Beam Induced Fluorescence Monitor

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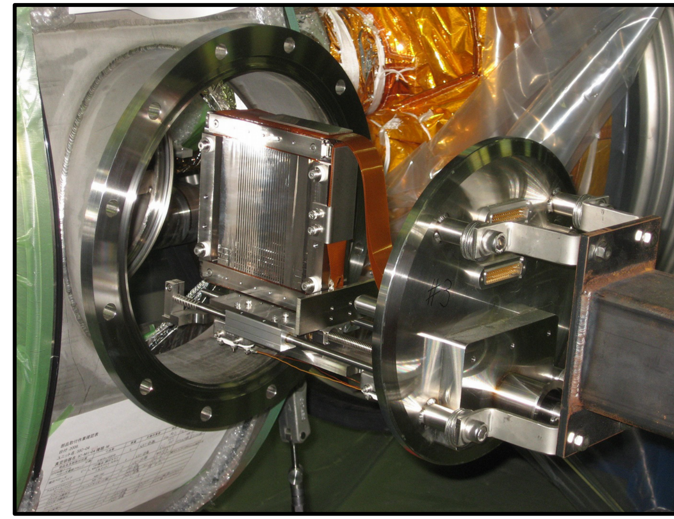
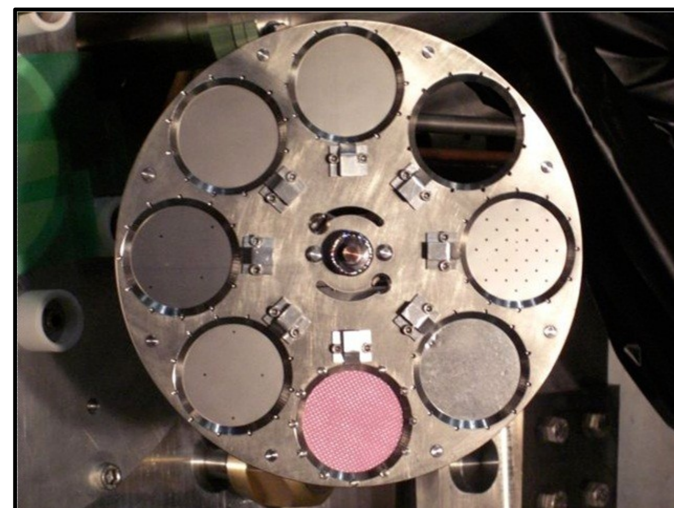
Introduction

- Current profile monitors (SSEM, OTR) use destructive methods: put titanium foils in the passage of the beam
- This could be a problem for high intensity runs (beam loss and foil degradation)
- To be less destructive, reduce amount of matter in the passage of the beam: gas instead of titanium





Try to construct a gas based profile monitor which works in the J-PARC neutrino beam line

Gas based profile monitor

2 main techniques

Passage of the beam will excite and ionize some of the gas molecules

Drift and detect ions
Ionization Profile Monitor

+ Large signal
- Sensitive to the electric field produced by the beam passage ("space charge effect")
- Need powerful magnet

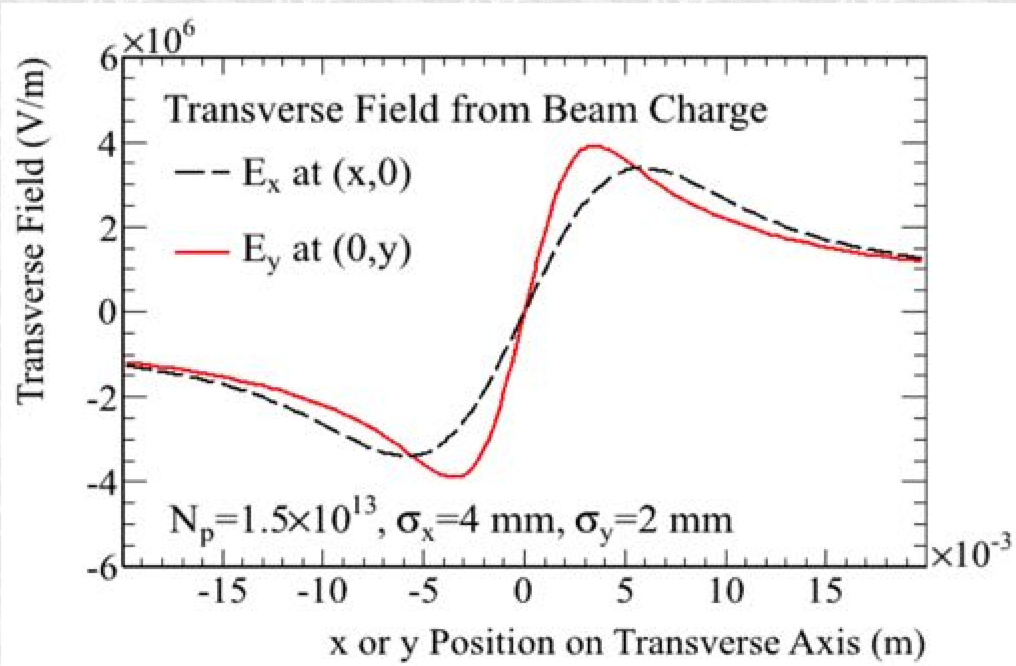
- or -

Detect fluorescence light
Beam Induced Florescence monitor (BIF)

- Smaller signal
+ Less sensitive to space charge effect, especially if fast photo-sensors and gas with fast decay time can be used

Space charge effect in J-PARC beamline

Large space charge effect



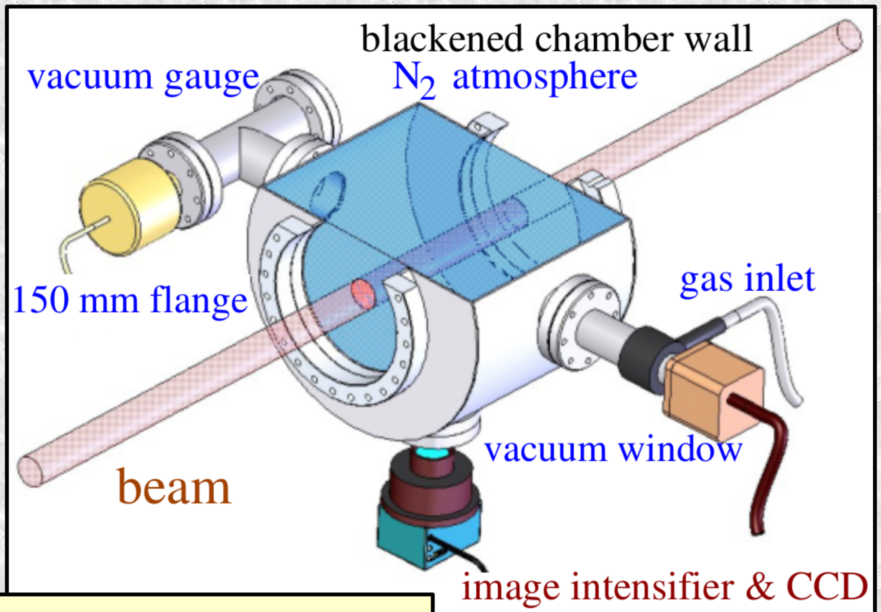
Charged particles will drift quickly in this field
=> can distort the profile

Need a >1T magnet for an Ionization Profile Monitor

Need to measure light before drift of the ions for a Beam Induced Fluorescence Monitor

Beam induced fluorescence monitor

Constructed and tested in a number of accelerators
(GSI-LINAC, CERN SPS, Orsay/Saclay,...)



Scheme of a BIF monitor,
(F. Becker et al., DIPAC 2007)

Inject gas to have large enough signal

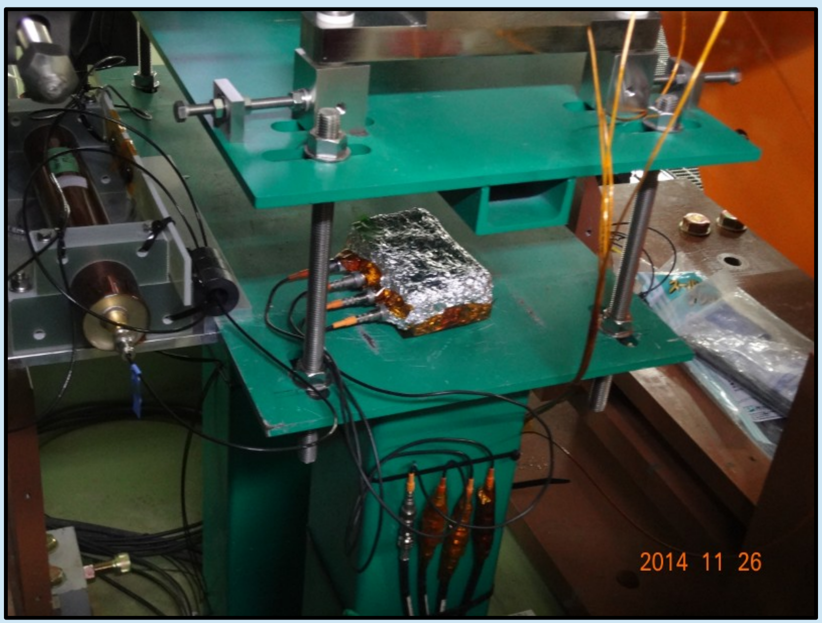
Use fast photo-sensors or gated camera to measure light emitted before drift of the ionized gas

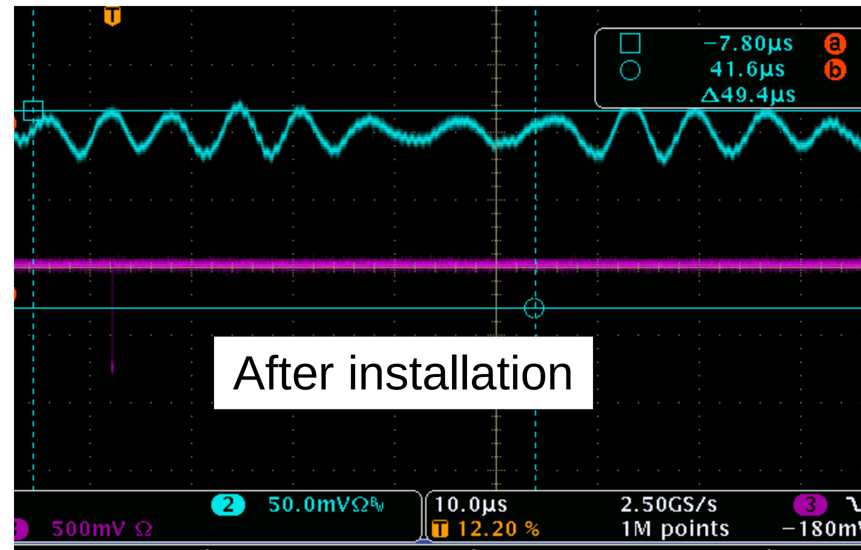
Main challenges:
- Detect enough light to reconstruct beam profile
- Drift of particles due to space charge effect
- Injected gas should not affect the rest of the beamline

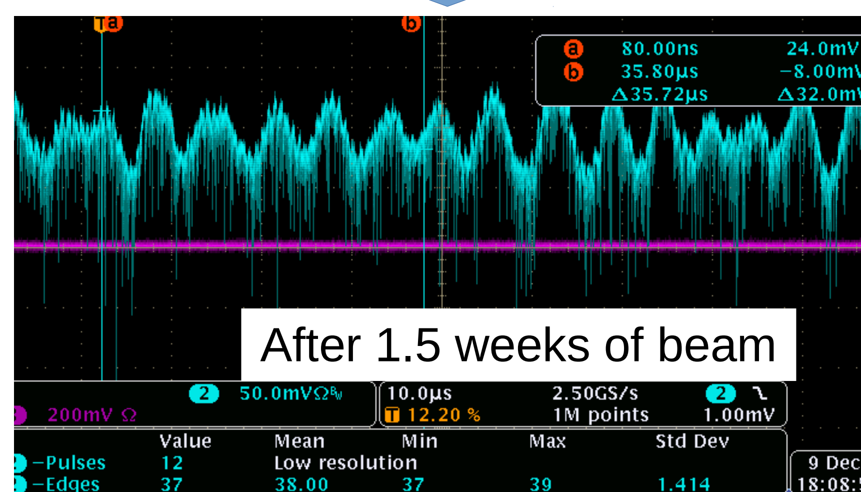
Fast photo-sensors
Initial test

Try to use Hamamatsu MPPC to detect the light: fast (and cheap) sensors

Put some MPPC near the beamline (~30cm) during beam operation to see the effect of radiation



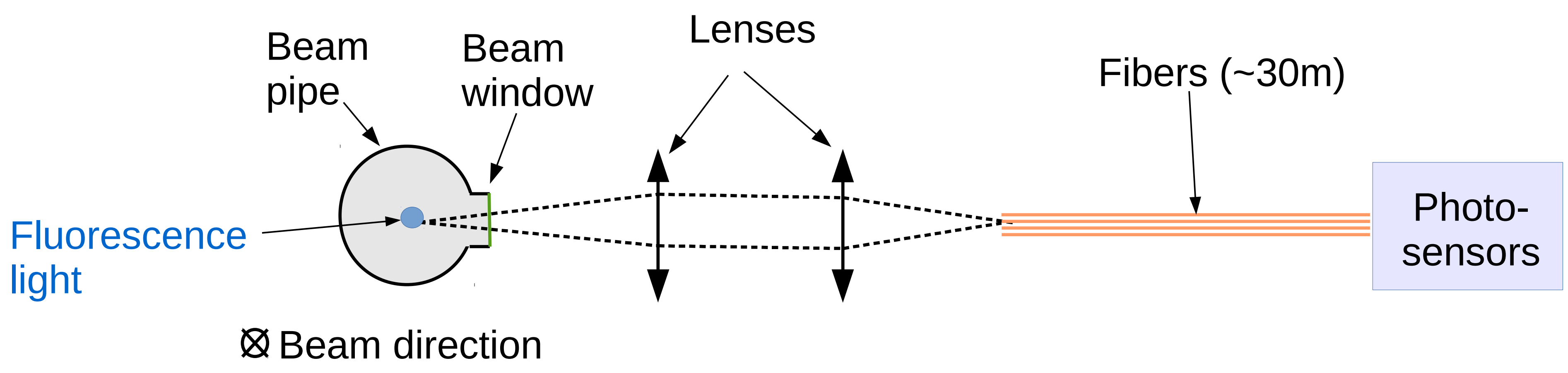




MPPCs cannot be be used close to the beamline

Fast photo-sensors
Transporting the light to MPPC

Found that MPPC did not get damaged if they were put in a sub-tunnel, ~30m away from the beam pipe. So try to transport the light to there using optical system, and optical fibers:

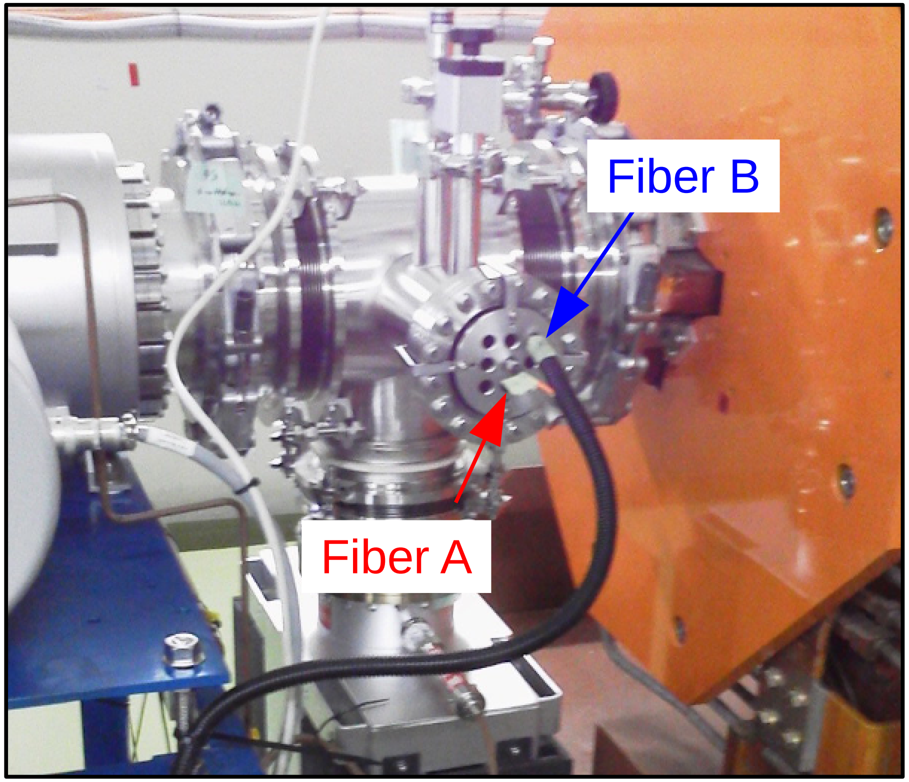


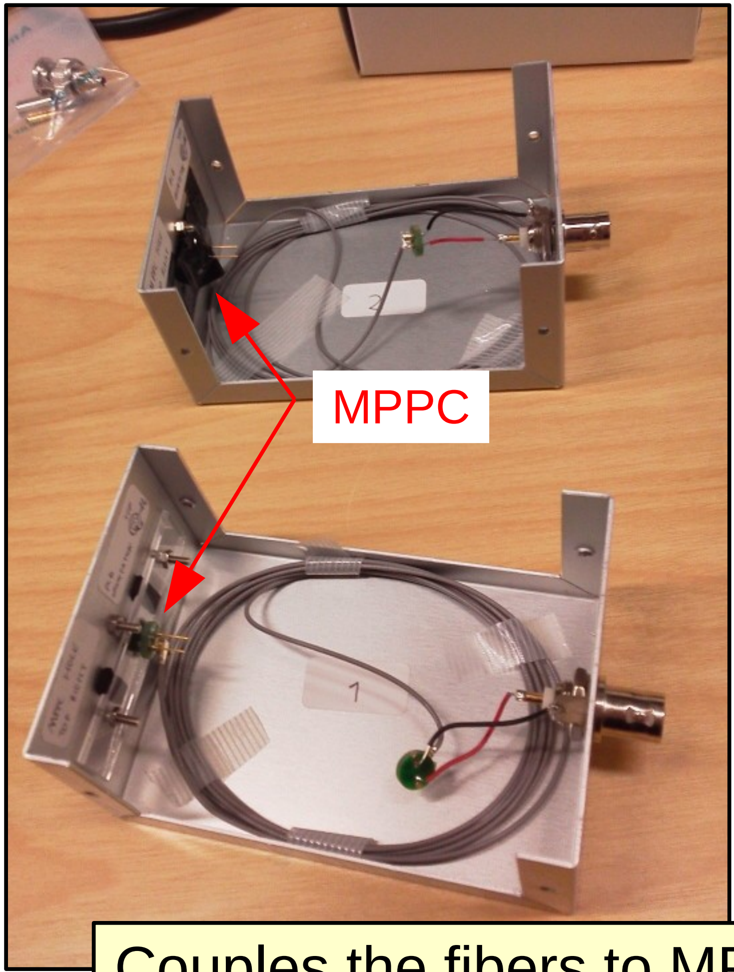
<u>Did a number of tests to check this could work</u>

- Long term effect (damage) of radiation on MPPC in the sub-tunnel
- Effect (damage) of radiations on optical fiber
- Measure background in the absence of gas:
  - beam off: light in the beam pipe
  - induced by the beam in the fiber

Fast photo-sensors
Testing new scheme

Installed two 40m optical fibers, going from a window installed on the beam pipe to the end of the sub-tunnel where the signal is read using 'MPPC boxes'



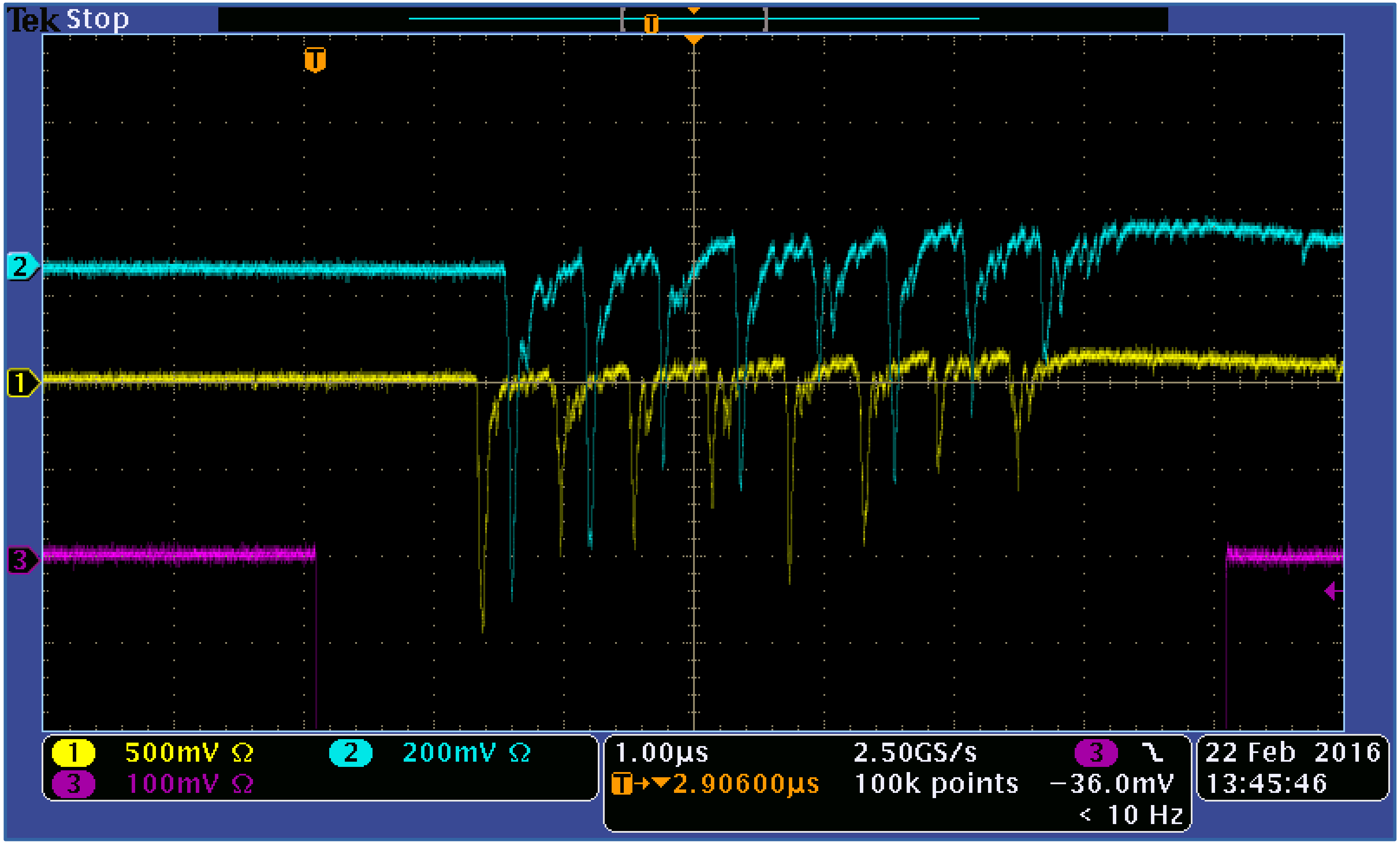


Couples the fibers to MPPC

One fiber is looking into the beam pipe, while the other one is masked using black tape

Fast photo-sensors
Beam induced signal

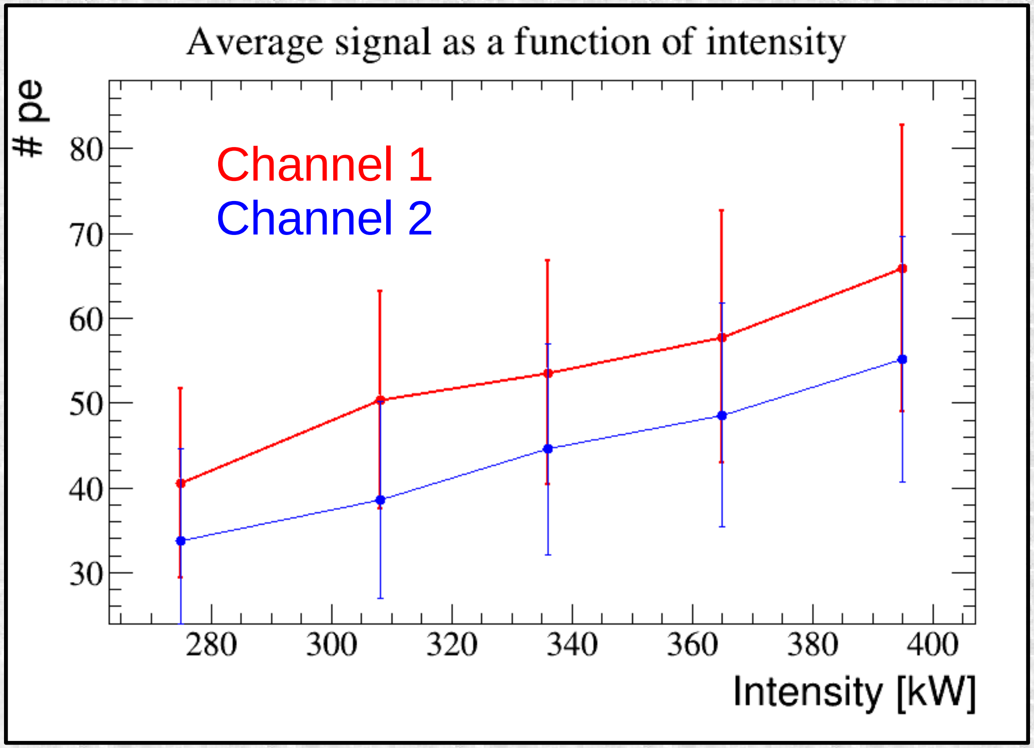
Saw a large beam induced signal on both fibers
→ Radiation and not direct light

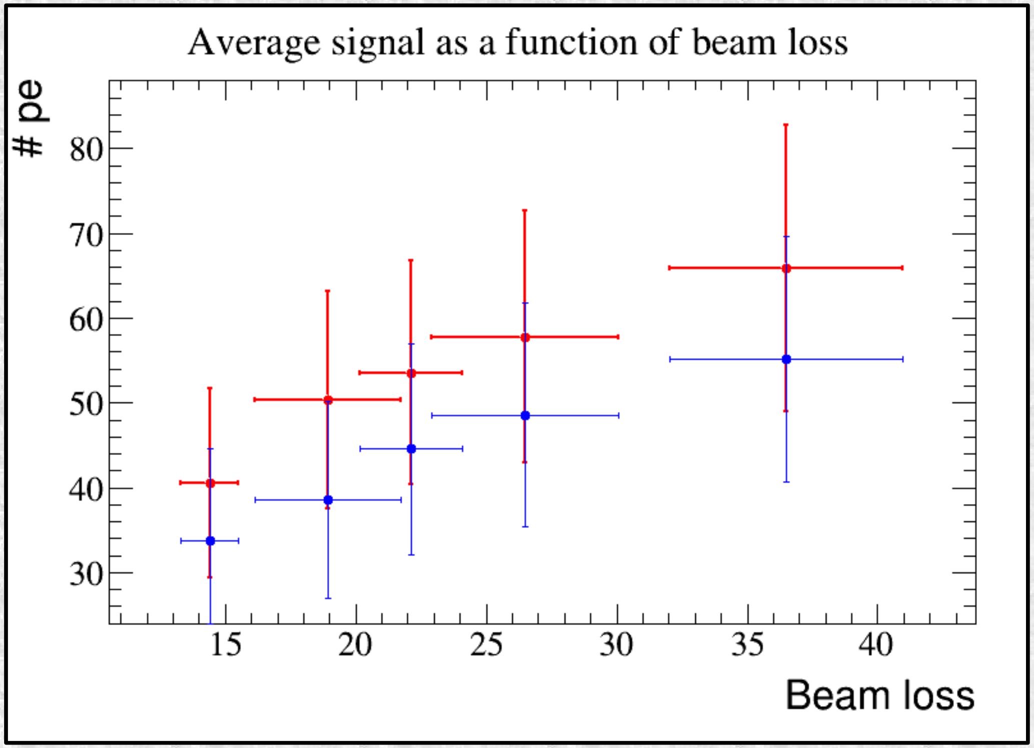


Larger background signal than expected signal

Fast photo-sensors
Beam induced signal

Looked at the correlation with beam intensity and beam loss measured by a nearby beam loss monitor

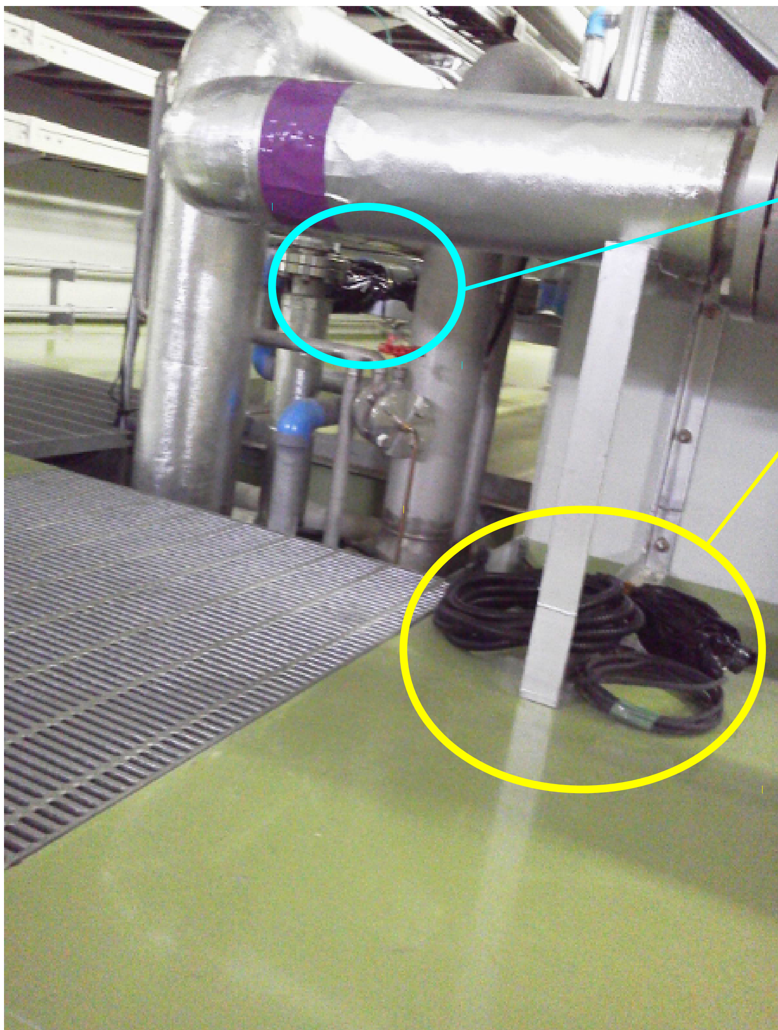


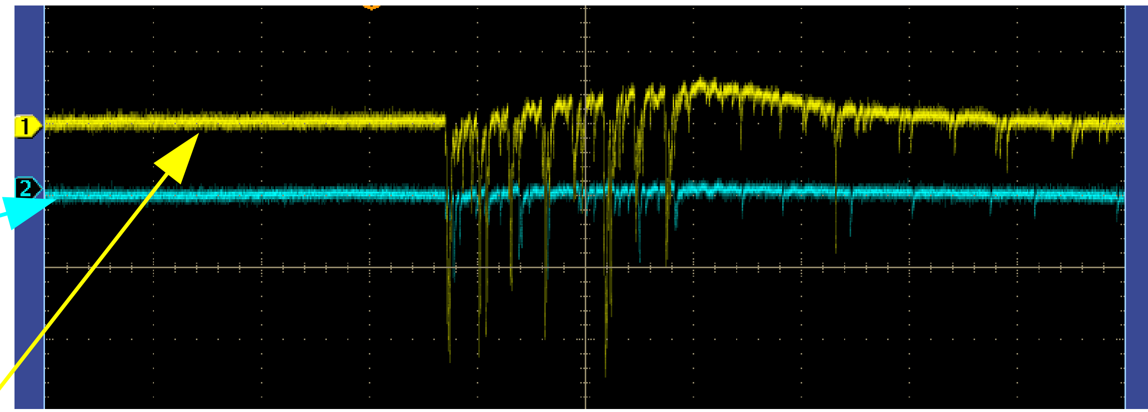


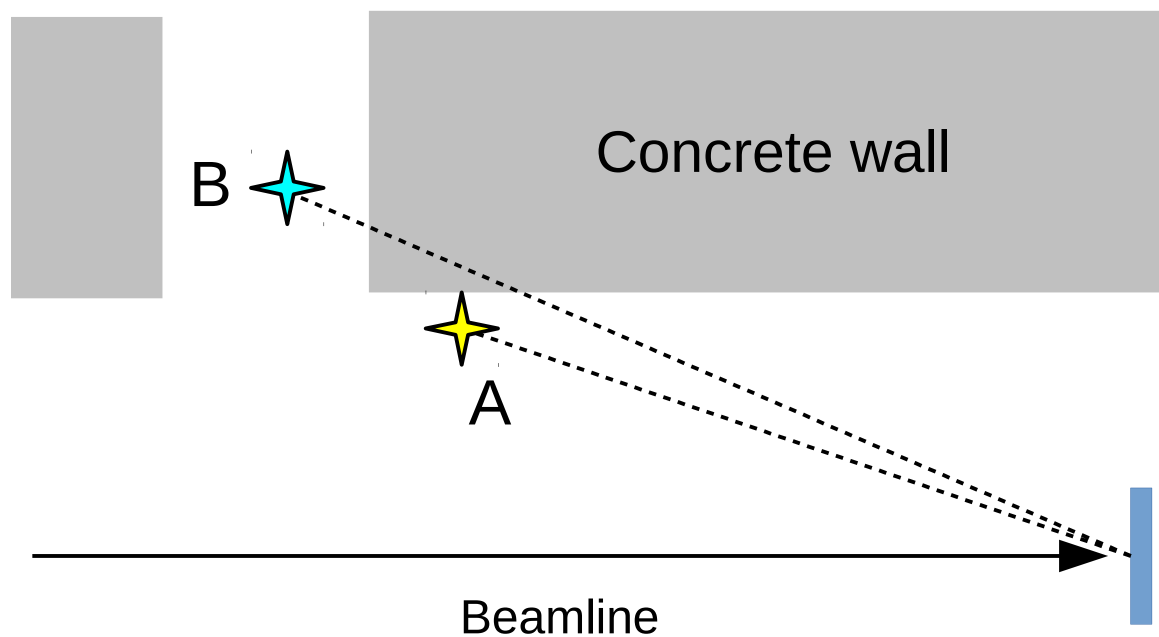
Clear dependance on beam intensity, but unexpected pattern for nearby beam loss (does not go to 0 at 0)

Fast photo-sensors
Beam induced signal

Found from various tests that the radiations were mainly coming from the beam window region



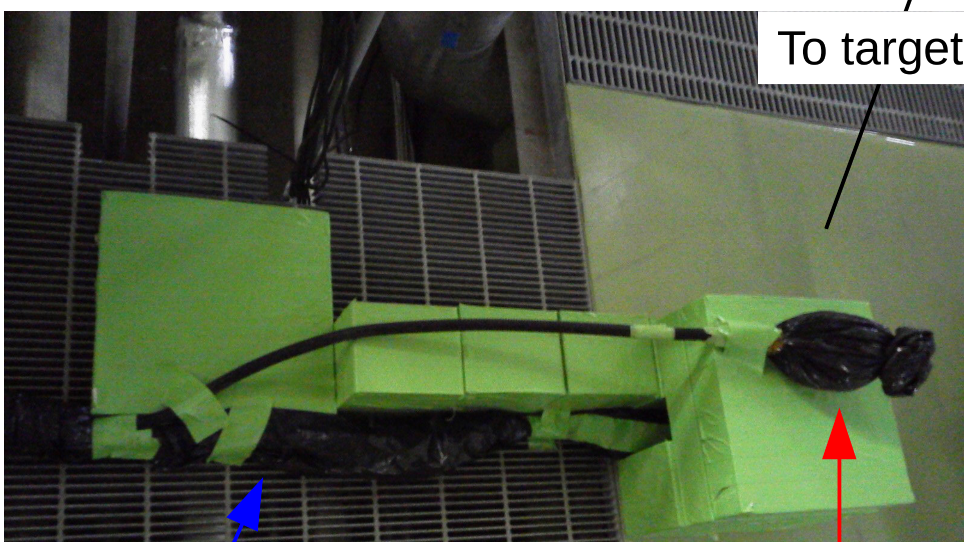




Fast photo-sensors
Reducing beam induced signal

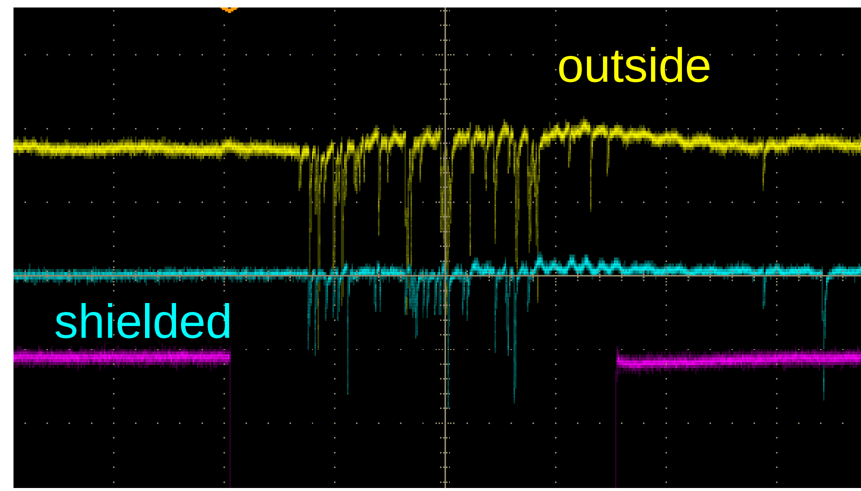
As the radiation comes mainly from one area, can try shielding in that direction

To target area



Fiber B, protected by concrete bricks

Fiber A, outside of the shielding



Will also try to filter this signal, as it might be at different wavelength than the fluorescence light

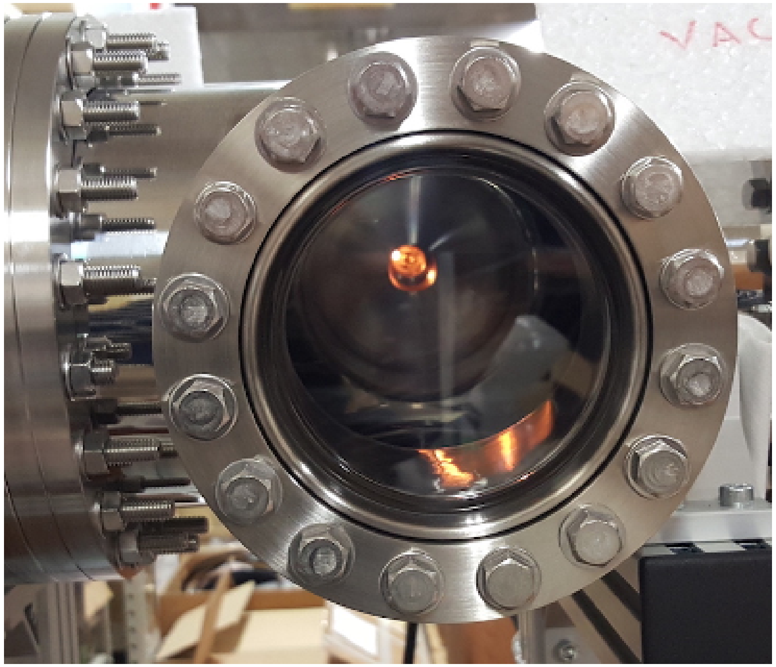
Background light from the beam pipe
Beam off

By comparing the trigger rates of the fiber looking into the beam pipe and of the fiber masked, saw there was light in the beam pipe even without beam

Config 1: A looking into the beam pipe, B masked
Config 2: B taped, A looking into the beam pipe

Fiber	Config 1	Config 2
A	1.2 MHz	77 kHz
B	82 kHz	820 kHz

Light source: filament of pressure gauges

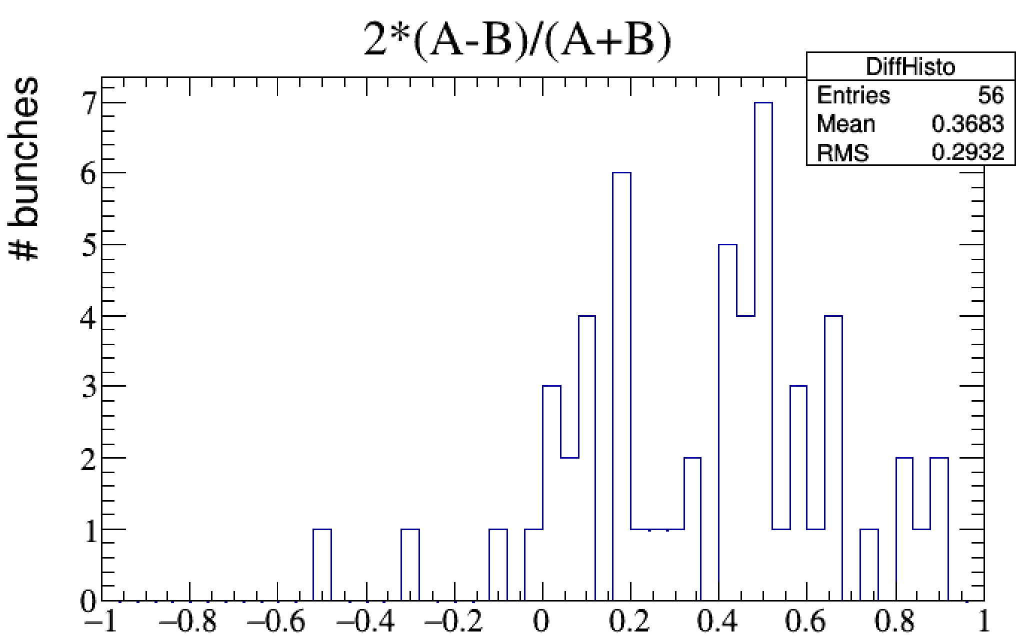


This level of light is not a problem for the monitor

Background light from the beam pipe
Beam on

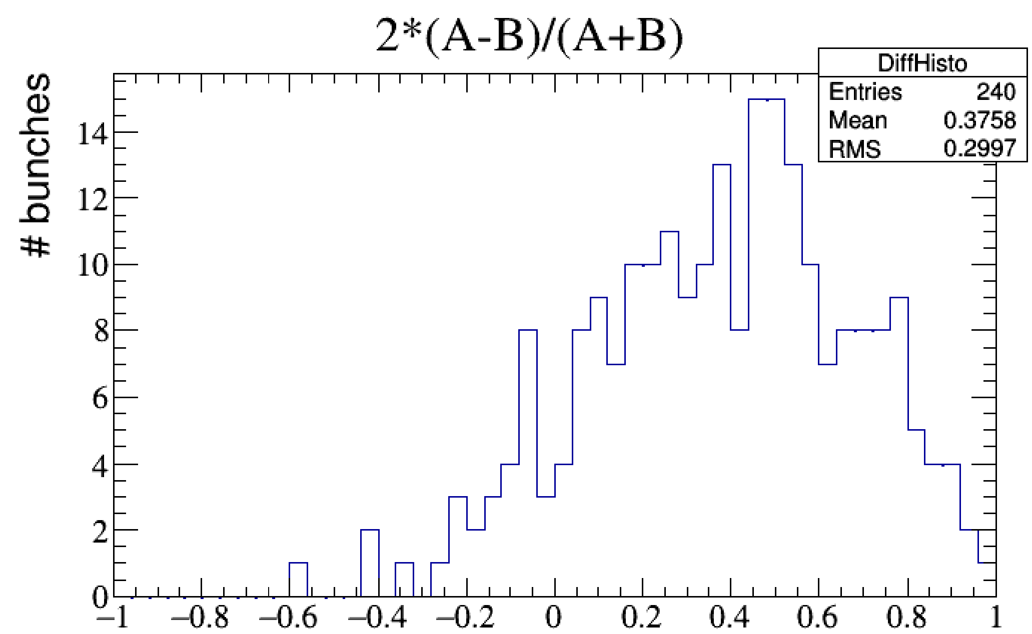
When beam is on, signal size is dominated by radiation.
Look for additional light coming from the passage of the beam, by checking if the fiber see a larger signal when looking into the pipe.

<u>Channel A looking, B masked</u>



0.3683 ± 0.2932

<u>Channel A taped, B looking</u>

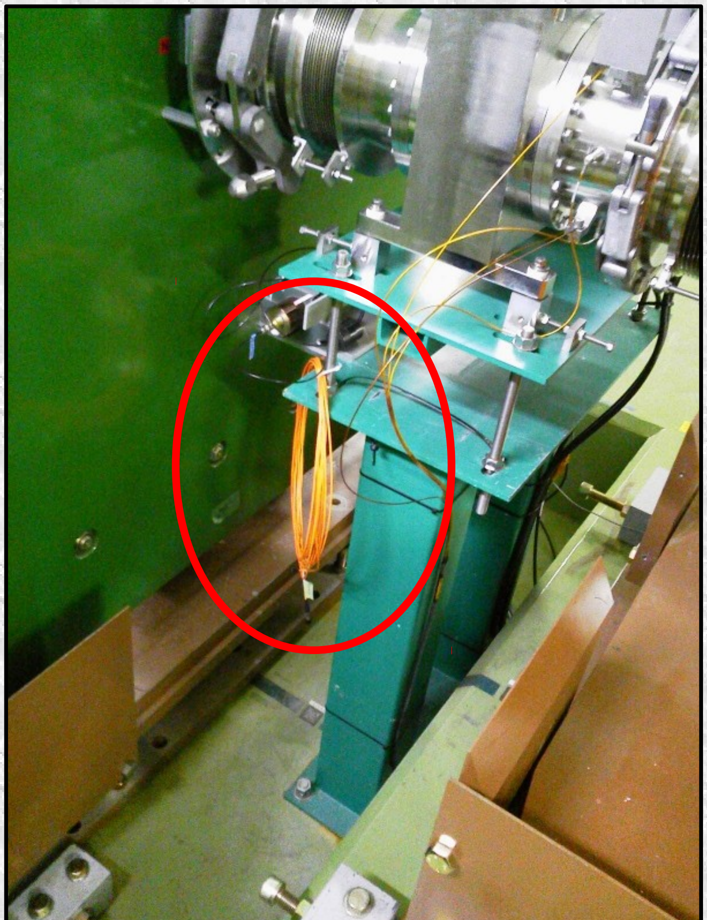


0.3758 ± 0.2997

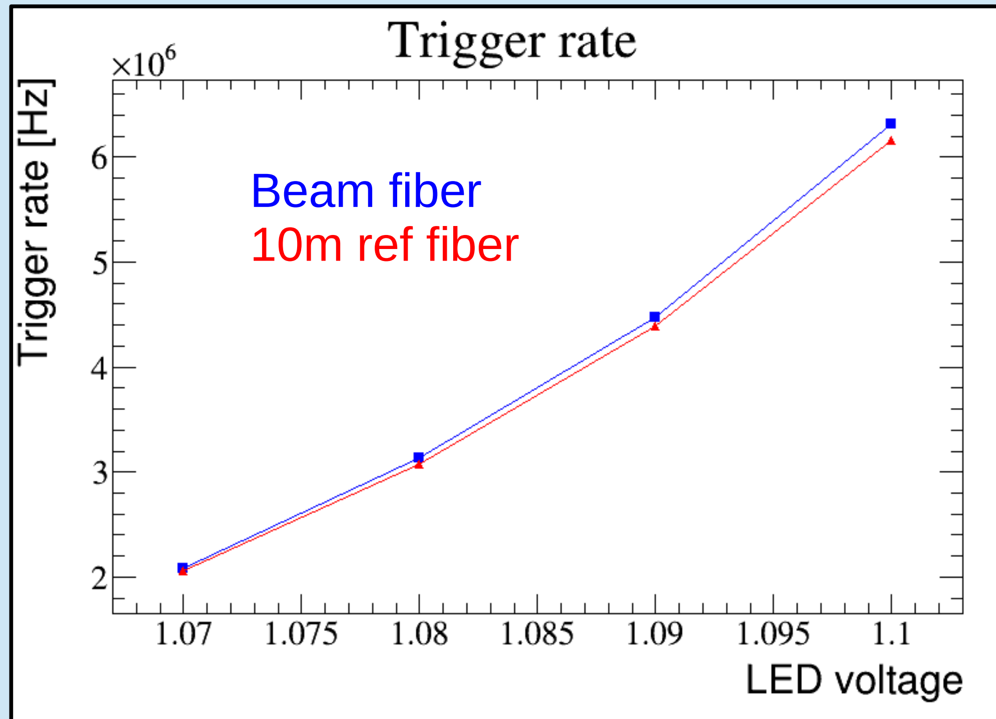
Any potential beam induced background light is smaller than radiation background

Effect of radiation on fibers

To test long term effect of radiations on fiber, put a 10m fibers near an SSEM



Compare transmission to the one of a similar fiber which stayed outside of the tunnel after few months of run



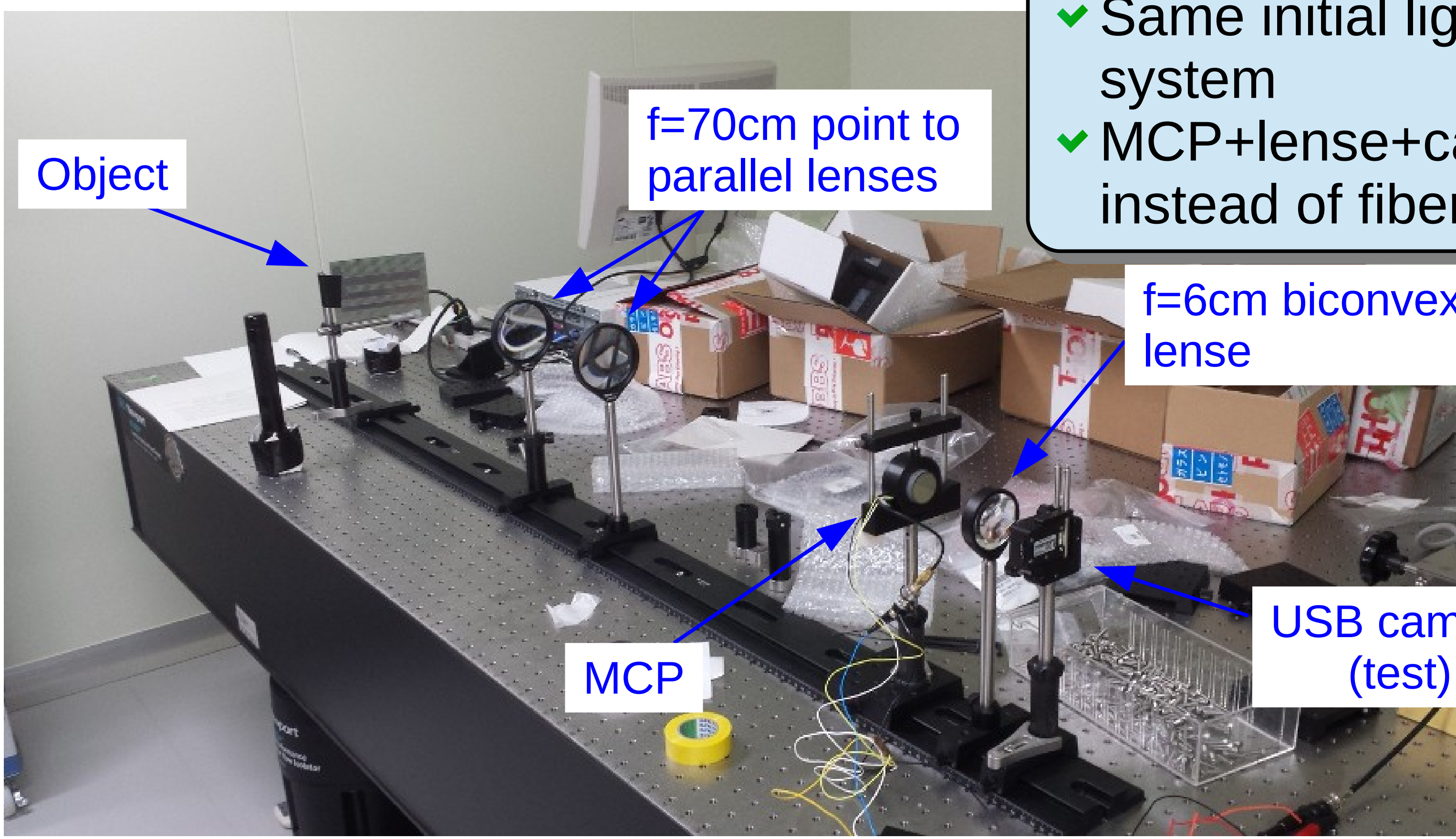
No signs of degradation

Alternative system: camera + MCP

Testing alternative system:
- radiation hard CID camera
- Multi-channel plate for amplification

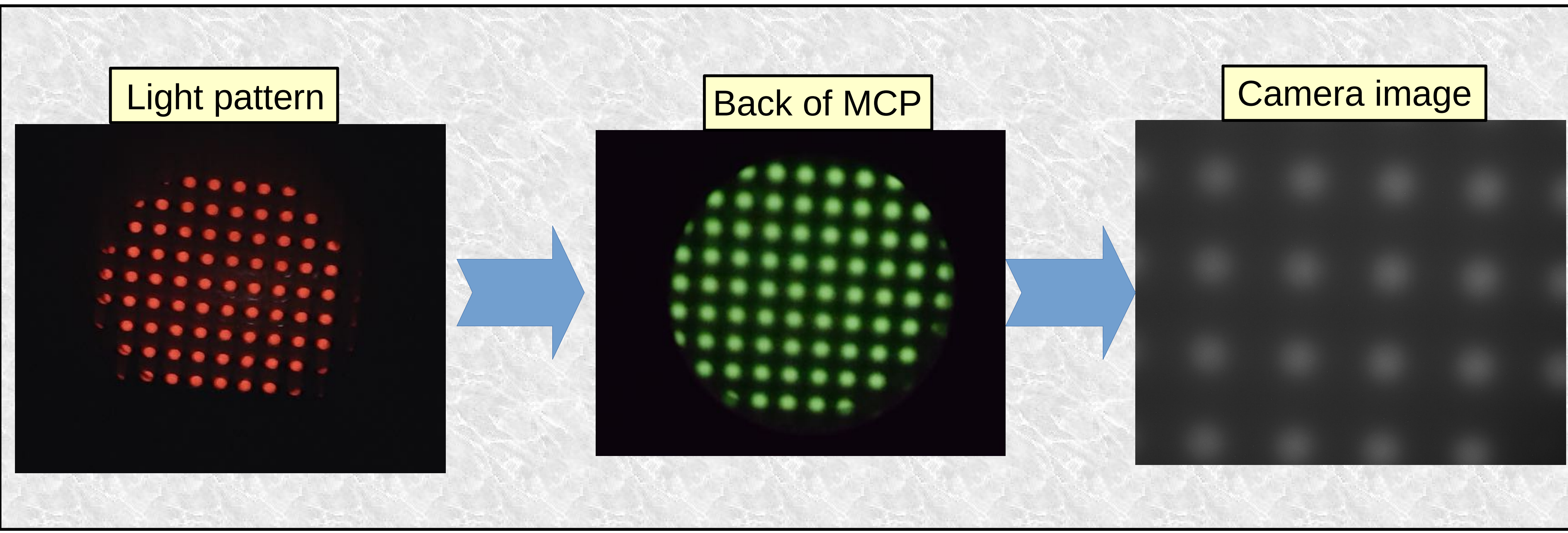
MCP can be gated to detect only initial light

- ✔ Same initial light transport system
- ✔ MCP+lense+camera instead of fibers+MPPC



Alternative system: camera + MCP

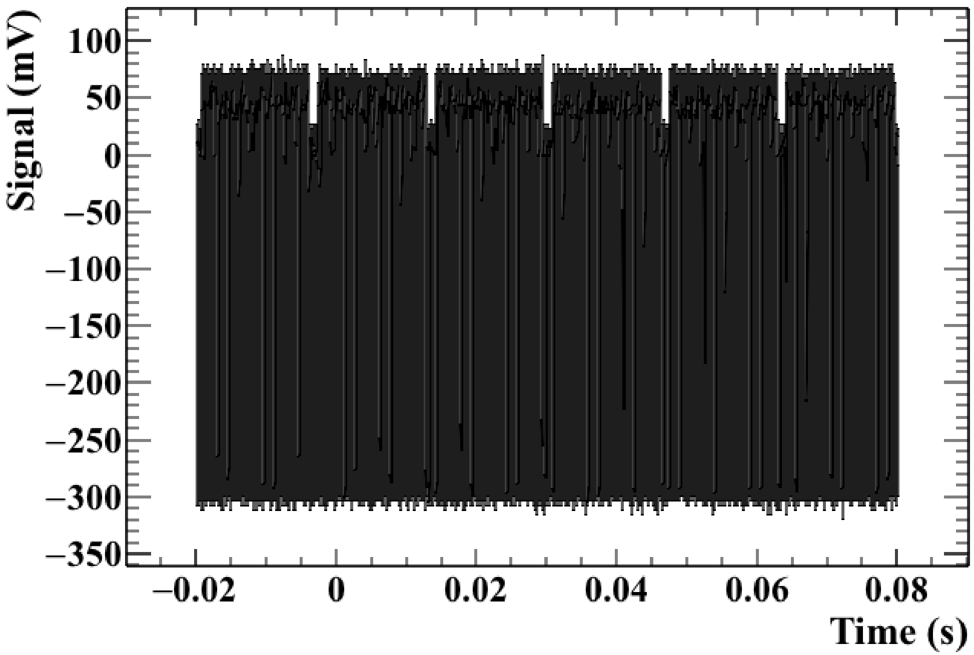
This alternative system has a better resolution than a fiber bundle: can propagate a pattern of millimeter size through this system



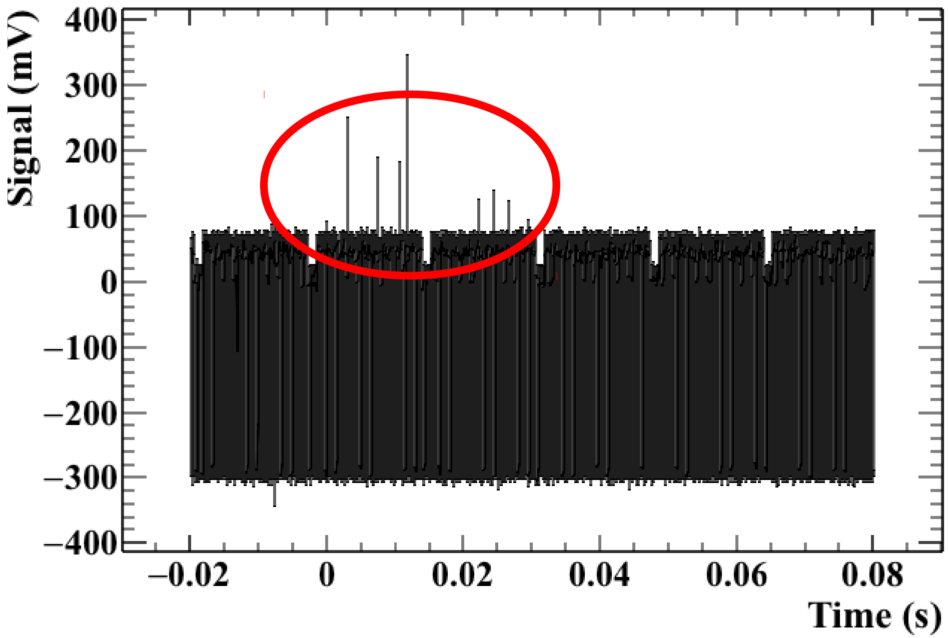
Alternative system: camera + MCP

Confirmed the CID camera can be used at a few meters from the beam pipe

<u>SSEM out</u>
(normal conditions)



<u>SSEM in</u>
(high radiation)



- Need to test MCP in those conditions
- Also check gain of the system is sufficient

Gas injection

<u>Requirements:</u>

- Should not affect the rest of the beamline
- Safety (if problem with gas injection)
- Produce enough light to reconstruct profile
- Reproducibility

To get ~1k photons per spill, need pressure increase $10^{-6} \rightarrow 10^{-3}$ Pa
Try to do by pulsed gas injection

Gas type: considering Xe and N_2

Xe

- Fast fluorescence time
- Heavy
- Smaller cross-section
- Might not work with ion pumps

N_2

- More light
- More susceptible to space charge effects

Gas injection
Target pressure calculation

Estimate required pressure to get 1000 photons with N_2 gas

γ per Deposited Energy $= \alpha_\gamma = 0.278\ \mathrm{keV}^{-1}$

Number of Protons $= N_p = 2e14$

Energy loss $= dE/dx = 0.2\ \mathrm{keV{*}m^2/g}$

Desired number of photons $= N_\gamma = 1000$

Acceptance times Efficiency $= \epsilon = 2.5e\text{-}4$

Imaged distance along beam pipe $= \Delta z = 0.02\ \mathrm{m}$

$$N_\gamma = dE/dx * \Delta z * \rho * \alpha_\gamma * N_p * \varepsilon$$

Energy deposited per proton
x photon per deposited energy
x number of protons
x acceptance and efficiency

$$N_\gamma = dE/dx * \Delta \frac{z * P * M}{R * T} * \alpha_\gamma * N_p * \varepsilon$$

$$P = \frac{N_\gamma * R * T}{dE/dx * \Delta z * M * \alpha_\gamma * N_p * \varepsilon}$$

Obtain: P=1.6e-3 Pa
Residual pressure ~3e-6 Pa

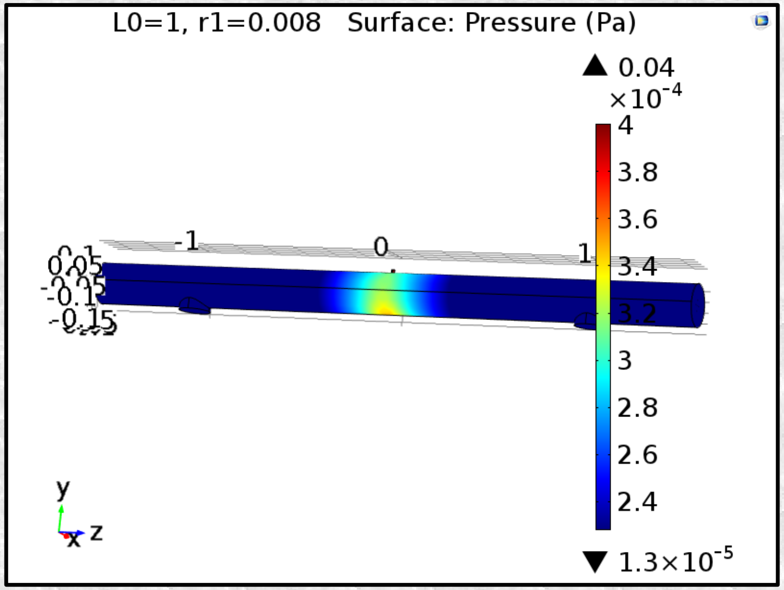
$$P = \frac{1000 * 8.31\ \mathrm{Pa{*}m^3/mol/K} * 300\ \mathrm{K}}{0.2\ \mathrm{keV{*}m^2/g} * 0.02\ \mathrm{m} * 28\ \mathrm{g/mol} * 0.278\ \mathrm{/keV} * 2e14 * 2.5e\text{-}4}$$

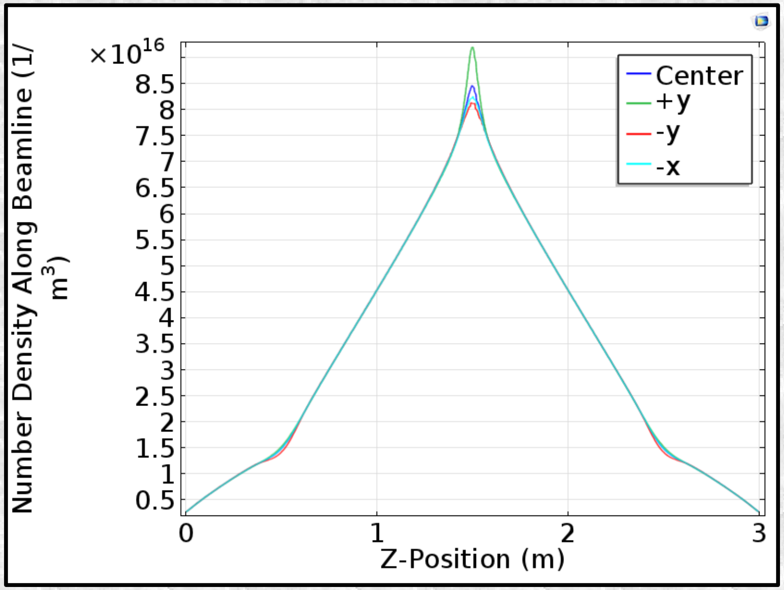
Gas injection Simulation

Study the design of the gas injection system using COMSOL simulation:

- Position of the different elements (injection point, pumps, window)
- Pressure as a function of position
- Pressure increase we can obtain
- Effect on the rest of the beamline

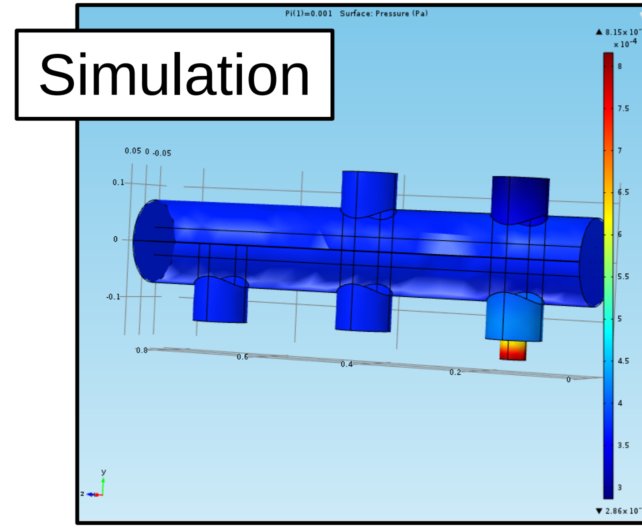
On first steady-state simulations, pressure looks more uniform a few centimeters away from the injection point: probably better to not do the measurement at this point





Gas injection
Test vacuum chamber

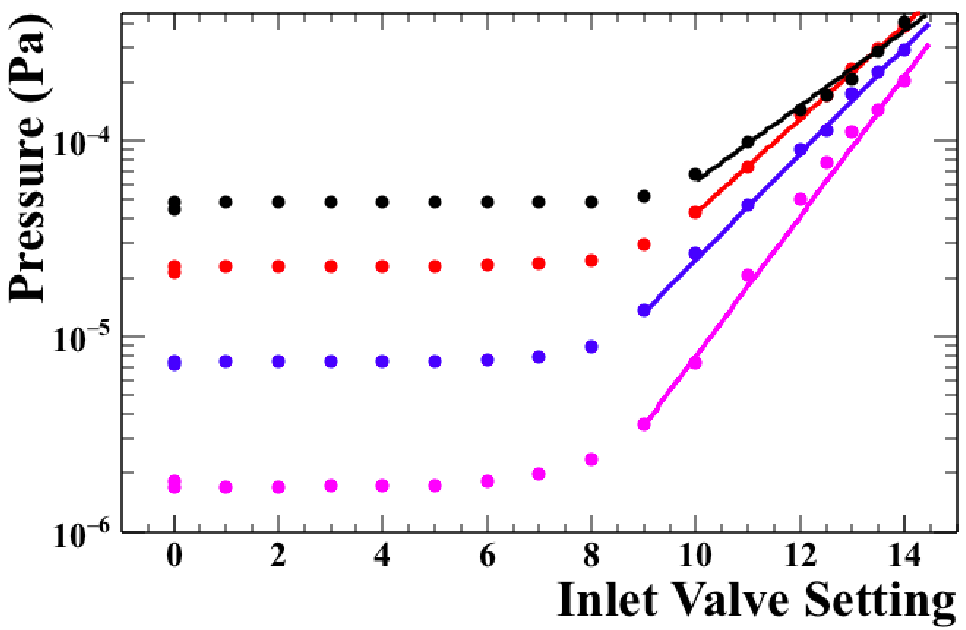
Built a test vacuum chamber
- Validate gas simulation
- Test ability to inject gas
- Check gas uniformity
- Check reproducibility



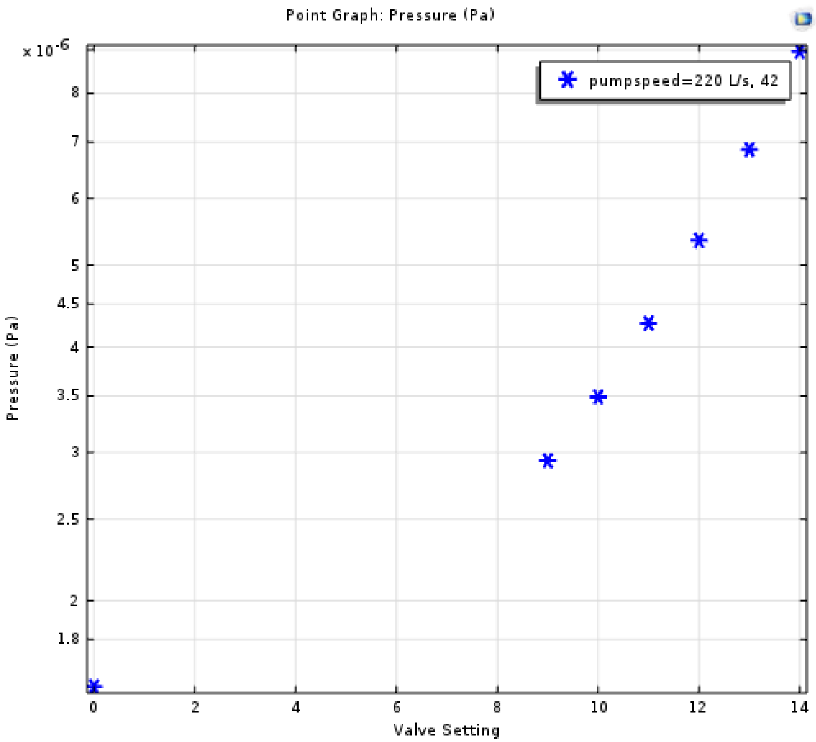
Gas injection
Test vacuum chamber

For now difficulties to reproduce data taken on this setup with simulation

Data



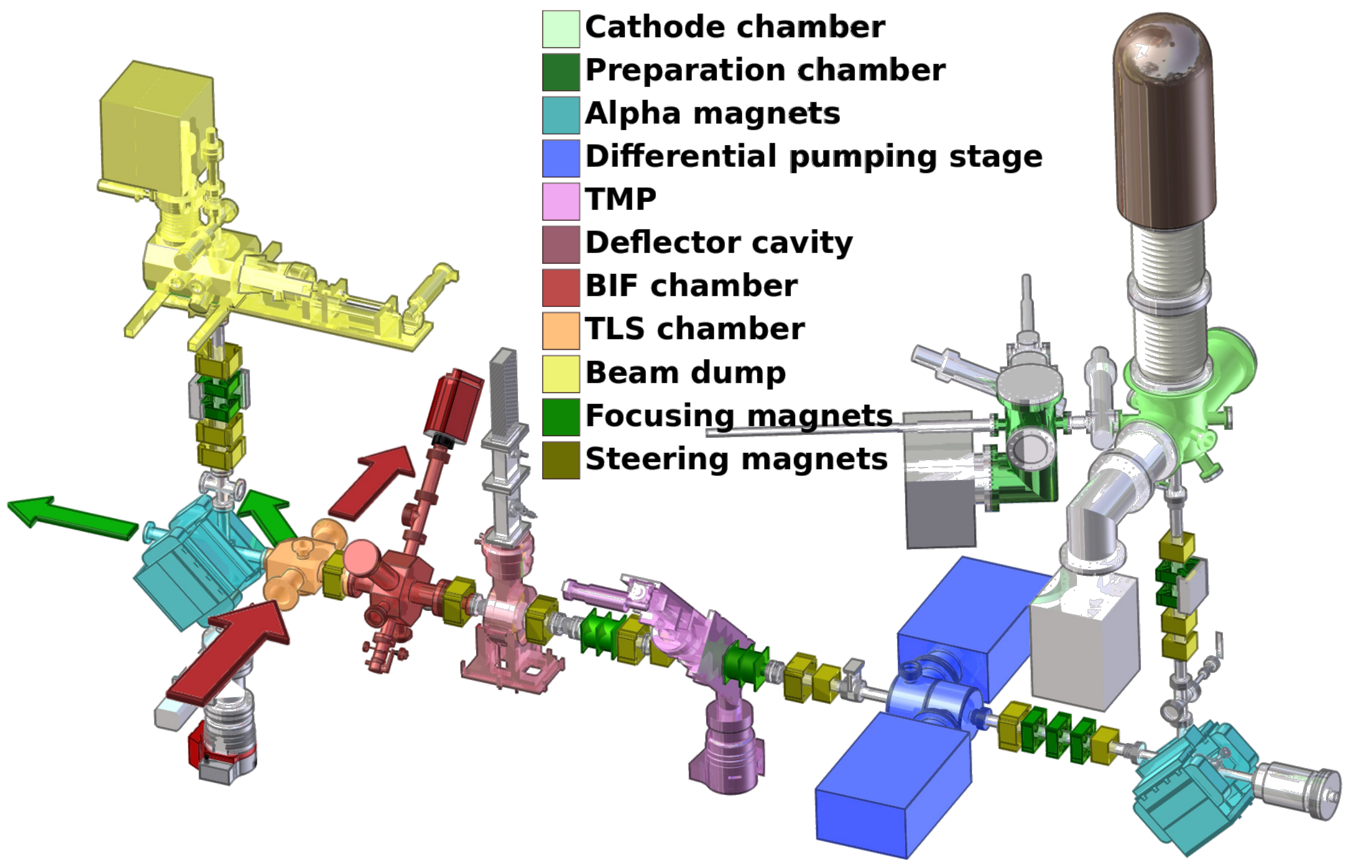
Simulation



Comparing equilibrium point in steady state (inlet open, pump running) between data and simulation, for different flows going through the inlet.

Large pressure differential demonstrated

- Group from Meintz achieved pressure increase 10^{-8} Pa → 10^{-3} Pa by differential pumping for their BIF with constant injection
- However smaller beam pipe than in our case



T. Weilbach, M. Bruker, K. Aulenbacher at IBIC2016

Summary

- Working on the design of a beam induced fluorescence profile monitor for the J-PARC neutrino beamline
- Main challenges are to produce enough light to reconstruct the profile and to mitigate the effects of the large space charge effect on ionized gas particles
- Testing two different light detection systems that would allow to detect light before the ions start to drift: fast photo-sensors MPPC, and camera with time-gated amplification
- Also found large background during beam operation caused by radiation coming from the beam window area
- Planning to inject gas in the beam line to obtain enough light
- Currently testing the different part, hoping to have a prototype ready for installation in 2018