Crystal-based Pre-shower Calorimeter Prototype - a Progress Report

Will Brooks
UTFSM

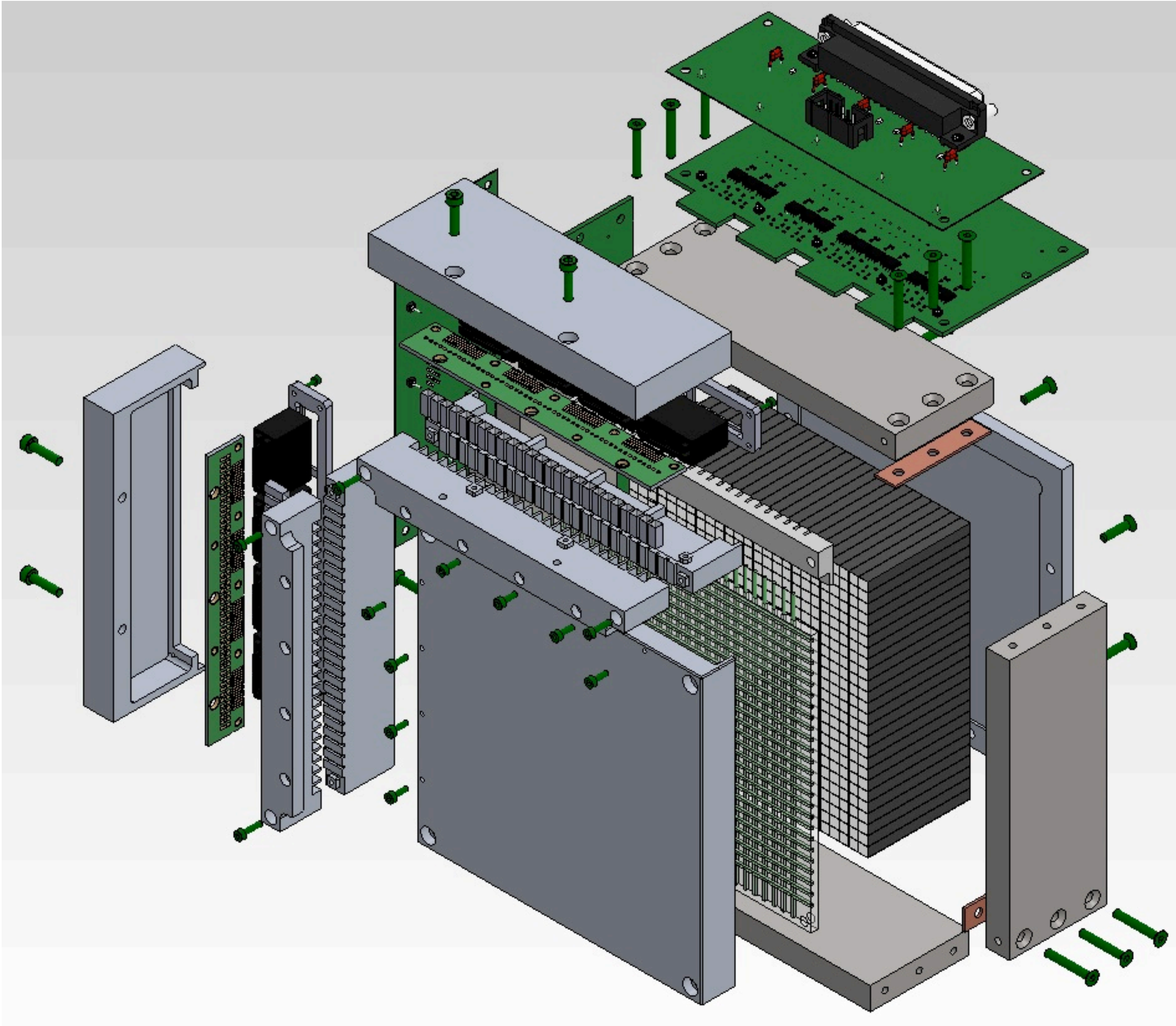
RD 2012-13: Preshower detector for forward EM calorimeters

Progress since June

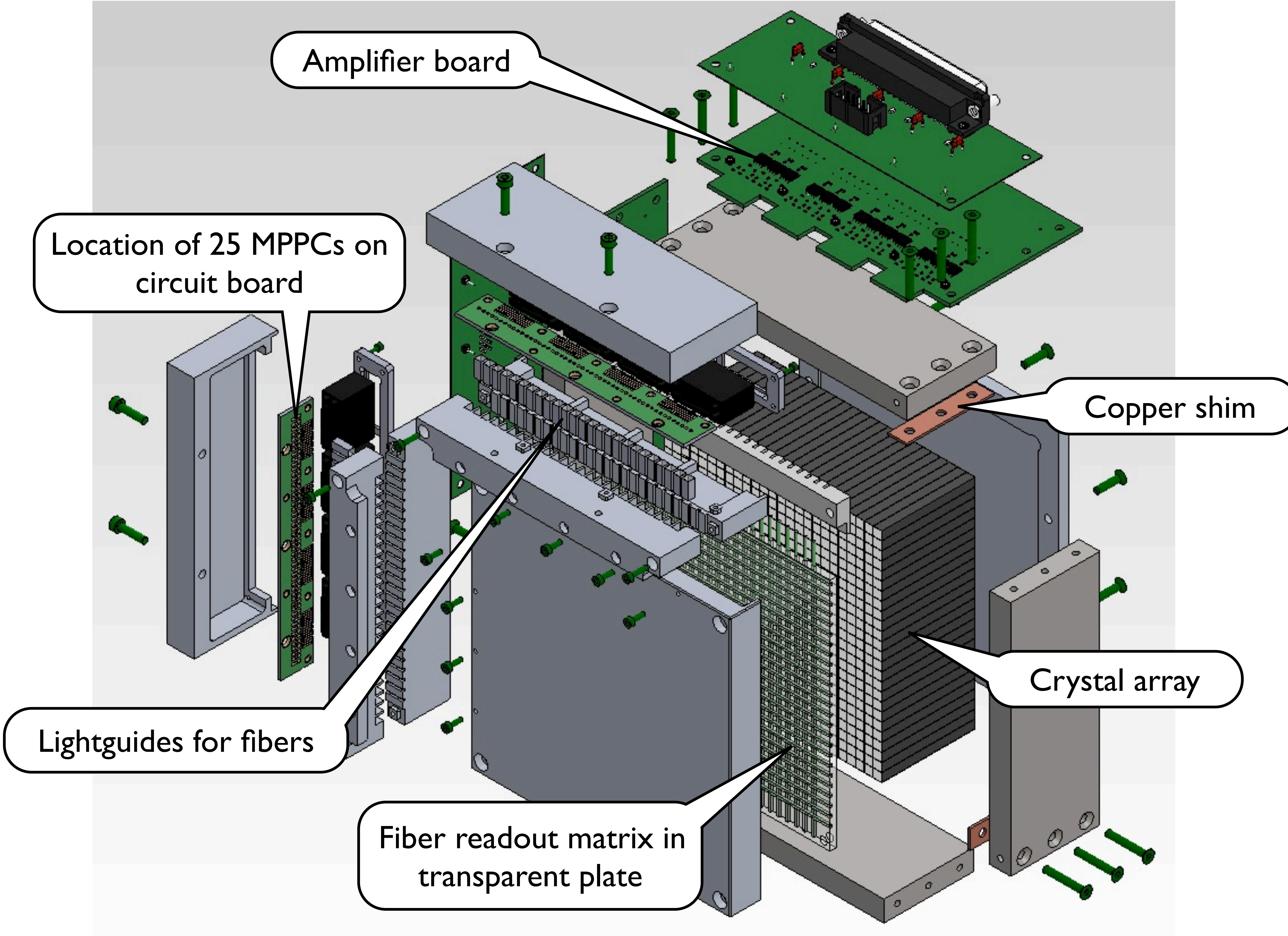
- prototyping of wrapping technique was finished (July)
- amplifiers board were received (July)
- data acquisition system was prepared (August)
- cosmic ray setup was completed (August)
- LED testing of MPPC readout was completed (August)
- production of wrapping for 625 crystals was finished (October)
- production of crystal array housing was finished (October)
- light covers were fabricated (October)
- crystal stacking was started (October) and finished (December)
- production of 50 light guides was finished (December)

Summary: detector has been constructed and assembled

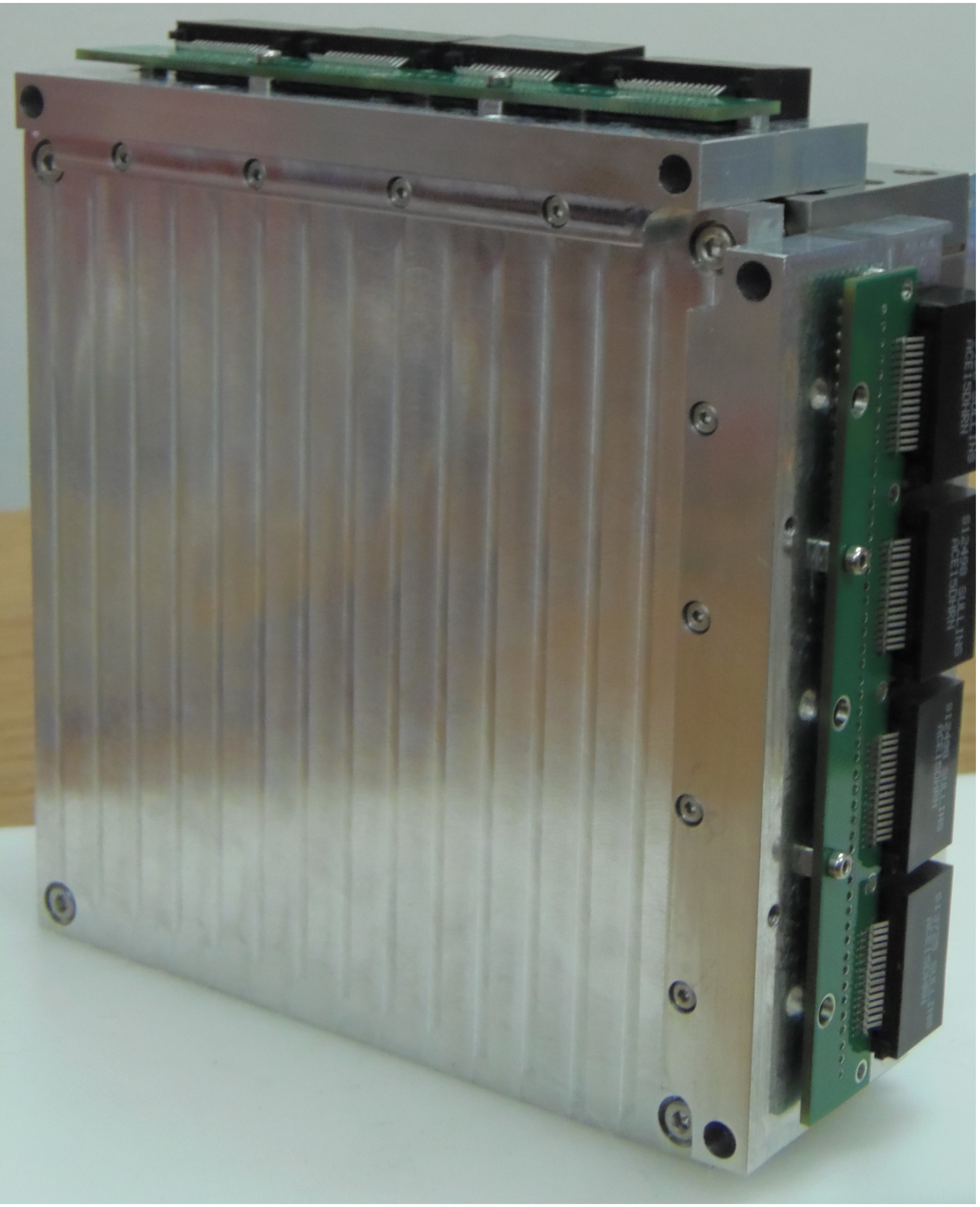
Preshower calorimeter: mechanical design layout

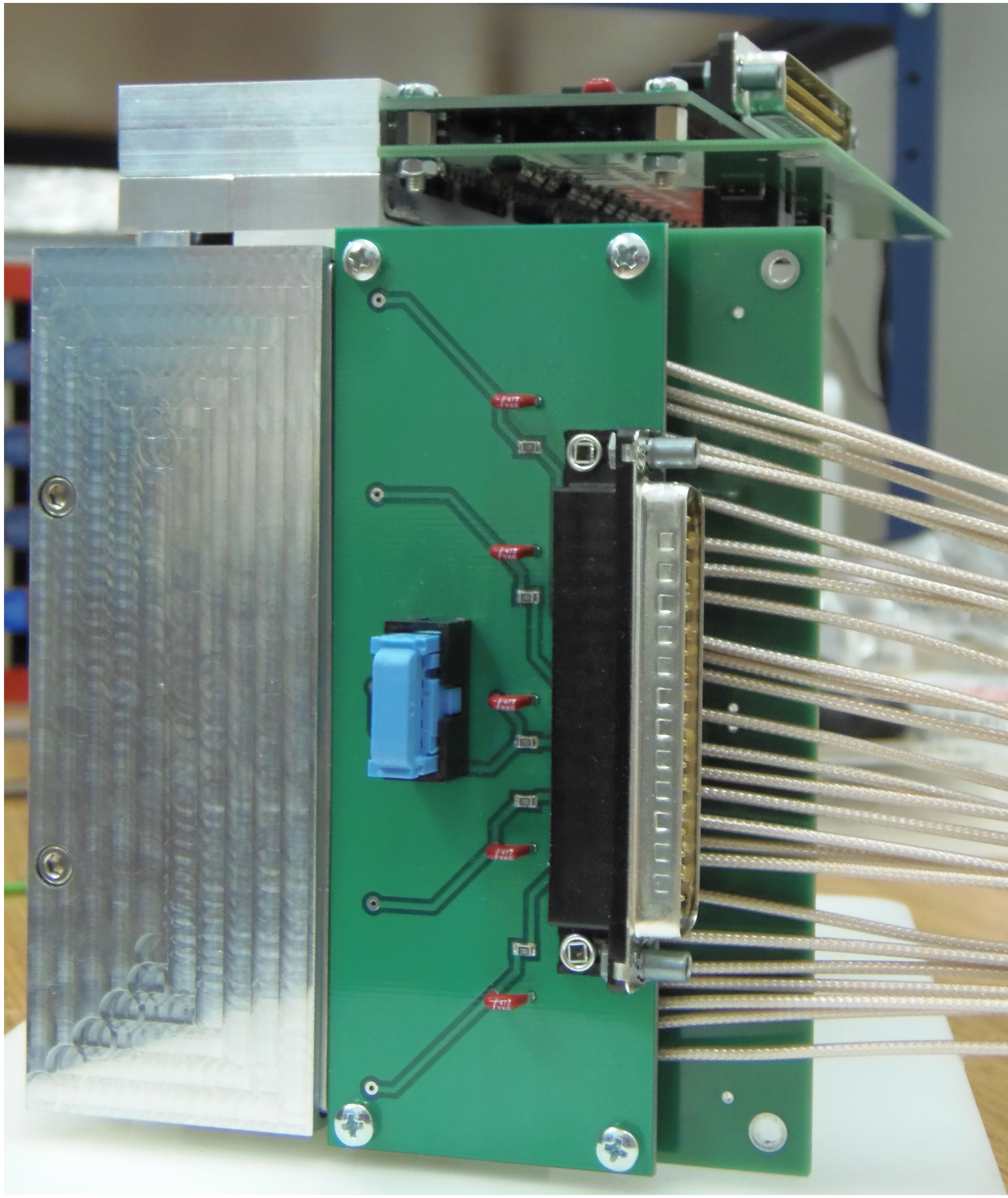


Preshower calorimeter: mechanical design layout



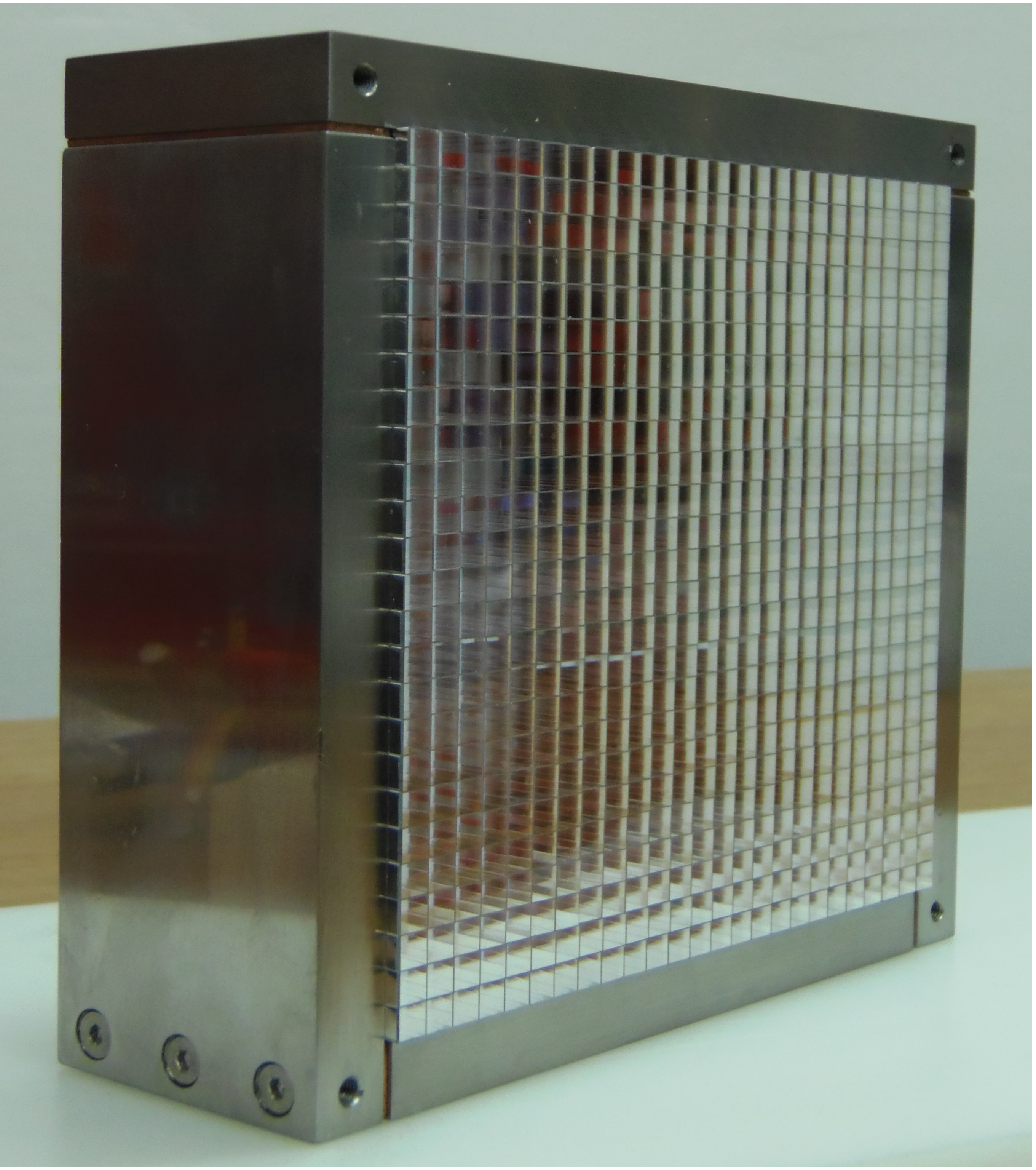
The fully-constructed detector!

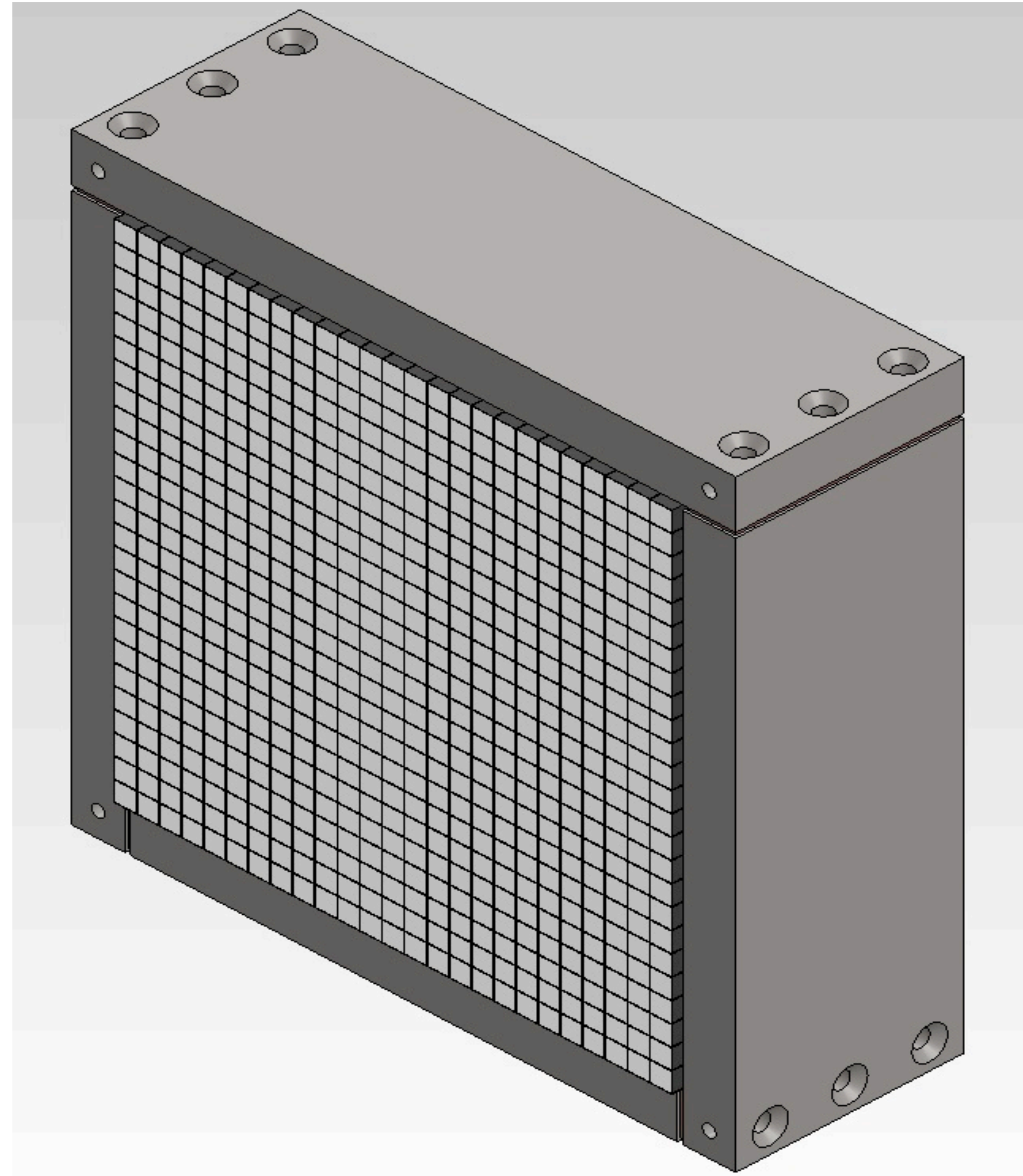




Active area is 10 cm x 10 cm

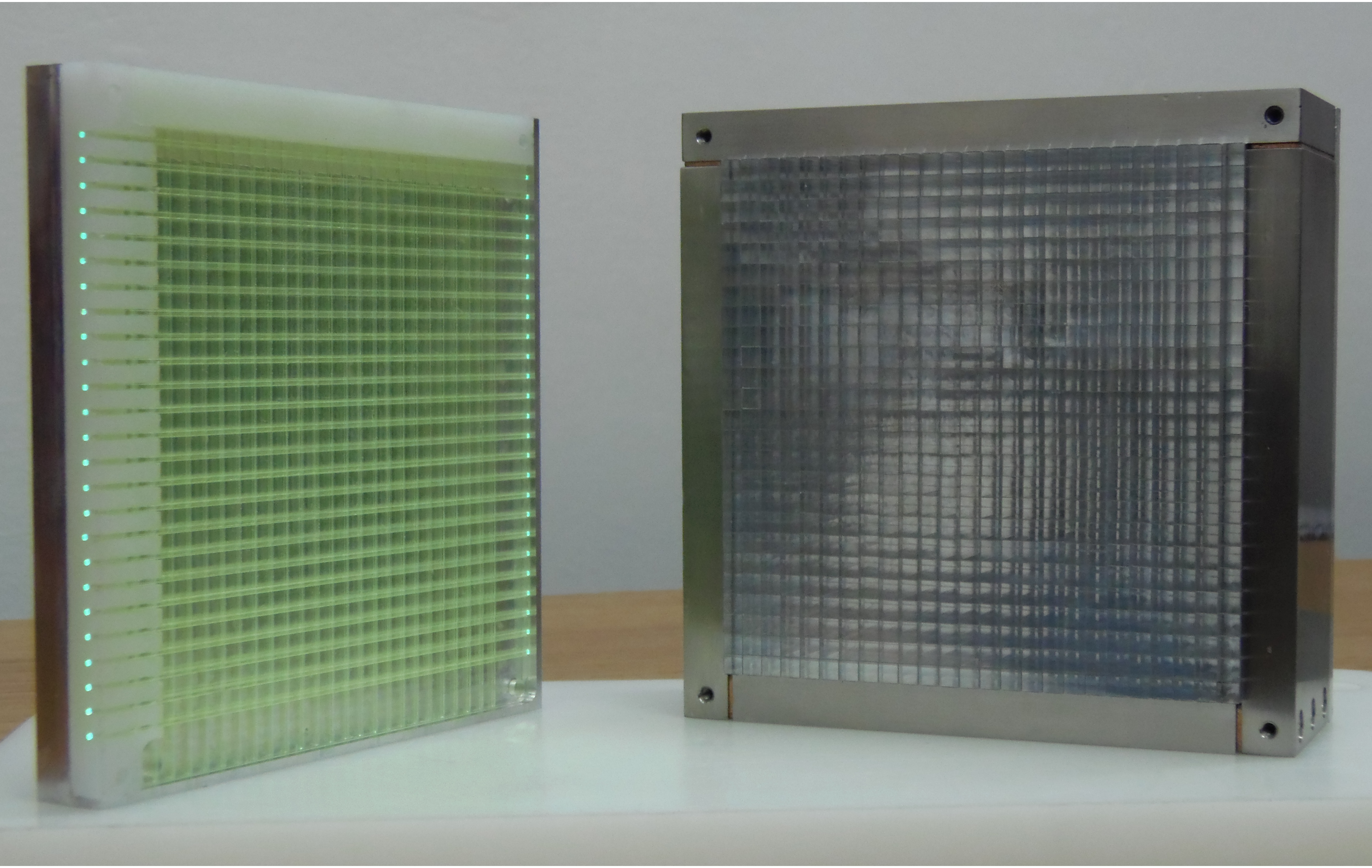
The crystal array





625 LYSO crystals, individually wrapped with formed ESR film

Crystal array with fiber readout matrix



25 x 25 Kuraray Y-11 fibers embedded in transparent plate

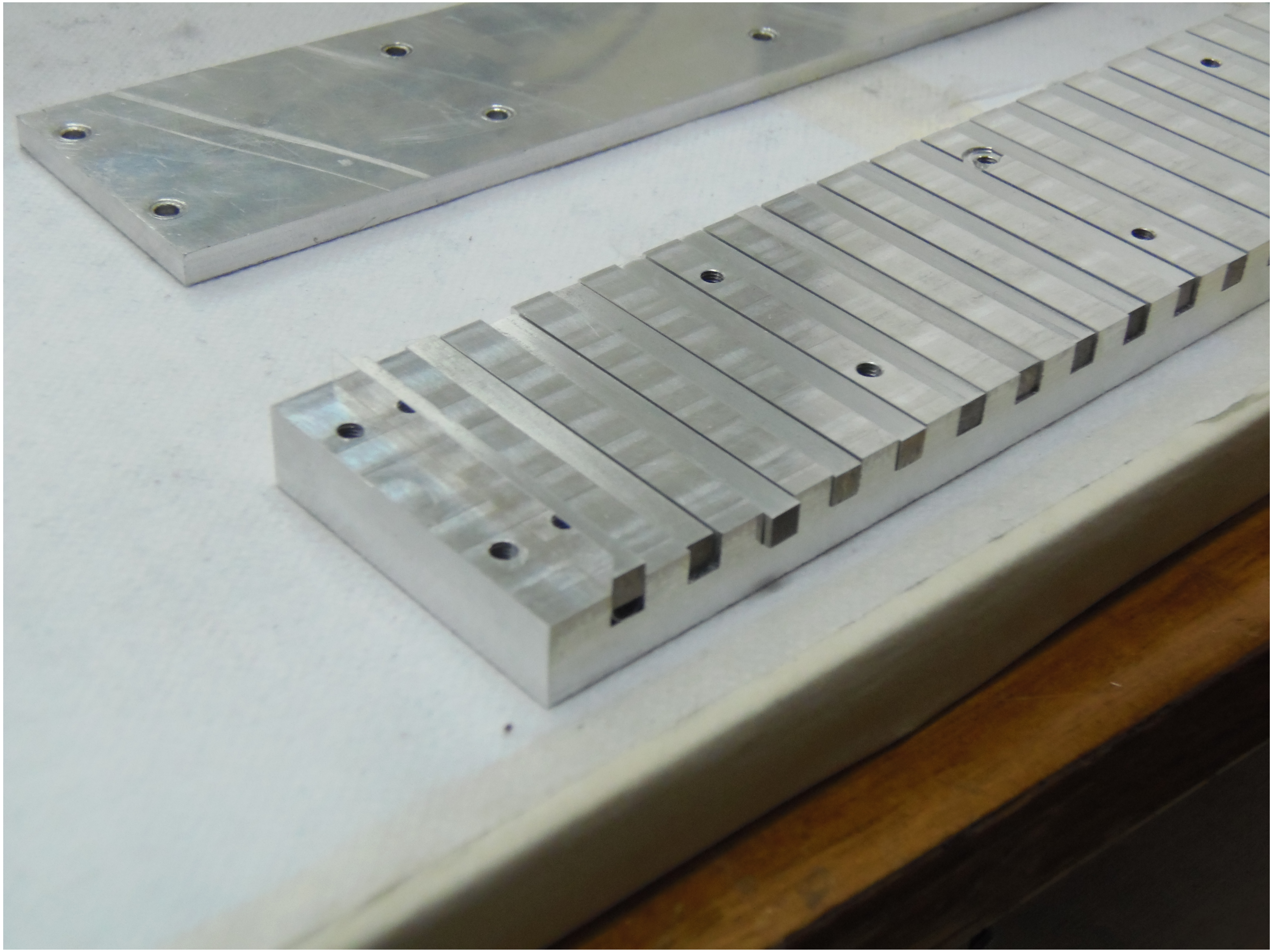
Cutting the wrapping film

3M Vikuiti Enhanced Specular Reflection film

Jig for forming reflective wrapping in oven

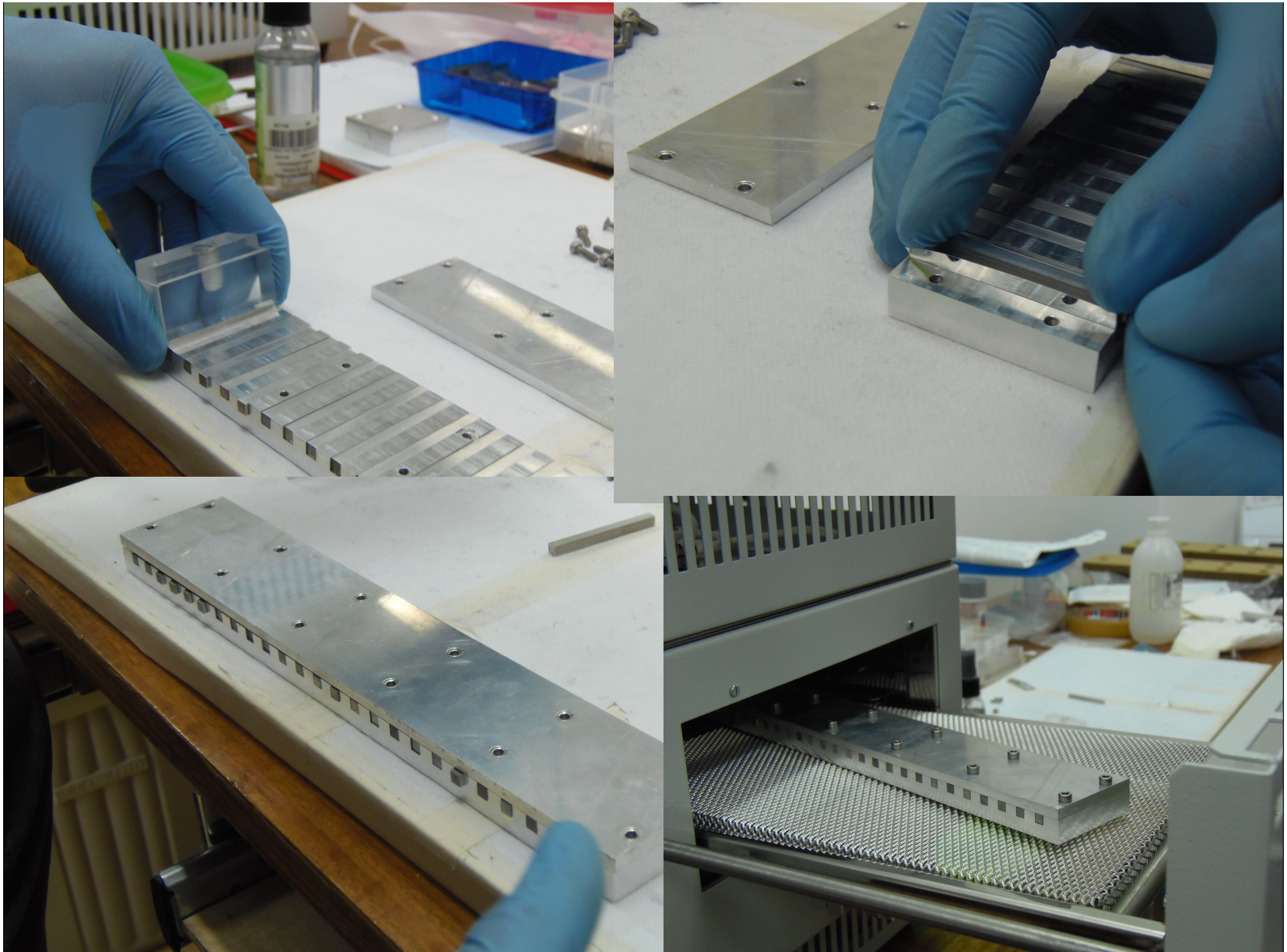
Capacity for forming 25 at a time

Forming jig with blanks



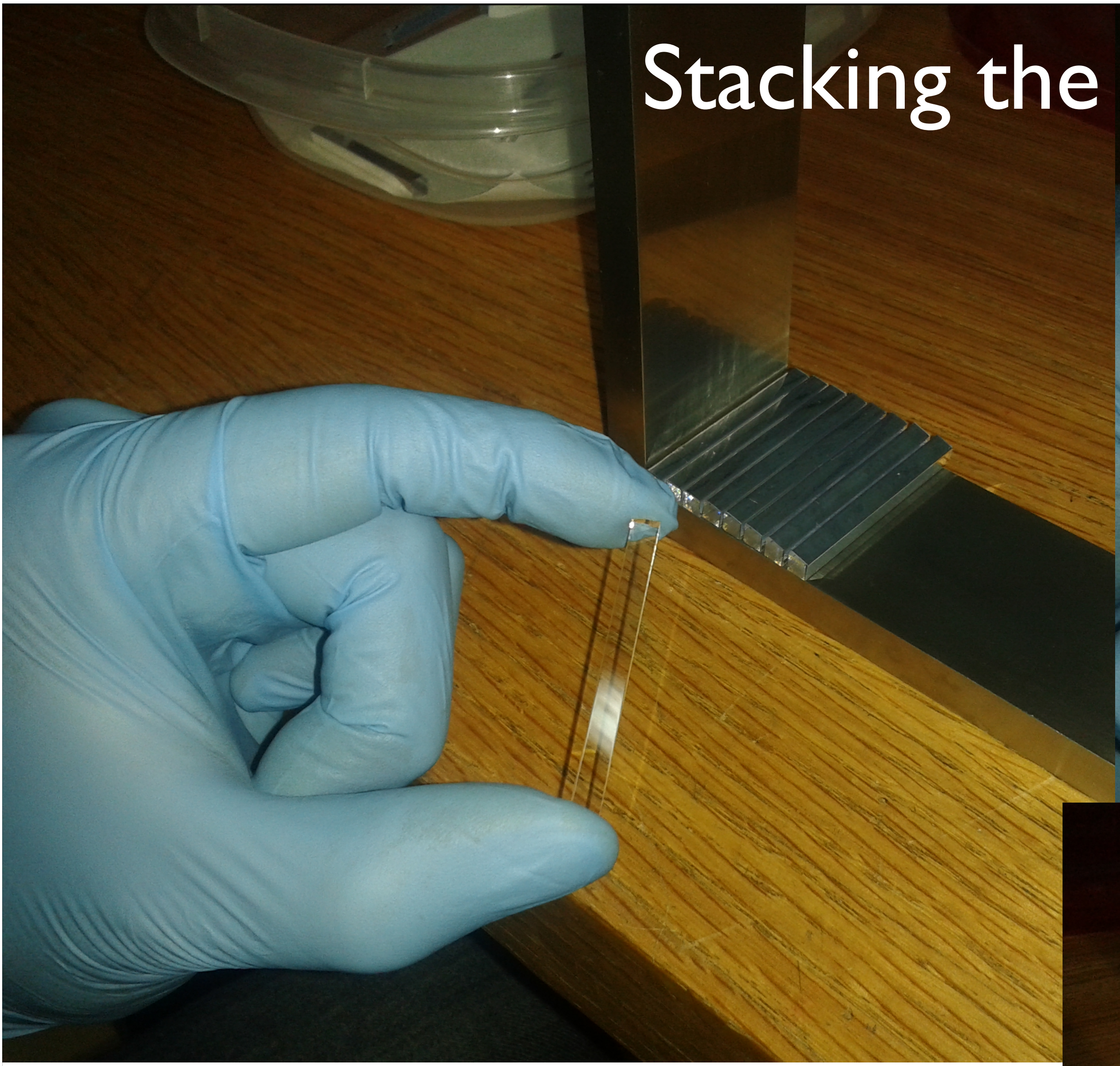
(Note film sample in last slot)

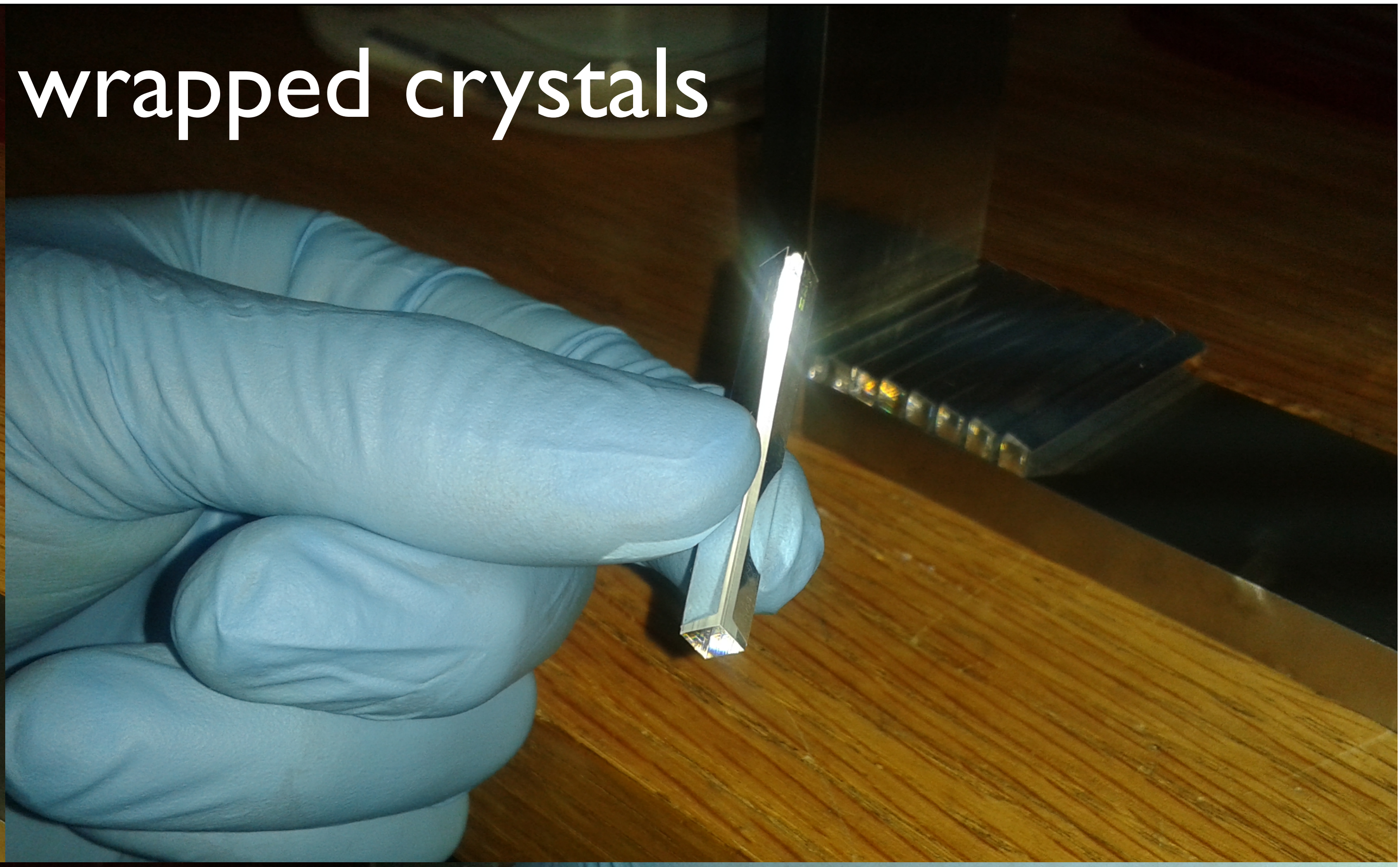
The foil forming process

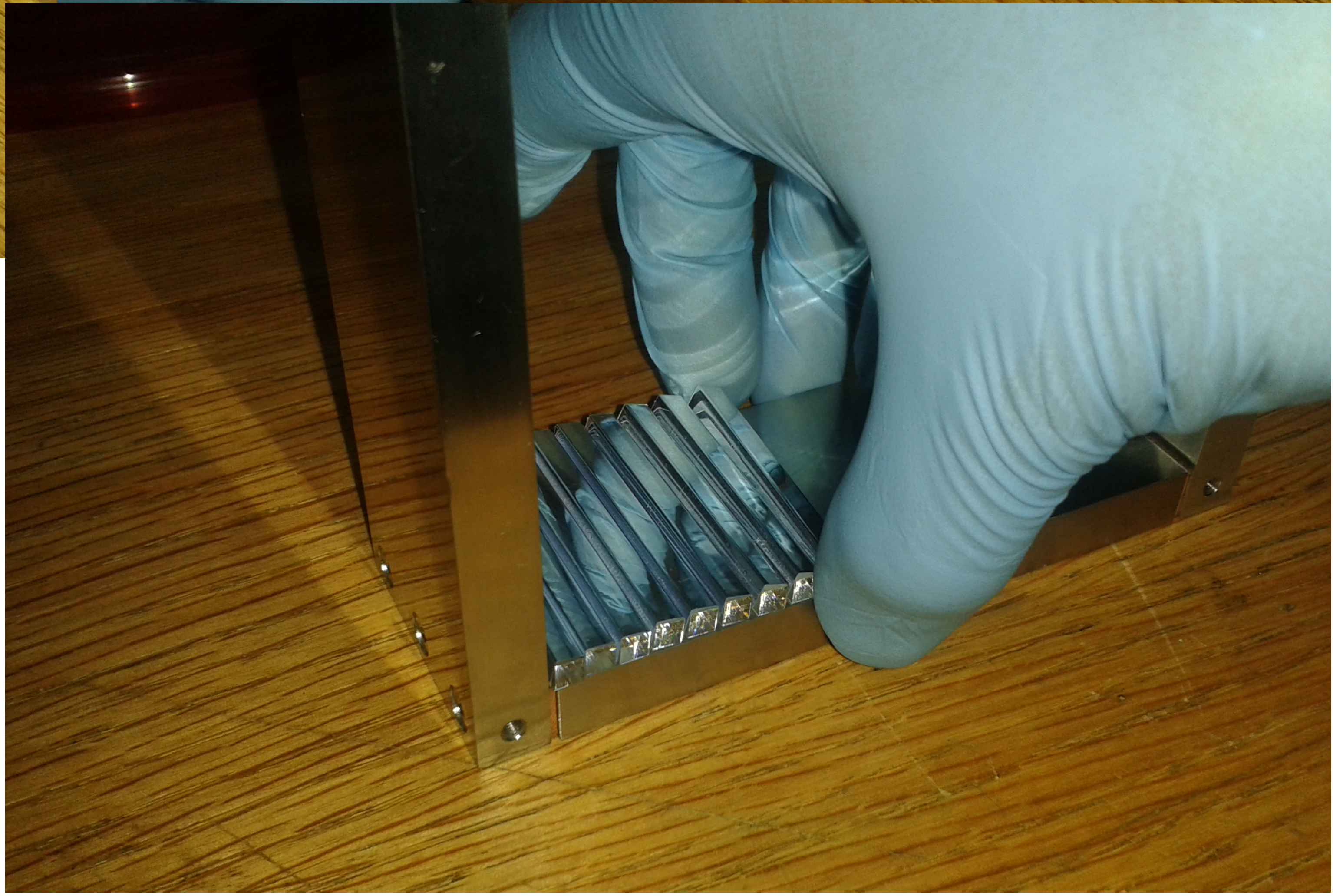


Preparation of jig for heating in oven

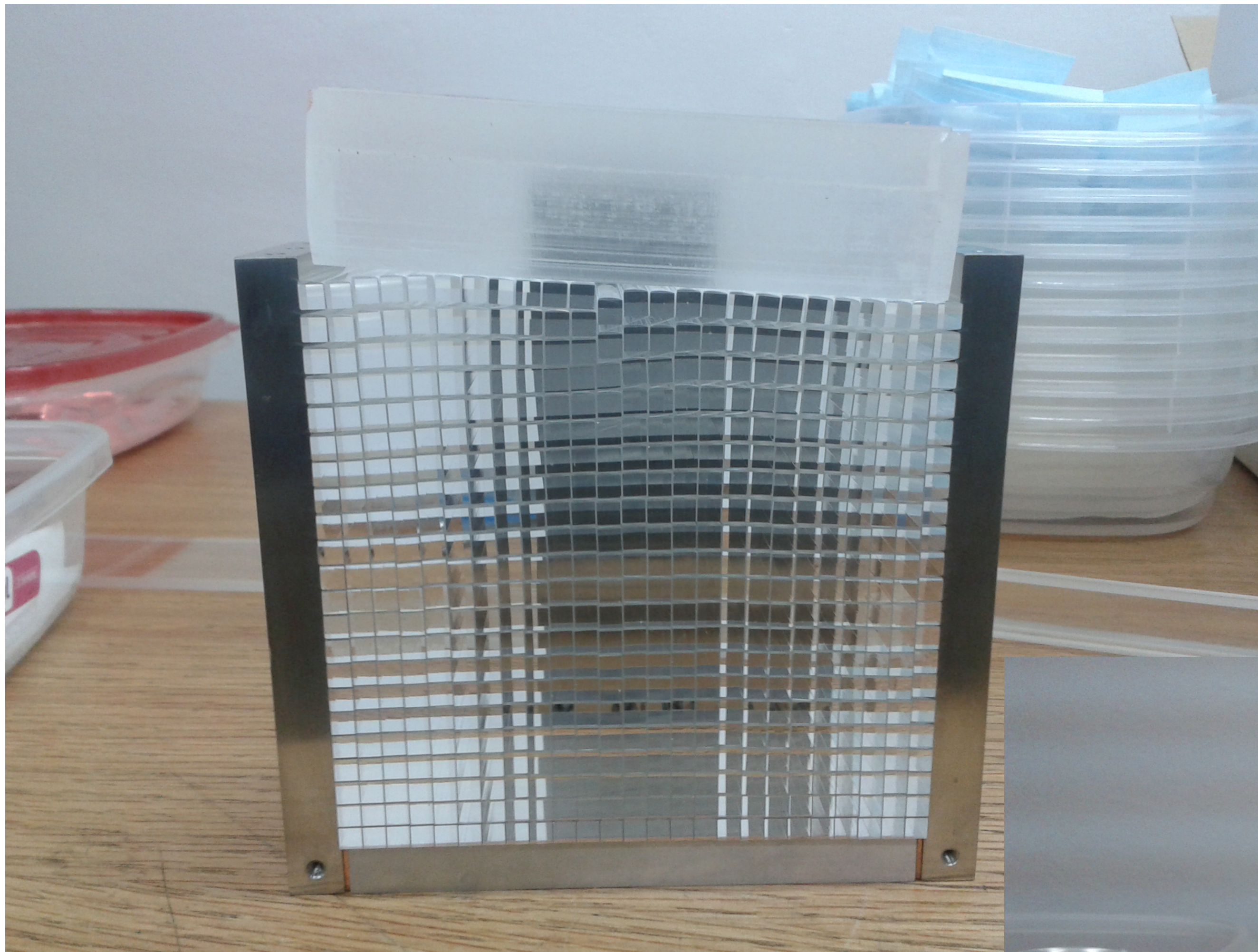
Stacking the wrapped crystals





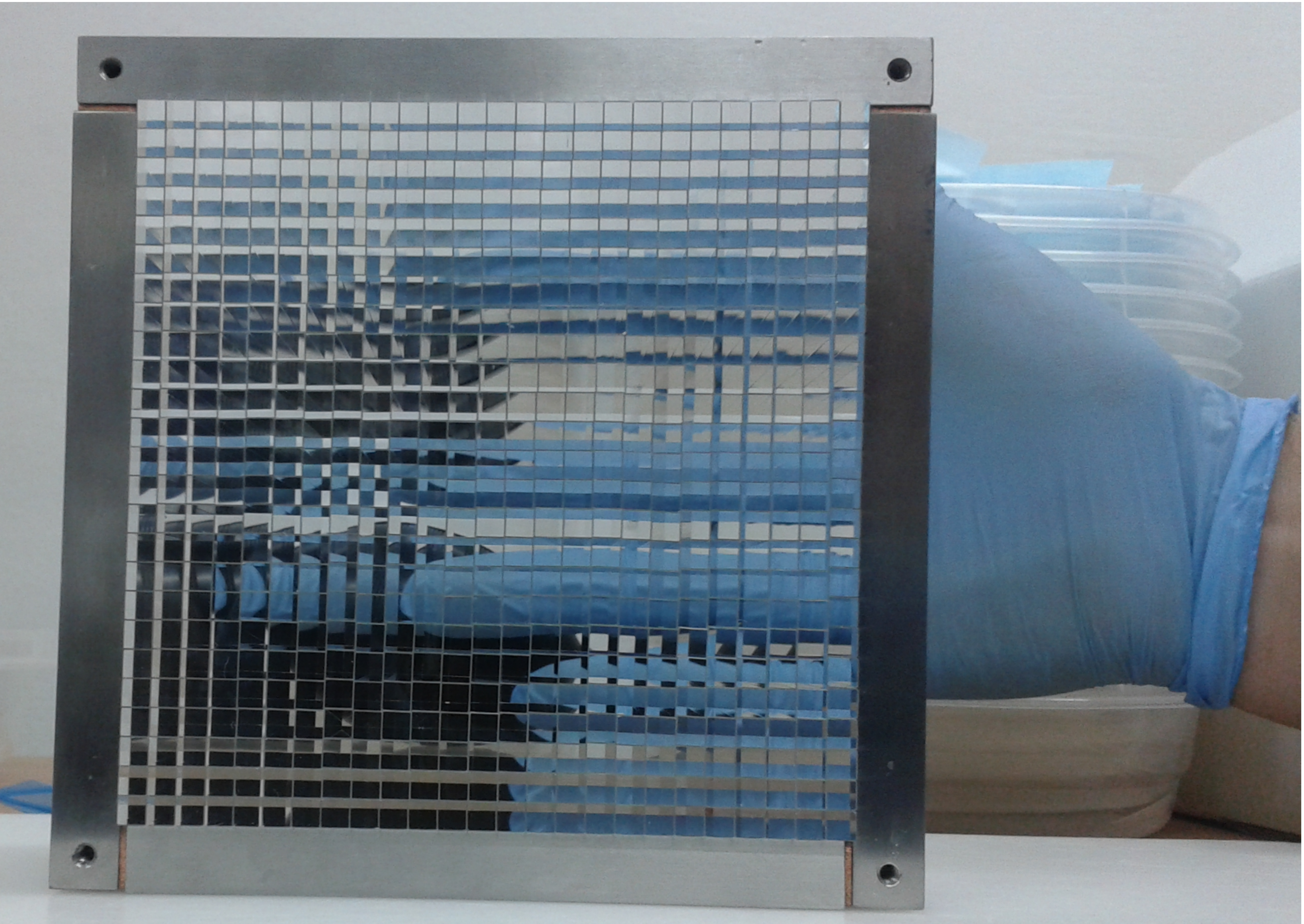


Finishing the stacking process

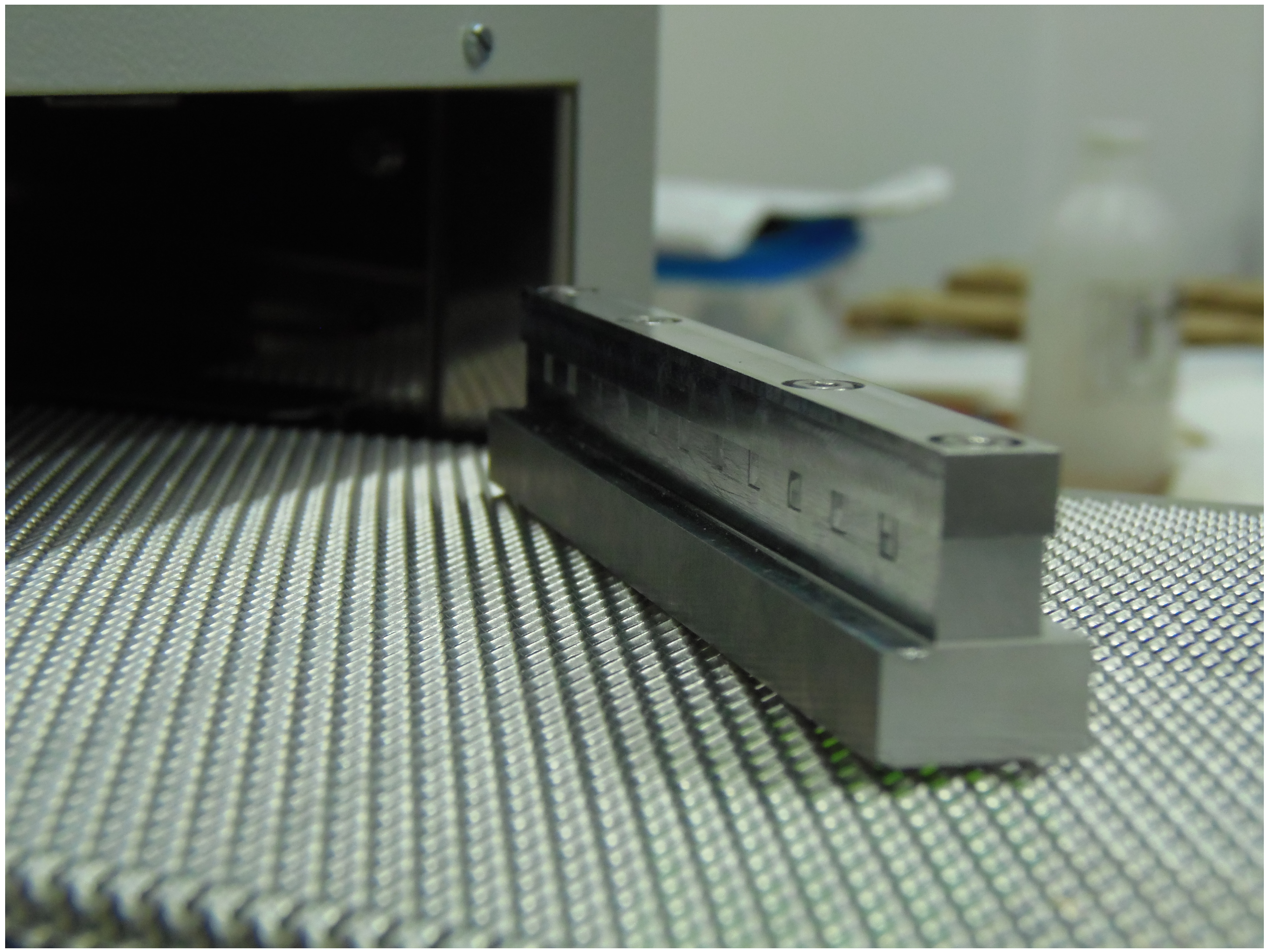


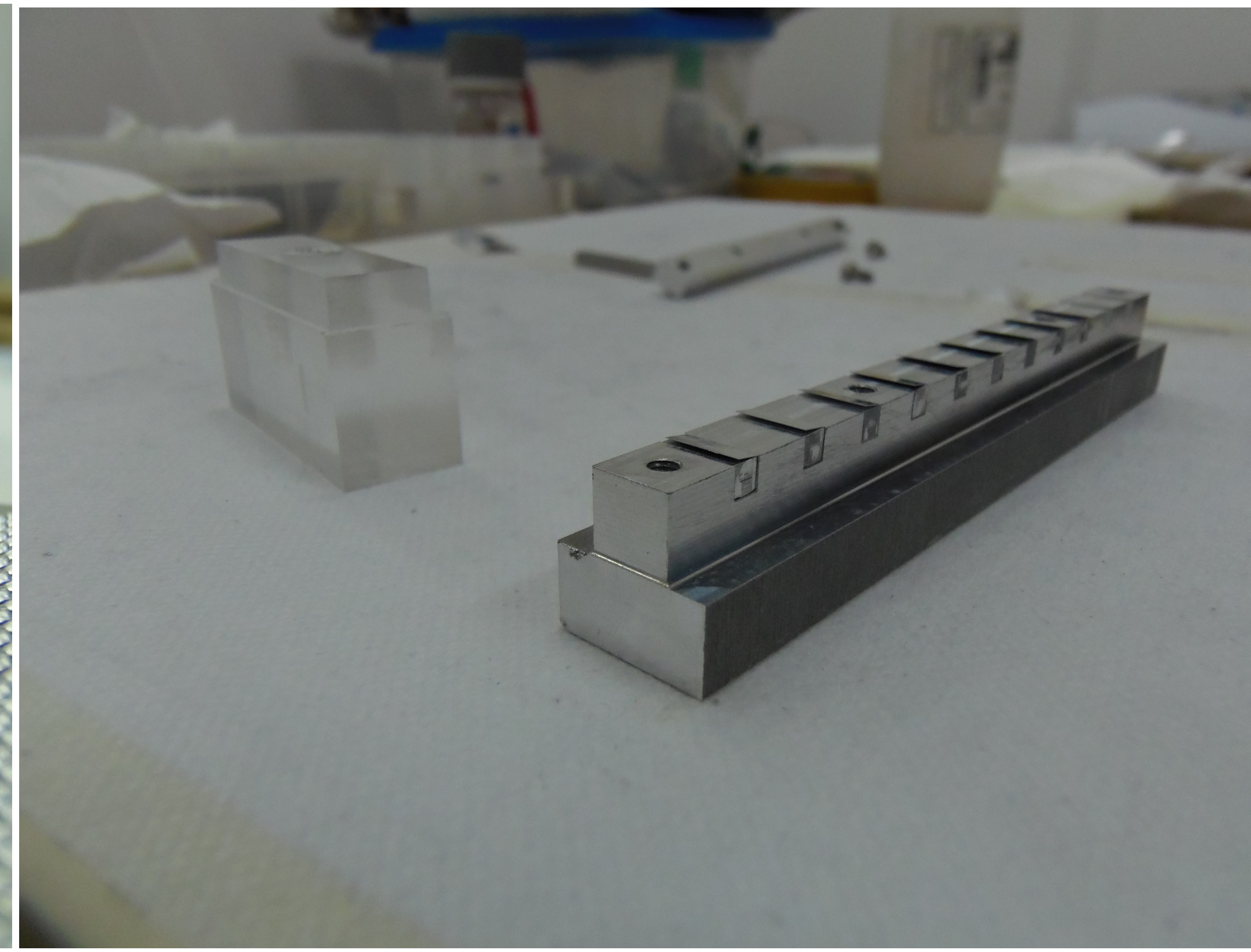
Mounting bolts torqued; 100% of crystals are held in place. (no loose crystals)

The stacked crystal array



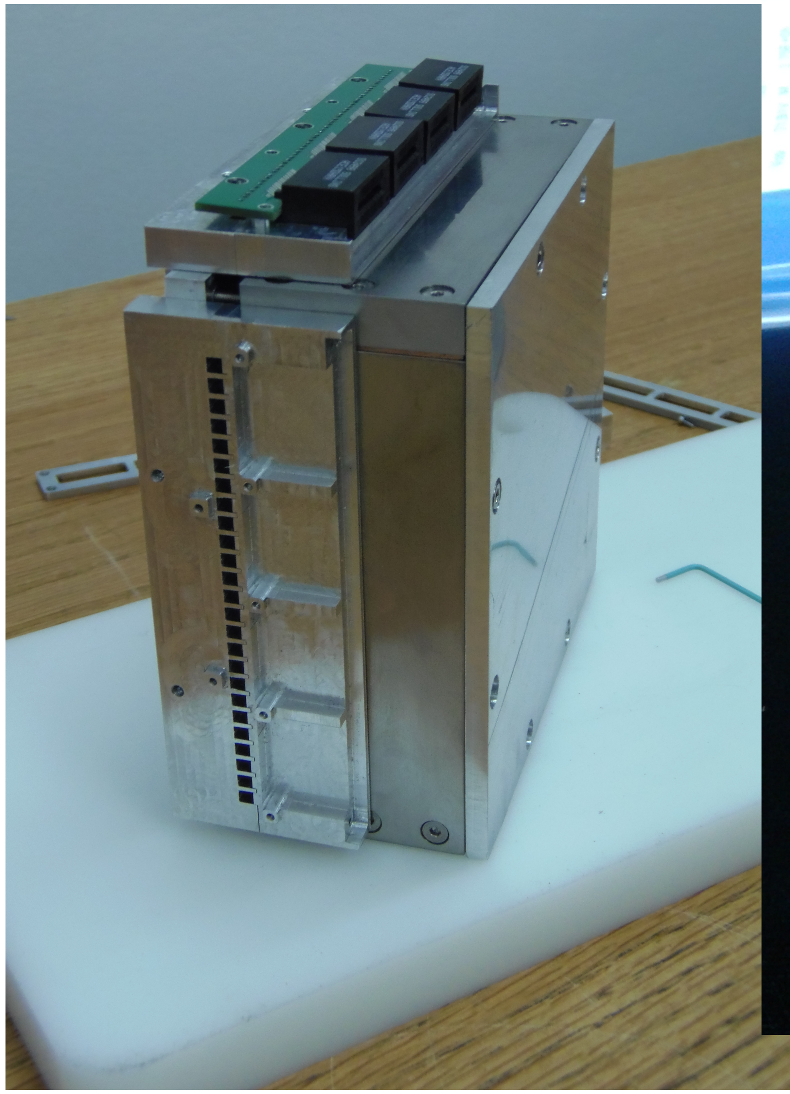
Forming the reflective films for the light guides

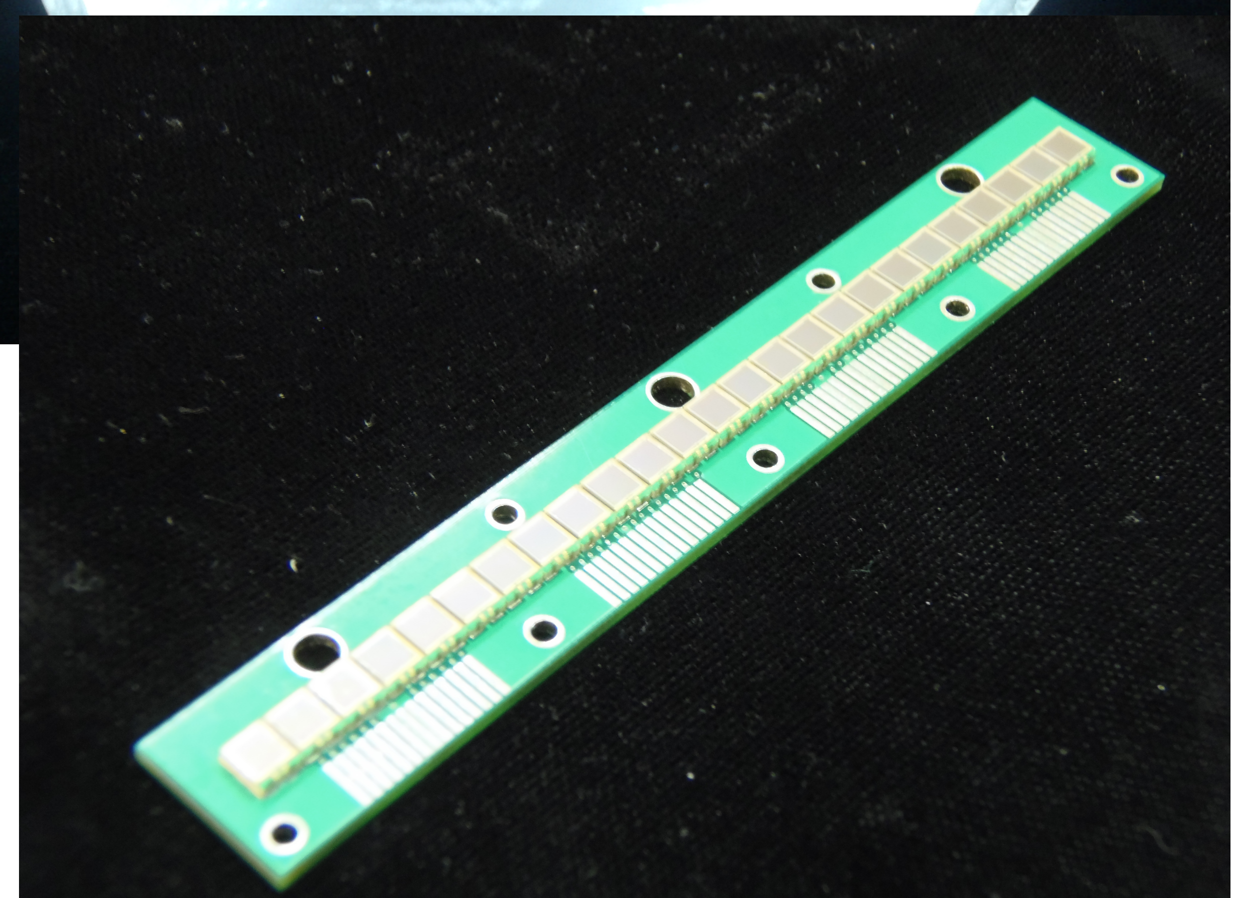




Fifty light guides in total

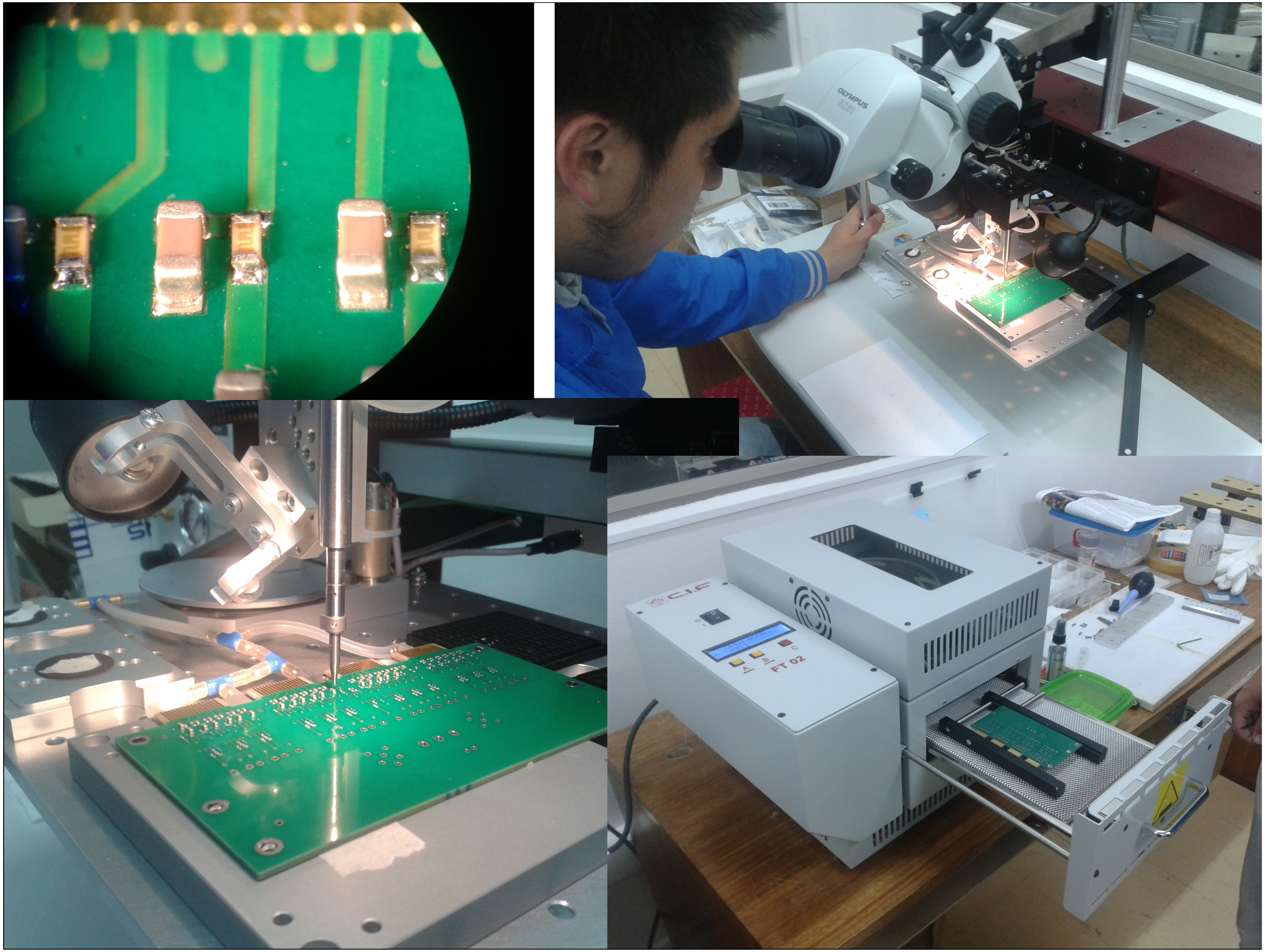
Jig for precisely positioning MPPCs for soldering



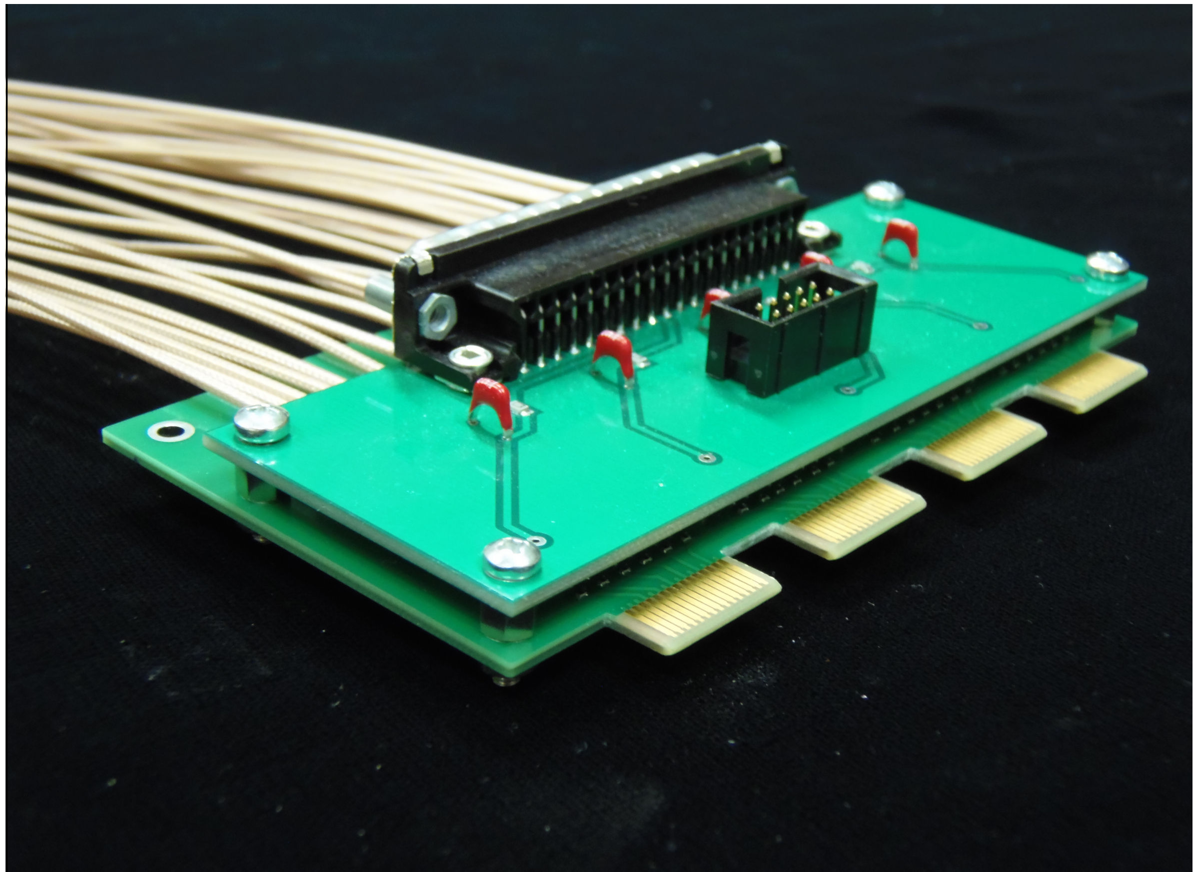


Pins align jig with circuit board

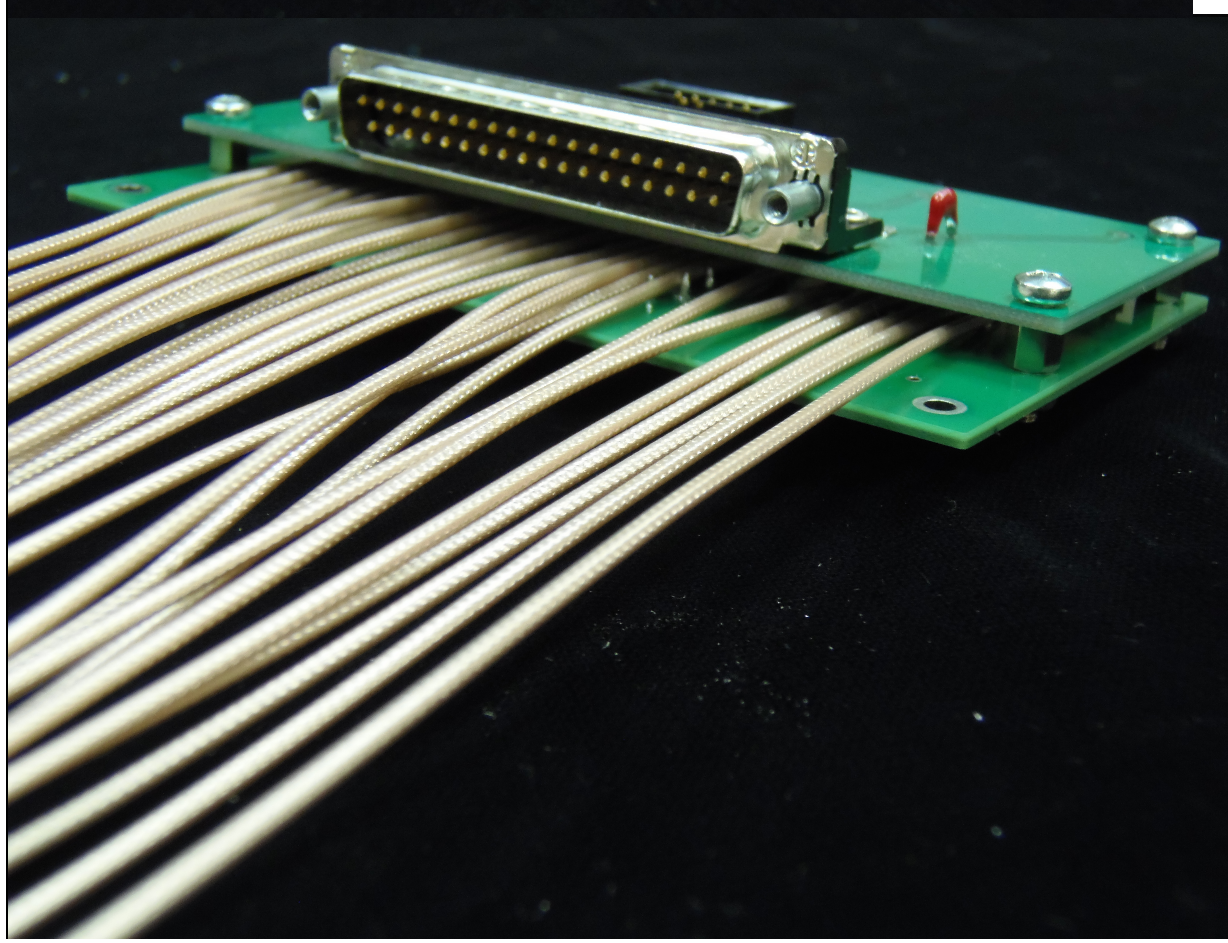
Soldering and testing surface-mounted electronics

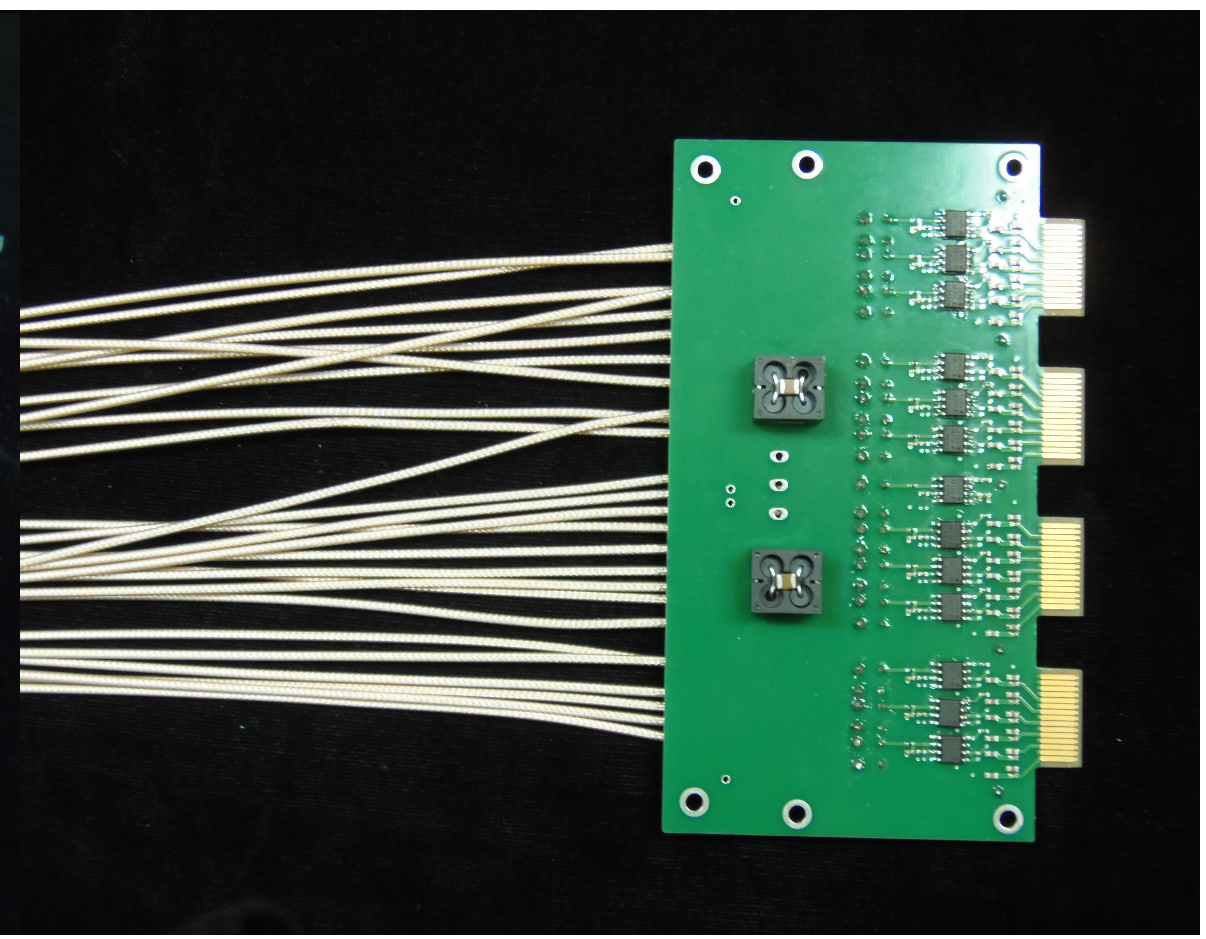


All operations performed in our new micro-electronics fabrication facility!

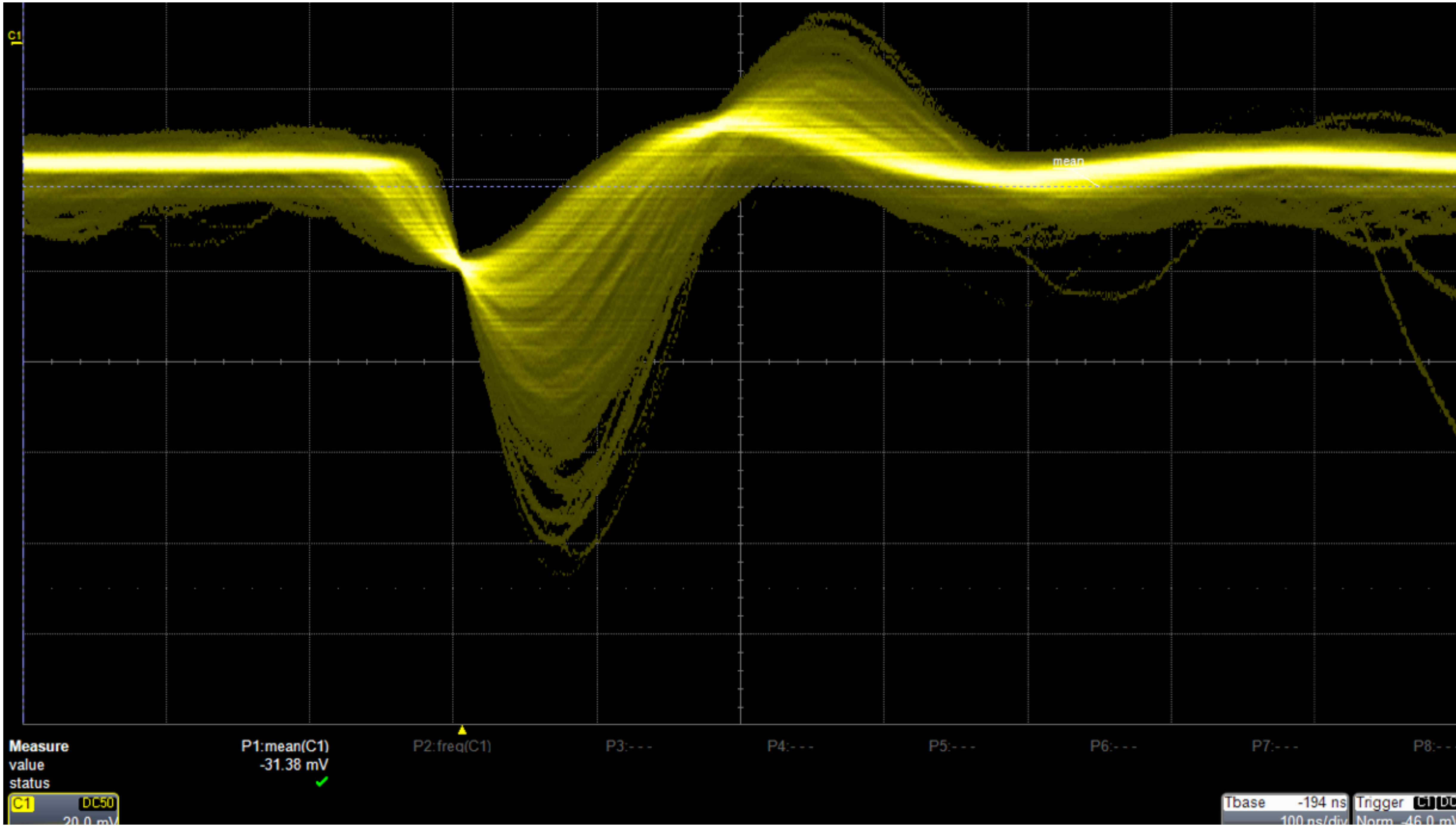


Amplifier boards



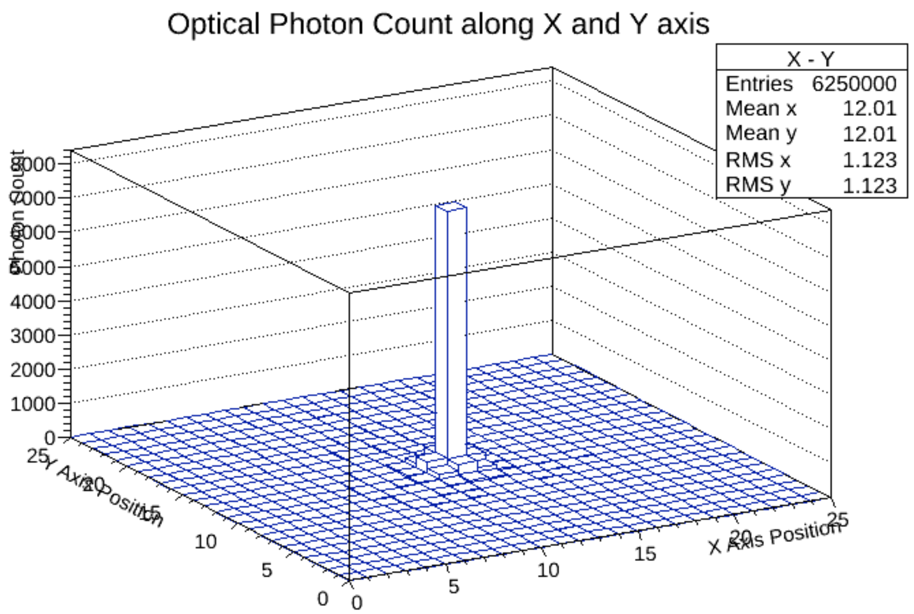


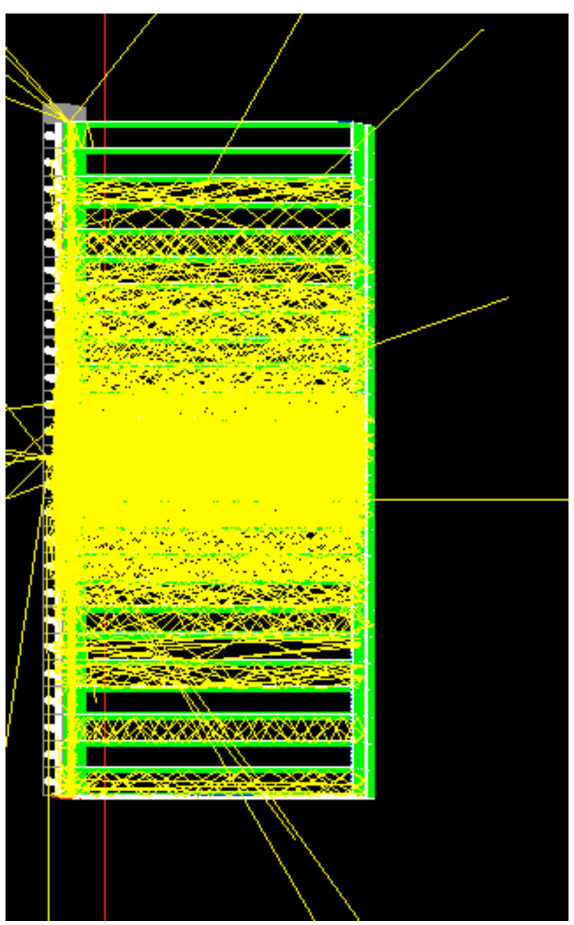
First signals



This is a signal from one channel of the assembled preshower calorimeter for a particular gain setting. The pulses come from the natural internal radiation of the crystal. Light intensity is approximately consistent with expectations.

Simulation status





- GEANT4 simulation fully functional, all optical elements included
- Optical photon generation works well; however, too slow for general use, only suitable for design studies
  - will make use of this for fiber matrix plate optimization
- implementation into overall EIC simulation is underway, but performance optimization is needed

Conclusions and next steps

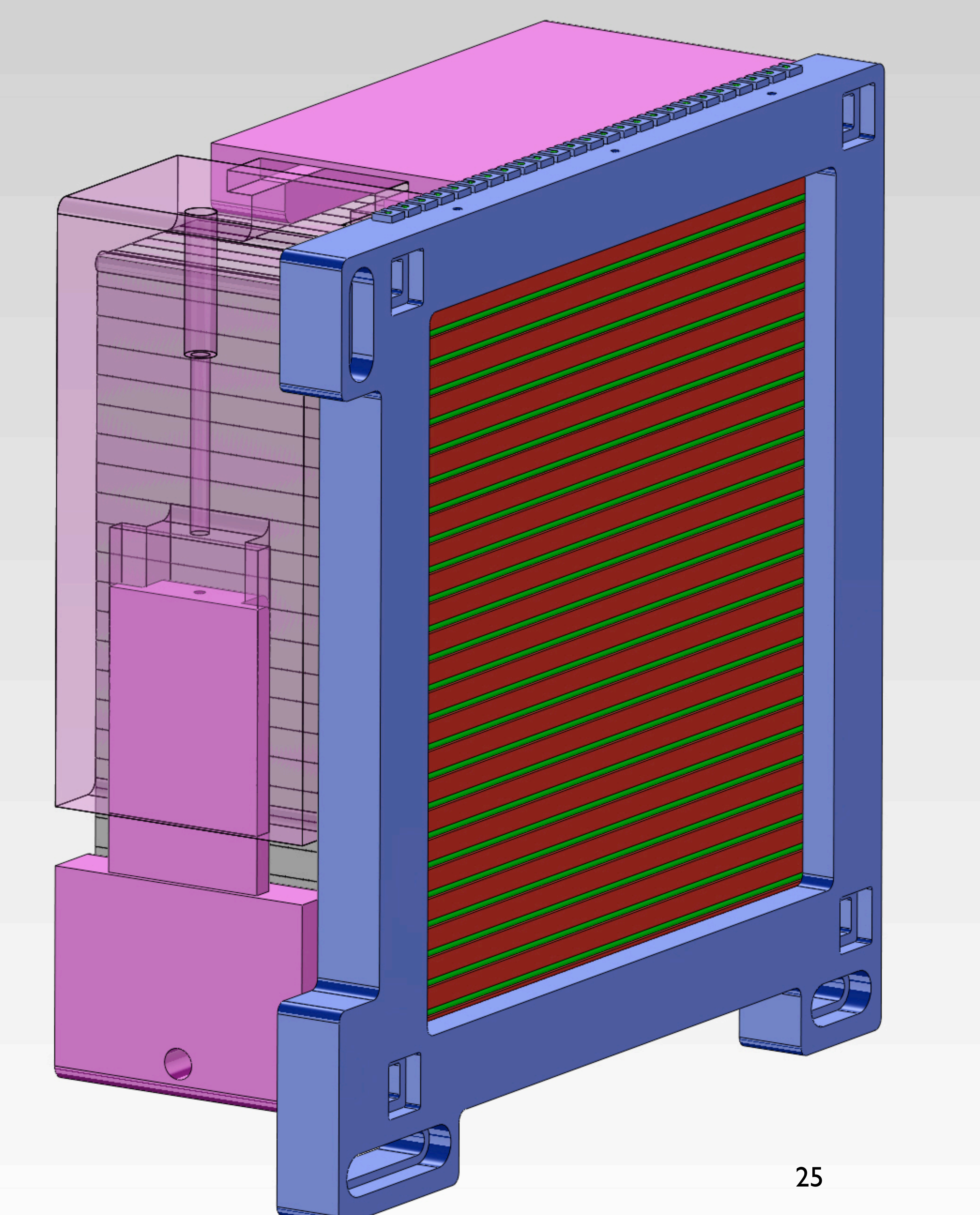
- The device has been constructed
- We need to characterize the response properties - light production uniformity, gain optimization, etc.
- Tests with the photon tagger and with cosmic rays (minimum ionizing; showering particles using a second calorimeter, if possible)
    - Comparison to GEANT4 simulation
    - Full testing will require about 5 months
- Optimization of the fiber matrix (reflective coating, absorptive coating, etc. on the mounting plate)
- Plan a run with test beam from an accelerator
- Exploration of mechanical design for full-sized detector ('tiling options')

Selected slides from the June, 2013 presentation

Mechanical Design: Fiber Positioning Plate

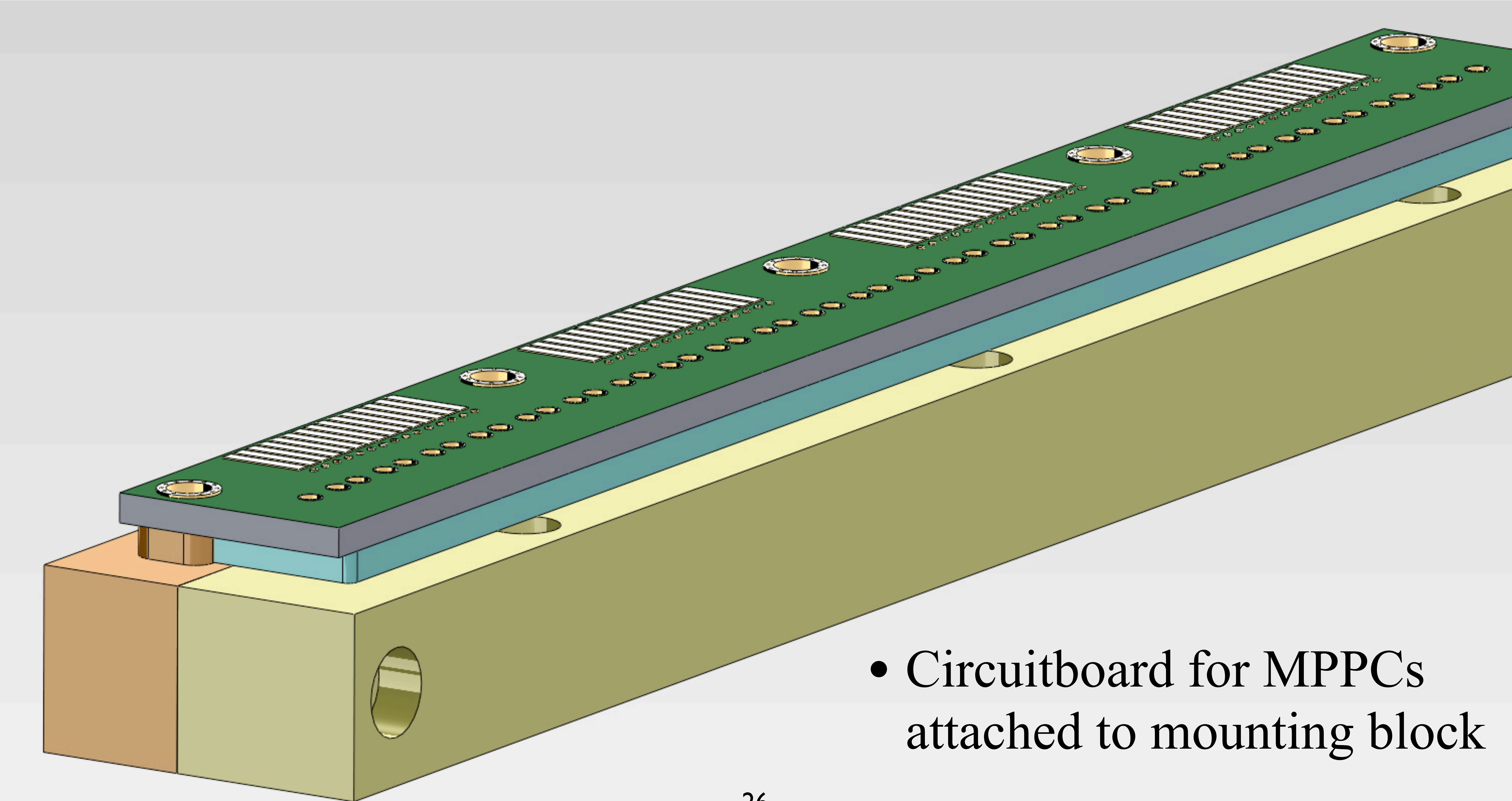
- Fiber lightguides, Y-11(200)M
- Currently supporting the fiber lightguides with a transparent plastic plate that has machined grooves on each side - fiber positioning plate
- No U, V information, but it could be added at 45 degree angle with a more complicated readout configuration.
- A second X, Y plate on the opposite side of the array, using 2 planes of crystals, could provide some directional information (this is the "3-D readout")

Mechanical Design: Crystals + Fibers



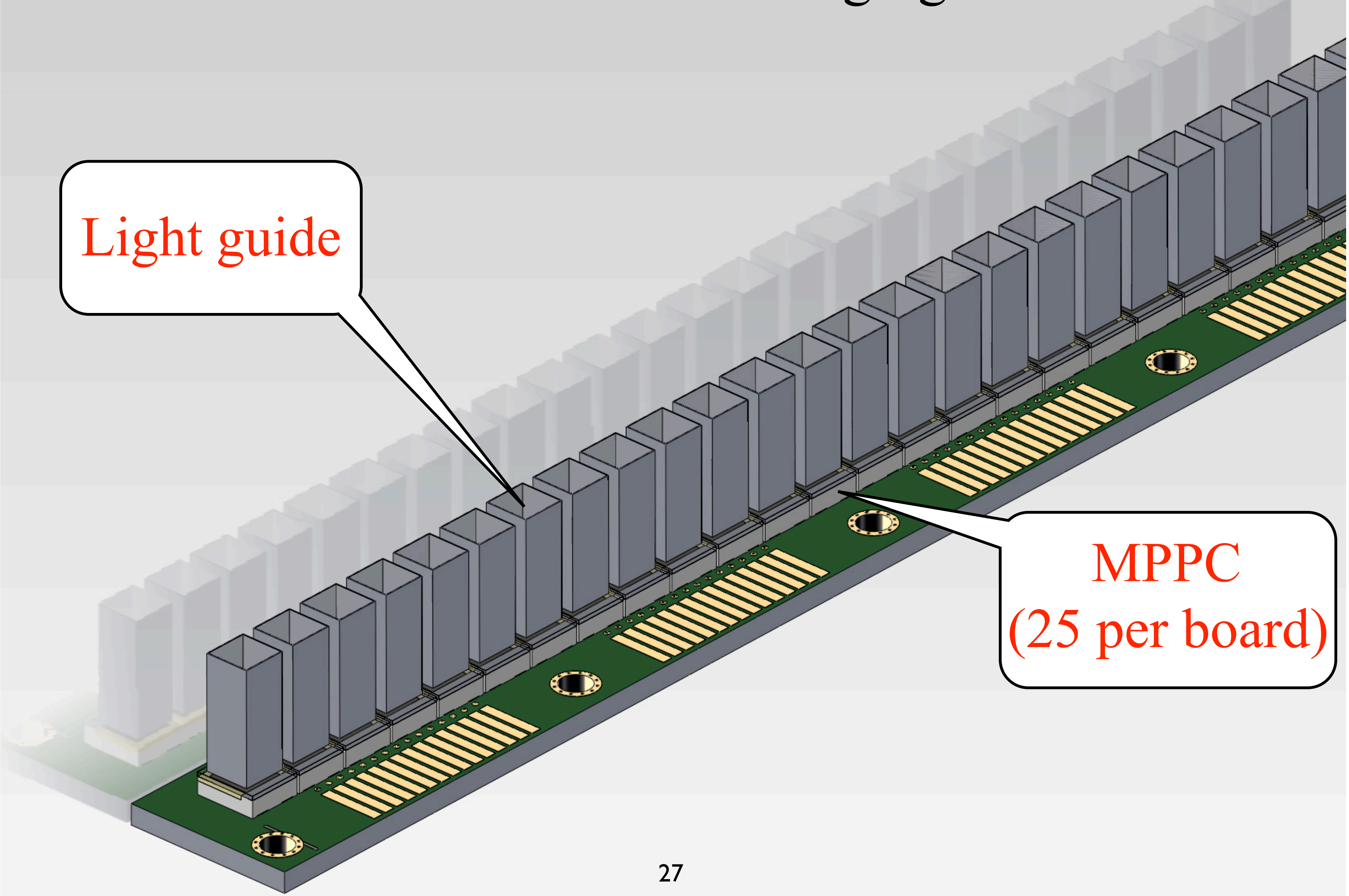
- Fibers mounted on the "front" of the calorimeter to reduce radiation exposure

Mechanical Design: MPPC Board

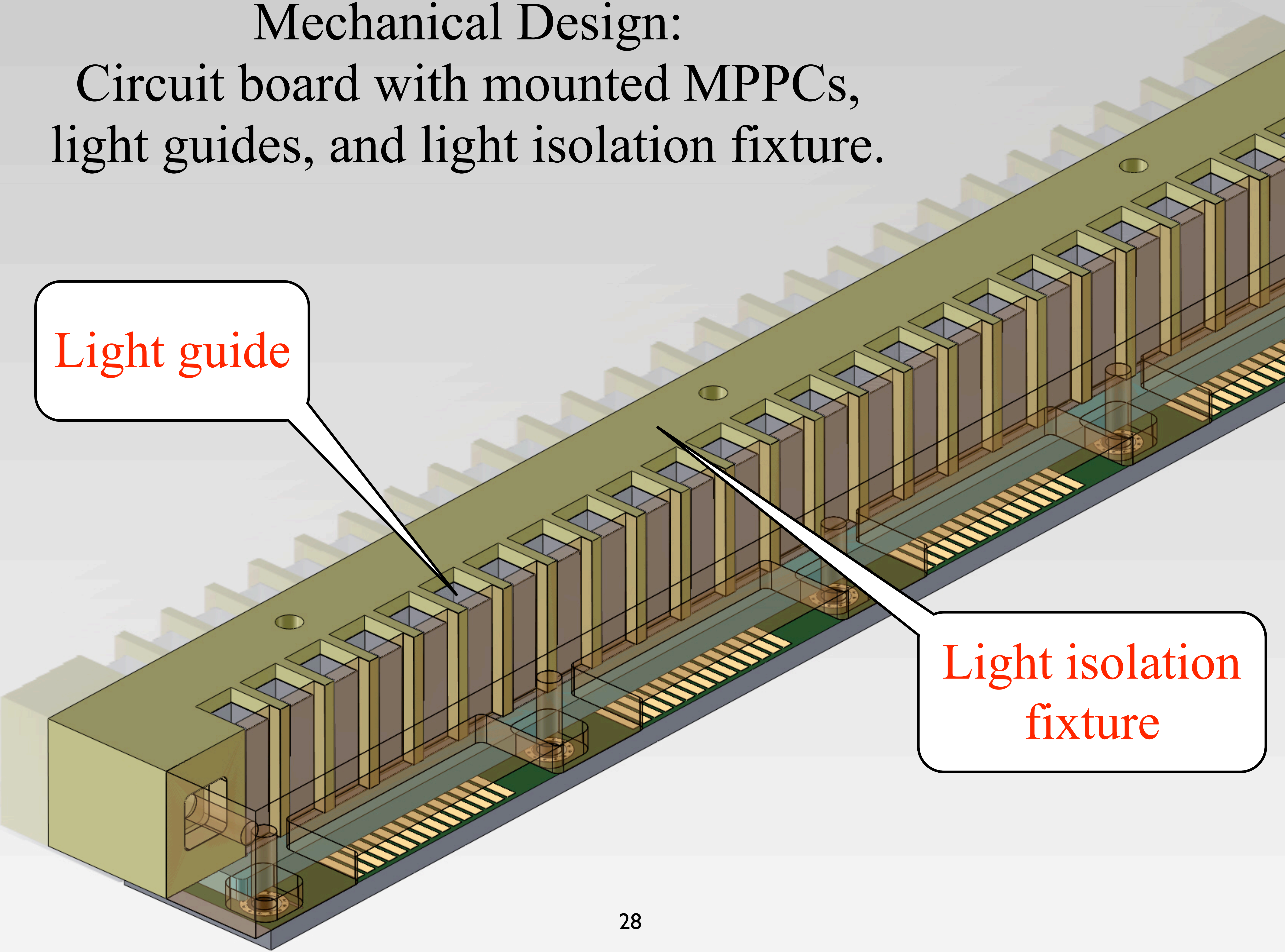


- Circuitboard for MPPCs attached to mounting block

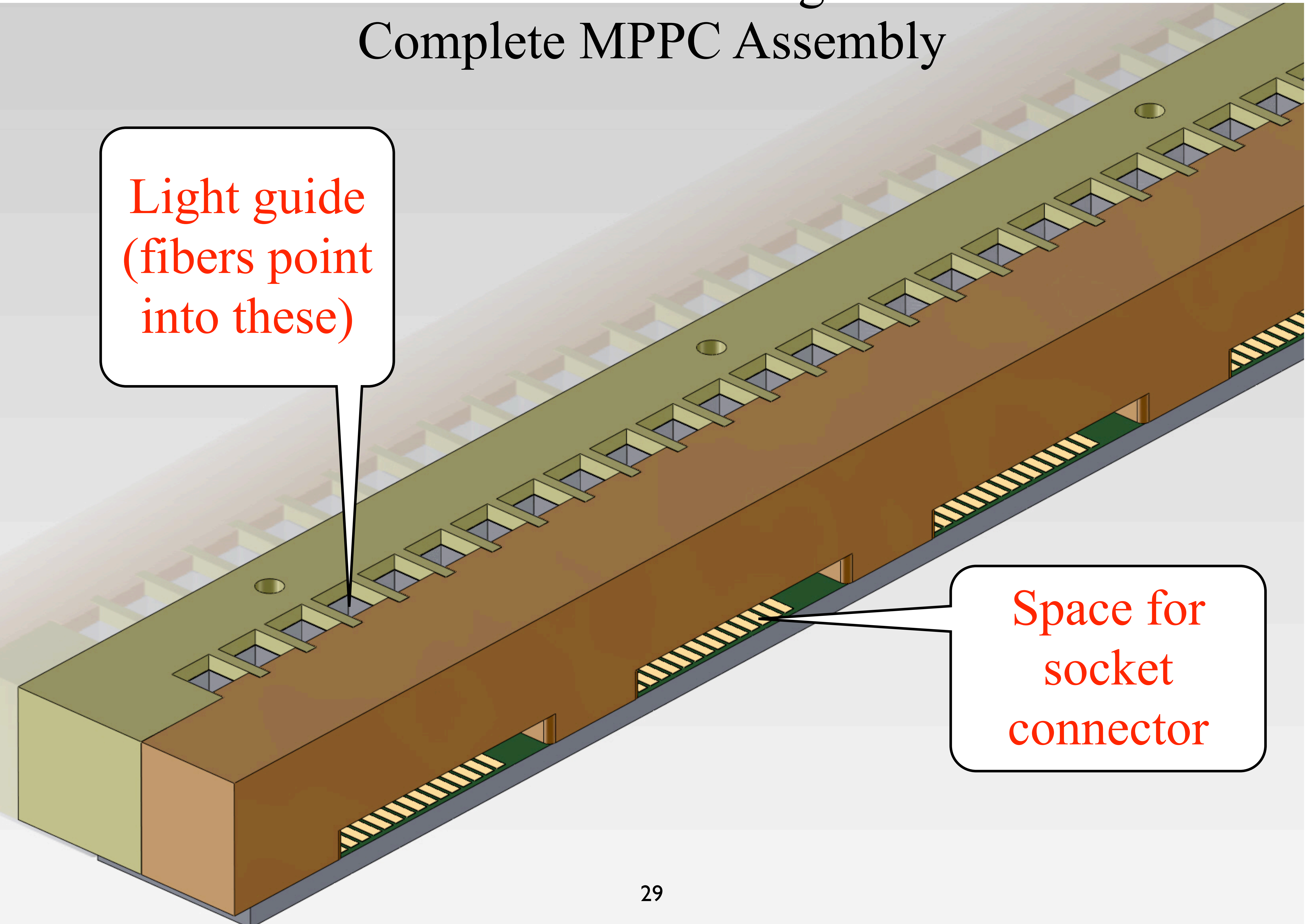
Mechanical Design:
MPPC Board with MPPCs and Lightguides Mounted



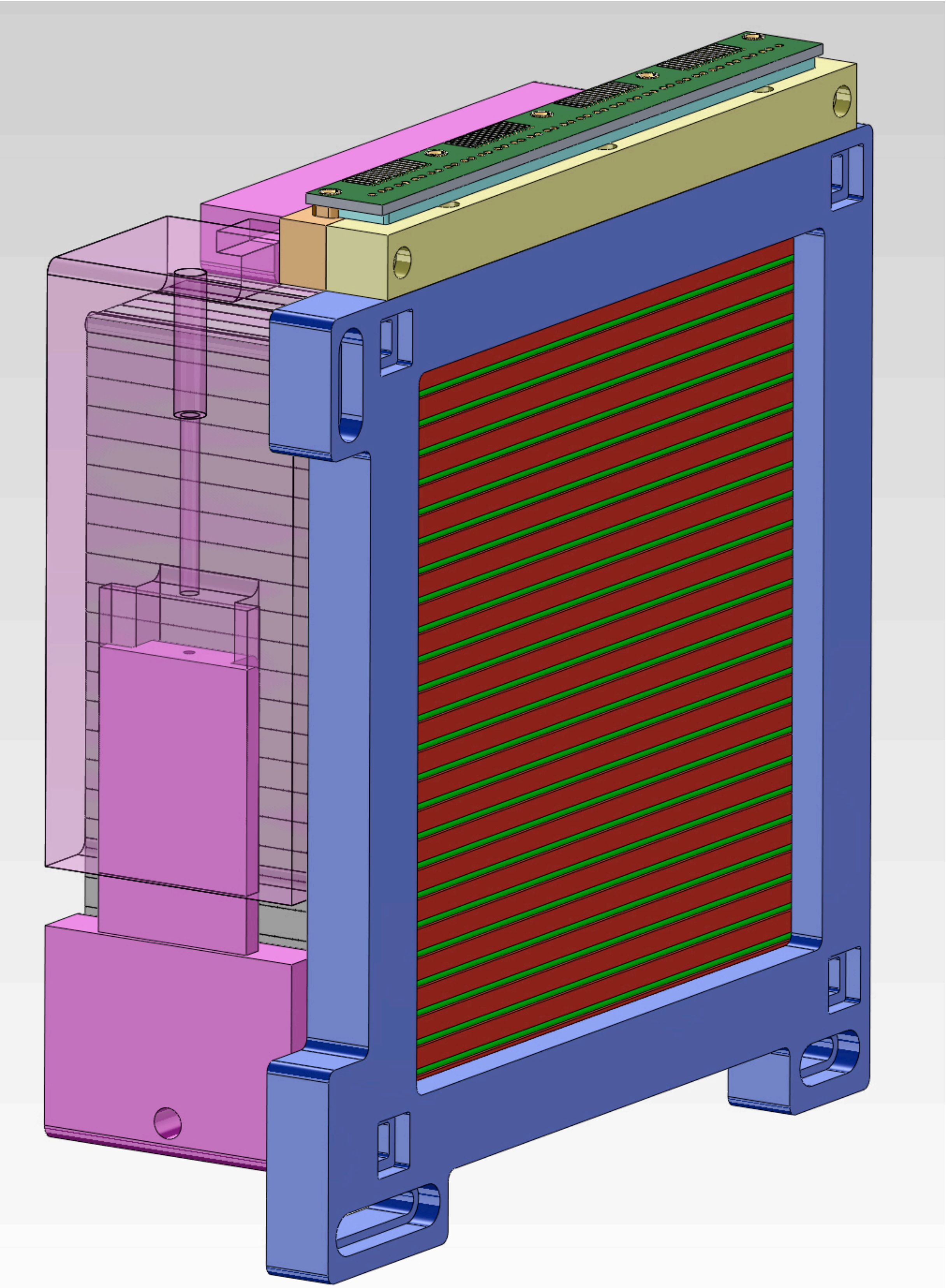
Mechanical Design:
Circuit board with mounted MPPCs, light guides, and light isolation fixture.

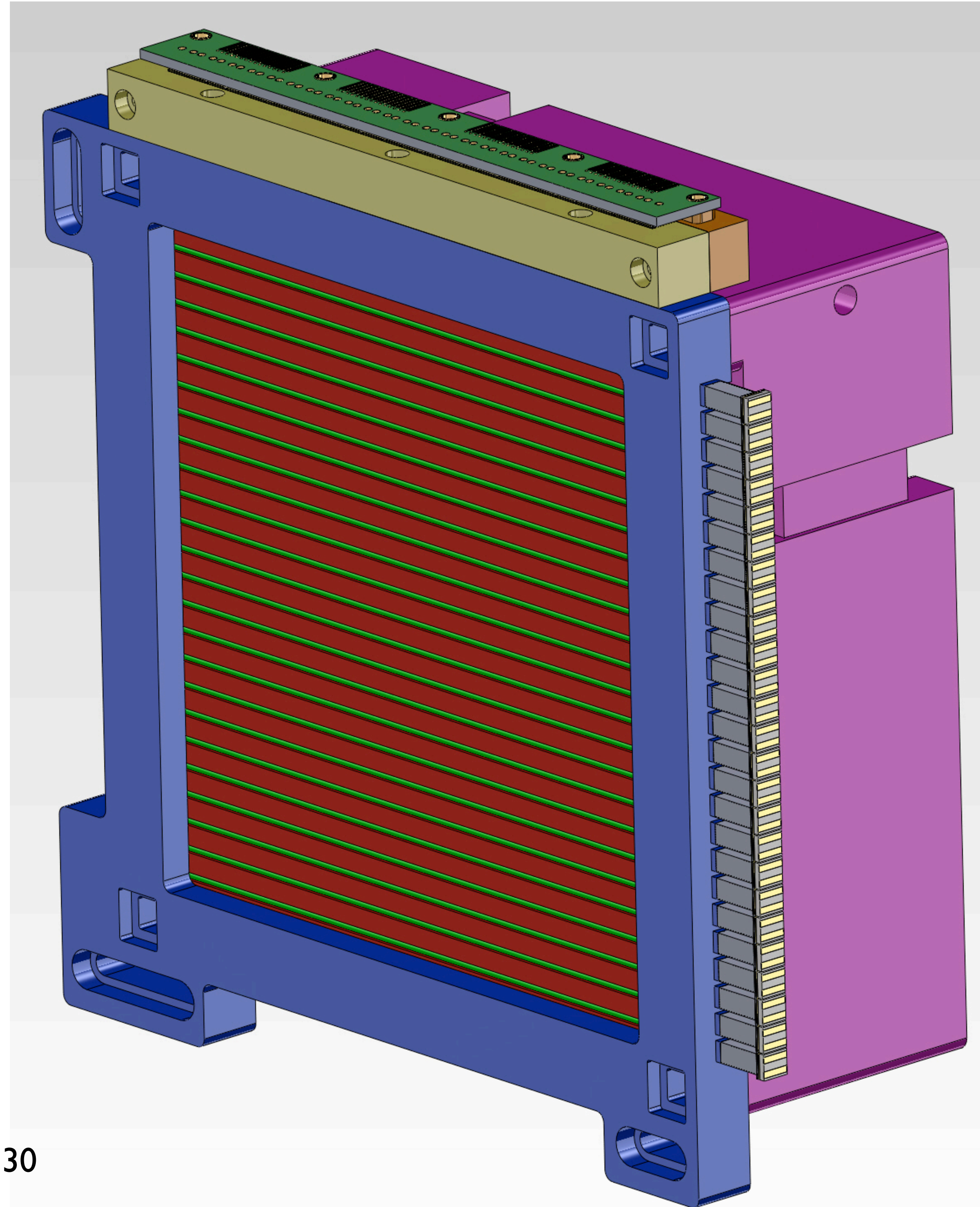


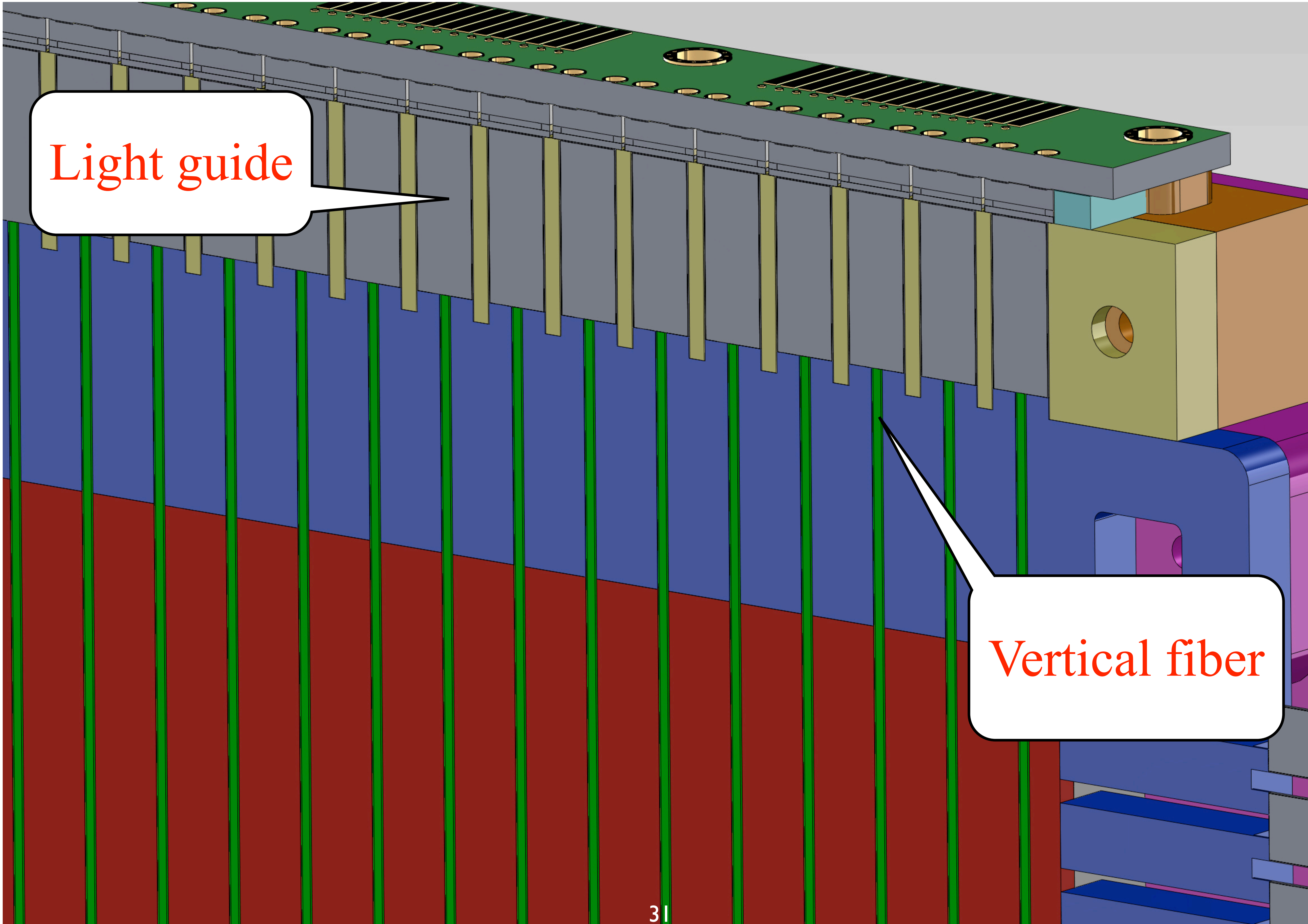
Mechanical Design: Complete MPPC Assembly



Mechanical Design:
MPPC Boards Attached to Fiber Mounting Assembly

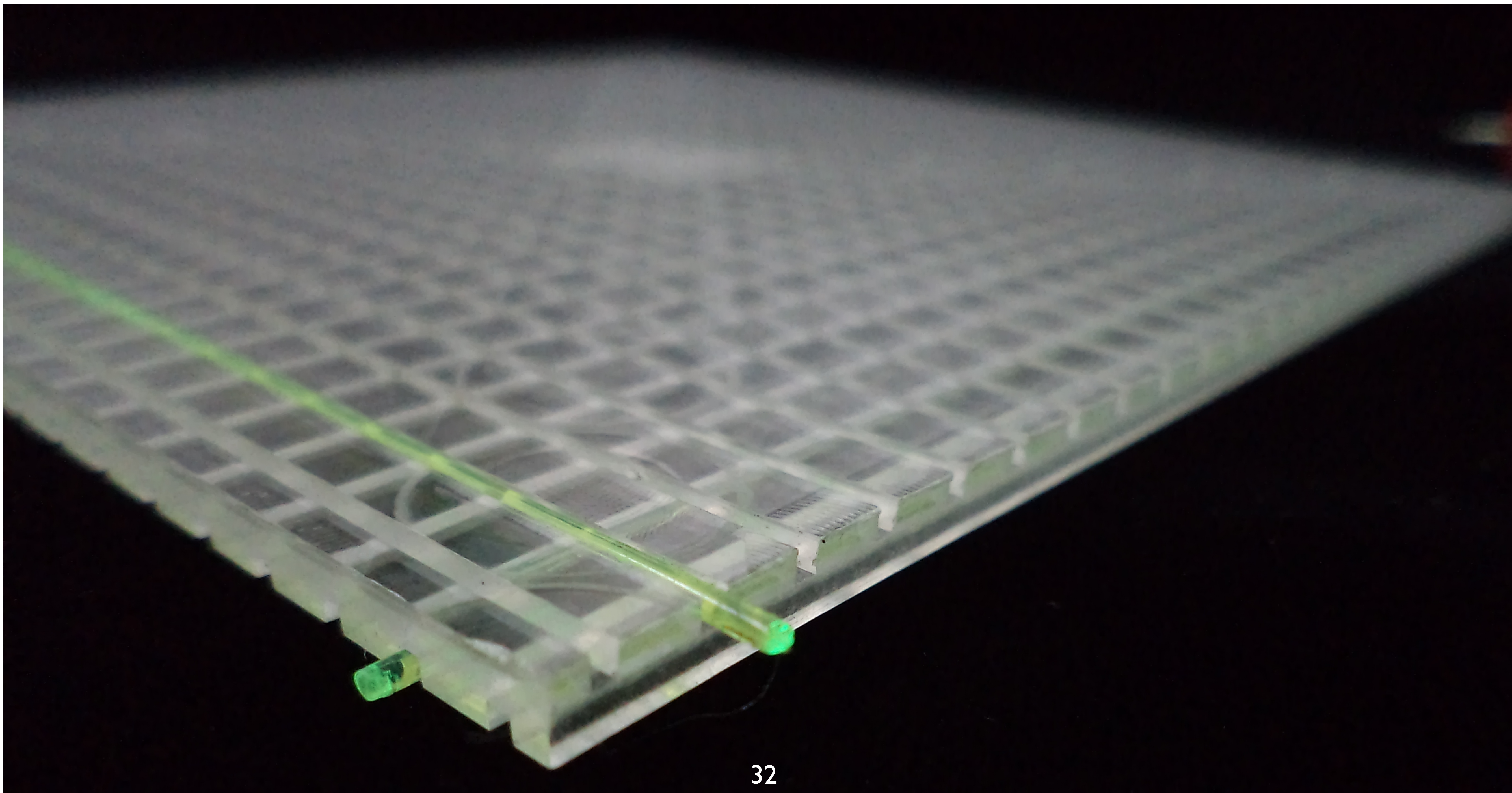




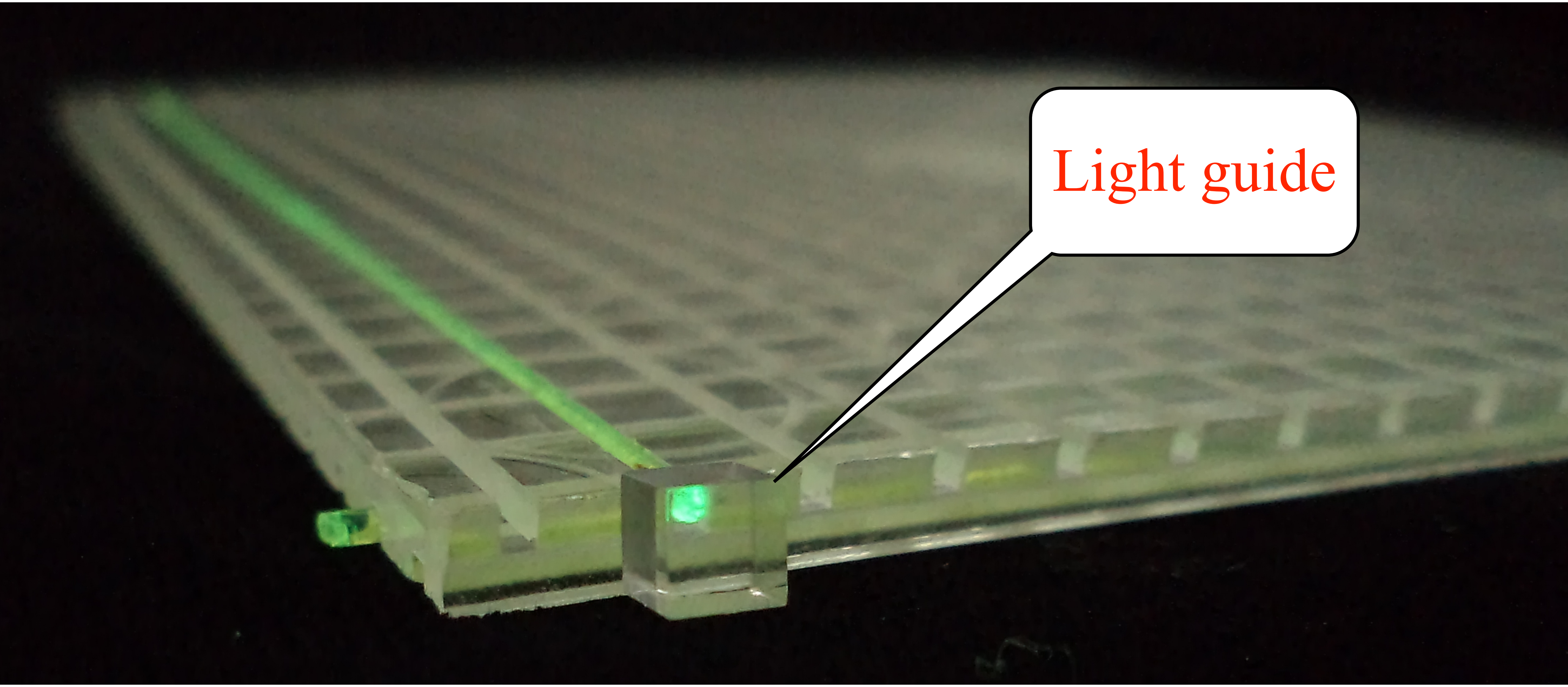

Light guide
Vertical fiber

Example of Fiber Positioning Plate

One X fiber and one Y fiber in place

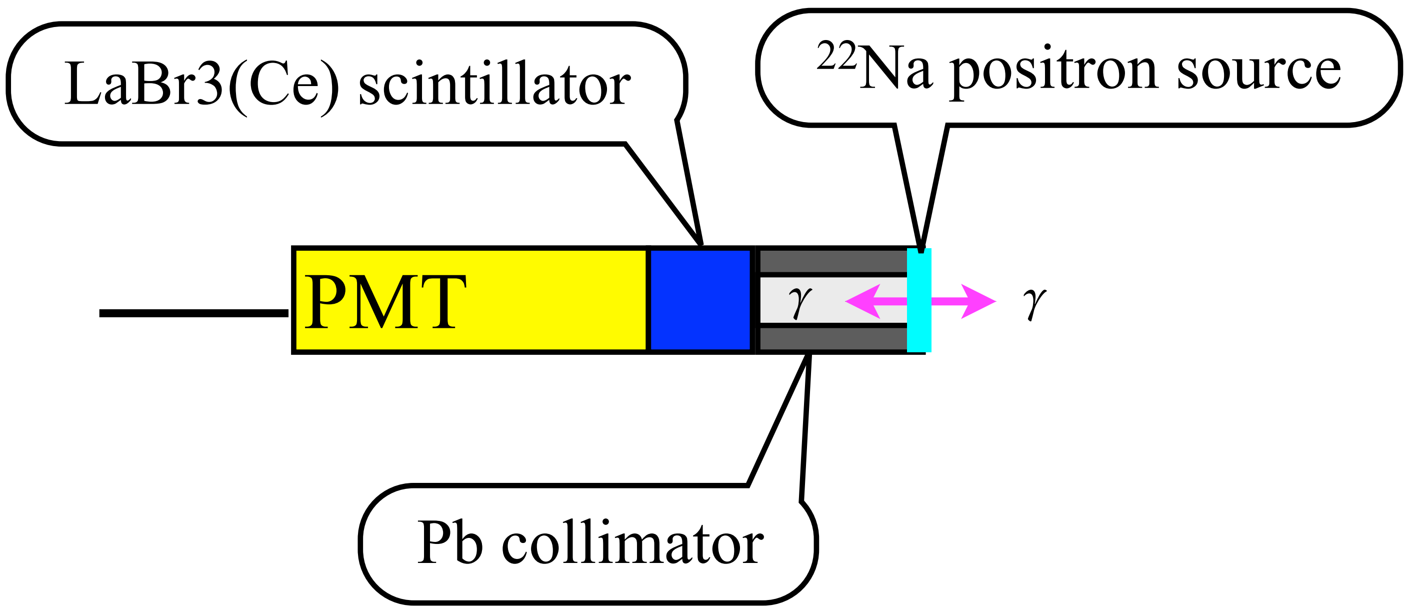


Fiber Light Viewed through Lightguide

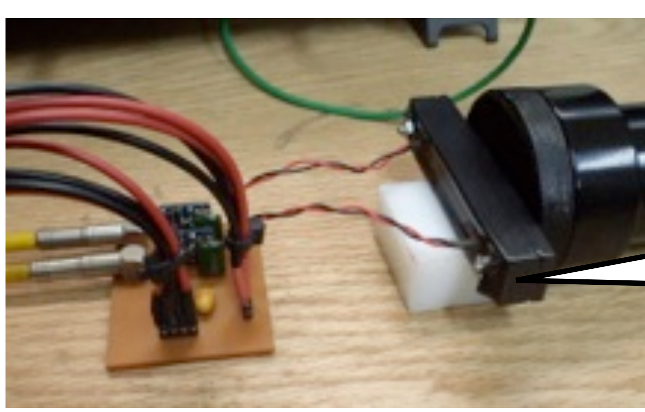


Single-Crystal Measurements

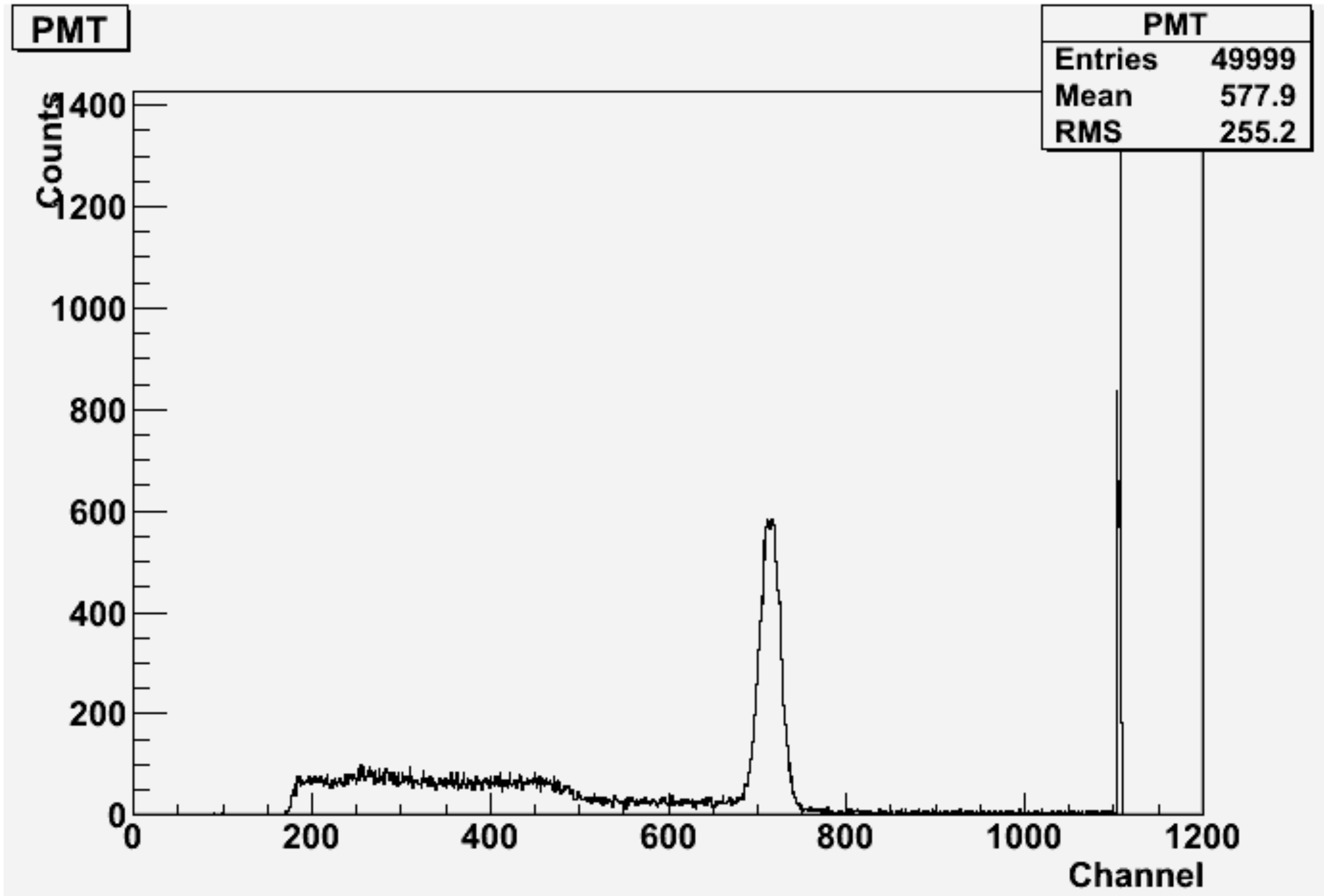
- Main purpose: measure the light attenuation length of a crystal
  - It has been reported as very short in the literature
- As detailed in our December report, we have built two photon tagging modules:



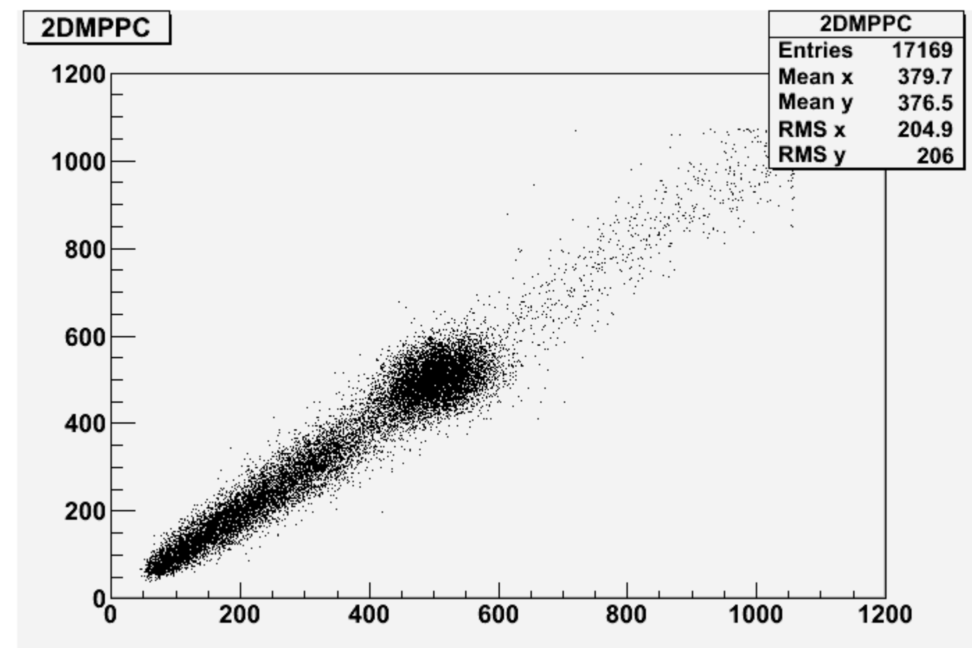
- We have used one of these modules to test a single crystal:



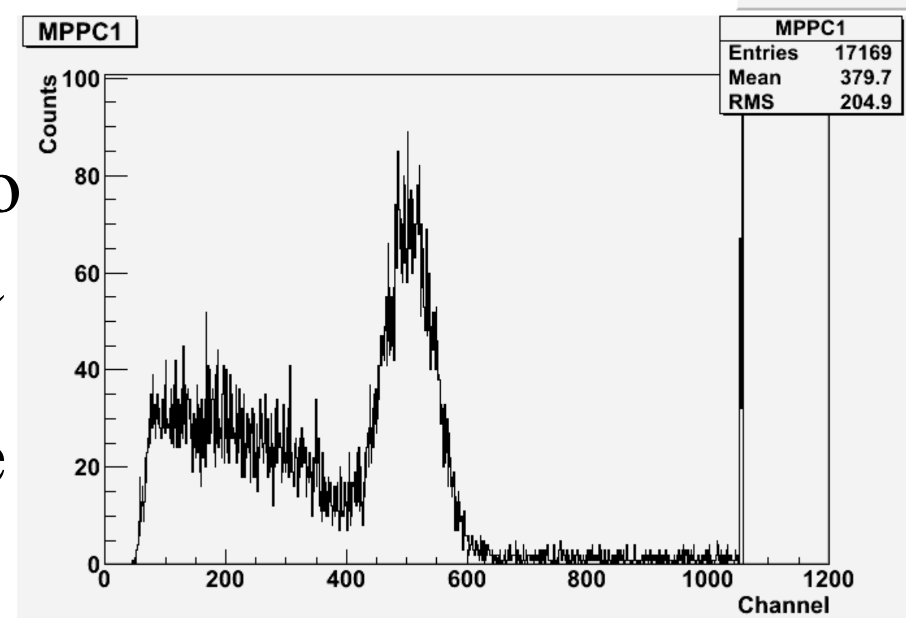
Single crystal housing
Double-sided readout
3-detector coincidence

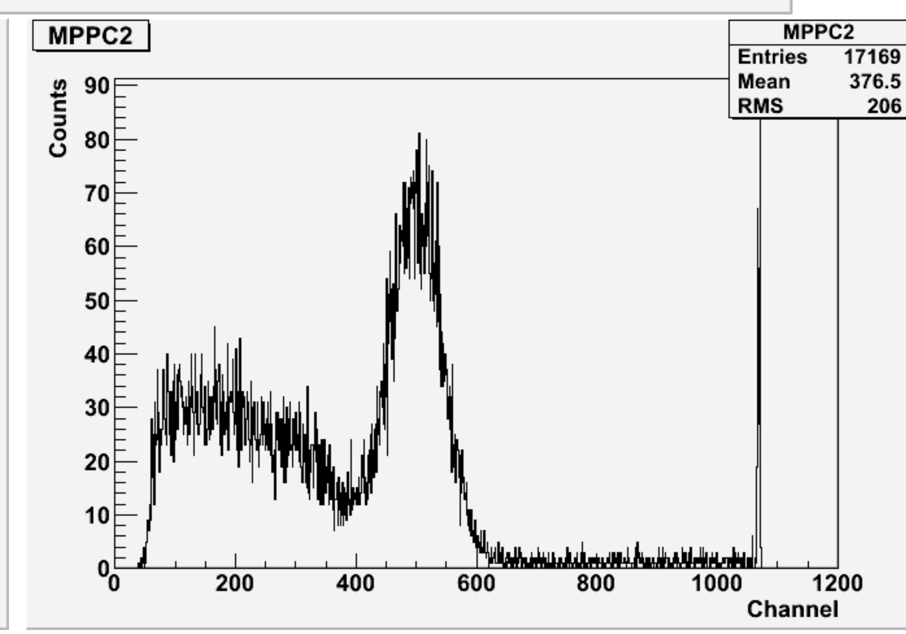


Distribution of signals from the gamma tagger in the case of a triple coincidence: gamma tagger plus both SiPMs on the LYSO crystal. A clear peak is seen, corresponding to the tagged photon.

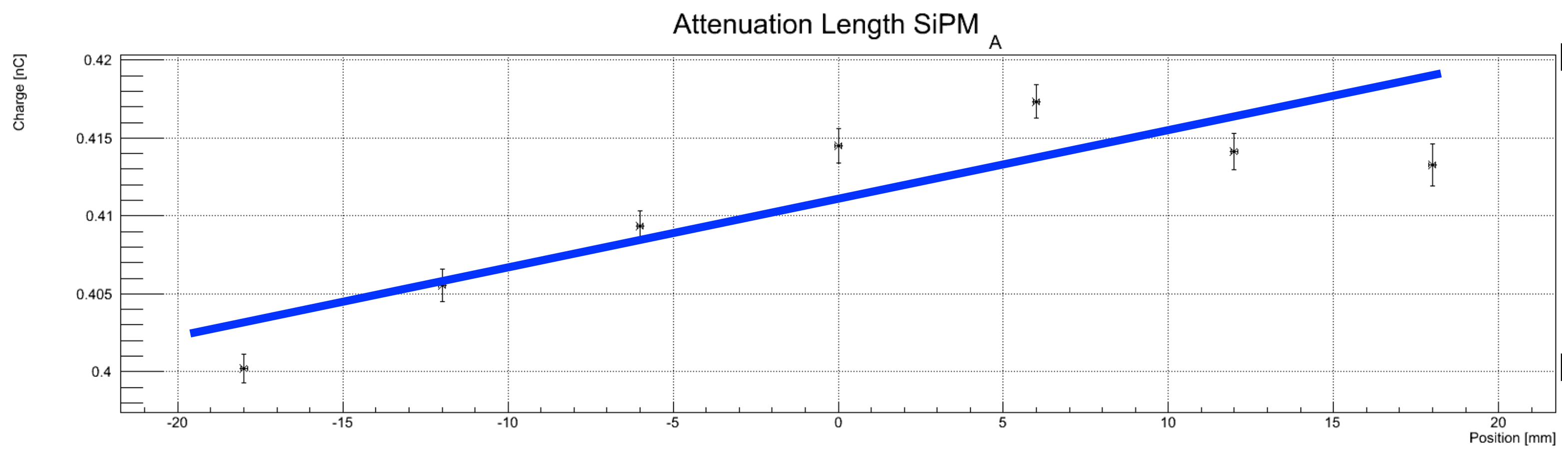


Signals from the two MPPCs in the case of the triple coincidence and also requiring a tagged gamma from the peak shown above. On upper right, the correlation plot between the two MPPCs.

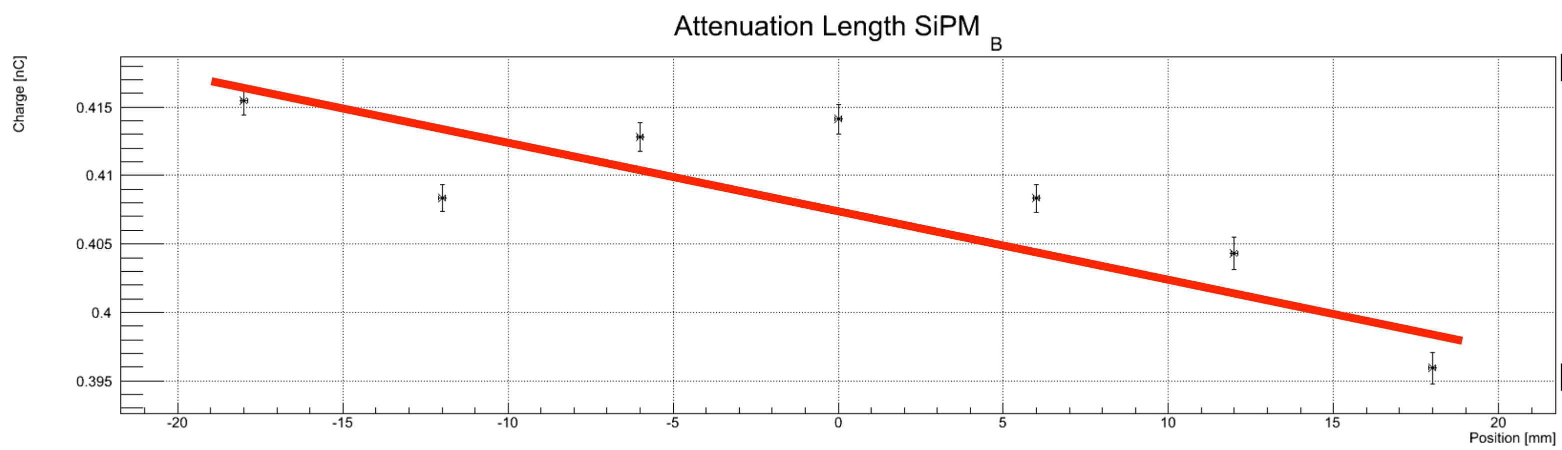




Single-Crystal Measurements: Attenuation lengths

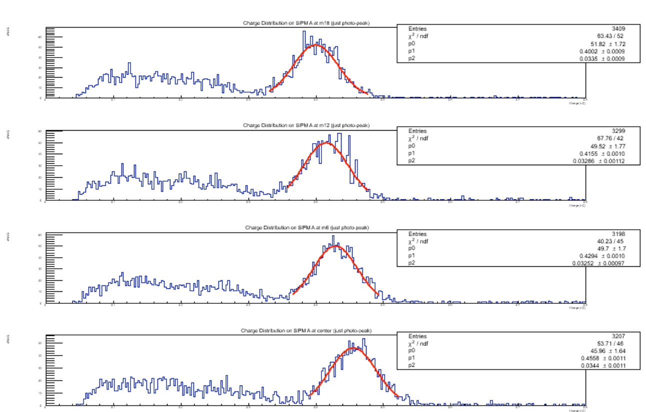


~5%



~5%

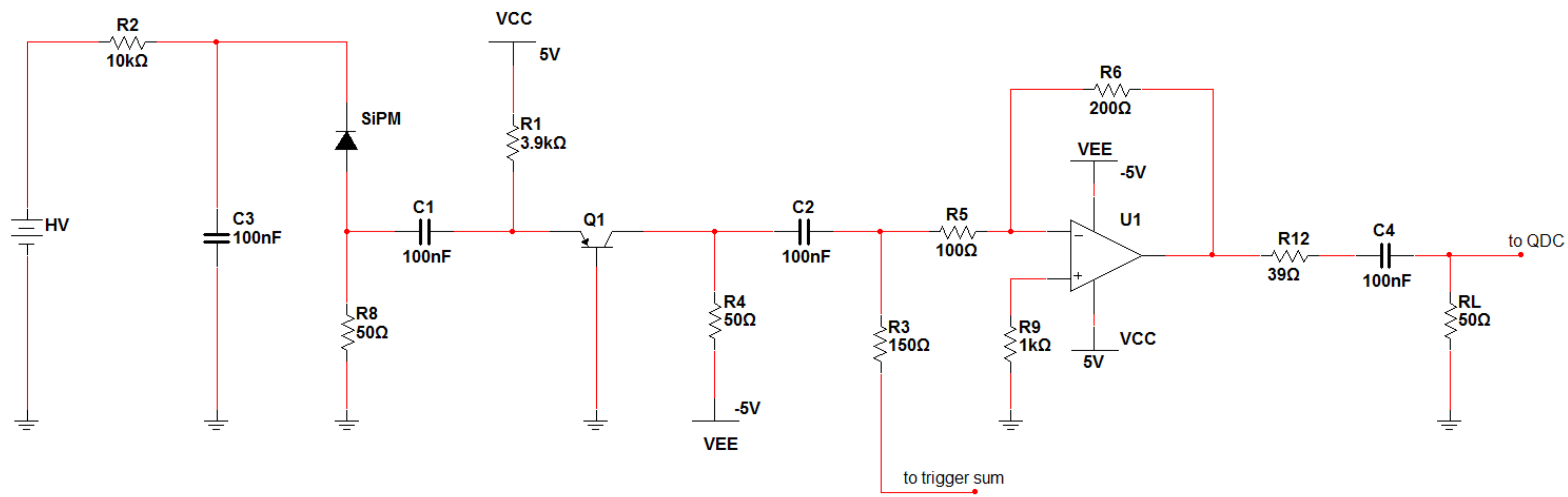
← Position along crystal →



Tagged signals vs. position

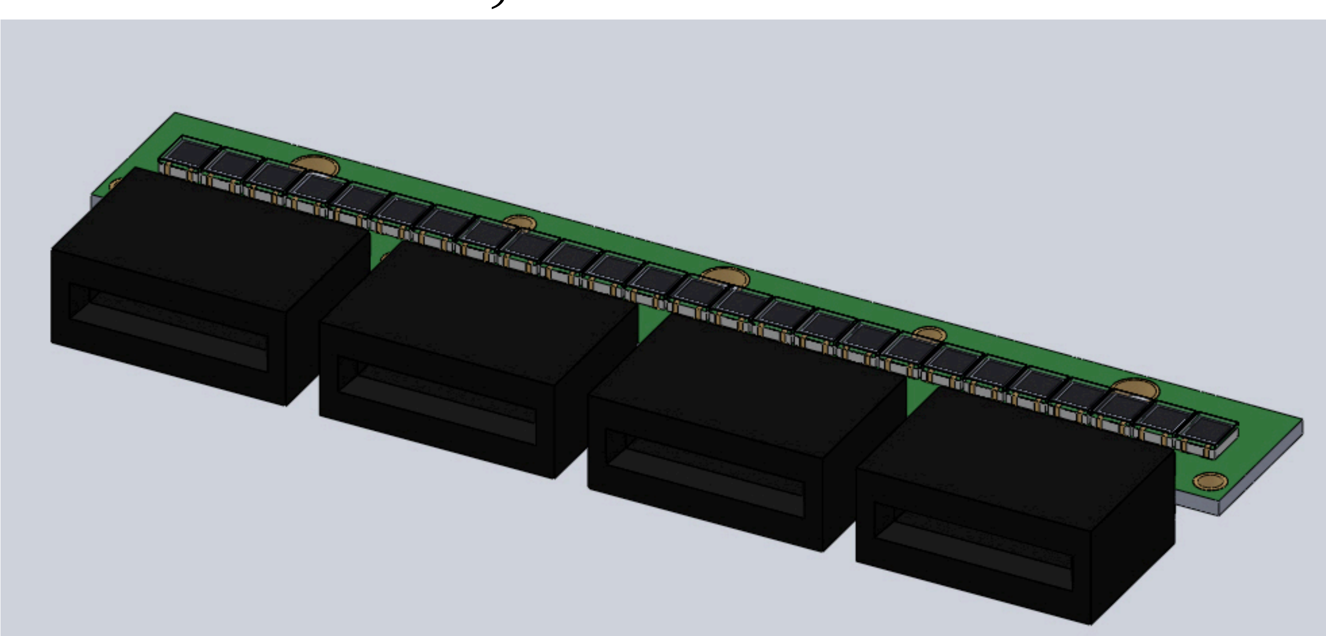
We tested 3 different wrapping materials; no significant dependence

→ attenuation is irrelevant to the design. Good!

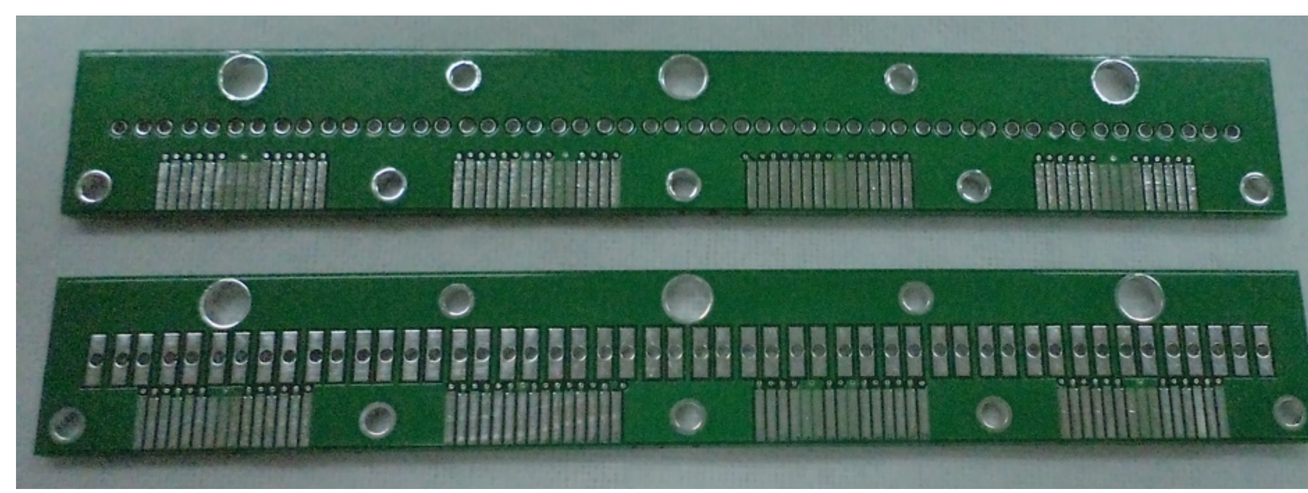


Circuit for amplifying and conditioning the MPPC pulse.

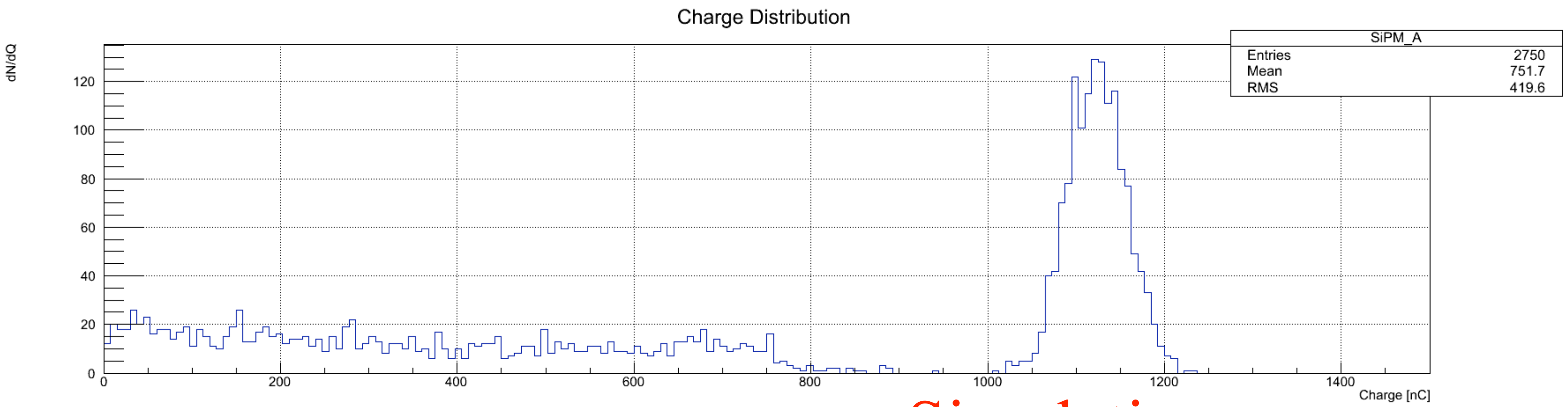
Design for circuit board for 25 MPPCs, with connectors



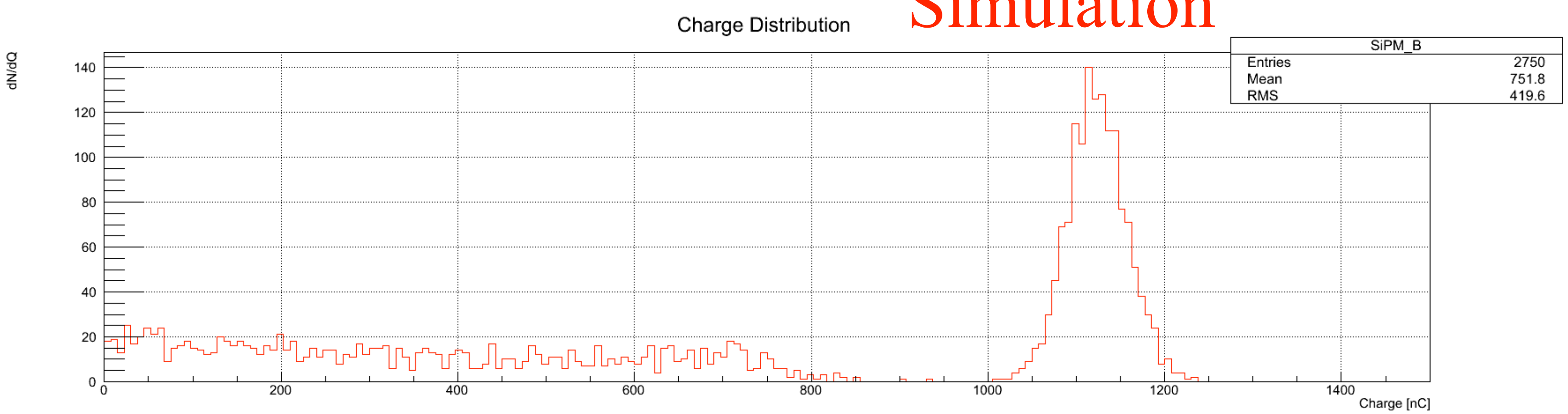
Circuit boards as fabricated (3-layer boards)

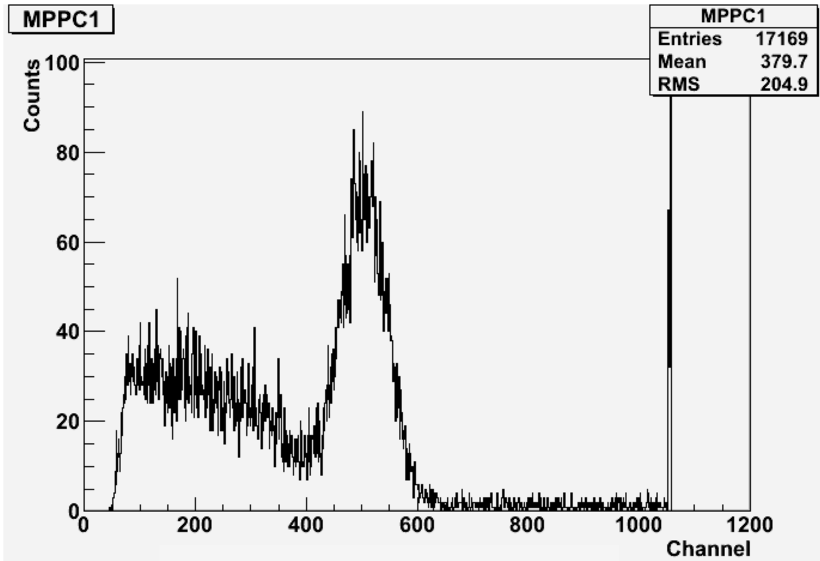


GEANT4 Simulations: Single-Crystal Tests

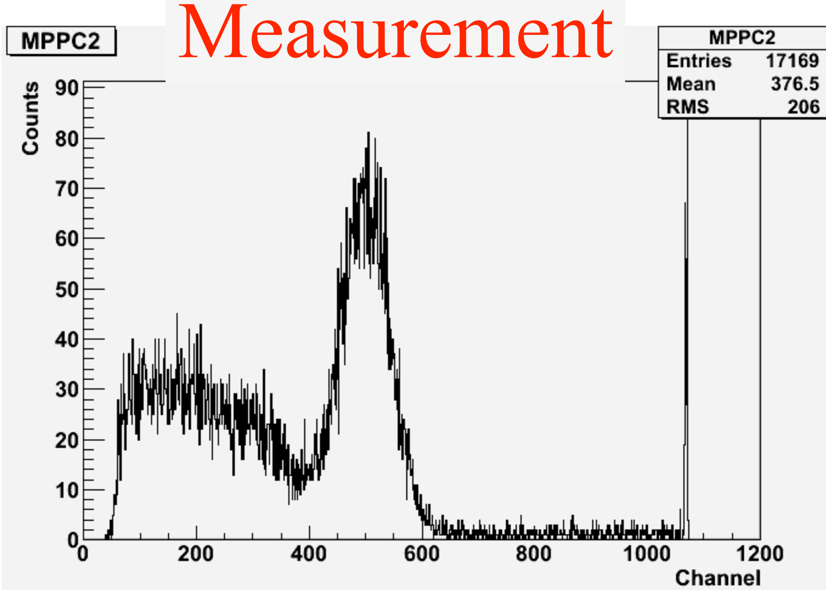


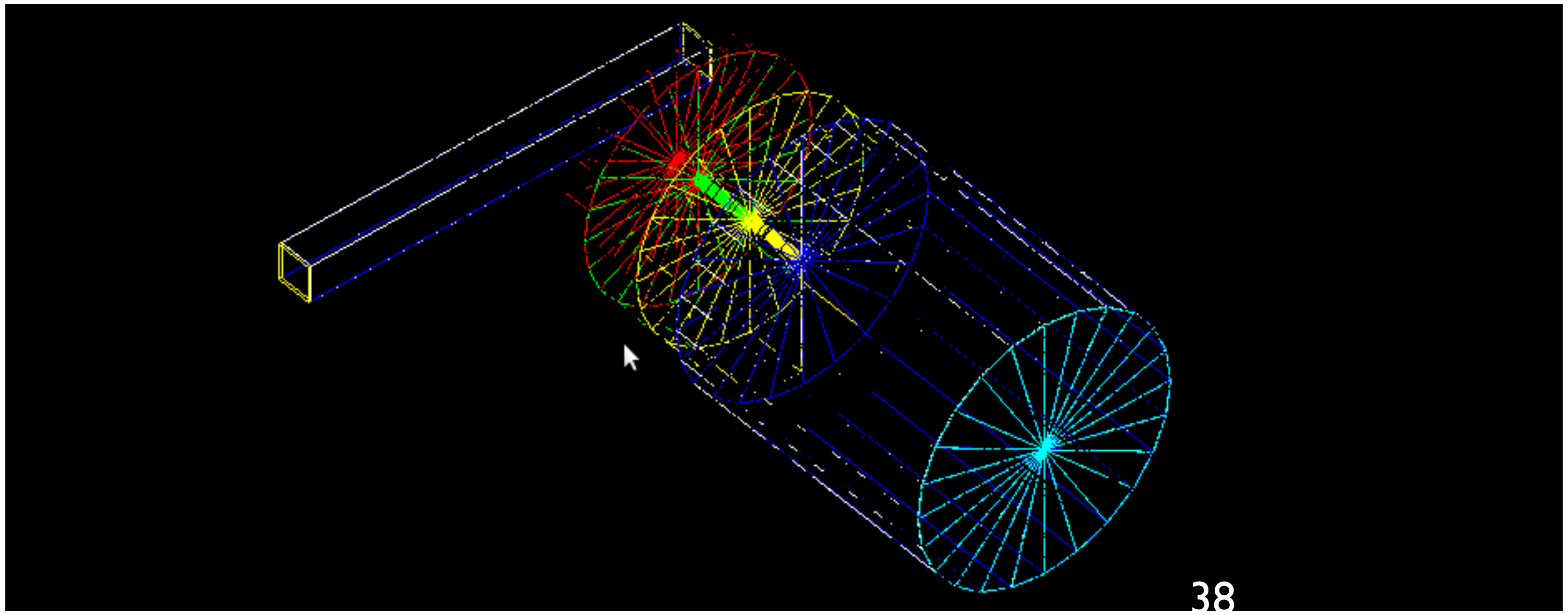
Simulation

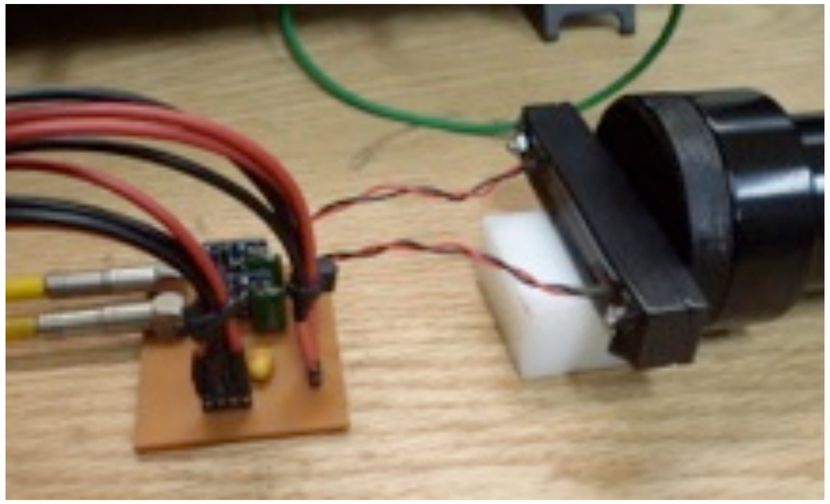




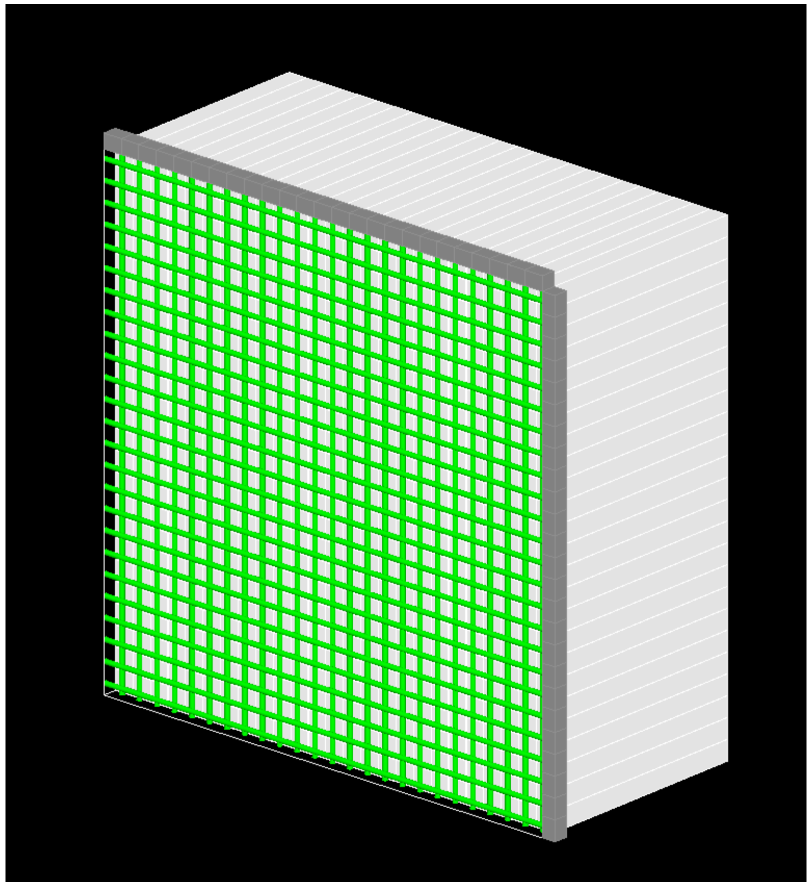
Measurement

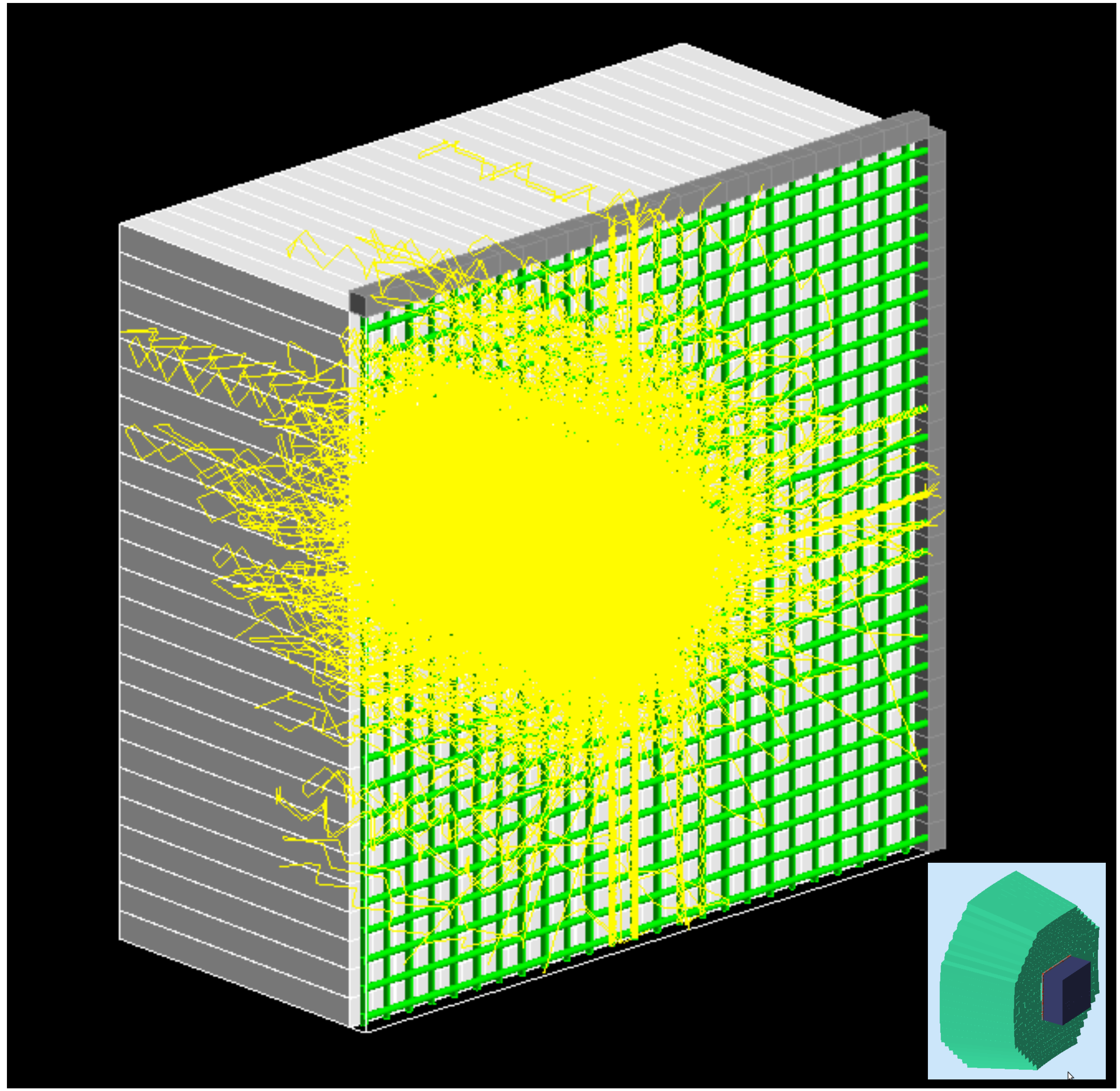






GEANT4 Simulations: Crystal Array





Simulation of an event including light propagation along the crystals and in the fiber lightguide.

Schedule - Long Term

We see this project as "phase 1" of a longer effort that will include:

- Beam test(s); where, when?
- Exploration of tiling options, in simulation and hardware (might mean buying new, shorter crystals)
- Exploration of alternative methods of achieving U, V readout (probably means buying more MPPCs)
- Simulations within larger frameworks
- Follow-up of new ideas that emerge

For phase 1, the timeline depends on the delivery dates of the MPPCs. They are scheduled to arrive this month (June).

Previous comments from the committee

“The Committee notes, that the layout of the crossing fibers still may have to be optimized (minimize shadowing of the fibers) and that a conceptual design for tiling is missing. The question of ambiguities has not been addressed and it is unclear if the concept can be developed into a large area pre-shower detector. Furthermore, the concept of "3D spatial resolution" has not been explained and is not understood. The group is encouraged to revisit their priorities with more emphasis on the performance of the concept in a real physics environment with emphasis on the shower separation in the presence of ambiguities. This should reference the more general detector requirements noted above under General Remarks. The development of a realistic tiling design that minimizes dead space for realistic EIC running conditions is encouraged.The Committee notes that a timeline for the R&D is missing.”

Crystal Materials, 1

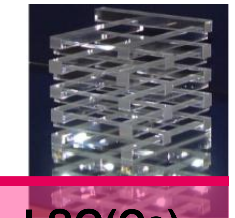
- Cerium-doped Silicate Yttrium Lutetium Crystal (Ce:LYSO)
- Lutetium Oxyorthosilicate (LSO)
- Naturally occurring lutetium (Lu) is composed of 1 stable isotope ^{175}Lu (97.41% natural abundance) and one long-lived radioisotope, ^{176}Lu with a half-life of 3.78×10^{10} years (2.59% natural abundance).

nuclide symbol	Z(p)	N(n)	isotopic mass (u)	half-life[n 1]	decay mode(s)[1][n 2]	daughter isotope(s)[n 3]	nuclear spin	representative isotopic composition (mole fraction)
	excitation energy							
^{175}Lu	71	104	174.9407718(23)	Observationally Stable[n 4]			7/2+	0.9741(2)
^{175m1}Lu	1392.2(6) keV			984(30) μs			(19/2+)	
^{175m2}Lu	353.48(13) keV			1.49(7) μs			5/2-	
^{176}Lu[n 5][n 6]	71	105	175.9426863(23)	**38.5(7)×10^{9} a**	β^-	**^{176}Hf**	7-	0.0259(2)
^{176m}Lu	122.855(6) keV			3.664(19) h	β^- (99.9%)	**^{176}Hf**	1-	
					EC (.095%)	**^{176}Yb**		

Crystal Materials, 2

- LSO/LYSO is a bright (200 times PWO), fast (40 ns) and radiation hard crystal scintillator. The light output loss of 20 to 28 cm long crystals is at a level of 10% after 1 Mrad γ–ray irradiation, much better than all other crystal scintillators. (See talk presented at Calor2012, Santa Fe, by Ren-Yuan Zhu, Caltech)

Crystals for HEP Calorimeters



Crystal	NaI(Tl)	CsI(Tl)	CsI(Na)	CsI	BaF_2	CeF_3	BGO	PWO(Y)	LSO(Ce)
Density (g/cm^3)	3.67	4.51	4.51	4.51	4.89	6.16	7.13	8.3	7.40
Melting Point (°C)	651	621	621	621	1280	1460	1050	1123	2050
Radiation Length (cm)	2.59	1.86	1.86	1.86	2.03	1.70	1.12	0.89	1.14
Molière Radius (cm)	4.13	3.57	3.57	3.57	3.10	2.41	2.23	2.00	2.07
Interaction Length (cm)	42.9	39.3	39.3	39.3	30.7	23.2	22.8	20.7	20.9
Refractive Index [a]	1.85	1.79	1.95	1.95	1.50	1.62	2.15	2.20	1.82
Hygroscopicity	Yes	Slight	Slight	Sligh t	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420	420 310	300 220	340 300	480	425 420	402
Decay Time [b] (ns)	245	1220	690	30 6	650 0.9	30	300	30 10	40
Light Yield [b,c] (%)	100	165	88	3.6 1.1	36 4.1	7.3	21	0.3 0.1	85
d(LY)/dT [b] (%/ °C)	-0.2	0.4	0.4	-1.4	-1.9 0.1	0	-0.9	-2.5	-0.2
Experiment	Crystal Ball	BaBar BELLE BES III	-	KTeV	(L*) (GEM) TAPS	-	L3 BELLE	CMS ALICE PANDA	Mu2e SuperB CMS?

a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

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Wavelength Shifting Fibers

Formulations

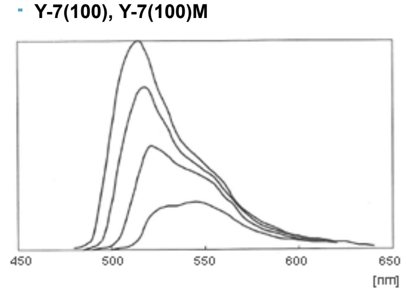
Description	Emission			Att. Leng.[2)][m]	Characteristics
	Color	Peak [nm]	Spectra		
Y-7(100), Y-7(100)M	green	490	See the following figure	>3.0	Green Shifter
Y-8(100), Y-8(100)M	green	511		>2.8	Green Shifter
Y-11(200), Y-11(200)M	green	476		>3.5	Green Shifter (K-27 formulation)
O-2(100), O-2(100)M	orange	538		>1.5	Green to Orange Shifter

1) Test fibers are Non-S type, 1mmΦ.
2) Measured by using bialkali PMT and blue LED(445nm).
Otherwise than descriptions mentioned above, various WLS fibers are available.
Ex. R-3(green to red shifter, peak is 607nm), Y-9(blue to green shifter, 485nm), B-1(428nm), B-2(437nm).

Technical Data

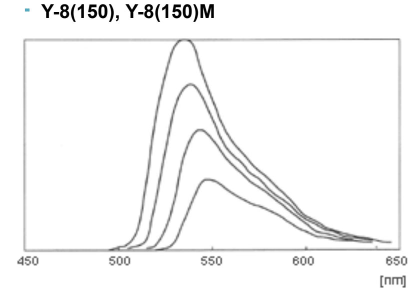
Emission Spectra

- Y-7(100), Y-7(100)M



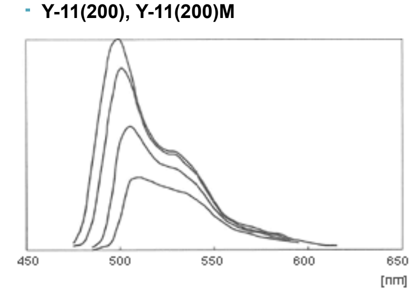
Exiting Wavelength: 440nm

- Y-8(150), Y-8(150)M



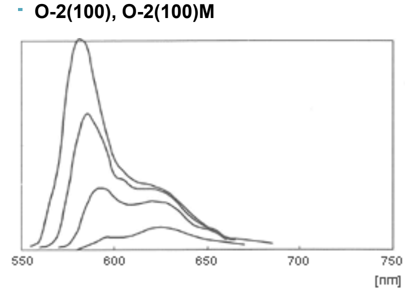
Exiting Wavelength: 455nm

- Y-11(200), Y-11(200)M



Exiting Wavelength: 430nm

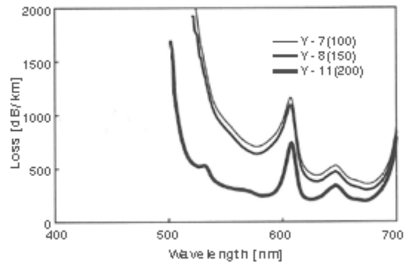
- O-2(100), O-2(100)M



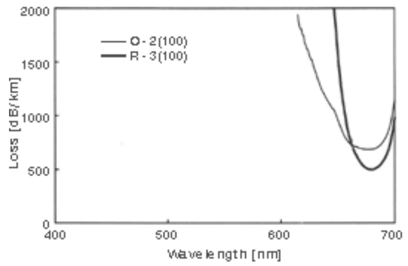
Exiting Wavelength: 430nm

Transmission Loss

- Y-7, Y-8,Y-11



- O-2, R-3



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PreLude® 420

It's what's Inside that Counts!

Scintillation Material

PreLude™ 420 ($Lu_{1.8}Y_{.2}SiO_5$:Ce) is a Cerium doped lutetium based scintillation crystal that offers high density and a short decay time. It has an improved light output and energy resolution compared to BGO ($Bi_4Ge_3O_{12}$), which has a similar density. Applications that require higher throughput, better timing and better energy resolution will benefit from using PreLude 420 material.

PreLude 420 scintillator has shown up to three to four times the light emission of BGO. The measured energy resolution for 662 keV photons for a 30mm diameter x 15mm long crystal is 7.1% (see the energy spectrum below). A typical value for BGO is 12%.

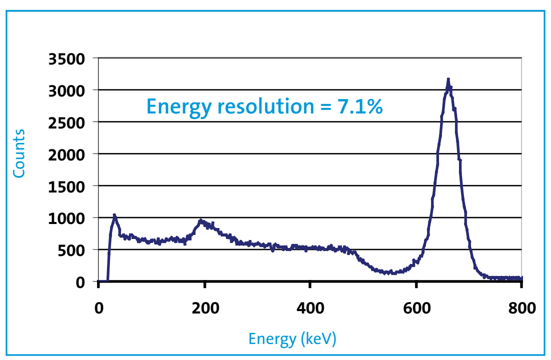


Figure 2. PreLude™ 420 Response to 662 keV Photons

The 1/e decay time of PreLude 420 crystal is 41ns, which is much shorter than the decay time of BGO. It is a single exponential with no long components present. This allows for higher rates, greater throughput and better timing.

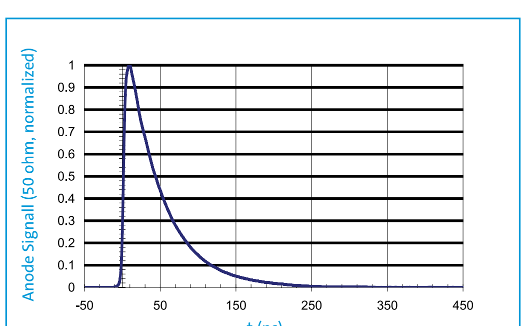


Figure 2. PreLude™ 420 response to 511 keV with R3241 PMT

The emission of scintillation light matches well with the sensitivity spectrum of most PMTs. The quantum efficiency (Q.E.) of a standard bialkali ETI 9266 PMT is 25% at the peak of the emission.

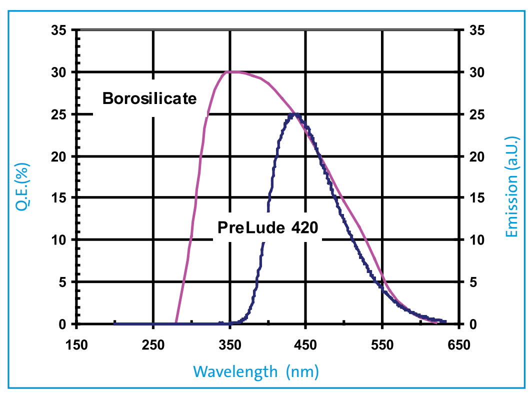


Figure 3. PreLude™ 420 Emission & ETI 9266 Q.E. (Q.E. data courtesy of Electron Tubes, Inc.)

PET applications have traditionally used arrays of BGO. PreLude 420 crystal competes directly on density and surpasses BGO on energy resolution, timing and throughput.

The PreLude 420 material is a lutetium-based scintillator which contains a radioactive isotope ^{176}Lu, a naturally occurring beta emitter. ^{176}Lu beta decays to ^{176}Hf 99.66% of the time to the 597 keV excited state. This state decays with a 3 gamma ray cascade of 307, 202 and 88 keV. The 1" diameter by 1" long PreLude 420 crystal absorbs

Properties	
Density [g/cm^3]	7.1
Hygroscopic	no
Attenuation length for 511keV (cm)	1.2
Energy resolution [%]	8.0
Wavelength of emission max [nm]	420
Refractive index @ emission max.	1.81
Decay time [ns]	41
Light yield [photons/keVγ]	32
Average temperature coefficient from 25 to 50° C (%/°C)	-0.28
Photoelectron yield [% of NaI(Tl)] (for γ-rays)	75

SAINT-GOBAIN CRYSTALS

USA

Saint-Gobain Crystals
17900 Great Lakes Parkway
Hiram, OH 44234
Tel: (440) 834-5600
Fax: (440) 834-7680

Europe

Saint-Gobain Crystals
104 Route de Larchant
BP 521
77794 Nemours Cedex, France
Tel: 33 (1) 64 45 10 10
Fax: 33 (1) 64 45 10 01

P.O. Box 3093
3760 DB Soest
The Netherlands
Tel: 31 35 60 29 700
Fax: 31 35 60 29 214

Japan

Saint-Gobain KK, Crystals Division
3-7, Kojimachi, Chiyoda-ku,
Tokyo 102-0083 Japan
Tel: 81 (0) 3 3263 0559
Fax: 81 (0) 3 5212 2196

China

Saint-Gobain (China) Investment Co, Ltd
15-01 CITIC Building
19 Jianguomenwai Ave.
Beijing 100004 China
Tel: 86 (0) 10 6513 0311
Fax: 86 (0) 10 6512 9843

India

Saint-Gobain Crystals and Detectors
Sy. No. 171/2, Maruthi Industrial Estate
Hoody Rajapalya, Whitefield Main Road
Bangalore 560048 India
Tel: 91 80 42468989

nearly 100% of the beta particles. However, some of the photons escape leading to four sets of beta+gamma distributions. These four sets of beta distributions, based on which gamma rays are detected in coincidence, are identified in Figure 4. The total rate for this activity is 39 cps/g.

The light yield as a function of temperature was measured with ^{137}Cs excitation at two amplifier shaping times of 1µs and 12µs. The temperature of the PMT was maintained constant while the temperature of the scintillator was varied from -65°C to +175°C. Results are shown in Figure 5.

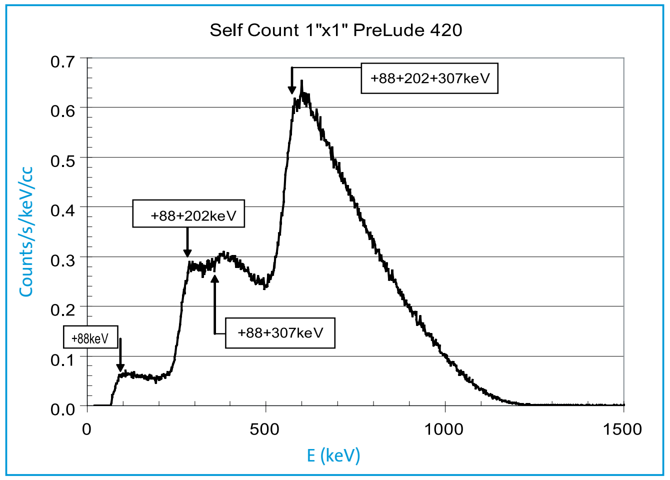


Figure 4. **Beta distributions**

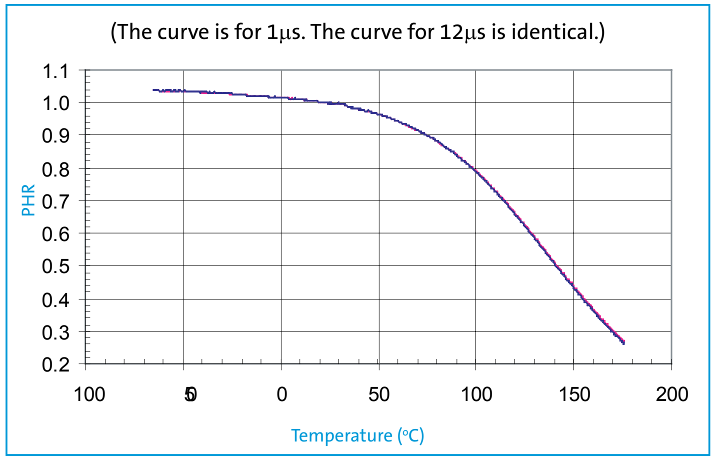
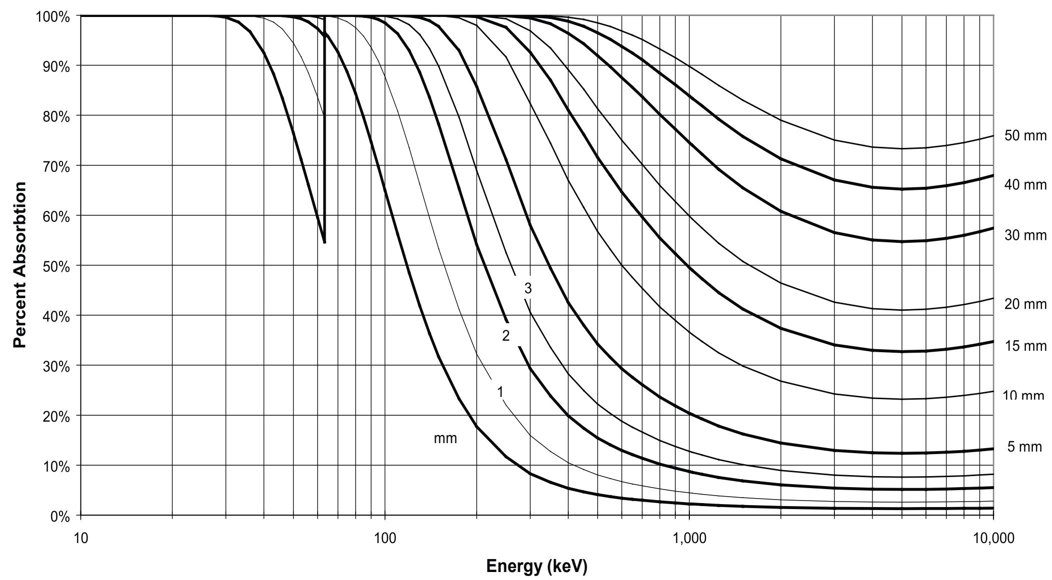


Figure 5. **Temperature response**



Absorption Efficiency of PreLude®420

Figure 6. Gamma and X-ray absorption efficiency for various thicknesses of PreLude 420 material. Data compiled by C. M. Rozsa (presented in Saint-Gobain Crystals brochure "Efficiency for Selected Scintillators.")

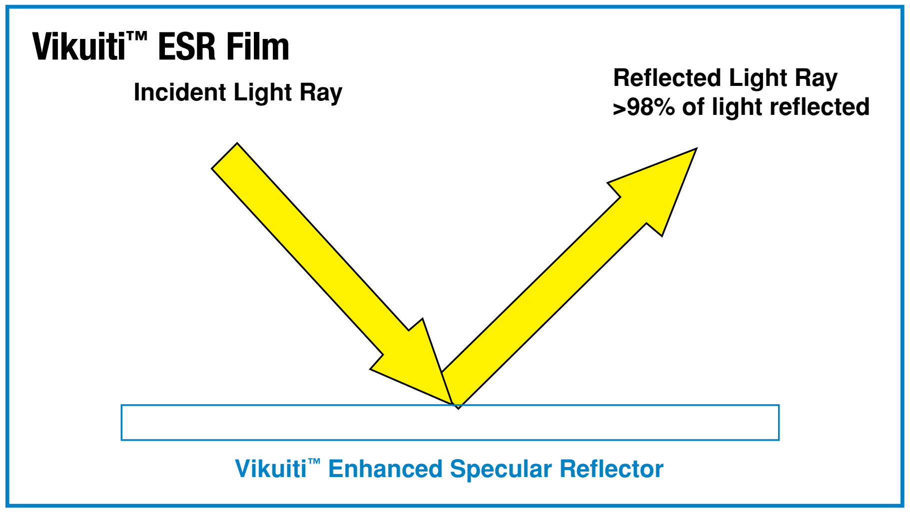
Table comparing principal properties of PreLude™ 420 versus BGO and LSO

Property	PreLude 420	BGO	LSO
Density [g/cm³]	7.1	7.1	7.4
Attenuation length for 511 keV (cm)	1.2	1.0	1.15
Decay time [ns]	41	300	40
Energy resolution	8.0	12.0	10.0
Light output, photons per keV	32	9	26
Average temperature coefficient 25 to 50°C (%/°C)	-0.28	-1.2	-1.3

Vikuiti™ Enhanced Specular Reflector (ESR)

How it works

Vikuiti™ Enhanced Specular Reflector (ESR) utilizes multi-layer optical film technology to create a highly efficient, specular reflector. Vikuiti ESR can be used alone or combined with other Vikuiti™ Display Enhancement Films for even greater performance improvement.

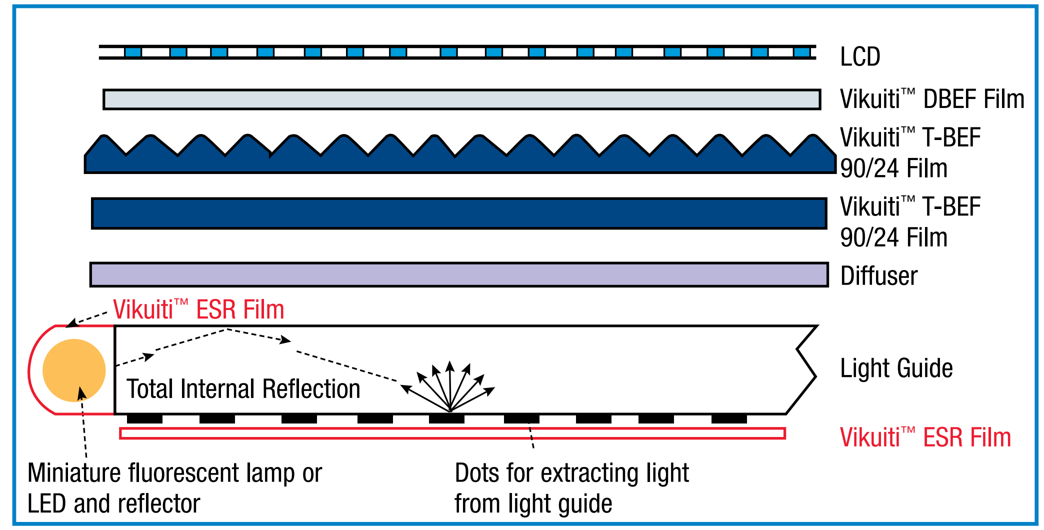


Nominal film properties

Film properties	Vikuiti™ ESR Film
Reflectance	>98%
Physical Characteristics	
• Thickness (microns)	65µm (2.6 mils)
• Shrinkage (15 minutes @ 150°C)	<1%
• Specific Gravity	1.29

The technical data for the products are typical, based on information accumulated during their life, and are not to be used in the generation of purchase specifications which define property limits rather than typical performance.

Vikuiti™ ESR Film in a typical LCD



Product Size Offering

- Custom Sizes—Converted to Customer Sizes
- Product Kits—30 Sheets 11″ x 11″