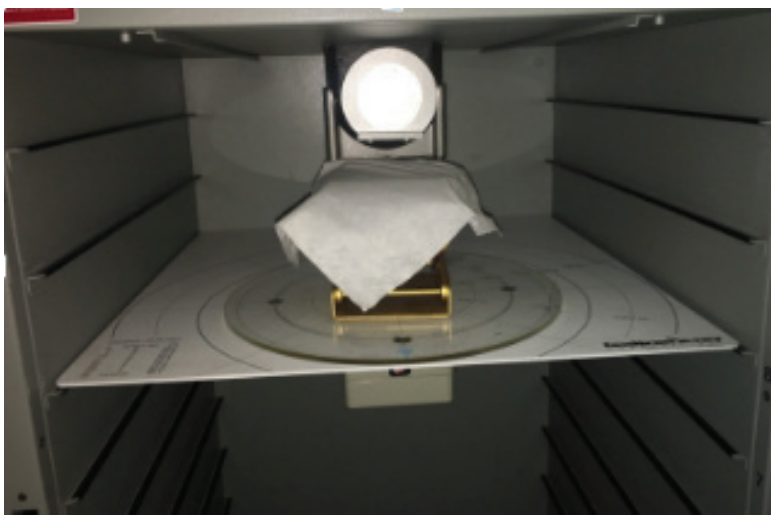
Transmittance measurements – some results

Longitudinal Transmittance: SICCAS 5031-5040, 5061-70, 5021-30, 5221-30, 5311-20, 5151-60 (Box #3, 2-1, #4, 2-7, 2-16)



Radiation hardness

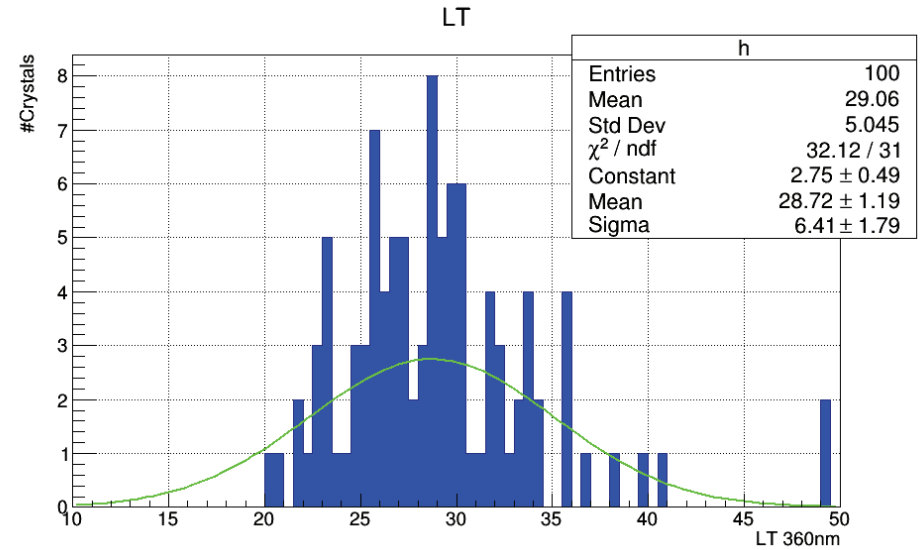
- To irradiate the crystals, a Faxitron CP160 was used It was set to 160kV and 6.3mA
- The calculated ionization rate was ~ 6,970 R/min
- A sharpie marker was used to indicate which side of the crystal was being irradiated so it was clear which side should have been facing front in the spectrometer when taking transverse transmittances before and after irradiation

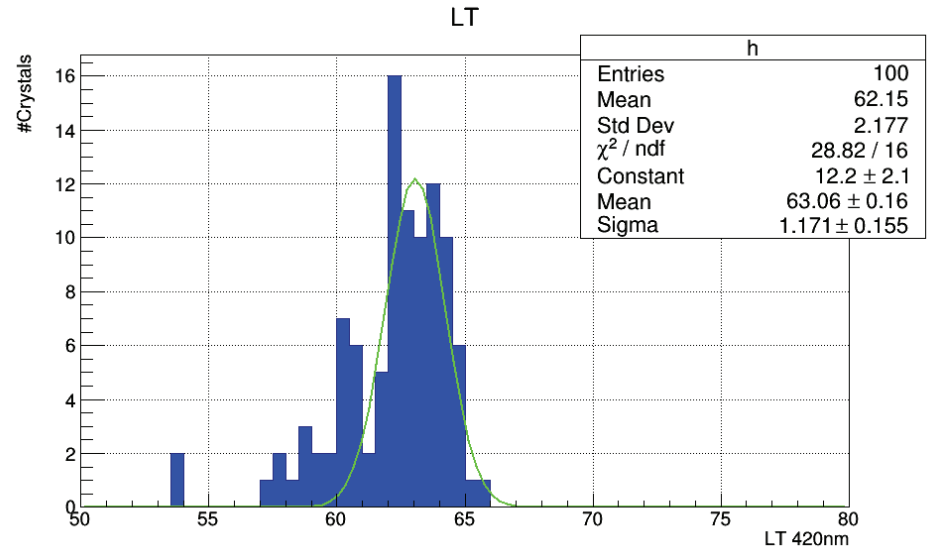


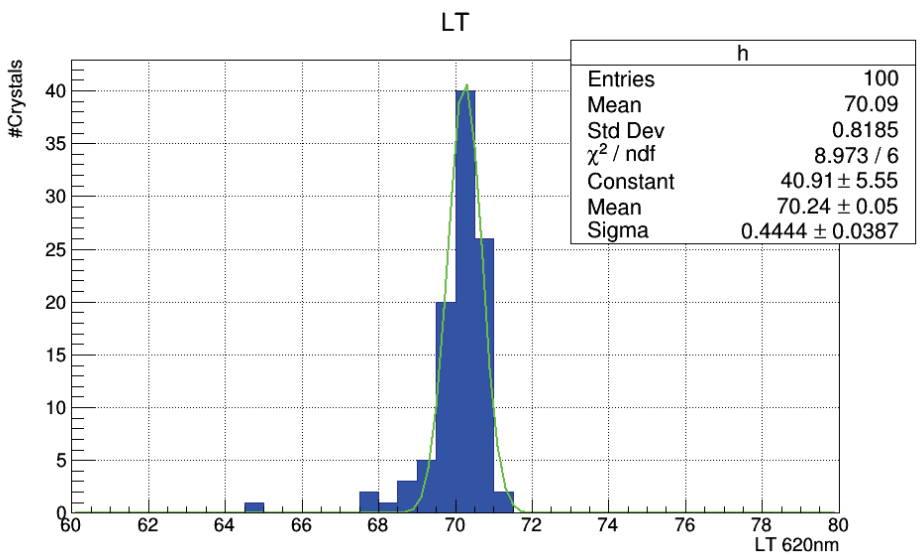
$$\text{Absorption coefficient} = dk = \frac{1}{\text{length}} \ln\left(\frac{T_{bef}}{T_{irr}}\right)$$

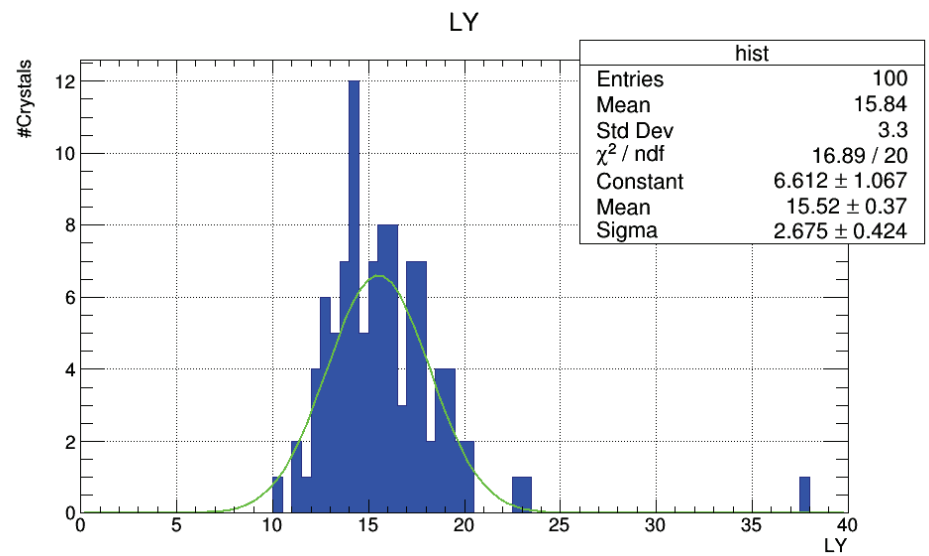
Crystal ID	dK
5021	2.6
5022	1.7
5023	5
5024	0.7
5025	0.7
5026	2.9

Measurements results



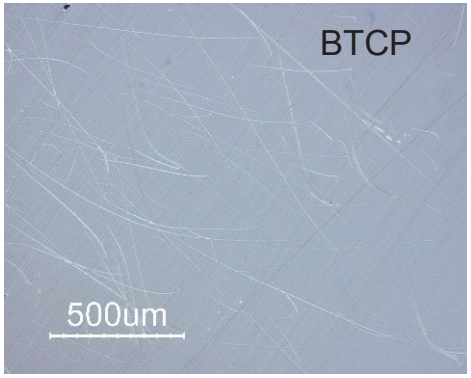




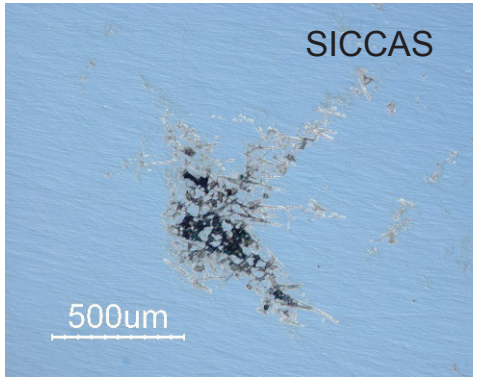


Crystal Quality - Surface Analysis

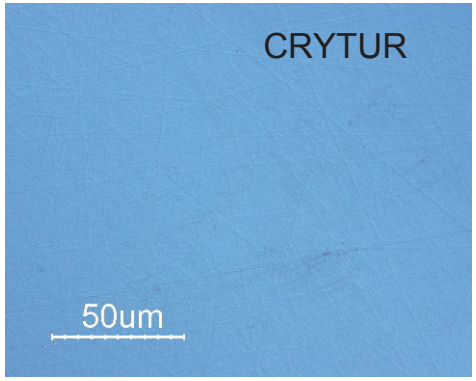
- Typical crystal surface quality



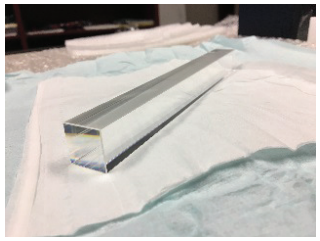
Out-of-business



Mass production may be available – 320 crystals delivered in 2017



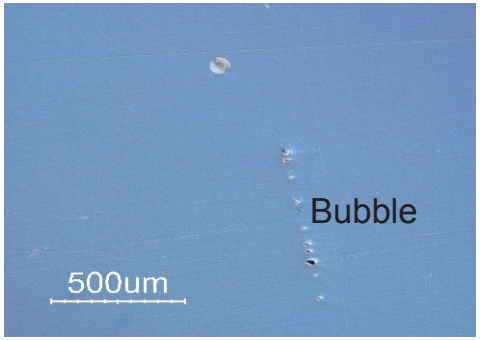
Mass production uncertain

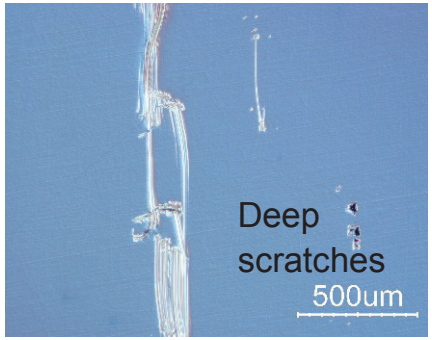


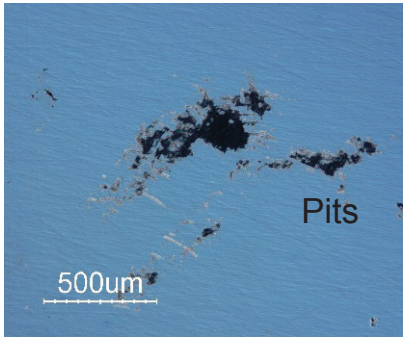
Measurements: scanning microscope in collaboration with VSL

➢ Scratches applied in a well-defined manner may benefit crystal properties – discussion with vendors ongoing

- Looking deeper into defects: SICCAS 2017 crystals





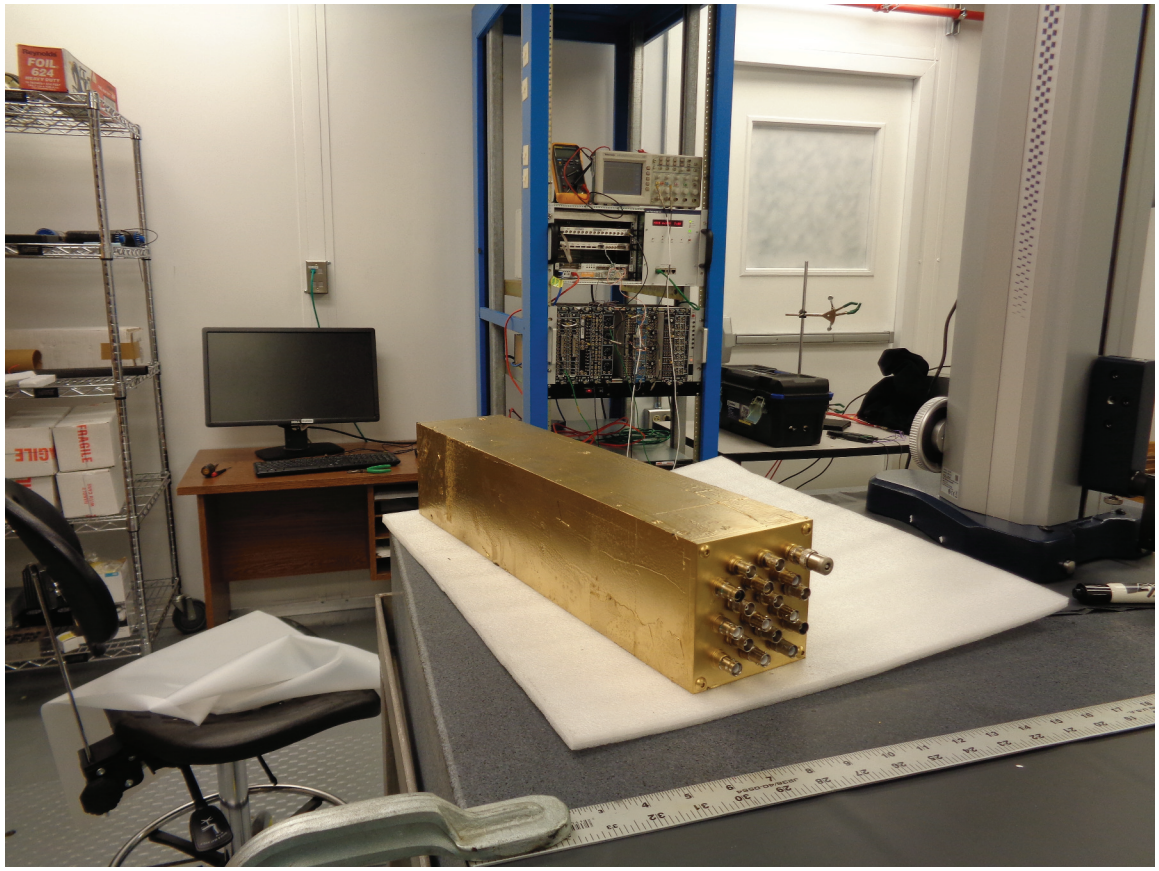


Anticipate 450 crystals from CRYTUR in collaboration with NPS project for testing

➢ Defects result in high, but non-uniform light yield – discussion with vendors about mitigation ongoing

Future plans

- Further tests with 3x3 prototype using DAQ in NPS cleanroom
- Assembling two types of prototype made from relatively “good” and “bad” crystals
- Compare the physical performance of such prototypes
- Assembling “big size” prototype and perform tests with cosmics and e-beam



Summary

- Crystal testing facility setups is done, some optimization is ongoing
- DAQ setup in NPS cleanroom is done
- 3x3 prototype is ready for further tests
- 460 crystals received from SICCAS
- Visual inspection, dimension measurements, optical measurements, radiation resistance measurements is ongoing (~100/460 is done)
- Surface and chemical composition studies is ongoing
- Working on setup of database is ongoing
- Looking forward for crystals package from CRYTUR

Acknowledgements

I would like to thank :

- Tanja Horn
- Hamlet Mkrtchyan
- Arshak Asaturyan

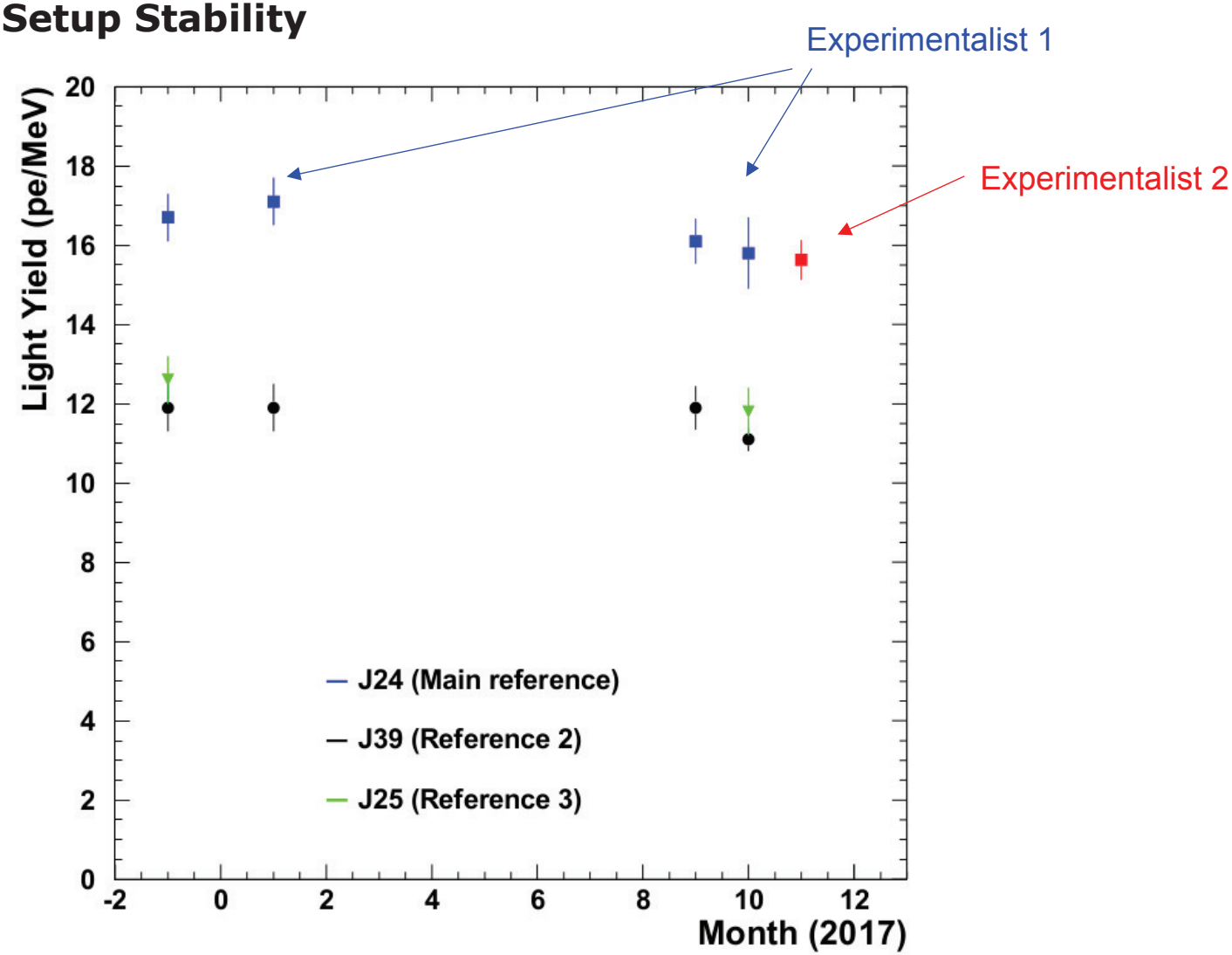
for help and useful comments.

“ *Better a diamond with a flaw than a pebble without.* “
- Confucius (551 BC - 479 BC)

Thanks for your attention !

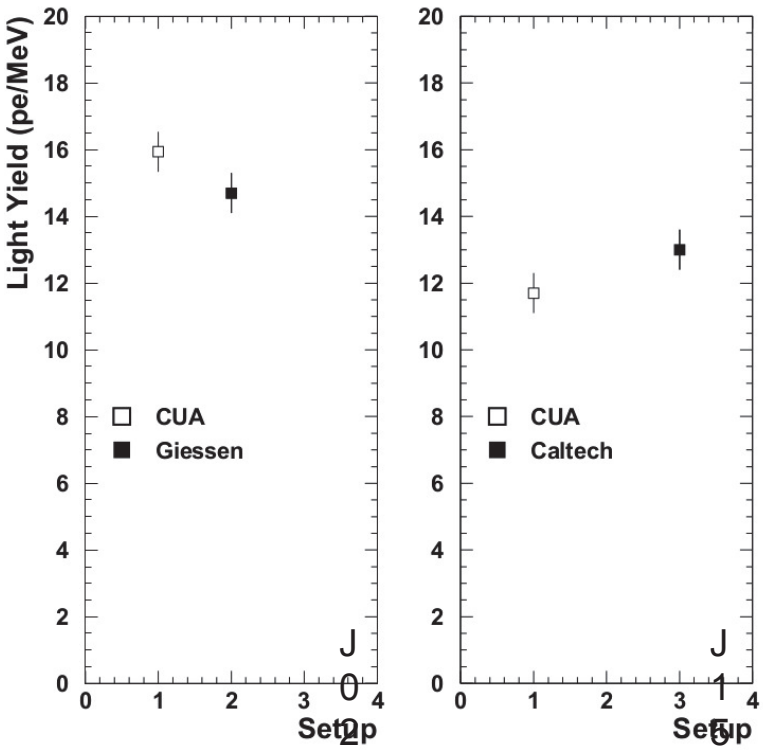
Back up slides

CUA Light Yield Setup Stability

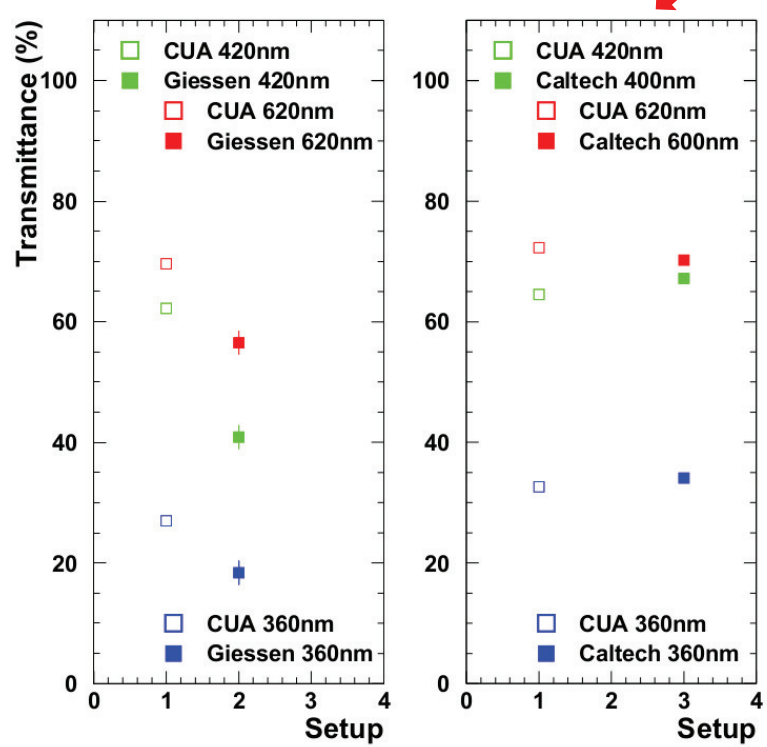


Comparison: CUA, Giessen, Caltech

Light Yield



Longitudinal Transmittance

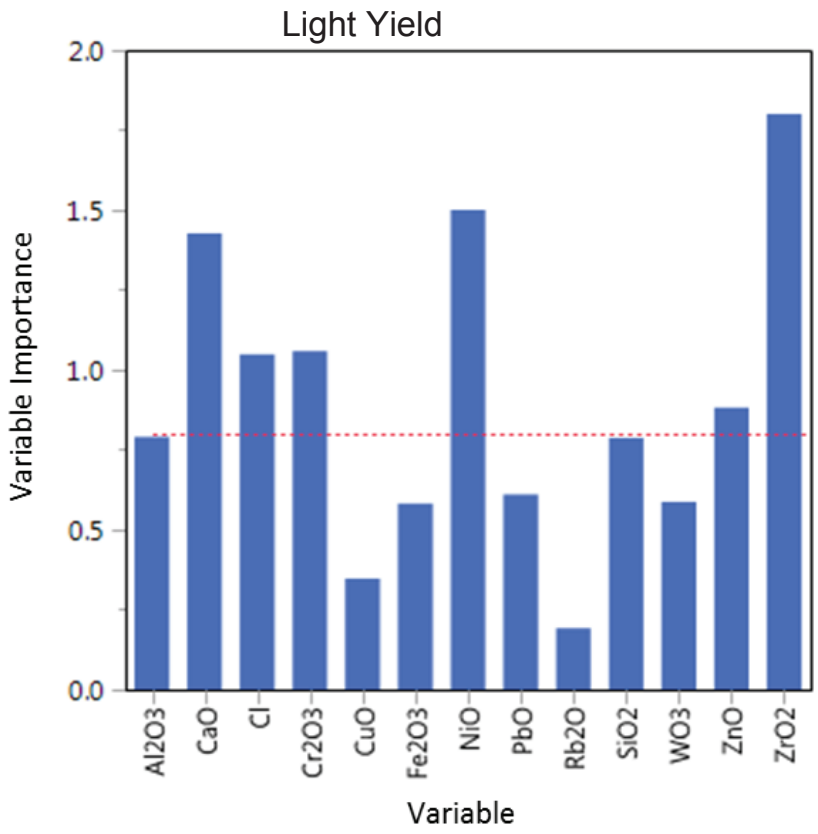


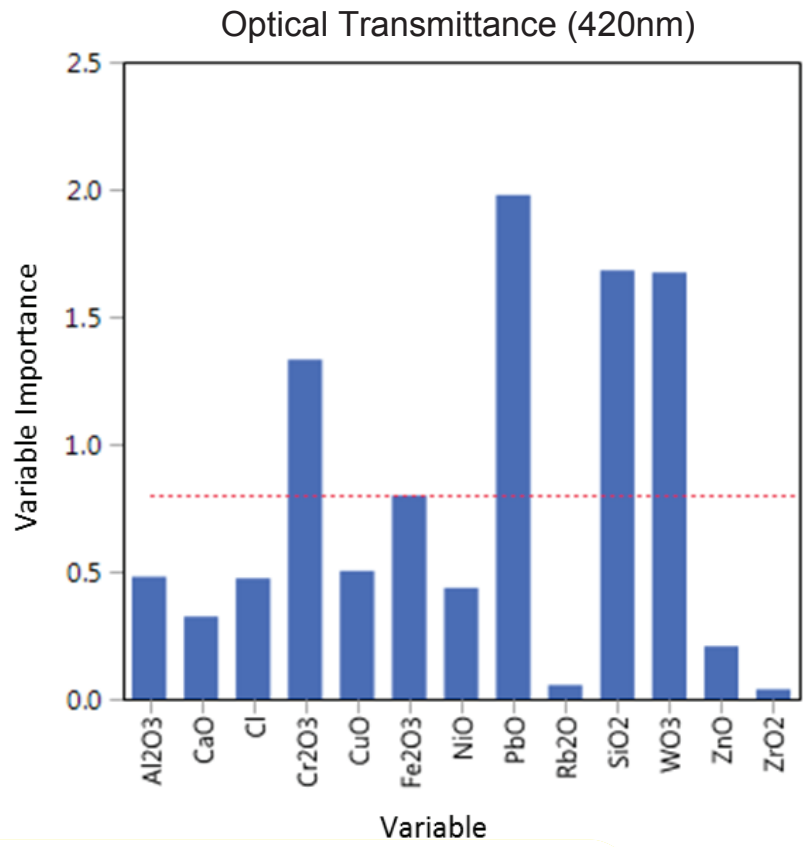
Note difference in wavelengths

Correlations: chemical composition and optical properties

The Catholic University of America

- To assess the impact of individual chemical components, correlation models were constructed using partial least squares





- Next steps:
  - Radiation hardness
  - Additional crystal samples – so far focused on samples that failed at least one optical specification