

Test results for the recent SIC PWO crystals

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SICCAS, Shanghai, July 23 (2018)

Red denotes relaxed parameters
in the 2018 procurement



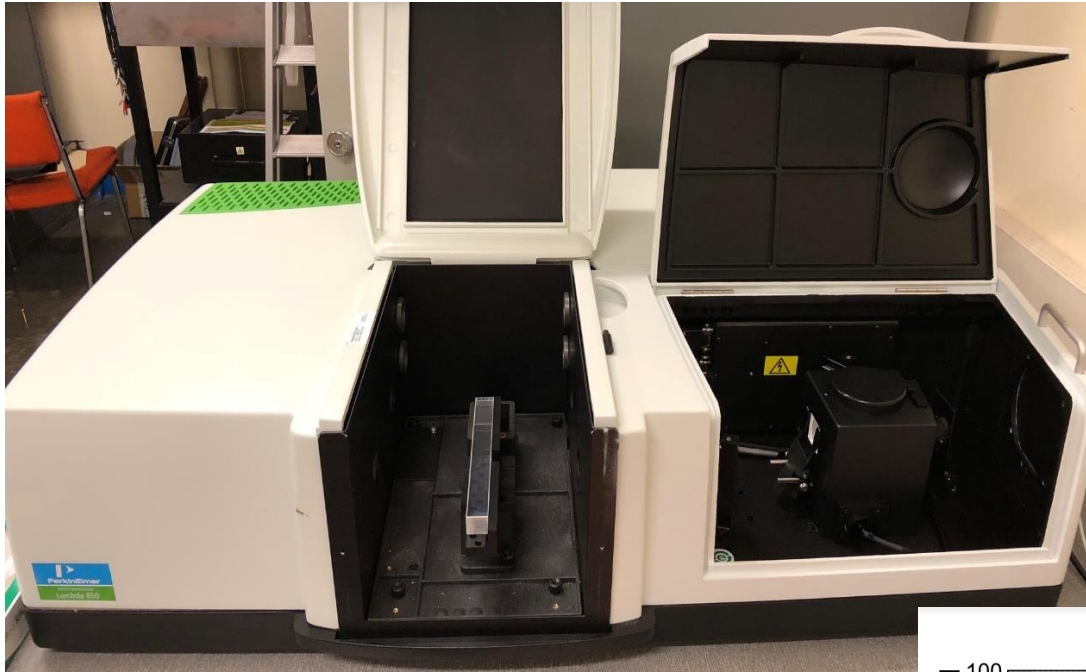
NPS: 2.05cm x 2.05cm x 20cm

PbWO4 crystal specification

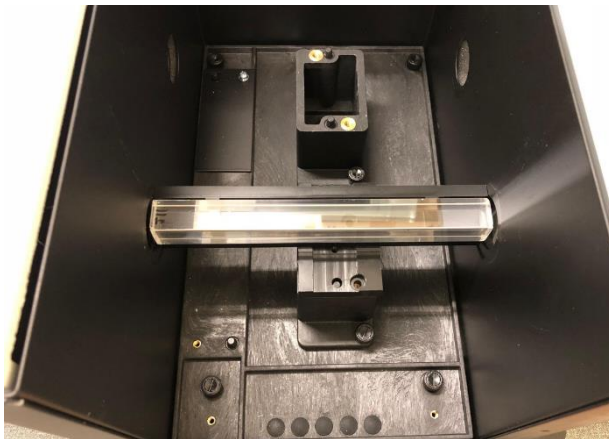
Parameter	Unit	NPS Required	COMCAL/FCAL	PANDA specifications
Light Yield at RT	phe/M eV	≥15	≥9.5	≥16
LY uniformity between the blocks (%)		<10 (<20)		
LY(100ns)/LY(1us)	%	>90	>90	>90
Longitudinal Transmission at				
λ = 360nm	%	≥35 (≥25)	≥10	≥35
λ = 420nm	%	≥60	≥55	≥60
λ = 620nm	%	≥70	≥65	≥70
Transverse Transmission and LY uniformity along the crystal	%	10		
Inhomogeneity of Transverse Transmission				
D λ at T=50%	nm≤	≤5	≤6	≤3
Induced irradiation absorption coefficient dk at λ =420nm and RT, for integral dose >10Gy	m-1	<1.1 (<1.5)	<1.5	≤1.1
Mean value of dk	m-1	≤0.75		≤0.75
Tolerance in Length	μm	≤±100	+0/, -100	≤±50
Tolerance in sides	μm	≤±50	+300, -0.	≤±50
Surface polished, roughness Ra	μm	≤0.02		
Tolerance in Rectangularity	degree	≤0.1		≤0.01
Mo contamination	ppm	<10		<1
La, Y, Nb, Lu contamination	ppm	<40ppm (≤100)		≤40

Prefer a method of labeling crystals that does not leave traces of glue when removing sticker

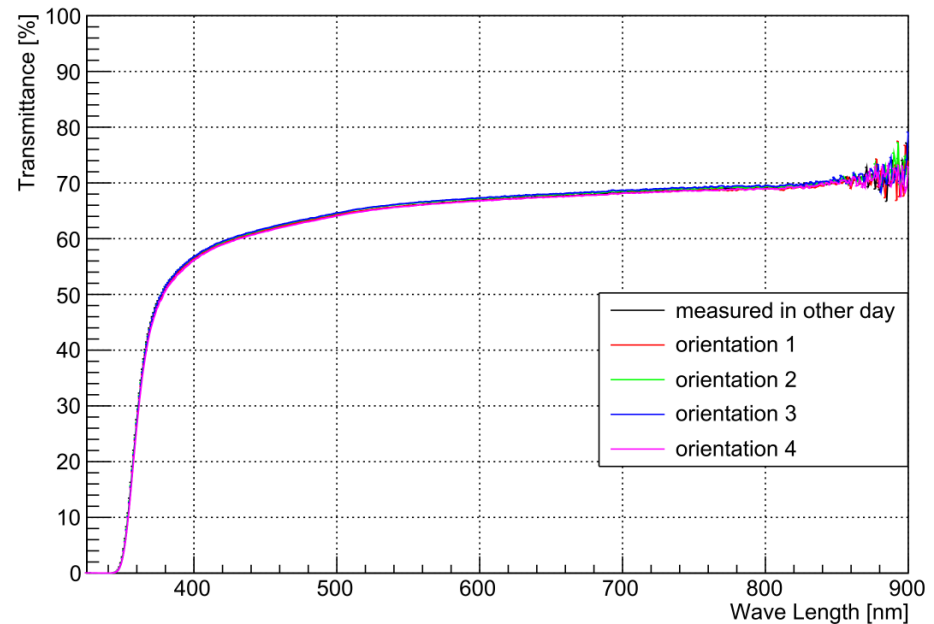
Optical transmittance measurements: PerkinElmer Lambda 850



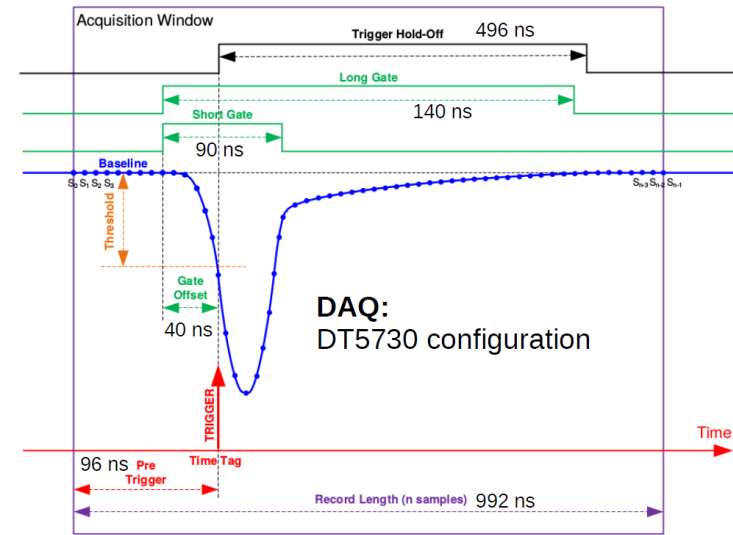
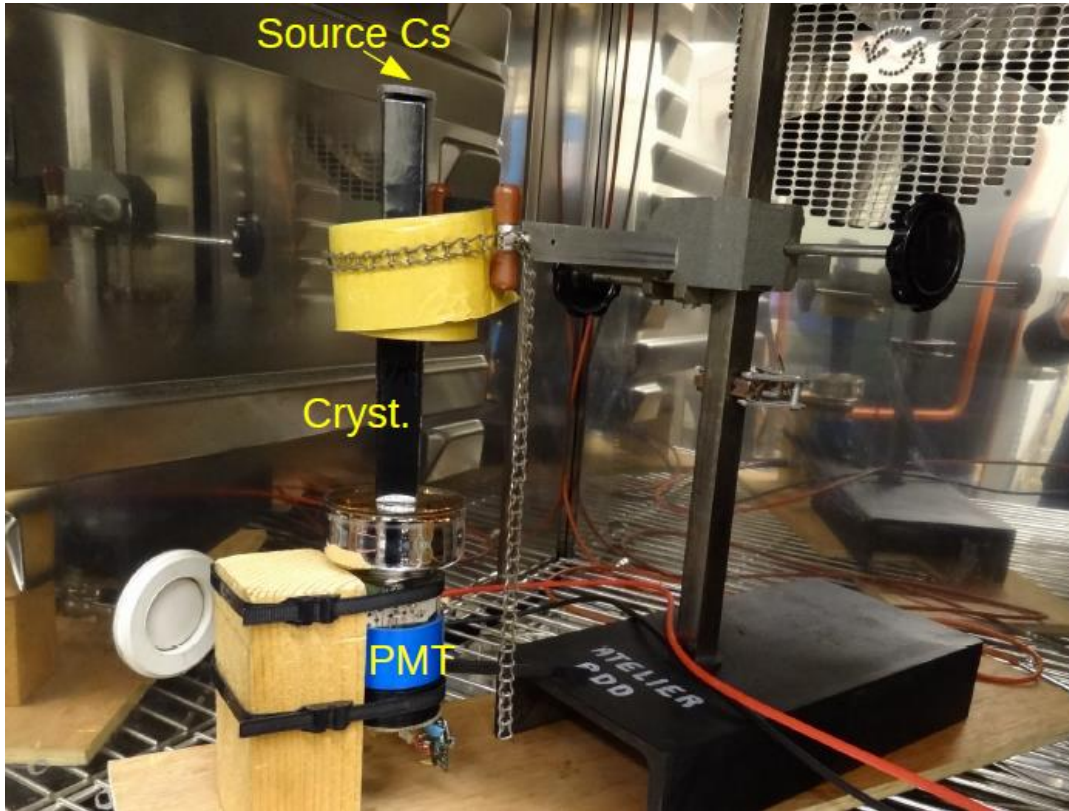
- Double beam spectrometer
- Integrating sphere
- Excellent (<0.1%) reproducibility of measurements



J11, Transmittance

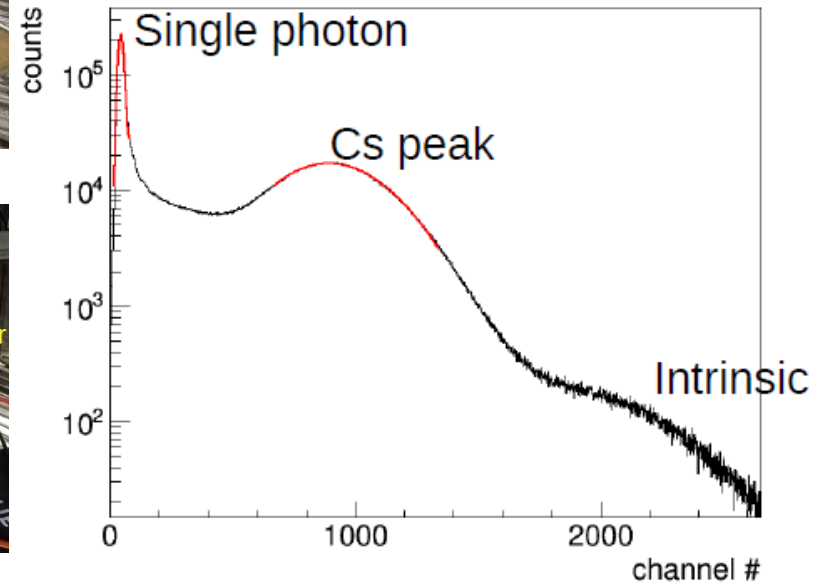


Light yield measurements: Cs-source in a temperature controlled chamber



Threshold: 20 lsb; CFD fraction: 75%

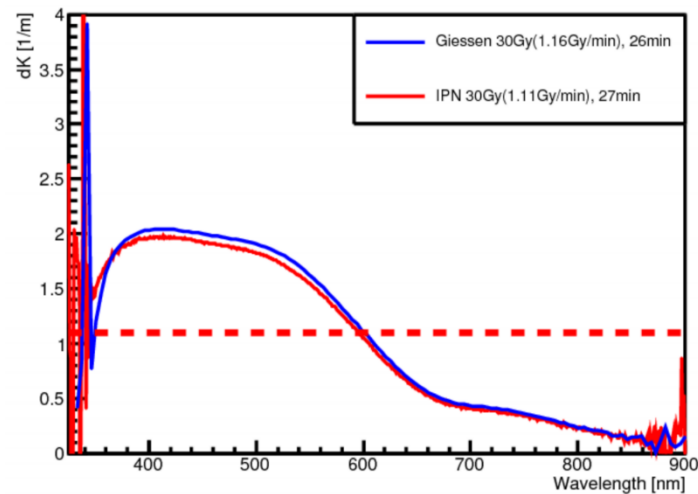
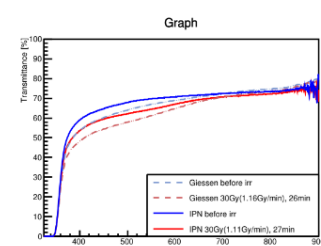
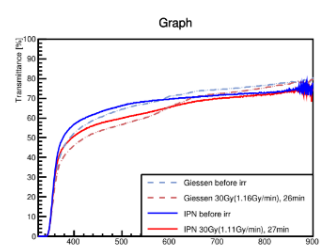
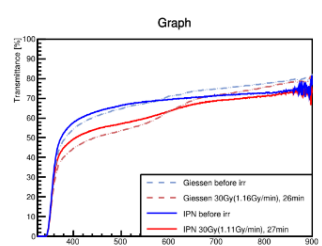
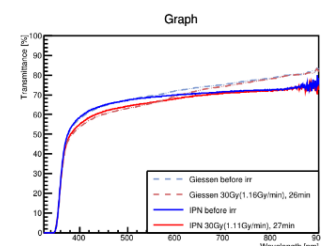
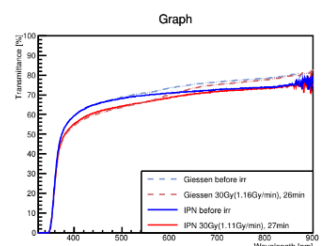
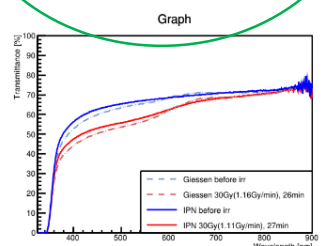
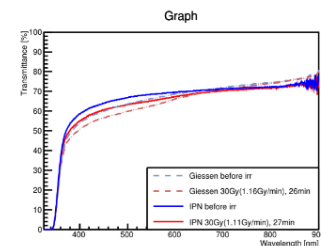
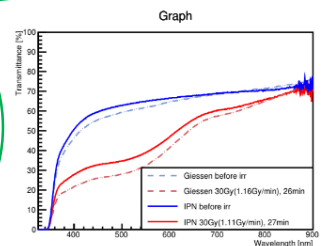
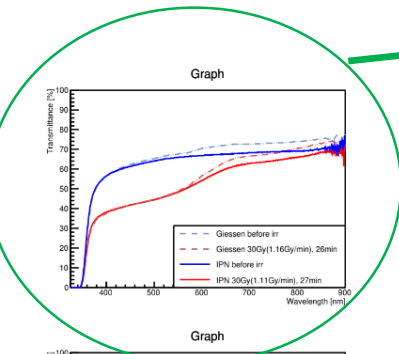
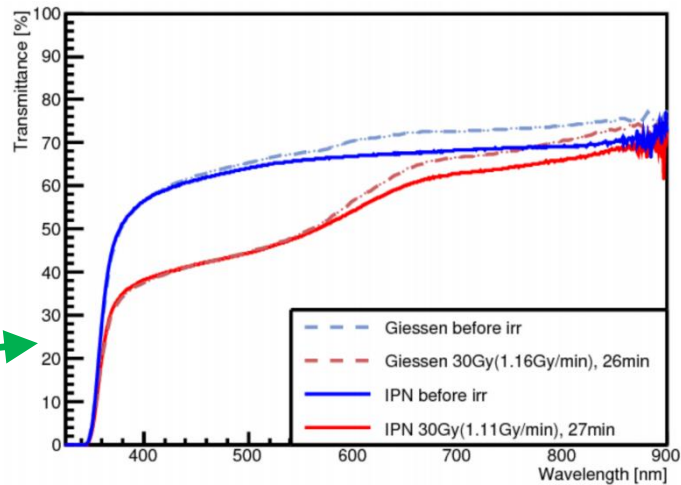
Temperature: 18 deg C



Radiation hardness measurements: high activity ^{60}Co source



30 Gy total dose, at a rate of $\sim 1\text{Gy/min}$



Experimental Investigations

Initial Inspection and Labeling

- Visual inspection including green laser
- Longitudinal and transverse dimensions

Optical transmission

- Longitudinal and transverse

Luminescence yield, temperature dependence, and decay kinetics

Radiation resistance

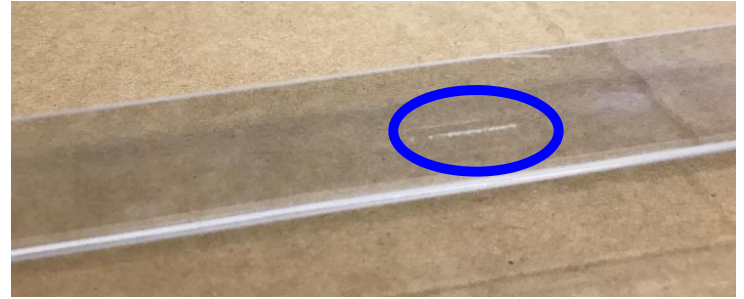
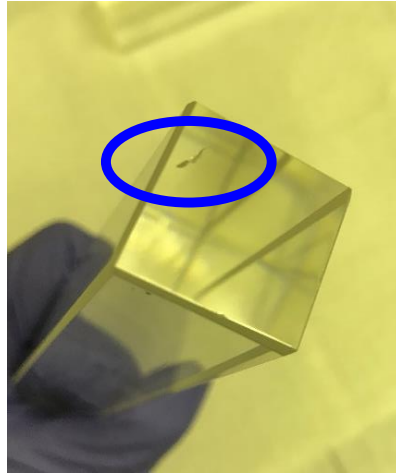
Chemical and surface analysis, as needed

Conditions for crystal certification and acceptance

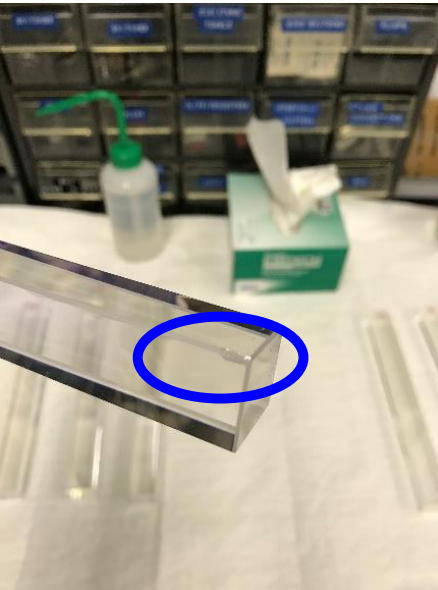
- ❑ NPS collaboration is responsible for the certification of the crystals delivered by SICCAS
- ❑ NPS collaboration is not obliged to disclose the results of the certification to SICCAS, except for rejected crystals
- ❑ Result of certification summary includes these parameters
 - Individual crystal number
 - Dimension of crystal
 - Visual inspection report
 - Optical properties of crystal
 - Scintillation yield
 - Radiation hardness (if measured)
 - Examples of additional items in 2018 procurement to ensure quality:
 - Scintillation kinetics (if measured)
 - Non-uniformity of transmission and light yield (if measured)
 - Contamination (if measured)

Visual Inspection

Long scratches and cracks

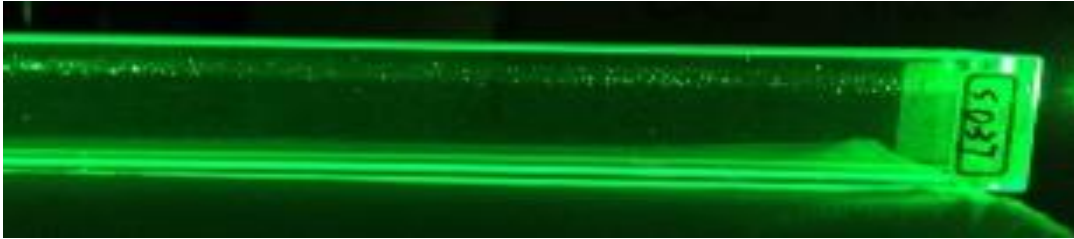


Excessive number of small chips along edges or large chips on corners

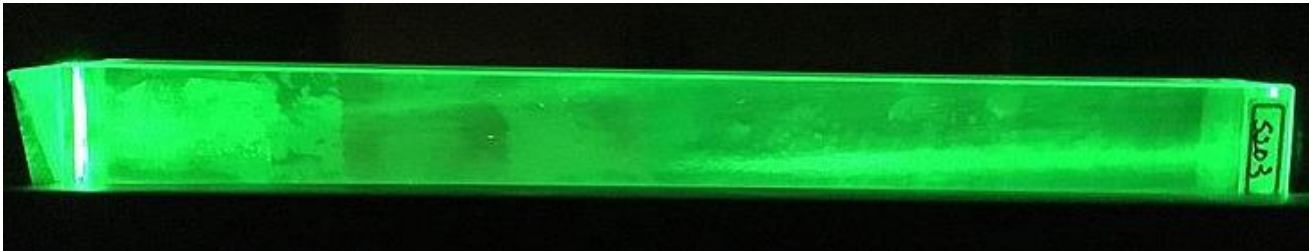


Visual Inspection – cont.

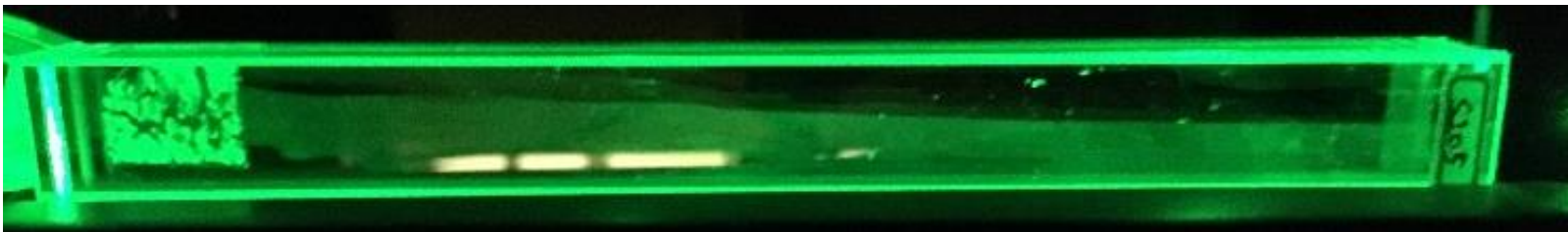
Excessive number of bubbles in bulk



Chemical film on surface

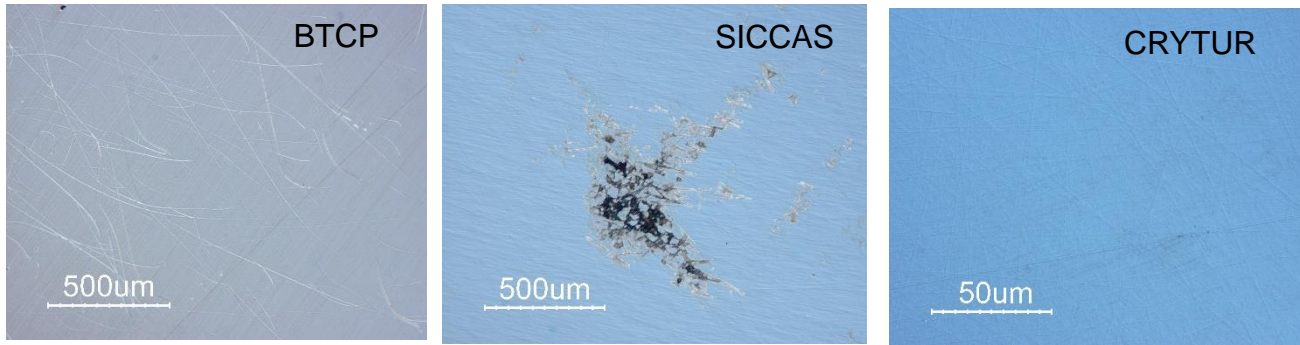


Traces of old labels or markings on surface

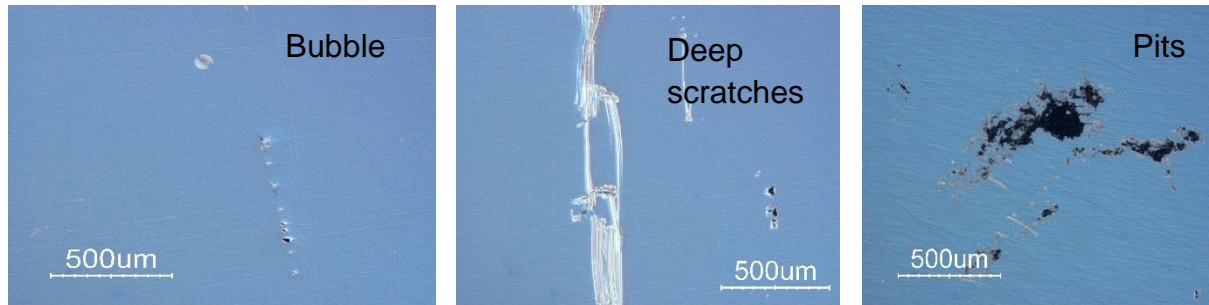


Surface analysis

□ Typical crystal surface quality

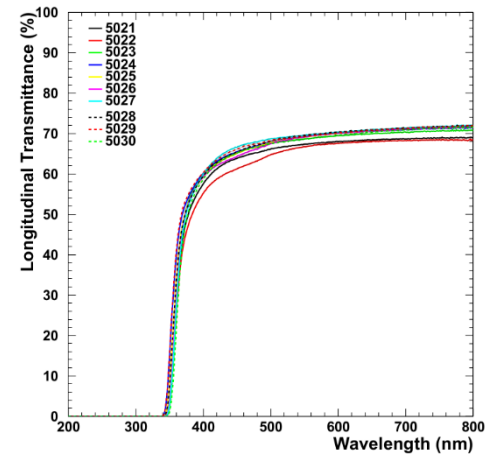
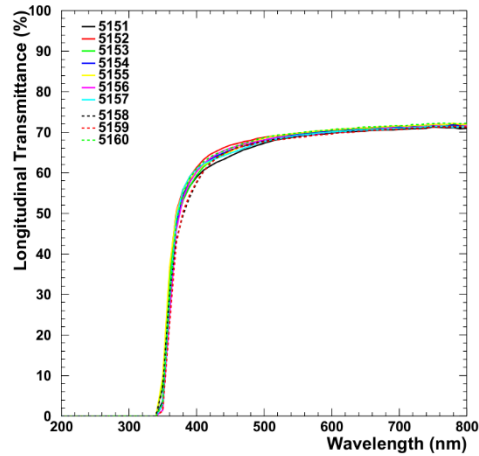
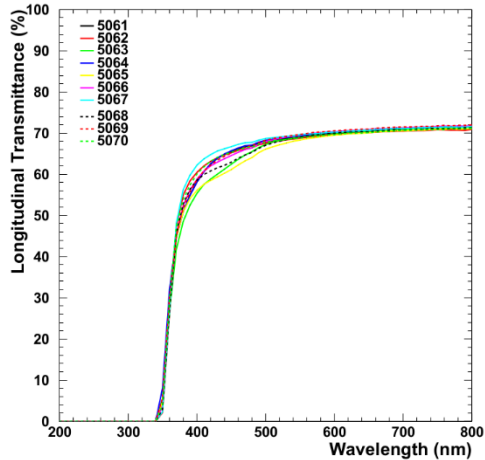
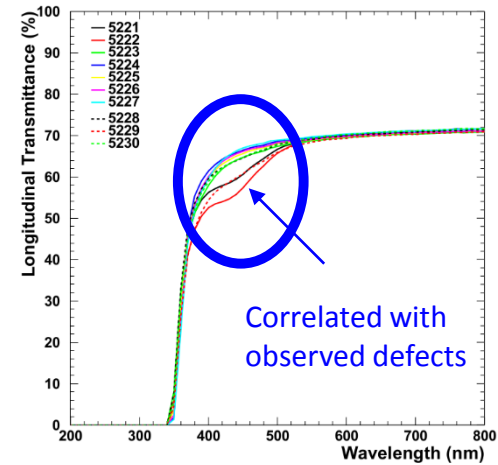
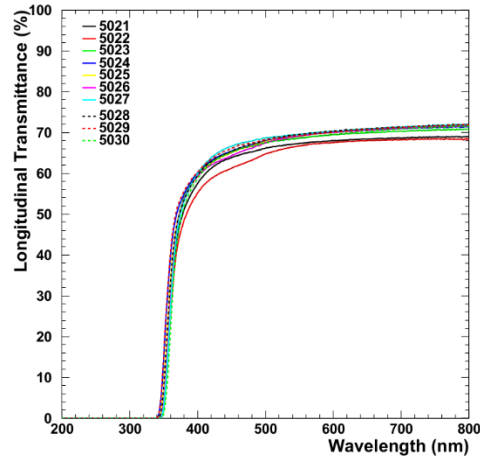
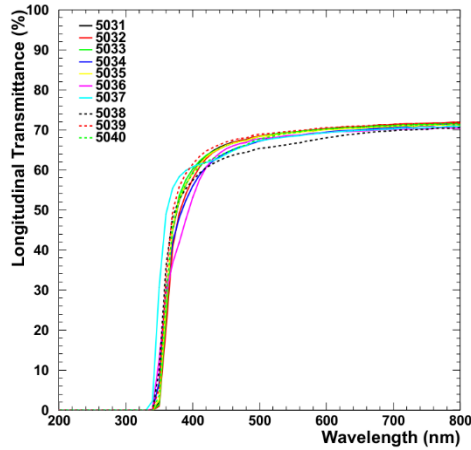


□ Looking deeper into defects:

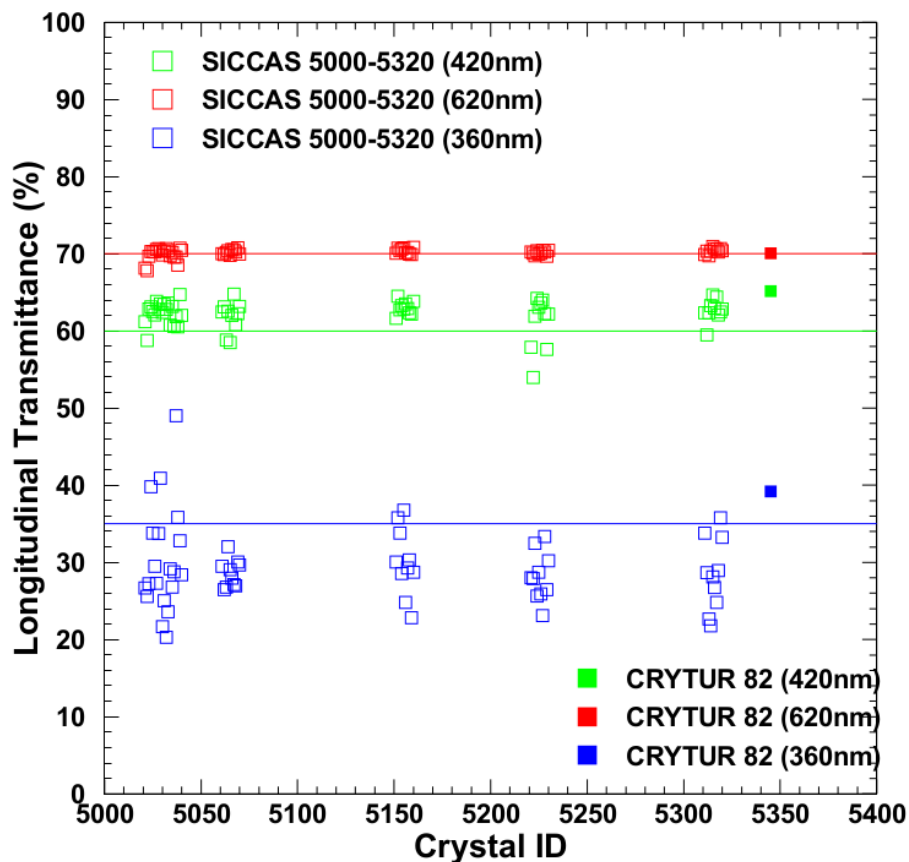


➤ Defects result in high, but non-uniform light yield

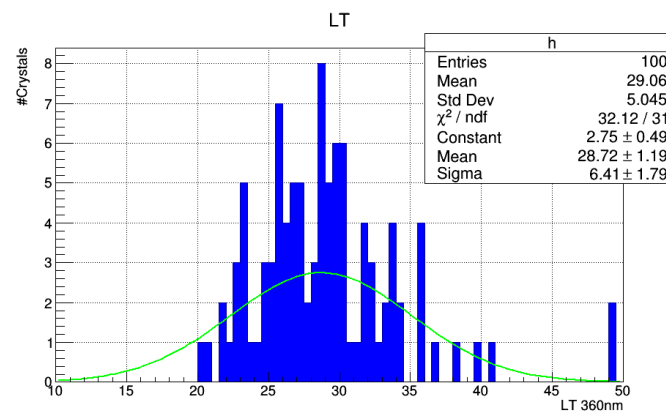
Longitudinal Transmittance:



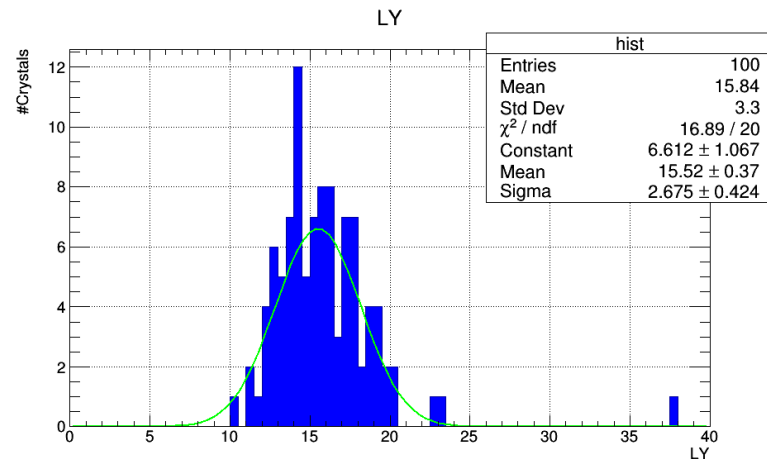
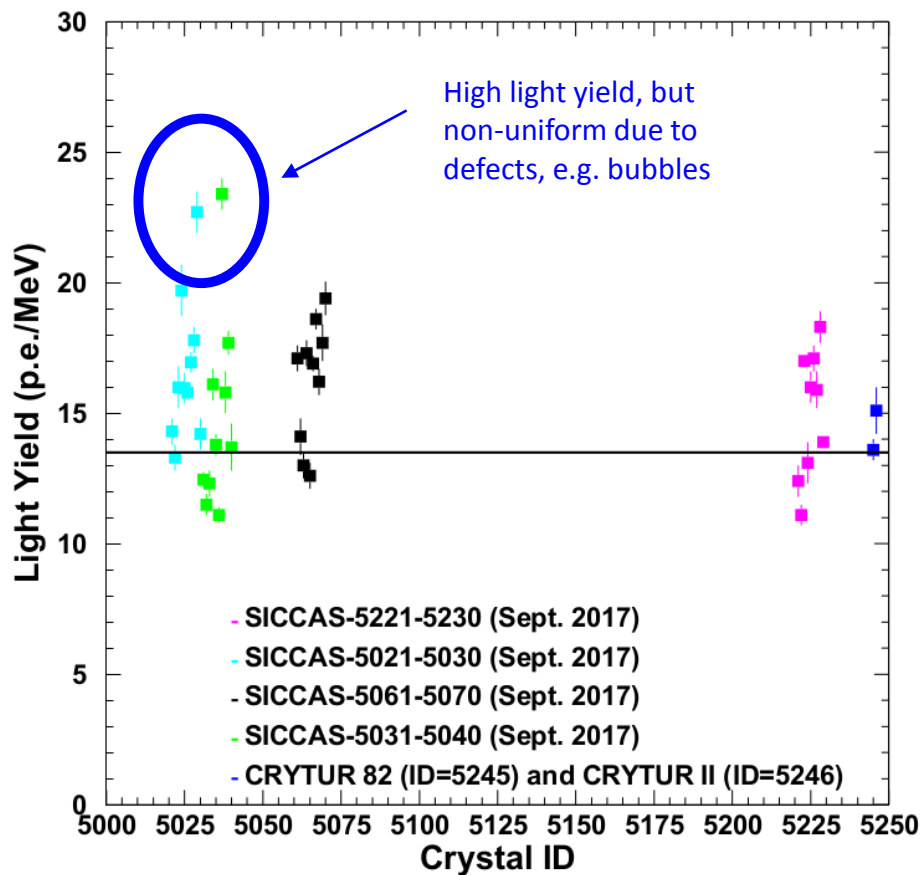
Longitudinal Transmittance:



Concern is the width of the distribution at each wavelength



Light Yield:



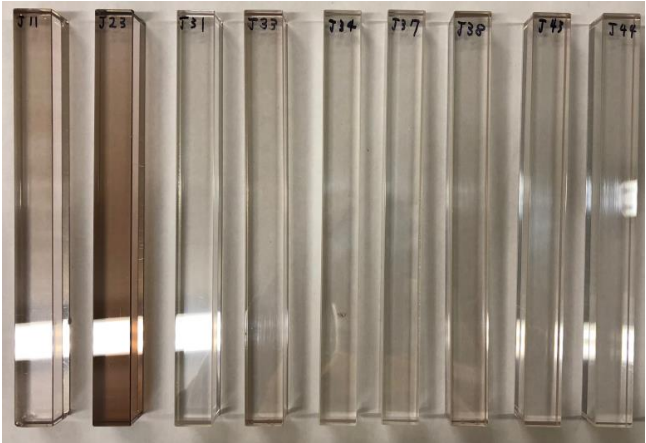
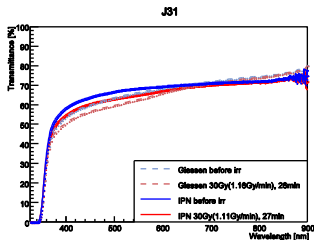
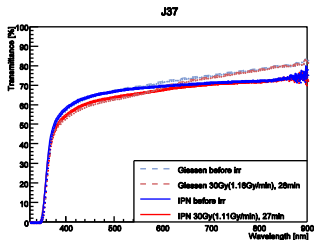
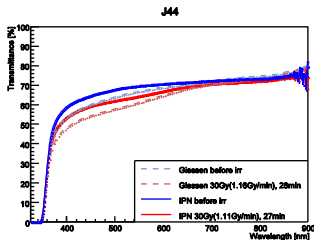
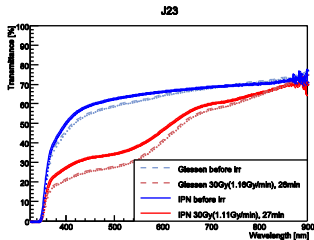
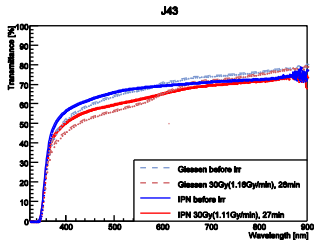
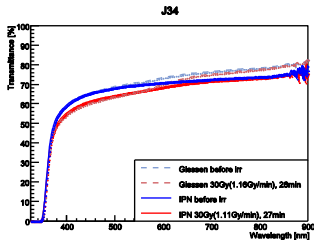
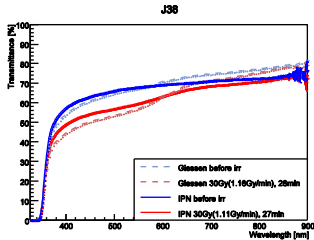
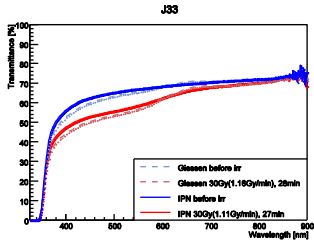
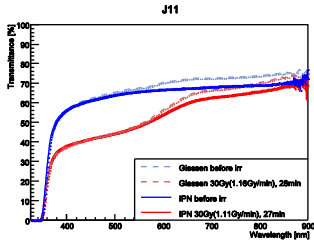
Concerns:

Large variations in light yield

Non-uniformity of light yield within one crystals due to defects

Very high light yields due to defects in crystal bulk

Radiation Resistance



Summary 2017: Three major failure categories

❑ Out of a subset of ~200 crystals tested, the “bad” crystals fall into three major categories:

- 8% fail: Chips, scratches, old labels
- 13% fail: Bubbles and other defects
- 10% fail: LY @420nm < 60% or light yield

Box	CRYSTALID	Visual Inspection	LY @420nm	LY @390nm	LY (p.e./MeV) @ 160c	L Length (mm)	maxL Width (mm)	dk (p.e-1)	Selected comments (more detail: http://www.slac.stanford.edu/~physlist/physlist/physlist/SuperCrystal.cry)	Selected photos (more detail: http://www.slac.stanford.edu/~physlist/physlist/physlist/SuperCrystal.cry)
4	5027	2.0	63.8	27.3	17.0			0.4		
4	5028	2.0	62.8	33.7	17.8			0.3		
4	5029	2.0	63.5	40.9	22.7			0.4	chip on top, some 10-20nm deep, many small defects	
3	5030	0.0	62.4	34.1	16.2			0.3		
3	5031	2	63.67	25.00	17.3		0.05	0.04		
3	5032	1	62.70	26.3	14.3		0.05	0.02		
3	5074	1	65.72	29.16	16.1		0.05	0.04		
3	5075	3	63.16	26.3	15.6		0.05	0.04		
3	5076	3	60.57	26.3	15.6		0.05	0.04		
3	5077	3	61.86	31	23.4		0.05	0.04	chip on top, some scratches, and a small bubble on top surface (100nm) and some in bulk	
3	5078	2	63.51	35.81	17.7		0.05	0.03		
3	5039	0	64.71	32.82	17.7		0.05	0.08		
3	5040	1	62.01	28.37	15.7		0.05	0.02		
2-7	5081	4	63.66	28.00	15.4			0.1		
2-7	5082	2	63.11	27.90	14.7			0.3		
2-7	5083	0	61.91	32.46	17.7			0.3		
2-7	5084	2	64.21	25.64	13.1			0.3		
2-5	5085	2	62.66	31.35	15.5			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5086	3	61.7	25.22	15			0.7	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5087	3	63.73	25.73	14.5			0.5	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5088	3	60.64	25.83	13.4			0.3	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5089	3	63.13	26.64	16.4			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5090	3	64.19	26.64	16.4			0.3	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5091	3	62.14	25.51	13.7			0.3	small crack at the edge, small crack at the bottom, cracks in bulk	
2-5	5092	3	60.65	29.77	13.5			0.3	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5251	3	64.67	28.31	14			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5252	2	60.65	29.77	13.5			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5253	2	60.69	29.31	13.5			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5254	2	62.32	28.91	13.4			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5255	3	62.32	34.91	16.4			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5256	1	63.88	31.2	17.1			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5257	1	63.88	25.97	13.8			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5258	1	63.88	31.2	17.1			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5259	2	64.37	31.54	16.6			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	
2-10	5260	2	60.43	27.35	15.3			0.2	small crack at the edge, small crack at the bottom, cracks in bulk	

Example report from SICCAS 2017

SICCAS results

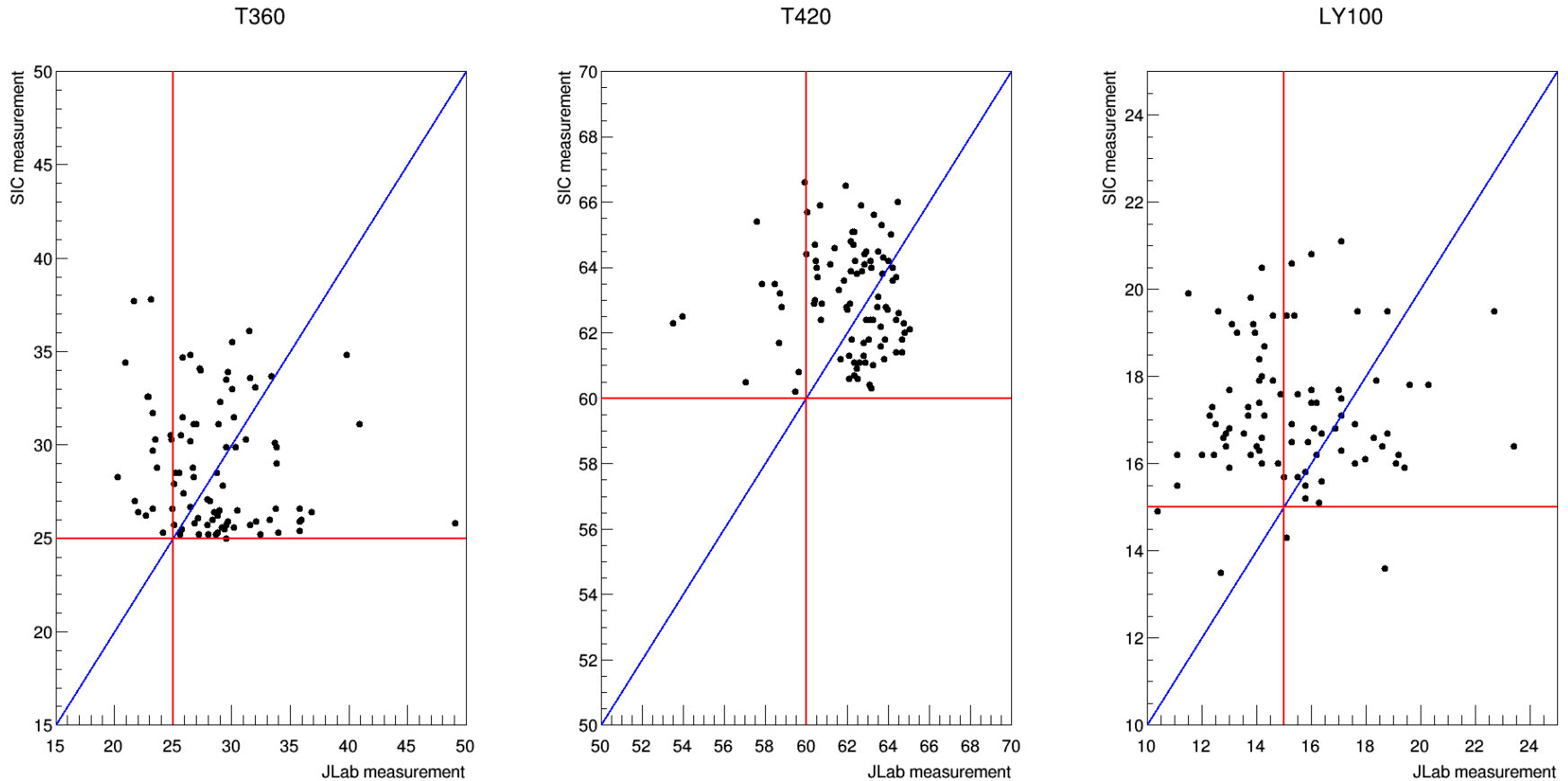
CX	T360	T420	LY100
S001	28.8	64.1	18.7
S002	25.2	61.7	19.0
S003	25.2	61.1	17.7
S004	34.8	60.4	28.9
S005	29.9	60.6	20.8
S006	33.5	60.6	15.8
S007	34.1	61.2	30.0
S008	30.1	61.7	28.1
S009	31.1	64.5	19.5
S010	37.7	64.2	20.5
S011	25.7	62.8	16.2
S012	28.3	61.3	19.9
S013	28.8	61.6	17.1
S014	25.6	62.4	16.8
S015	25.8	60.3	16.2
S016	25.3	63.7	15.5
S017	25.8	63.6	16.4
S018	25.4	64.0	15.5
S019	25.1	64.9	17.1
S020	26.0	62.7	17.3
S021	25.0	60.9	17.4
S022	26.7	62.4	17.9
S023	28.3	62.8	17.7
S024	33.1	61.1	21.1
S025	32.3	63.5	19.5
S026	27.1	62.8	16.8
S027	26.1	62.3	16.4
S028	31.1	62.9	16.2
S029	35.5	65.1	19.5
S030	25.9	64.0	15.9
S031	25.2	63.5	17.3
S032	25.7	62.5	16.2
S033	25.2	66.5	17.7
S034	30.5	64.0	19.2
S035	26.4	61.8	17.4
S036	27.4	62.2	16.3
S037	37.8	62.7	25.7
S038	33.7	61.8	16.6
S039	30.2	65.4	19.2
S040	25.6	63.9	17.6
S041	33.0	63.3	17.4
S042	25.9	66.0	16.2
S043	29.0	63.9	17.5
S044	26.4	65.6	16.5
S045	26.4	64.1	16.9
S046	30.3	63.1	14.3
S047	27.8	64.5	17.6
S048	29.9	61.1	16.7
S049	32.6	64.8	18.4
S050	28.5	61.8	16.5
S051	26.6	60.7	17.9
S052	25.2	60.2	15.9
S053	26.2	65.1	16.3
S054	27.0	62.4	13.5

NPS results

CX	NPS T360	NPS T420	NPS LY100
S021	26.7	61.2	14.3
S022	25.6	58.7	13.3
S023	27.2	62.9	16.0
S024	39.8	63.1	19.7
S025	33.8	62.5	16.0
S026	29.5	62.1	15.8
S027	27.3	63.8	17.0
S028	33.7	62.8	17.8
S029	40.9	63.5	22.7
S030	21.7	62.4	14.2
S031	25.06	63.47	12.45
S032	20.3	62.8	11.5
S033	23.6	63.6	12.3
S034	29.2	60.7	16.1
S035	26.8	66.2	13.8
S036	28.8	60.6	11.1

➤ Measurement methods used?

SIC and JLab measurements comparison (~200 samples)



- No clear correlation of results
- Transmittance and LY generally lower at JLab than SIC

Should discuss methods and measurement procedures