Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Development of transverse beam position and shape monitor (BPSM) for IOTA

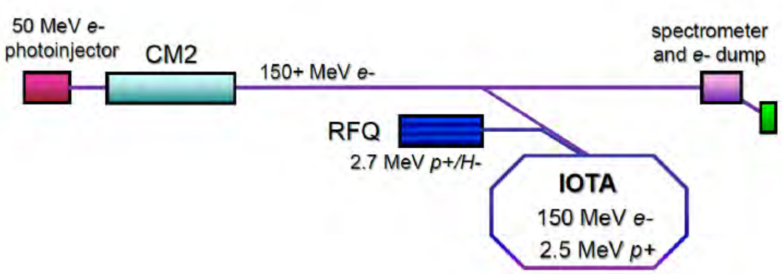
Nadezda Afonkina
Summer PARTI intern
Master 1, *Aix-Marseille University*
(Optics, photonics and imaging)
Graduate engineer *BMSTU, Moscow*

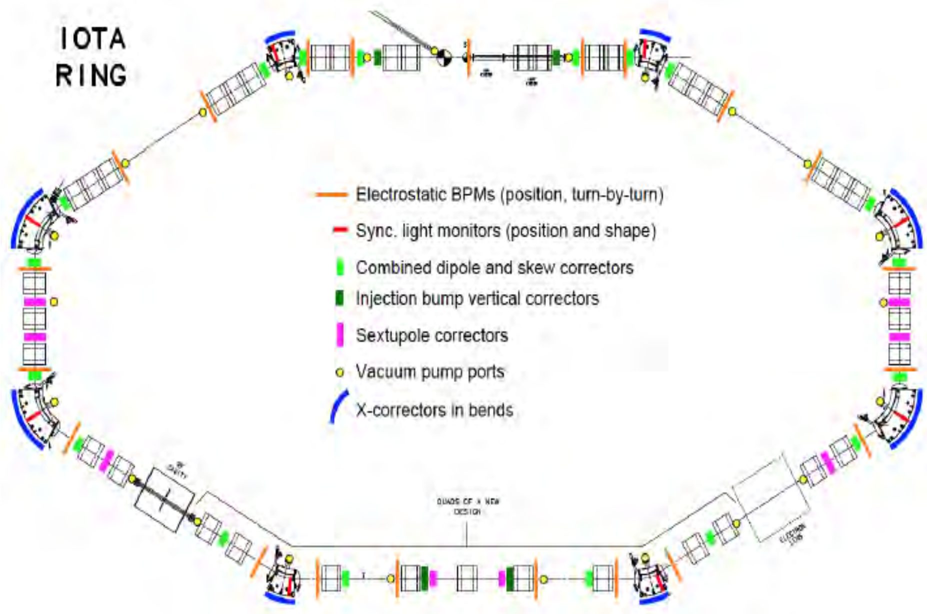
Supervisors:
Jinhao Ruan
James Santucci

10 August 2016

Preliminary questions

- What is IOTA?
  - flexible high stable storage ring for accelerated charged particles of *40 m* circumference that enables electron beams up to *E = 150 MeV* and proton beams up to *E = 2.5 MeV*
  - under the construction stage at *FAST/IOTA* facility until FY 2018.
- What type of beam instrumentation is needed for IOTA?
  - beam position monitors (BPMs)
  - Beam position and shape monitors





Specific questions

- What detector I need to build?
  - ➢ Fast detector, which enables to get turn by turn images of both beam shape and position for IOTA beam
- For which purposes this detector can be used?
  - ➢ analyze long-term beam evolution
- What measurement technique will be used to detect the beam?
  - ➢ non-destructive optical synchrotron radiation (OSR) measurements
- Which parameters of IOTA beam and it's OSR are important to know to build the detector?
  - ➢ Time of one turn in IOTA ring: ~133 ns (7.5 MHz)
  - ➢ Bunch length: 12 cm (~4 ns)
  - ➢ Wavelength range of OSR (filtered) : 533±20 nm
  - ➢ Intensity of OSR for $2\cdot10^{9}$ 150 MeV e^{-} : $\sim10^{5}$ photons

Proposal:
Use PMT array

Hamamatsu H7546B	
Dimensions	18.1 x 18.1 mm
Spectral sensitivity range	300 — 650 nm
Peak sensitivity	80 mA/W
Gain	$2\cdot10^{3} - 3\cdot10^{6}$
Rise time	~1 ns
Transit time	~12 ns

Fermilab

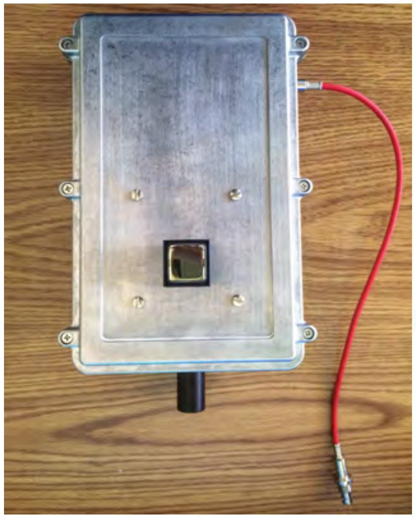
Steps of the project

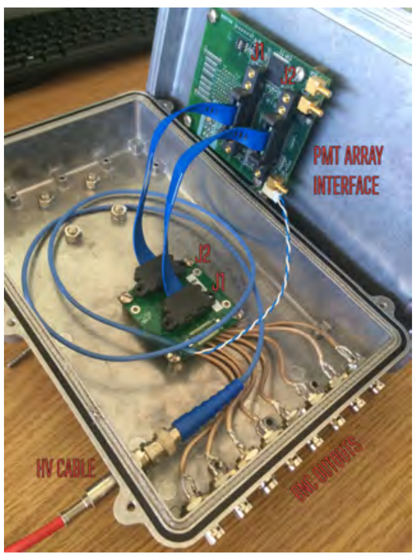
Internship (2 months)

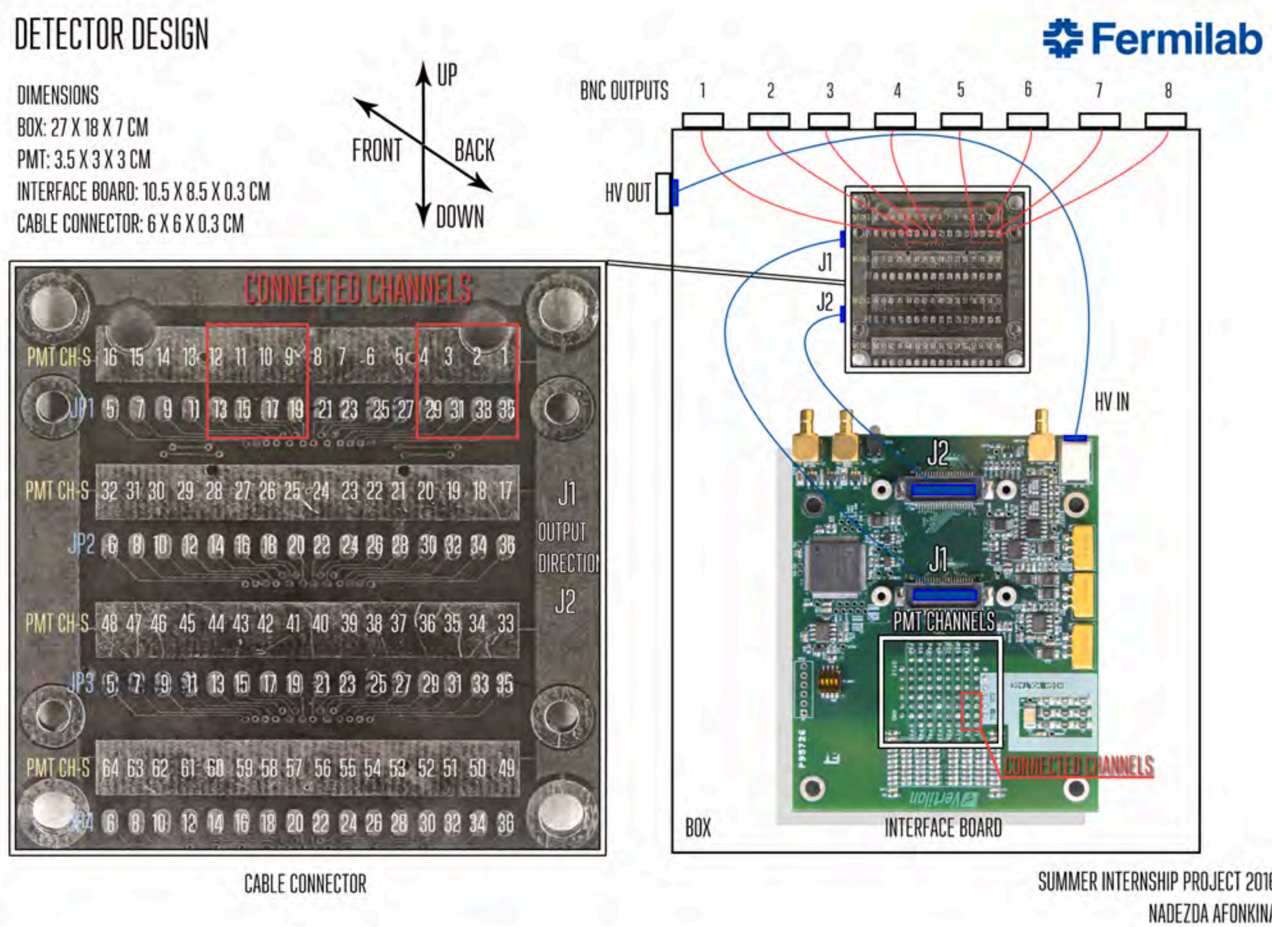
- **Detector design (for 8 of 64 PMT array channels)**
  1. Defining and purchasing components.
  2. Building device, checking connections and electronics.
- **LED test (response and sensitivity) –** *close to IOTA frequency*
  1. Setup installation and optical alignment.
  2. Detect different beam shapes and intensities with possible gain voltages.
  3. Conclusions.
- **OTR test (response speed) –** *close to OSR from IOTA beam*
  1. Align BPSM for OTR light from FAST photo injector.
  2. Reserve a beam time.
  3. Take data, analyze speed response.
  4. Conclusions.
- **Green laser test (digitalization) –** *close to OSR from IOTA beam*
  1. Hazard analysis, safety requirements.
  2. Obtain permission to run experiment.
  3. Setup installation, optical alignment.
  4. Tests, conclusions.

Write a report with all technical specifications and test results of BPSM.

BPSM design



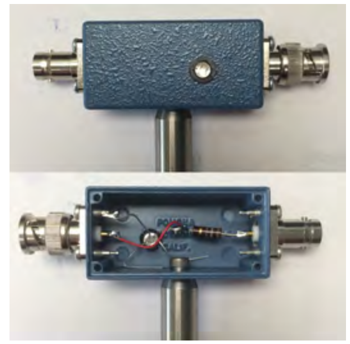


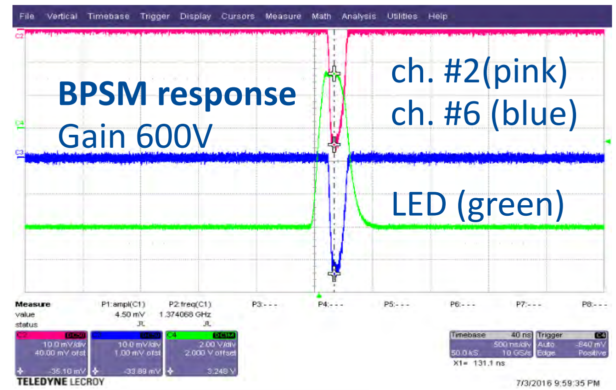


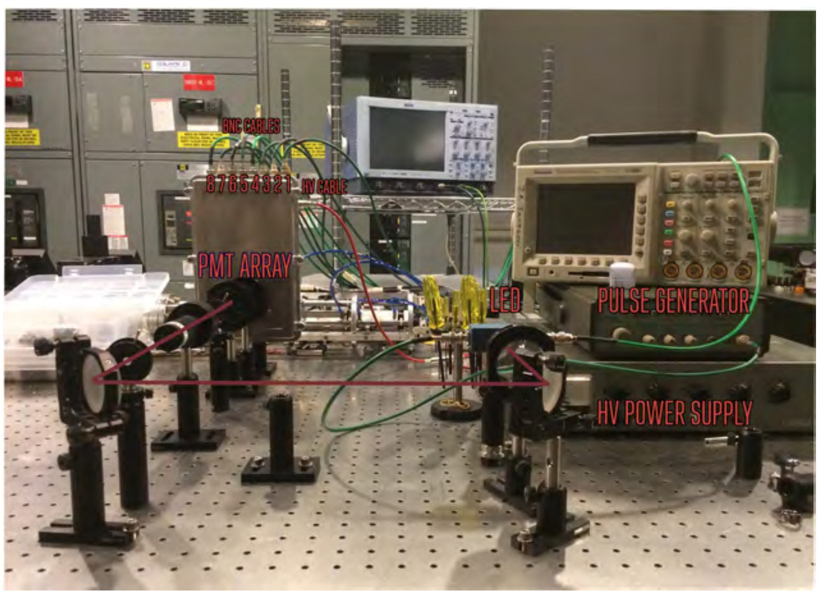
Device was built with priceless help of *Kermit Carlson.*

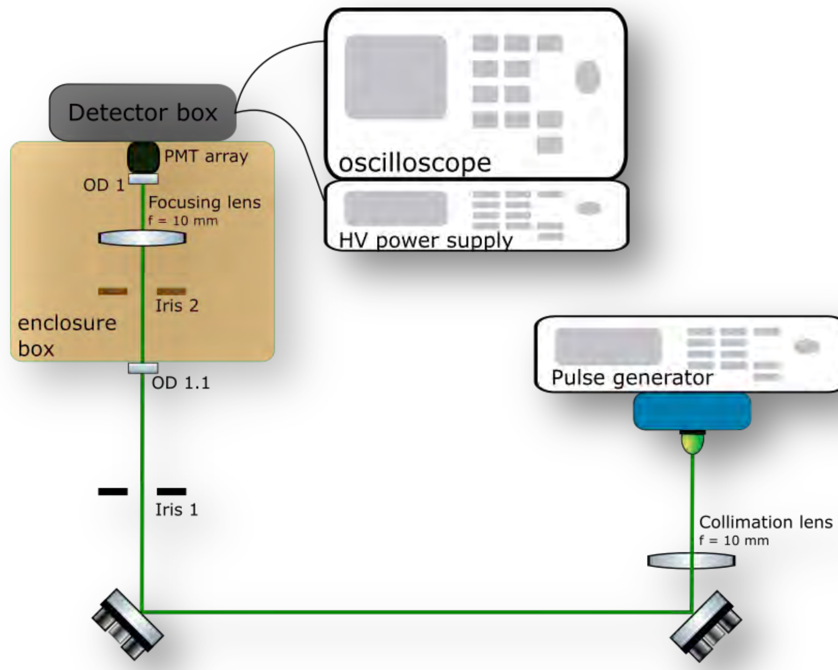
LED test - Experimental setup

Green LED	
Operating frequency	6 MHz (close to IOTA frequency)
Wavelength	520 nm
Pulse length	0.5 μs
Peak intensity	$3.1\ V$
Attenuation filter	OD 2.1



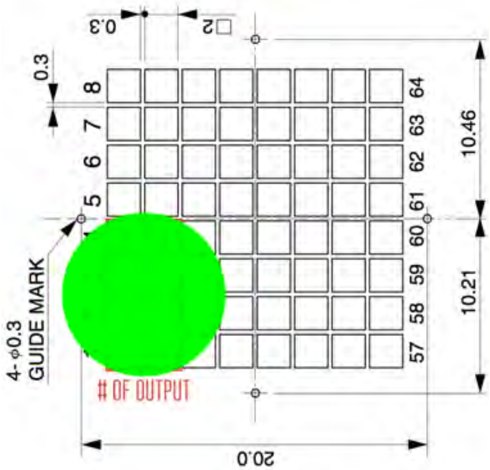


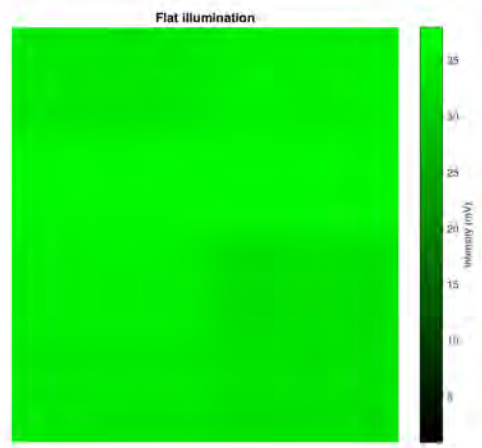




LED test - Experimental Results

- **Intensity test**



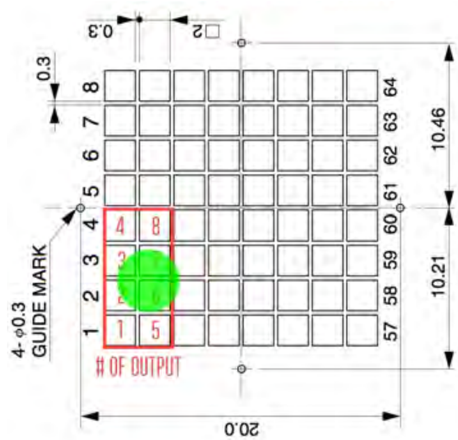


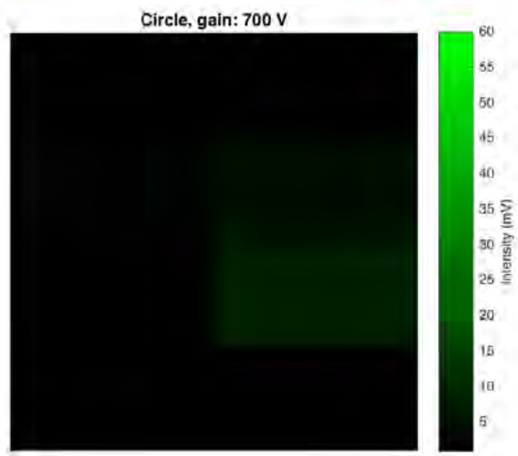
Results are inside the uncertainty intervals:

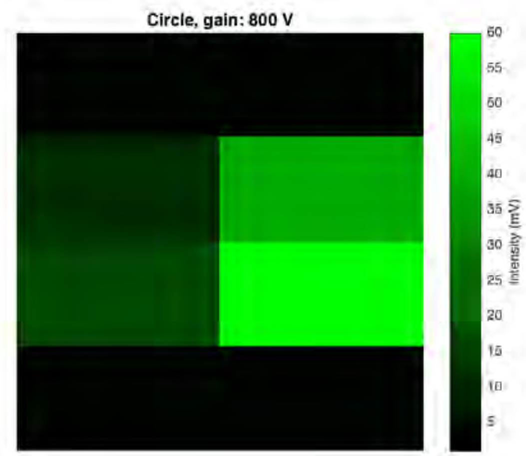
Measured voltage
0.8 V – 1.4 V

Estimated voltage
1.1 V – 2.6 V

- **Beam shape, gain test**







Result :100 V difference in gain voltage gives expected x3 gain in detected voltage.

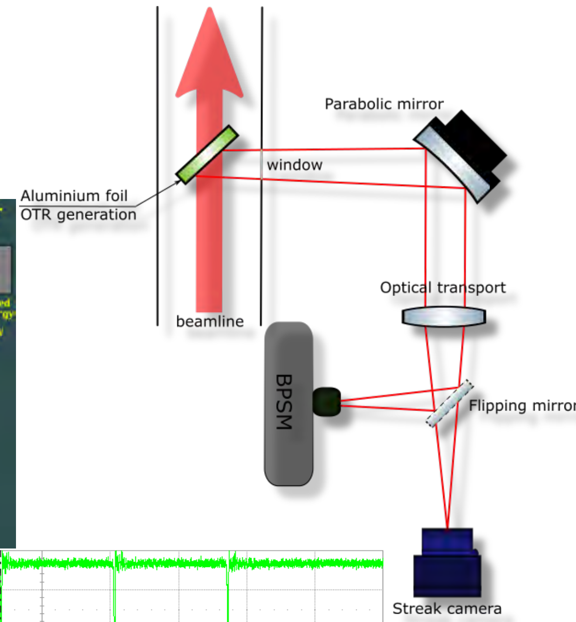
OTR test (response speed)

Optical Transition Radiation (*OTR*) – generated when charged particles transit the interface of 2 different media (in our case: vacuum-Al)

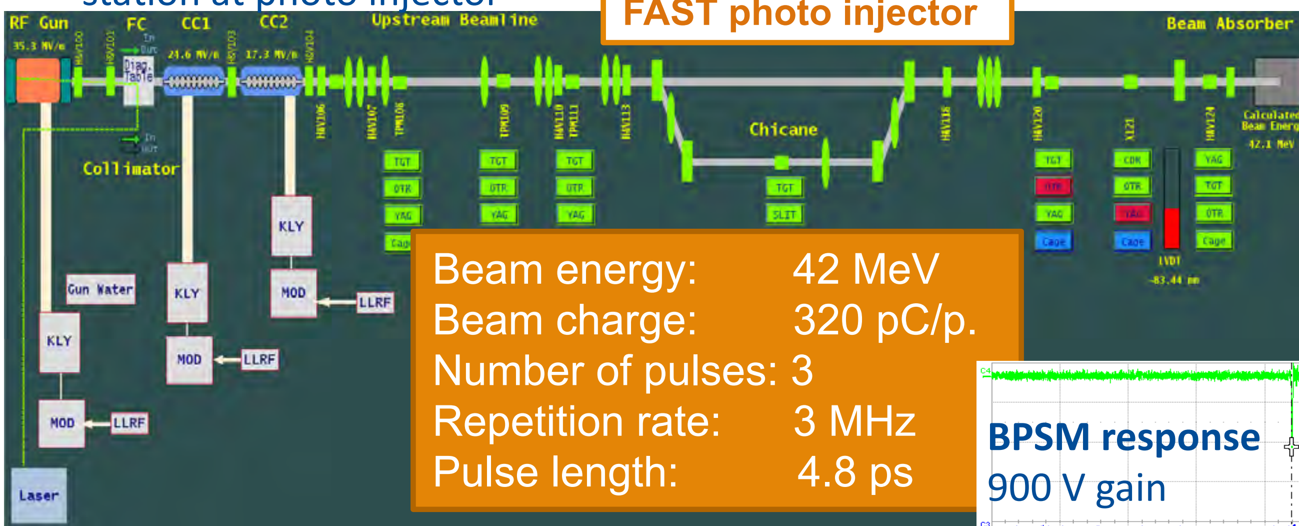
Why OTR?

- To some extent similar to OSR (final goal on IOTA)
- Already aligned in "streaky hut" optical enclosure from X121 station at photo injector

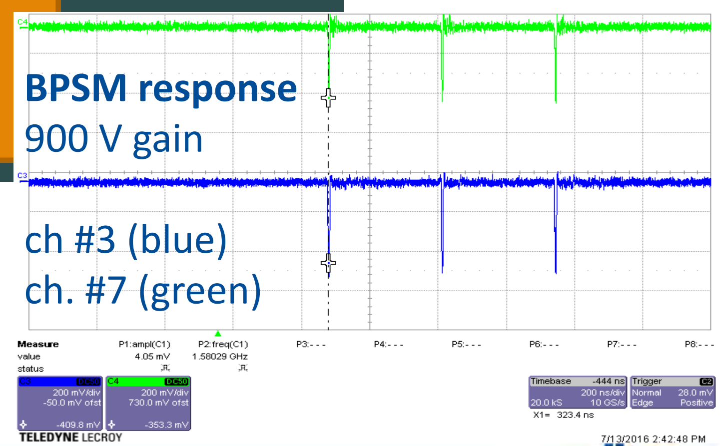
Experimental Setup



FAST photo injector



Beam energy:	42 MeV
Beam charge:	320 pC/p.
Number of pulses:	3
Repetition rate:	3 MHz
Pulse length:	4.8 ps



BPSM response
900 V gain

ch #3 (blue)
ch. #7 (green)

Results:

- ✓ BPSM response correspond to the OTR from the beam
- ✓ Response on 4.8 ps pulse (Dirac for PMT channels) is 7.25 ns ⇒ <u>integrator is needed for digitalization</u>

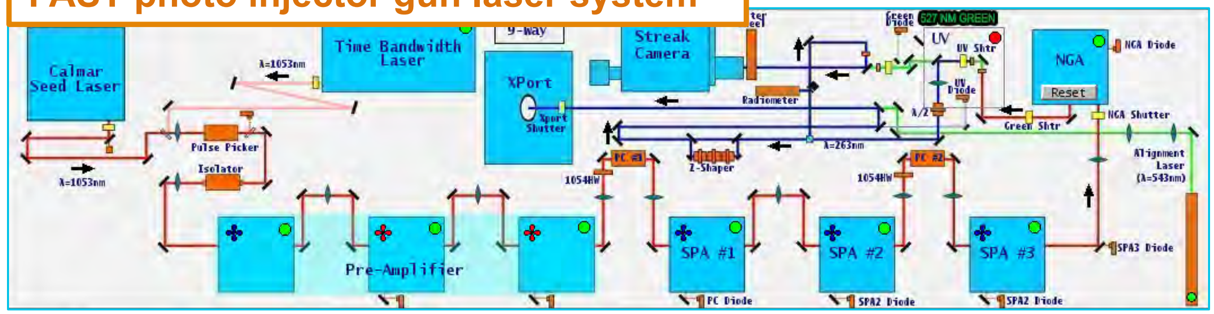
Green laser test

Goal of experiment:

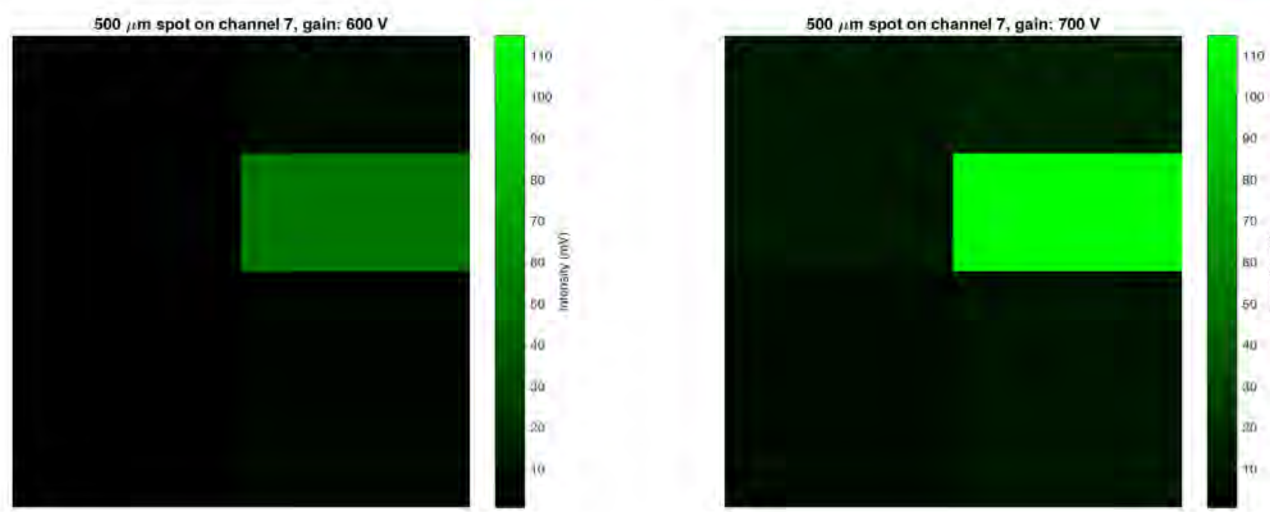
- More precise response tests
- Digitalization (125 MHz digitizer)

Green laser (2nd harmonic IR Nd:YLF)	**Value**
Operating frequency	3 MHz
Number of pulses	30
Wavelength	527 nm
Pulse length	4 ps
Energy	25 μJ
Spot size	500 μm
Attenuation filter	OD 4

FAST photo injector gun laser system



Images from 8 digitized channels:



Fermilab

Green laser test

Results

✓ Integrator is still needed: w/o integrator digitizer works at the limit of BPSM response ⇒ under sampling (violation of Shannon condition)

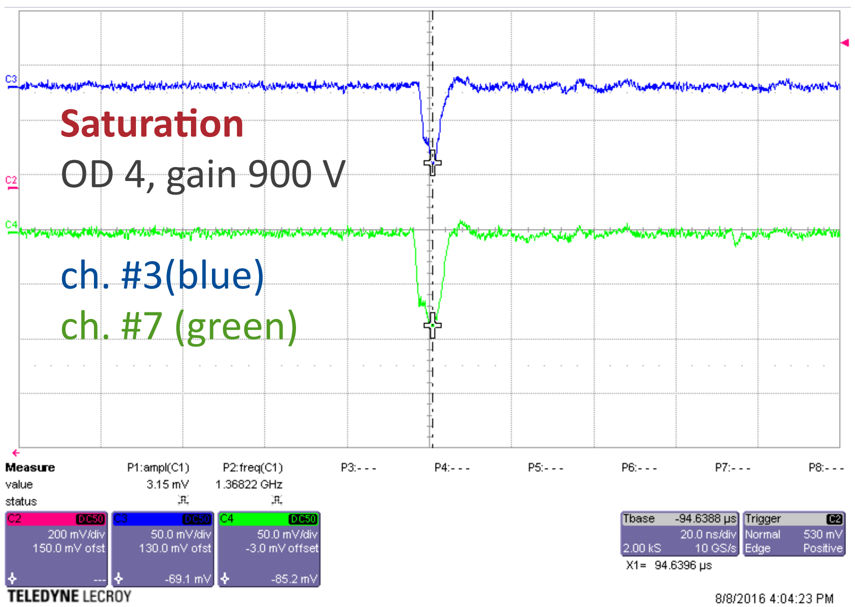
✓ Be careful: Choose optimal combination of filters and gain voltage!

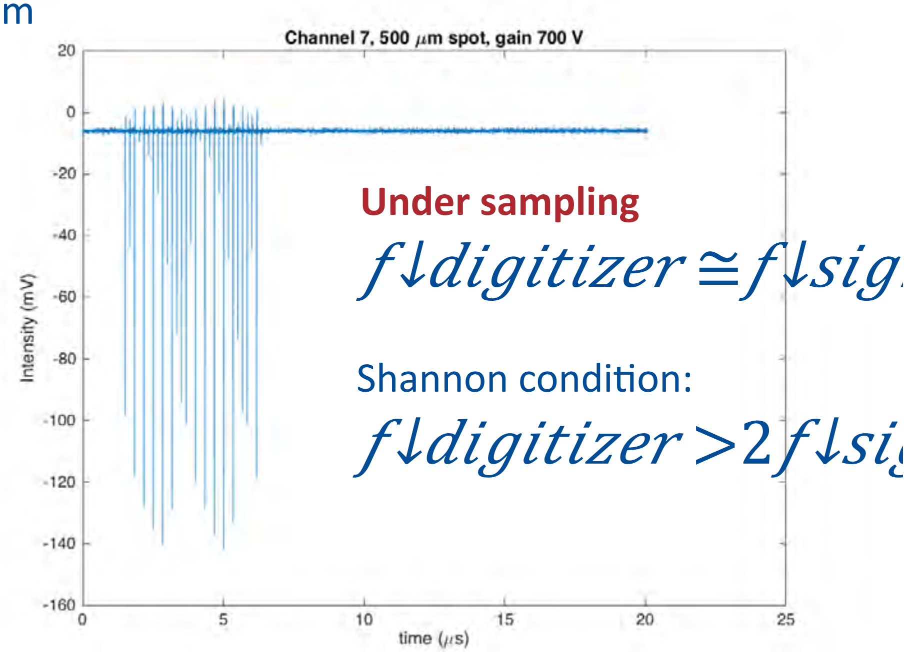
↓ filter, ↓ gain ⇒ proper results

↑ filter, ↑ gain ⇒ risks for BPSM (saturation), risk of false results, risk to loose signal in background noise

✓ Maximum isolation of from background light is needed for best performance of BPSM

✓ Don't forget: BPSM resolution on shape is low - 2 mm





Conclusion

Present:

- ✓ 8 channels of BPSM are ready for use
- ✓ Sets of tests were pursued in the conditions closest to future experiments on IOTA with:
  - Possible operational regimes (voltage gains, background lights)
  - Possible light sources (beam shapes, intensities, bunch lengths)
  - Optical transition radiation from FAST photo injector
- ✓ BPSM proved expected performance capability
- ✓ Detector signals were digitized
- ✓ Requirements for future utilization of BPSM are stated.
- ✓ Requirements for future digitizing system for BPSM are concluded.
- ✓ Detector is ready for final design and future commissioning on IOTA.

Future:

1. Finalize design of BPSM (connect all 64 channels).
2. Build a DAQ (digitizer + integrator + PC software).
3. Build and install full system on IOTA.
4. Commissioning of detector. Start of real experiments.