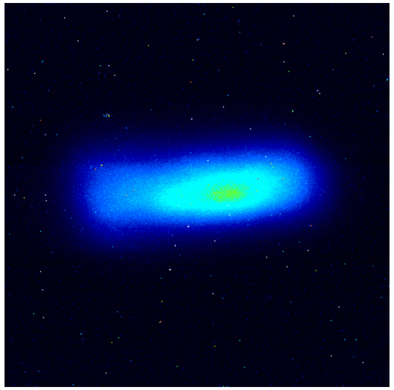
Synchrotron-light detection for FAST and IOTA experiments



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Fermi National Accelerator Laboratory

Workshop on Megawatt Rings and IOTA-FAST Collaboration Meeting
Fermilab, May 10, 2018

Fermilab

`https://indico.fnal.gov/event/16269`

Motivation

Characterize synchrotron-light signal and backgrounds in IOTA/FAST environment for

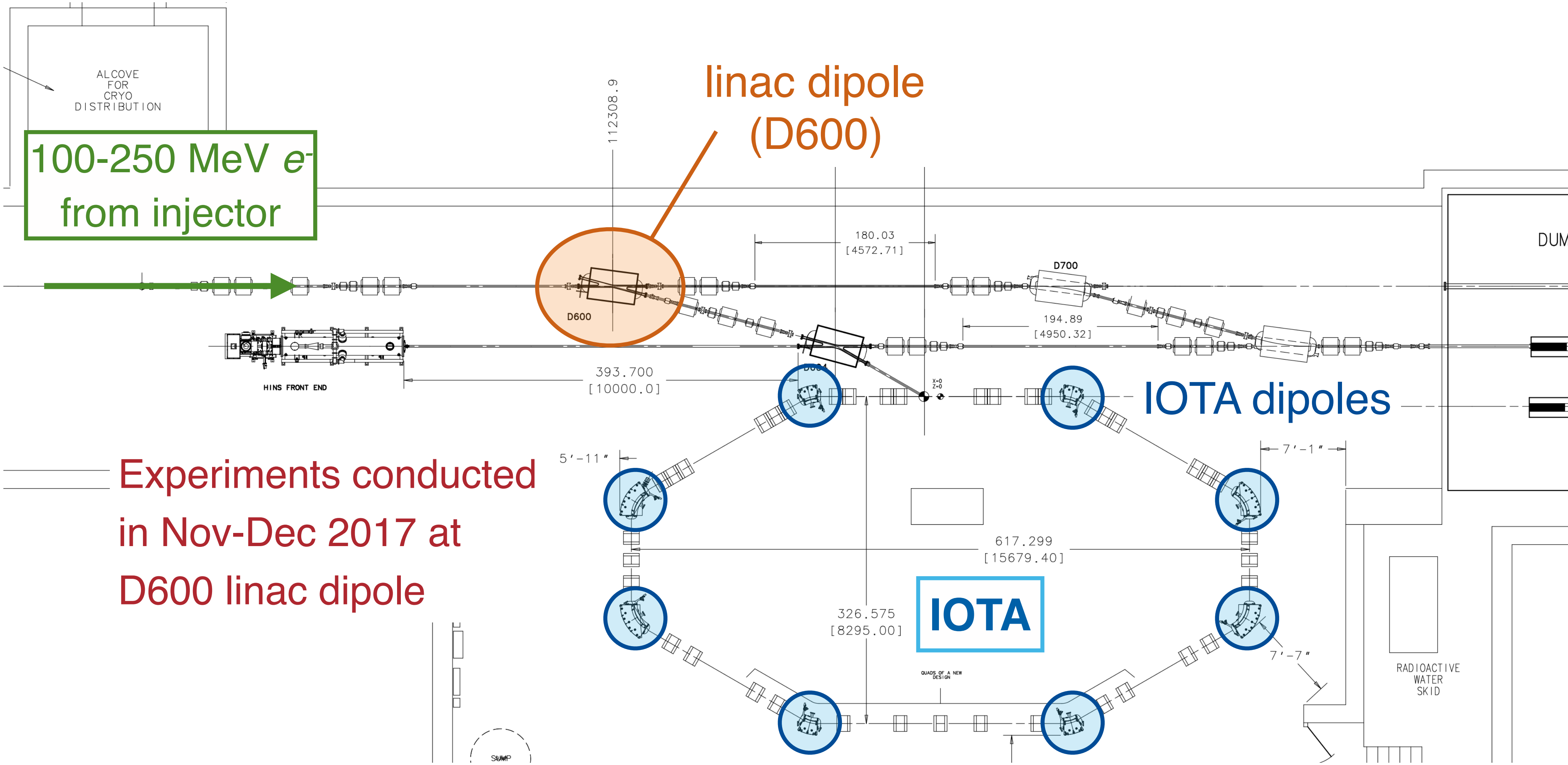
1. **Beam diagnostics**: bunch-by-bunch (for linac) and turn-by-turn (for IOTA) **intensity monitor** with **wide dynamic range**, from **nominal intensities** down to **a few picocoulombs** (linac) or **single electrons** (IOTA)

2. **Scientific experiments** in IOTA
   - what is the time structure of radiation emission from a single electron in a storage ring? Is it random, regular, chaotic?
   - is there correlation between the emission from different dipoles?
   - many other ideas...

see also yesterday's talk by Nagaitsev

Stancari et al., FERMILAB-FN-1043-AD-APC

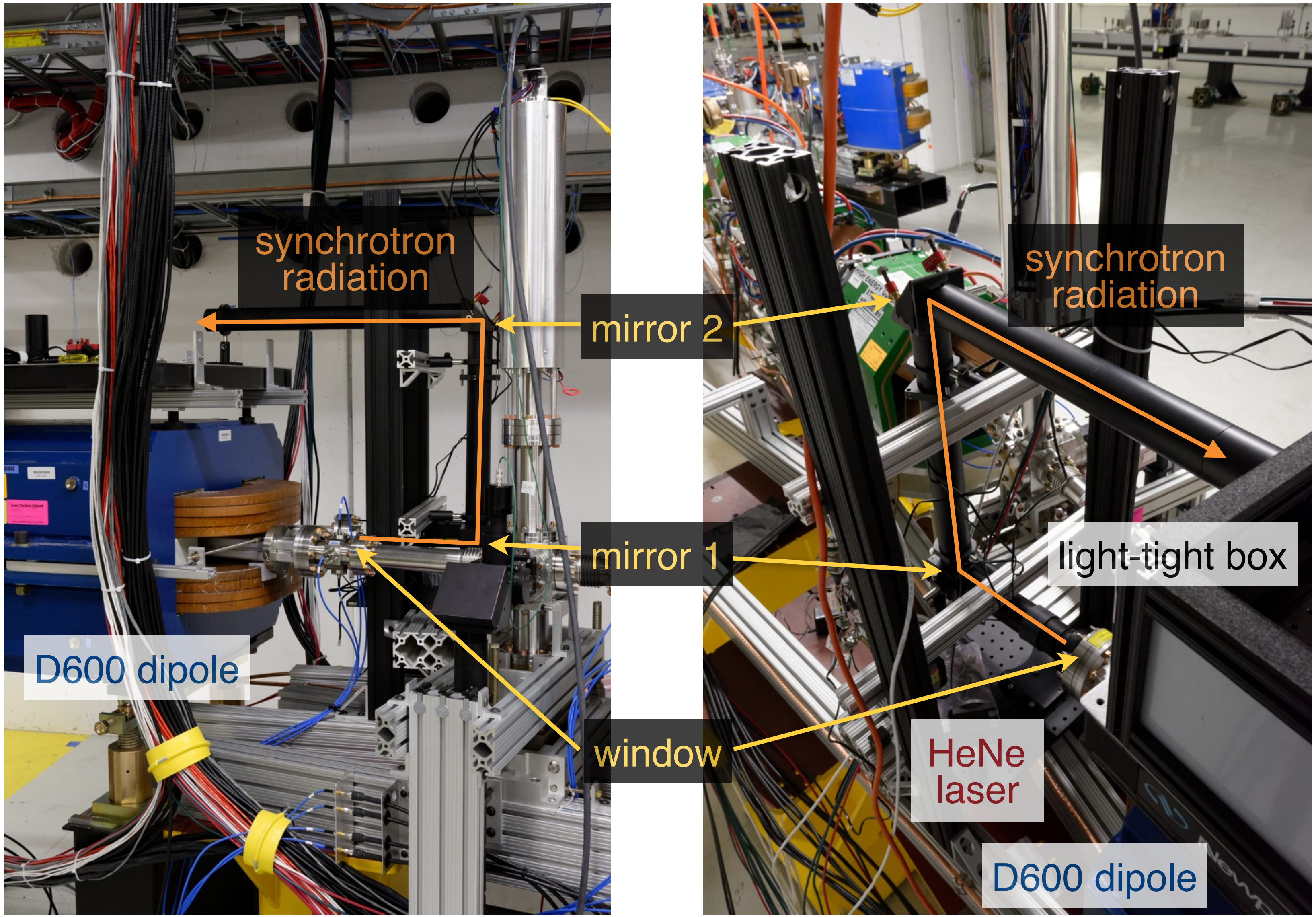
Experimental layout



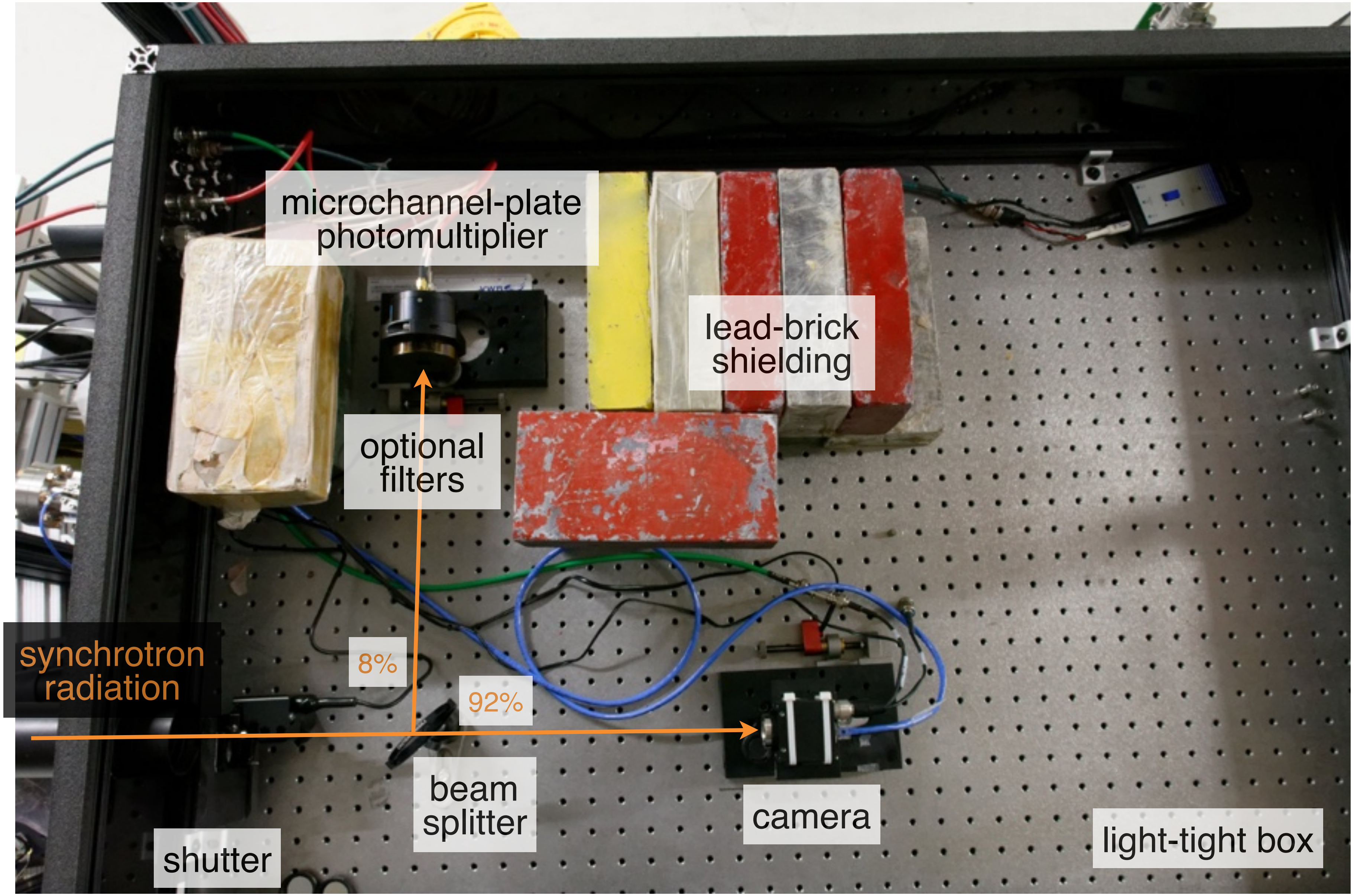
Experiments conducted in Nov-Dec 2017 at D600 linac dipole

- Linac bunch spacing (333 ns) used as a proxy for IOTA revolution period (133 ns)
- Synchrotron light intensity and spectrum in D600 at 300 MeV are very similar to what we expect from IOTA dipoles at 150 MeV

Experimental apparatus



Experimental apparatus

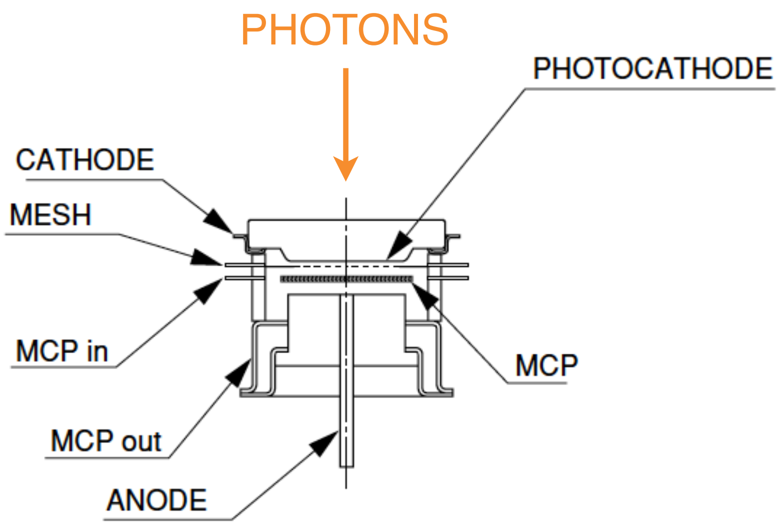


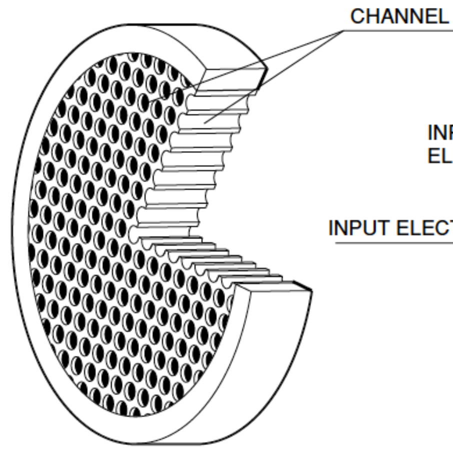
Microchannel-plate photomultiplier (MCP-PMT) features

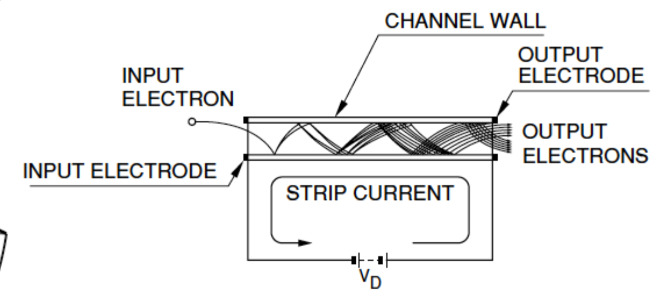
Excellent timing (sub-ns) and high gain (10^3-10^7). Can be gated.

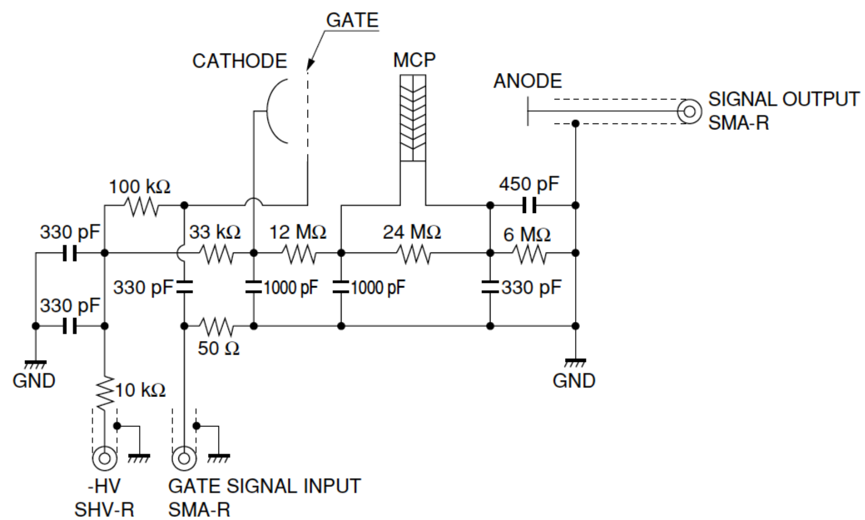
Limited current at high rate.

Hamamatsu R5916U-50 mod. 2 reused from Tevatron Synclite.

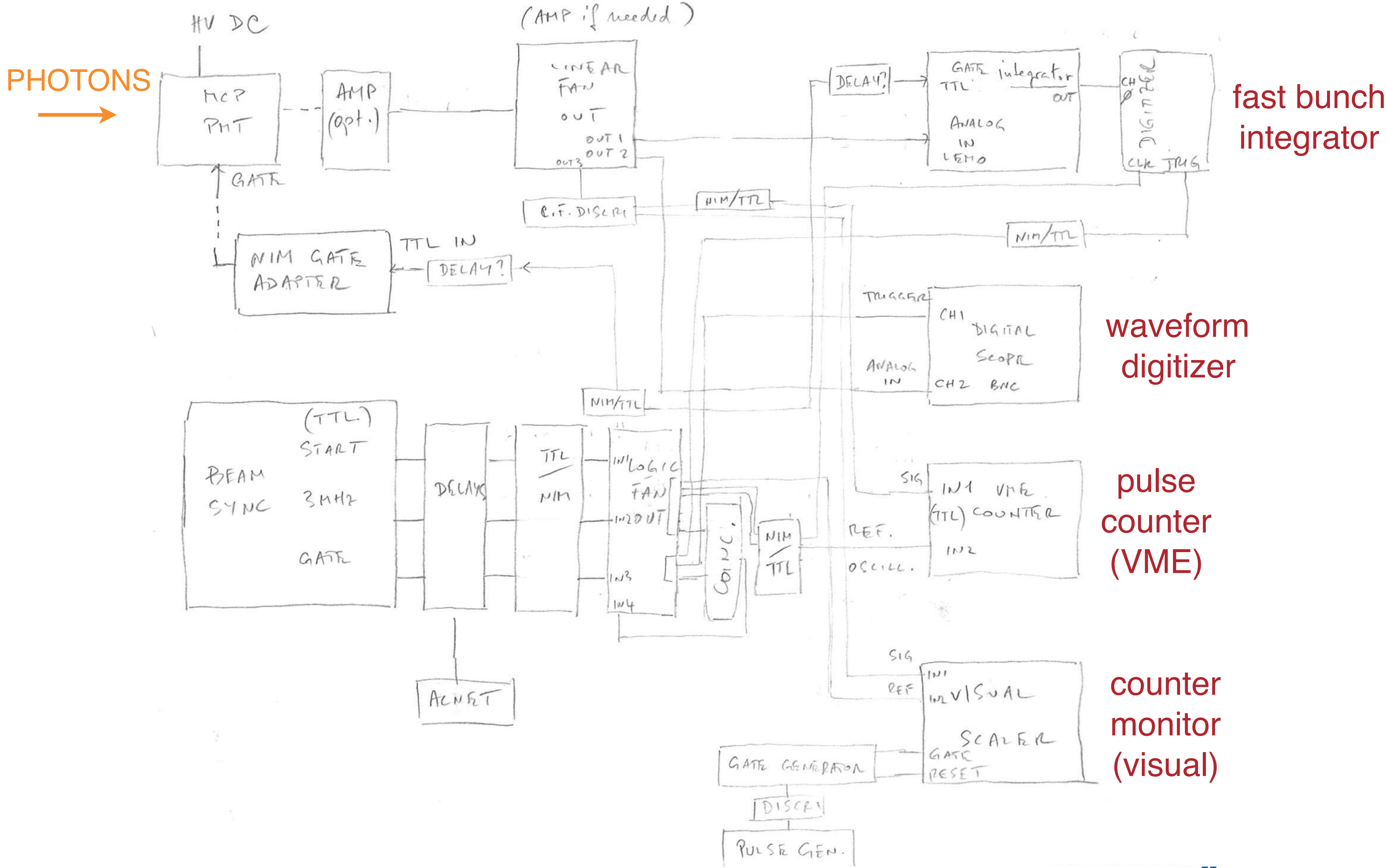




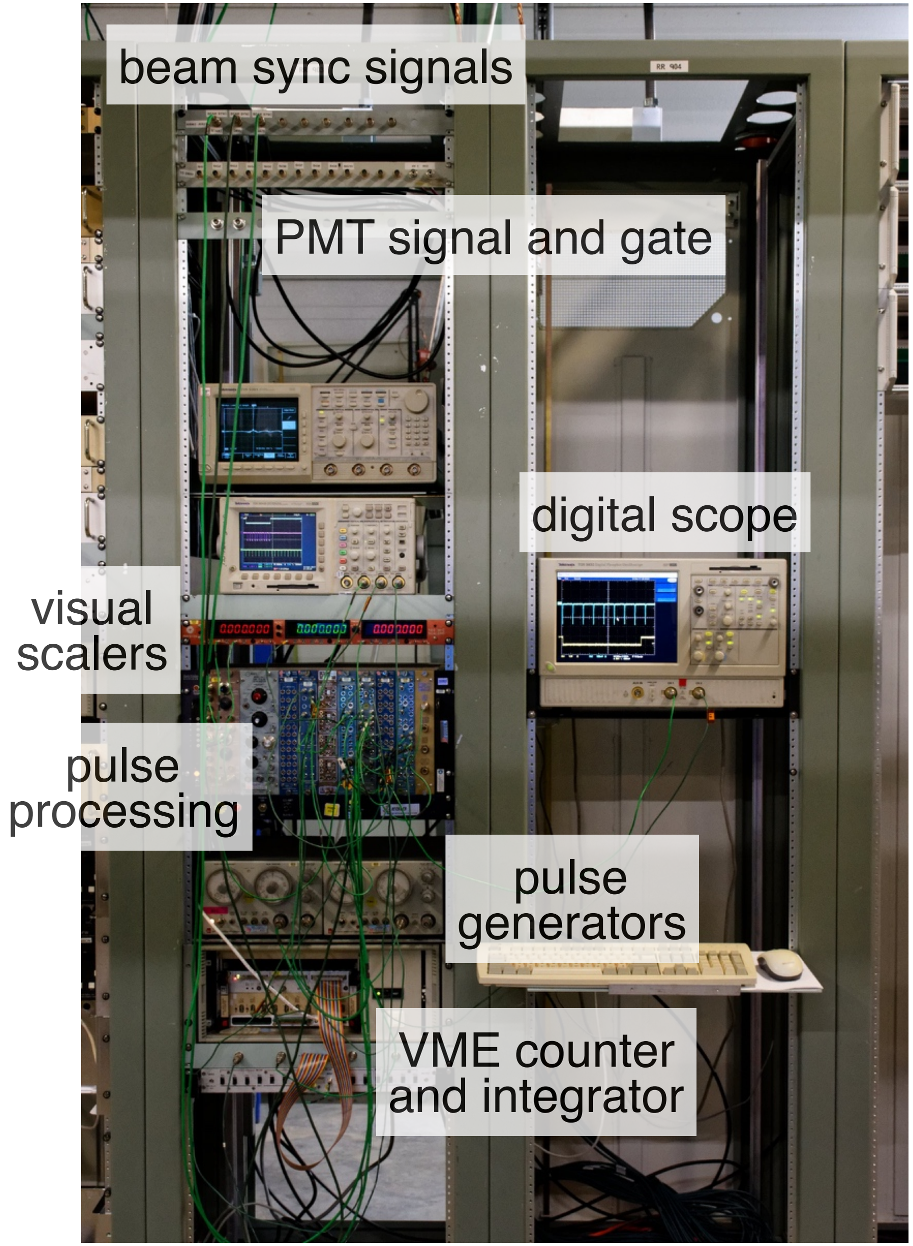




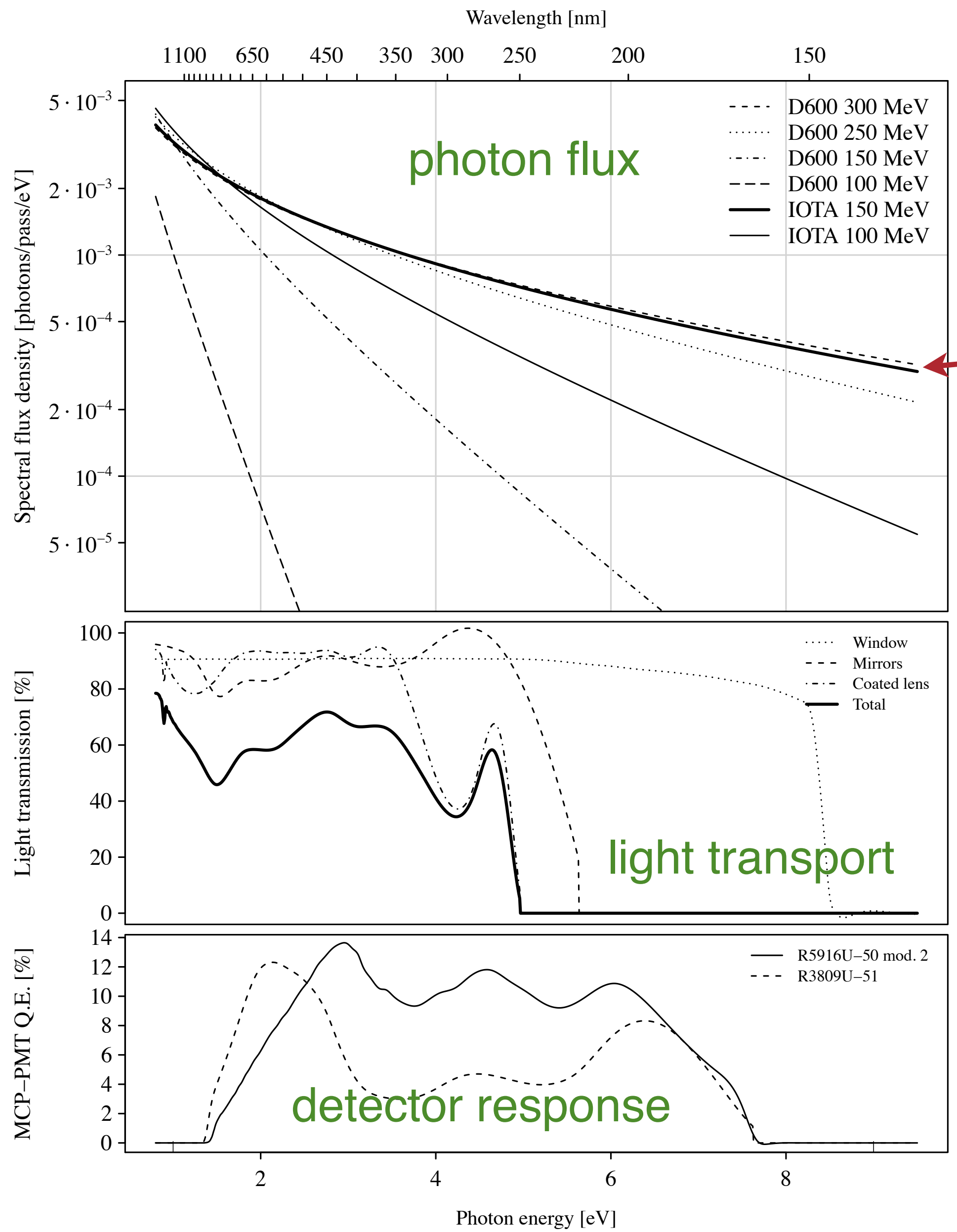
Data acquisition schematic



Data acquisition system



Expected signal



D600 dipole at 300 MeV and IOTA dipoles at 150 MeV yield similar spectra

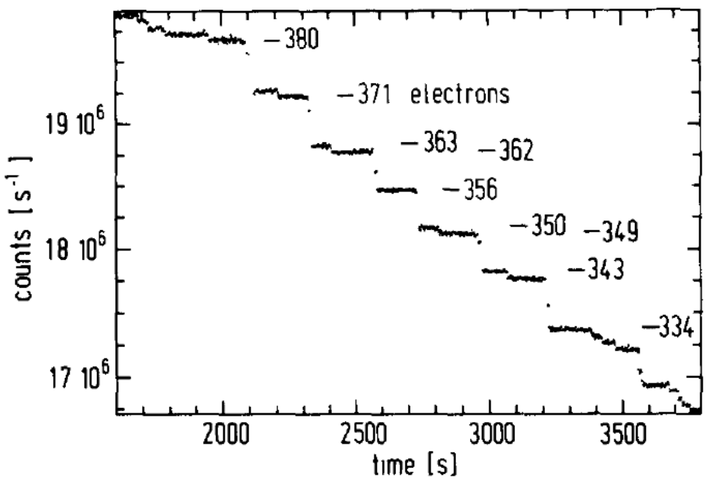
Typical photoelectron yield is ~ 2×10^{-4} / e^-

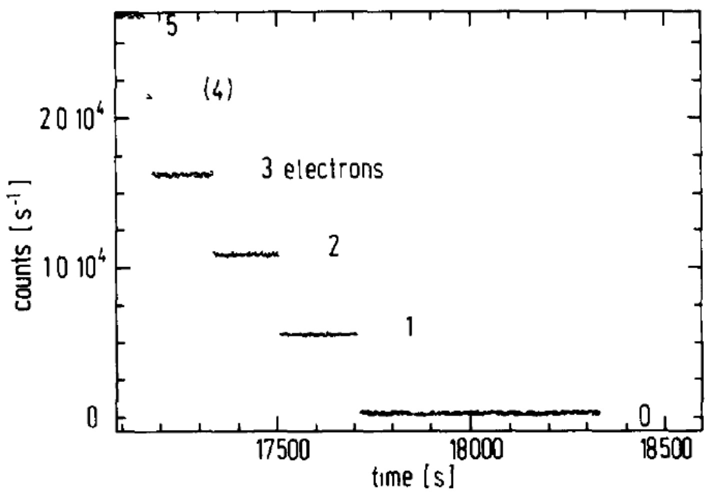
Table II. Calculation of expected photoelectron yield for each sample case.

	Avg. Q.E. [10^{-3}]	Error on avg. Q.E. [10^{-5}]	Average number of collected photoelectrons N_{pe} [$10^{-4}/e^-$/pass]	Integration error on N_{pe} [$10^{-6}/e^-$/pass]
D600 300 MeV	10.8	2.47	2.27	0.52
D600 250 MeV	10.5	2.65	2.22	0.558
D600 150 MeV	3.95	3.1	0.832	0.652
D600 100 MeV	0.151	1.58	0.0318	0.332
IOTA 150 MeV	10.8	2.52	2.28	0.531
IOTA 100 MeV	8.01	0.193	1.69	0.0407

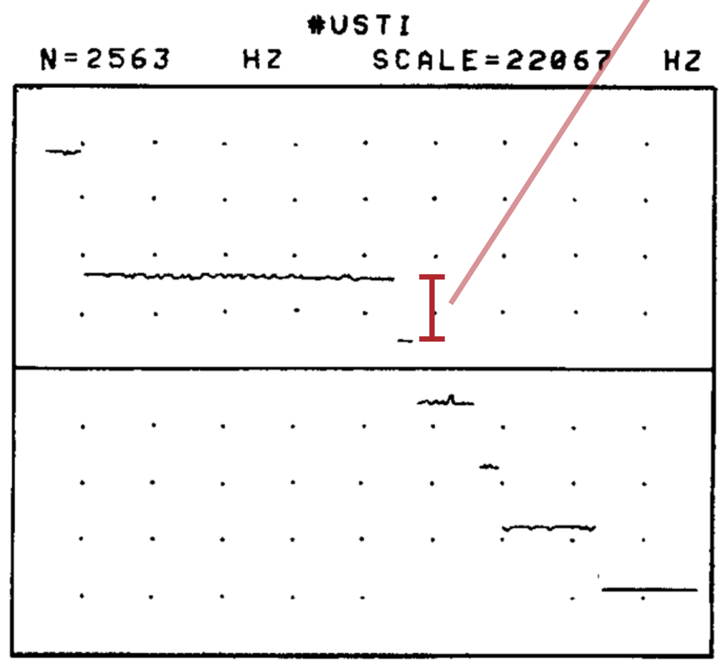
Stancari et al., FERMILAB-FN-1043-AD-APC (calculation assumes full cone acceptance; updated calculation with 2 mirrors)

Observation of discrete steps in photon flux





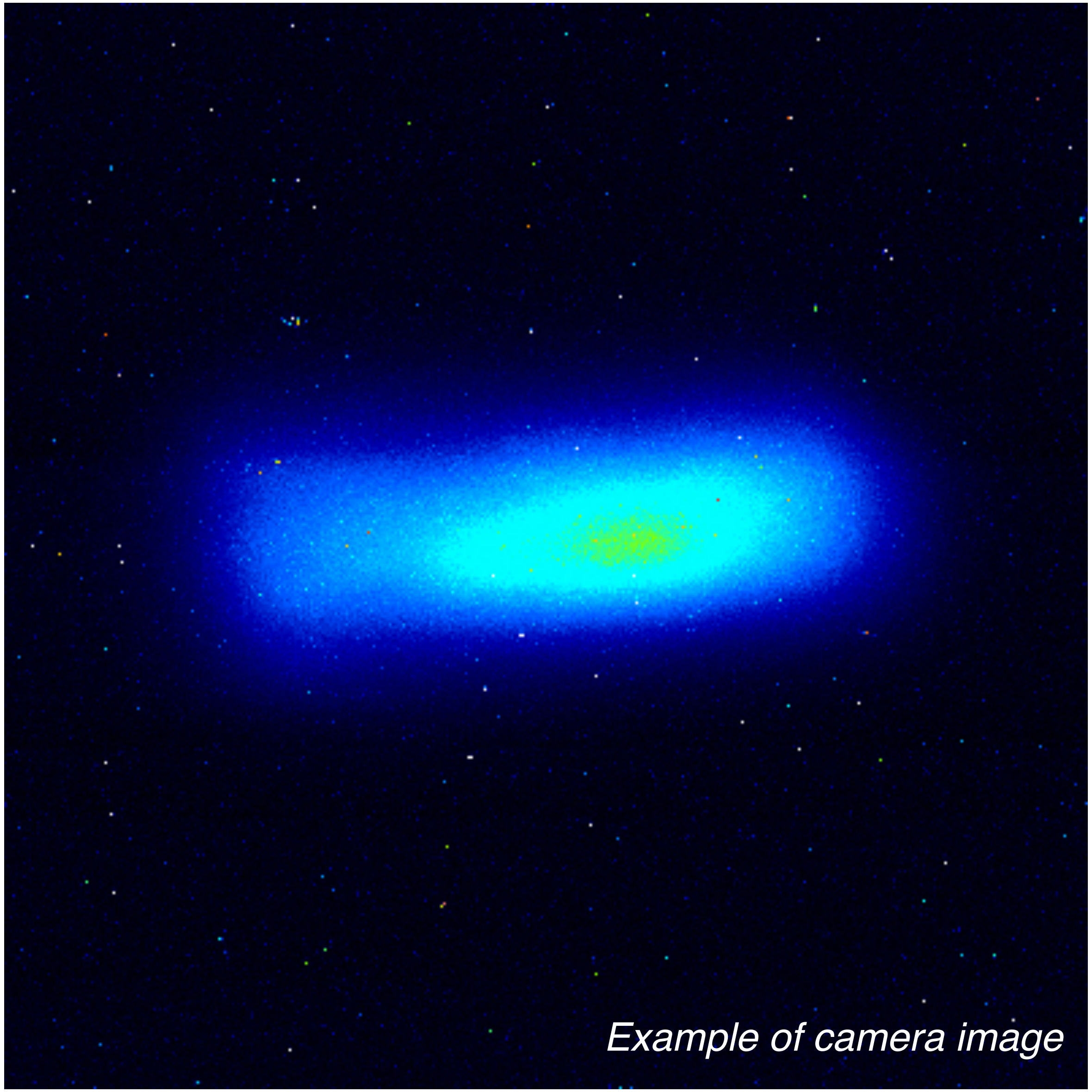
From IOTA dipoles (no undulator), we expect single-electron photon fluxes of (2×10^{-4}) (7.5 MHz) = **1.5 kHz** (well above noise and background)



Riehle et al., NIMA **268**, 262 (1988)
BESSY storage ring

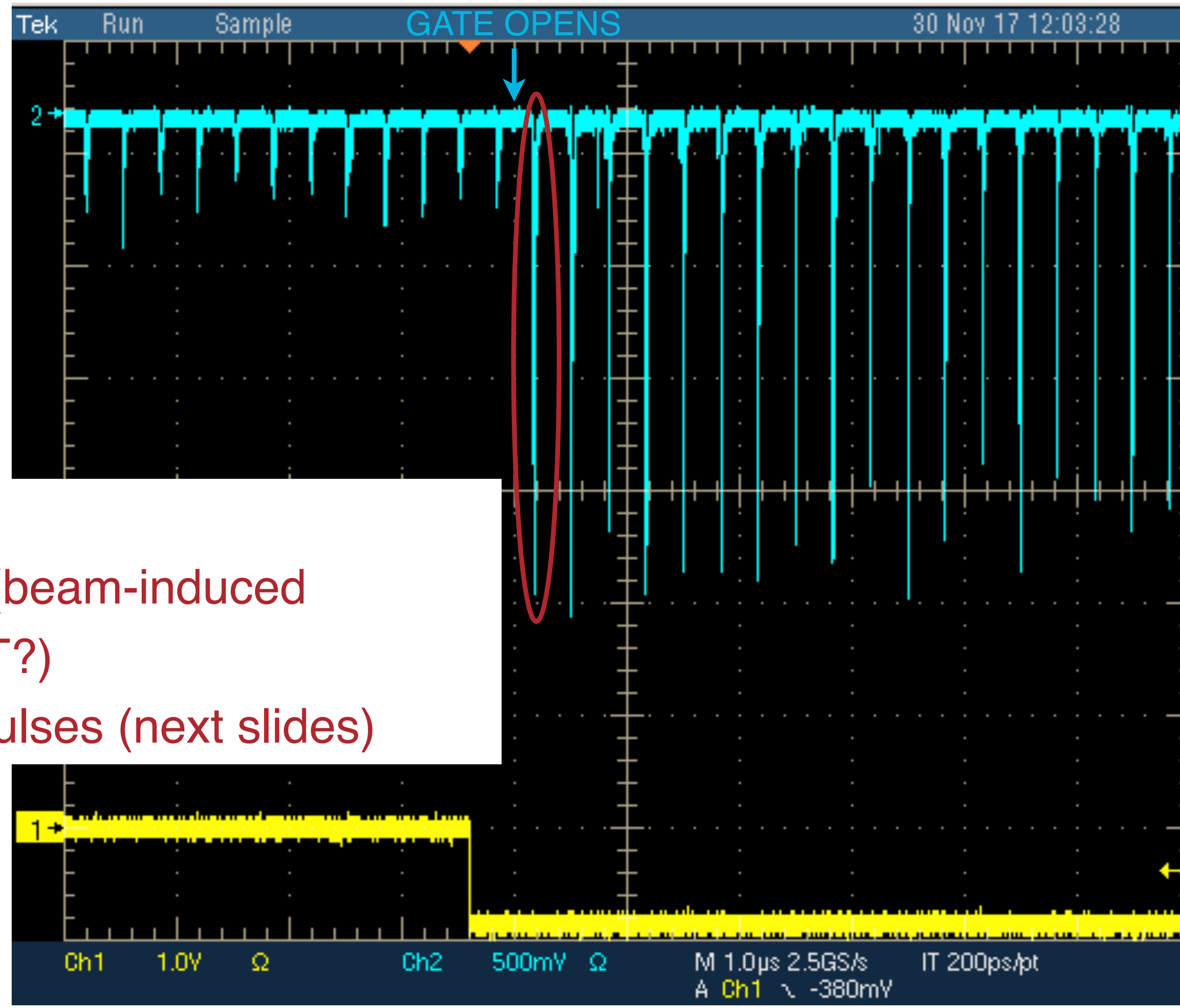
Pinayev et al., NIMA **341**, 17 (1994)
VEPP-3 storage ring

Experiments with linac beam, 100-250 MeV



Photomultiplier signal with linac beam

150 MeV, 250 pC/bunch, 30 bunches (12 before gate, 18 after)
PMT HV = 3.8 kV, PMT gate = 8.2 V, no filters

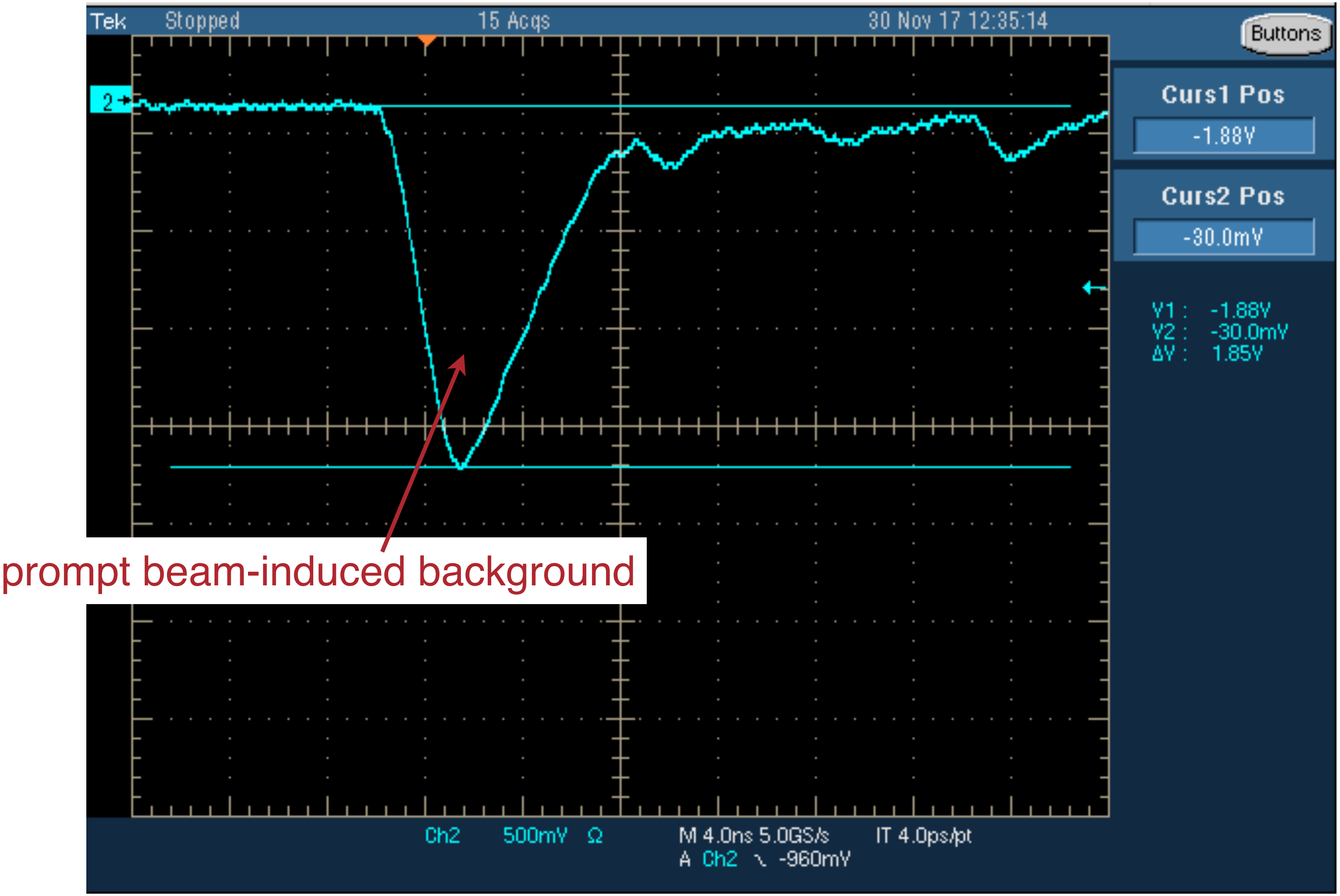


Large signal ~ volts

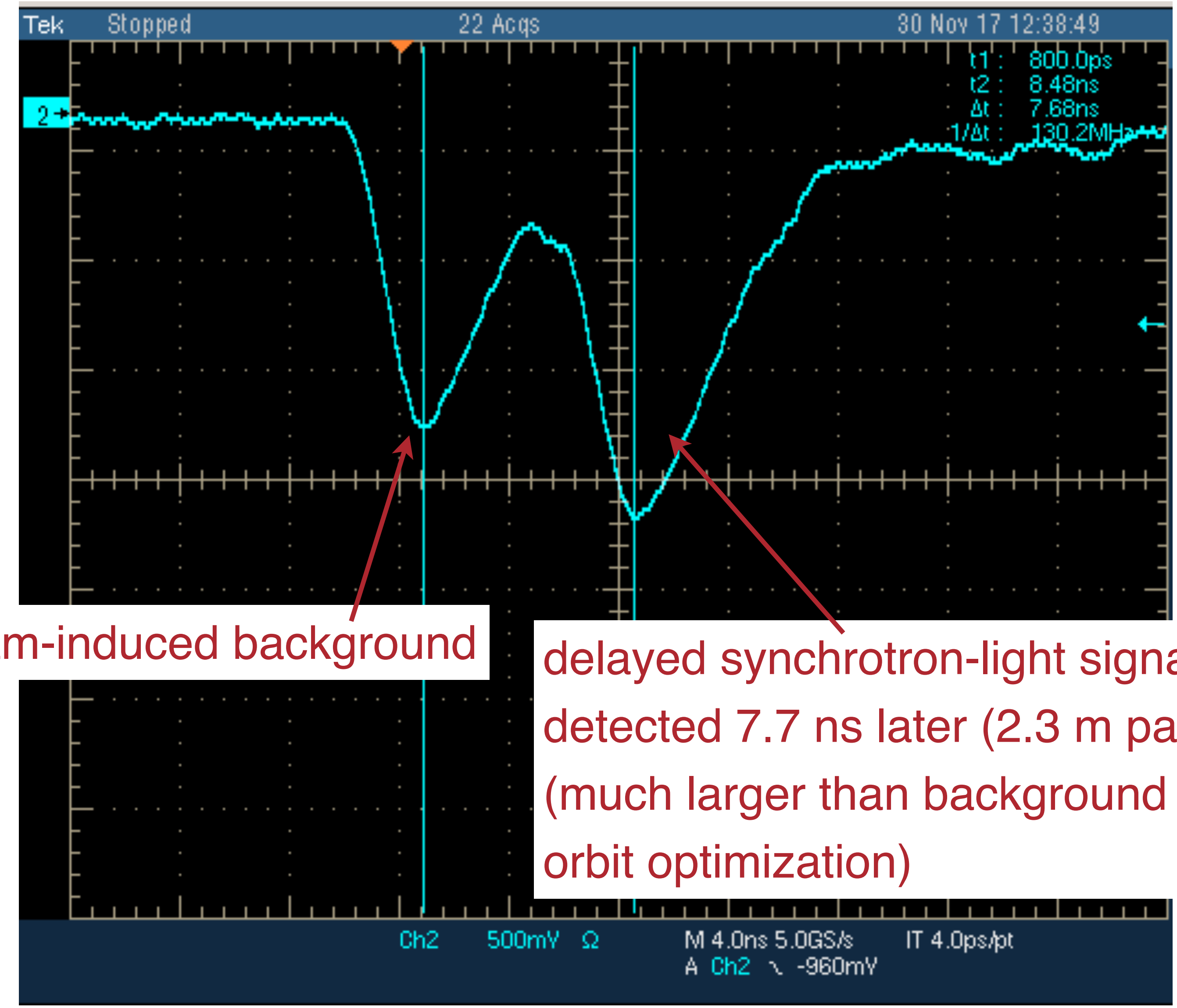
Non-zero signal before gate (beam-induced background hitting MCP-PMT?)

Microstructure of individual pulses (next slides)

Individual pulse, shutter closed



Individual pulse, shutter open

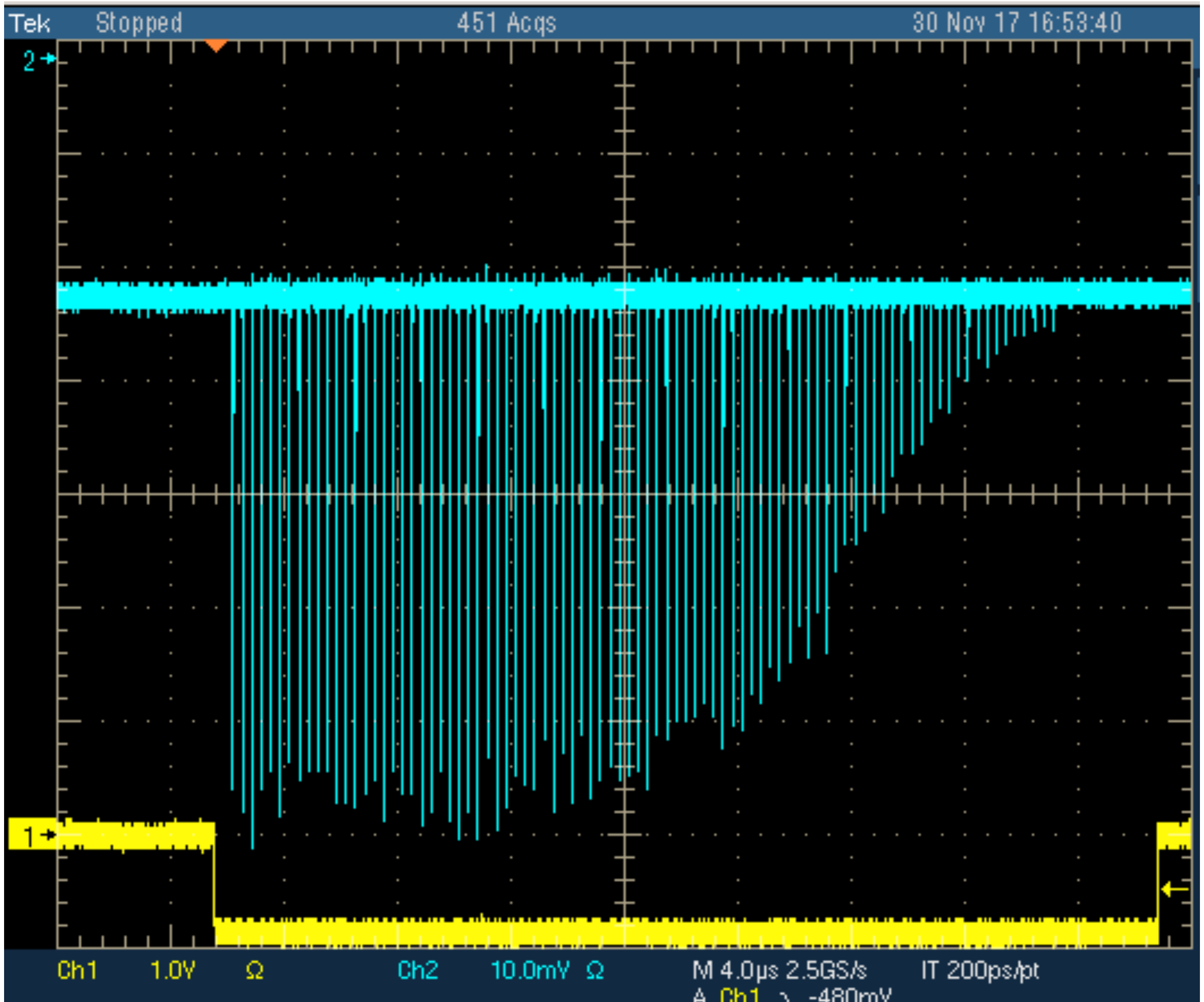


beam-induced background

delayed synchrotron-light signal detected 7.7 ns later (2.3 m path) (much larger than background after orbit optimization)

Signal drooping with long bunch trains

150 MeV, 400 pC/bunch, 100 bunches (12 before gate, 88 after)
PMT HV = 2.9 kV, PMT gate = 8.2 V, no filters

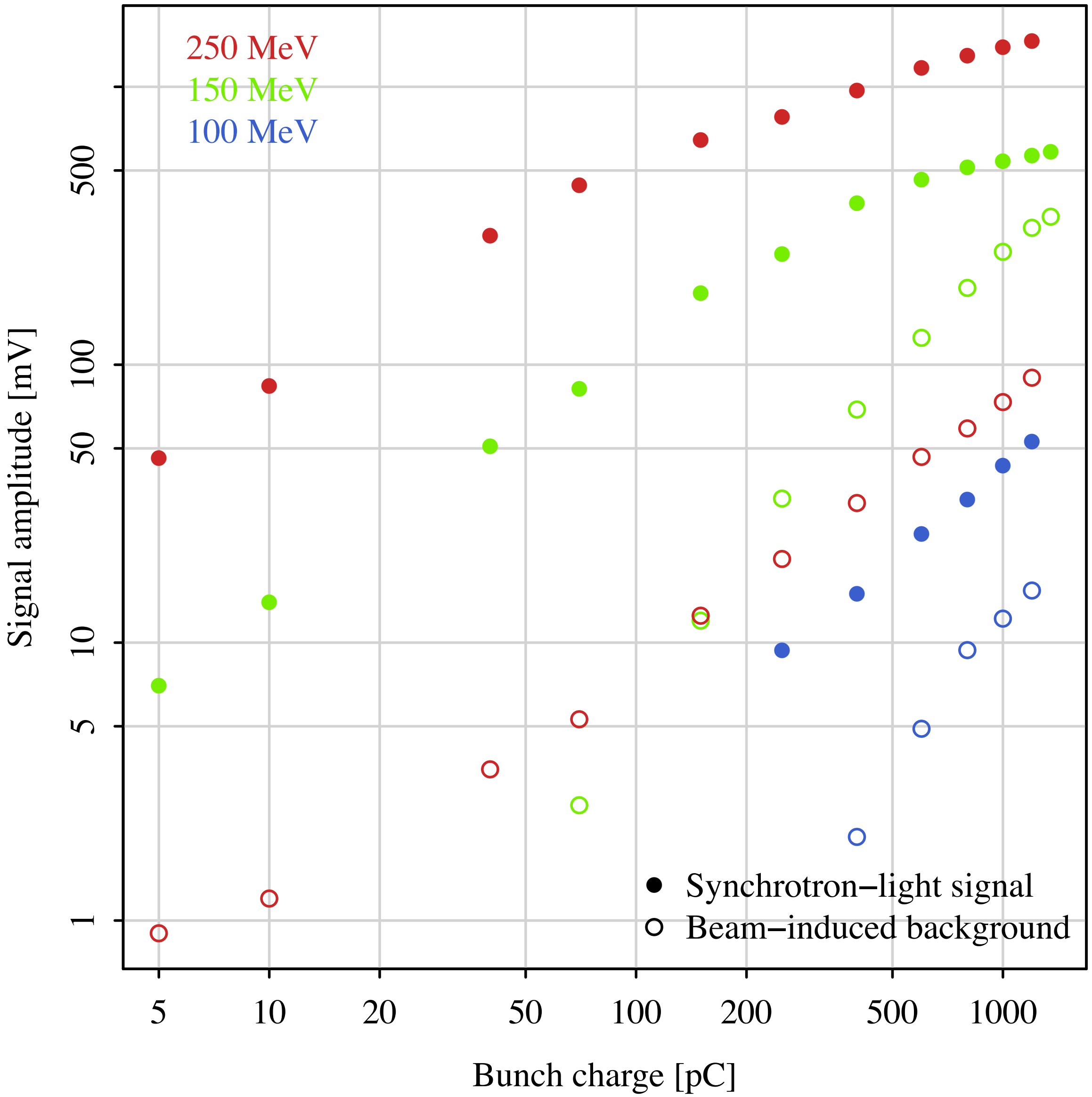


At high repetition rates, gain of MCP-PMT sags due to charge accumulation

This is a problem for measuring many consecutive turns in IOTA at high charge

Alternatives are available

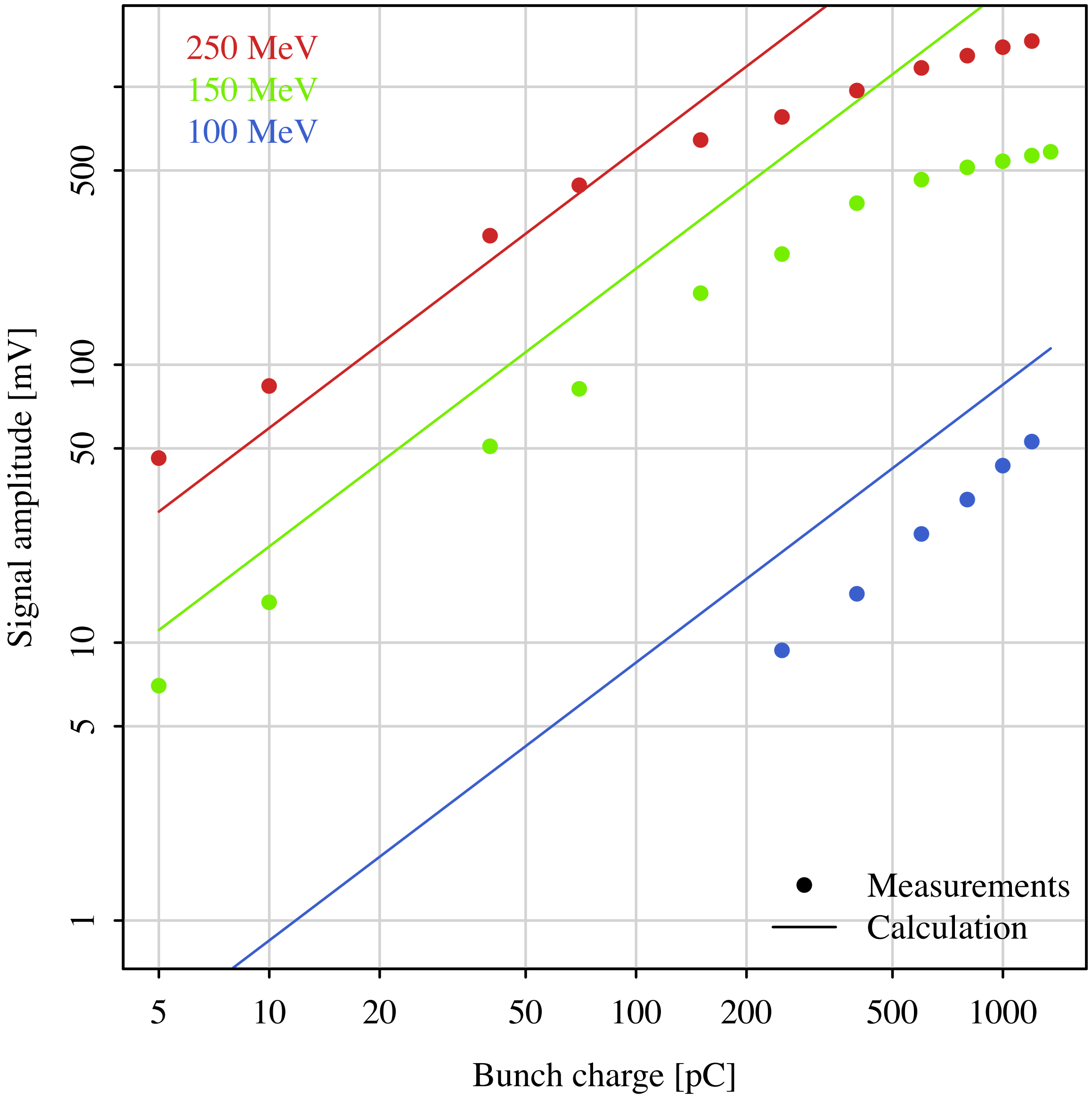
Synch-light and background vs charge and energy



Measured linearity, energy dependence, and signal/background ratios

(Data at 150 MeV was taken before optimizing cryomodule phases)

Measured sync-light signal and calculation



Measured signal is ~ 2 times smaller than calculation at lower energies; larger at 250 MeV (likely due to acceptance cone)

Typical MCP-PMT saturation is visible at high charge or gain

250 pC/bunch at 100 MeV can be clearly detected

Conclusions

Observed and studied synchrotron-radiation signal and beam-induced backgrounds from D600 linac dipole

Experiments were done in preparation for IOTA commissioning and scientific program

The D600 apparatus will stay and can be used for linac diagnostics

Alternative options for photon detection at high repetition rate will be tested with laser: MCP-PMT, conventional PMT, SiPM, etc.

Further analysis is ongoing: signal timing, fluctuations, detection limits

Thank you for your attention

https://cdcvs.fnal.gov/redmine/projects/sync-light-d600/wiki