A pre-shower detector for forward electromagnetic calorimeters

Status report

June 2013

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Outline

- Overview
- Participating staff
- Mechanical design
- Mechanical fabrication thus far
- Single-crystal measurements
- Electronics design and fabrication
- Simulation

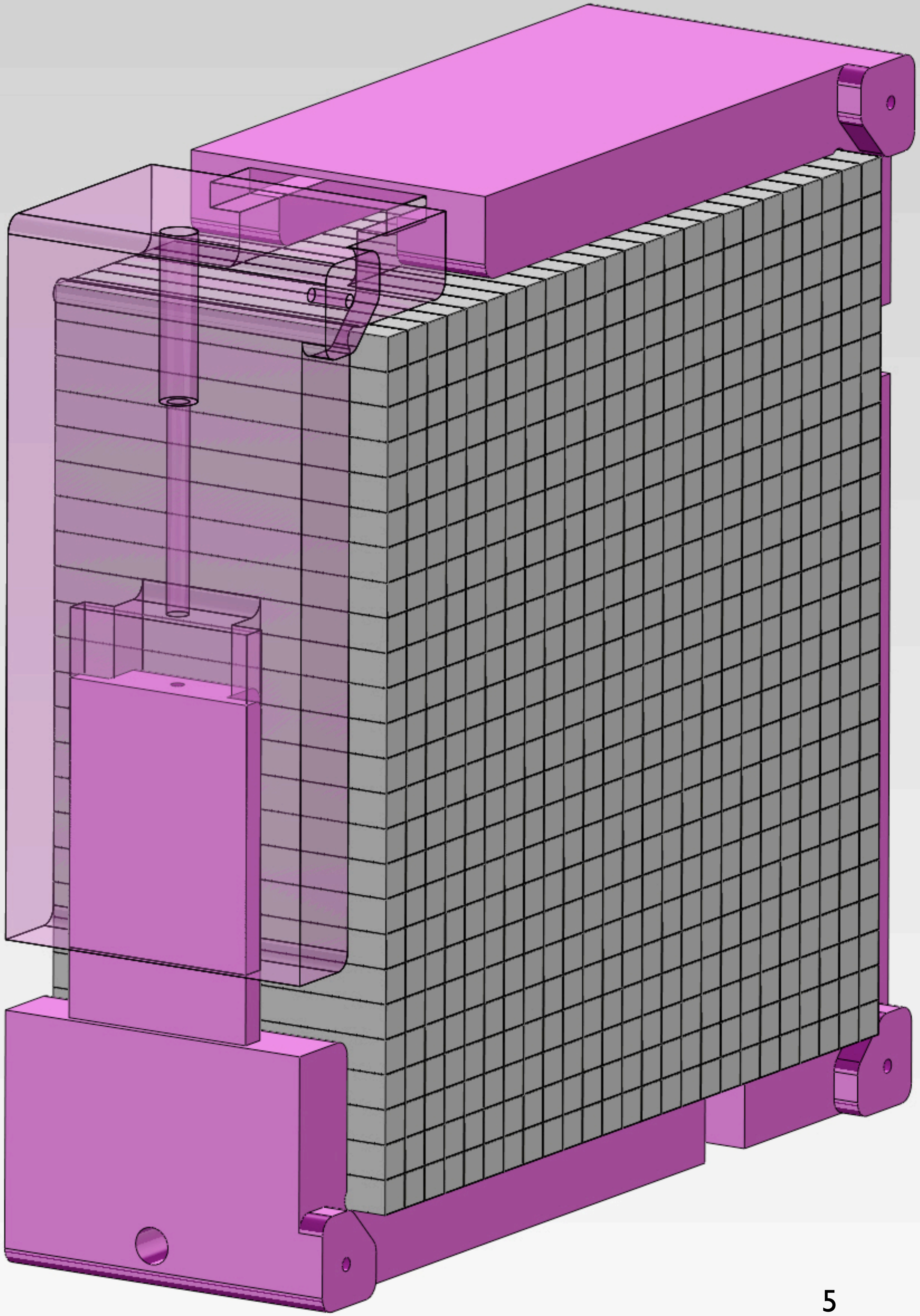
Overview

- Main purpose: positively identify neutral pions at high energies, distinguish them from single photons/electrons/positrons
- Envisioned implementation: a fine-grained 4 X_0 preshower calorimeter in front of, e.g., an 18^+ X_0 main calorimeter with moderate granularity
- Exploring a crystal-based design - different radiation tolerance, different cost point, could also be used in hybrid design
- Medical applications → mass production well-developed
- LSO/LYSO crystals: fast and bright scintillation, high density format (>7 g/cm^3, 1.14 cm X_0) → unprecedented compactness
    - being explored for calorimetry at the future ILC, CMS upgrade

Participating Staff

- Dr. Sergey Kuleshov, physicist, head of detector lab, project leader
- Dr. William Brooks, physicist, project coordination
- Dr. Hayk Hakobyan, physicist, simulation coordination
- Ms. Alison Sherman, senior administrative specialist, detector lab
- Mr. Alam Toro, electronics engineer, electronics design
- Mr. Juan “Iñaki” Vega, mechanical engineer, mechanical design
- Mr. Juan Pavez, Informatics PhD student, GEANT4 simulation
- Mr. Esteban Zambrano, electronics engineering undergraduate student, single-crystal measurements and GEANT4 simulation (student thesis)
- Elias Rozas, CNC technician, CNC mill programming and operation
- Pavlo Bazalyeyev, expert technician, mechanical fabrication

The preshower calorimeter is our highest priority laboratory project now that we have completed our two previous major projects (fabrication of 4000 lightguides, characterization of 2800 16-cell MPPC devices).

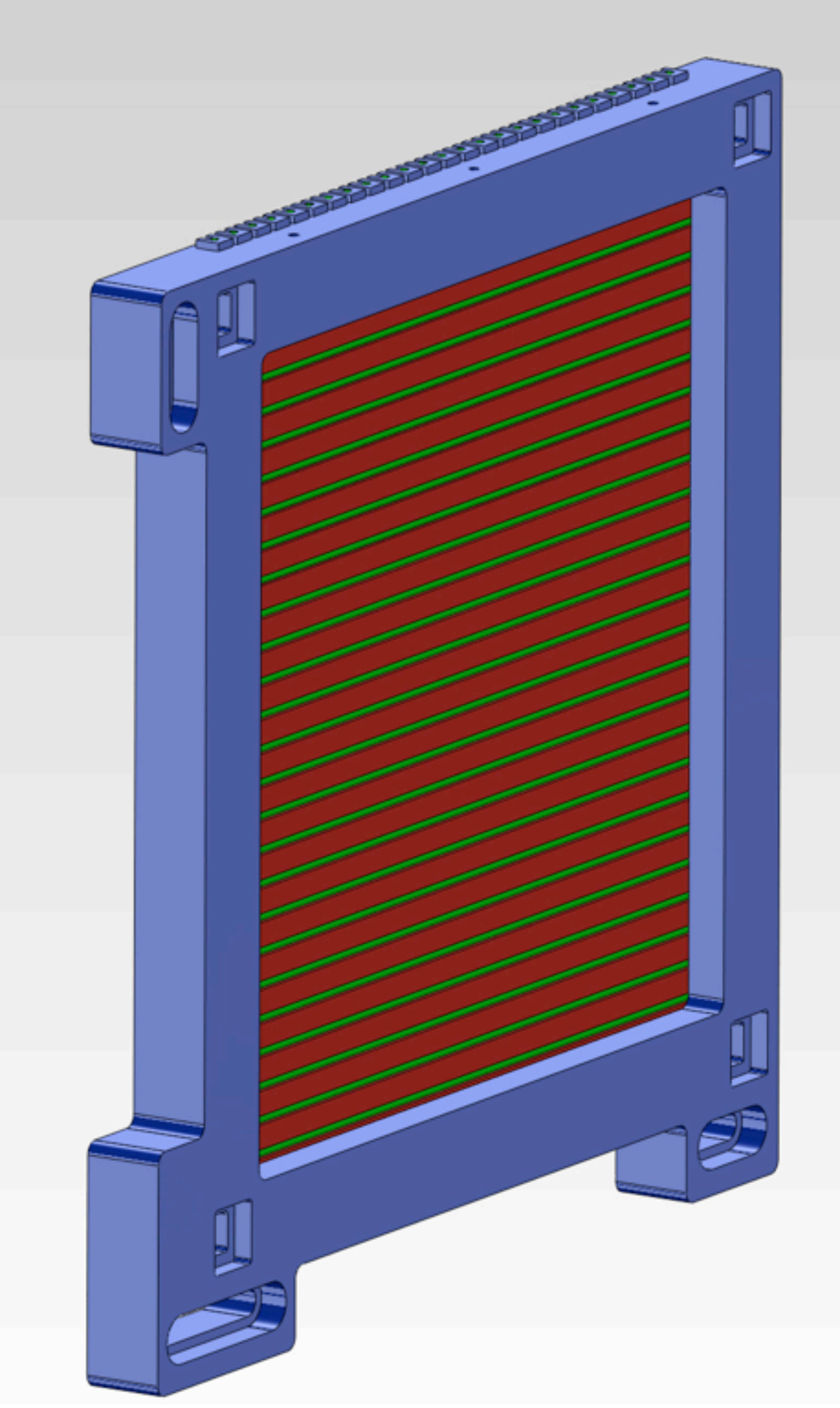


Mechanical Design: Crystal Array Housing

- 625 crystals, 4mm x 4mm x 4.5cm
- Saint-Gobain Prelude 420 ($Lu_{1.8}Y_{0.2}SiO_5$:Ce)
- frame is made of a soft plastic material
- compress in horizontal and vertical directions

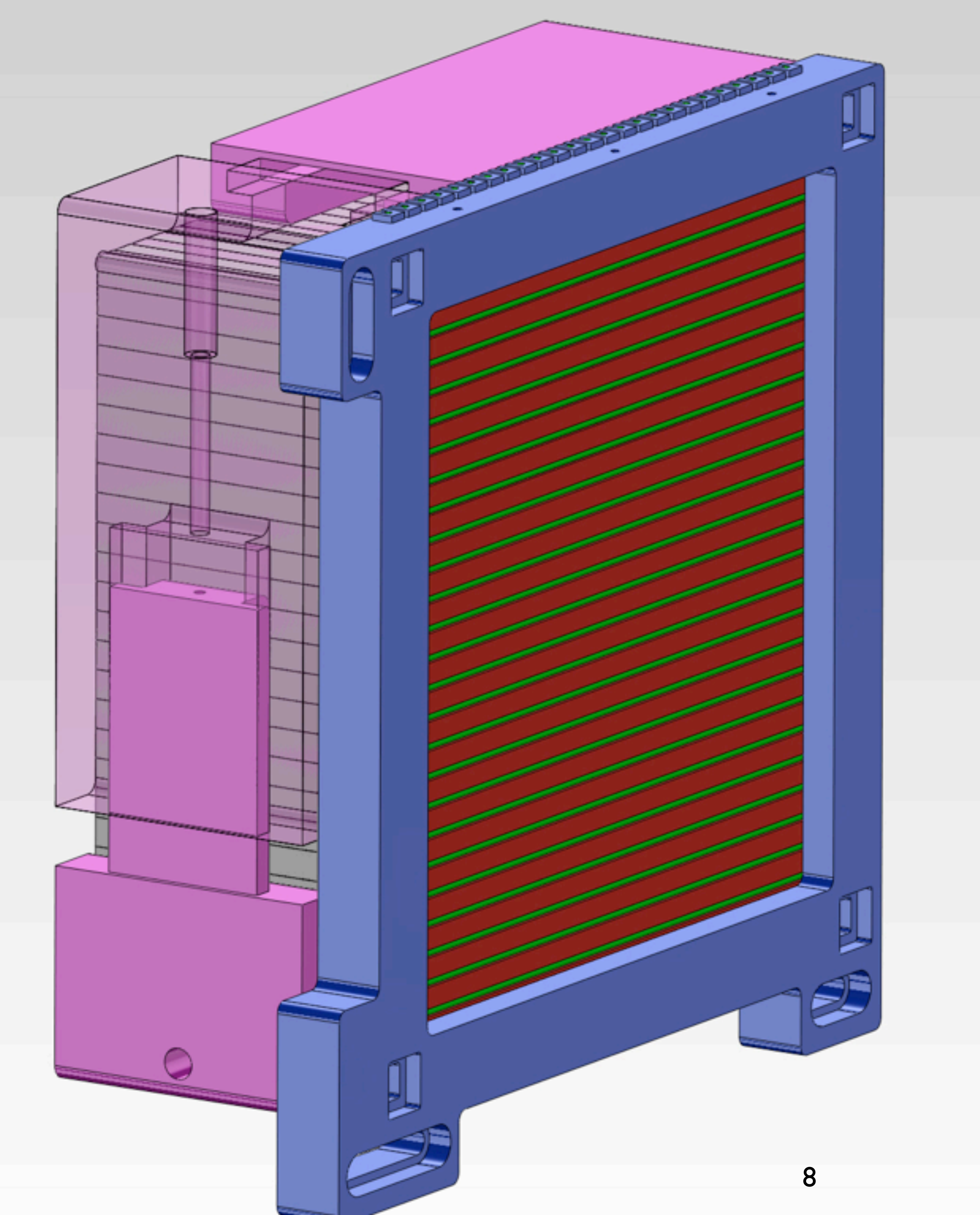
Mechanical Design: Fiber Positioning Plate

- 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: Fiber Mounting Assembly

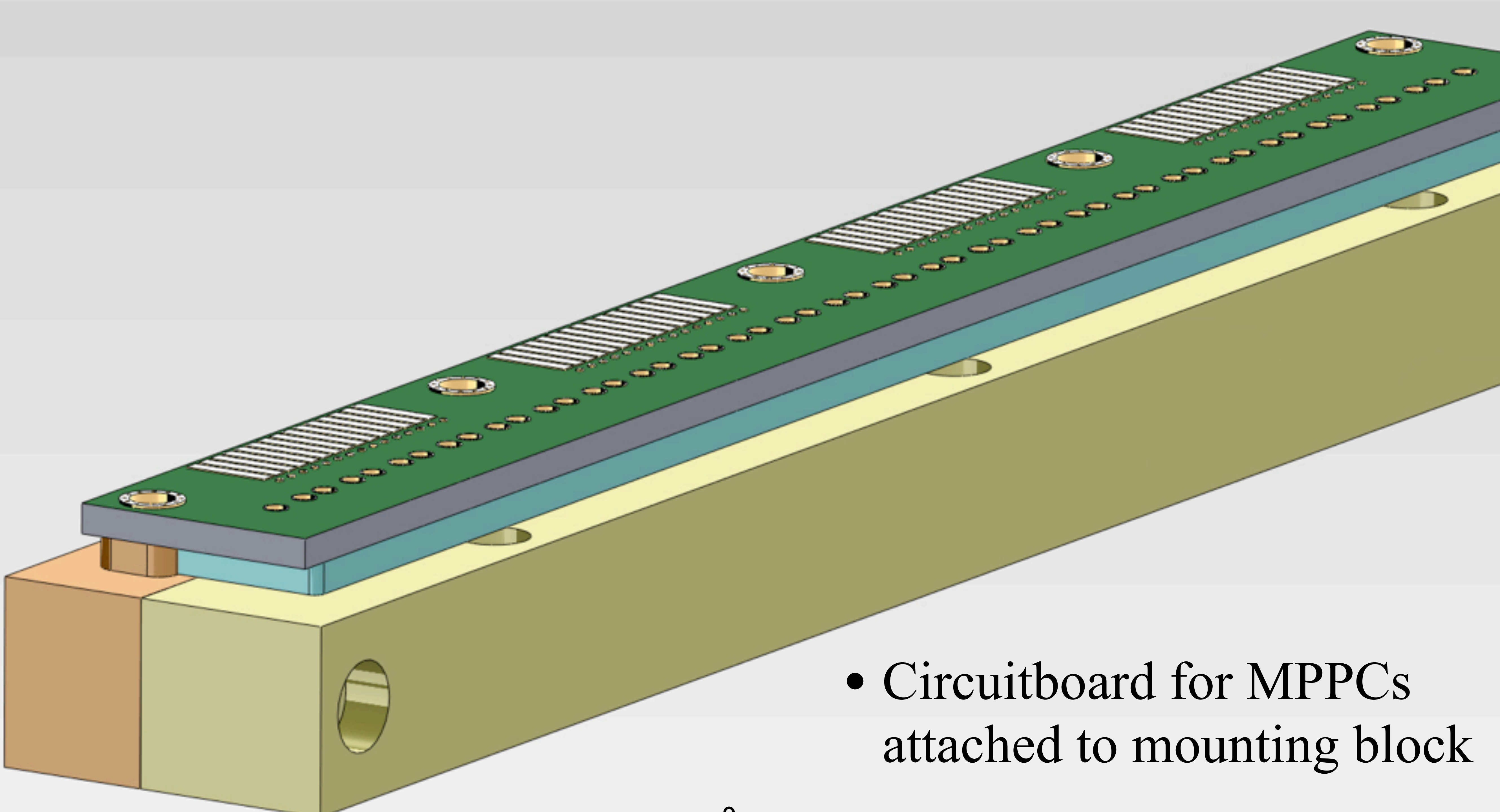
- The fiber mounting assembly holds the fiber positioning plate securely against the crystals in the crystal frame



Mechanical Design: Crystals + Fibers

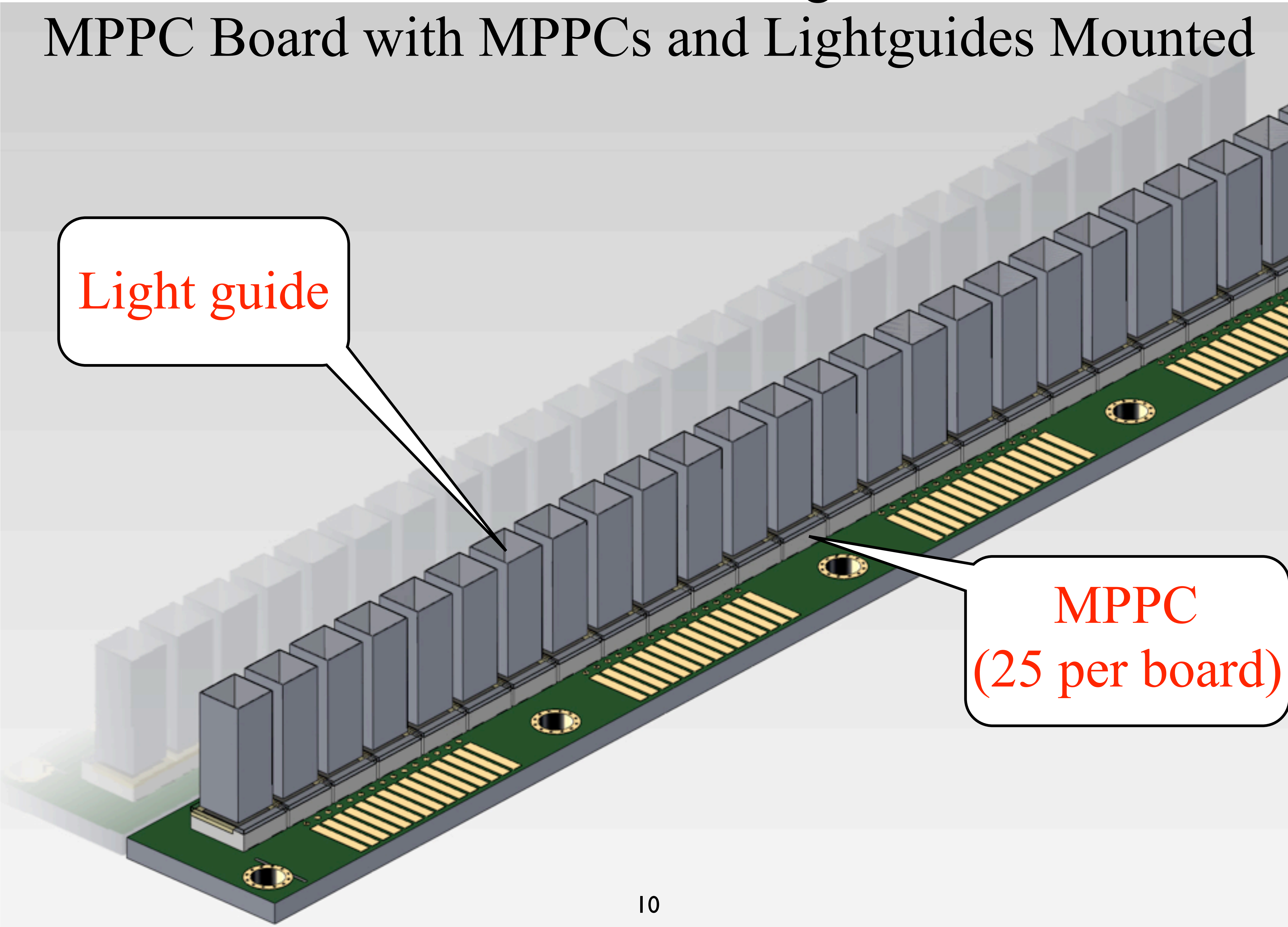
- Fibers mounted on the "front" of the calorimeter to reduce radiation exposure

Mechanical Design: MPPC Board

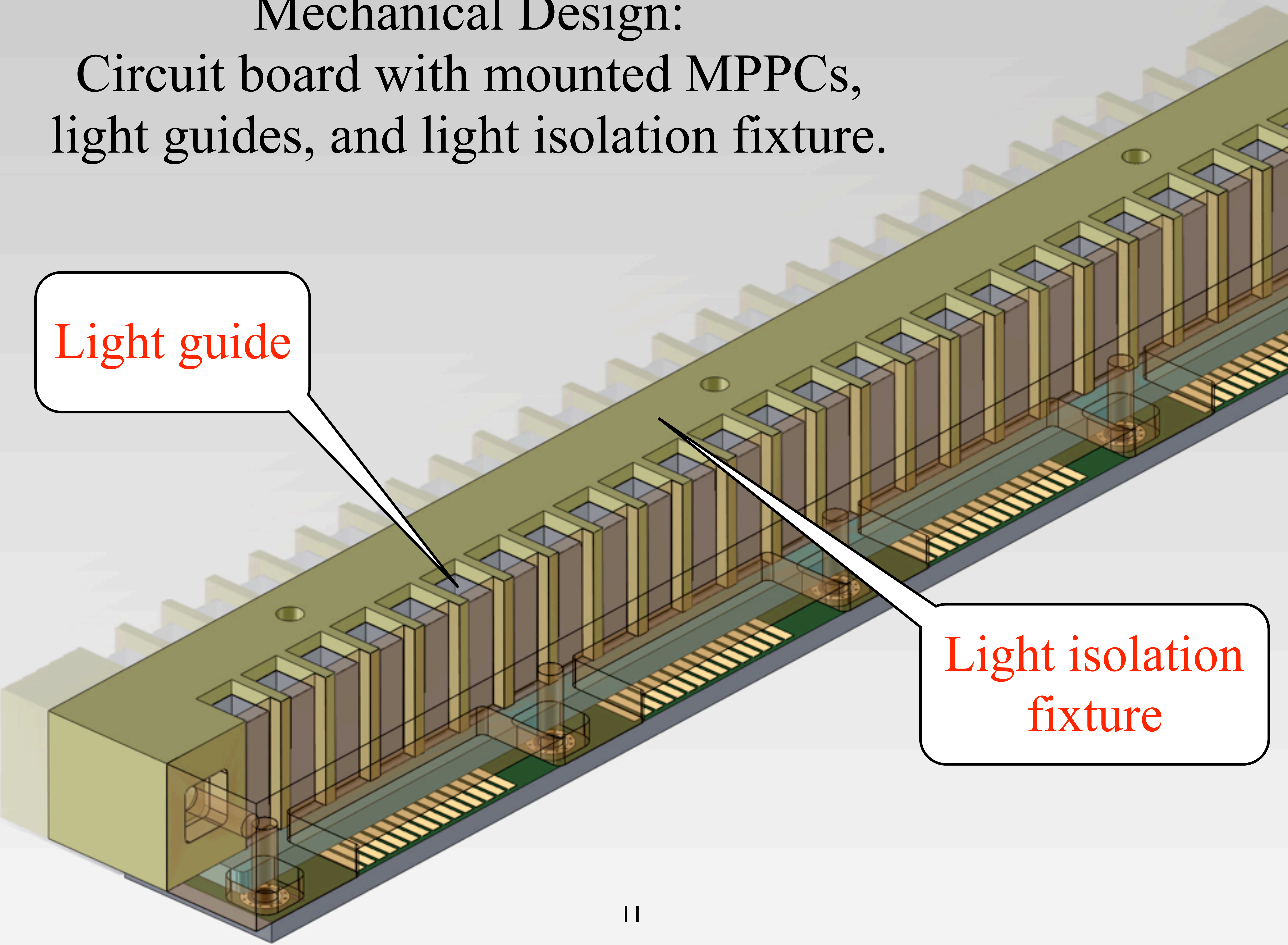


- Circuitboard for MPPCs attached to mounting block

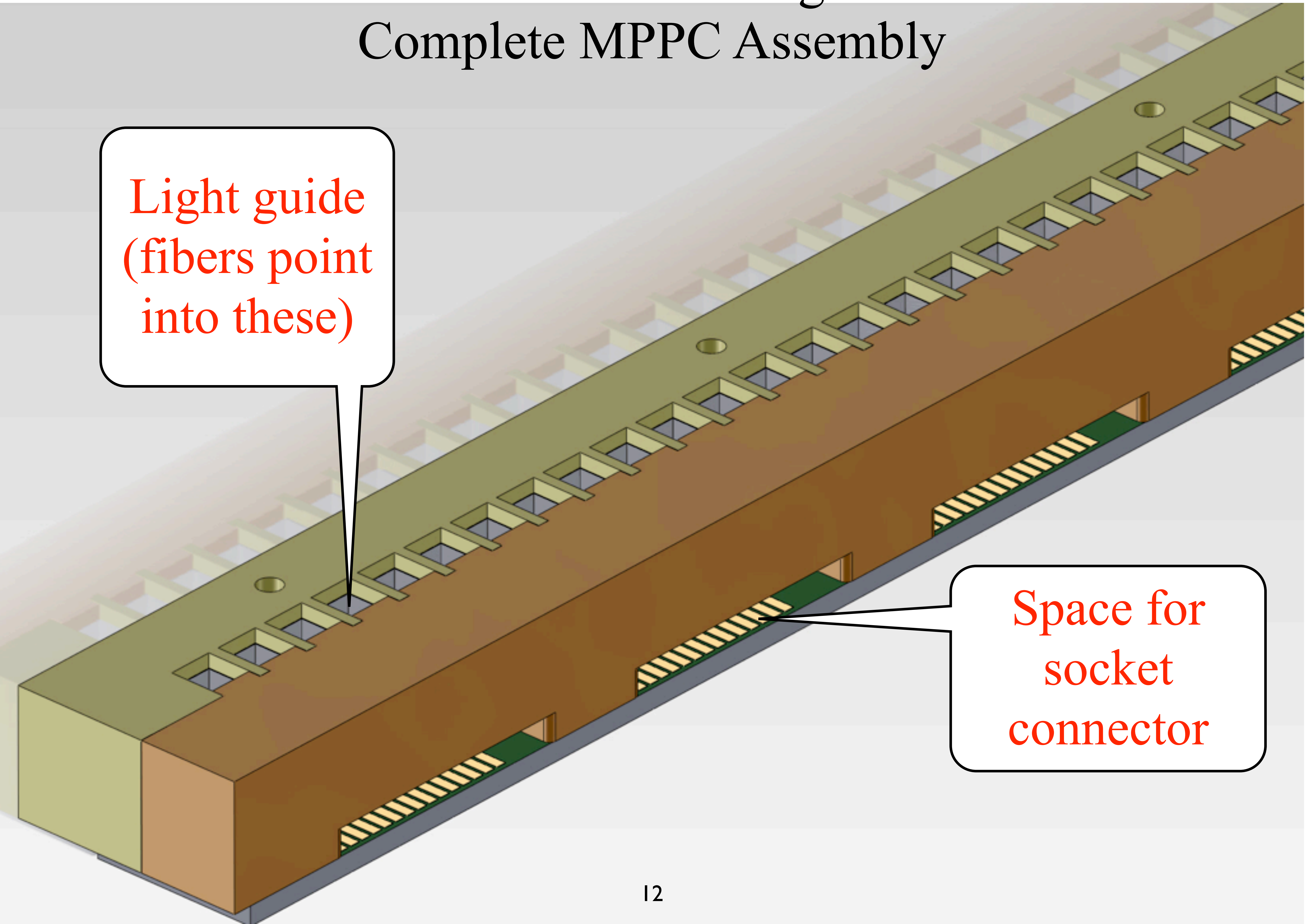
Mechanical Design:
MPPC Board with MPPCs and Lightguides Mounted



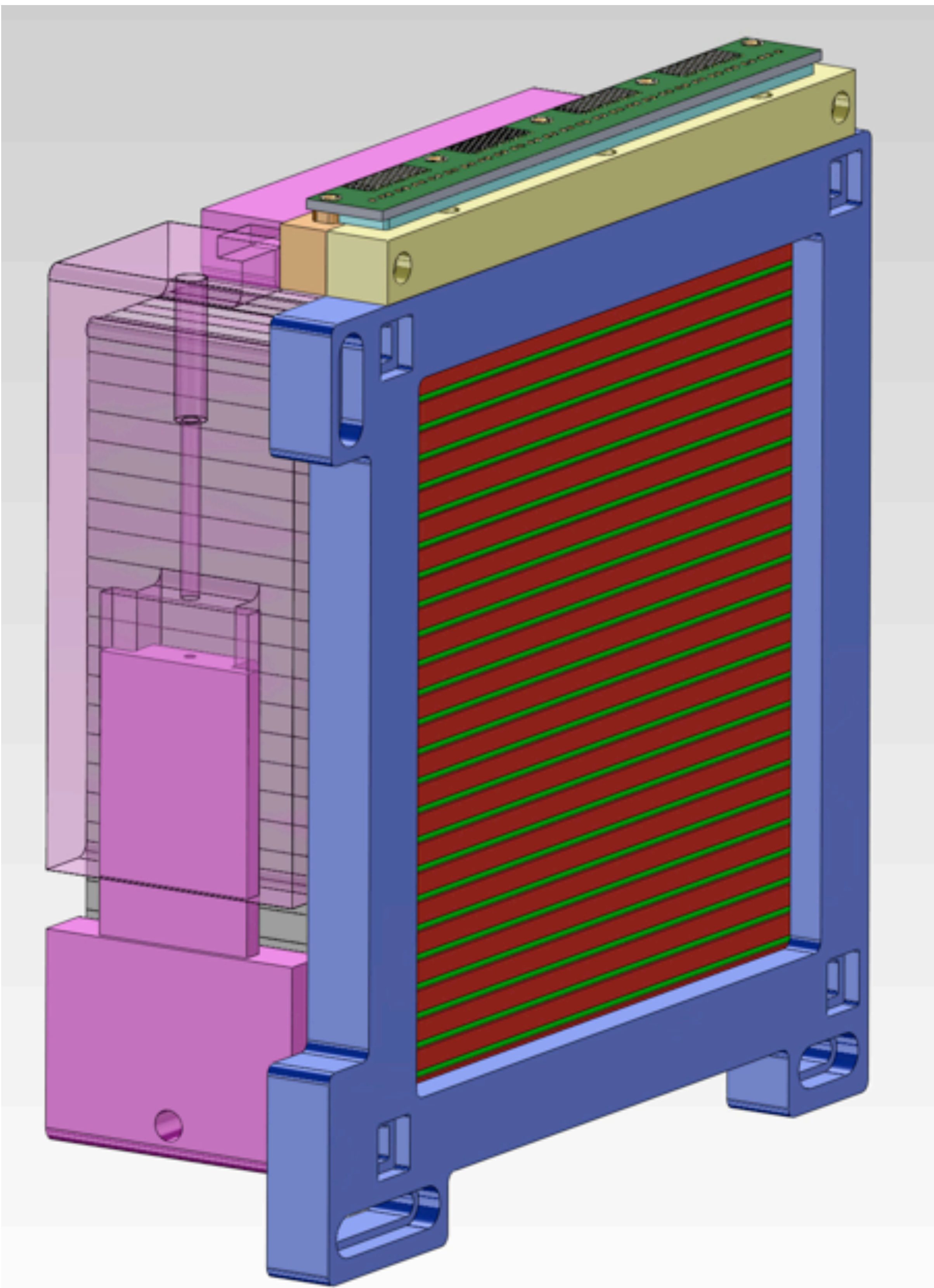
Mechanical Design:
Circuit board with mounted MPPCs, light guides, and light isolation fixture.

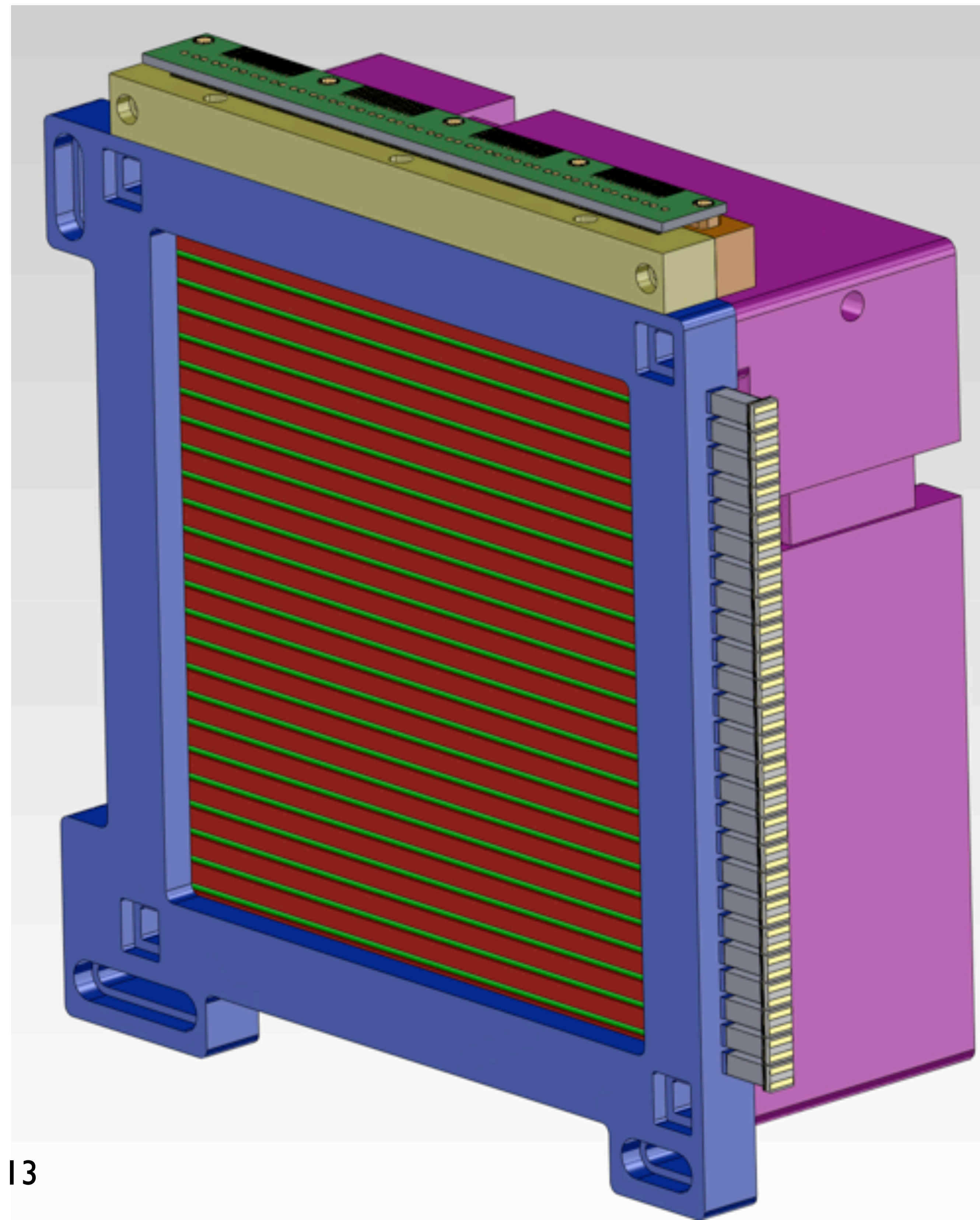


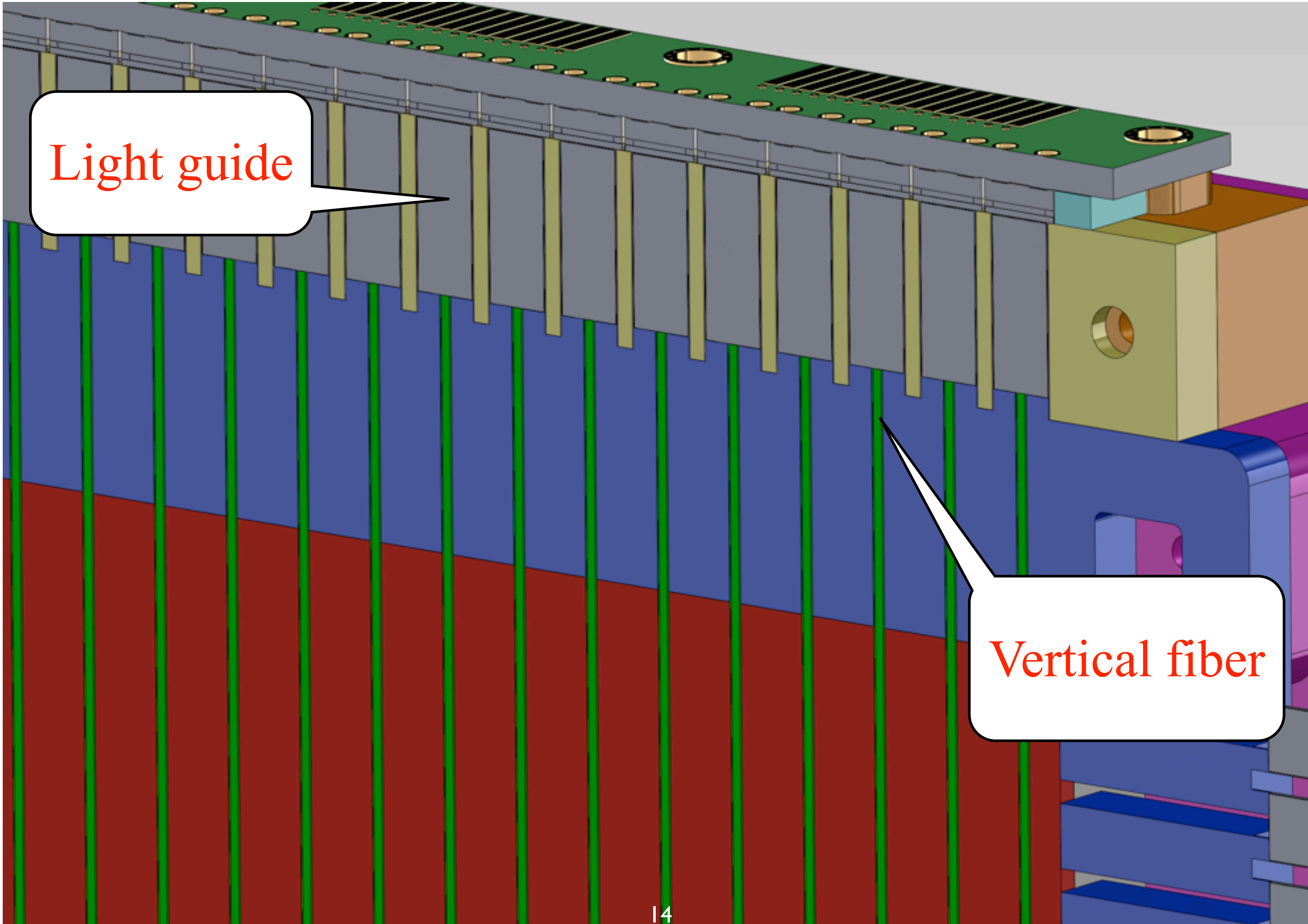
Mechanical Design: Complete MPPC Assembly



Mechanical Design: MPPC Boards Attached to Fiber Mounting Assembly

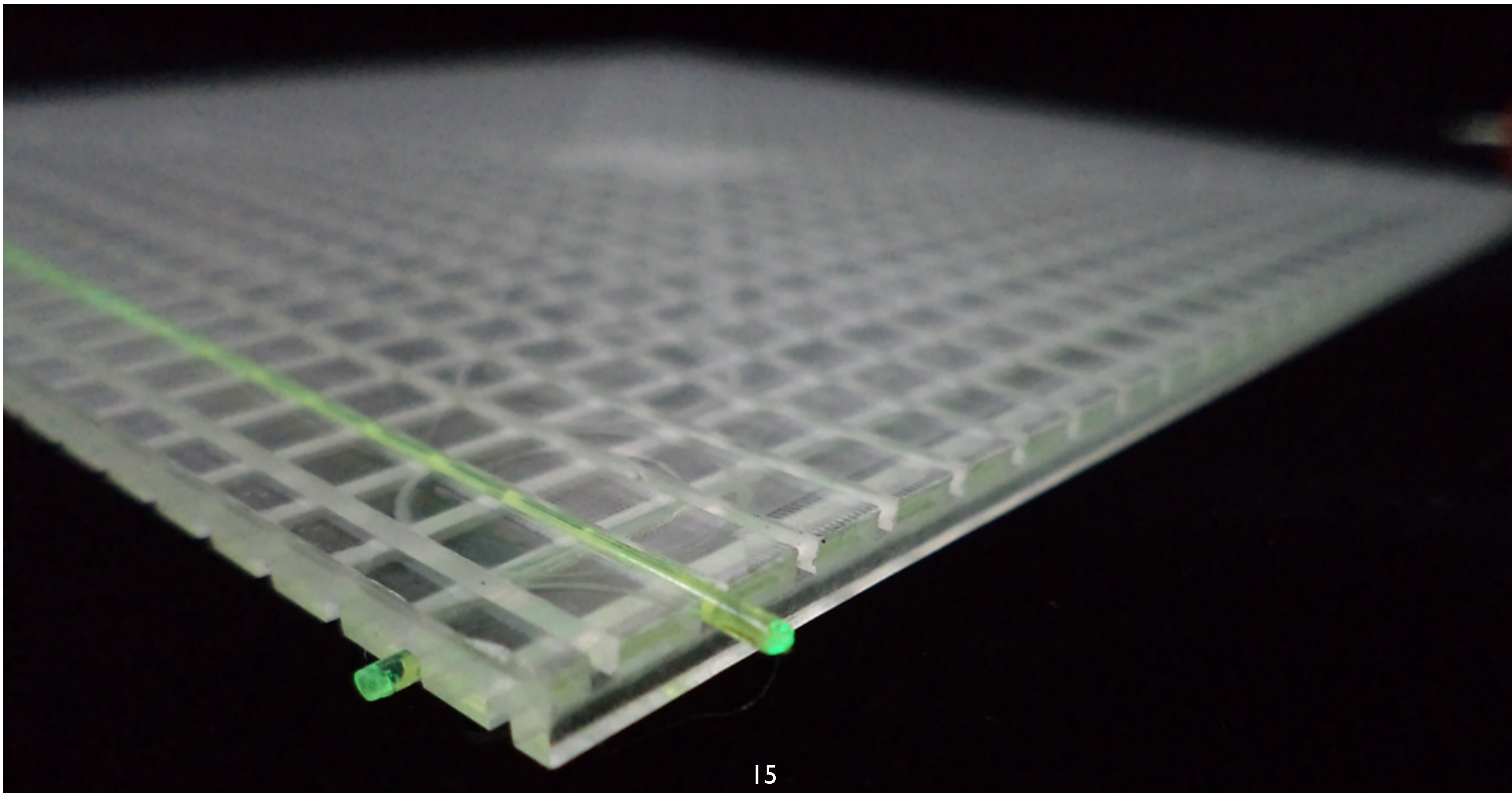





Light guide
Vertical fiber

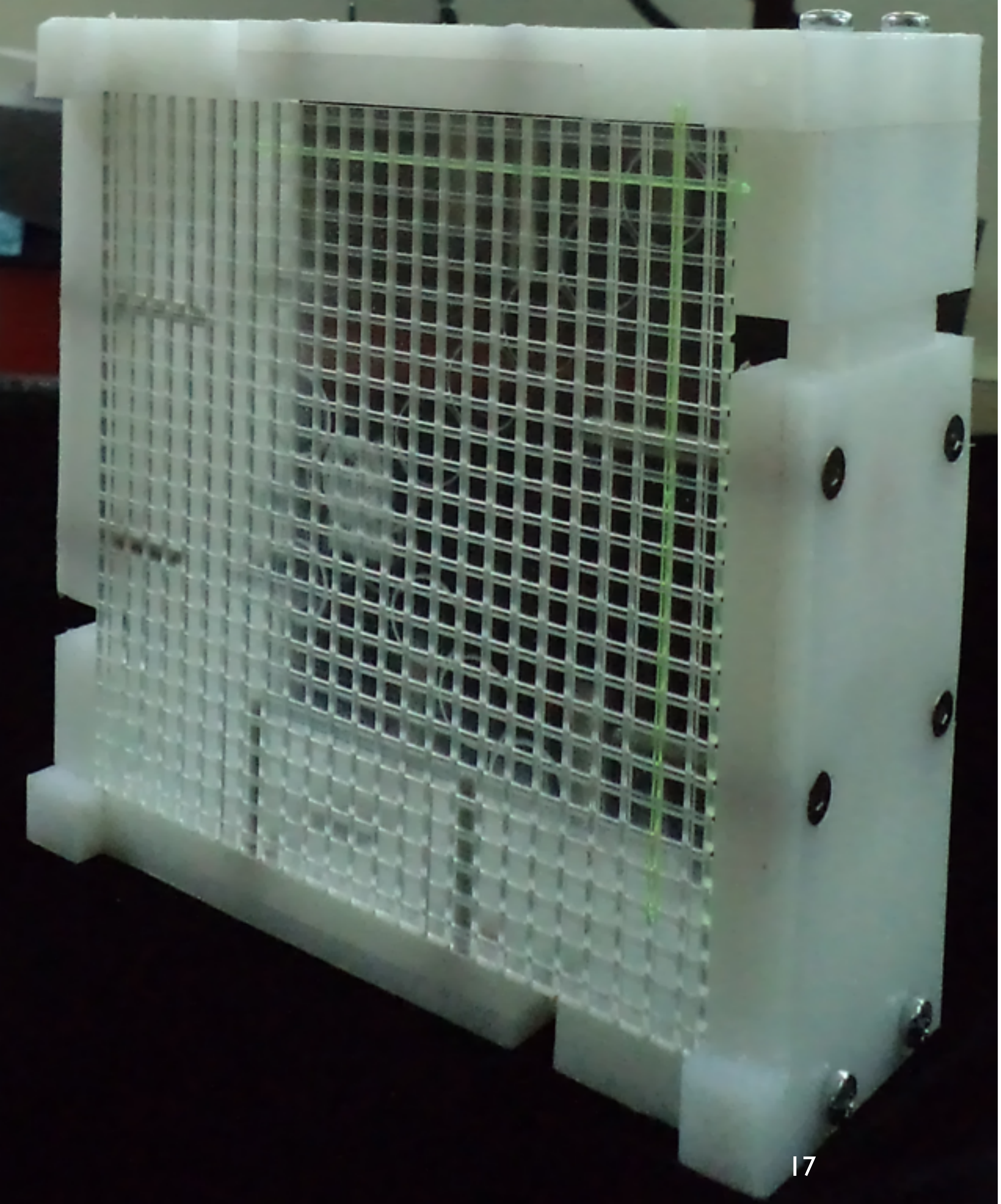
Example of Fiber Positioning Plate

One X fiber and one Y fiber in place



Crystal Array Housing

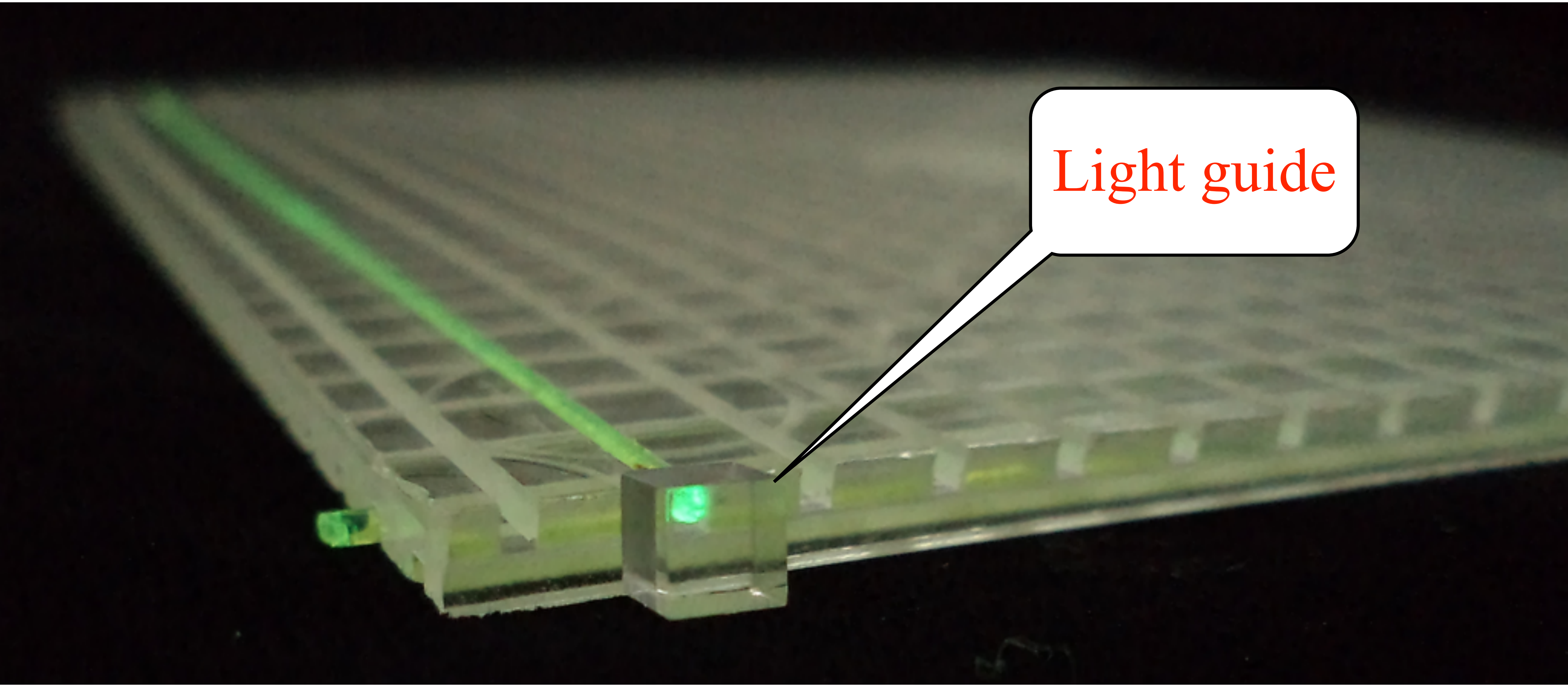
(The long screws are just temporary)



Crystal Array Housing

Front view

Fiber Light Viewed through Lightguide

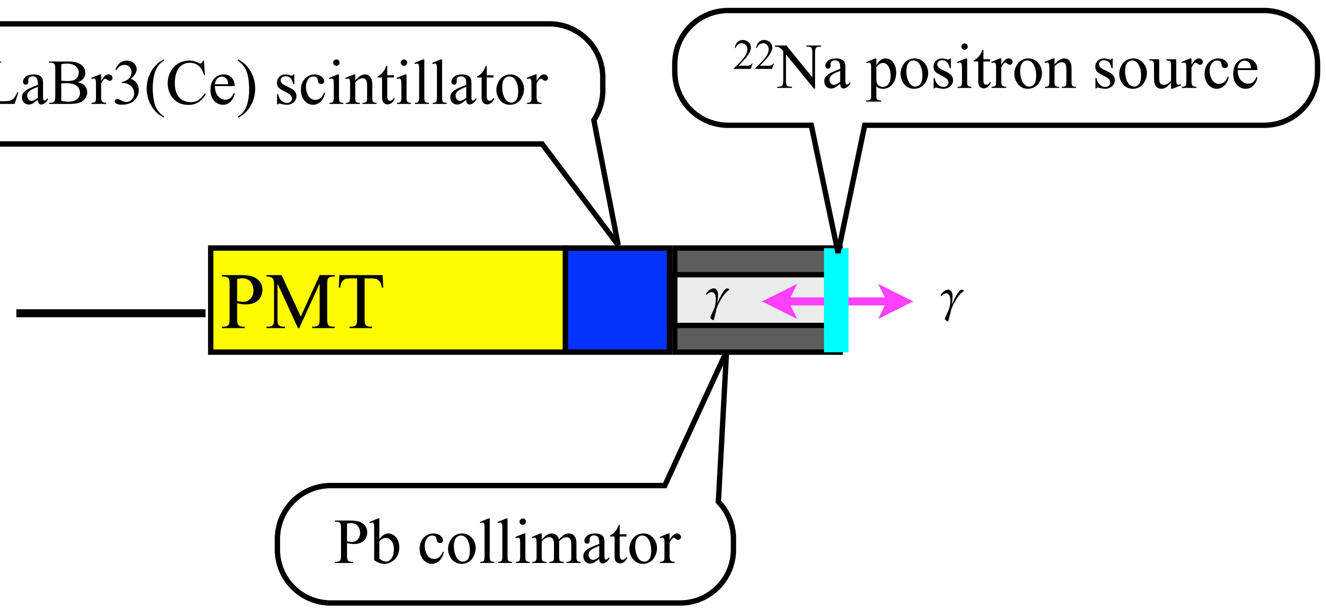


Crystal Wrapping

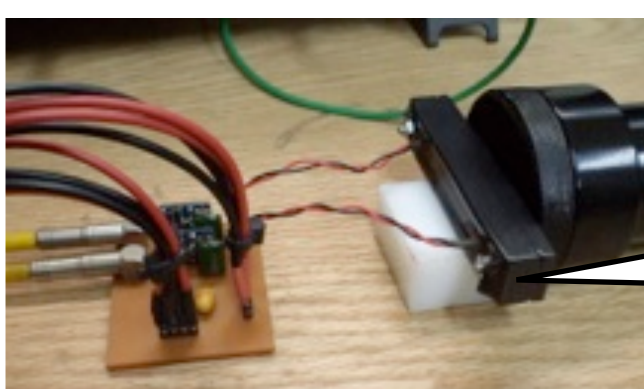
- We have purchased a vacuum oven specifically for forming the ultra-thin crystal wrapping (50-250 °C)
- We have experience with this technique from previous crystal calorimeter projects (CLAS IC)
- We will use 3M Vikuiti Enhanced Specular Reflector film (65 μm thickness, c.f. $\pm$30 μm crystal dimensional tolerance) or 5 μm aluminized Mylar

Single-Crystal Measurements

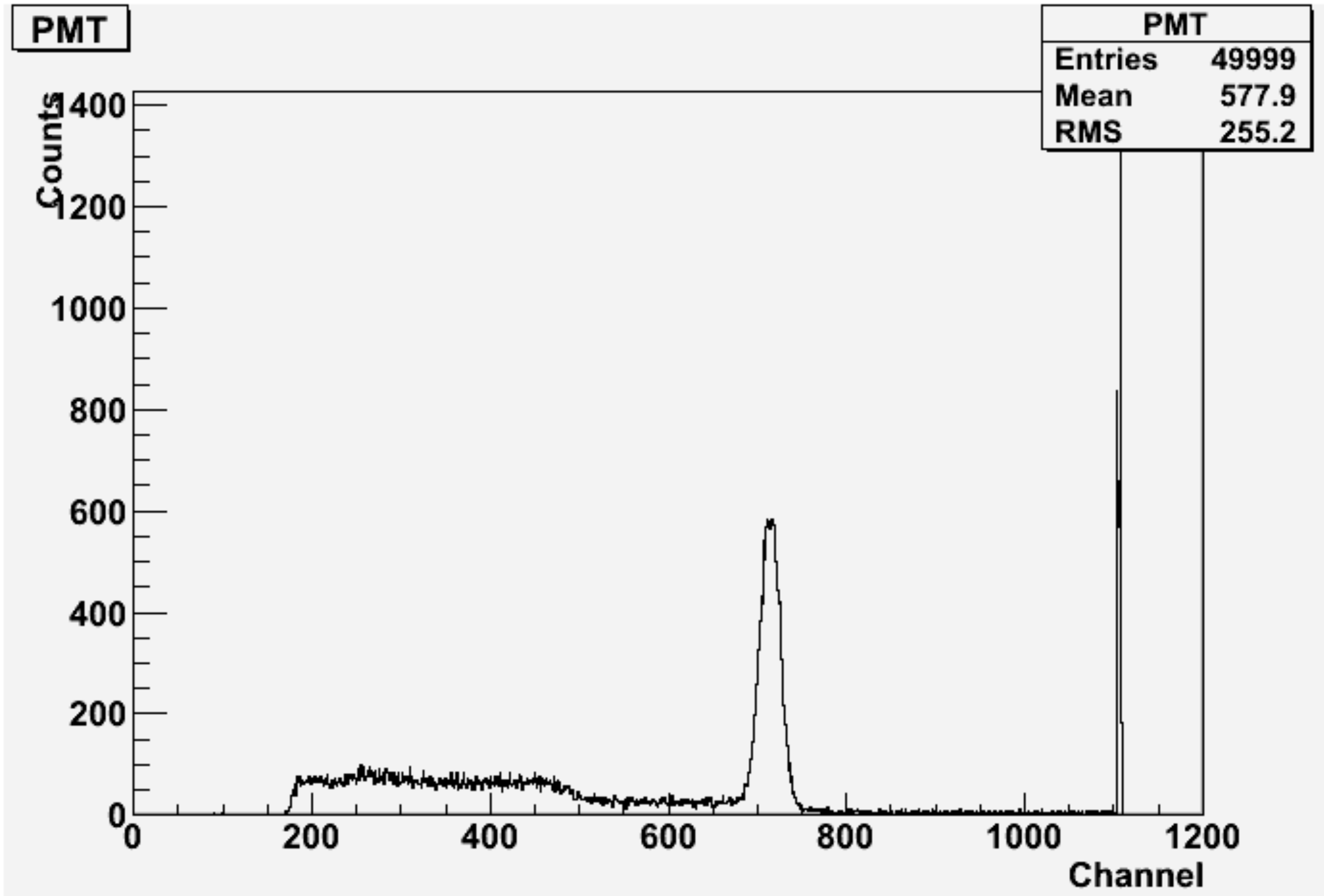
- Main purpose: measure the light attenuation length of a crystal
  - It has been reported as very short in the literature
- As detailed in our December report, we have built two photon tagging modules:



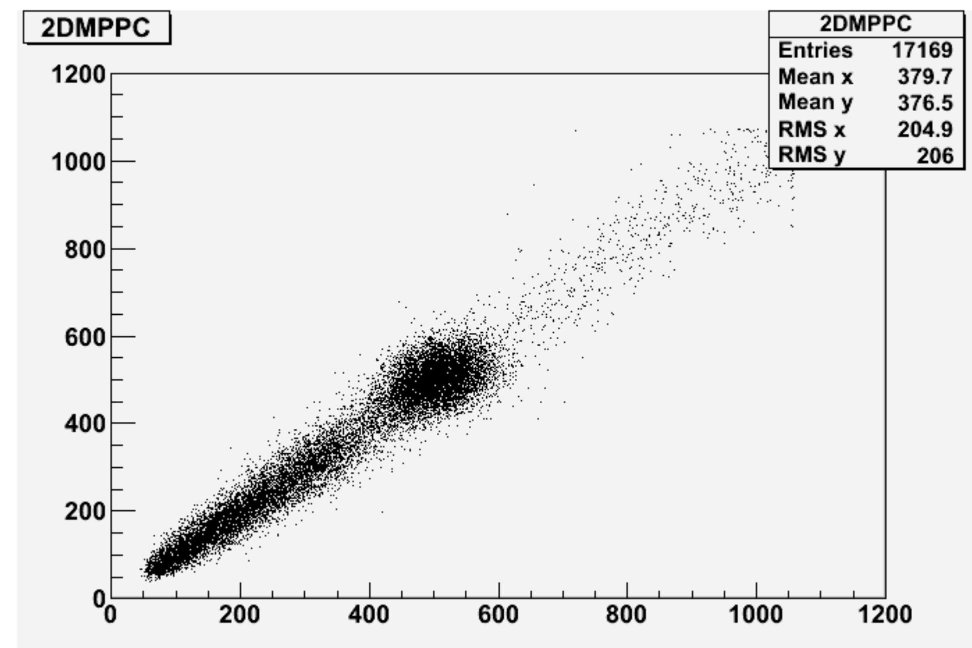
- We have used one of these modules to test a single crystal:



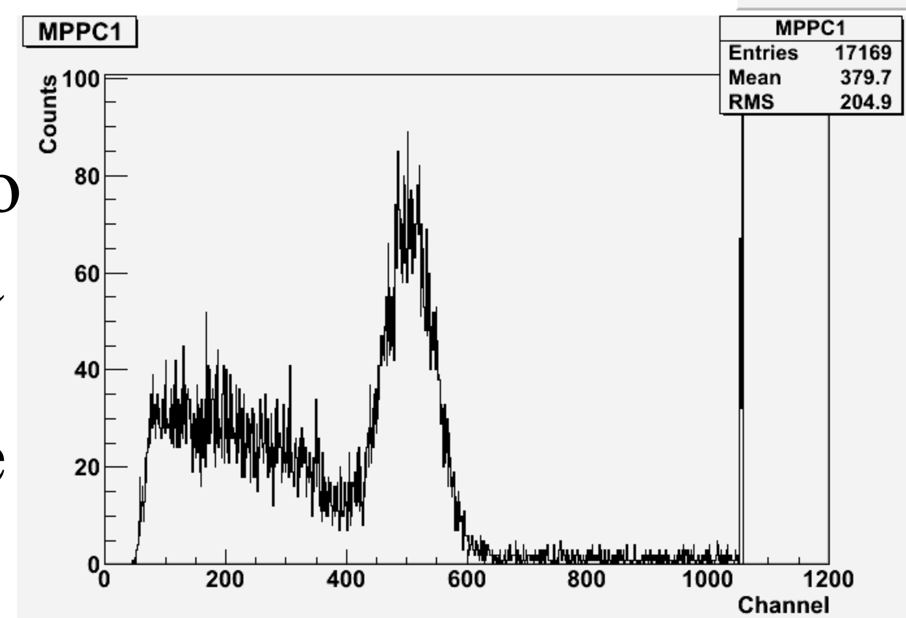
Single crystal housing
Double-sided readout
3-detector coincidence

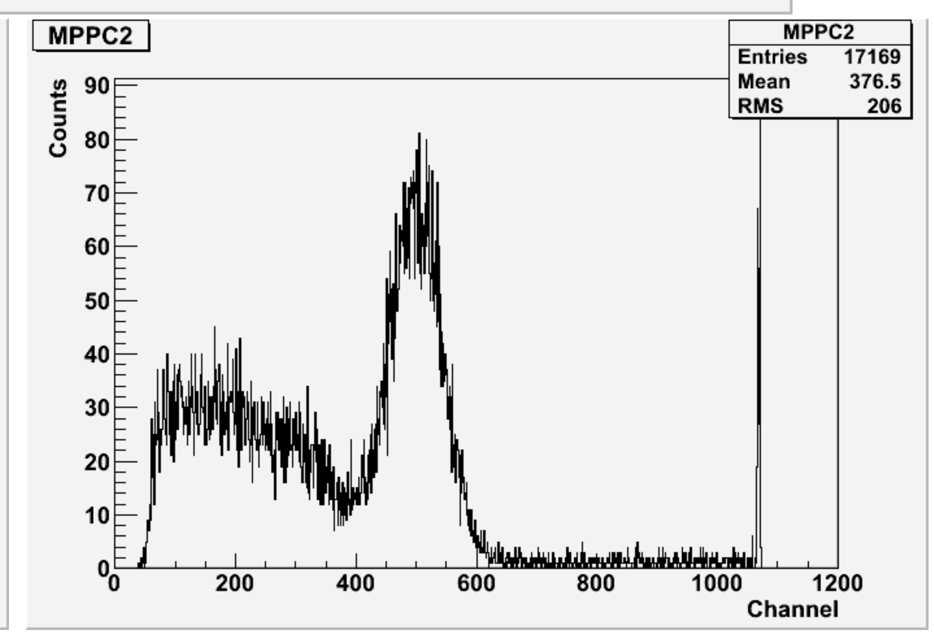


Distribution of signals from the gamma tagger in the case of a triple coincidence: gamma tagger plus both SiPMs on the LYSO crystal. A clear peak is seen, corresponding to the tagged photon.

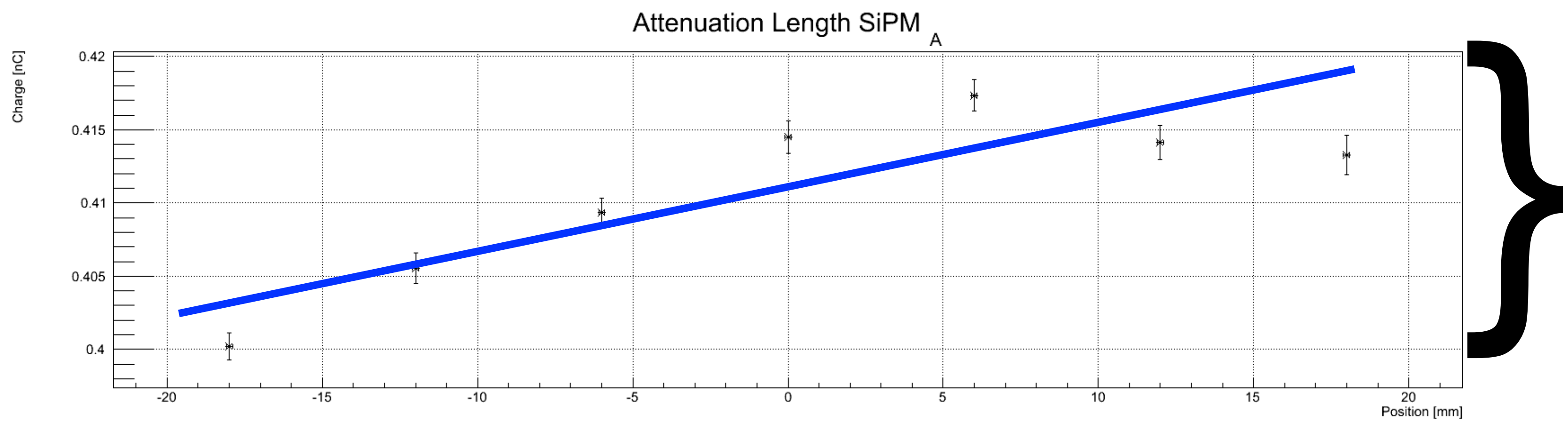


Signals from the two MPPCs in the case of the triple coincidence and also requiring a tagged gamma from the peak shown above. On upper right, the correlation plot between the two MPPCs.

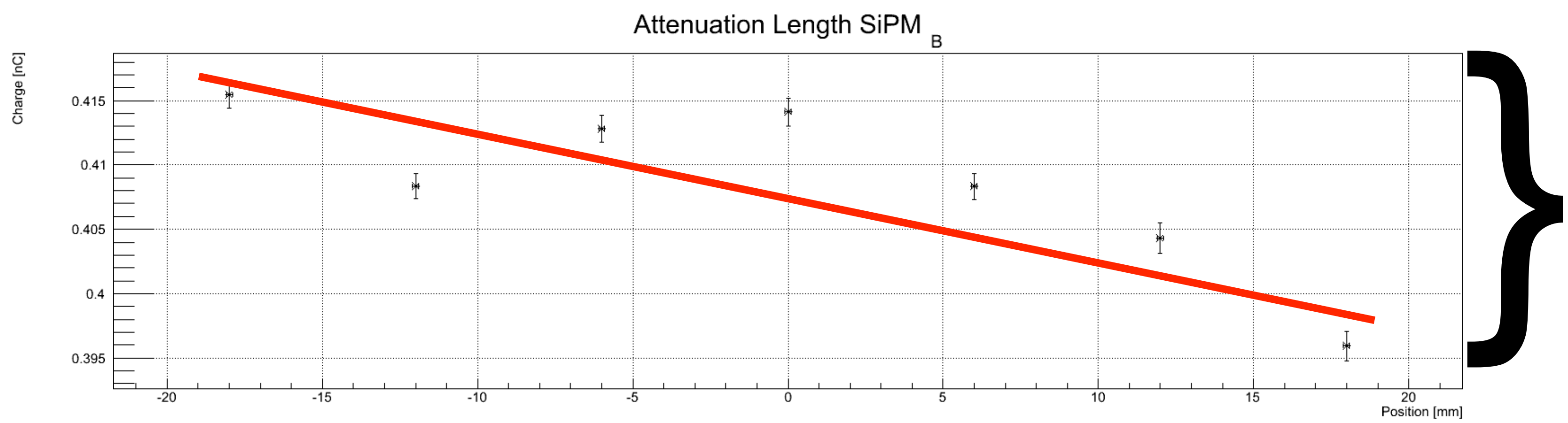




Single-Crystal Measurements: Attenuation lengths

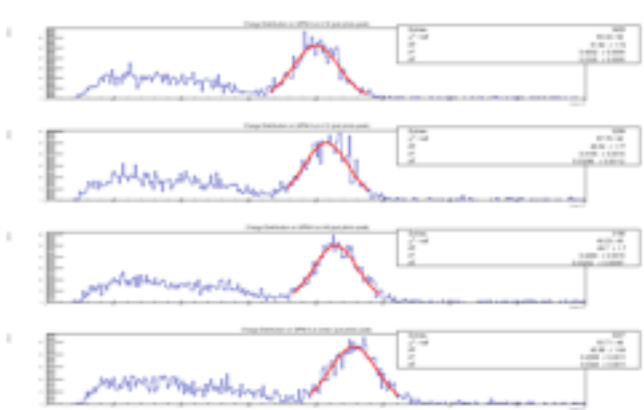


~5%



~5%

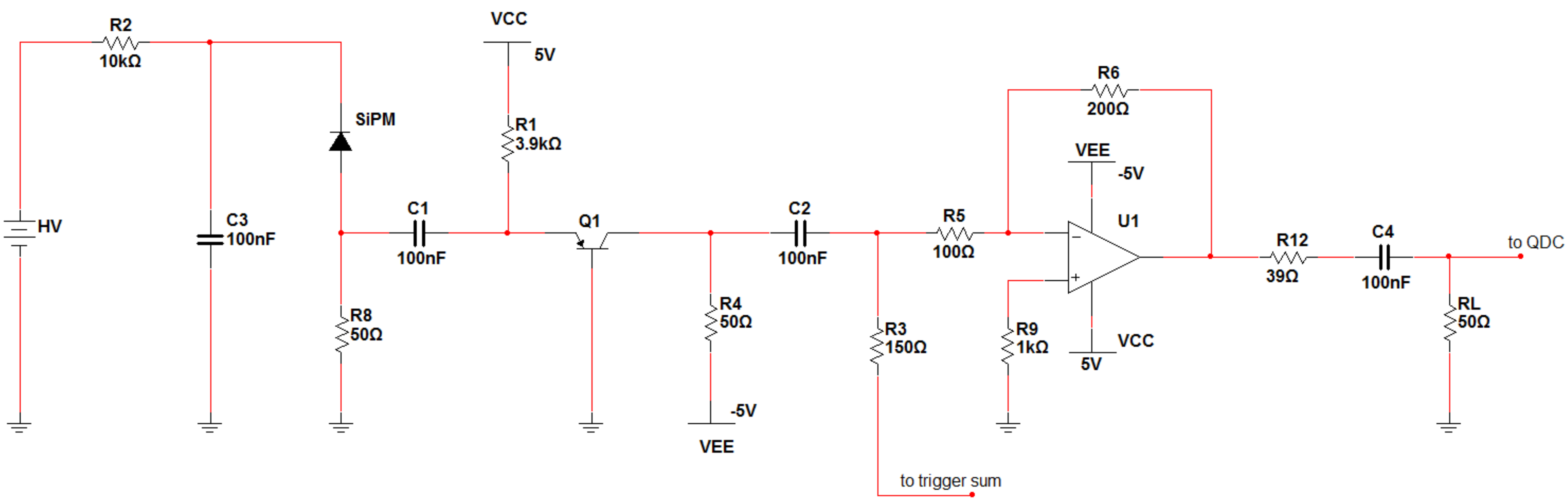
← Position along crystal →



Tagged signals vs. position

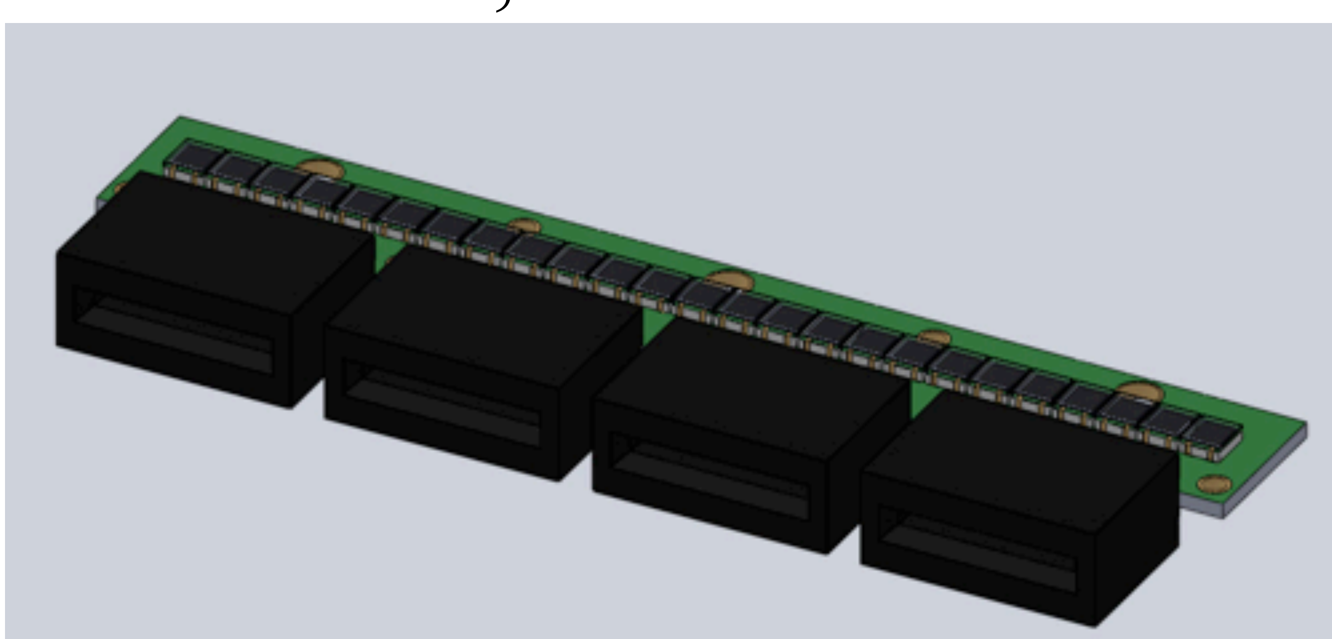
We tested 3 different wrapping materials; no significant dependence

→ attenuation is irrelevant to the design. Good!

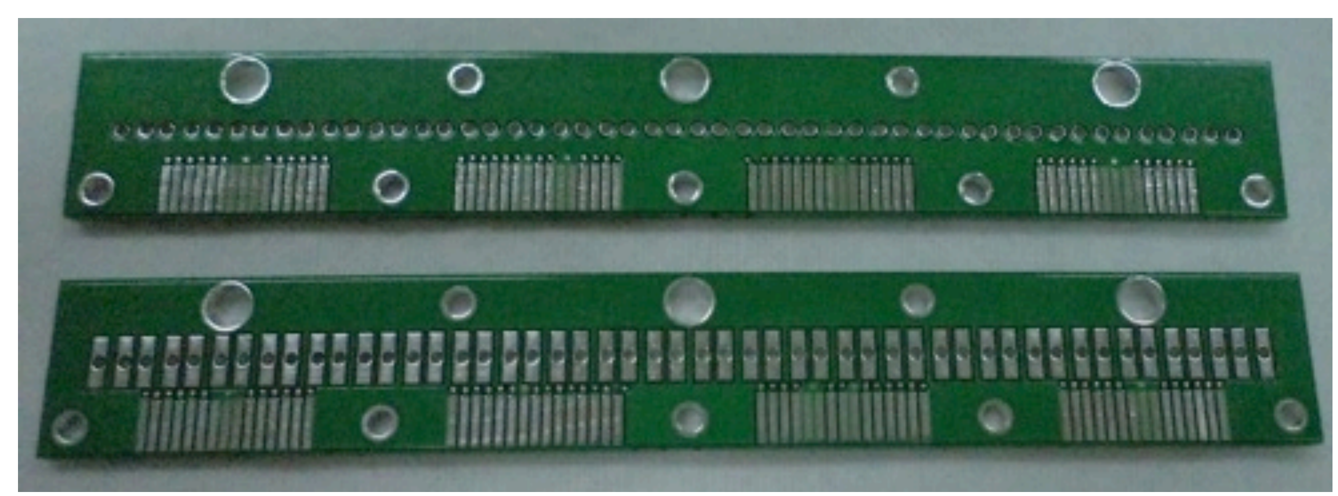


Circuit for amplifying and conditioning the MPPC pulse.

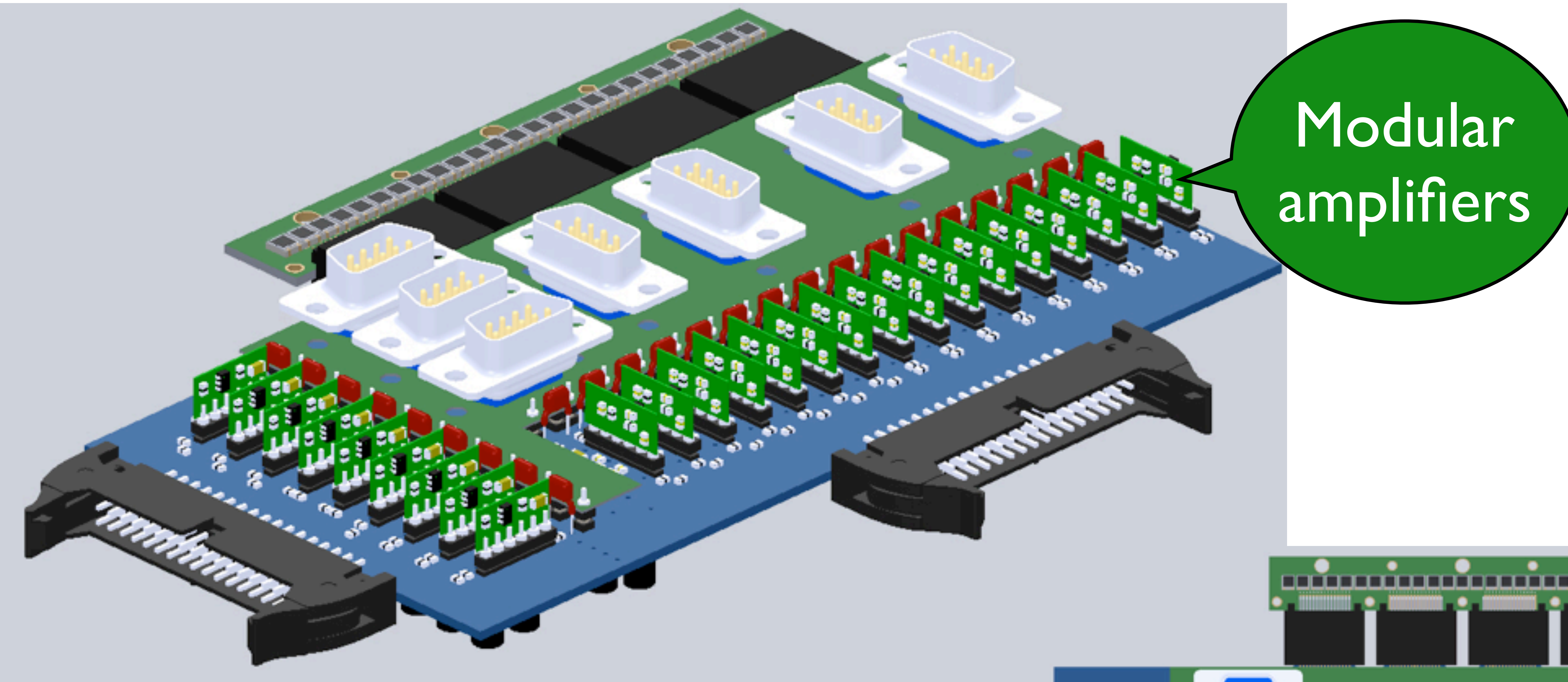
Design for circuit board for 25 MPPCs, with connectors

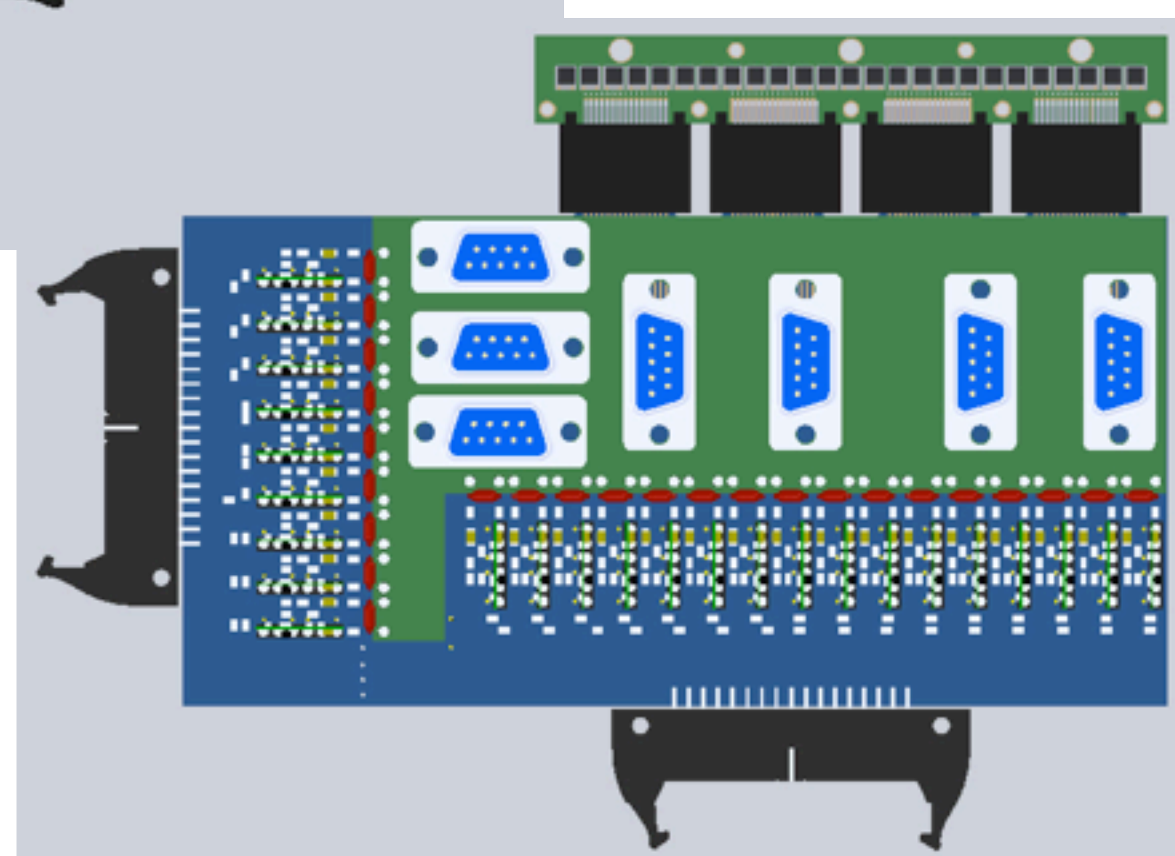


Circuit boards as fabricated (3-layer boards)



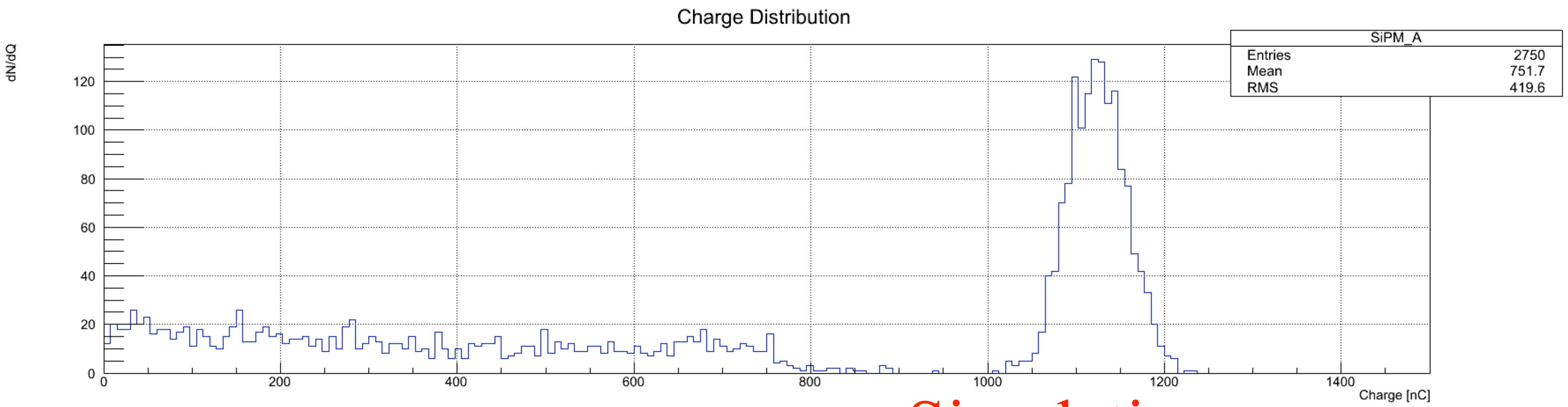
Signal processing board



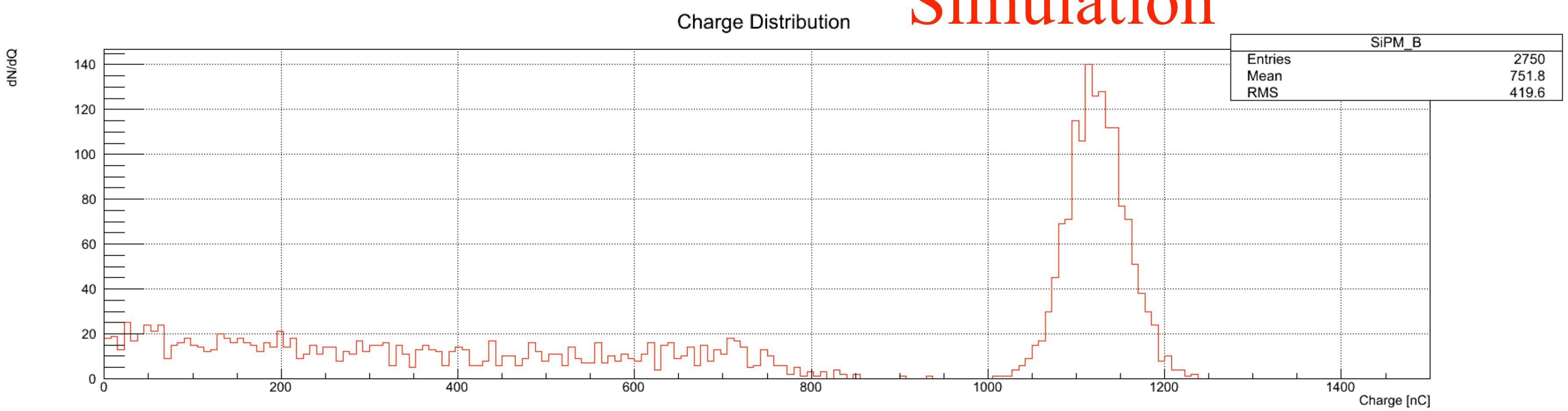


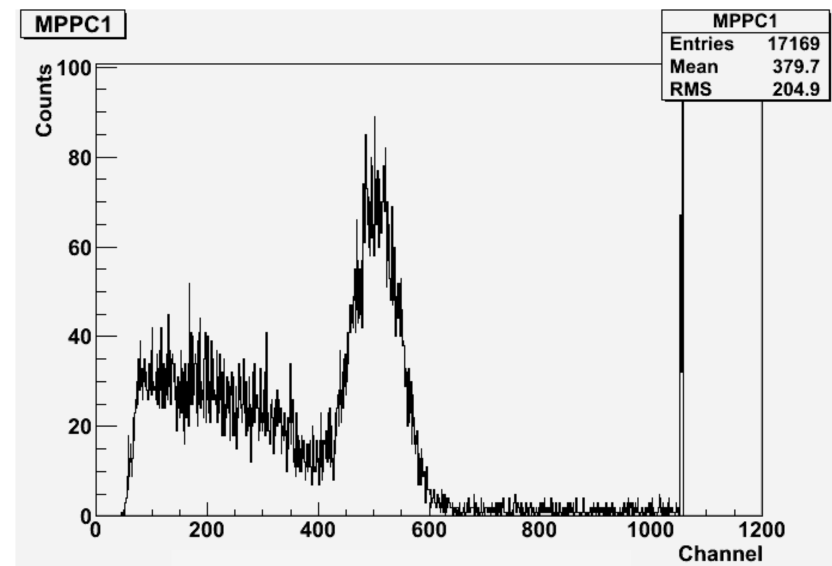
We have a large supply of these modular amplifiers from our previous MPPC project, for which we designed and fabricated them.

GEANT4 Simulations: Single-Crystal Tests

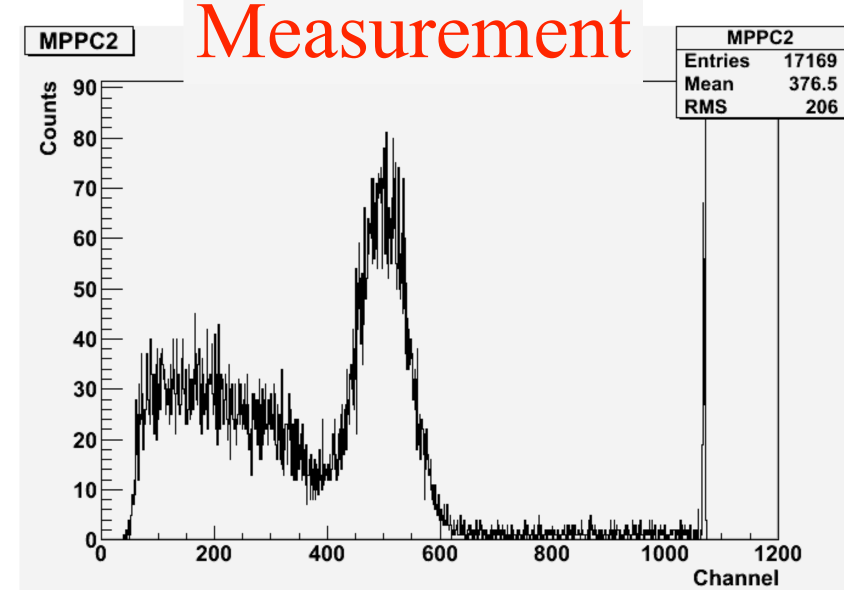


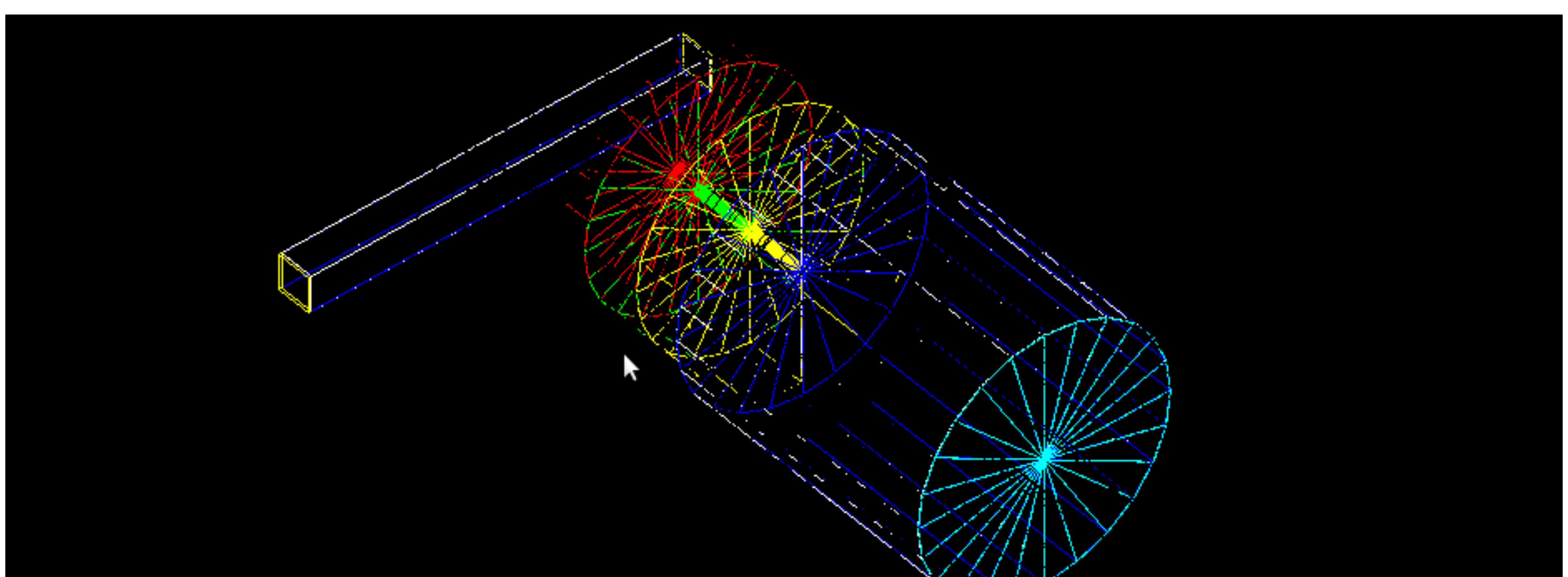
Simulation

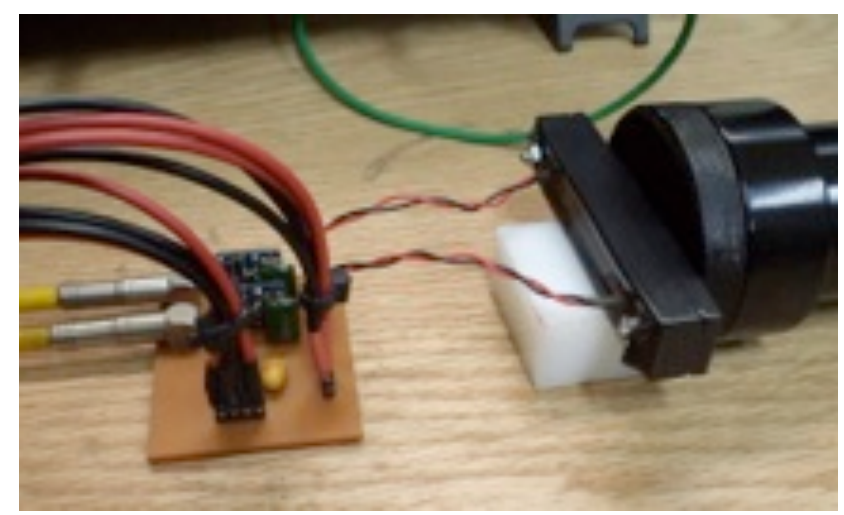




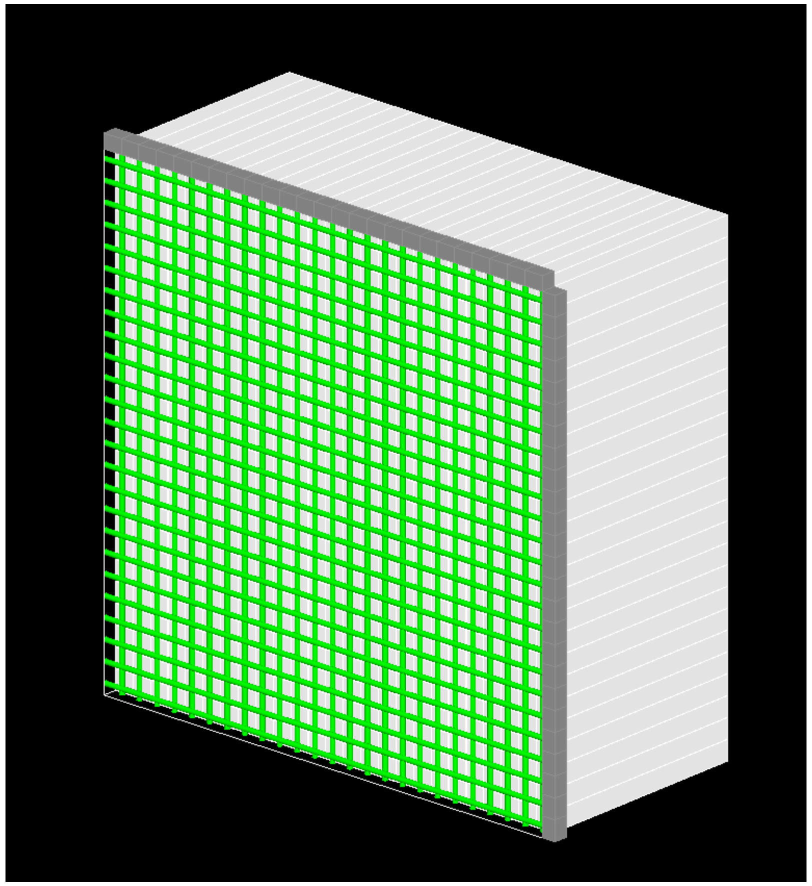
Measurement

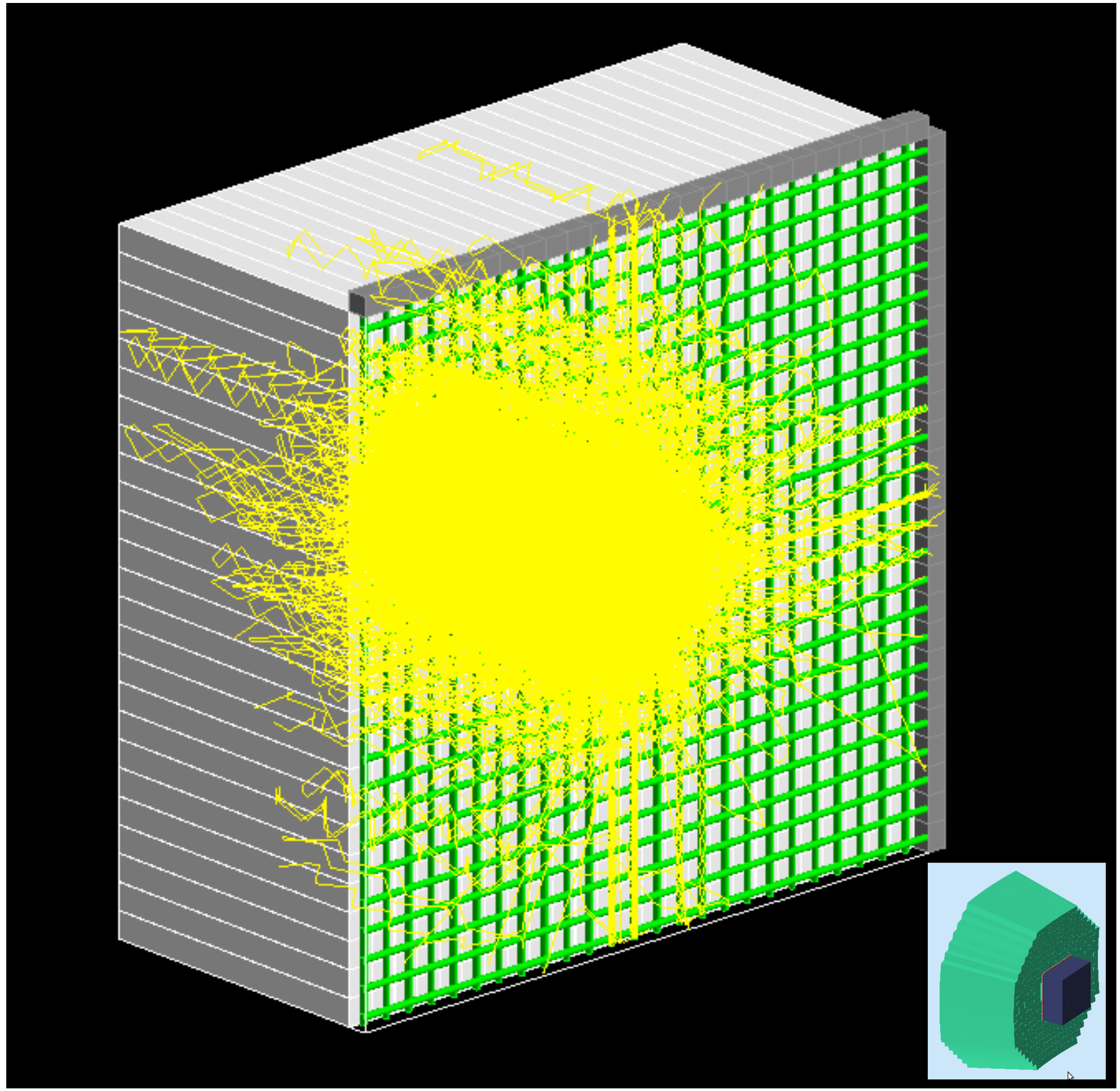






GEANT4 Simulations: Crystal Array





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).

Schedule - Short Term

For phase 1, the timeline depends on the delivery dates of the MPPCs. Assuming a timely delivery in June:

- prototyping wrapping - finish by July 15
- make wrappings for 625 crystals - finish by September 1
- begin stacking - start August 1
- finalize production of crystal array housing - finish August 1
- finish stacking - finish by September 1
- receive amplifier board - by July 15
- make 50 light guides - by August 1
- glue light guides, populate MPPC boards - by August 20
- prepare data acquisition system - by August 20
- fabricate light covers - by July 15
- fabricate outer light cover - finish September 1
- make cosmic ray test set up by August 10
- test MPPC read out with LED by September 1
- tests with cosmic rays/photon tagger starting September 15
- provide test results of the full prototype by December 1

Conclusions

- Project picking up speed now that funding is flowing and other major projects in our detector lab are finished
- We are about 40% finished with initial mechanical construction and electronics fabrication
- The design is modular, which allows different configurations of readout to be tested
- Light attenuation in the crystal has been measured to be small, using tagged annihilation photons
- Simulations are working at a basic level. They need to be carefully checked and integrated into larger frameworks
  - The optimization of the preshower can be influenced by the main calorimeter design; need detailed simulations with both

Backup slides

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)	**$38.5(7)\times10^9$ 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/cm³)	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.

Text

Wavelength Shifting Fibers

Formulations

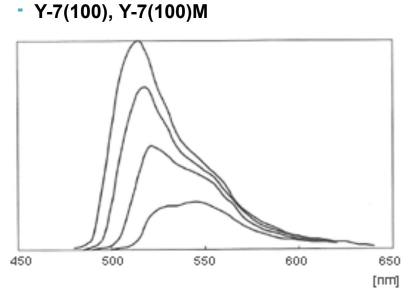
Description	Emission			Att. Leng.2) [m]	Characteristics
	Color	Peak [nm]	Spectra		
Y-7(100), Y-7(100)M	green	490	See the following figure	>3.0	Green Shifter
Y-8(100), Y-8(100)M	green	511		>2.8	Green Shifter
Y-11(200), Y-11(200)M	green	476		>3.5	Green Shifter (K-27 formulation)
O-2(100), O-2(100)M	orange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

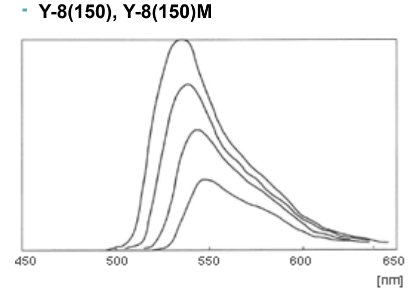
Emission Spectra

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



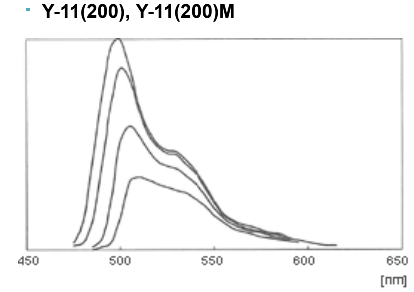
Exiting Wavelength: 440nm

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



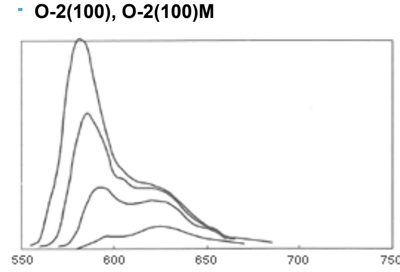
Exiting Wavelength: 455nm

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



Exiting Wavelength: 430nm

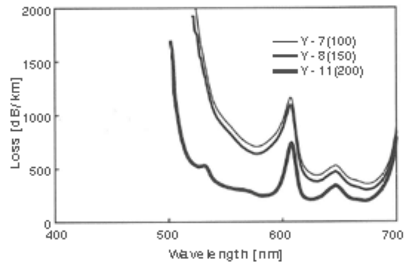
- O-2(100), O-2(100)M



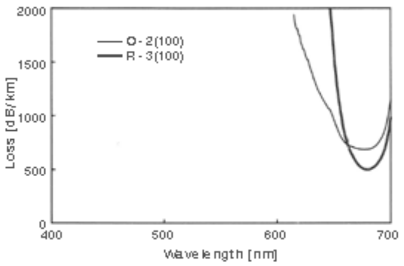
Exiting Wavelength: 430nm

Transmission Loss

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



- O-2, R-3



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%.

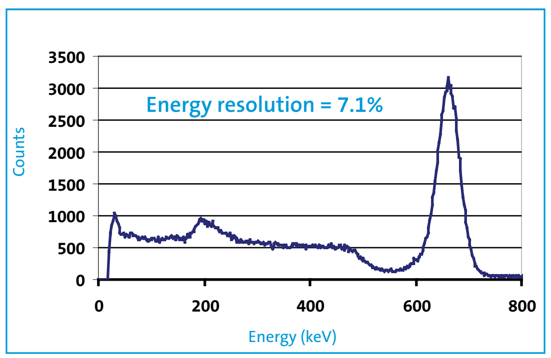


Figure 2. PreLude™ 420 Response to 662 keV Photons

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.

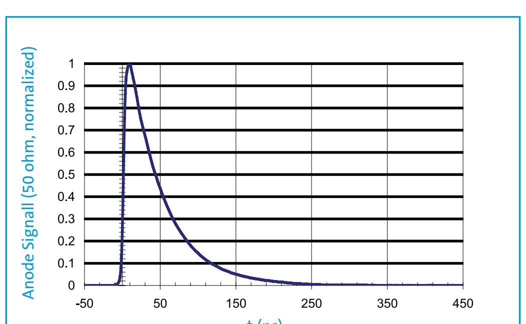


Figure 2. PreLude™ 420 response to 511 keV with R3241 PMT

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.

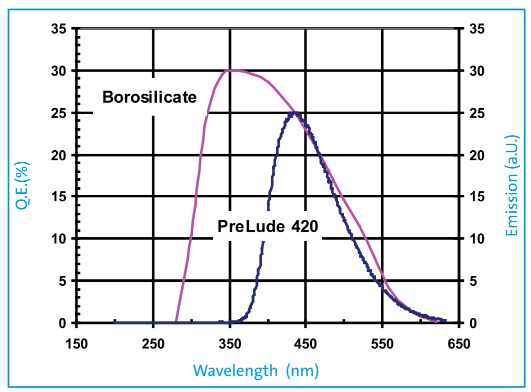


Figure 3. PreLude™ 420 Emission & ETI 9266 Q.E. (Q.E. data courtesy of Electron Tubes, Inc.)

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

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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.

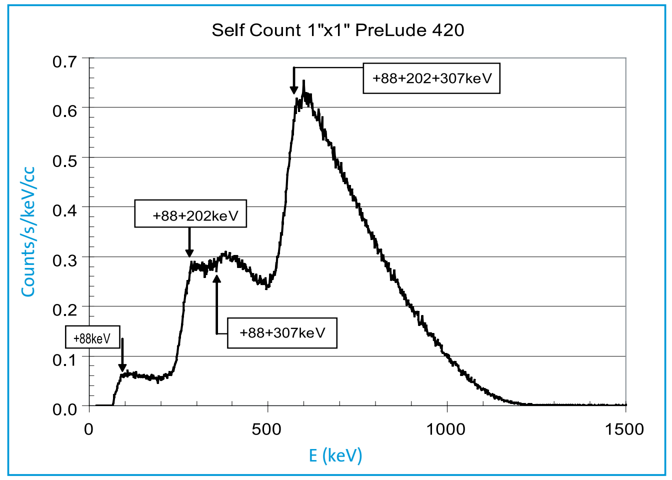


Figure 4. **Beta distributions**

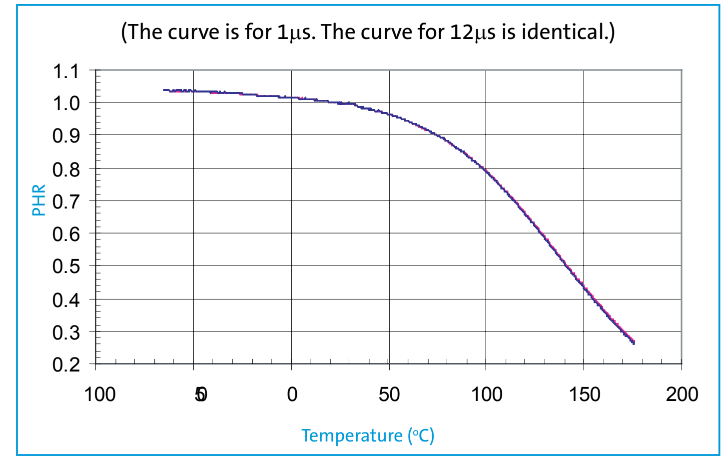
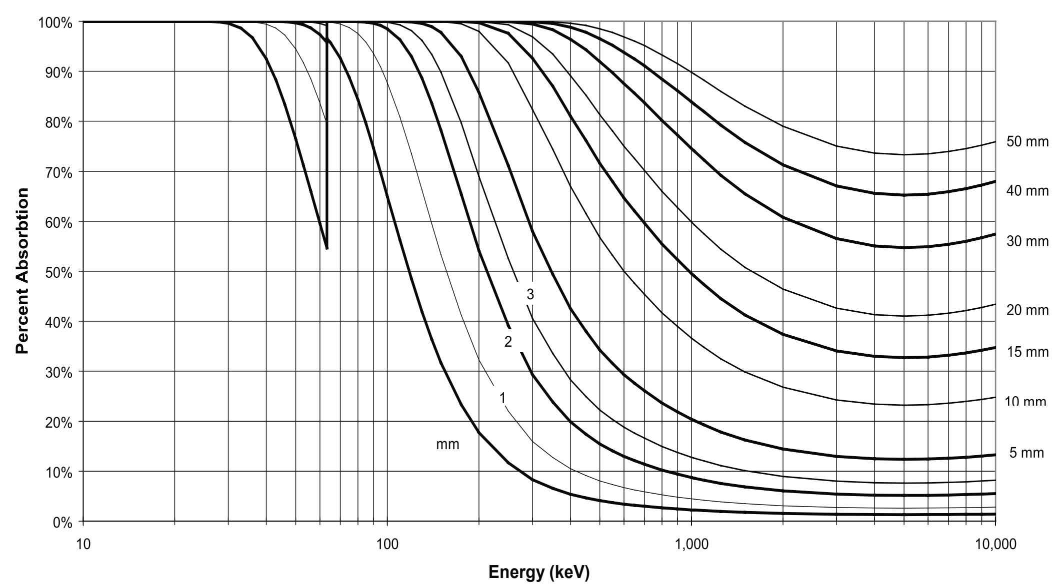


Figure 5. **Temperature response**



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.")

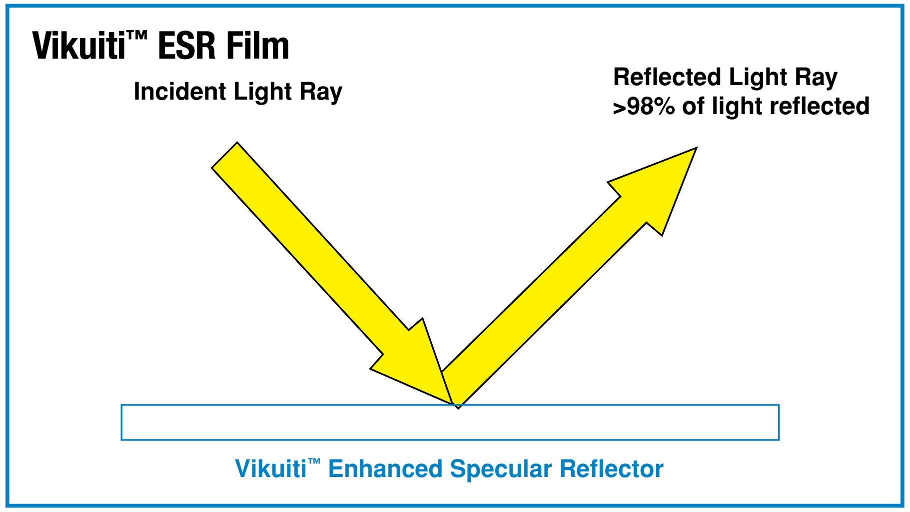
Table comparing principal properties of PreLude™ 420 versus BGO and LSO

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.

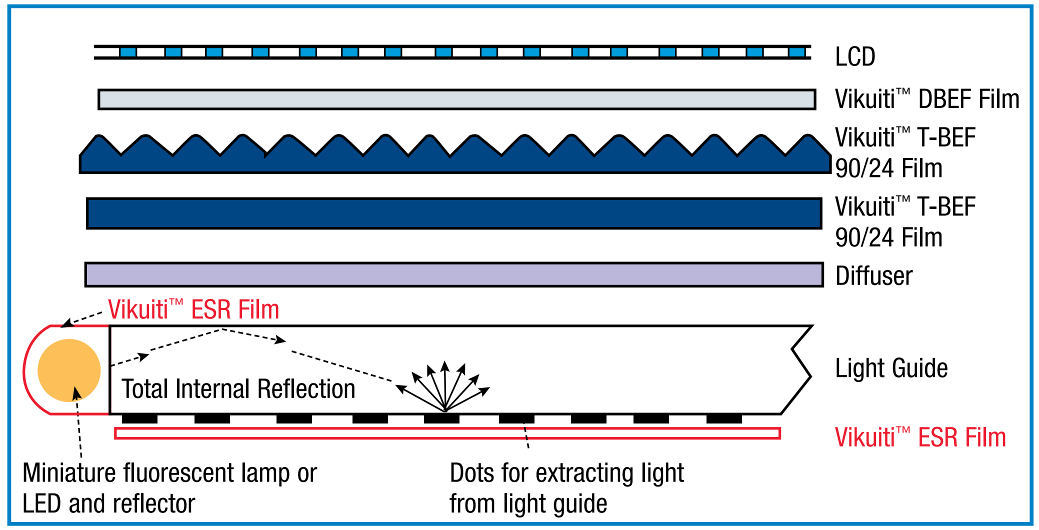


Nominal film properties

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″