# Test results for the recent SIC PWO crystals

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Red denotes relaxed parameters in the 2018 procurement

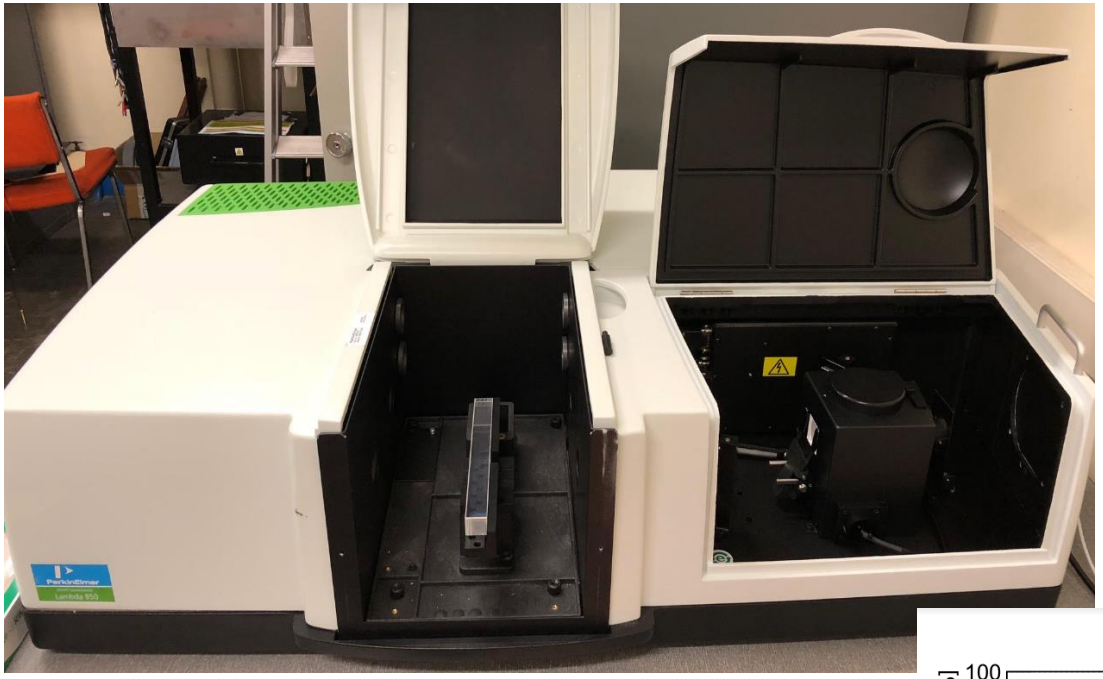
NPS: 2.05cm x 2.05cm x 20cm

# PbWO4 crystal specification

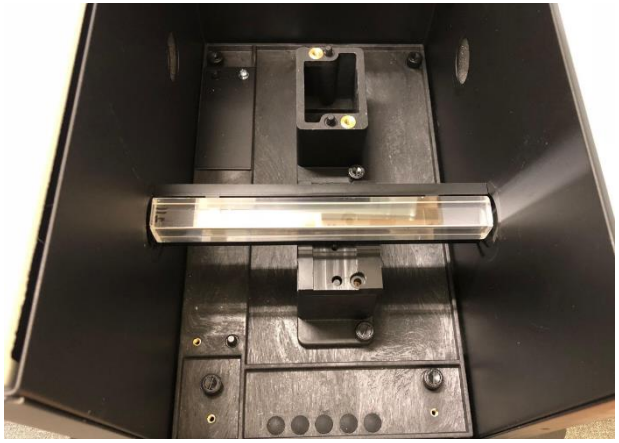
| Parameter | Unit | NPS Required | COMCAL/FCAL | PANDA specifications |
|---|---|---|---|---|
| Light Yield at RT | phe/MeV | ≥15 | ≥9.5 | ≥16 |
| LY uniformity between the blocks (%) | | <10 (<20) | | |
| LY(100ns)/LY(1us) | % | >90 | >90 | >90 |
| Longitudinal Transmission at | | | | |
| λ = 360nm | % | ≥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 |

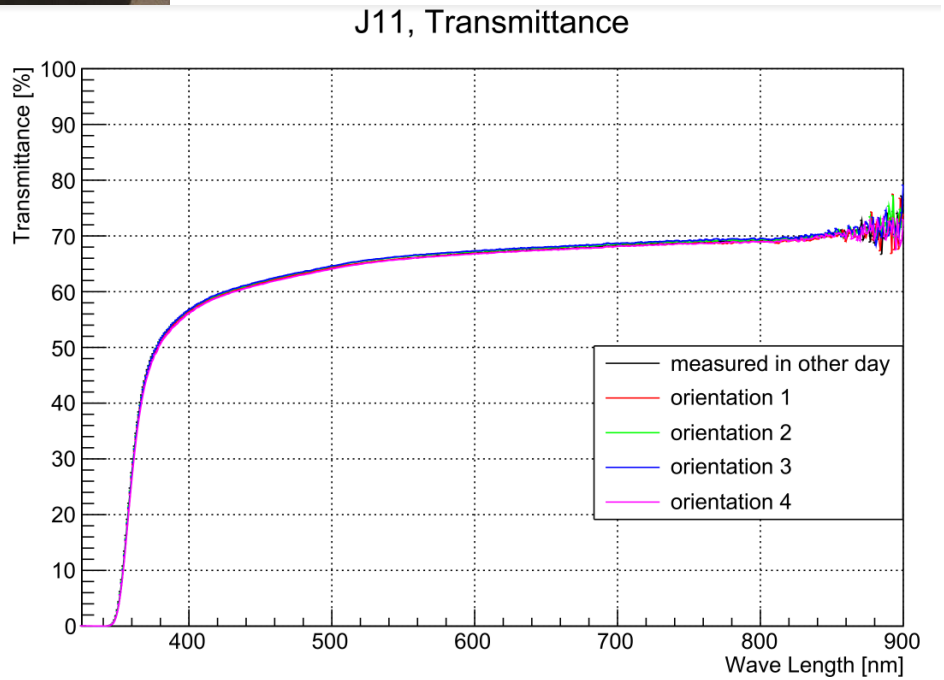
Prefer a method of labeling crystals that does not leave traces of glue when removing sticker

# Optical transmittance measurements: PerkinElmer Lambda 850

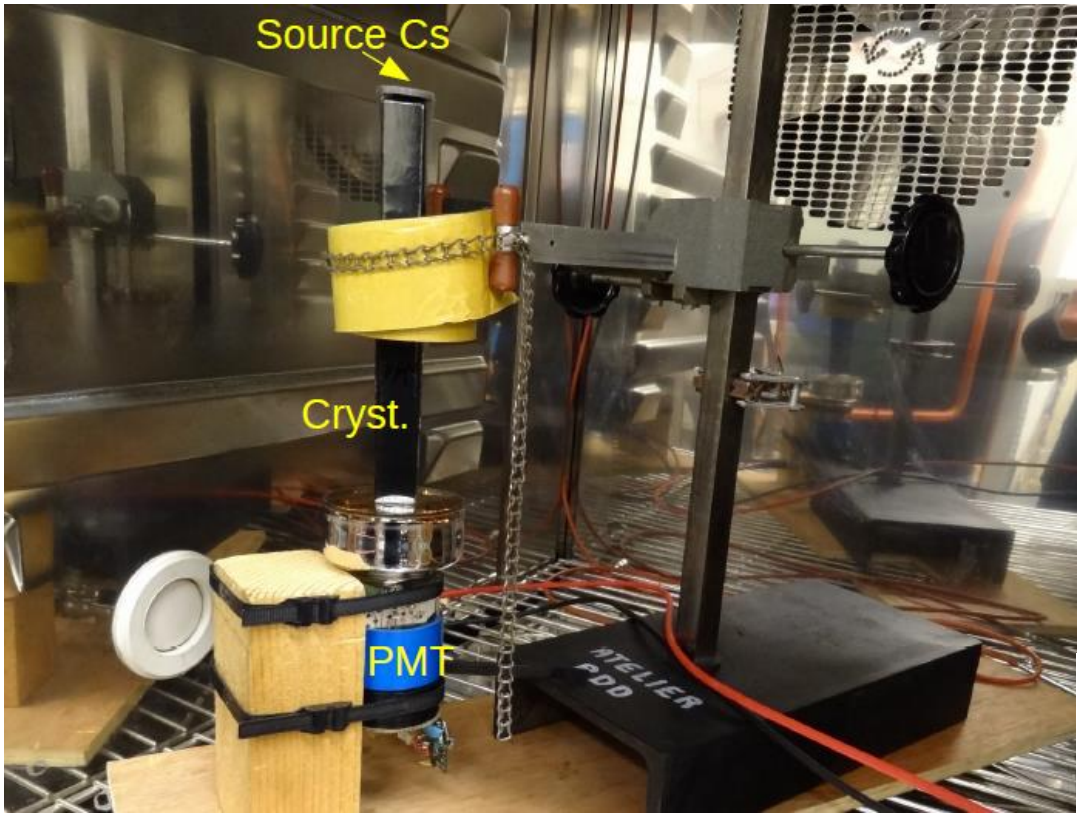


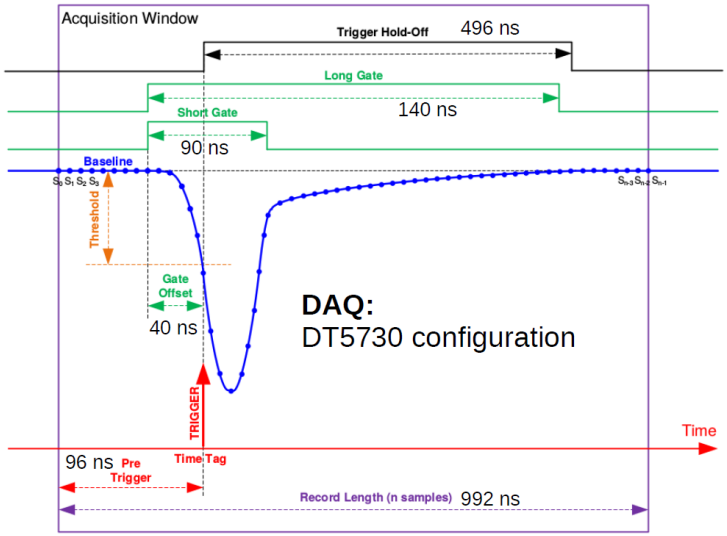
- Double beam spectrometer
- Integrating sphere
- Excellent (<0.1%) reproducibility of measurements





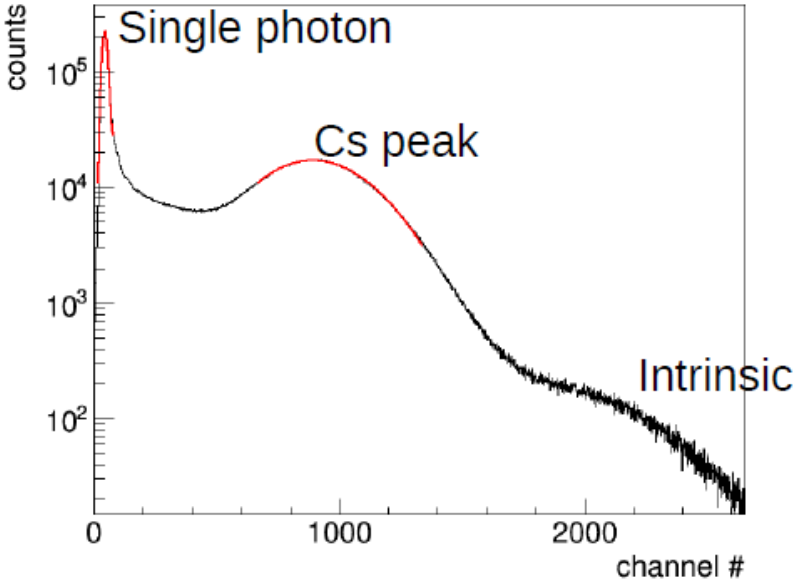
# Light yield measurements: Cs-source in a temperature controlled chamber



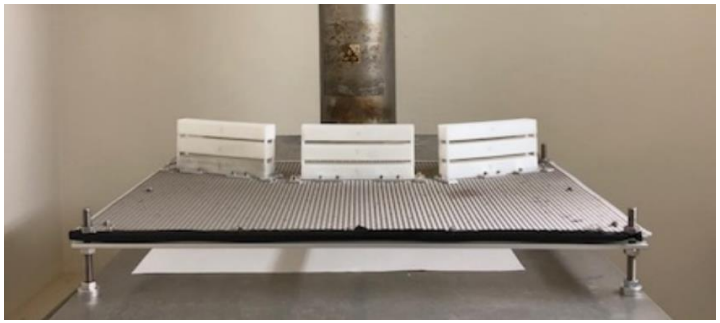




Threshold: 20 lsb; CFD fraction: 75%

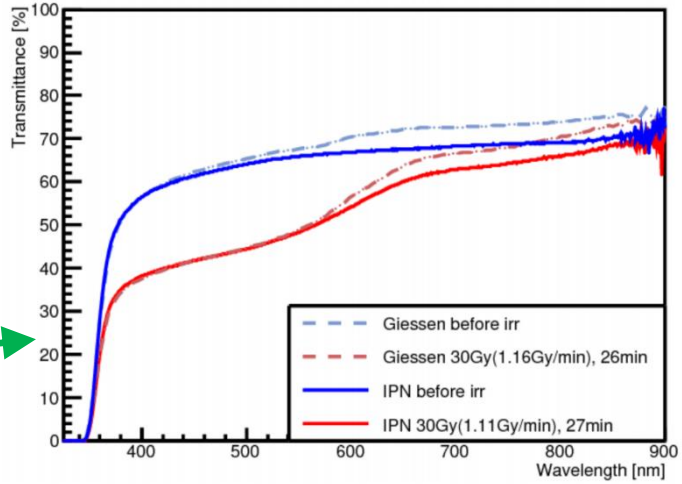

Temperature: 18 deg C

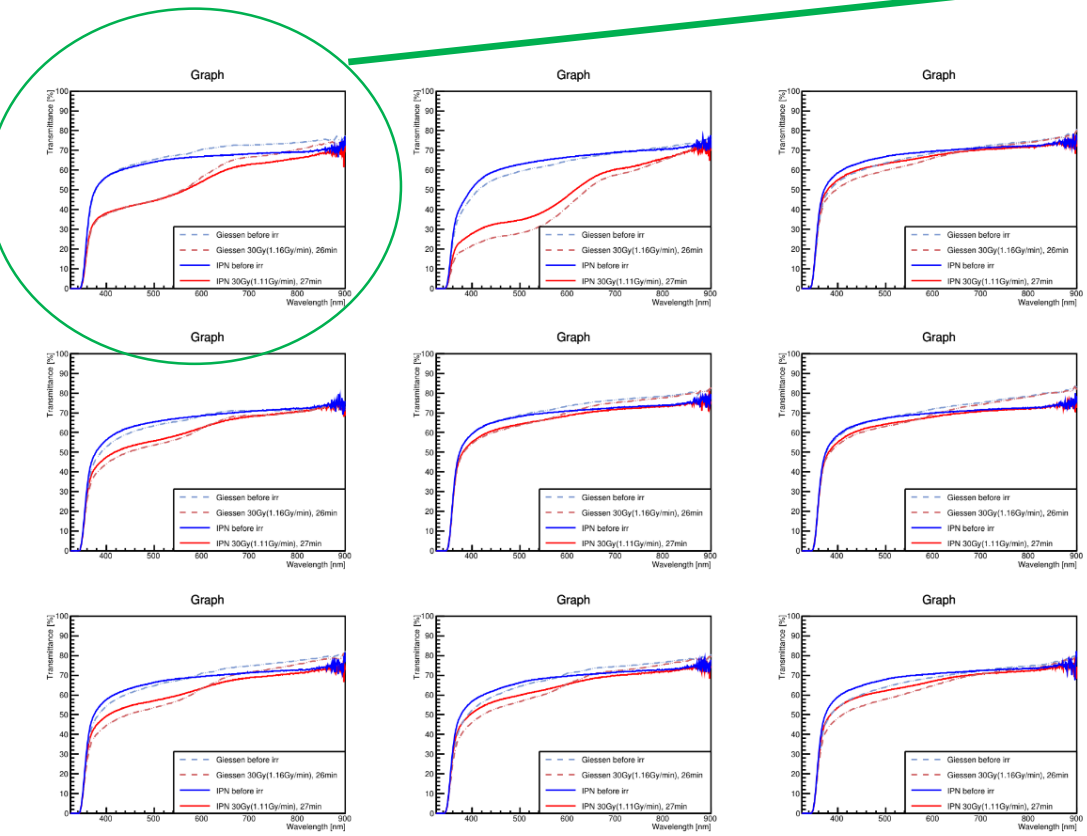


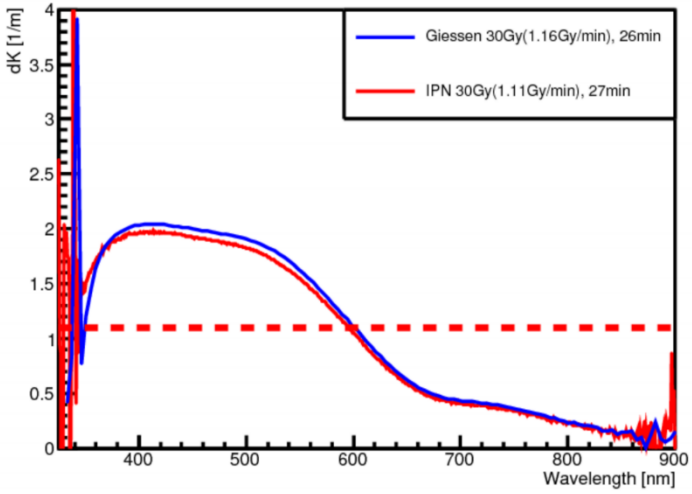
# Radiation hardness measurements: high activity $^{60}Co$ source



30 Gy total dose, at a rate of ~1Gy/min



# Experimental Investigations

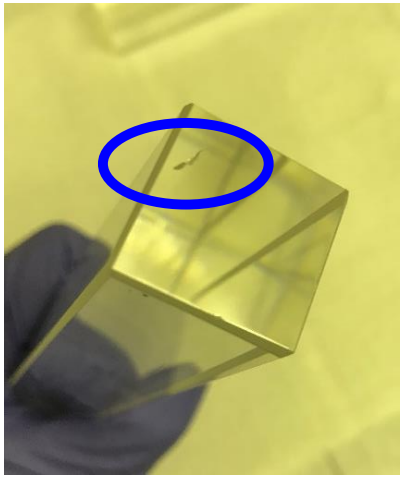
- Initial Inspection and Labeling
  - Visual inspection including green laser
  - Longitudinal and transverse dimensions
- Optical transmission
  - Longitudinal and transverse
- Luminescence yield, temperature dependence, and decay kinetics
- Radiation resistance
- Chemical and surface analysis, as needed

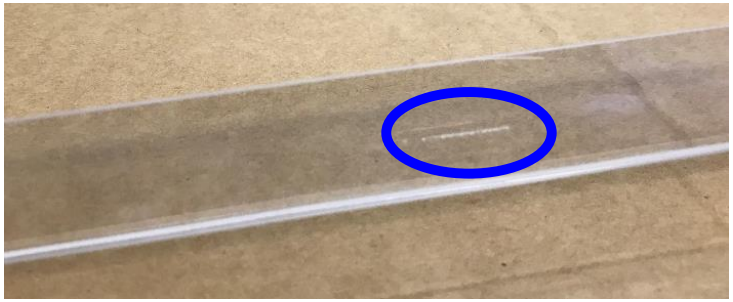
# Conditions for crystal certification and acceptance

- 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

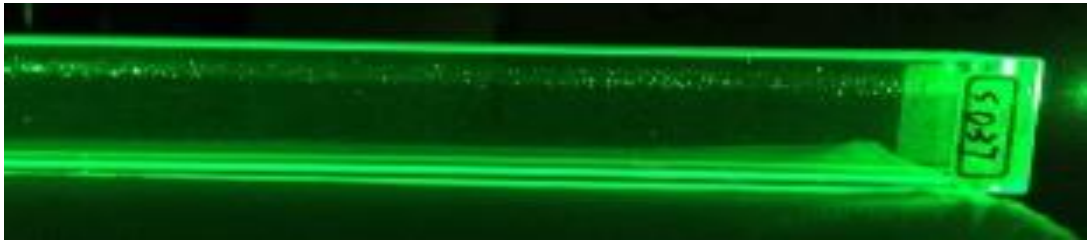




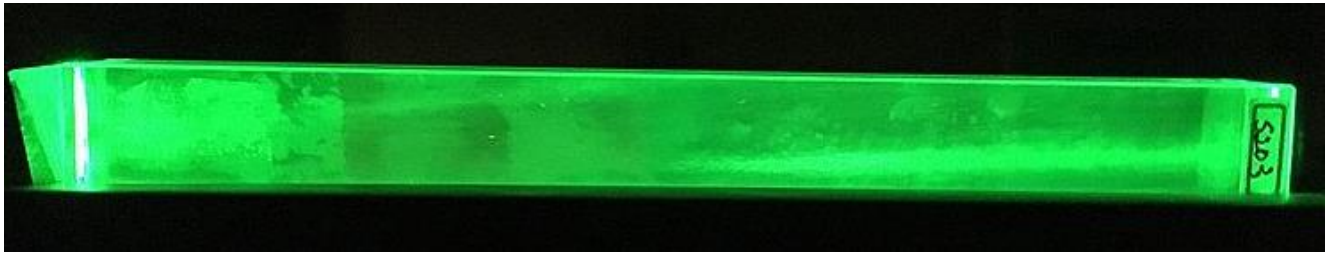
Excessive number of small chips along edges or large chips on corners

# Visual Inspection – cont.

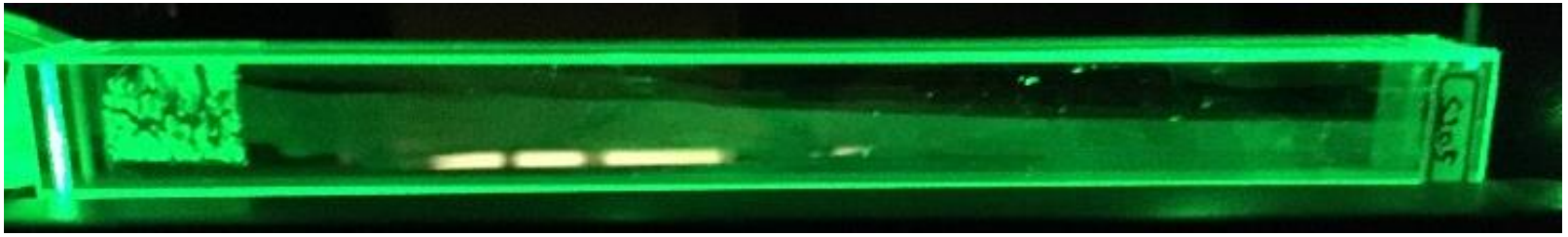
Excessive number of bubbles in bulk



Chemical film on surface

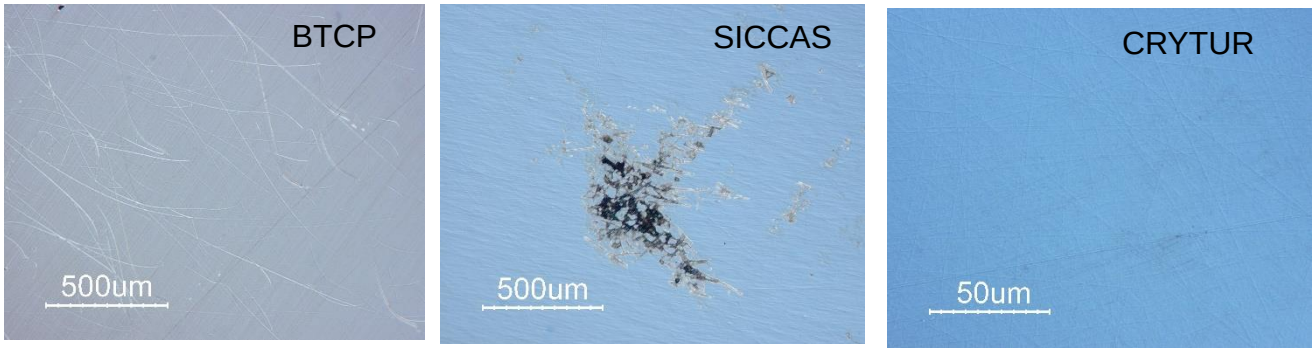


Traces of old labels or markings on surface

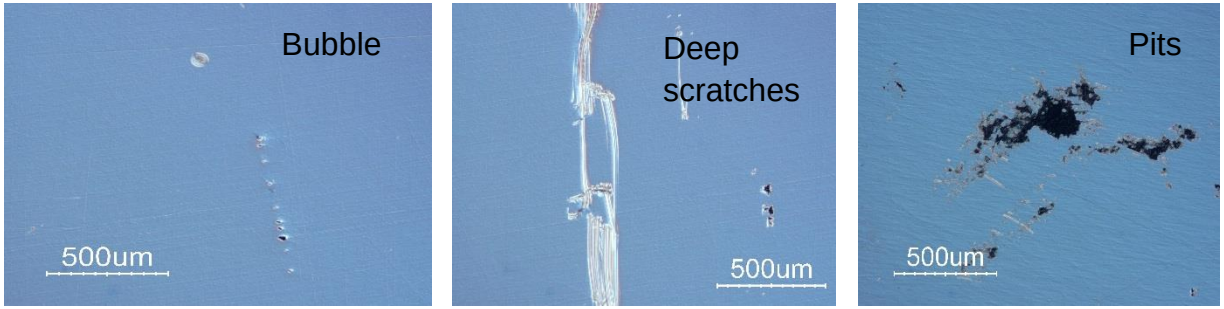


# Surface analysis

- Typical crystal surface quality

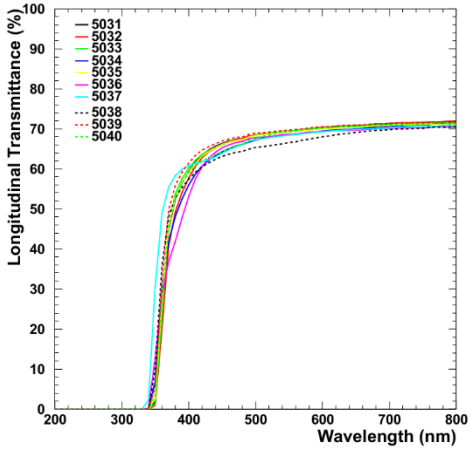


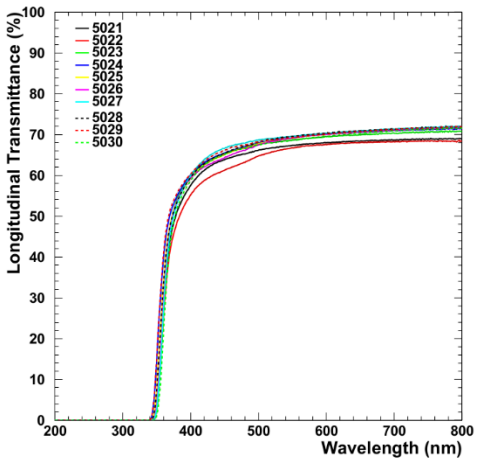

- Looking deeper into defects:

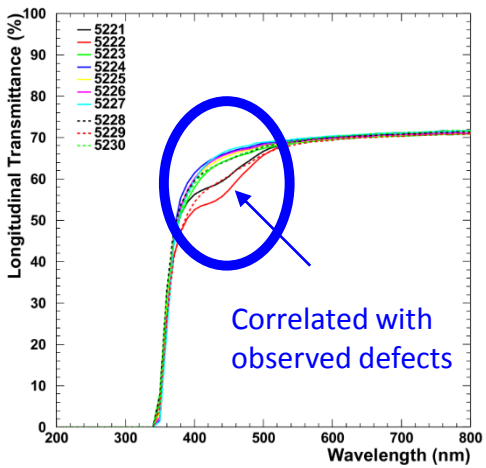


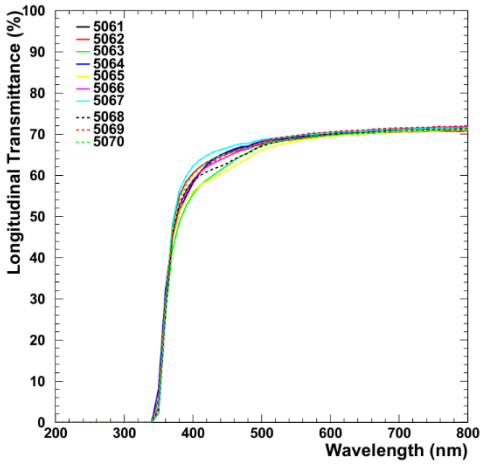

  - Defects result in high, but non-uniform light yield

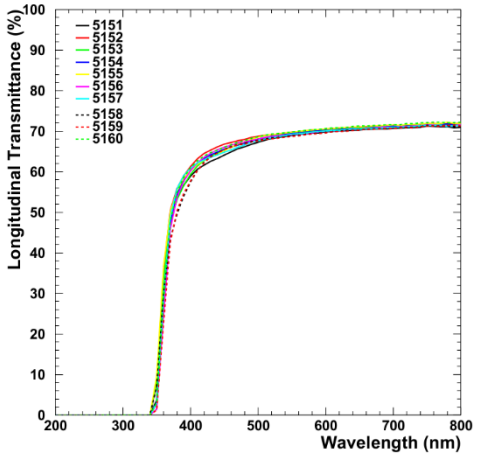
# Longitudinal Transmittance:

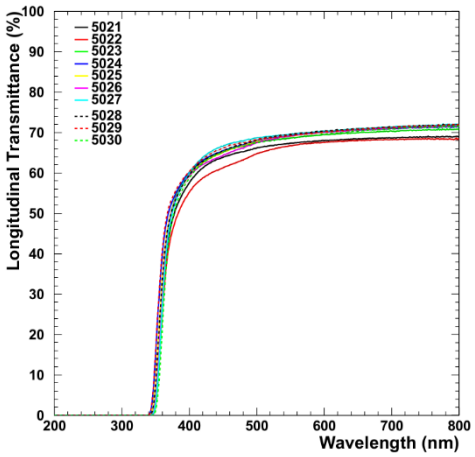


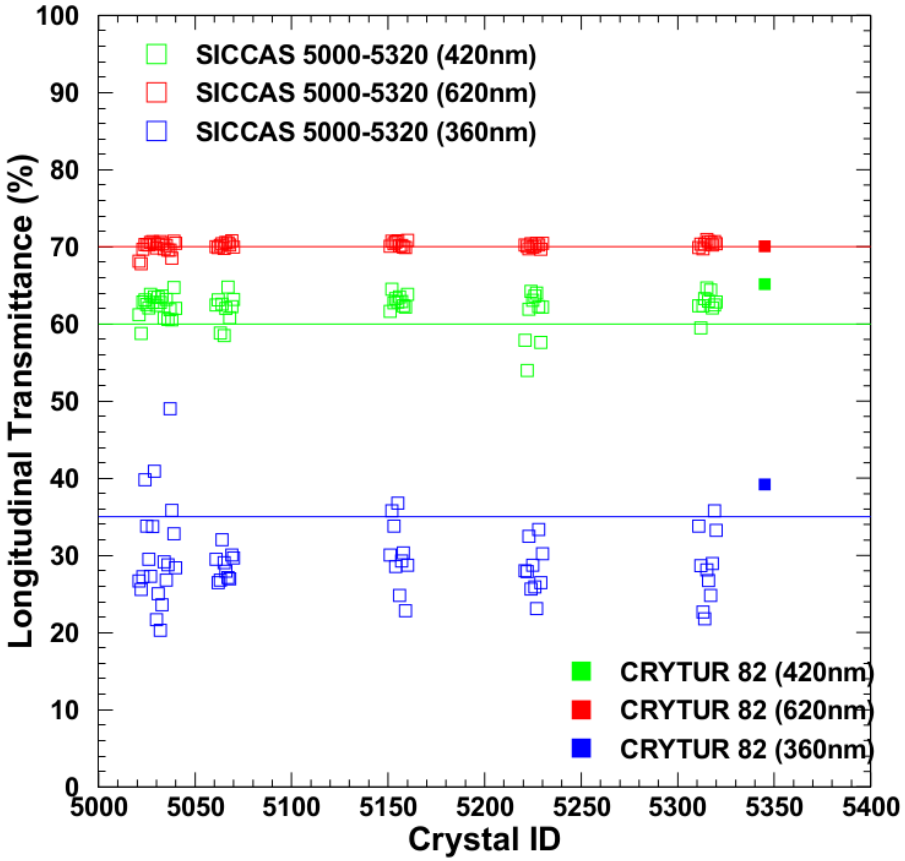



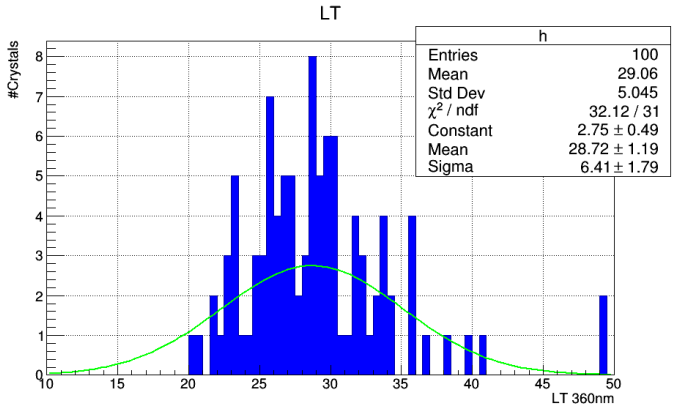



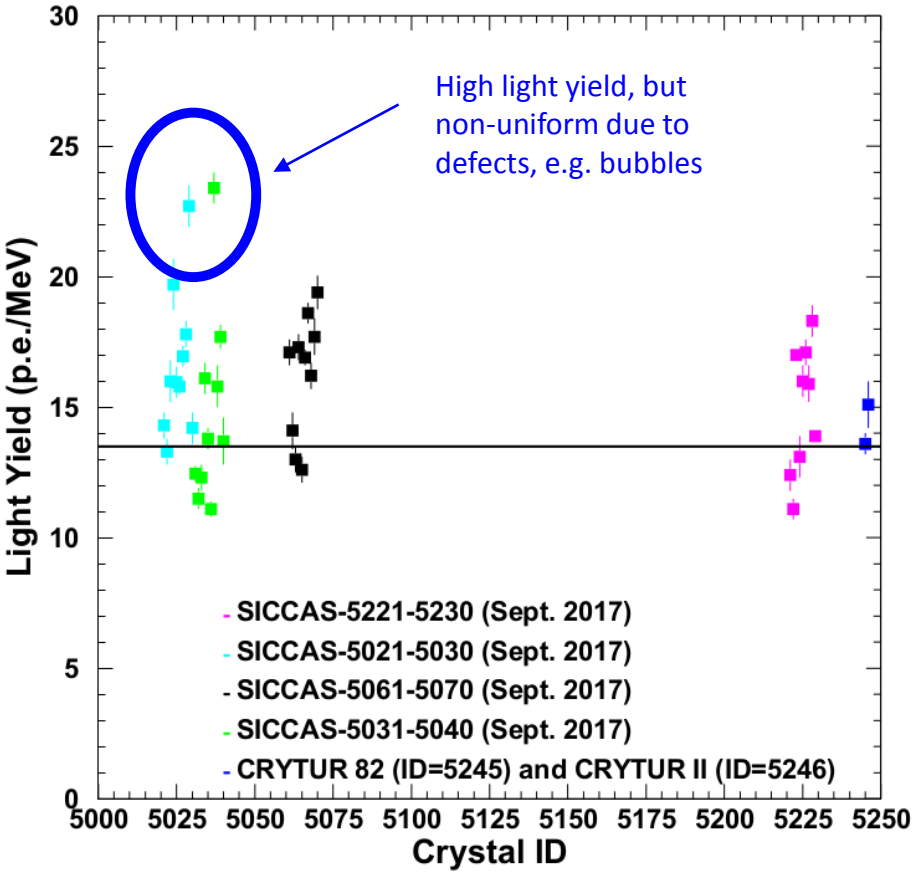
# Longitudinal Transmittance:

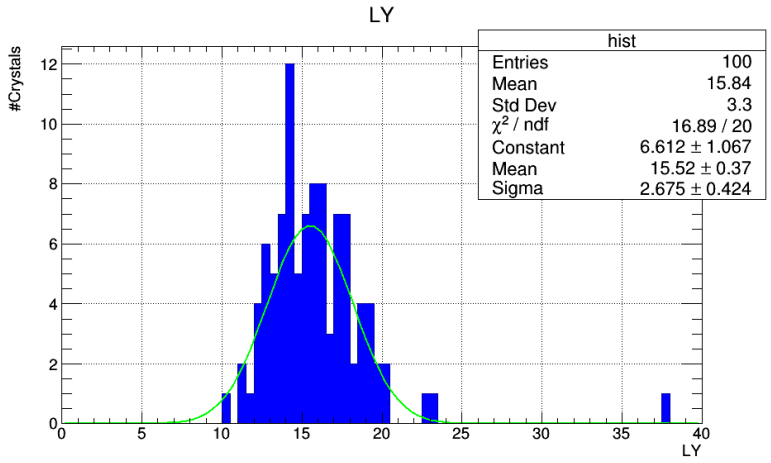



Concern is the width of the distribution at each wavelength



# Light Yield:



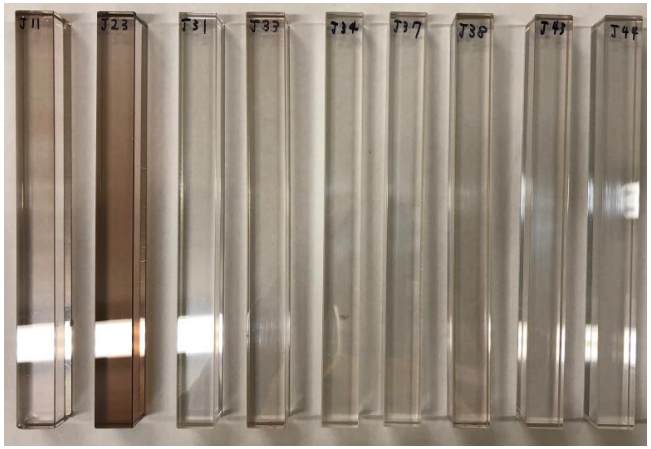

Concerns:

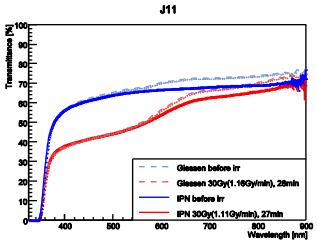
Large variations in light yield

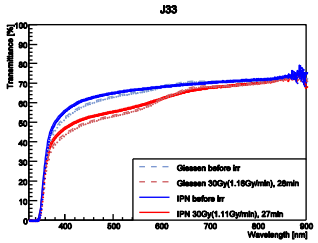
Non-uniformity of light yield within one crystals due to defects

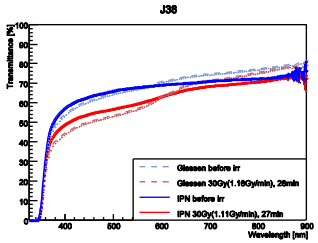
Very high light yields due to defects in crystal bulk

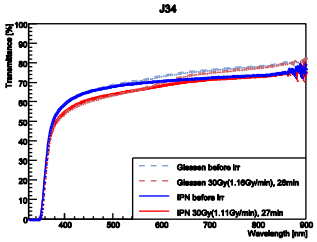
# Radiation Resistance

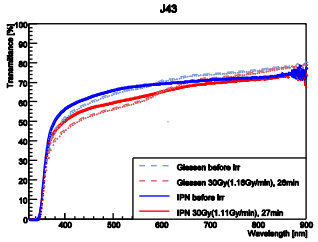


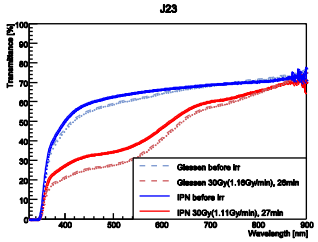



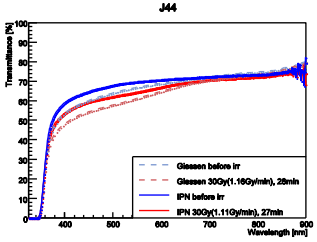



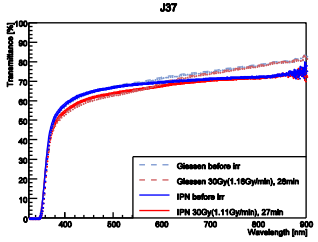



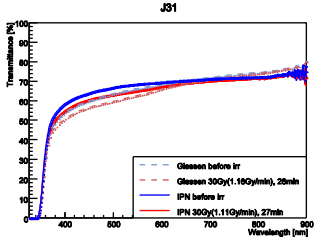



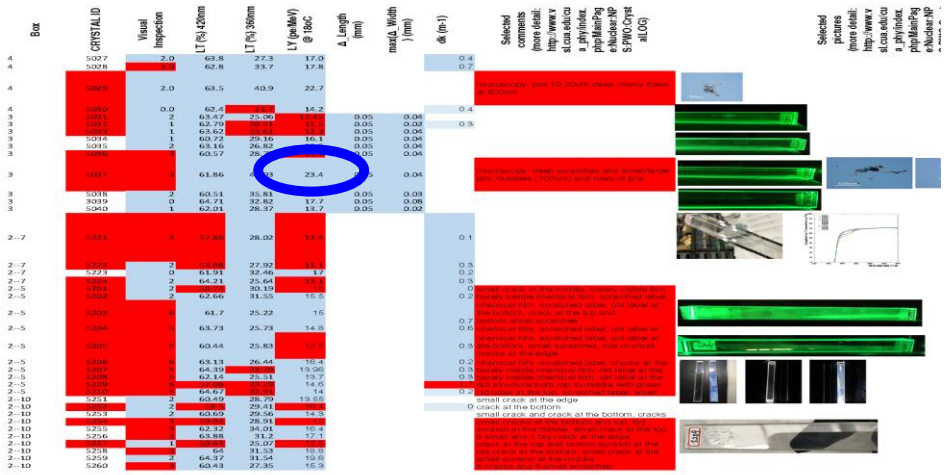



# Summary 2017: Three major failure categories

- 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



# Example report from SICCAS 2017

SICCAS results

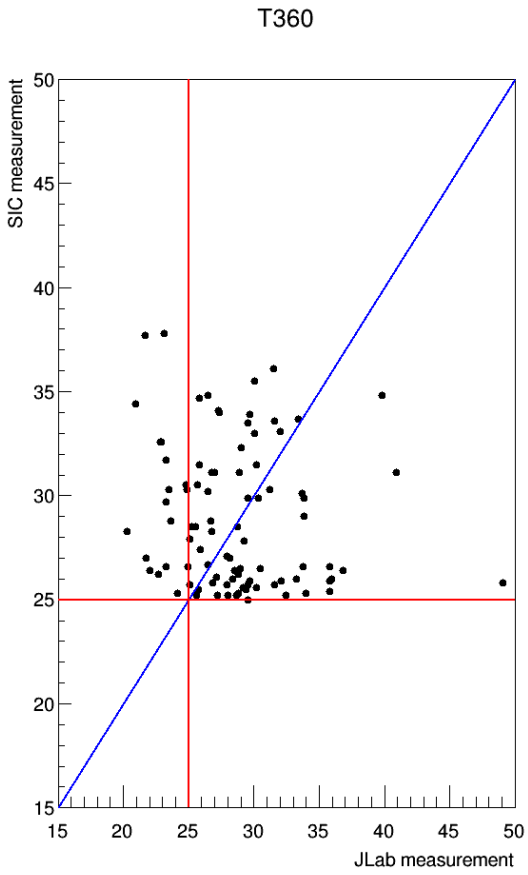
| CX | T360 | T420 | LY100 |
|---|---|---|---|
| S001 | 28.8 | 64.1 | 18.7 |
| S002 | 25.2 | 61.7 | 19.0 |
| S003 | 25.2 | 61.1 | 17.7 |
| S004 | 34.8 | 60.4 | 28.9 |
| S005 | 29.9 | 60.6 | 20.8 |
| S006 | 33.5 | 60.6 | 15.8 |
| S007 | 34.1 | 61.2 | 30.0 |
| S008 | 30.1 | 61.7 | 28.1 |
| S009 | 31.1 | 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 |

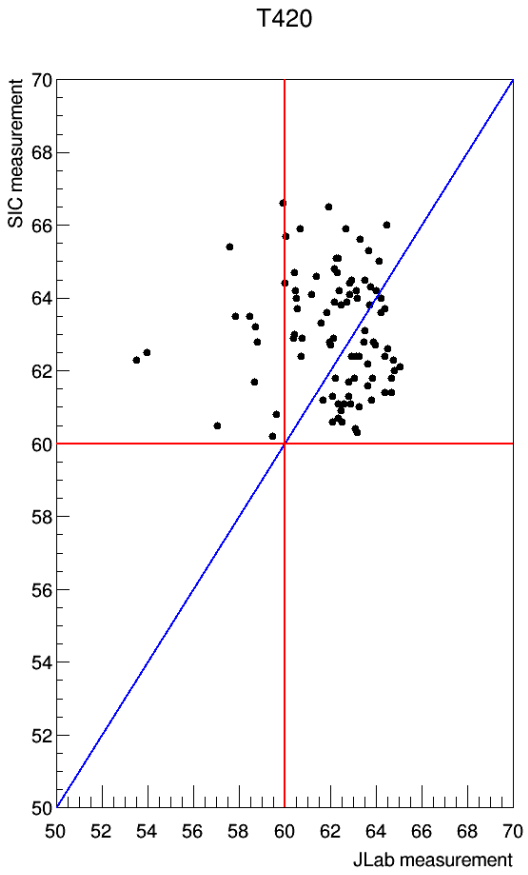
NPS results

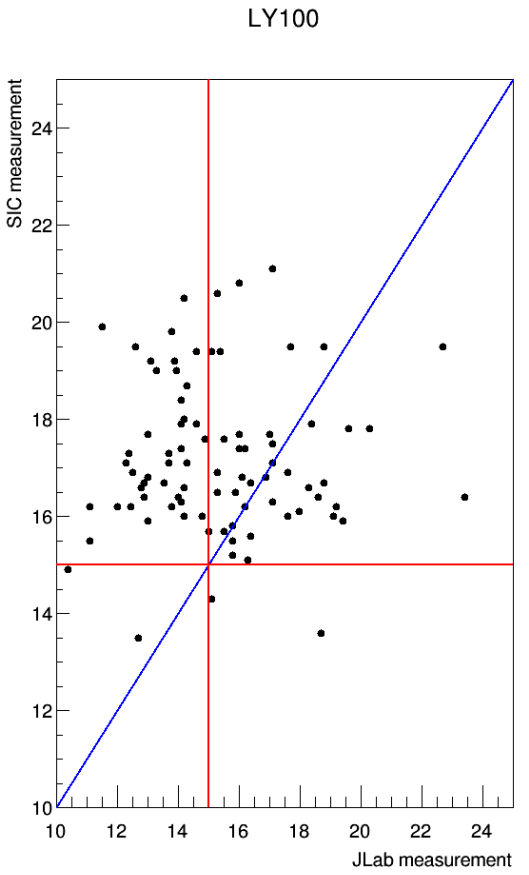
| CX | NPS T360 | NPS T420 | NPS LY100 |
|---|---|---|---|
| S021 | 26.7 | 61.2 | 14.3 |
| S022 | 25.6 | 58.7 | 13.3 |
| S023 | 27.2 | 62.9 | 16.0 |
| S024 | 39.8 | 63.1 | 19.7 |
| S025 | 33.8 | 62.5 | 16.0 |
| S026 | 29.5 | 62.1 | 15.8 |
| S027 | 27.3 | 63.8 | 17.0 |
| S028 | 33.7 | 62.8 | 17.8 |
| 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 comparaison (~200 samples)




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

Should discuss methods and measurement procedures