Search for Hidden-Photon Dark Matter with FUNK

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Hidden photons as dark matter candidates

Hidden photon

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}\tilde{X}_{\mu\nu}\tilde{X}^{\mu\nu} - \frac{\chi}{2}F_{\mu\nu}\tilde{X}^{\mu\nu} + \frac{m^2_{\gamma'}}{2}\tilde{X}_\mu\tilde{X}^\mu + J^\mu A_\mu$$

kinetic mixing, coupling

mass term

U(1) is simplest extension of SM, predicted by many theories

WISPy cold dark matter

JCAP06(2012)013

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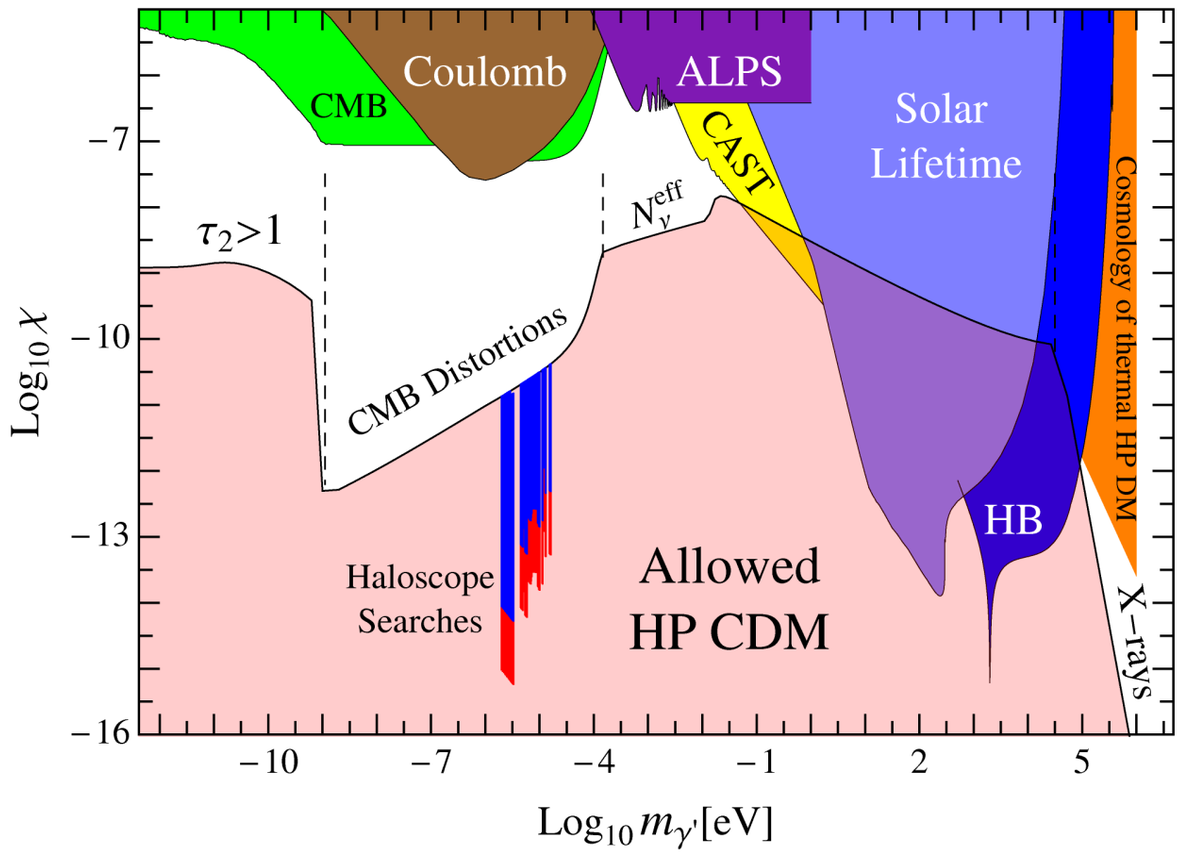
Non-thermal production, formation of a condensate

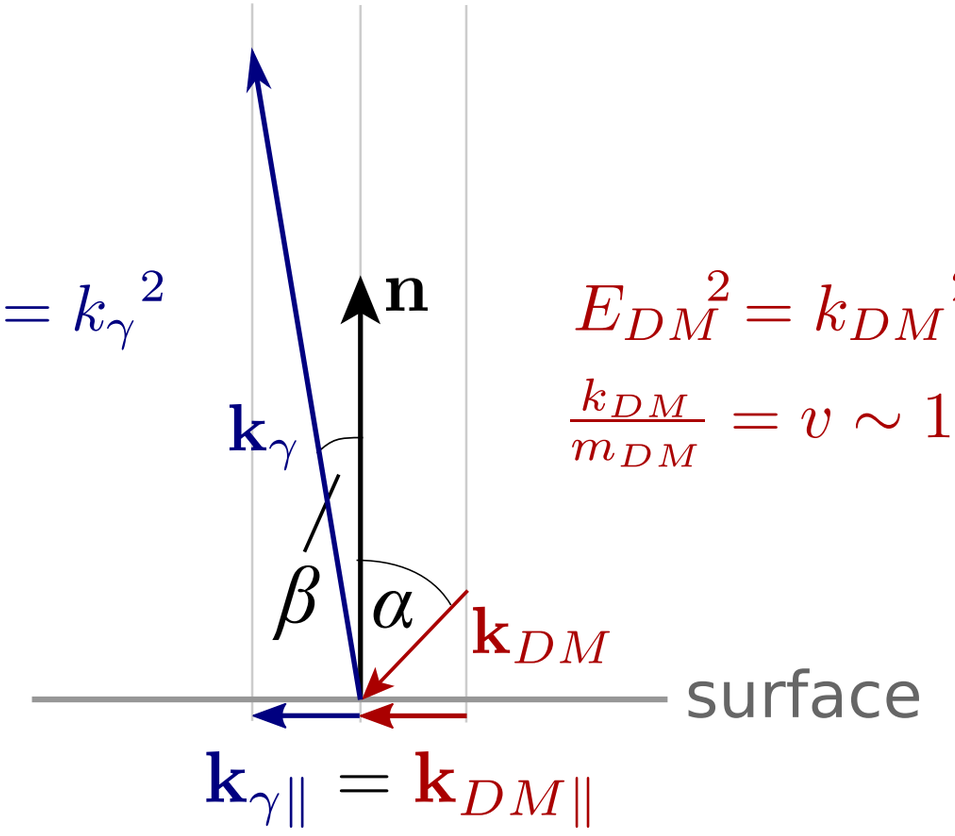
$$\rho_{\rm CDM} = \frac{m^2_{\gamma'}}{2}|\mathbf{X}|^2$$



New detection idea: spherical mirror

Transition conditions at metallic mirror

$$E_\gamma{}^2 = k_\gamma{}^2$$



$$E_{DM}{}^2 = k_{DM}{}^2 + m_{DM}{}^2$$

$$\frac{k_{DM}}{m_{DM}} = v \sim 10^{-3}$$

(Knirck & Jaeckel, PATRAS 2016)

$$\sin\beta = v\ \sin\alpha \approx 10^{-3}$$

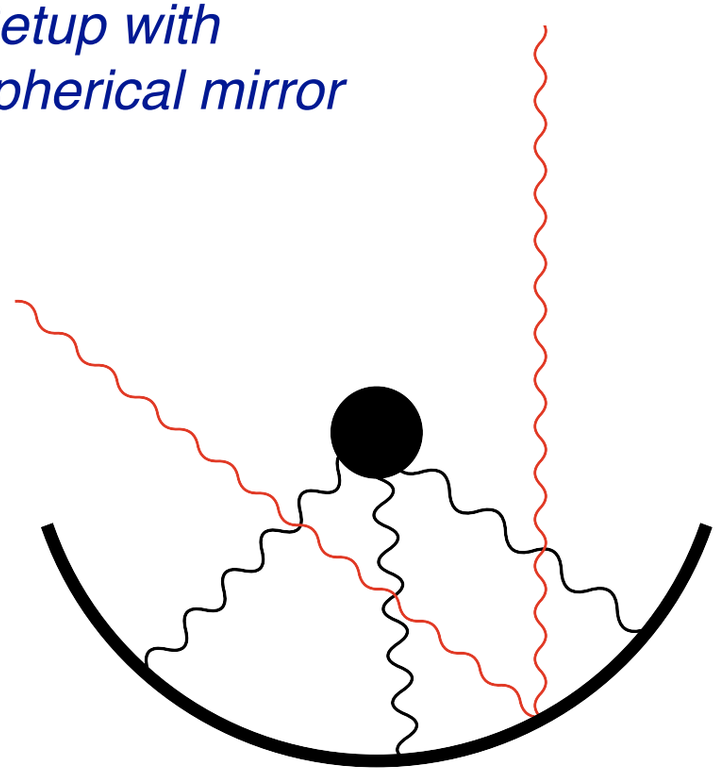
- *Signal in radius point*
- *Daily / seasonal shift by ~ few mm*

Searching for WISPy cold dark matter with a dish antenna

Dieter Horns,[a] Joerg Jaeckel,[b,c] Axel Lindner,[d] Andrei Lobanov,[e,1] Javier Redondo[f,g] and Andreas Ringwald[d]

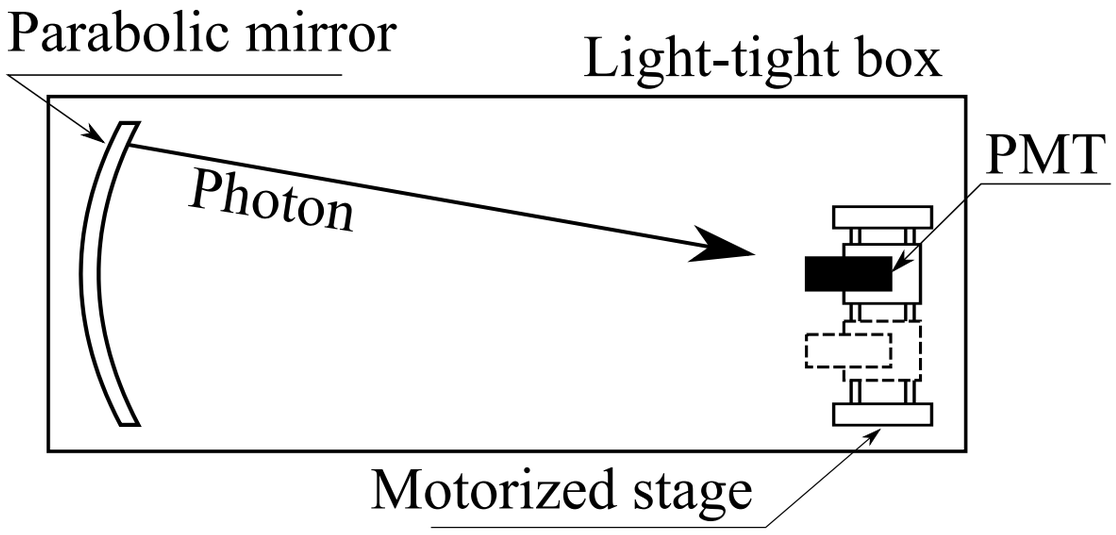
JCAP04(2013)016

Setup with spherical mirror



$$P_{\text{center}} \approx \chi^2\ \rho_{\text{CDM}}\ A_{\text{mirror}}$$

First measurement: Tokyo group



Experimental search for hidden photon CDM in the eV mass range with a dish antenna

JCAP09(2015)042

J. Suzuki,[a] T. Horie,[a] Y. Inoue[b] and M. Minowa[a,c]

Comparison of signal of low-noise PMT in radius point and outside (motorized stage)

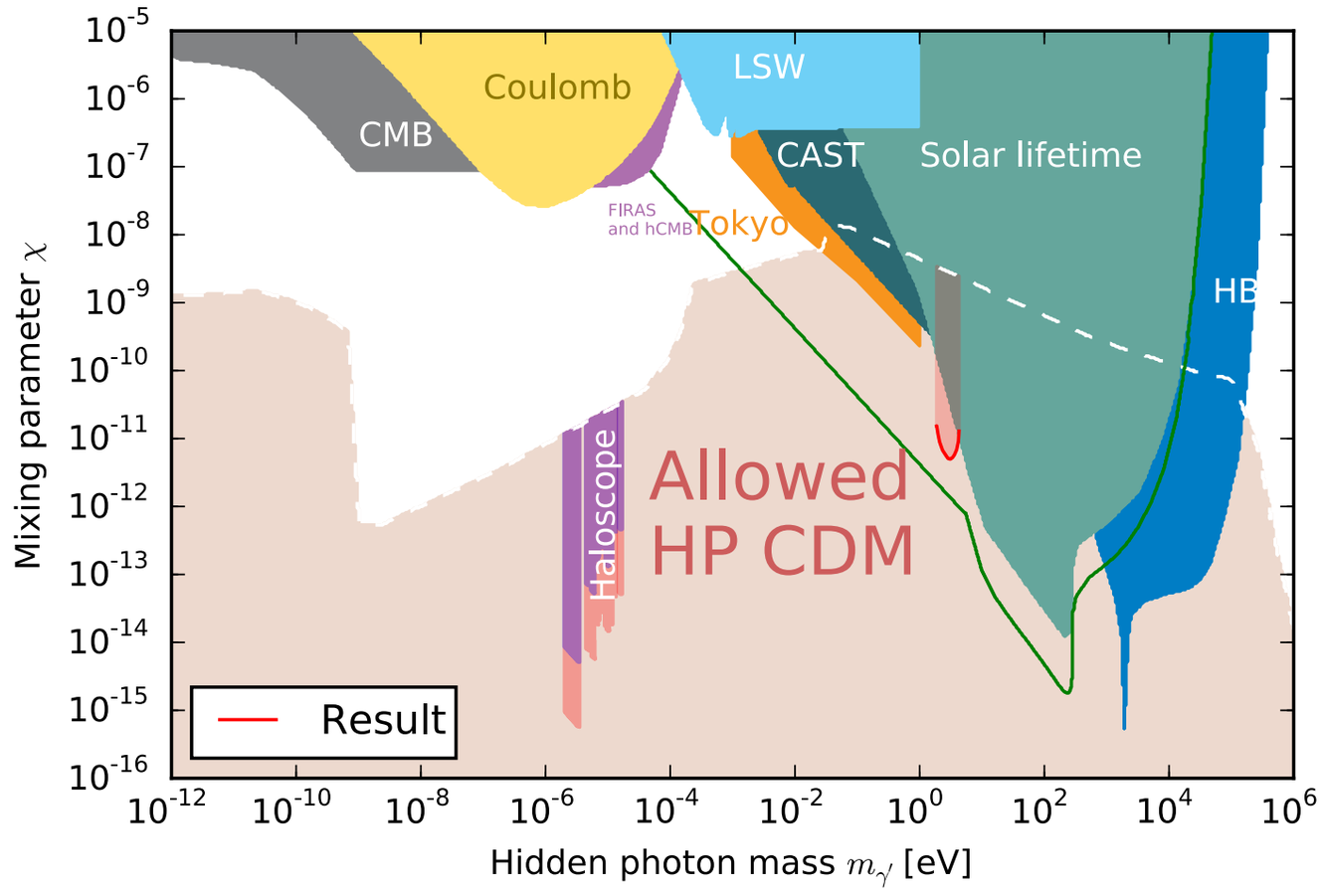
Dark box of 1 x 1 x 3 m³

Mirror of d = 0.5 m (A = 0.196 m²)

Data taking ~ 1 month

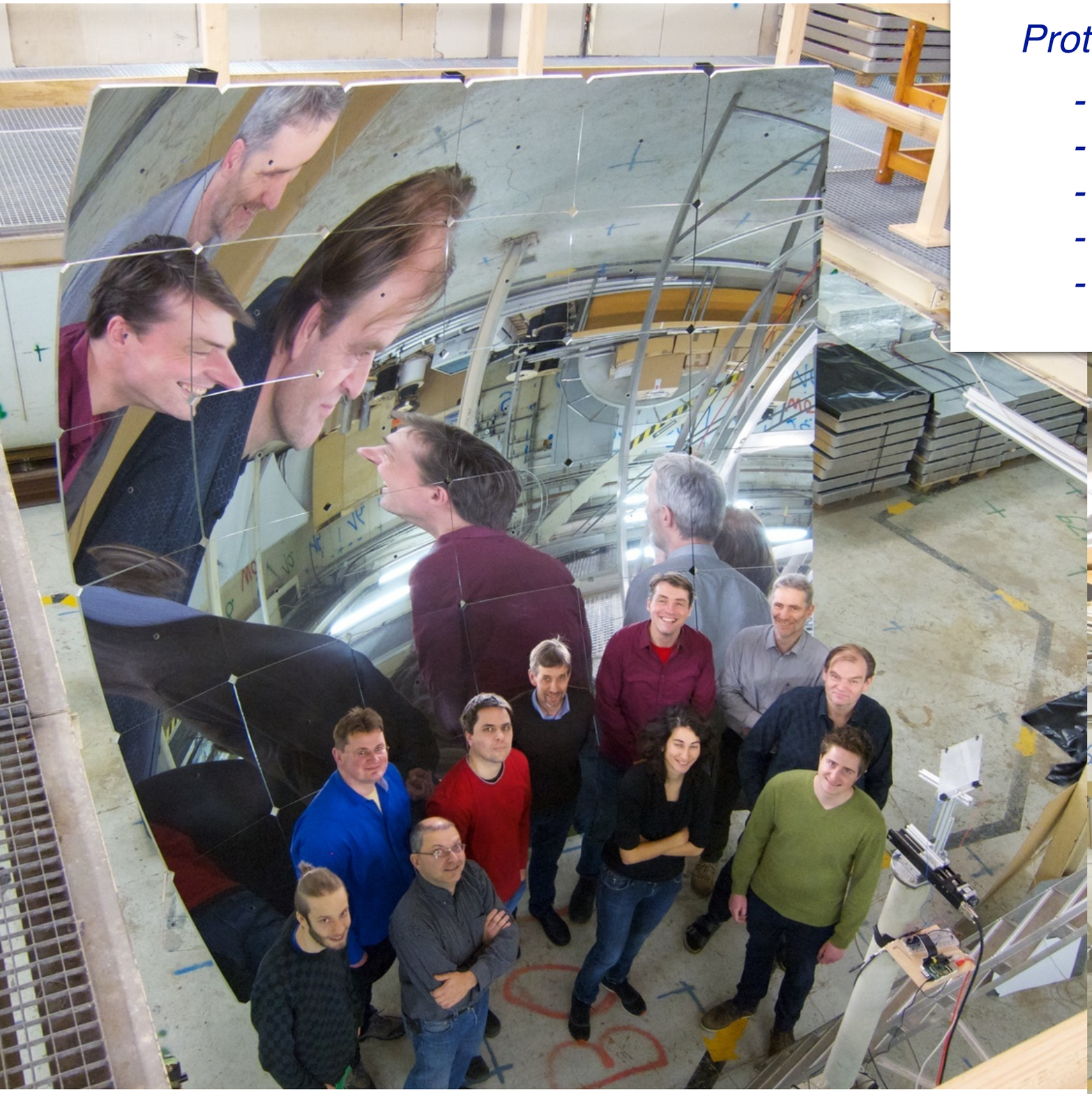
Photon rate In - Out (at 4.5 Hz rate):

$$N = (-1.9 \pm 3.8(\text{stat.}) \pm 0.5(\text{sys.})) \times 10^{-3}\,\text{Hz}$$



$$m_\gamma = 3.1 \pm 1.2\,\text{eV}$$

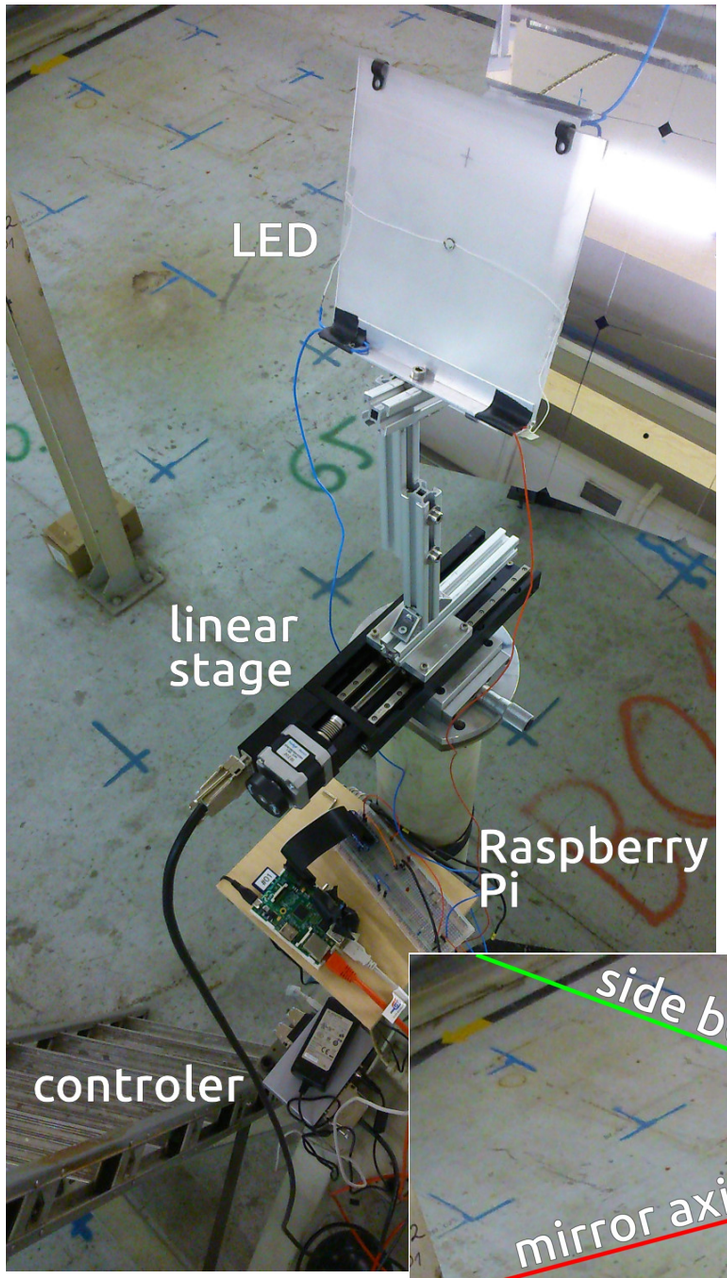
Finding U(1)s of a Novel Kind – FUNK

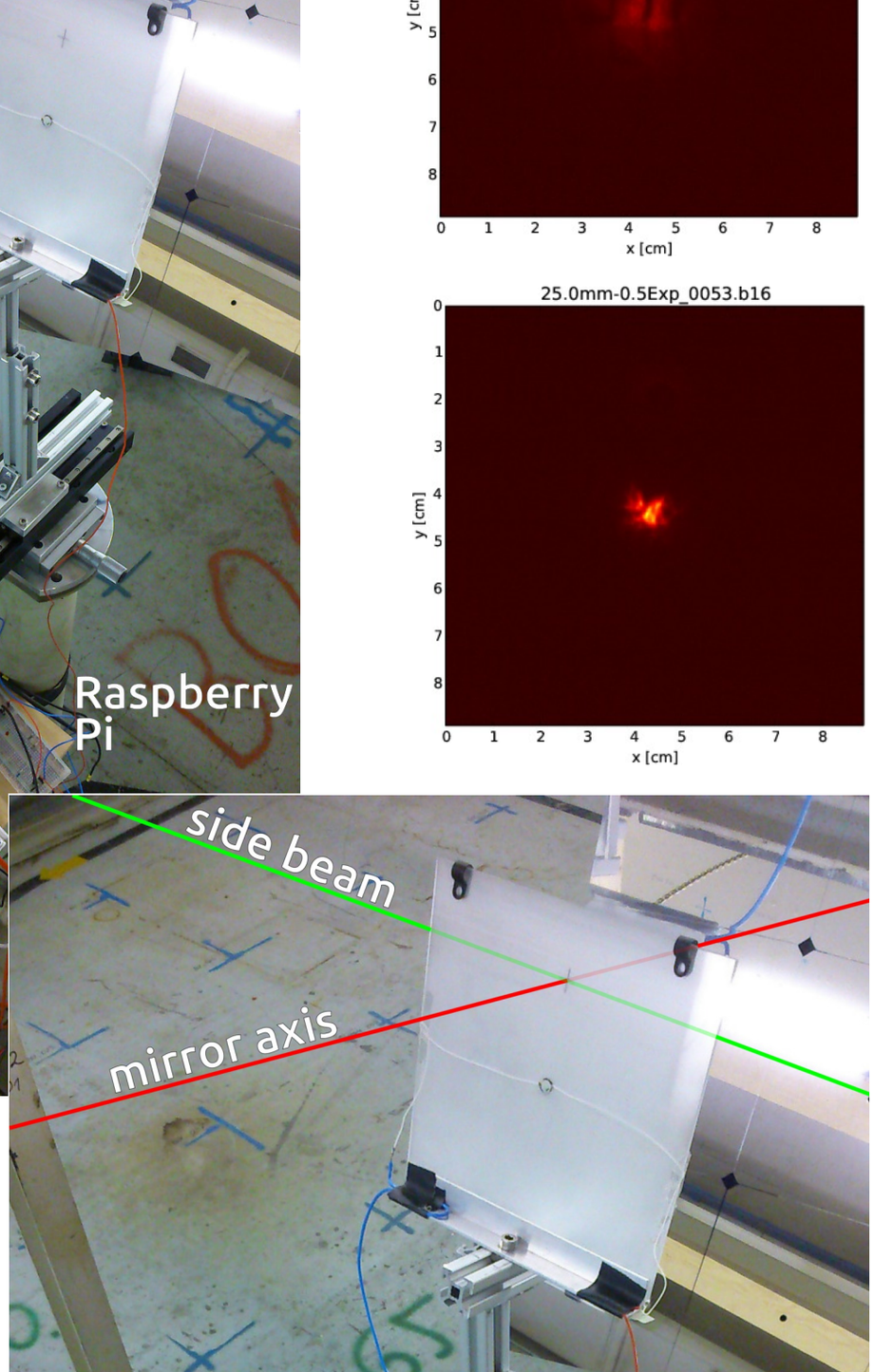


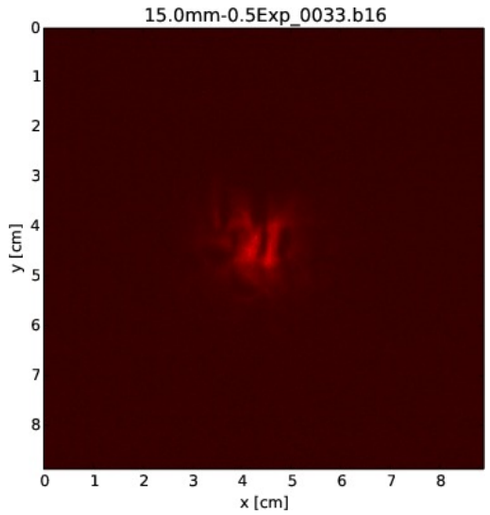
Prototype mirror (Auger Observatory)

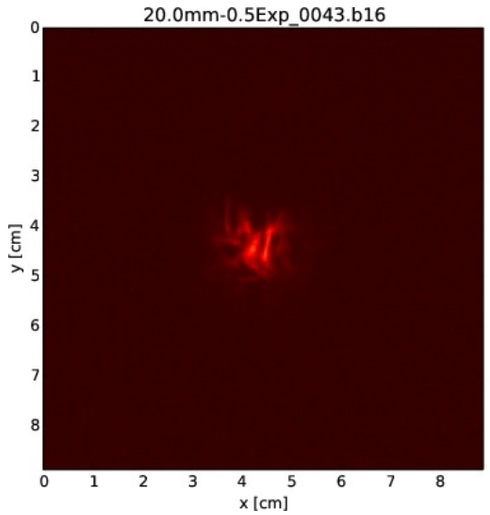
- *solid aluminum mirror*
- *6 x 6 segments*
- *R = 3.4 m*
- *A = 14.56 m2*
- *reflectivity ~ 0.7*

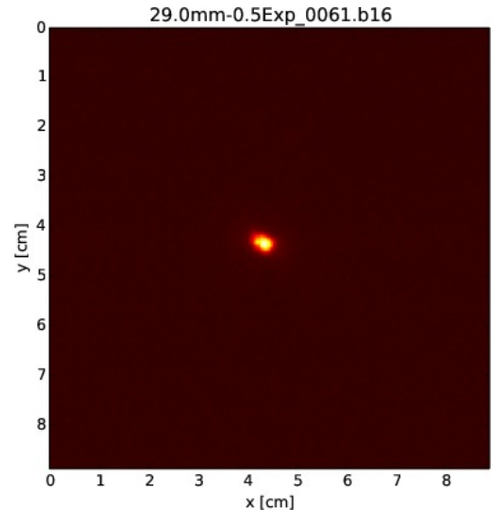
Alignment of mirror segments

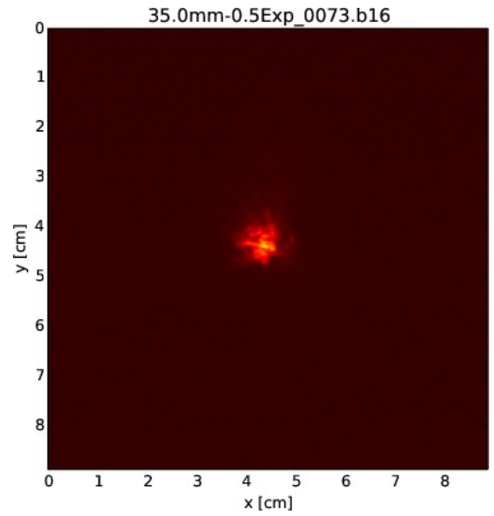


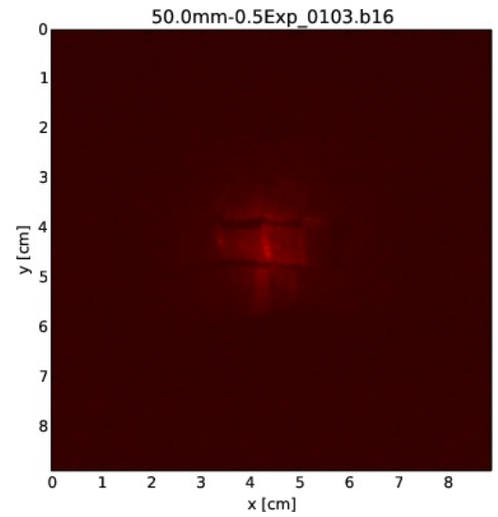








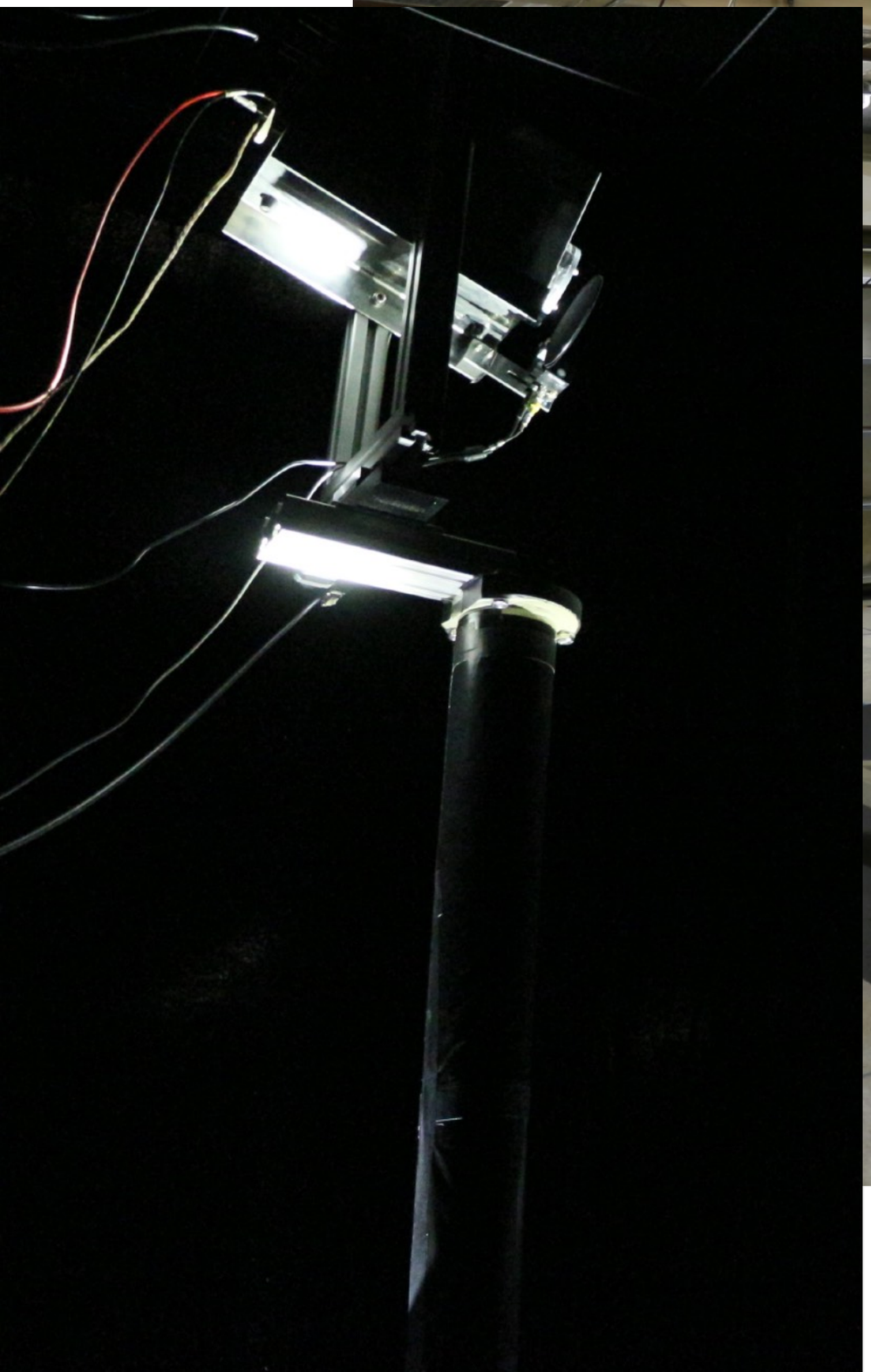




Spot size 2 mm after alignment

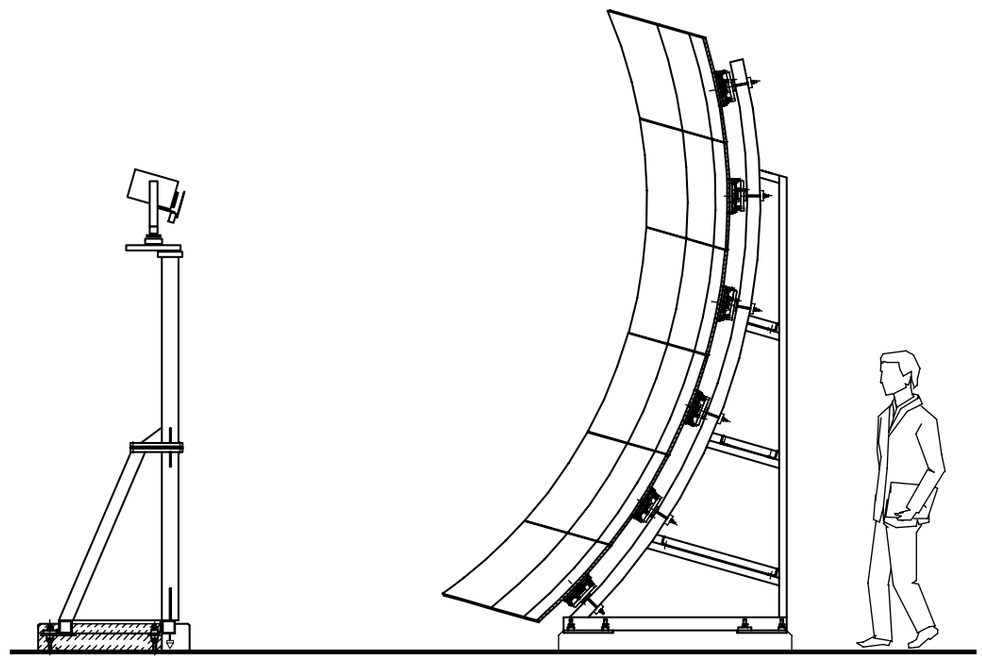
Radius point marked by lasers

New setup



Low-noise PMT (can be cooled)

Motorized stage and shutter

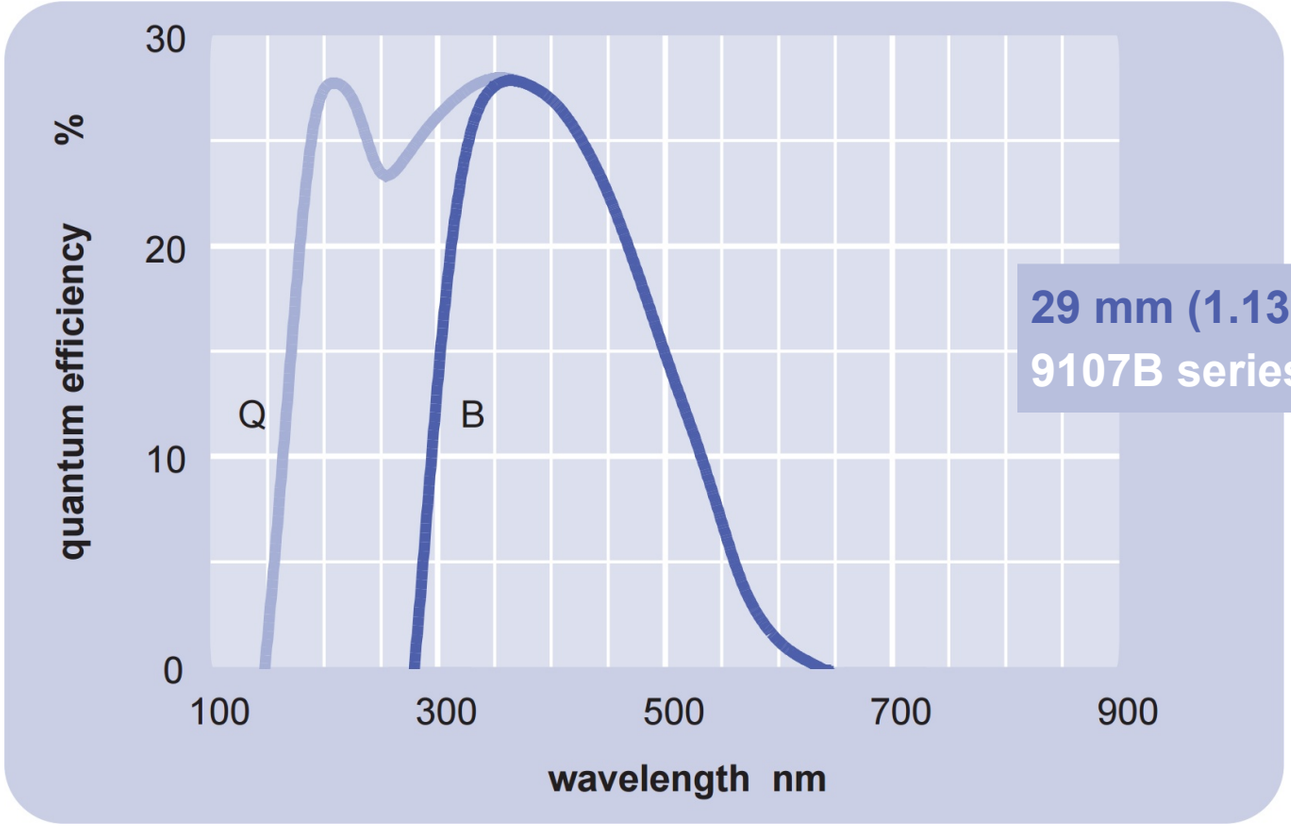


Measurement with low-noise, UV-extended PMT

	9107B borosilicate	9107QB* fused silica
spectral range**(nm)	280 - 630	160 - 630
refractive index (n_d)	1.49	1.46
K (ppm)	300	<10
Th (ppb)	250	<10
U (ppb)	100	<10

ET Enterprises electron tubes

far-UV extended sensitivity (Q)

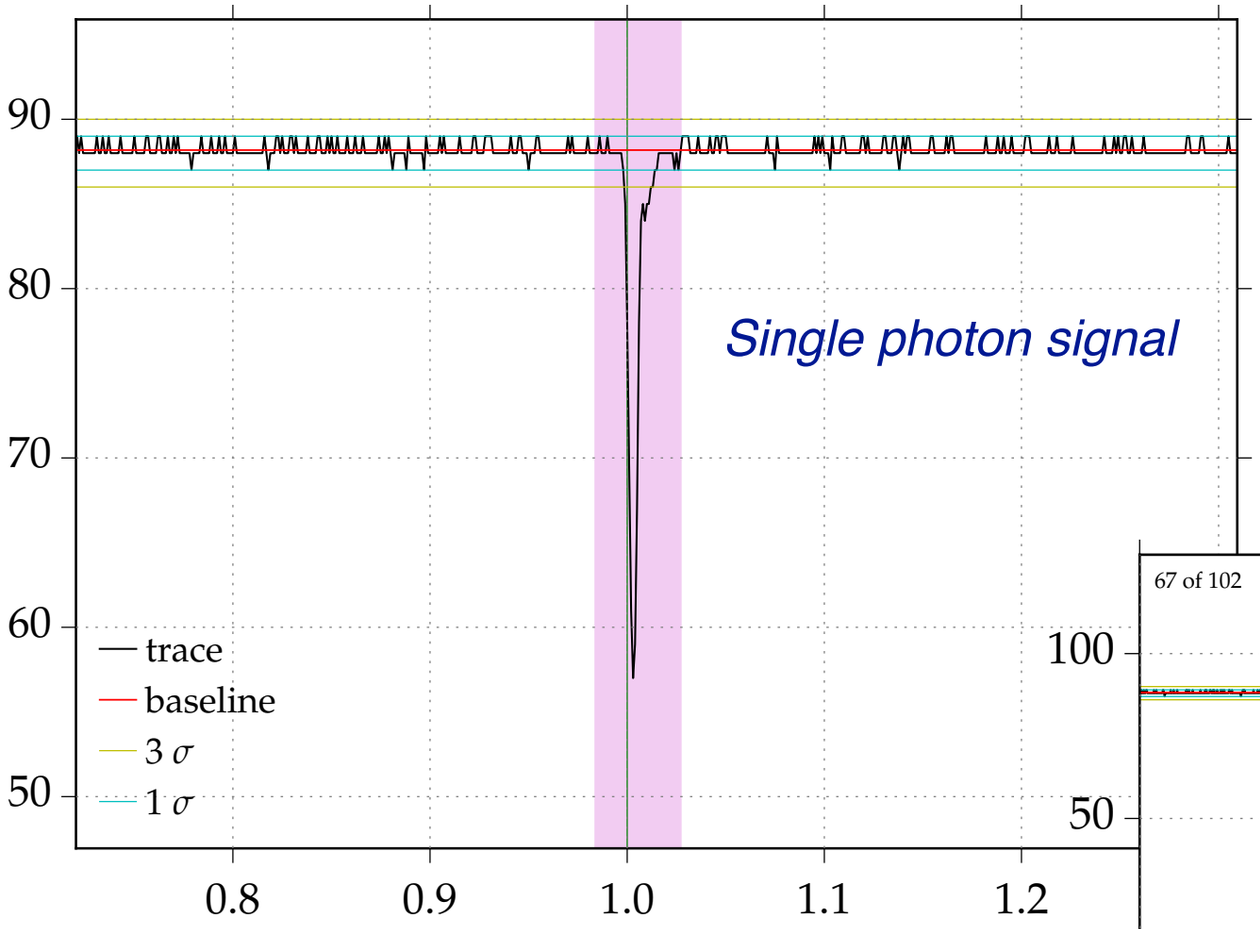


cooled encasing

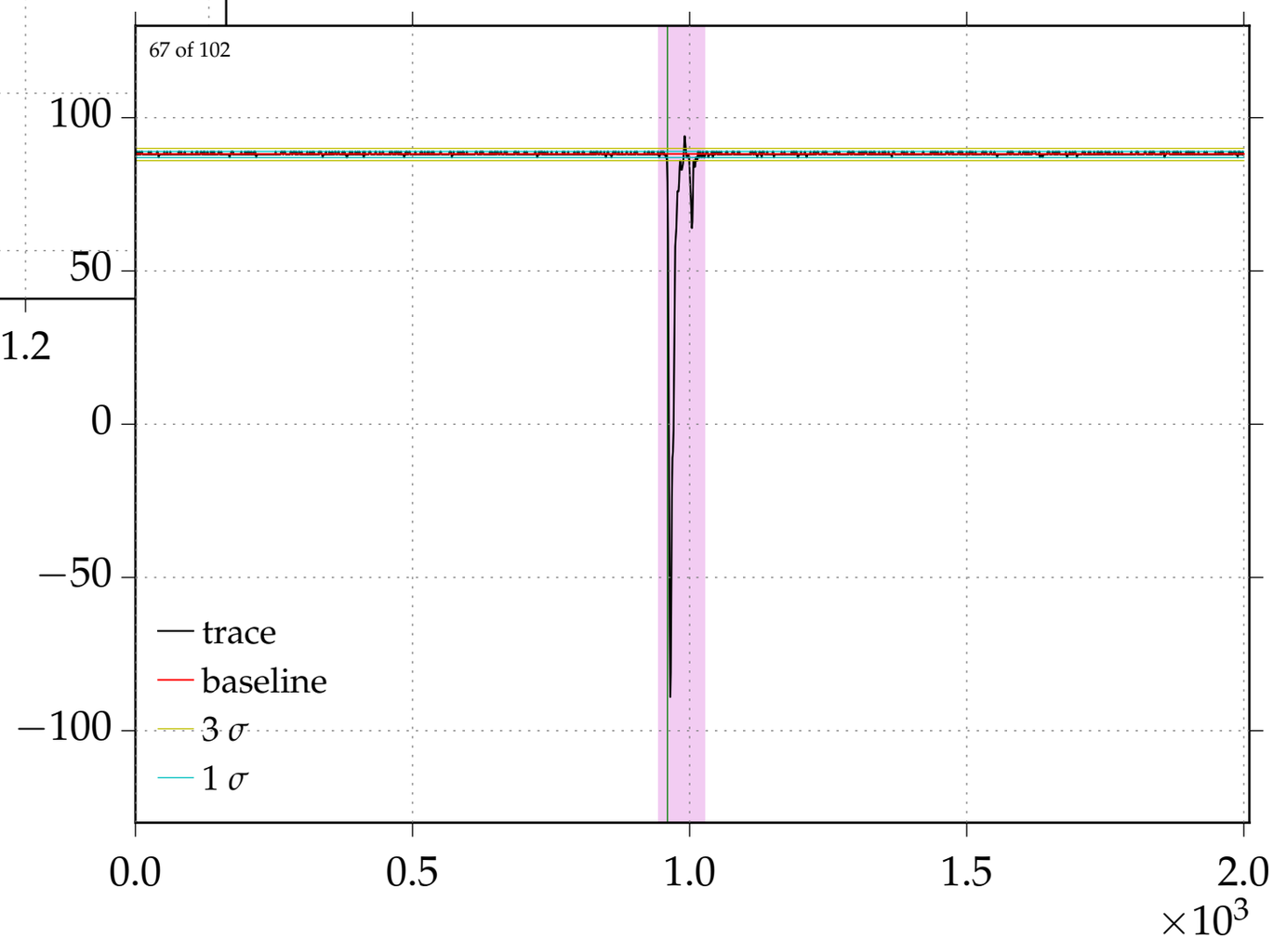
29 mm (1.13") photomultiplier
9107B series data sheet

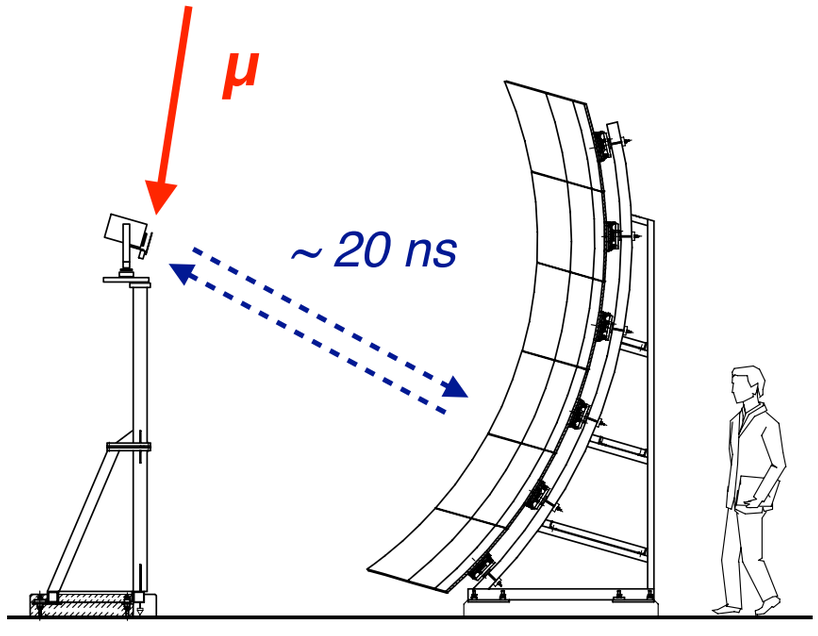
Data runs: examples of traces

Trace of 2000 bins of 0.8 ns size
(800 μs before and after trigger)



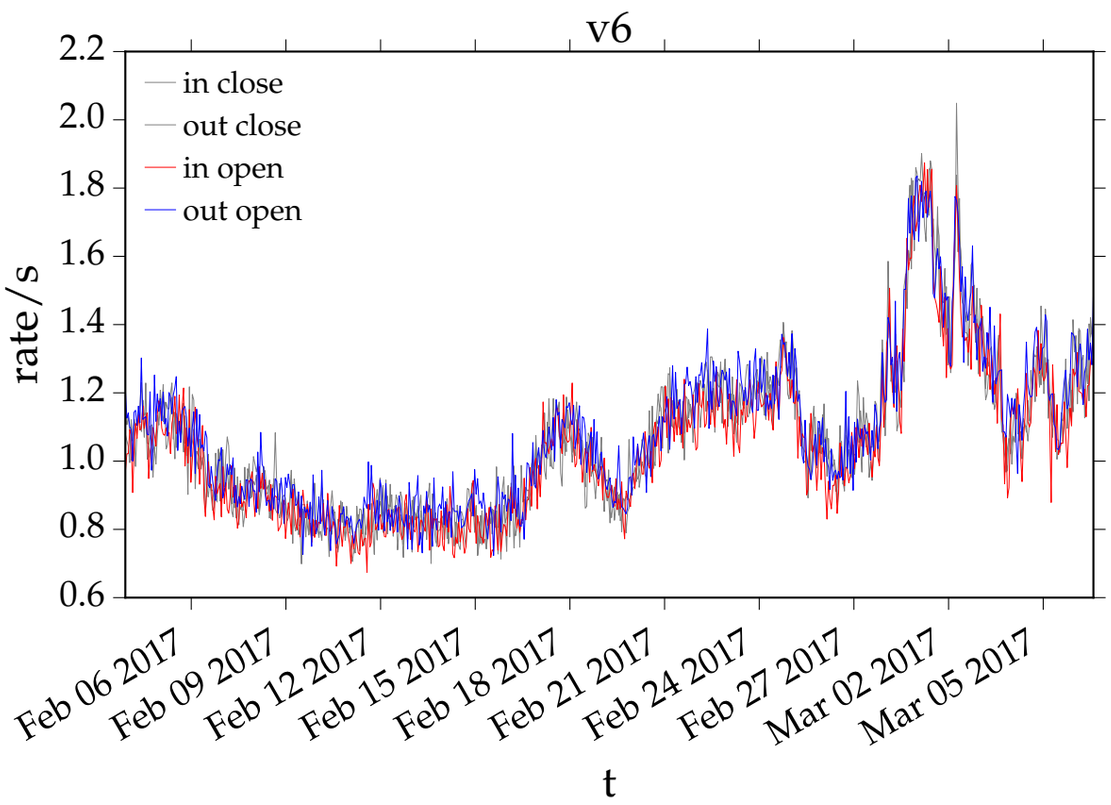
Muon hit of PMT (signal with echo?)



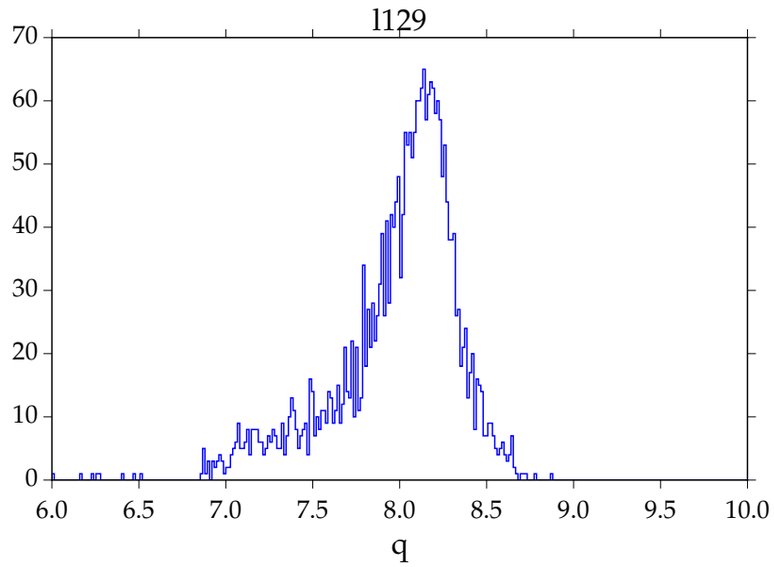


Data analysis – work in progress

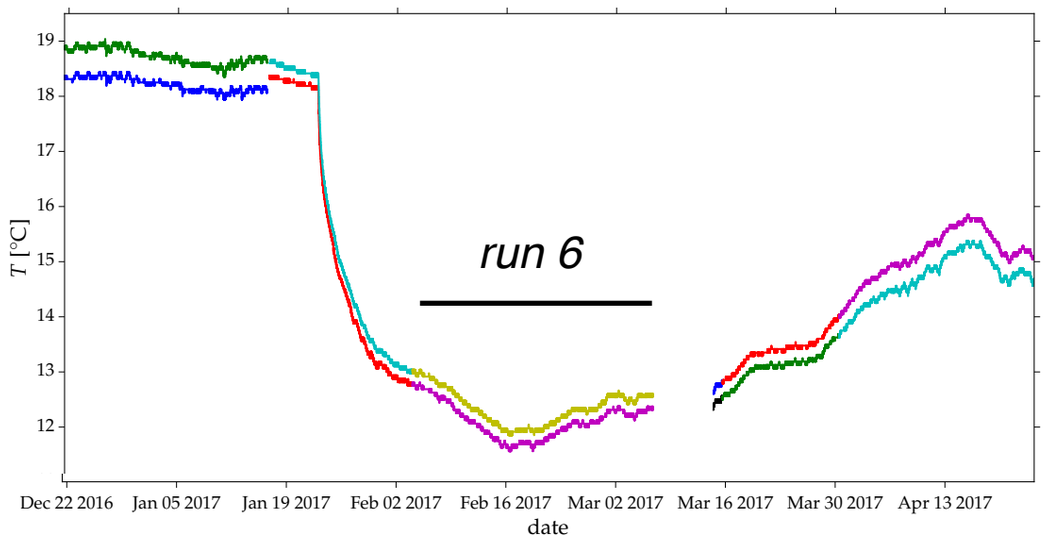
Raw trigger rate



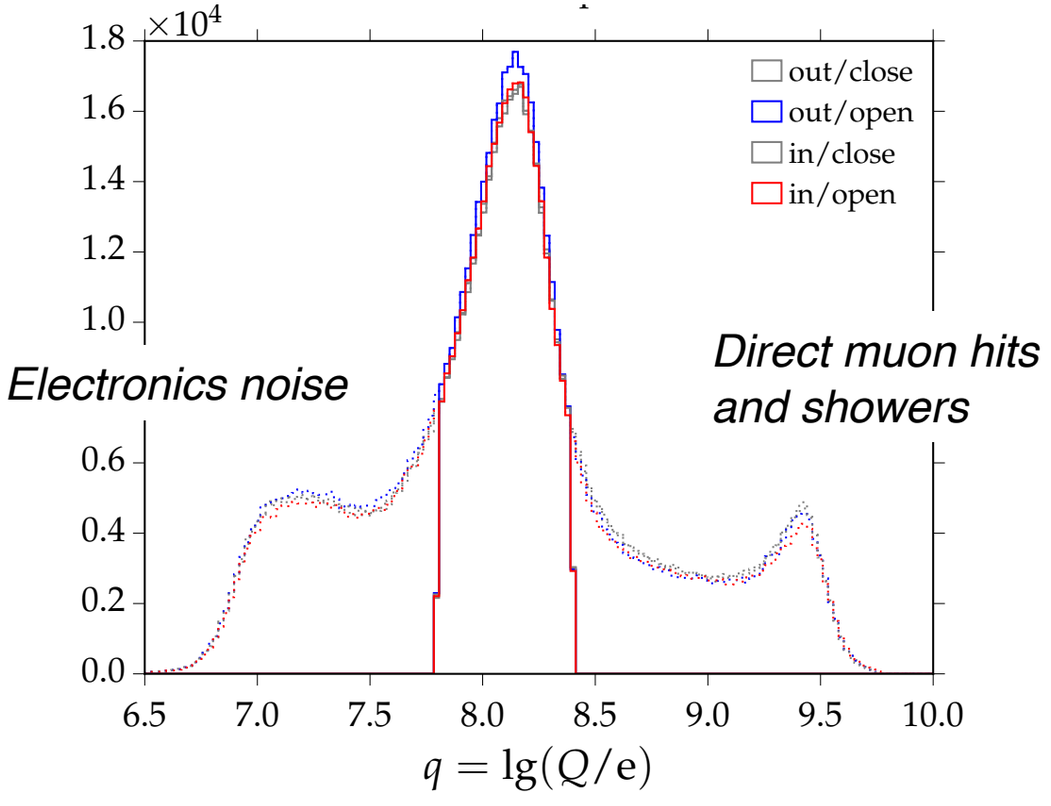
SPE data taken with flasher



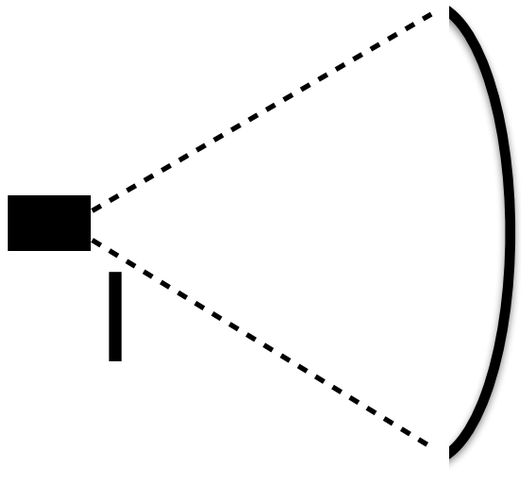
Temperature



Selection of single photons

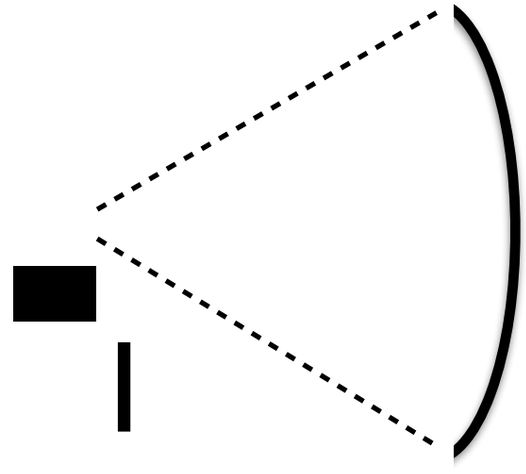


Preliminary analysis of data – four configurations



in/open

$\Delta R = -0.0228 \pm 0.0014$



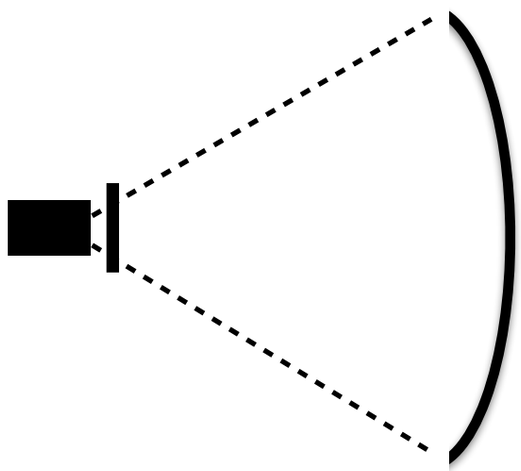
out/open

Measurement sequence (60 s in each position):

- *out/open*
- *out/close*
- *in/open*
- *in/close*

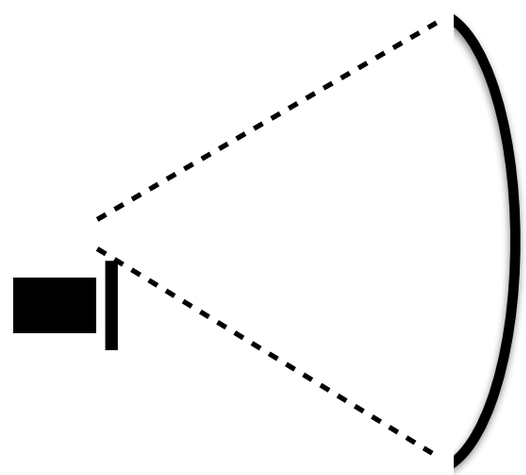
$\Delta R = 0.0032 \pm 0.0014$

$\Delta R = 0.0253 \pm 0.0014$



in/close

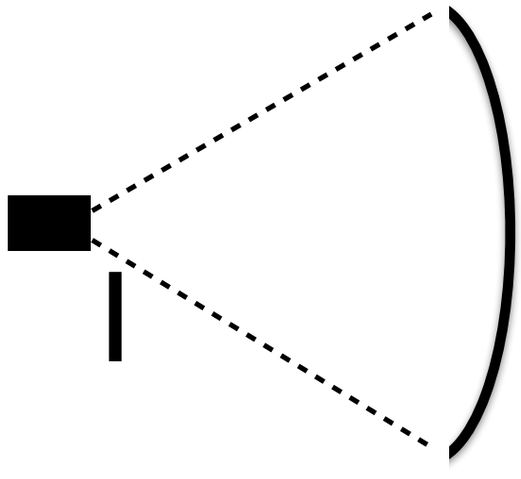
$\Delta R = -0.0007 \pm 0.0014$



out/close

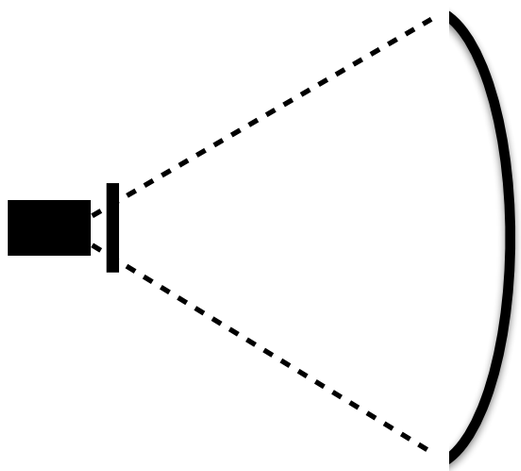
(run 6, all rates in Hz)

Preliminary analysis of data – four configurations



in/open

$\Delta R = 0.0032 \pm 0.0014$



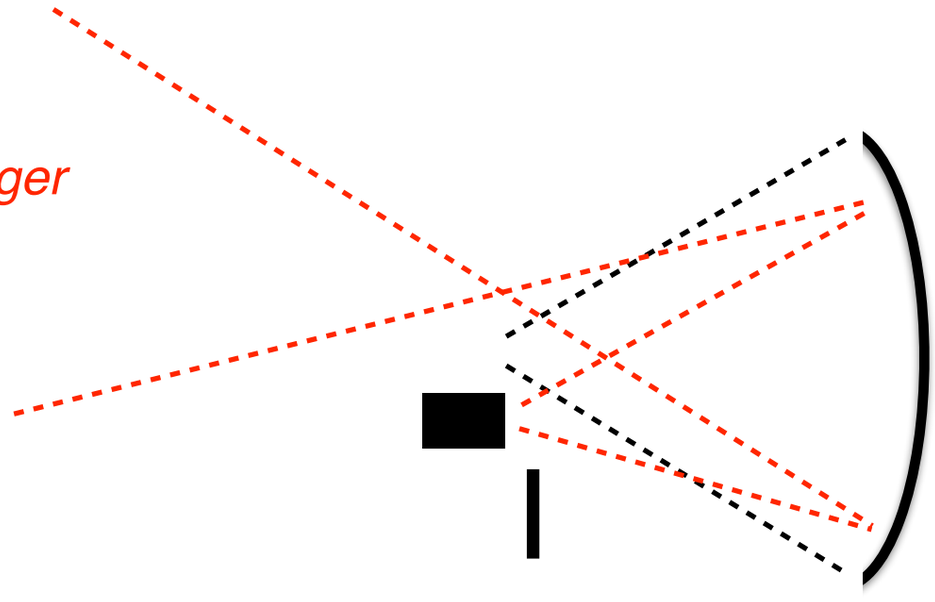
in/close

Different region and larger volume in FoV of PMT

Measurement sequence (60 s in each position):

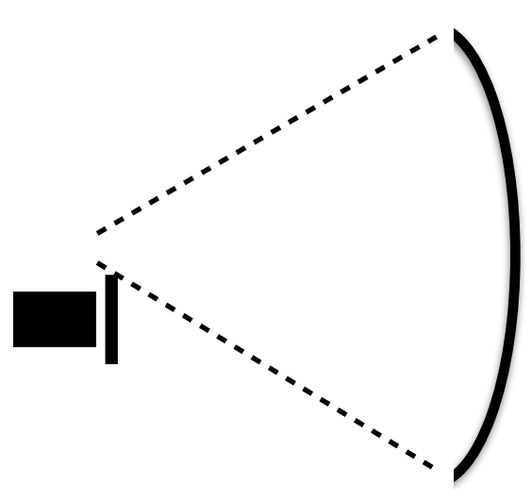
- *out/open*
- *out/close*
- *in/open*
- *in/close*

$\Delta R = -0.0007 \pm 0.0014$



out/open

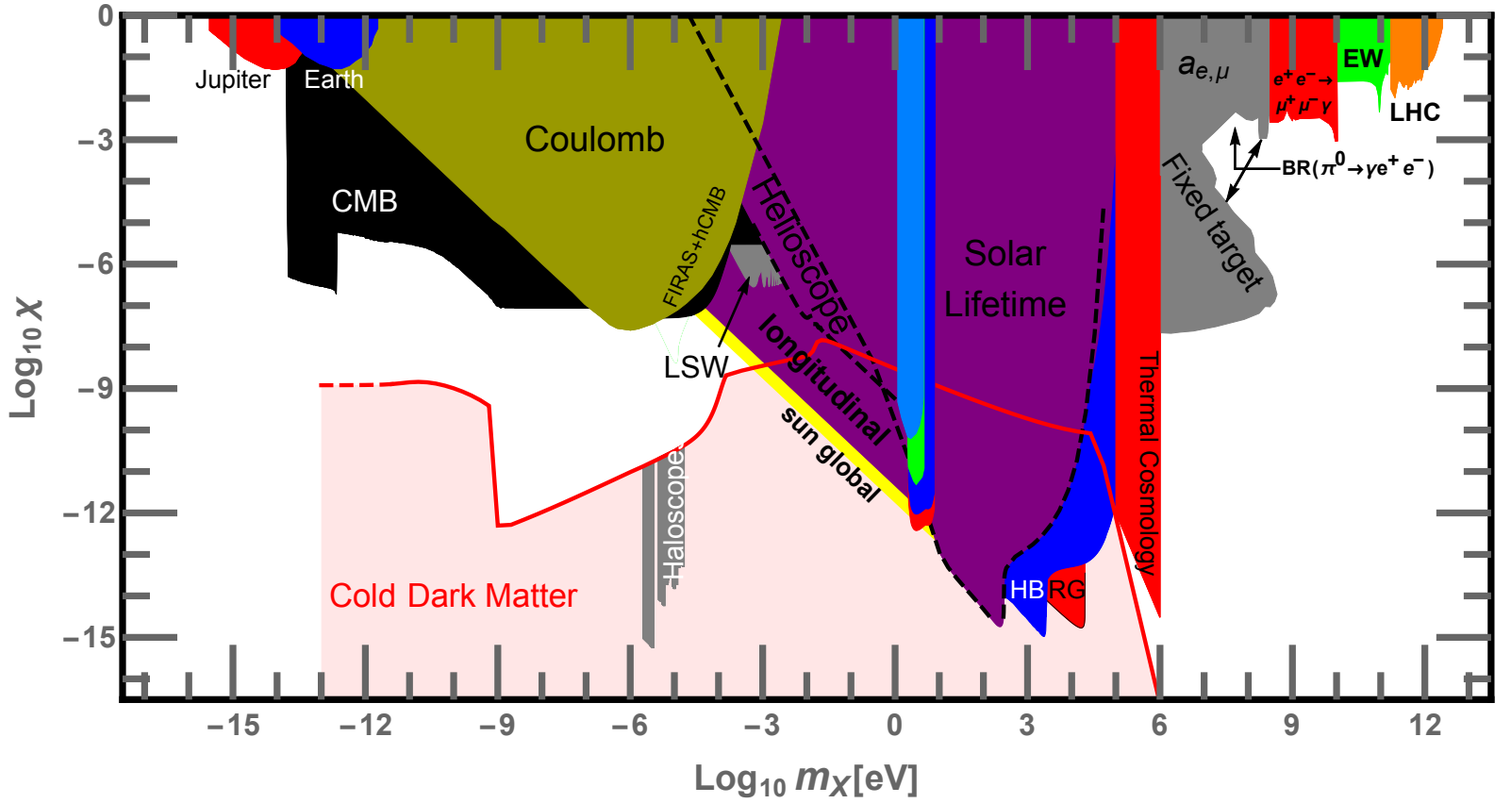
$\Delta R = 0.0253 \pm 0.0014$



out/close

(run 6, all rates in Hz)

Preliminary FUNK results

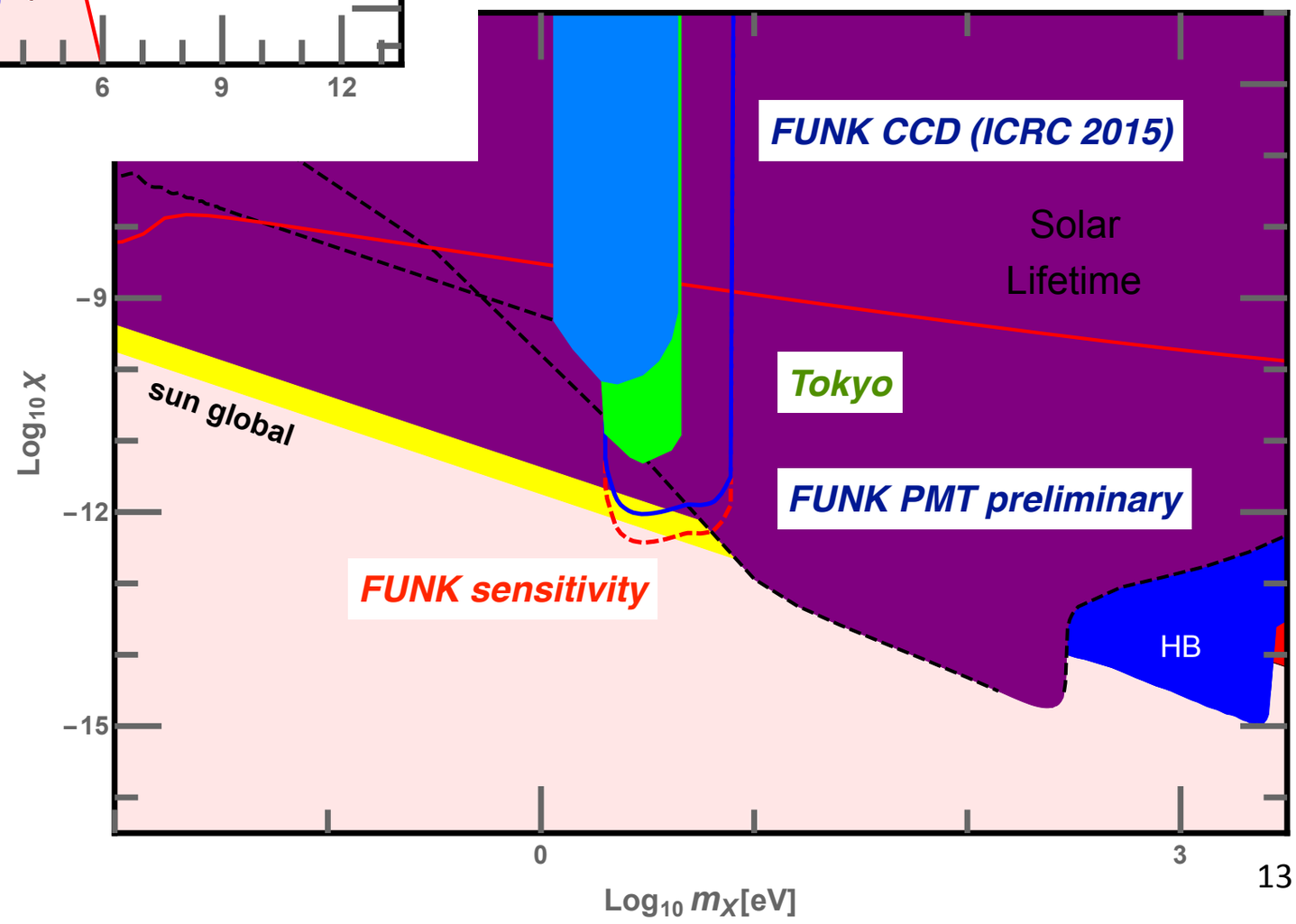


Shutter and motorized stage unique tools for studying systematic uncertainties

Work in progress

Systematics of measurement not yet understood

- *use estimated sys. uncertainty as max size of possible signal*
- *envisaged sensitivity given by statistical uncertainty*



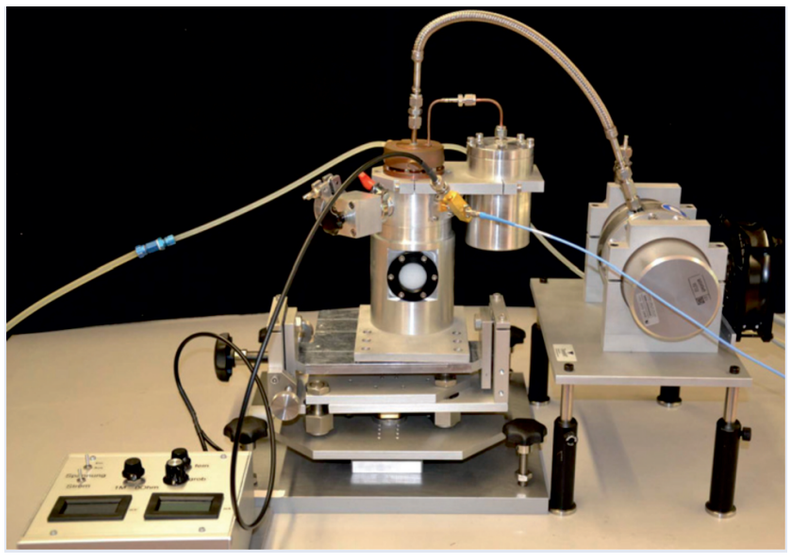
Outlook

Improve measurement in visible and UV range

- *Study of systematic effects, check FoV effect and search for possible light leaks*
- *Improvement of setup (light shielding, temperature stability, monitoring)*
- *Use of signal time correlation (time echo) to measure Cherenkov background*
- *Correction for temperature-dependent gain of PMT*

Perform measurements with other sensors to cover other phase space regions

GHz receivers (commercial)
Ku bands: 11 - 14 GHz



THz detector developed at KIT (LN2)

Backup slides

Hidden photons as source of photons

Re-definition to find classic e.o.m.

$$\tilde{X}^\mu \to X^\mu - \chi A^\mu$$

Spatially constant oscillating field

$$\left.\begin{pmatrix}\mathbf{A}\\ \mathbf{X}\end{pmatrix}\right|_{\rm DM} = \mathbf{X}_{\rm DM}\begin{pmatrix}-\chi\\ 1\end{pmatrix}\exp(-i\omega t)$$

Constraint on energy density

$$\frac{m_{\gamma'}^2}{2}\langle|\mathbf{X}_{\rm DM}|^2\rangle = \rho_{\rm CDM,halo} \sim \frac{0.3\,{\rm GeV}}{{\rm cm}^3}$$

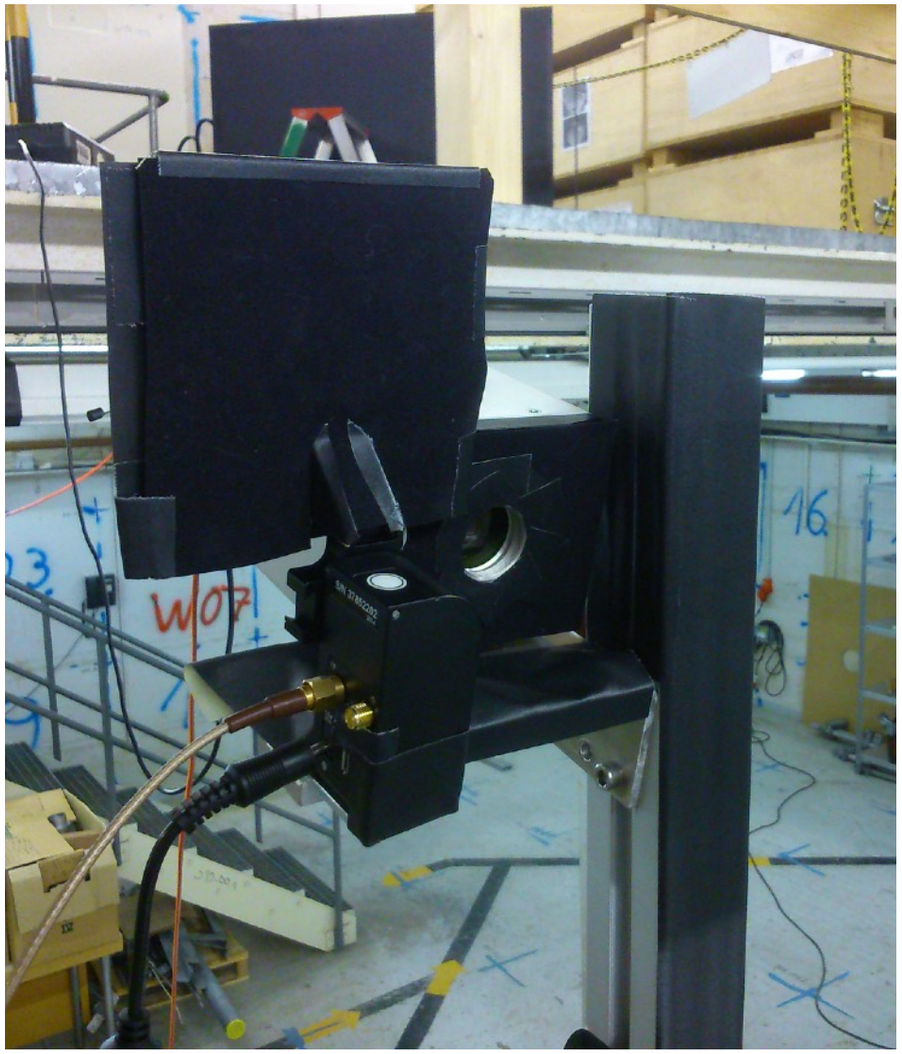
Small oscillating electric field

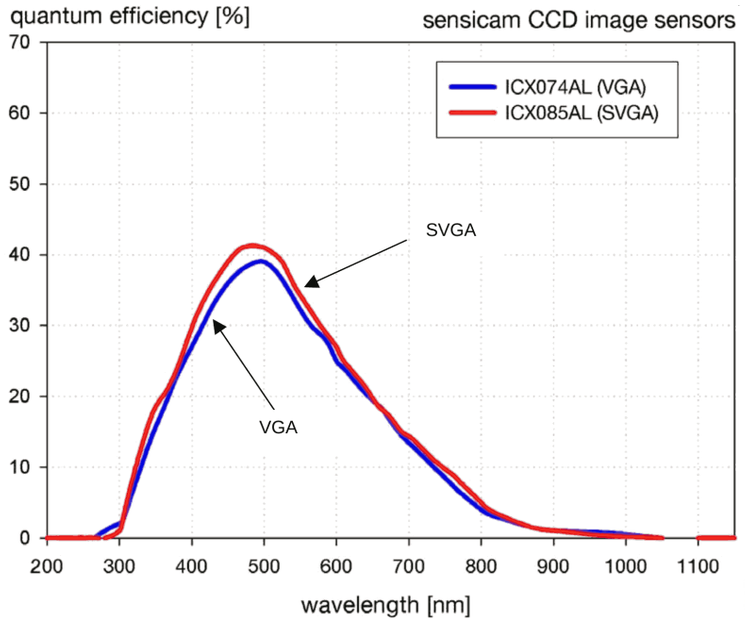
$$\sqrt{\langle|\mathbf{E}_{\rm DM}|^2\rangle} = \chi\sqrt{2\rho_{\rm CDM,halo}} \sim 3.3\times10^{-9}\ \frac{V}{\rm m}\left(\frac{\chi}{10^{-12}}\right)\left(\frac{\rho_{\rm CDM,halo}}{0.3\,{\rm GeV/cm}^3}\right)$$

$$f = \frac{m_{\gamma'}}{2\pi} = 0.24\ {\rm GHz}\ \left(\frac{m_{\gamma'}}{\mu{\rm eV}}\right)$$

Test measurement with cooled CCD camera

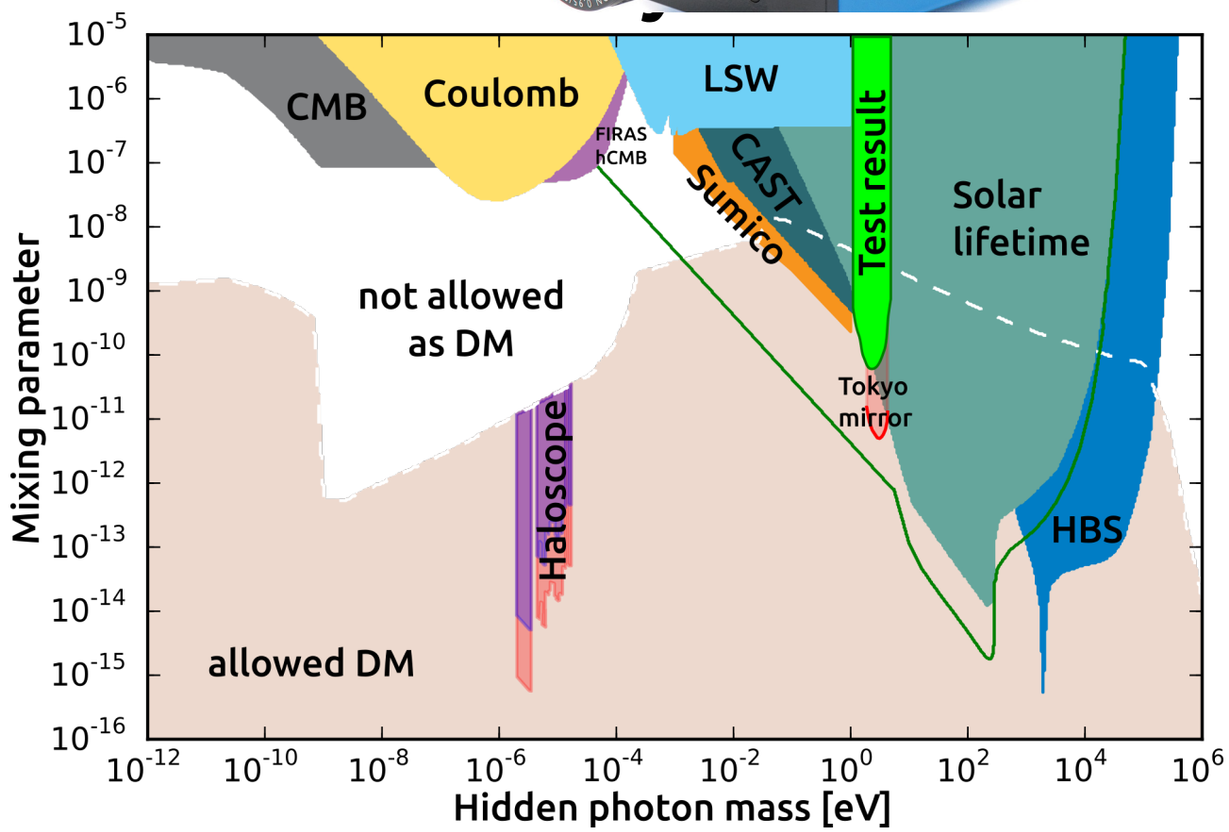
Motorized shutter for camera





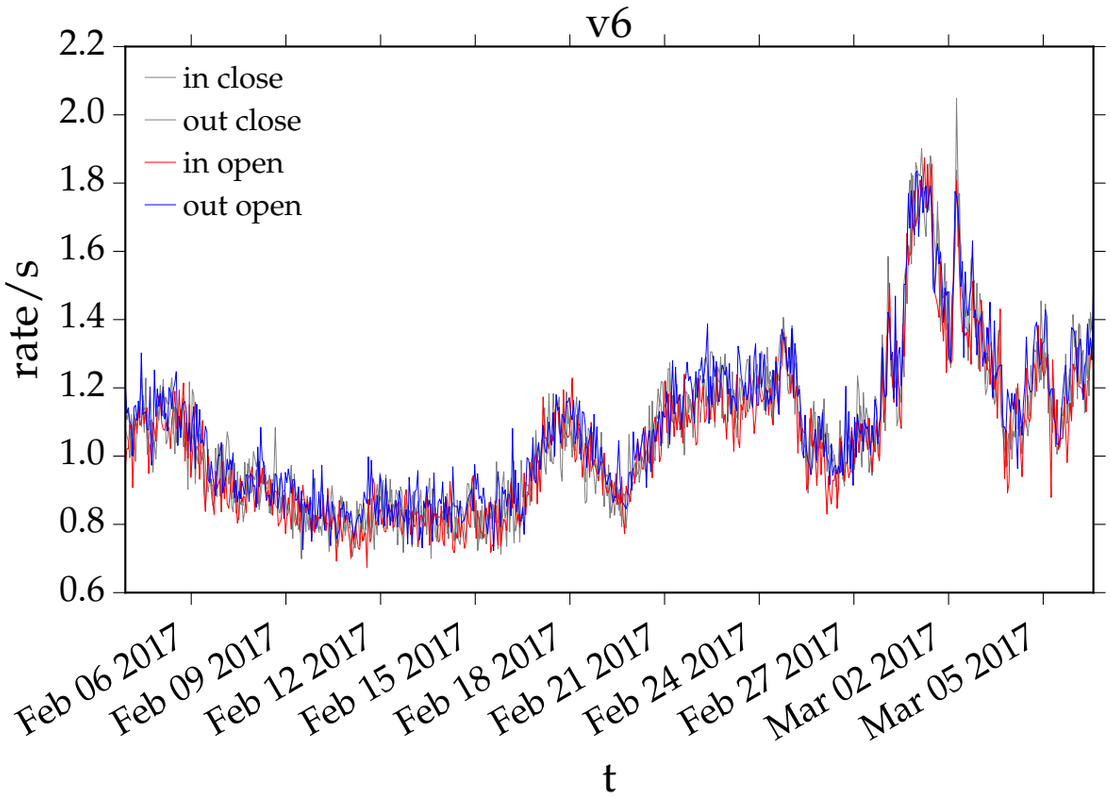
PCO Sensicam VGA
640x480 pixel CCD
internally Peltier-cooled –15°C

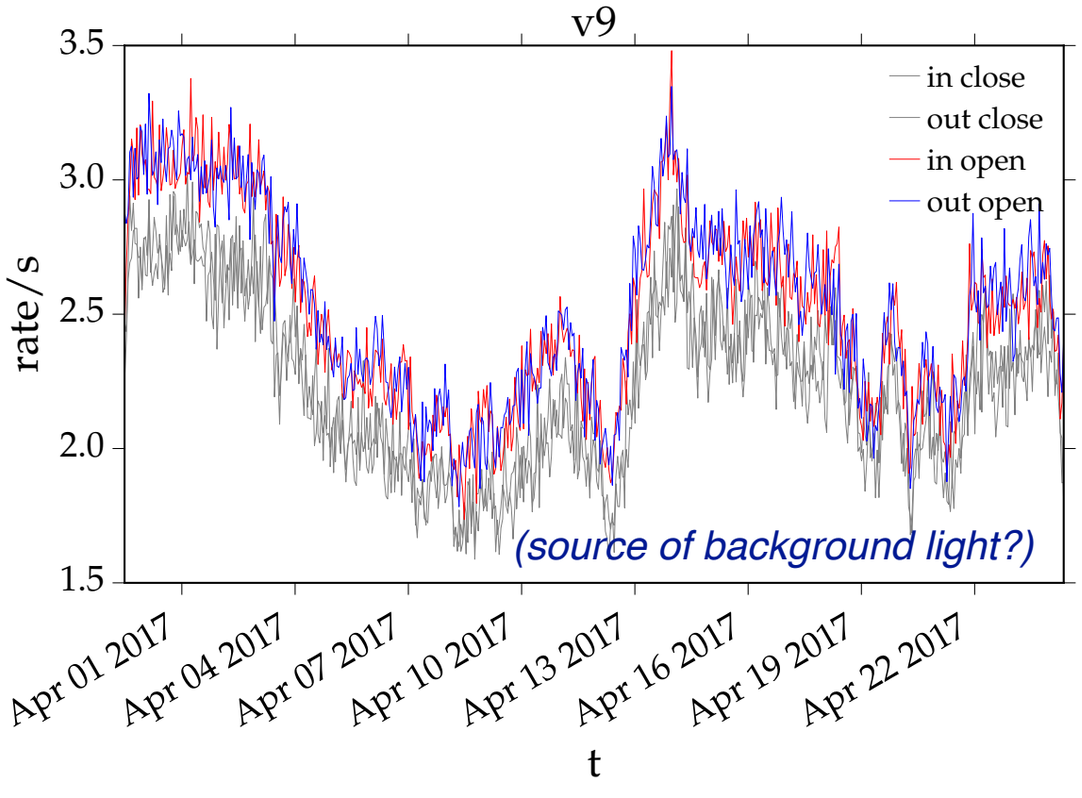
no lens, exposed CCD
total image intensity

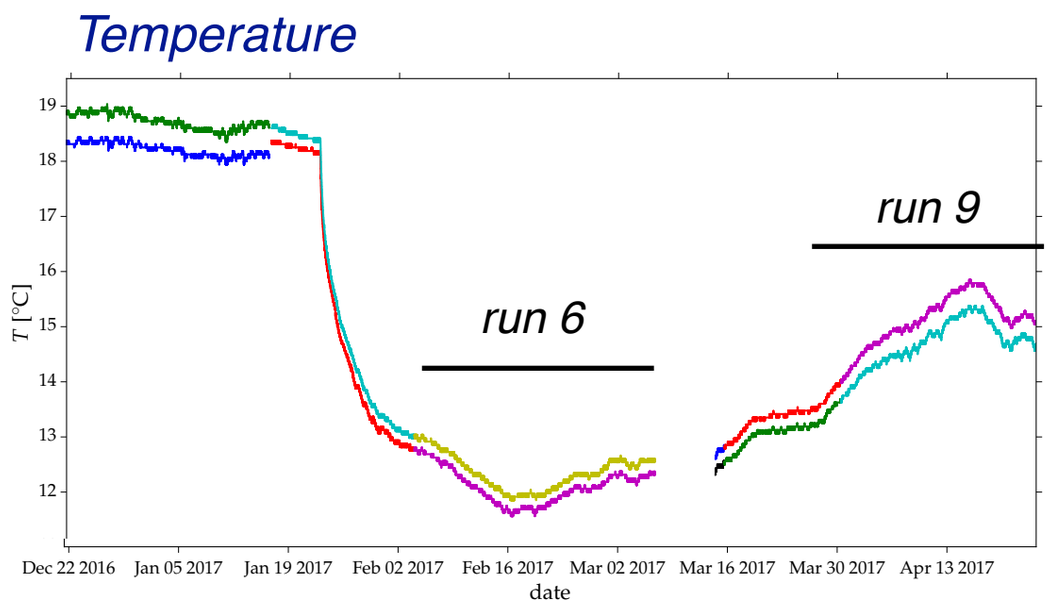


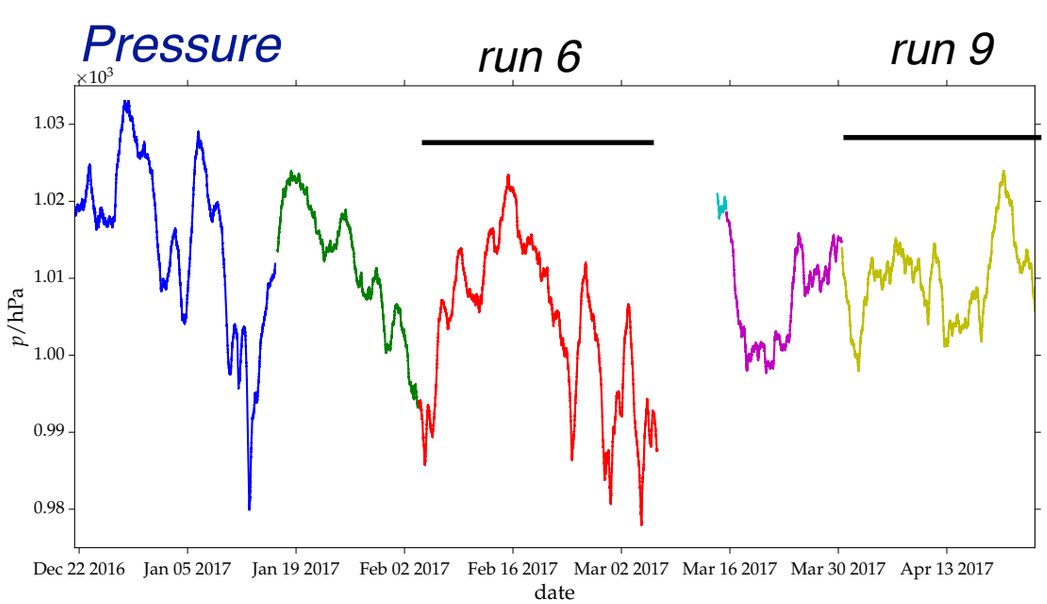
Veberic et al. ICRC 2015 (1509.02386)

Data runs: raw trigger rates

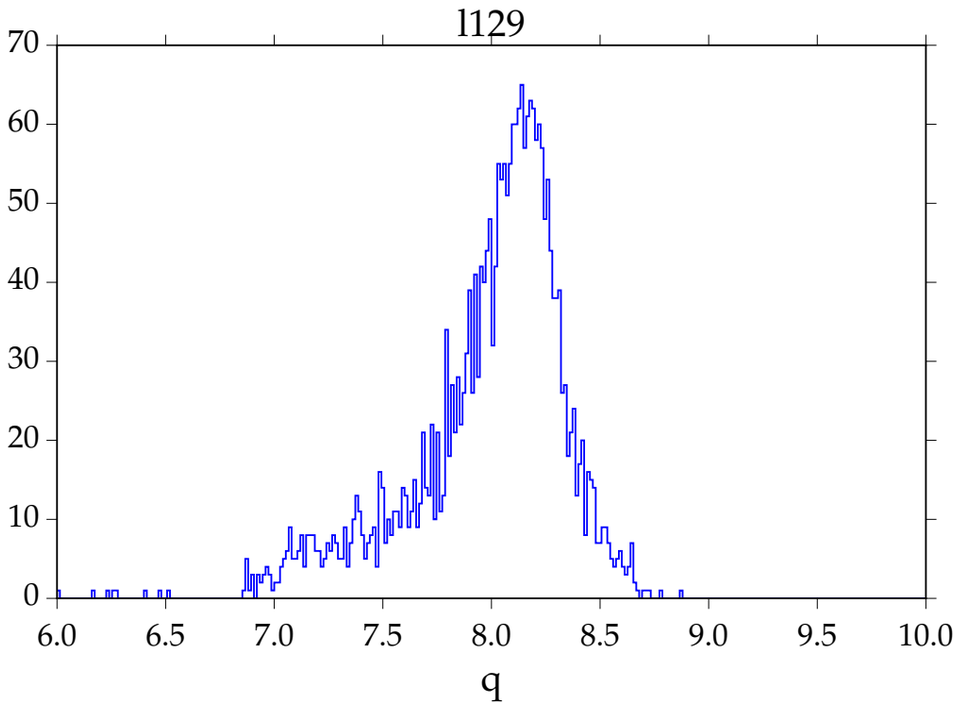








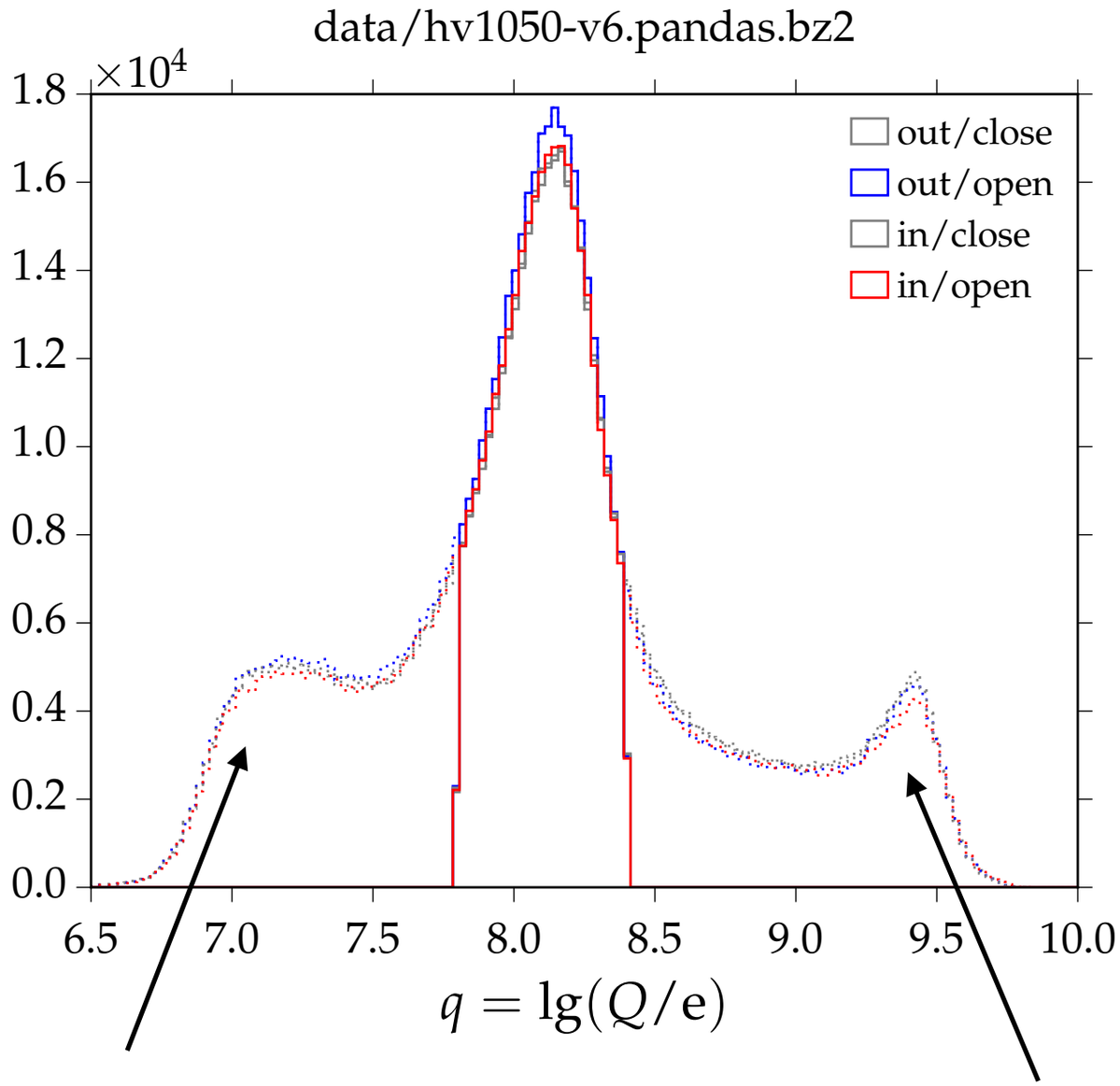
Charge distribution of measured signals



Calibration: single-photon trace measured with flasher (direct trigger)

Selection window for single photons (selection efficiency 0.75)

Charge obtained by integrating traces



Electronics noise

Muon hits and showers

Larger mirrors available ?

Pierre Auger Observatory, Argentina

Fluorescence telescope of Auger Observatory