Elettra Sincrotrone Trieste

DEELS 2025

Beam Loss Monitor

High Speed Detection System

Sandi Grulja , 10th of may 2025

Elettra Sincrotrone Trieste

Introduction

As Elettra 2 advances toward becoming a next-generation synchrotron light source, achieving higher brightness and stability, the demand for precise and time-resolved diagnostics becomes increasingly critical. Among these fast and sensitive beam loss monitoring is essential to safeguard components optimize beam tuning and support machine protection systems.

- ELETTRA 2.0

In this context we are developing a novel beam loss monitor (BLM) system based on scintillating optical fiber coupled to a silicon photomultiplier (SiPM or MPPC). This approach offers several advantages over traditional BLMs. It provides a nanosecond scale time resolution and sensitivity to individual bunch losses. Such capabilities are particularly suited to Elettra 2's low-emittance high repetition rate environment enabling both fast detection of beam loss events and detailed analysis of bunch dynamics.

This presentation outlines the motivation, design principles and expected performance of the fiber based BLM system tailored to the evolving needs of Elettra 2.

BLM

What is a Beam Loss Monitor (BLM)?

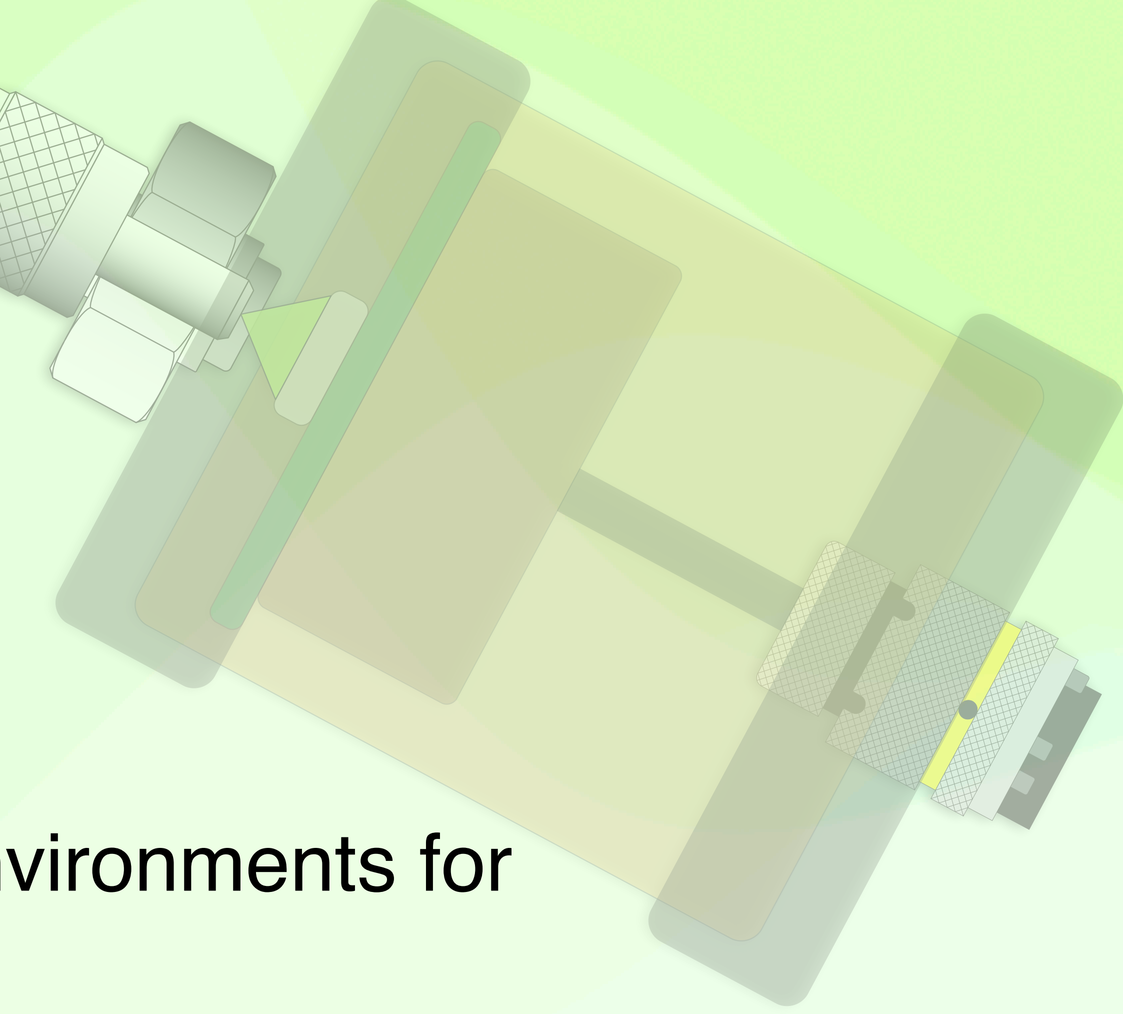
A **beam loss monitor (BLM)** is a device used in particle accelerators to detect and measure the loss of beam particles from the intended path. Beam losses occur when particles deviate from the main beam and hit the surrounding structures which can damage components or create unwanted radiation.

Key functions of a BLM:

- ☑ **Detect beam losses** in real time.
- ☑ **Protect accelerator components** by triggering beam shutdown if losses exceed safe thresholds.
- ☑ **Optimize beam tuning** by providing feedback on beam quality and alignment.
- ☑ **Measure radiation** generated by beam losses to ensure safety.

Why BLM with Scintillating Fiber?

- ☑ Continuous spatial coverage
- ☑ Fast response time
- ☑ No electronics in Tunnel exposed to a high level of radiation
- ☑ No electrical signals from detector to the measuring point
- ☑ Cost effective and easy to use



A beam loss monitor (BLM) using **scintillator fiber** is a common and effective choice in accelerator environments for detecting beam losses along the beamline.

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Beam Loss Monitor Setup

Saint-Bobain Scintillating Fiber:

- ☑ Emission peak: 492 nm (green)
- ☑ Decay time: ~ 2.7 ns
- ☑ Attenuation length: < 4 m

Key Components:

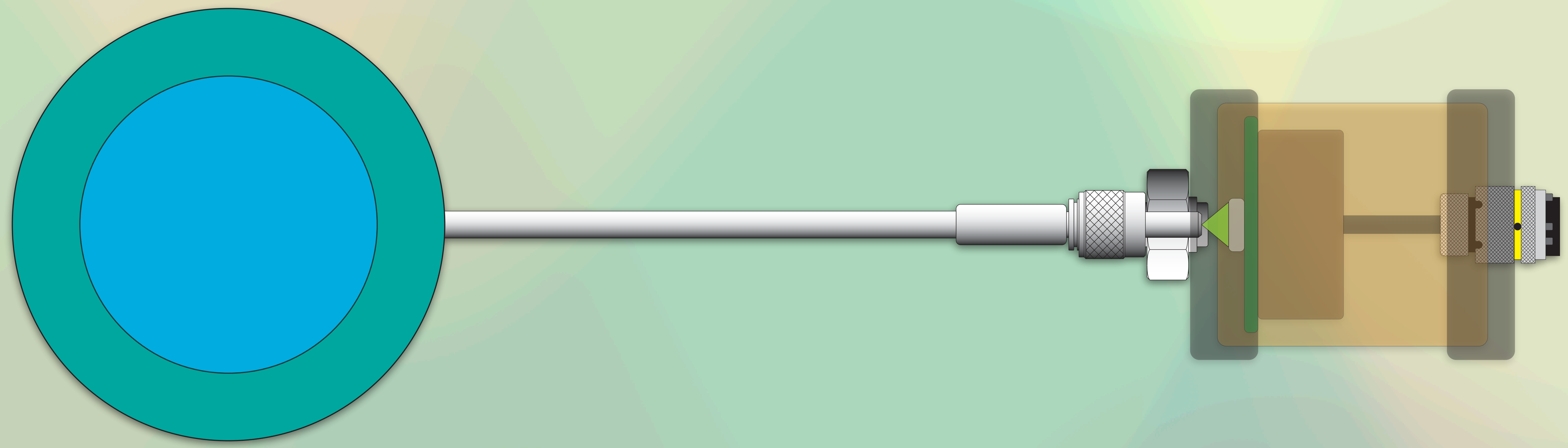
- ☑ BCF-20XL scintillating fiber
- ☑ Hamamatsu MPPC S14160-3010PS SiPM
- ☑ Fast preamplifier
- ☑ High speed ADC
- ☑ FPGA based DAQ

For High-Speed Detection:

- ☑ Fast decay scintillator (2.7 ns)
- ☑ Wide-bandwidth amplifiers (>100 MHz)
- ☑ Short shaping times (<10 ns)

Operating Principle

- ☑•**Beam loss particles** (e.g., electrons, protons, neutrons) interact with the fiber → emit scintillation light.
- ☑•**Light travels through the BCF-20XL fiber** and is detected by the **MPPC**.
- ☑•**MPPC output pulses** are amplified, shaped, and digitized.
- ☑•**Pulse rate and amplitude** indicate **location and severity** of beam loss.



Example Analysis of type 1 scintillator geometry

BCF-20XL scintillator plugged to Si MPPC exposed to 2ns electron shower of 100Mev

Total photons generated per shower:

$N_{Total} = 8000 * 100 = 800000$ *photons*

Photon energy:

$E_{492} = hc / lambda = 6.626\ 10^{-34} * 3\ 10^{8}\ / 492\ 10^{-9} = 4.04\ 10^{-19}\ J$

Total Efficiency to Detector:

$P_{hotons\ at\ MPPC} = 800000 * 0.0298 = 23840$

MPPC Efficiency:

$N_{Photonelectrons} = 23840 * 0.40 = 9536$

Signal Amplitude:

$Q = 9536\ 10^{6} * 2.2\ 10^{6} * 1.6\ 10^{-19} = 3.36\ nC$

$V_{signal} = Q/t*R = 3.36\ 10^{-9}\ / 2\ 10^{-9} * 50 = 33.36\ mV$

For a 50 Ω load

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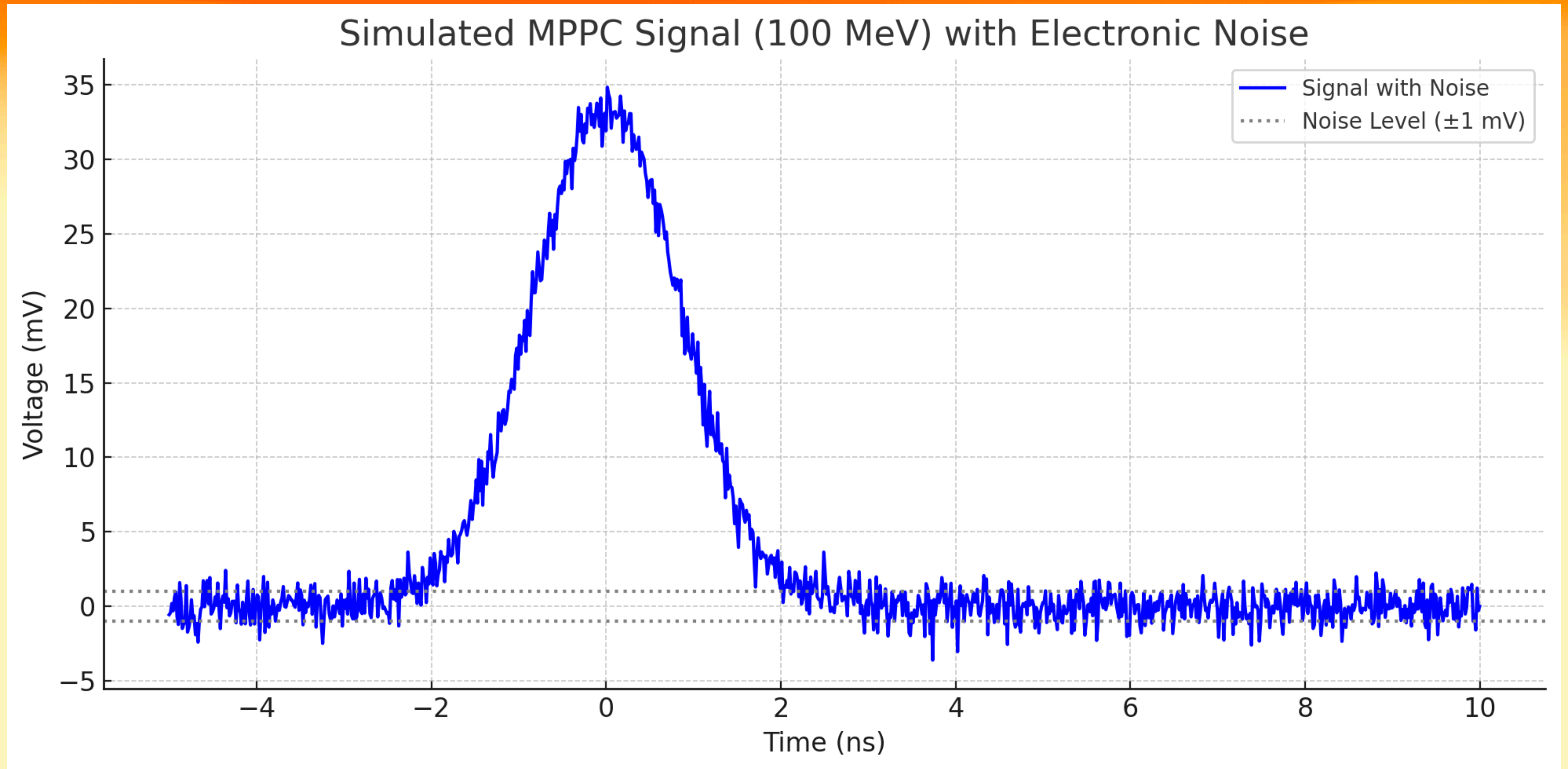
Timing Characteristics:

BCF-20XL decay time: ~2.7 ns
MPPC TTS (transit time spread): ~200–300 ps
Fiber propagation delay: ~5 ns/m
Timing resolution dominated by scintillator and MPPC jitter

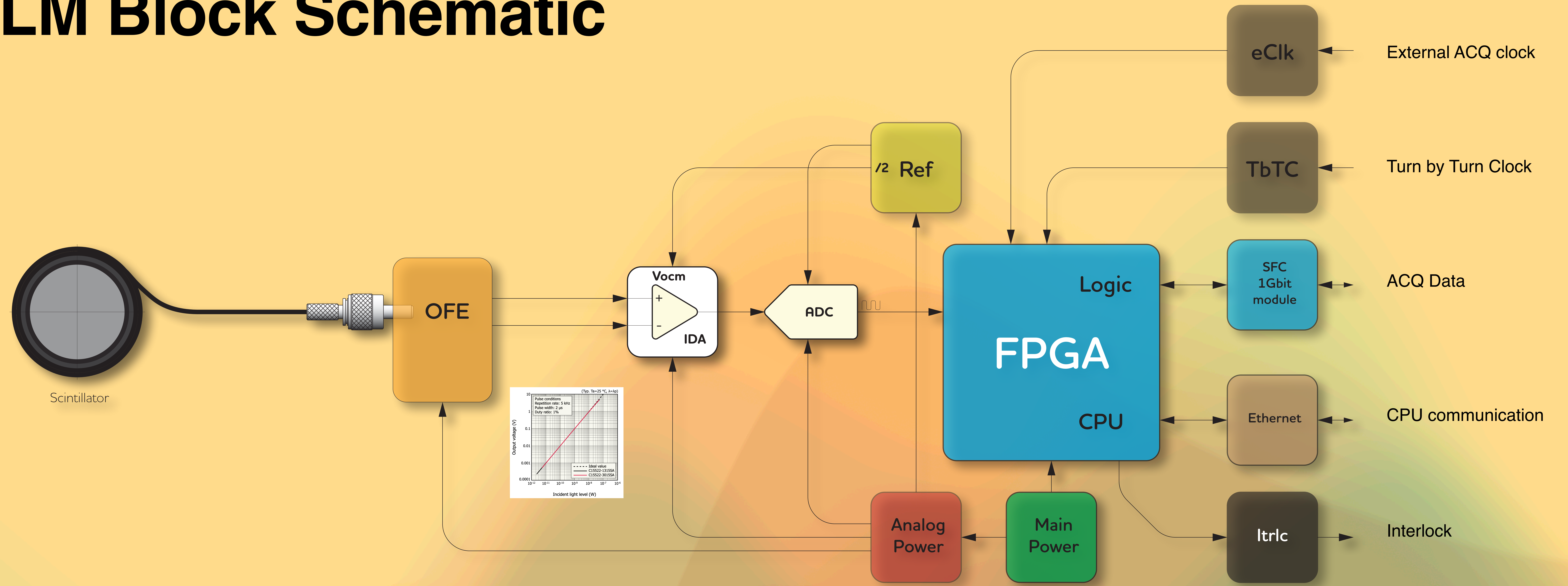
Estimated timing jitter (σ):

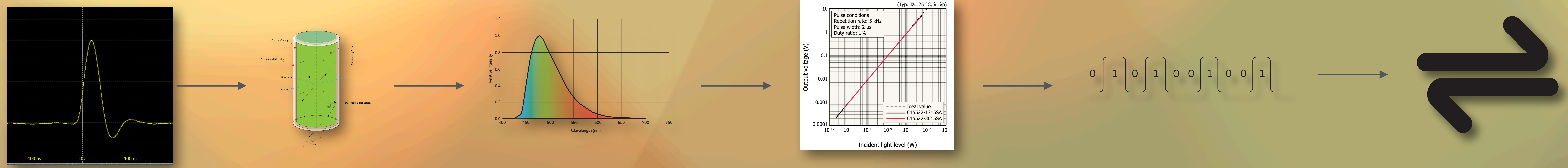
$\sigma_t = sqrt\{ (2.7ns * sqrt\{7488^2\} + 0.3^2 ns \} = 0.32\ ns$



MPPC signal with realistic electronic noise of a type 1 scintillator geometry

BLM Block Schematic





From Losses to the System

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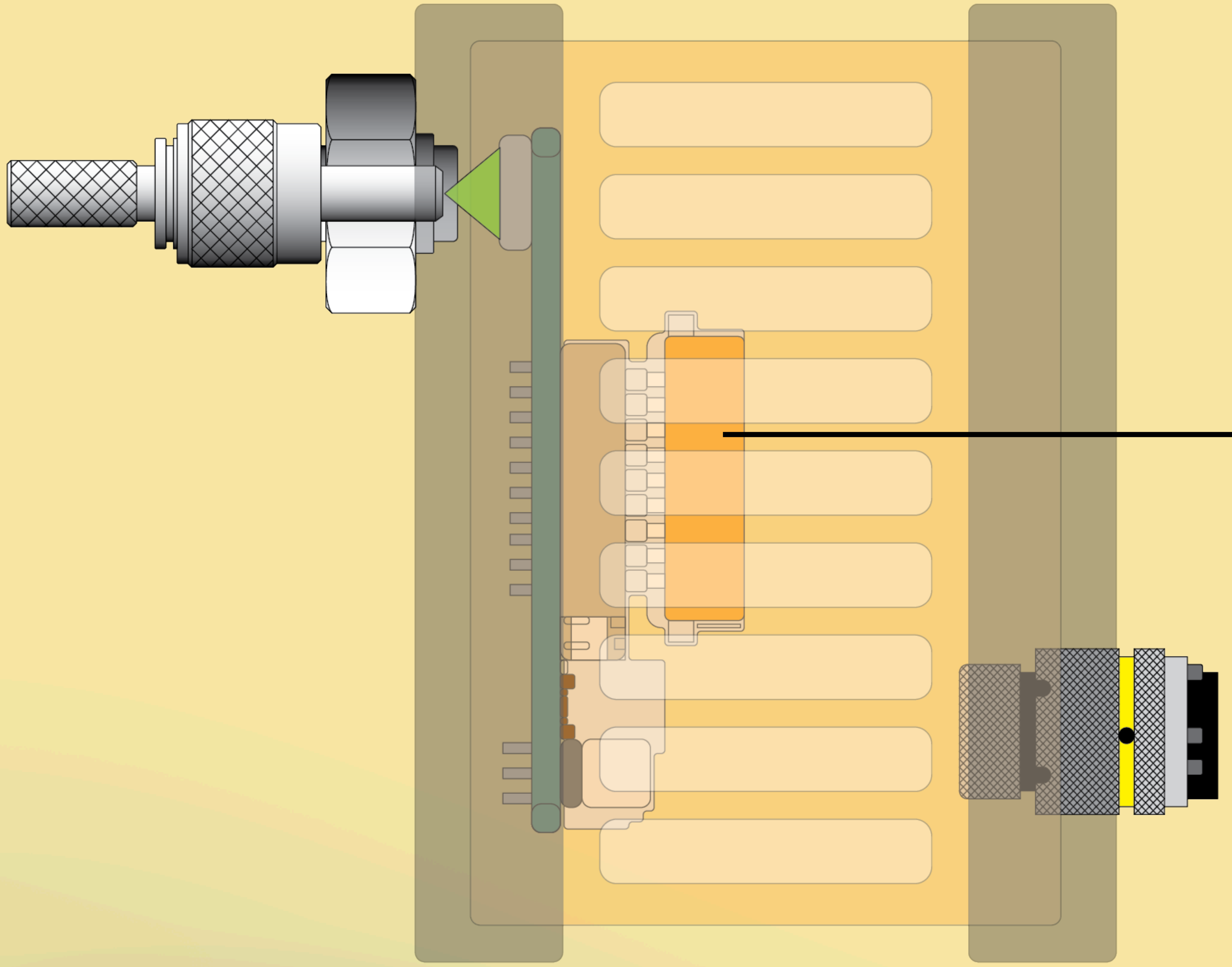
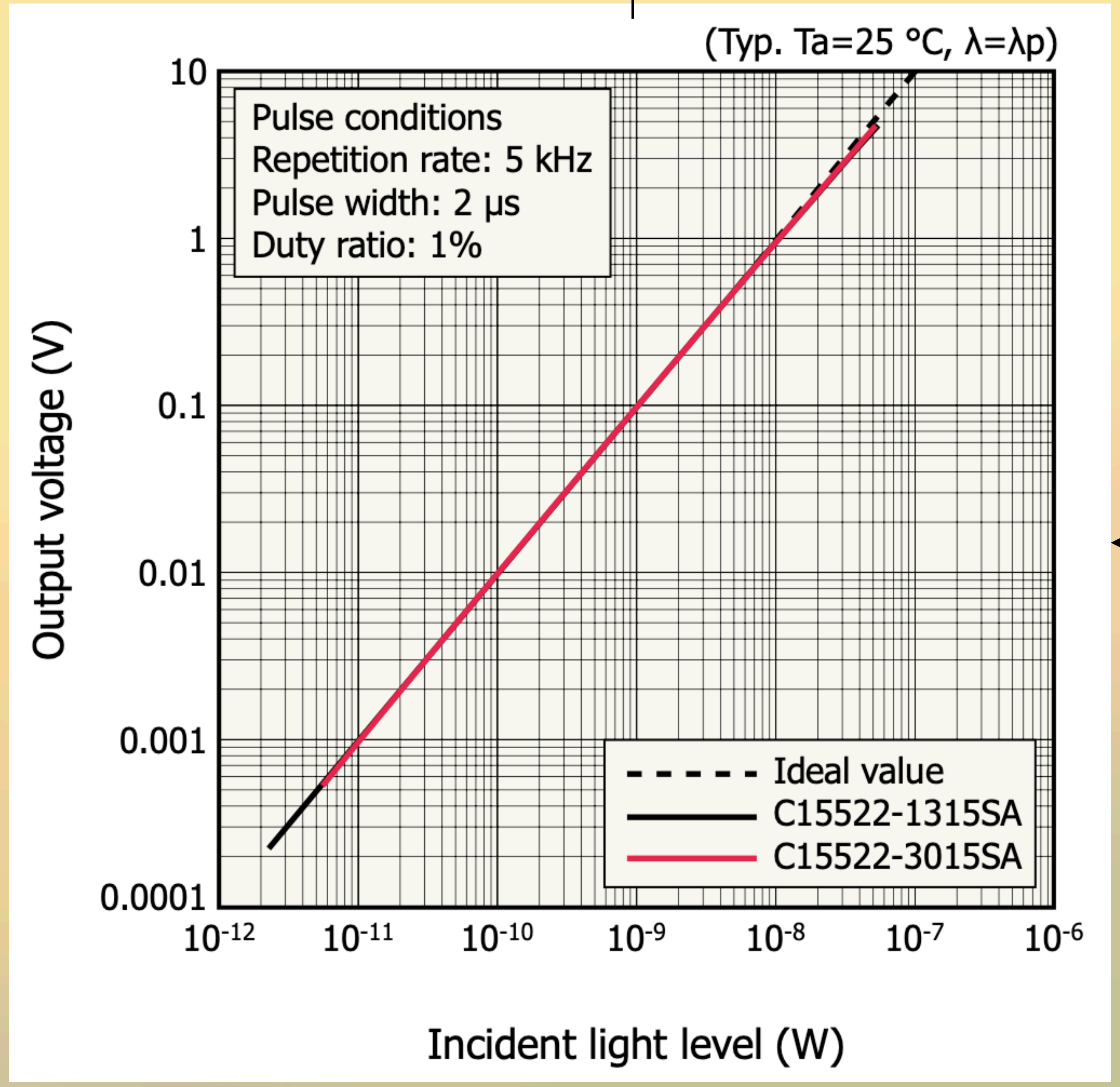
Optical Front End

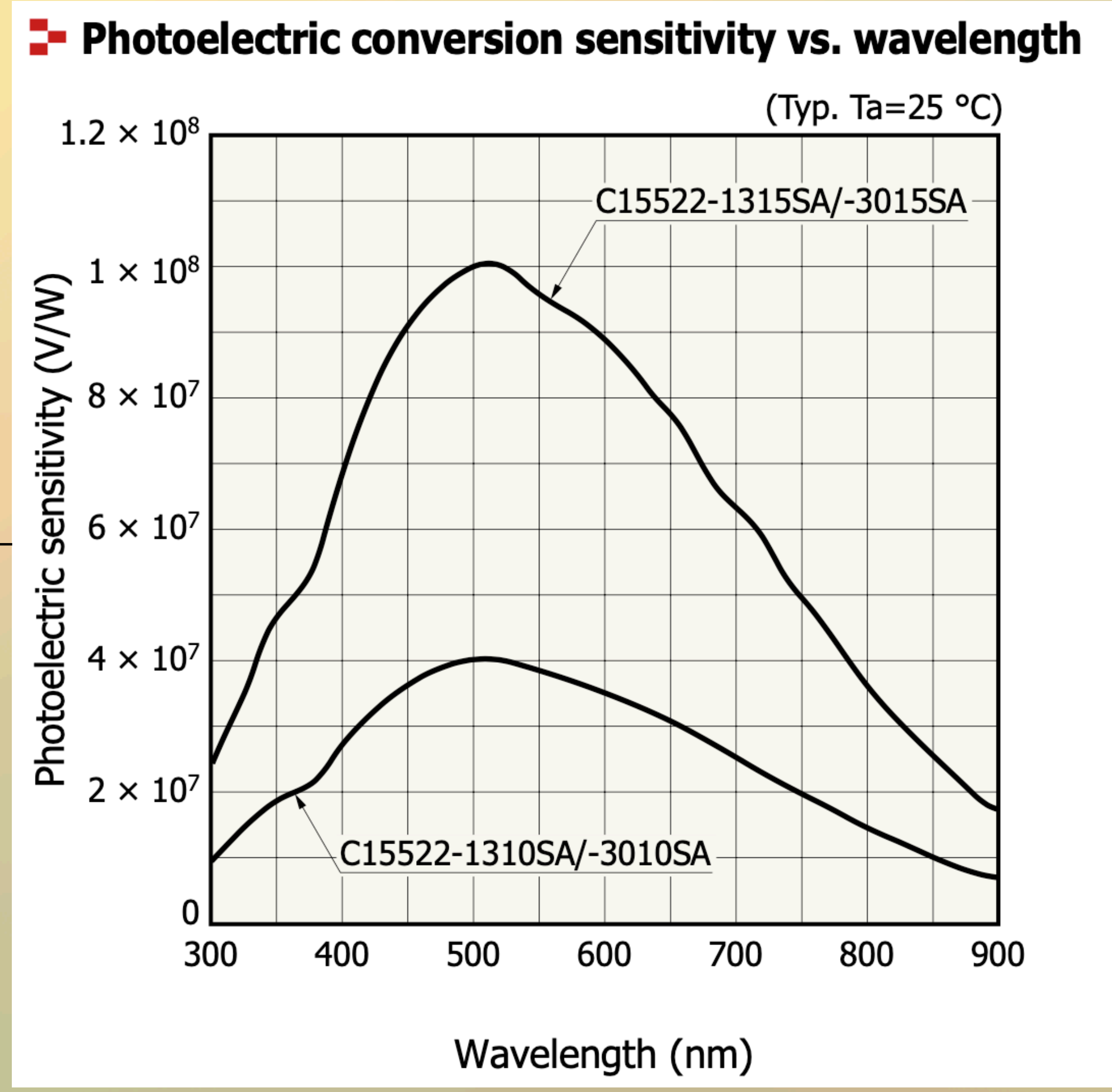
MPPC Frond End



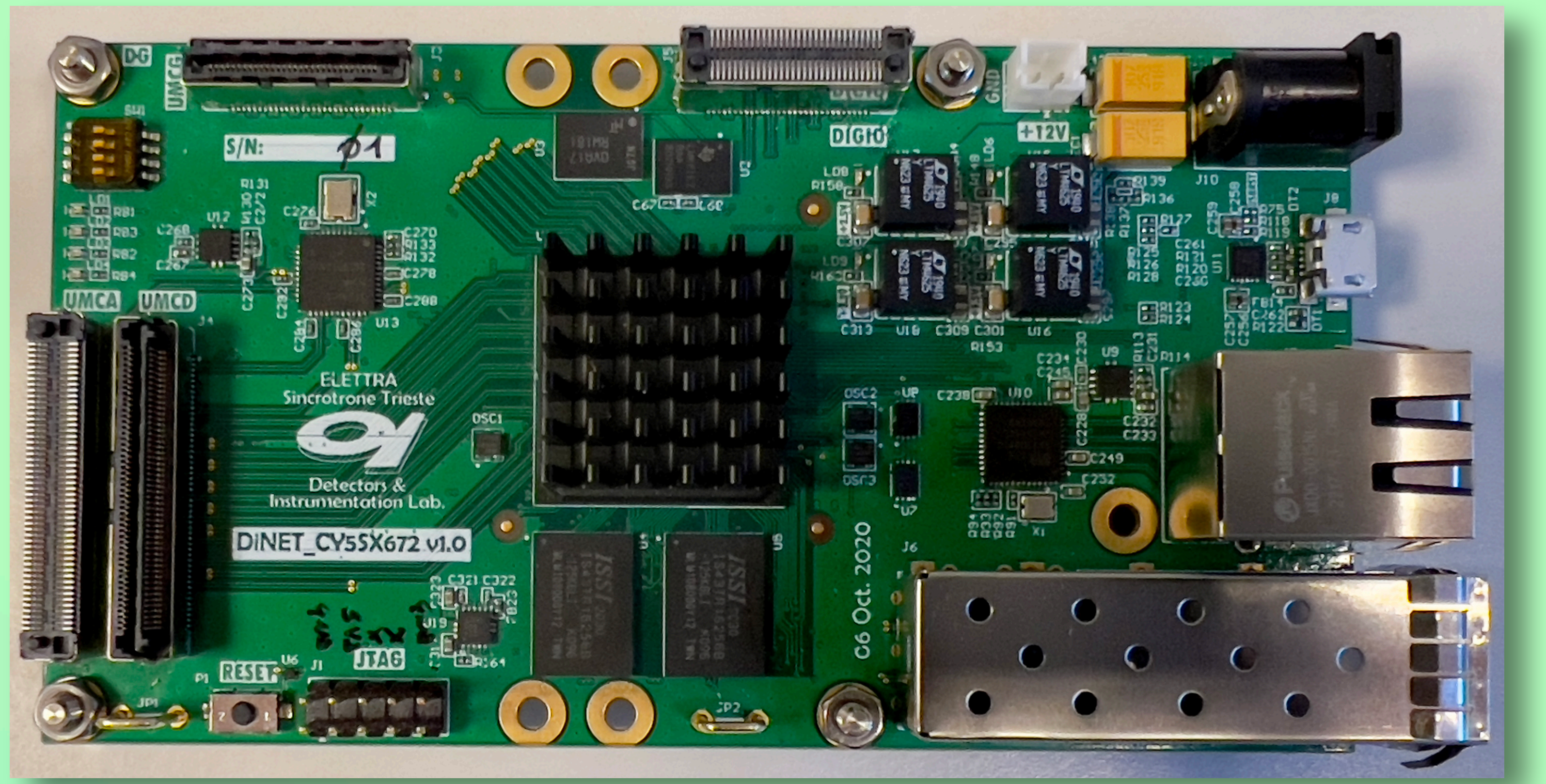
Spectral response range	λ	290 - 900 nm
Photoelectric sensitivity	λ=λp	0.3 - 0.7 x 10^8 V/W
Temperature stability of output voltage	Ta=25	-5 to +5 %
Peak sensitivity wavelength	λp	500 nm
Minimumdetection limit		10 pW rms
Maximum output voltage		4.7 V

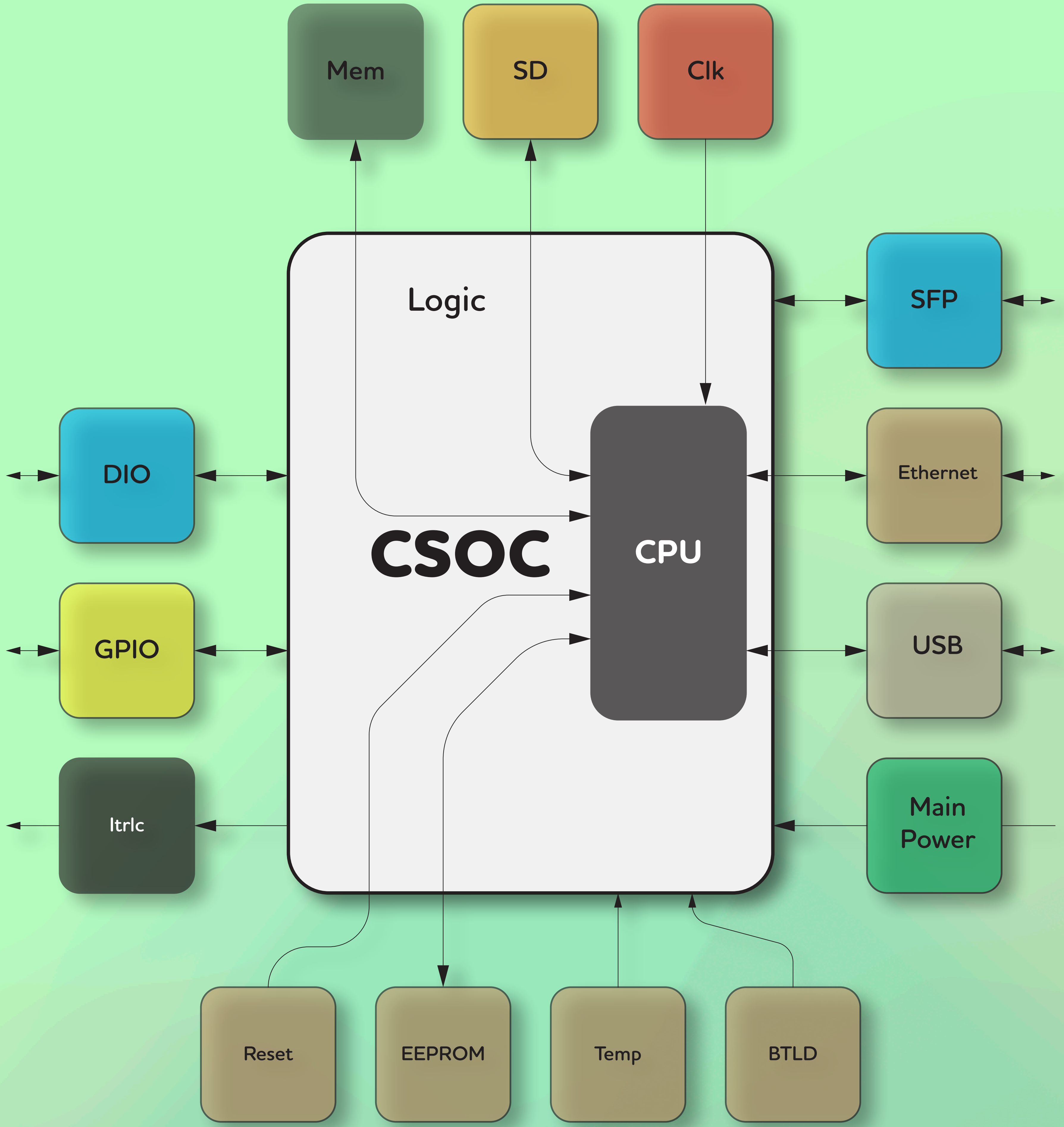
Electrical and Optical characteristics





ACQ Logic Board with CPU



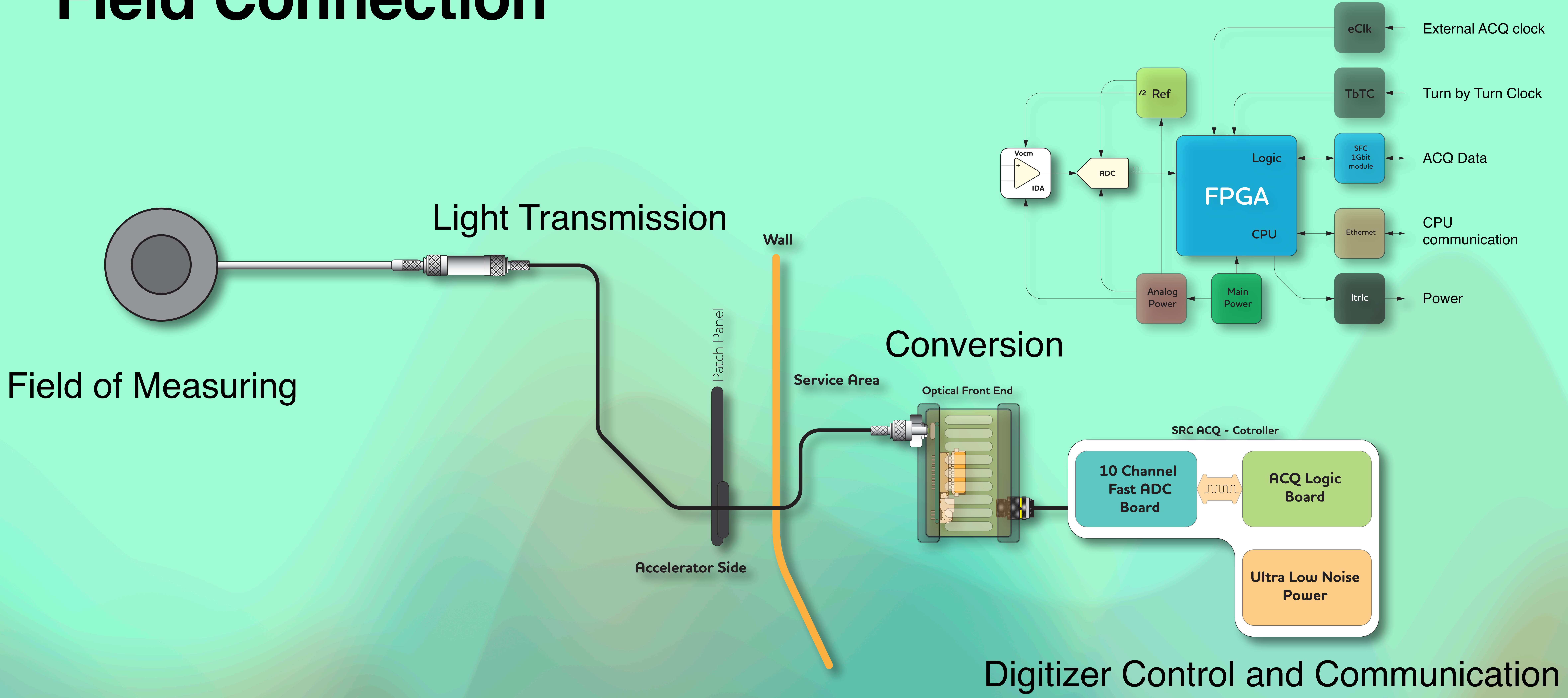


ACQ Logic Board with CPU:

- 10 Channel SRC Input
- 8 Channel GPIO
- SFC high speed Data Transmitter
- Ethernet, USB protocol Port
- Single 12V, 36W Powe Supply
- External Turn by Turn Clock
- External ACQ Clock
- 3 Level Interlock Outputs

Tango Server Interface

Field Connection



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BLM Architecture

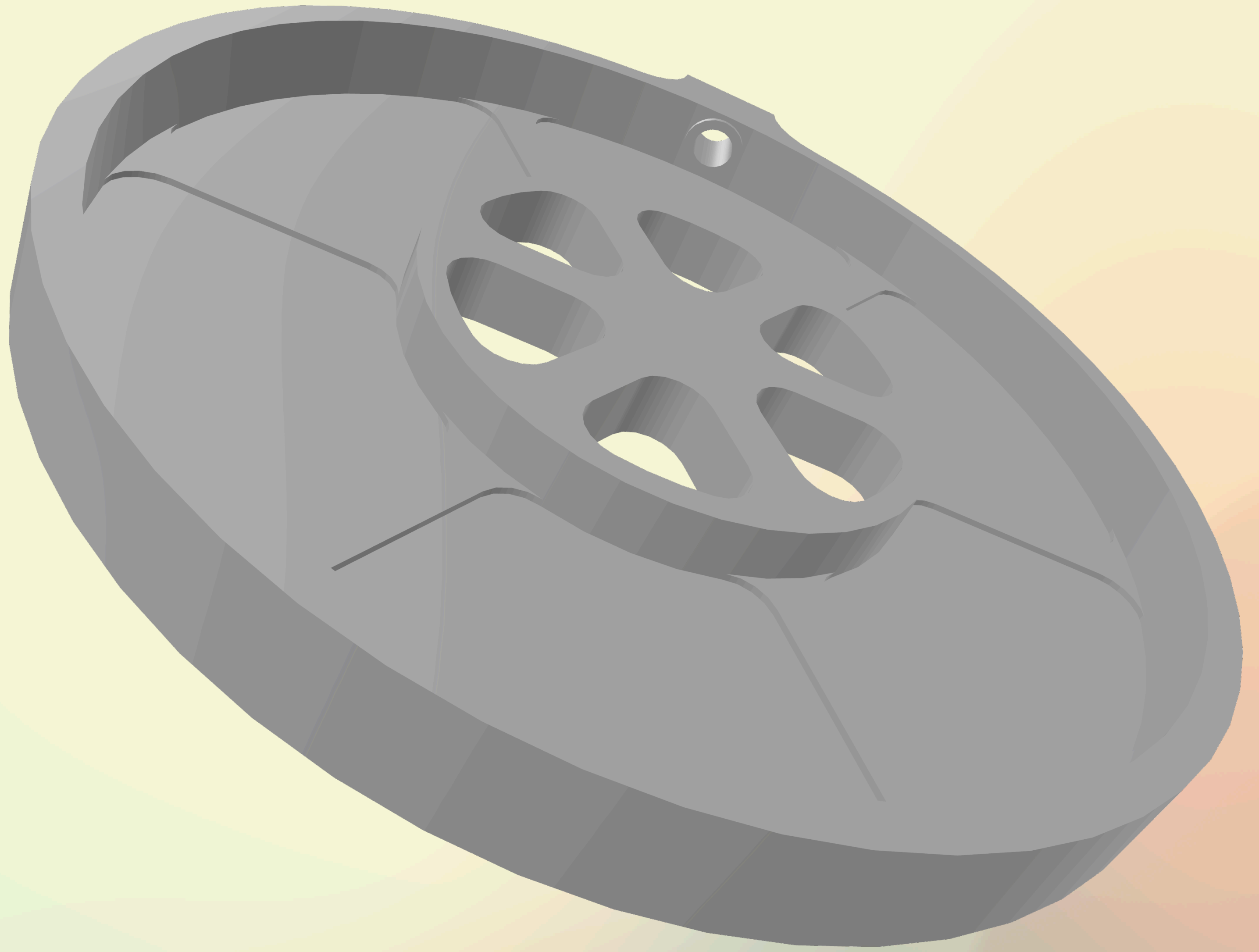
Scintillator Fiber Head Shell

Type 1

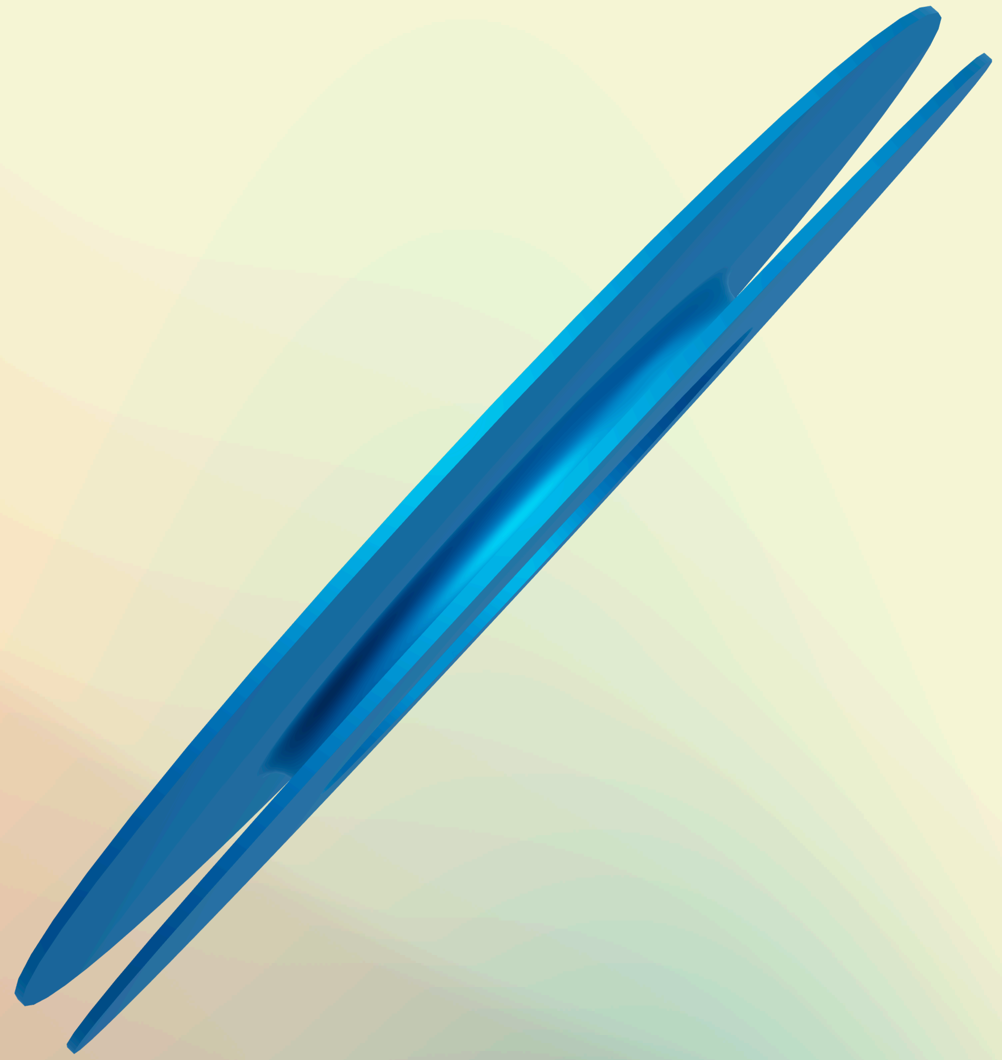
Specifications:

- External diameter 80mm
- Inner section from 74 to 40mm diameter
- Wall thickness 1mm
- Total hight 8mm

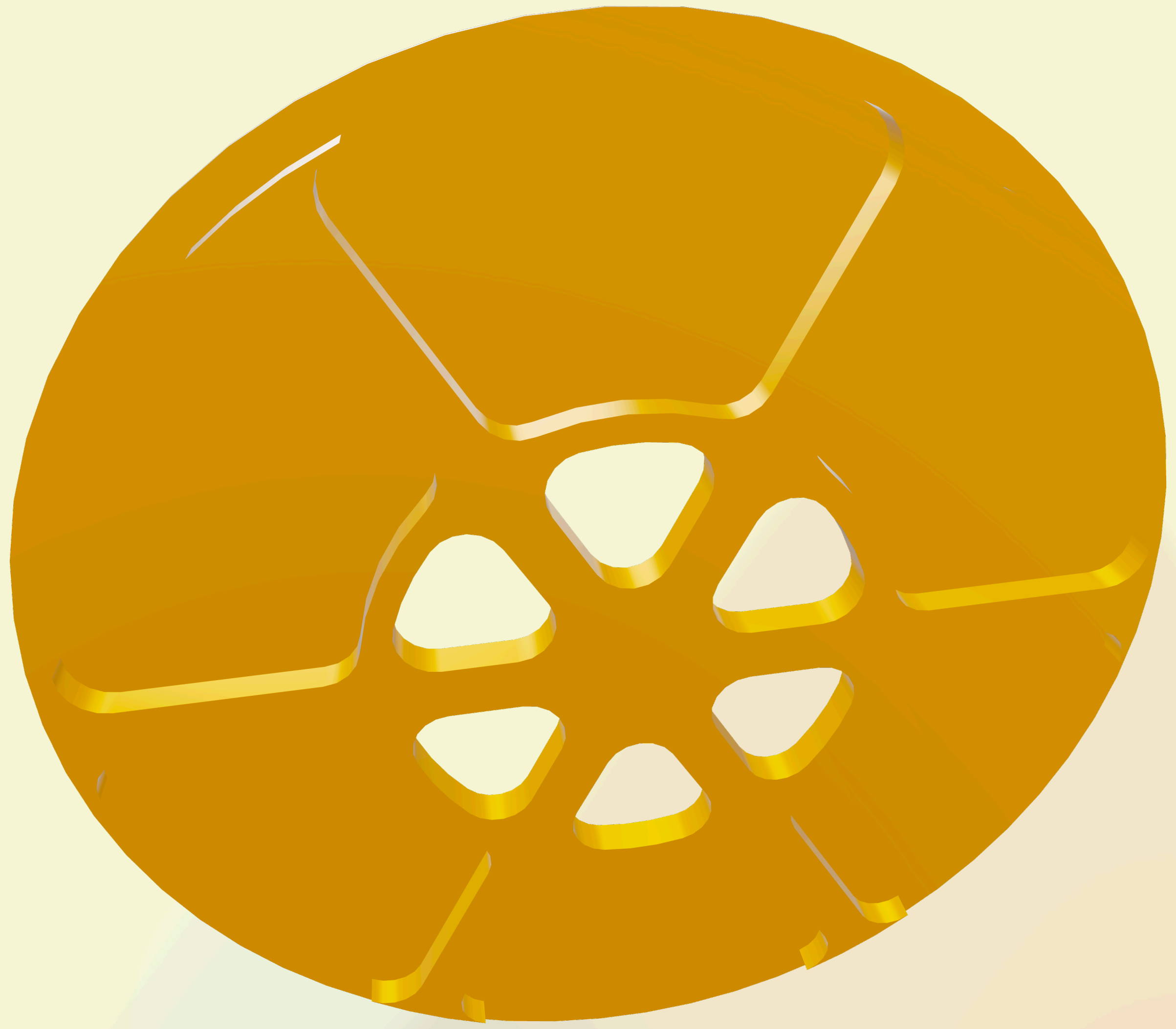
1



Shell bottom



Fiber disk



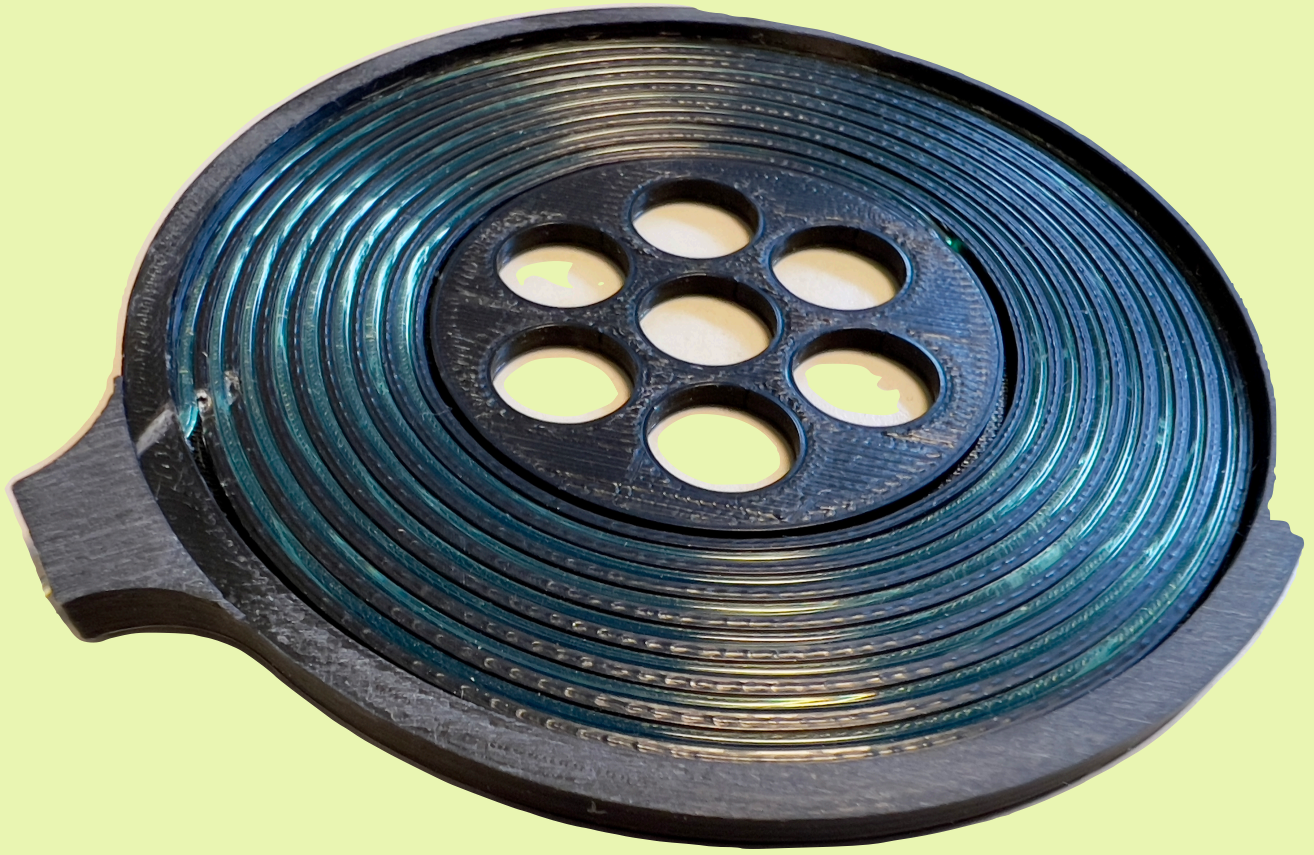
Shell cover

3D models printed with 3D printer in high density mode

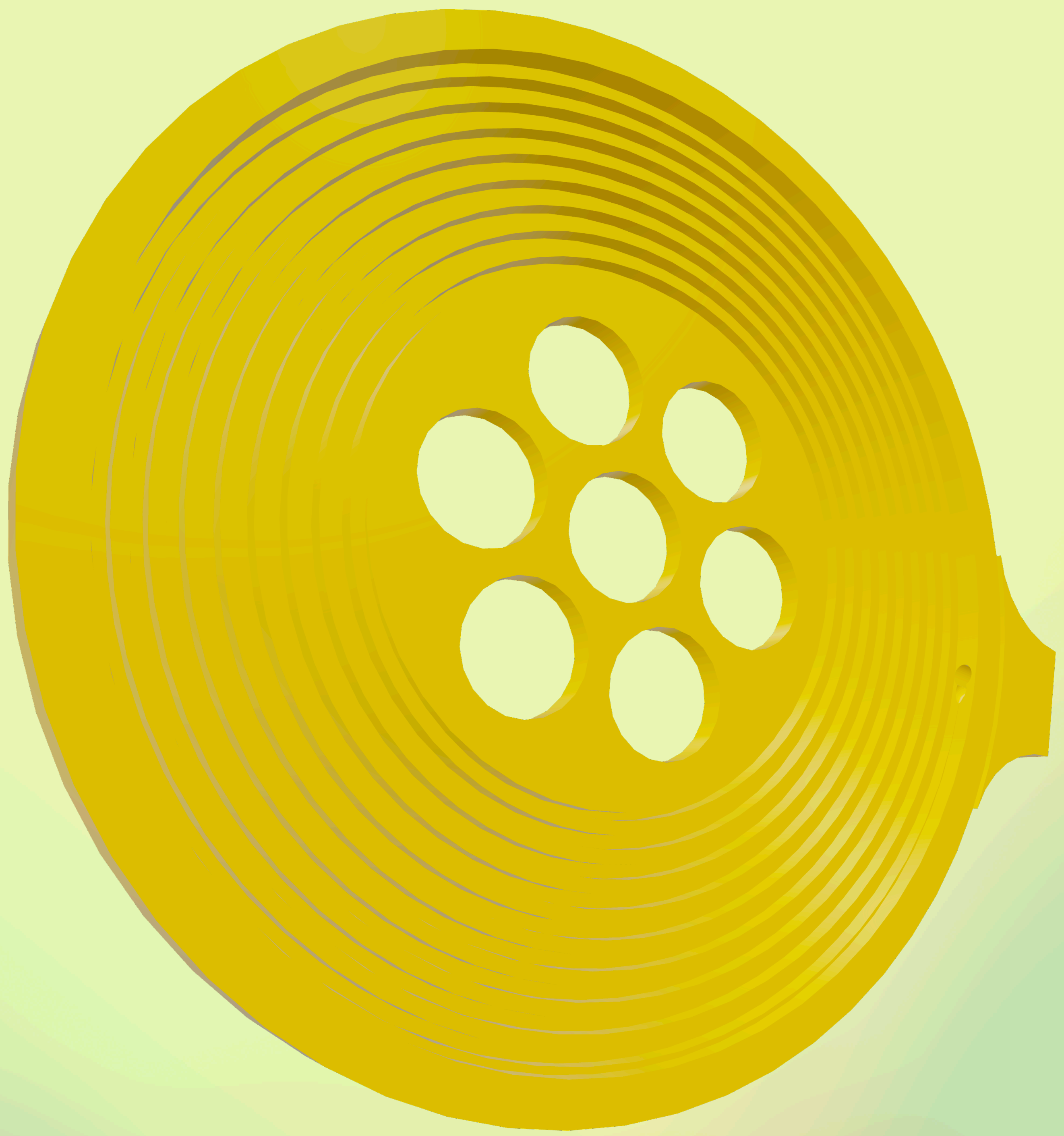
BLM Architecture

Scintillator Fiber Head Shell

Type 2

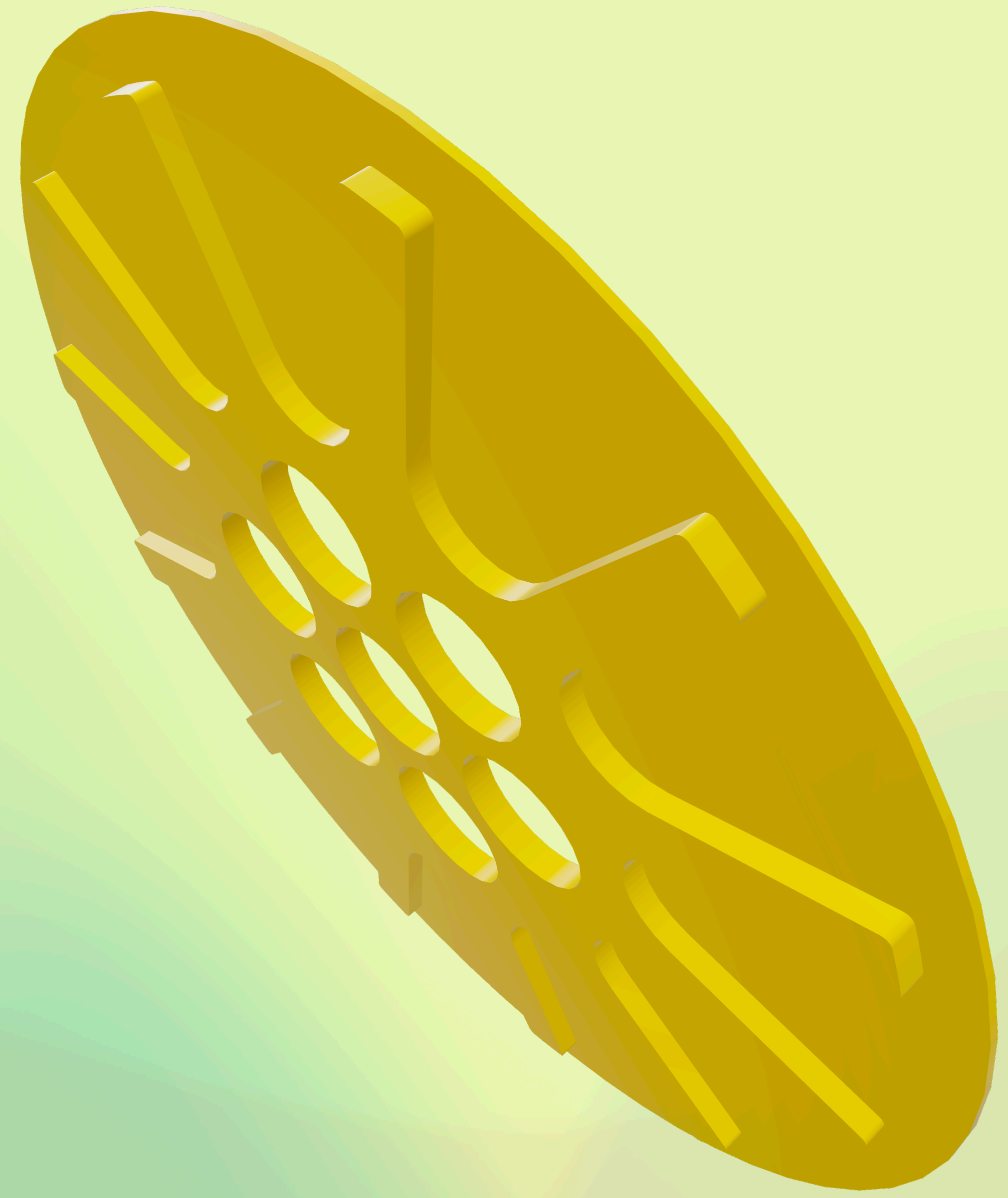


2



Reduced assembled shell to 4mm total hight.
Other specifications identical to version 1.

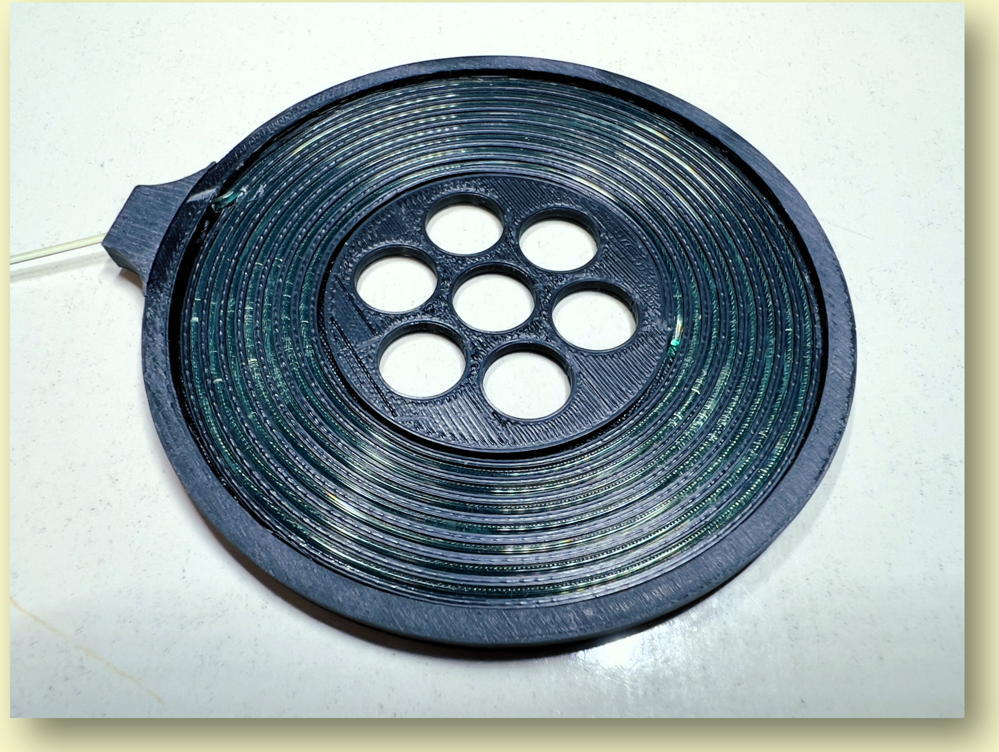
The wall thickness is 1mm



Shell with imprinted 1mm spiral for scintillator fiber position

3D Printed shells with radiation tolerant material

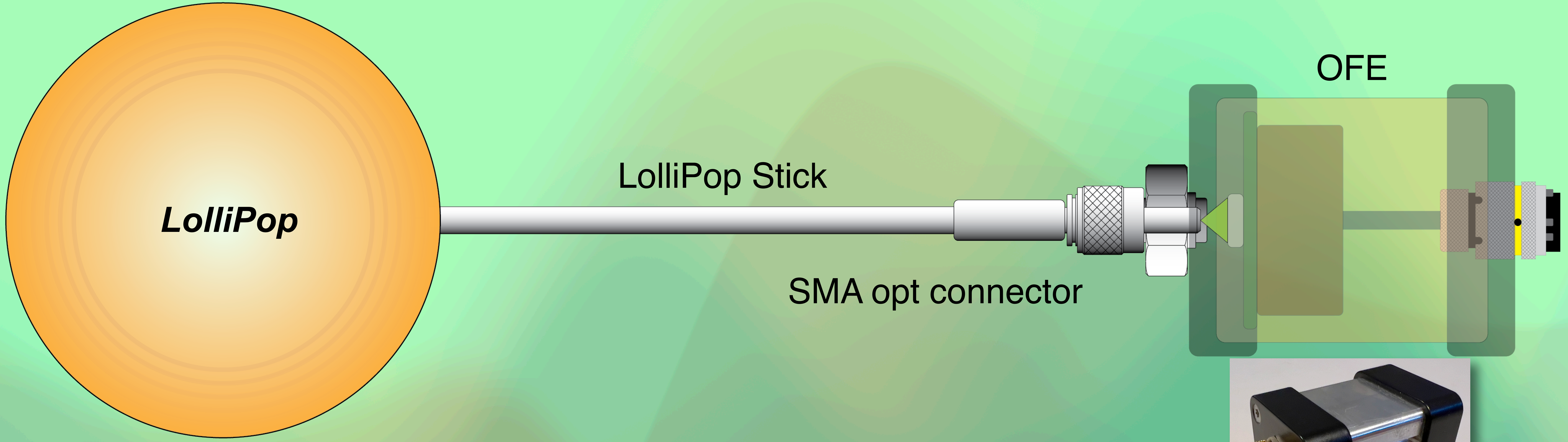
3

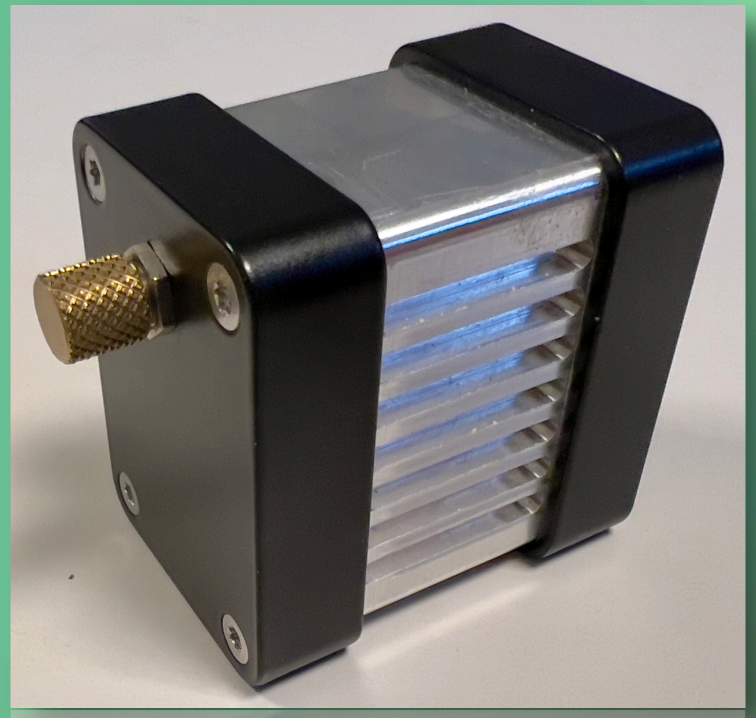


Scintillator Head with Optical front end

Assembled Scintillator and OFE

Scintillator Pickup

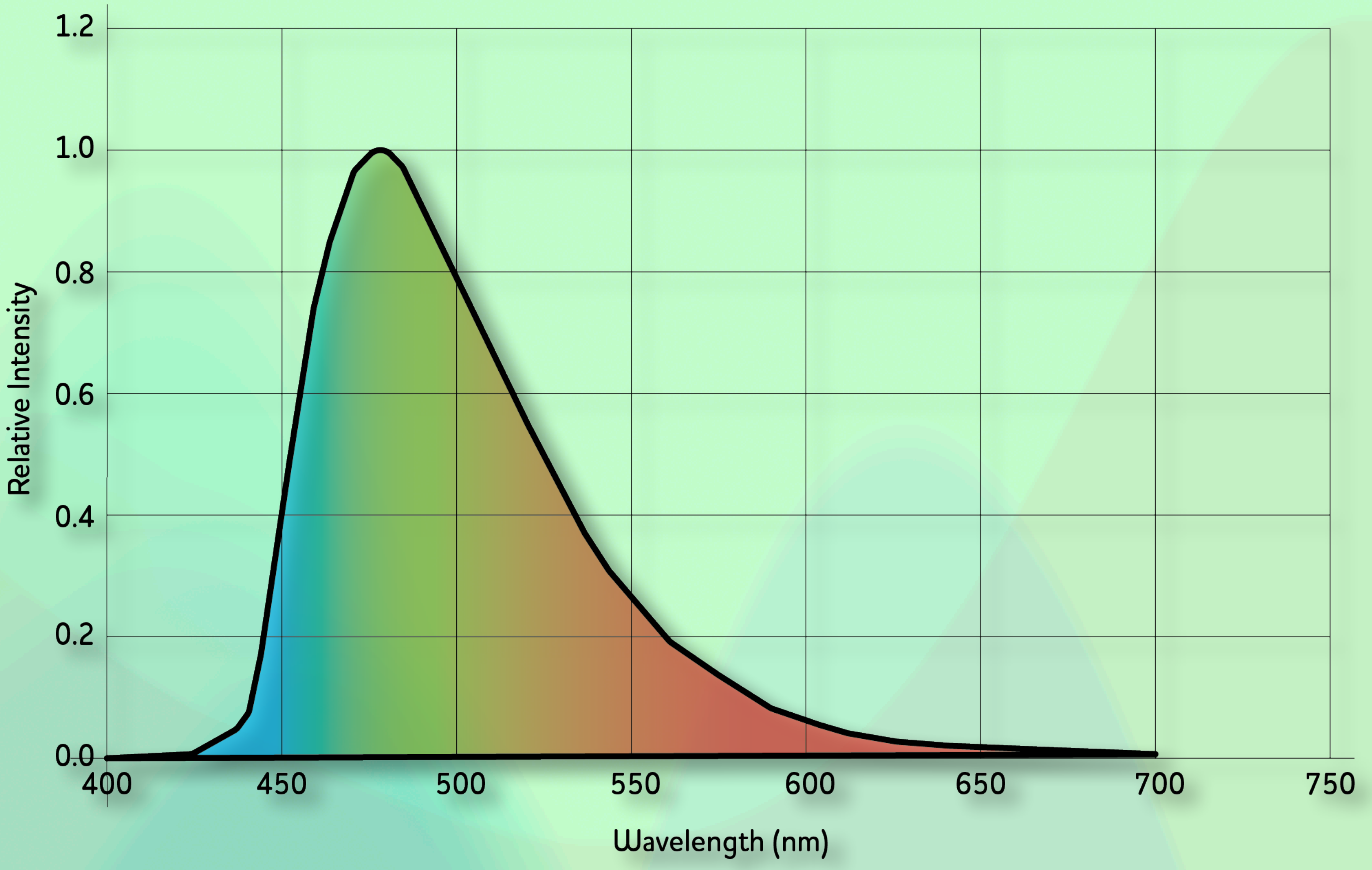




Fast Scintillator Fiber

BCF-20XL

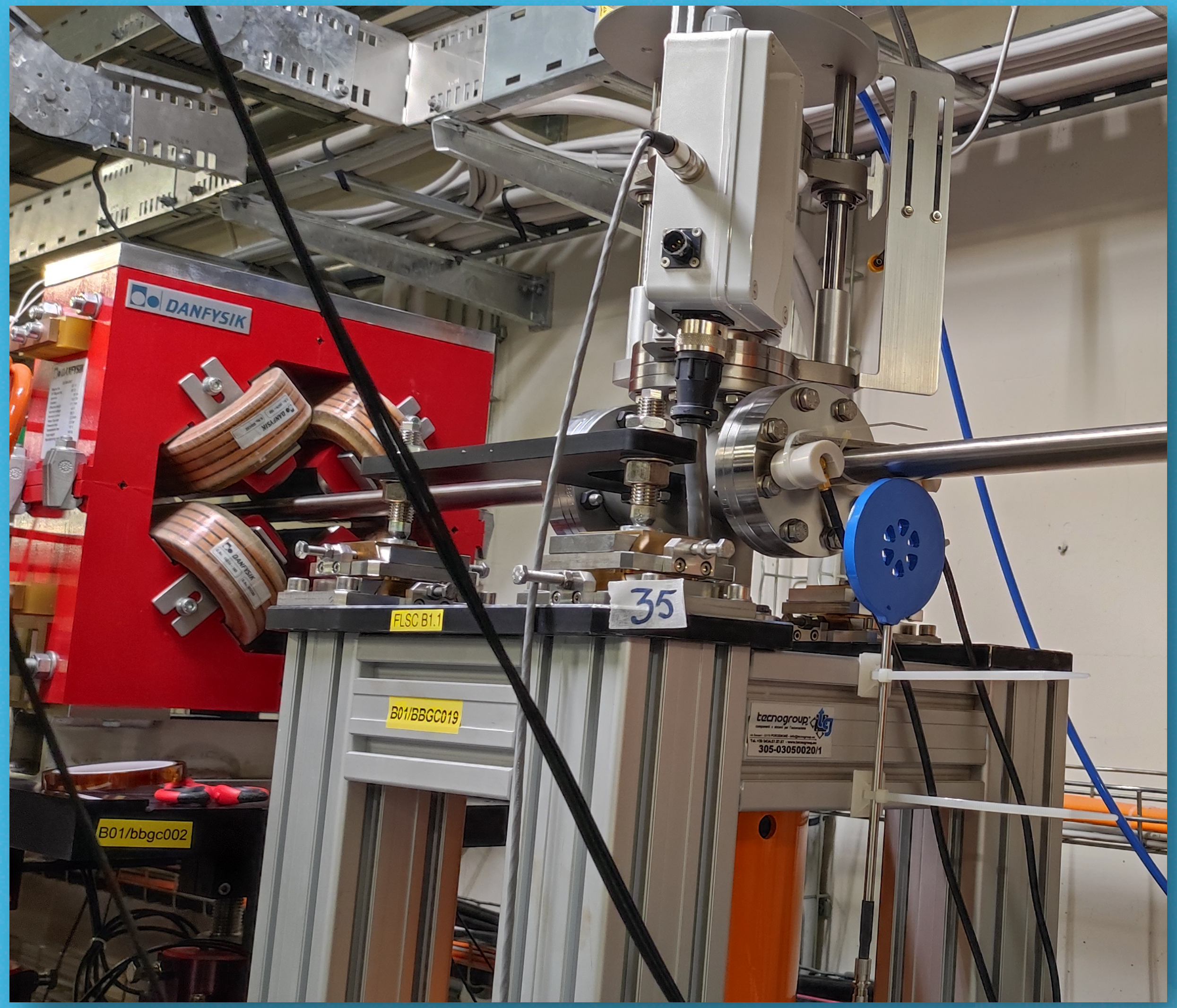
- Fast Green-Emitting Scintillator Fiber
- BC-428 is a clear, transparent plastic scintillator with bright green fluorescence.
- For use with photodiodes which have optical sensitivities in the green and red portions of the spectrum.
- Base material is Polyvinyltoluene and a very low expansion.
- Light output at +60°C = 95% of that at +20°C. Independent of temperature from -60°C to +20°C. Softening point is at 70°C



- All scintillating fibers are sensitive to fast neutrons through proton recoil.
- The light output as # of photons per MeV for minimum ionizing Particle, which is approximately 8000.
- The typical bend radius is 30-40 times the diameter of the fiber.

Fiber Type	*Emission Color*	*Emission Peak, nm*	*Decay Time, ns.*	*# of Photons per MeV**	*Attenuation Length (m)**.*	*Characteristics*
BCF-20XL	**green**	**492**	**2.7**	**~8000**	**>4**	**Fast green scintillator**

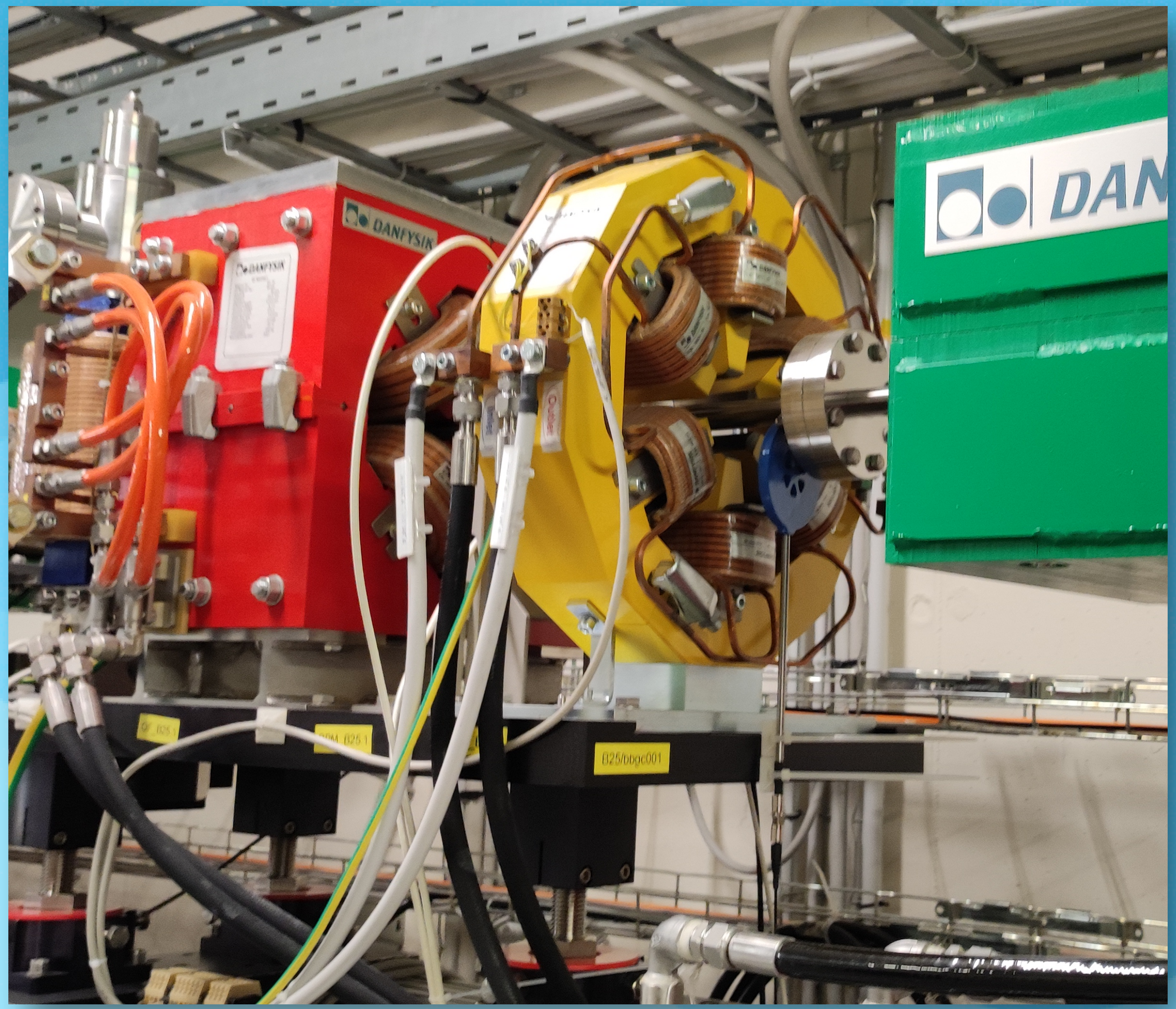
Beam Losses in ELETTRA Booster



Location close to Injection

Current about 300uA

Location at the end of Booster



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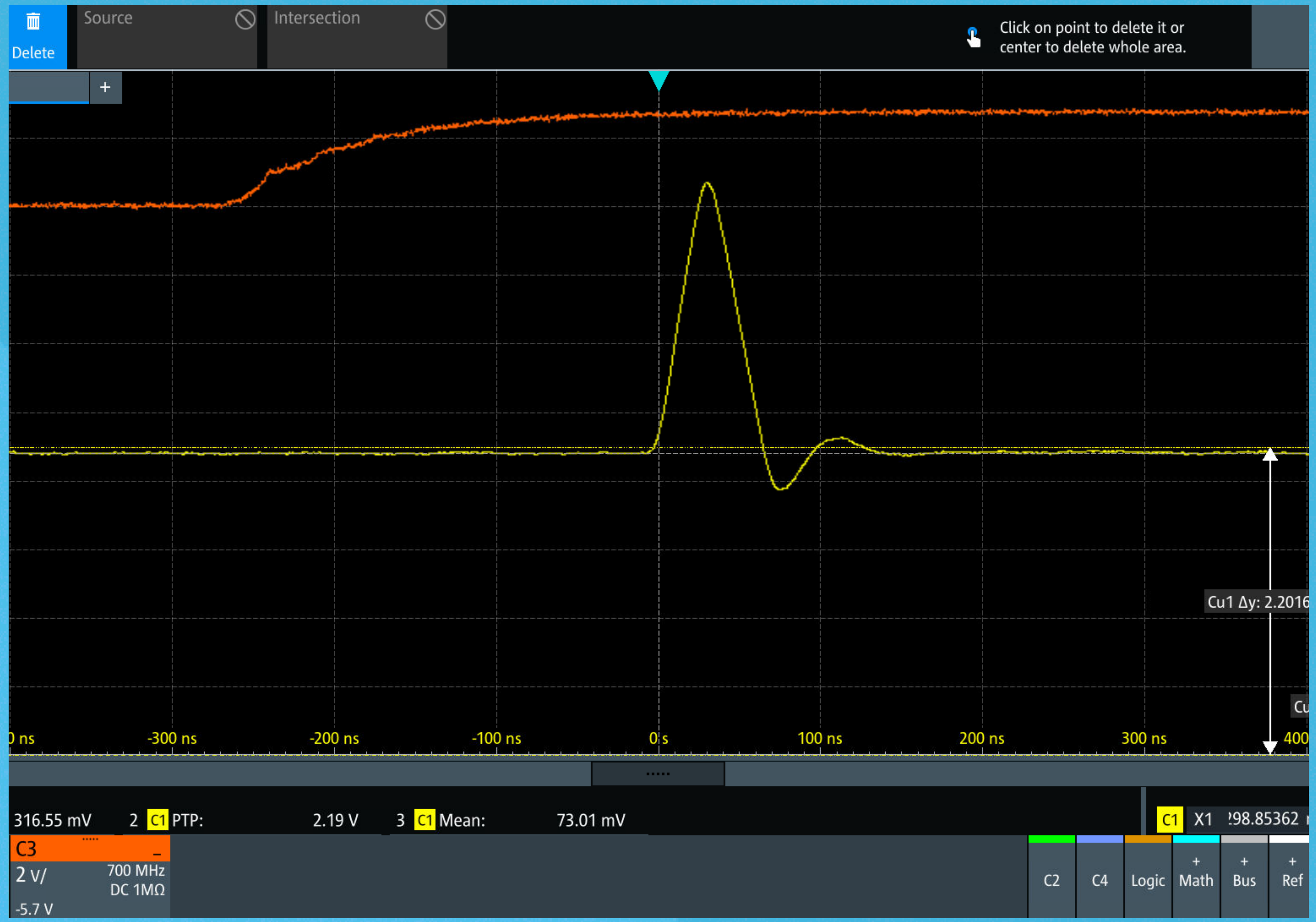

Image of Beam in ELETTRA Booster

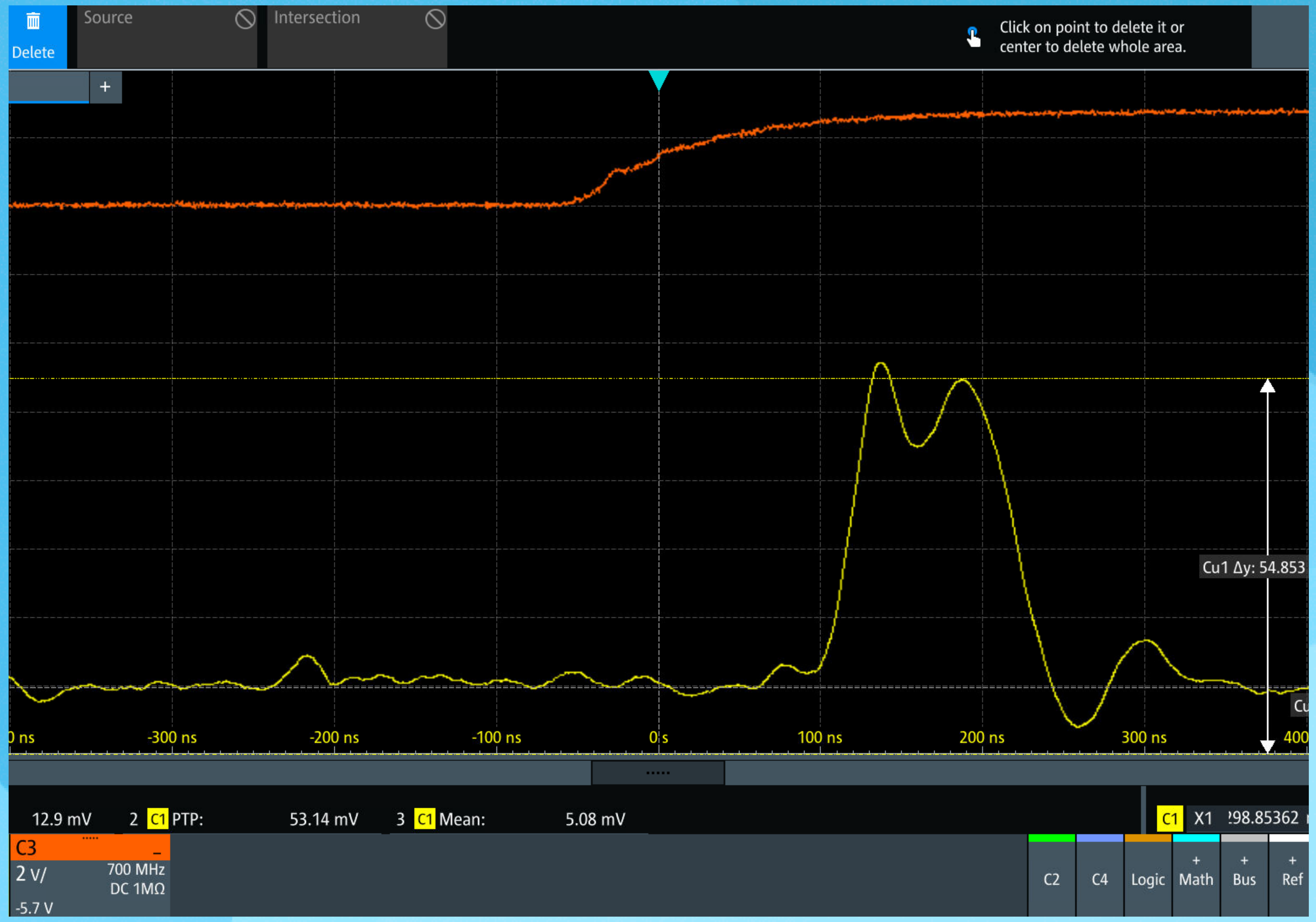

Image of Beam in ELETTRA Booster

Conclusions

The signal clearly rises above the noise band, indicating strong detectability.
Excellent results in single bunch mode with clear and strong signal.

Efficiency Component	Value
Scintillation Yield	8000 ph/MeV
Trapping Efficiency	5.4%
Transmission	69%
Coupling Efficiency	80%
MPPC PDE @ 492 nm	40%
Total Photoelectrons/MeV	~95

Thank you For Your Attention