Cerium-doped Scintillating Fused-silica Fibers

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Motivation

- Radiation hard Scintillators

  High radiation doses in the modern/future detectors for High Energy Physics experiments

- Dual readout calorimeters

  Better performance – many benefits for the HEP detector. Scintillation and Cherenkov signals in the same fiber.

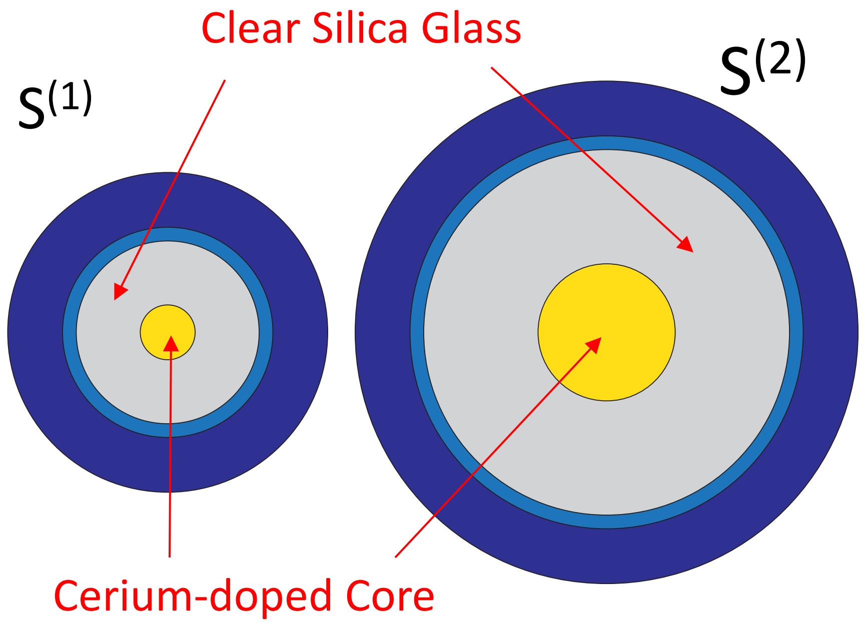
- Radiation hard wavelength shifter

Fibers configuration

We have tested

- ❑ two configuration of cerium doped scintillating fibers ($S^{(1)}$ and $S^{(2)}$)
- ❑ Cherenkov radiating (Q) fused-silica fibers were

produced by Polymicro Technologies



Fiber	Core dia. [μm]	Glass [μm]	Cladding [μm]	Buffer [μm]	NA
$S^{(1)}$	60 ± 7	200 ± 6	230^{+5}_{-10}	350 ± 15	0.37
$S^{(2)}$	150 ± 20	400 ± 10	330 ± 10	550 ± 30	0.37
Q	-	600 ± 10	630^{+5}_{-10}	800 ± 30	0.33

S-fibers have hard-polymer cladding and acrylate buffer

Mass Spec Analysis

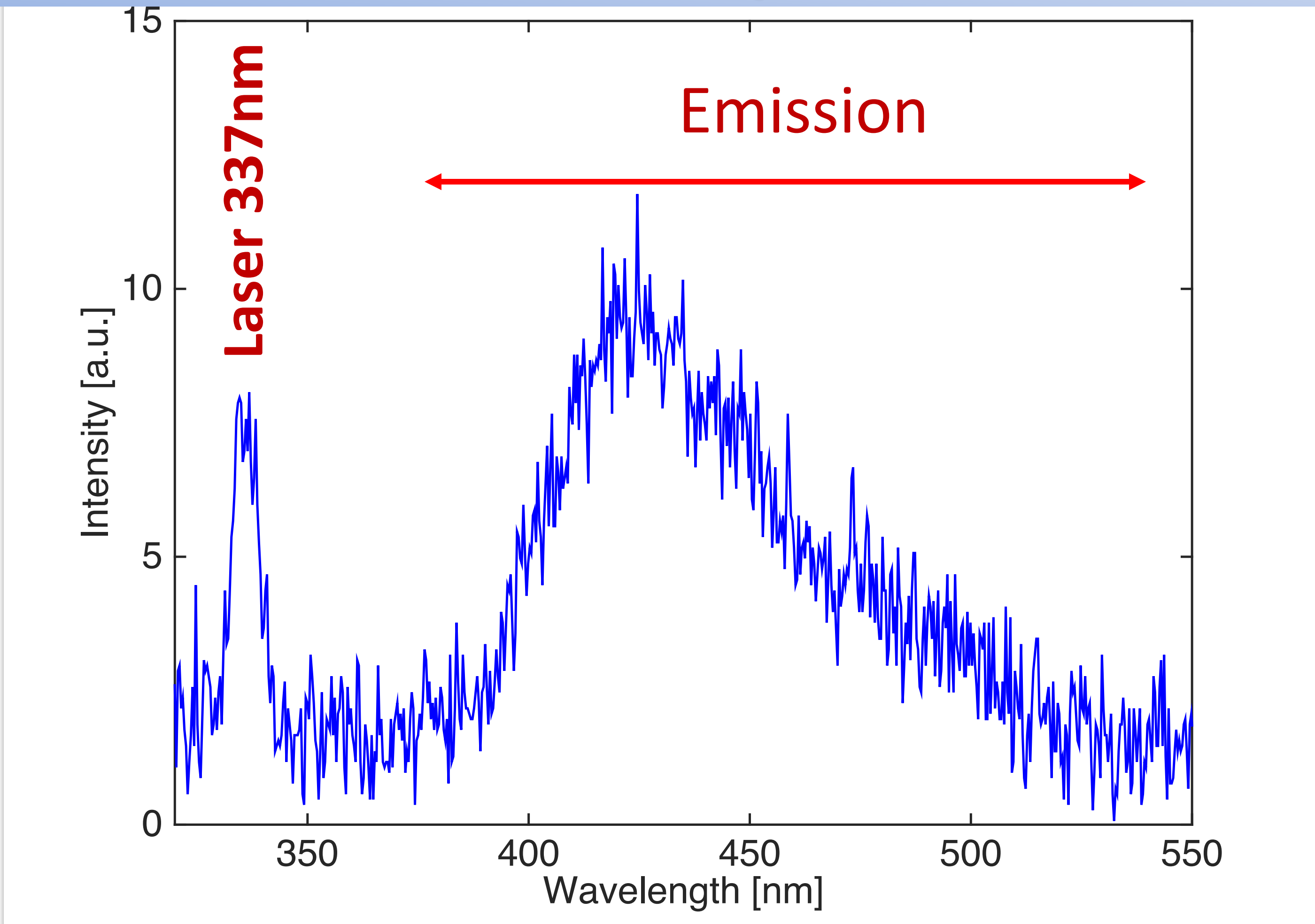
The element concentrations in the core of scintillating cerium-dope core silica fiber (S) are compared to the clear fused-silica fiber (Q) using laser ablation inductively-coupled plasma quadrupole mass spectrometer.

The units are given in ppm.

Fiber	B	Al	P	Sc	Ga	Y	Zr	La	Ce	Gd
S	<3	13,000	160	5	160	1	0.2	1.2	5,000	7
Q	6.5	-	95	5	-	-	0.1	-	-	-

No quantitative data is provided if the measurement is below detection level.

Emission spectra



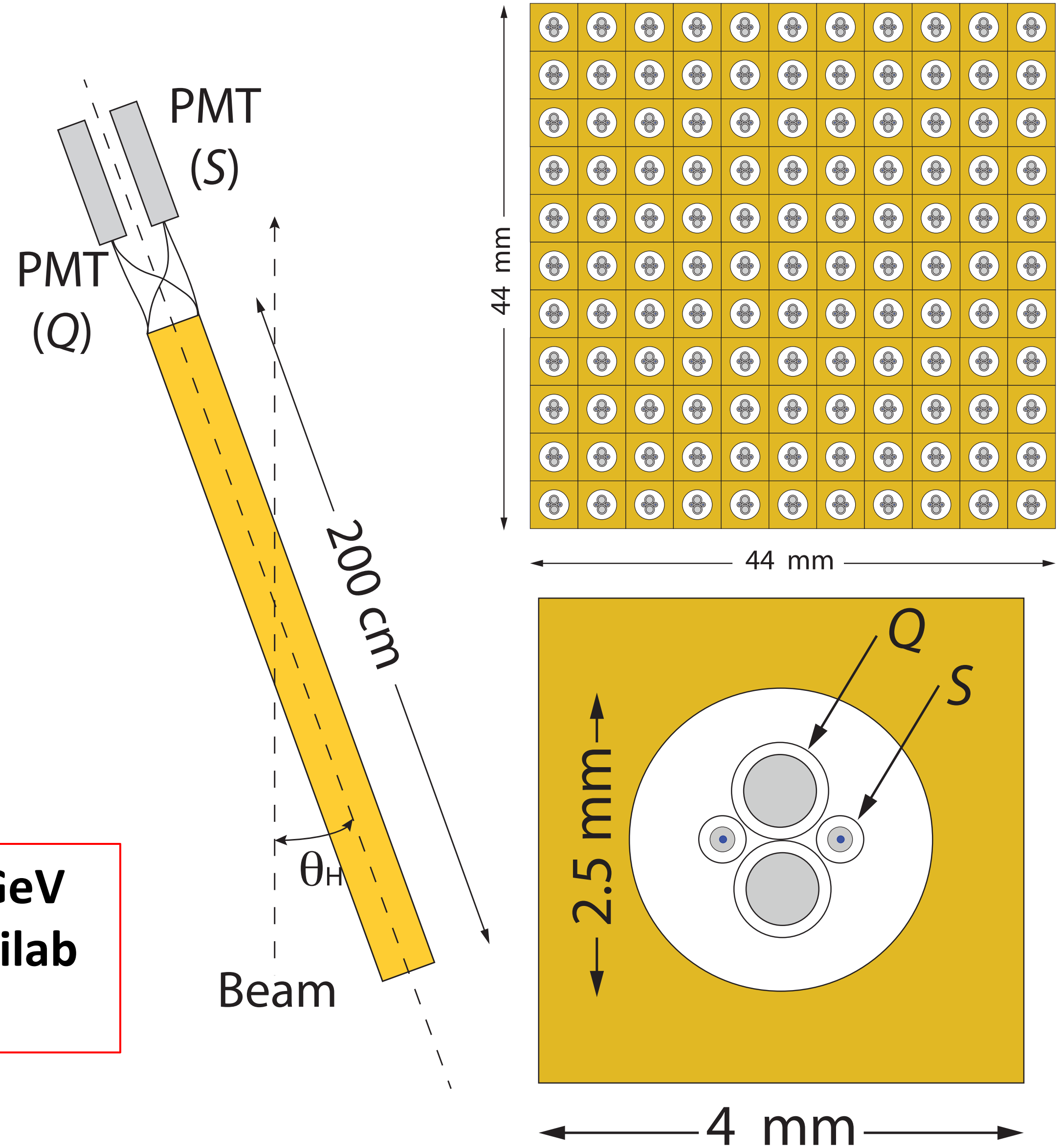
- Emission spectrum of the $S^{(1)}$ -fiber when excited by a pulsed N_2 laser (***337 nm***)

Hamamatsu R6427
Hamamatsu R6427

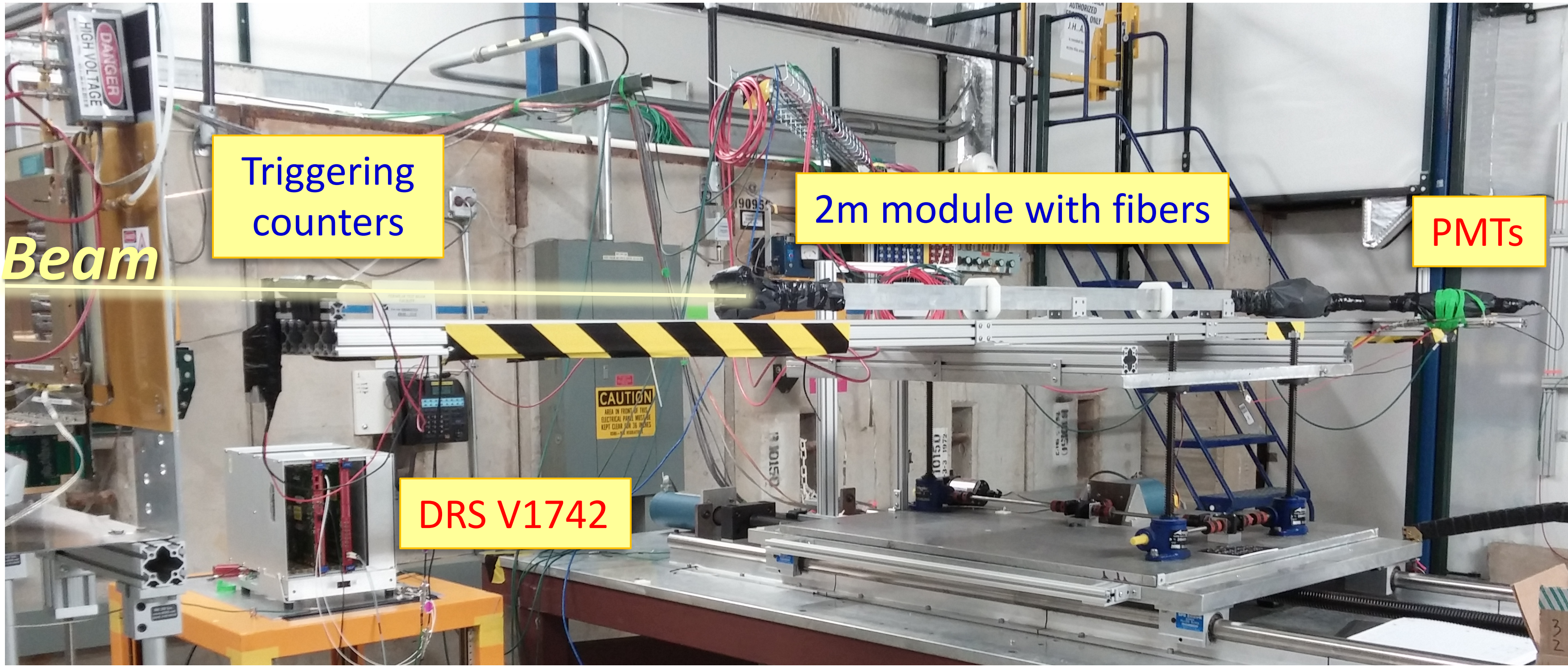
Measurements with beam

- The S[1] and Q fibers were embedded in a copper matrix.
- Transverse size of the matrix was **4.4x4.4 cm^2**.
- The length was **200 cm**.
- S and Q- fibers are readout separately by PMT (Hamamatsu R6427)

Exposed to positrons at 4 - 32 GeV at the MTest beam line at Fermilab in 2014 and 2015



Experimental setup



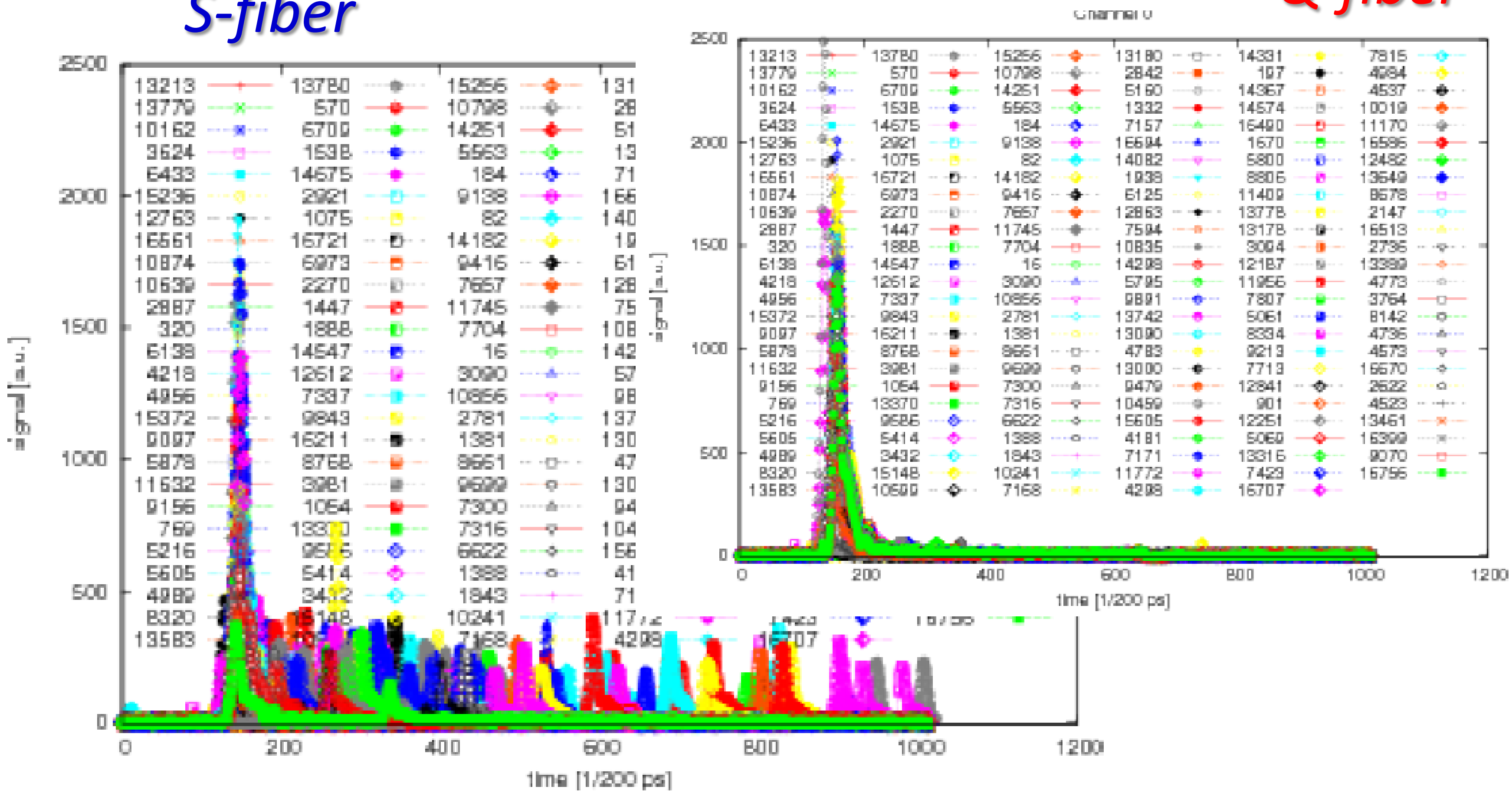
- ✓ The module is installed on a movable table.
  - ➢ Positioned at 2, 90 and 182 degree with respect to the beam axis
- ✓ 1 x 1 cm triggering counters
- ✓ Signal from S and Q fibers is detected separately by two PMTs
- ✓ Signal is digitized and recorded in 200ns by DRS V1742 operating at 5GHz.

Observed signal – individual pulses

The data acquisition comprised the CAEN domino-ring sampler (DRS) V1742 system. Operates at 5 GHz.

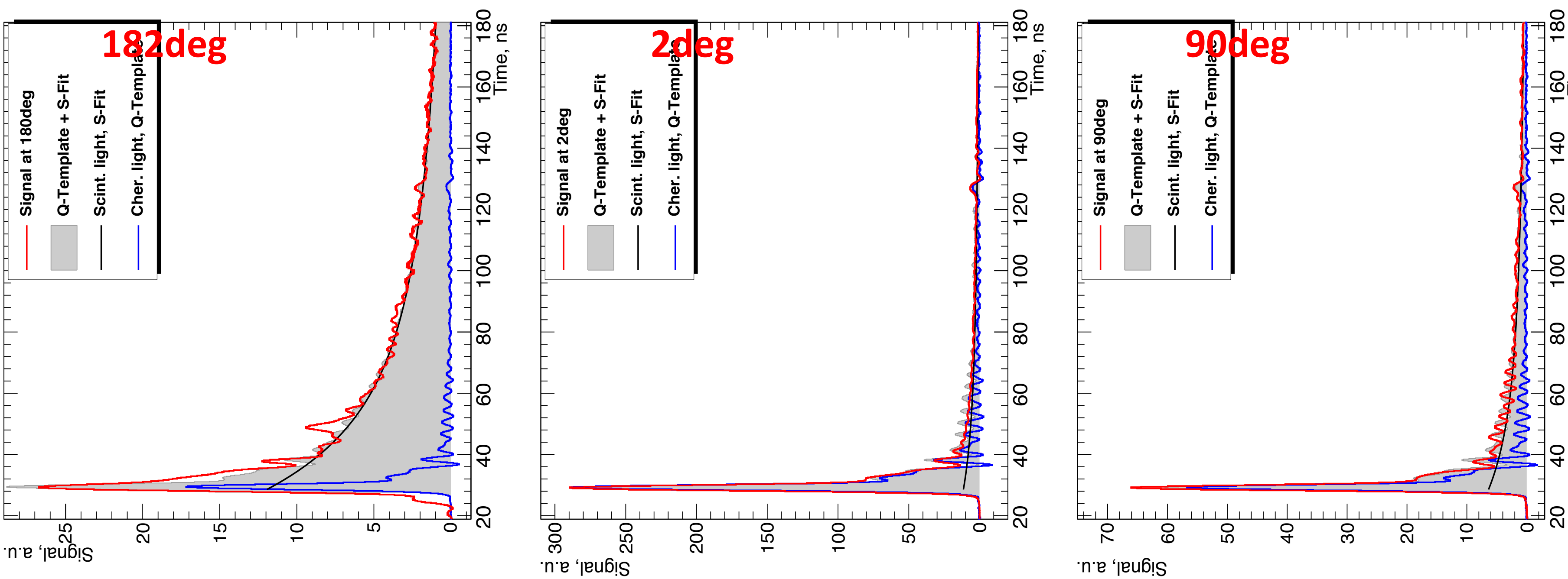
S-fiber

Q-fiber



Signal from Ce-doped scintillating fibers

➢ The light from S-fibers is admixture of ***Cherenkov and Scintillation*** photons.



❖ the emission of scintillation photons from the doped fiber core is isotropic,

❖ while the capture of Cherenkov photons in the fiber depends on the orientation of the fiber axis.

Scintillation pulse shape parameters

Tail of the scintillation pulse is described by double-exponential function :

$$S_S^{(1)}(t) = a_1.\exp(-t/\tau_1) + a_2.\exp(-t/\tau_2)$$

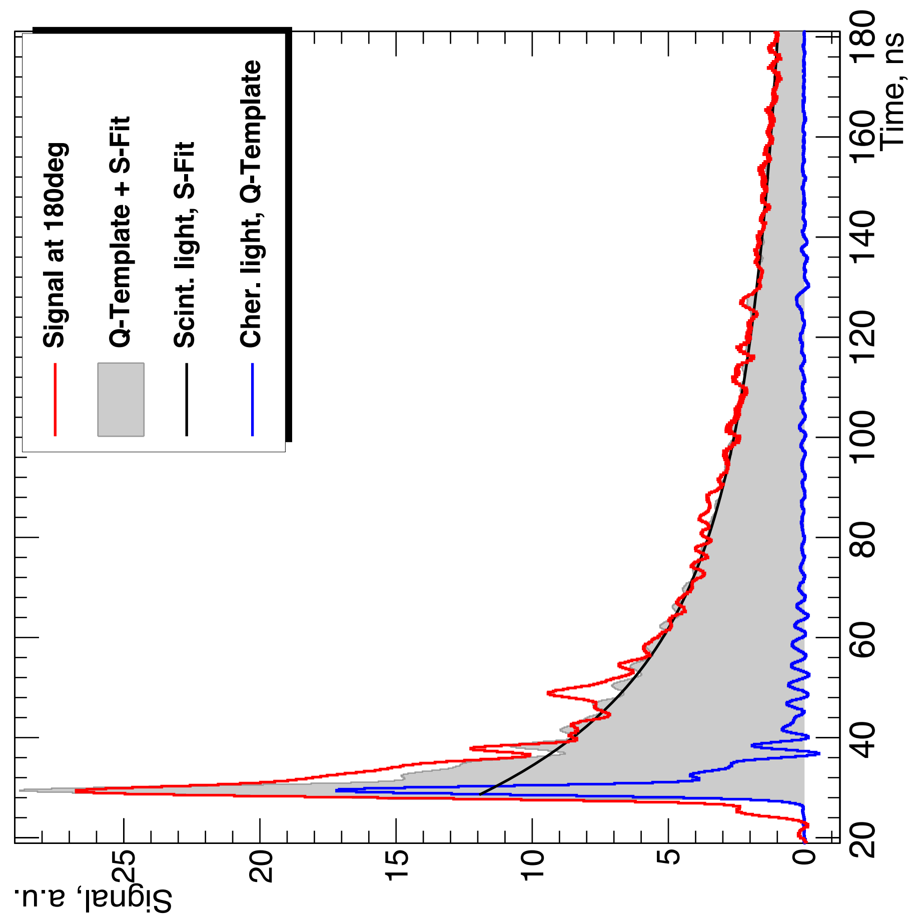
τ_1, τ_2 – timing constants

a_1, a_2 – relative amplitude

$\tau_1 = 20.8 \pm 5.4$ ns

$\tau_2 = 93.0 \pm 12.6$ ns

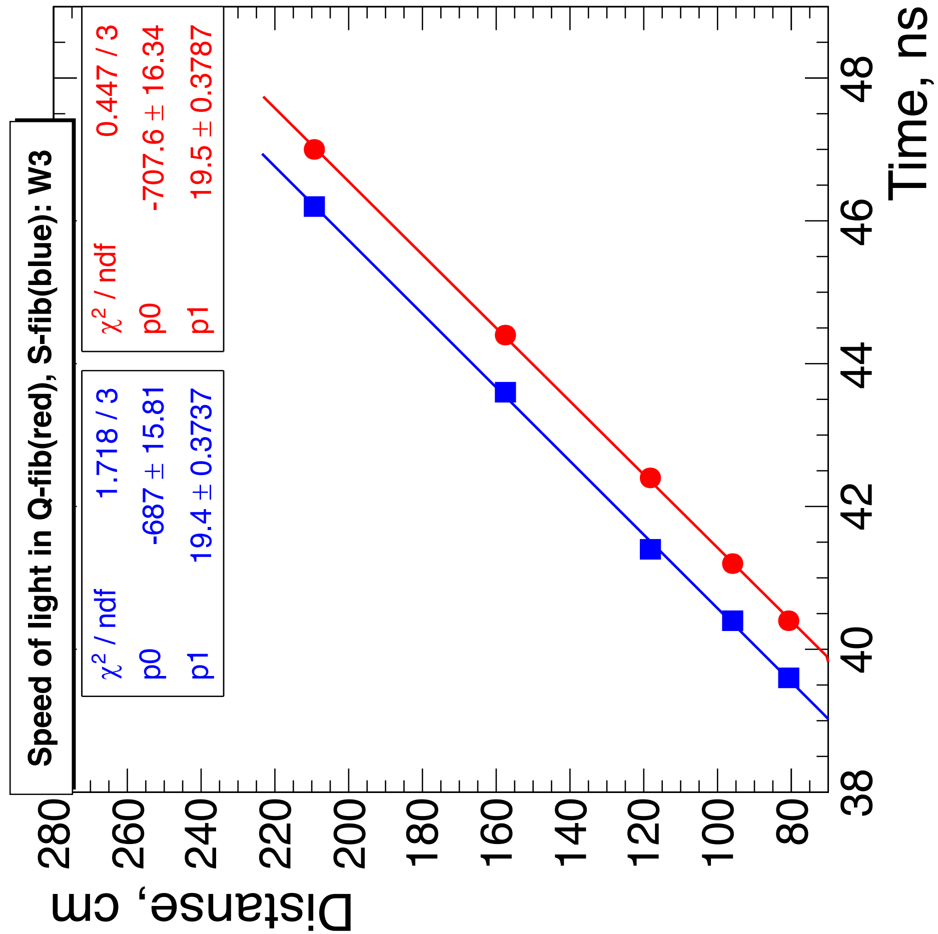
with relative contribution of **23.9 ± 5.3 %** and **76.1 ± 5.3 %** respectively.



Light propagation speed

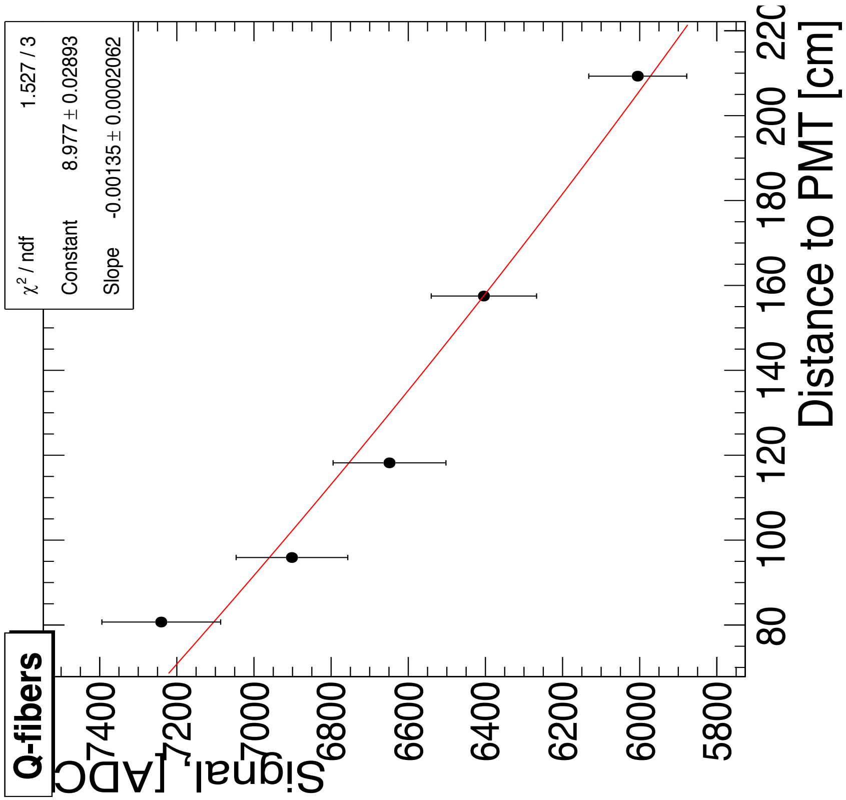
❖ The speed of light propagation was measured in the Q- (red circles), and the $S^{(1)}$- (blue squares) fibers.

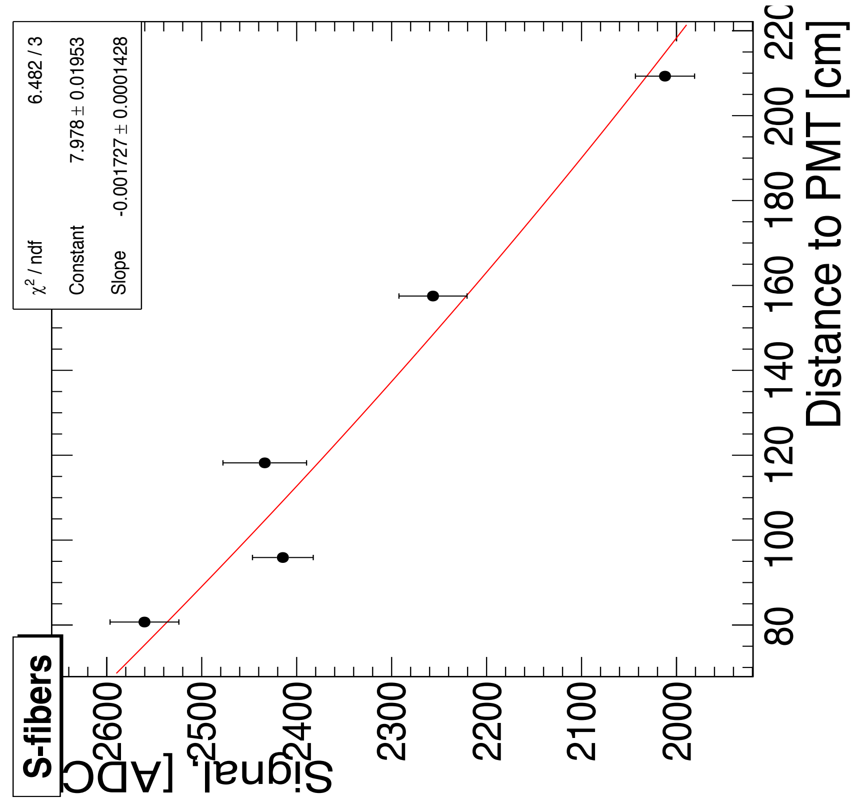
The fibers were positioned perpendicularly do the beam direction for the measurement. Each data point represents the time difference between the time of trigger and the arrival of the signal (time-over-threshold) at the PMT.



➢ The speed of light propagation in the $S^{(1)}$ and **Q** - fibers were measured to be **19.4 ± 0.4 cm/ns** and **19.5 ± 0.4 cm/ns**, respectively

Light attenuation length





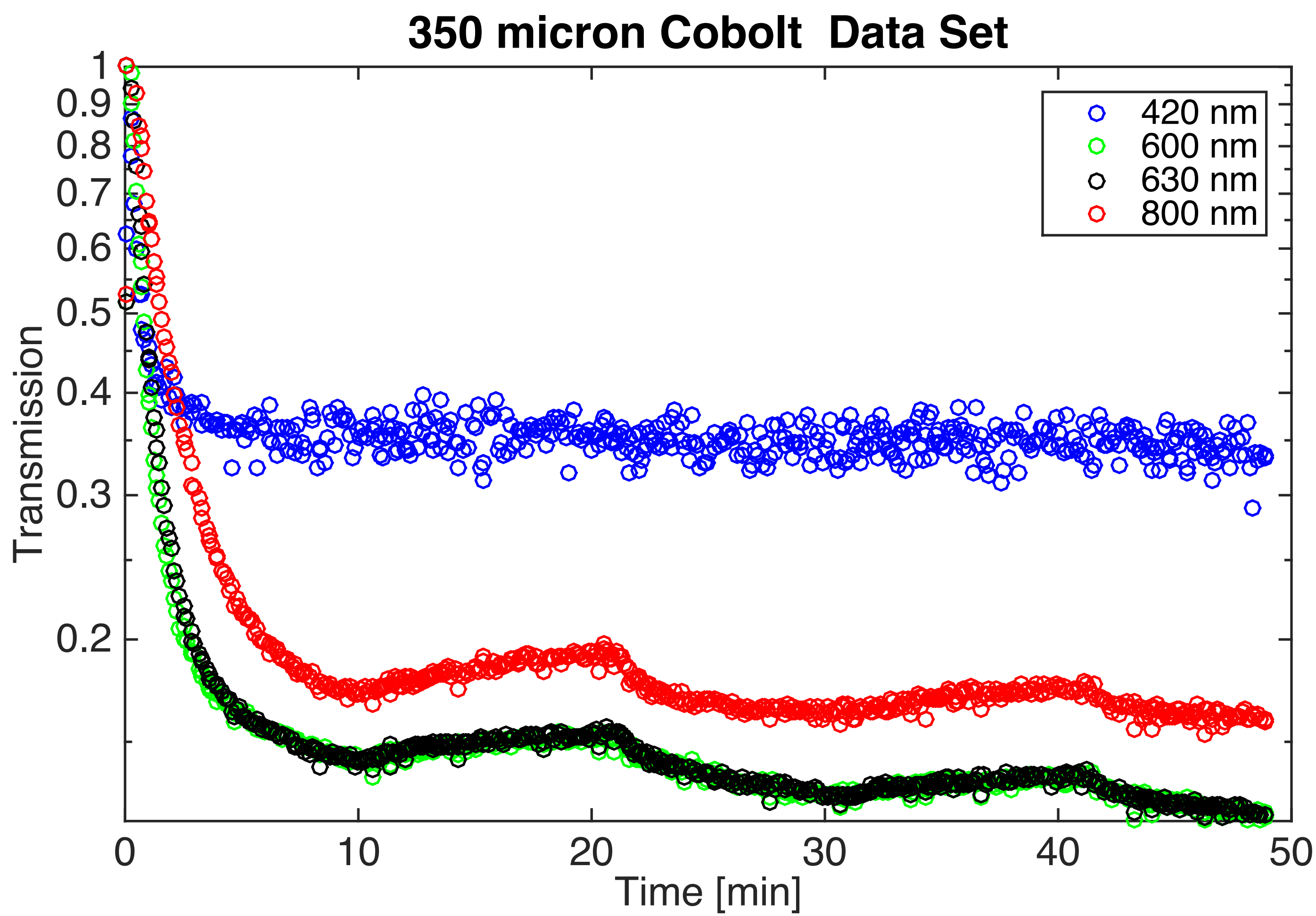
Parametrization of the signal amplitude as function of the traveled distance

$$S^{(1)}(x) = S_0^{(1)} \exp\left(-x/\lambda_{S^{(1)}}\right) \qquad Q(x) = Q_0 \exp\left(-x/\lambda_Q\right)$$

Measured attenuation length for S and Q-fibers

$$\lambda_{S^{(1)}} = 5.8 \pm 0.7 \text{ m} \qquad \lambda_Q = 7.4 \pm 0.5$$

Radiation hardness tests



Radiation damage measurement for S(1) cerium-doped scintillating fibers. Irradiated with Co-60 at ~1kGy/hr

Summary

- ❖ We have tested Ce-doped scintillating fused-silica fibers in two configurations – important technology for HEP detectors, operating in high radiation environment (as HL-LHC)
- ❖ We have measured the basic characteristics of these fibers
  - Emission spectra, attenuation length, pulse shape, light propagation speed, transmission after irradiation.

- ❖ Ongoing studies:
  - Light yield measurement (in conjunction with detailed MC simulation)
  - Wavelength shifting properties - promising initial on-bench results.
  - More radiation harness tests.

Acknowledgments

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