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Beam Loss Measurements Using the Cherenkov Effect in Optical Fiber for the BINP e-e+ Injection Complex

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Outline

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- Application to the BINP Injection Complex
  - Beam loss detection requirements
  - Optical fiber selection
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Introduction

- Optical fiber based beam loss monitor has been developed at several facilities, e.g.:

  CTF3 (CERN), Australian Syncrotron (ANSTO), SPring-8 (RIKEN/JASRI),

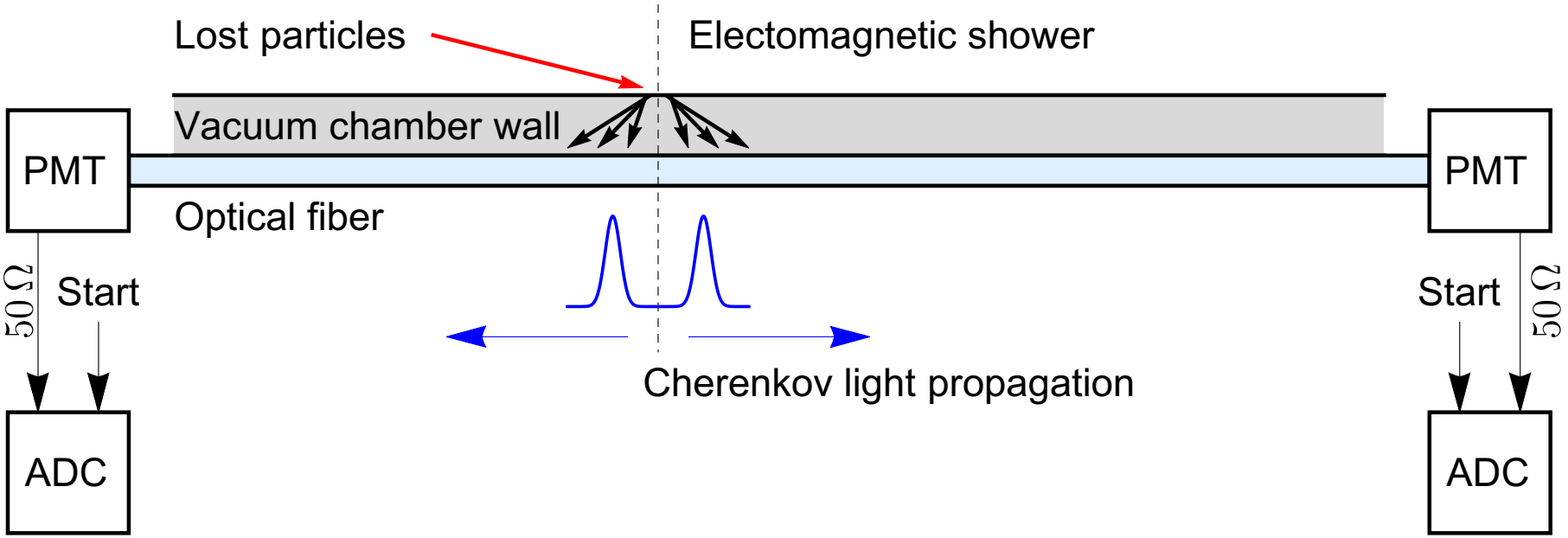
  FLASH (DESY), ALICE (Cockcroft Inst.),

  Injection Complex (BINP)

- Compared with other distributed BLMs:

  - ✔ Fast response time, < 1 ms
  - ✔ Near-zero sensitivity to background rad.
  - ✔ Insensitive to the magnetic field
  - ✔ Radiation resistant
  - ✖ Calibration of absolute beam loss value
  - ✖ Expensive, PMT+HVPS

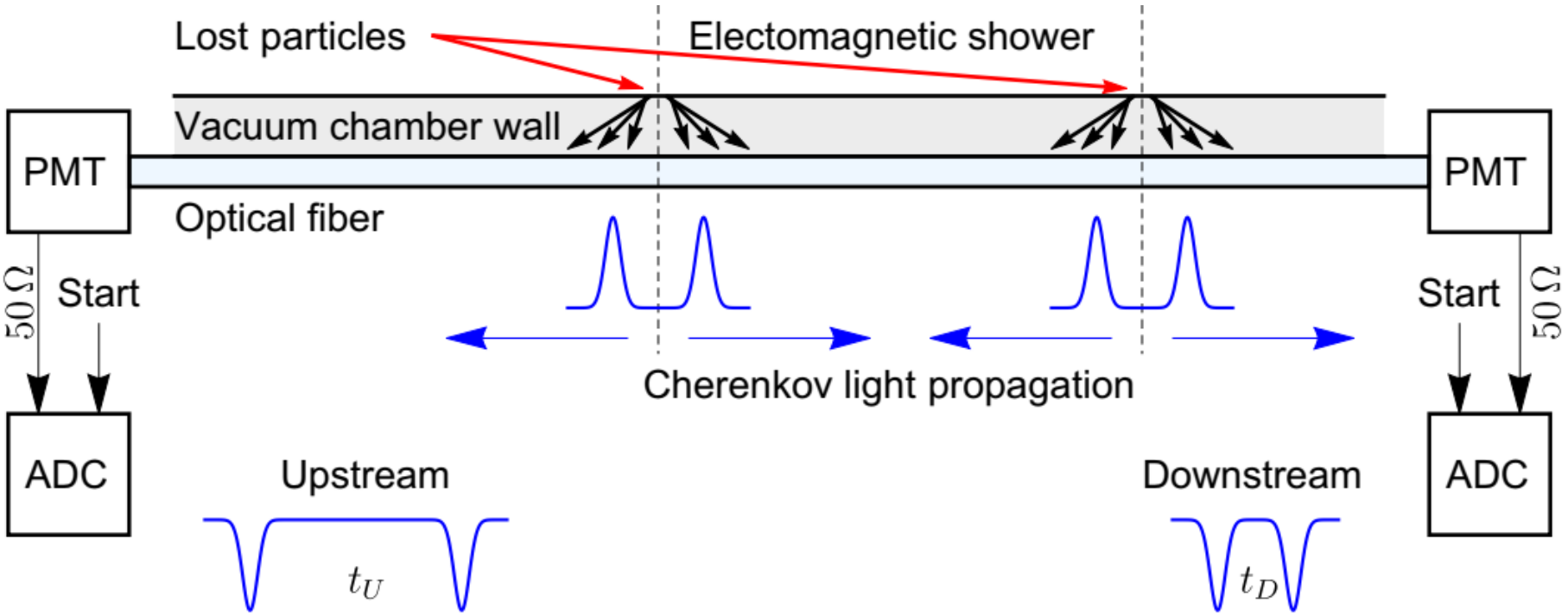
Operation principle



- Timing of the PMT signal – beam loss location
- Intensity of the PMT signal – number of registered lost particles

This device is able to detect losses for 5 MeV e-e+ primary beams.

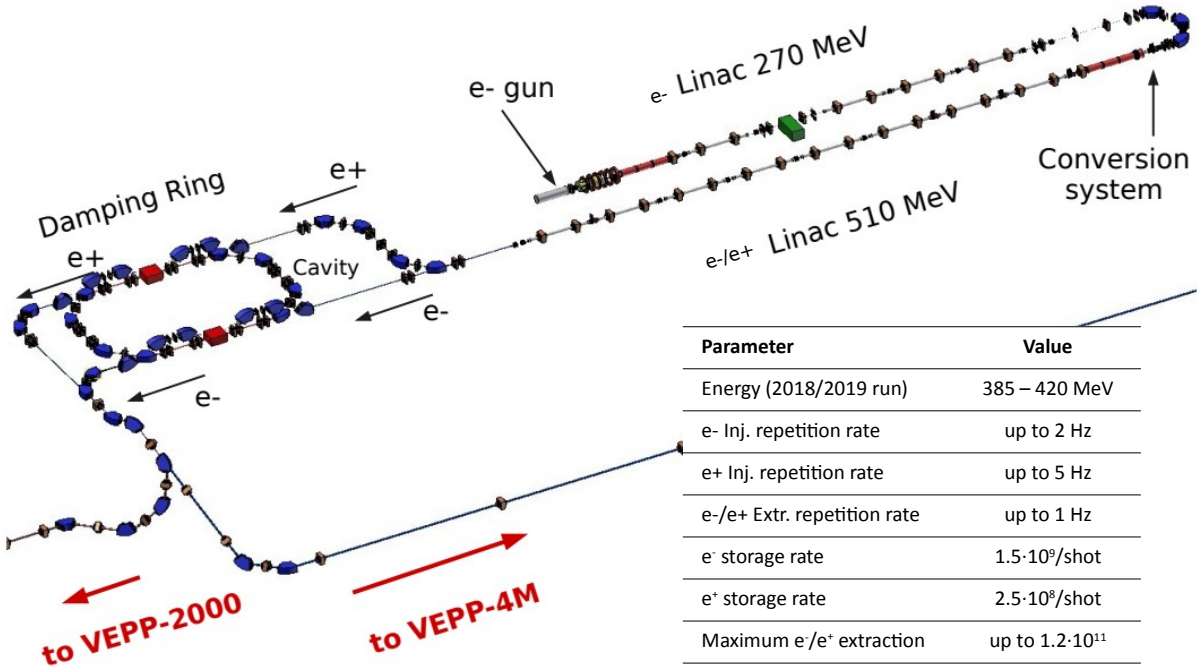
Operation principle



$$s_U = \frac{t_U c}{n+1} \qquad for\ n=1.5,\ \frac{s_D}{s_U}=5 \qquad s_D = \frac{t_D c}{n-1}$$

Application to the BINP Inj. Complex

- The Injection Complex is not equipped with any operational BLM system, we proposed to use the optical fiber based BLM.
- The typical value of beam losses during the transfer to the users is near 50%.



Parameter	Value
Energy (2018/2019 run)	385 – 420 MeV
e- Inj. repetition rate	up to 2 Hz
e+ Inj. repetition rate	up to 5 Hz
e-/e+ Extr. repetition rate	up to 1 Hz
e^- storage rate	$1.5 \cdot 10^9$/shot
e^+ storage rate	$2.5 \cdot 10^8$/shot
Maximum e^-/e^+ extraction	up to $1.2 \cdot 10^{11}$
Bunch train, ns	<1

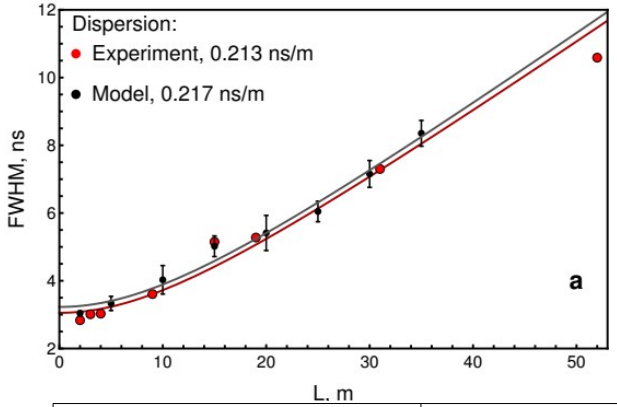
Beam loss detection requirements:

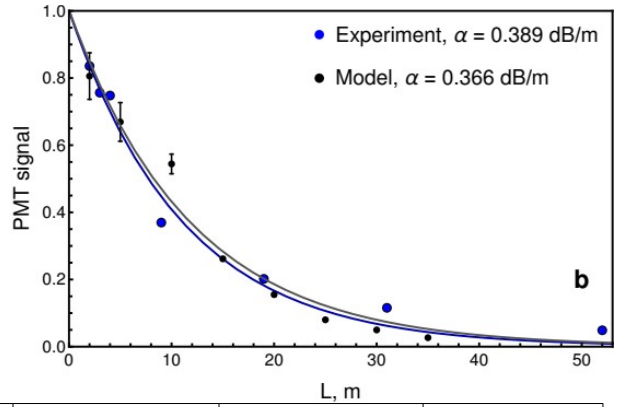
- Spatial resolution < 1m;
- Sensitivity to detect up to 0.1 nC;
- Radiation hardness (up to 10^3 Gy);
- Cost-efficiency;

Optical fiber selection

Requirements for the optical fiber:

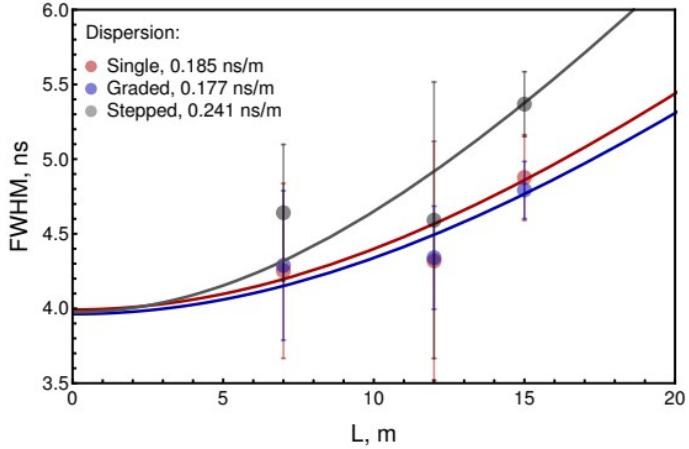
- Good time resolution ⇨ Small light dispersion: silica <0.1 ns/m, plastic 0.25 ns/m
- High photon emission rate ⇨ large core: either silica or plastic
- Radiation hardness ⇨ silica (up to 10^5-10^7 Gy), plastic (up to 10^4 Gy)
- Cost-efficiency: plastic (cheap), silica (expensive, the cost increases with Ø value)





model	Broadcom, HFBR-RUS	Fiberware, G400/560A	Fiberware, SM400/125PI	Thorlabs, FG550UEC
material	plastic	silica	silica	silica
mode	multi	multi	single	multi
index	stepped	graded	stepped	stepped
Øcore/clad,um	1000/-	400/560	2.2/125	550/600
NA	0.47	0.29	0.2	0.22
Measured dispersion, ns/m	**0.241**	**0.177**	**0.185**	**0.19**

***FG550UEC* silica step-index multimode (Ø core 550 um) is suitable.**

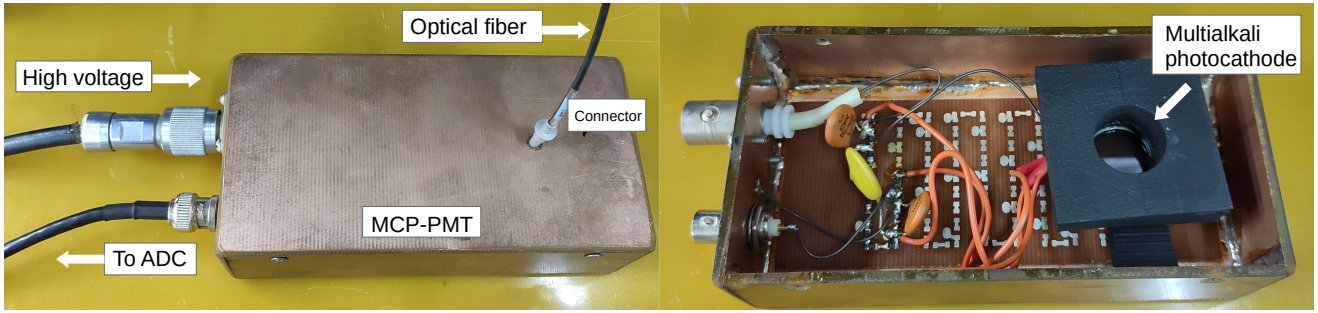


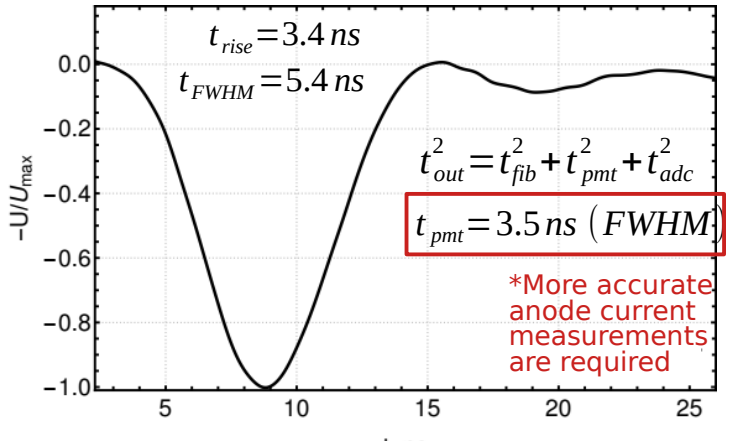
PMT and ADC selection

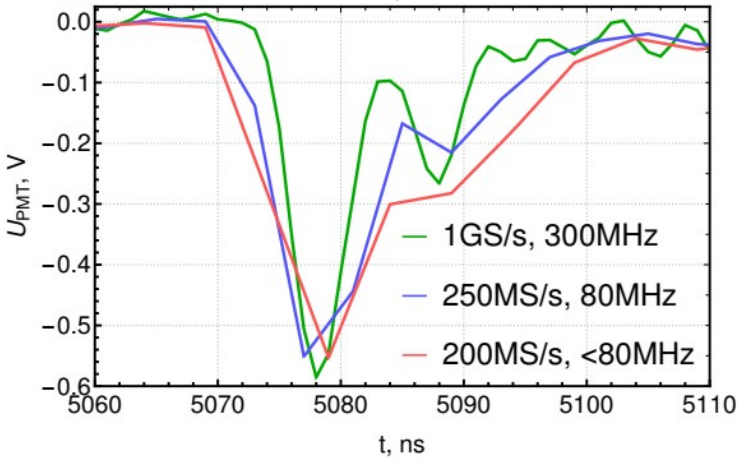
Microchannel plate photomultiplier (MCP-PMT)

manufactured in Novosibirsk, Russia, multialkali photocathode

- Good time characteristics: jitter - 100 ps, rise-time - 0.5 ns, output pulse FWHM - 1.5 ns
- Spectral sensitivity range 300-900 nm
- Gain ~ 10^6
- Compact (h=17 mm, d=31 mm)
- weak sensitivity to magnetic field (the gain reduces by a factor of 3–5 in the 1.8T field)
- comparatively low cost

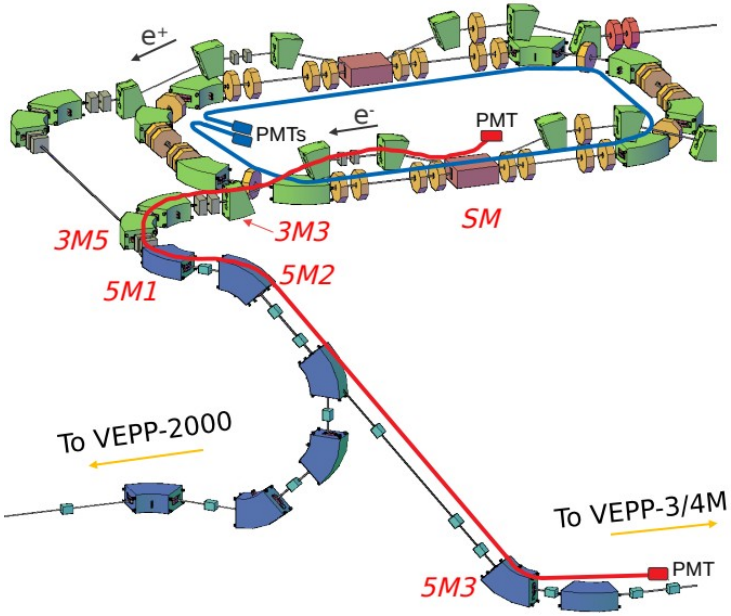


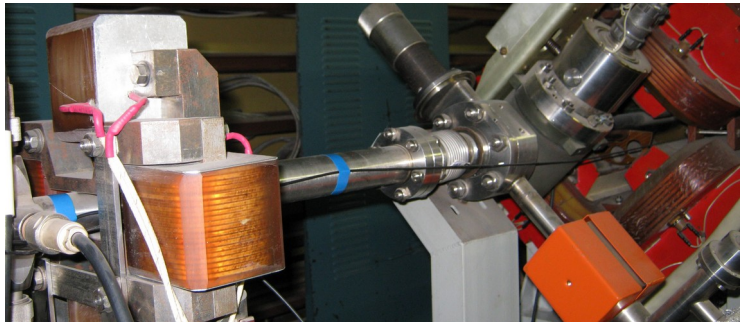




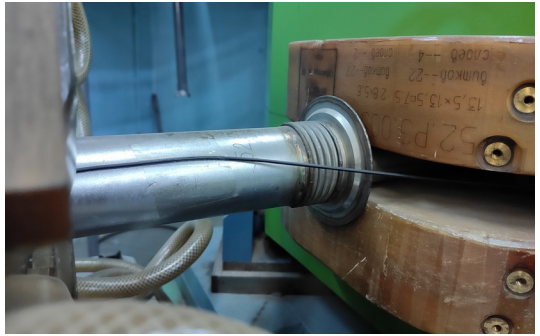
Experimental setup

- @Extraction channel: 50 m silica multimode step-index fiber (ø550 um), MCP-PMT
- @ Damping ring: 50 m plastic fiber, MCP-PMT

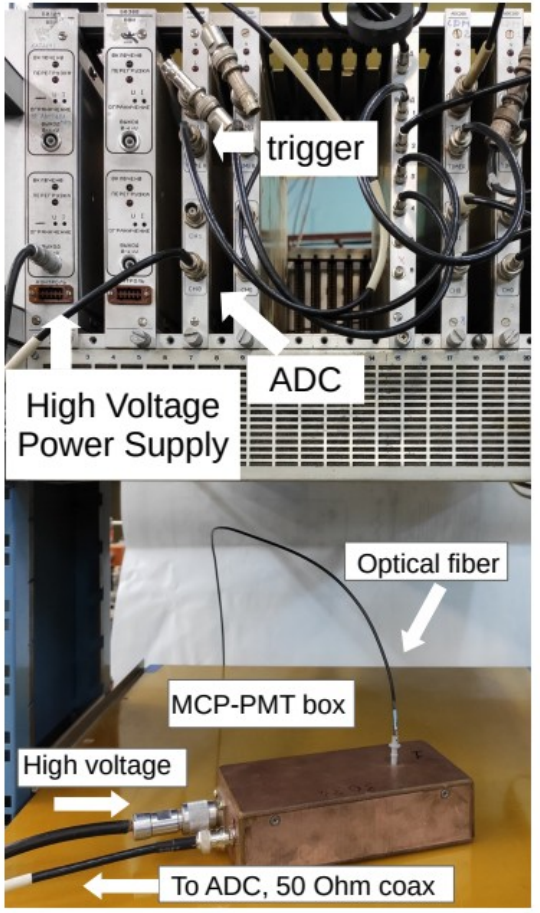




Optical fiber is attached to the vacuum chamber wall

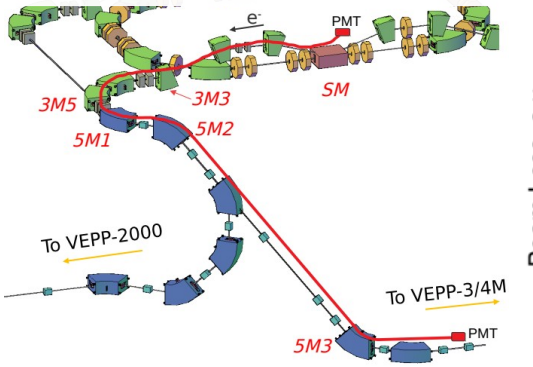


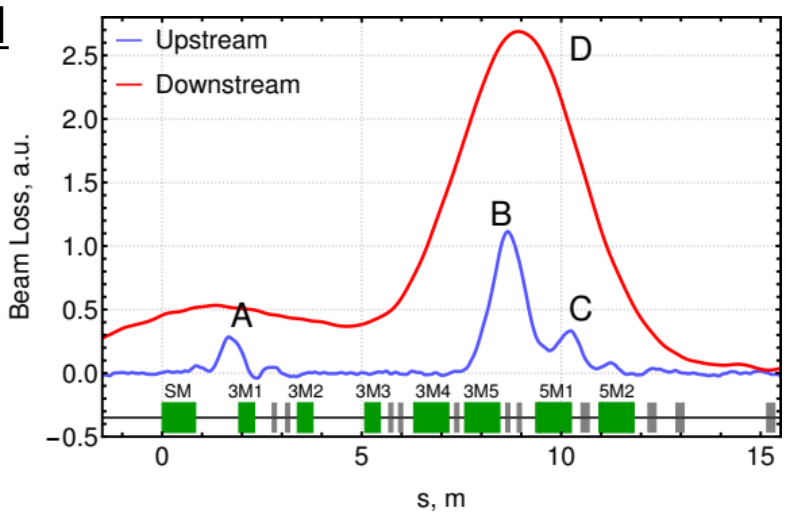
Inside the magnet



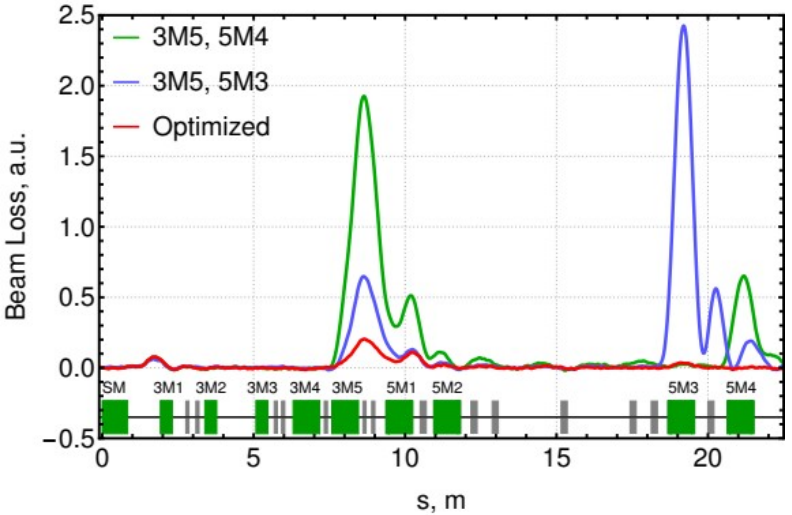
Experimental results

➔ Extraction channel





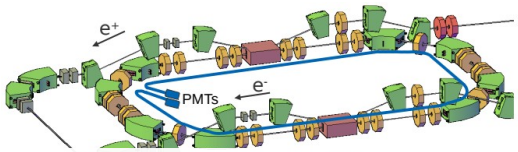
4 times better spatial resolution during upstream detection



Loss distribution along the extraction channel during alignment

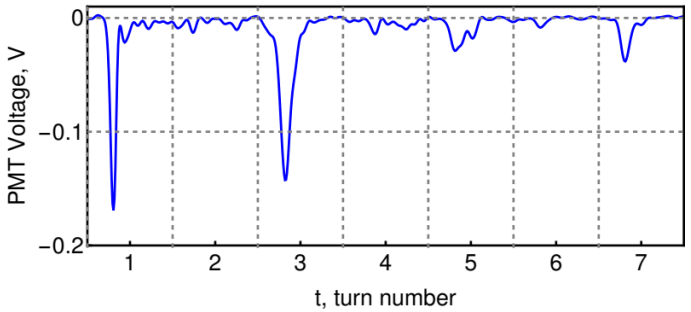
Required spatial res. (<1m) for 45 m fiber was achieved.

➔ Damping ring



Ring circumference: 27.4 m

*2 fiber sections should be used to avoid overlapping of beam losses from different turns



- Monitor allows detecting turn-by-turn beam losses
- It can be used as a useful tool for optimal tune alignment

Summary

- Beam loss diagnostics is one of the important tasks during machine commissioning and operation
- Optical fiber based BLM is widely used
- This monitor has been developed for the 500 MeV BINP Injection Complex
  - Numerical studies for plastic fiber are in good agreement with experimental results
  - Methods to optimize monitor spatial resolution were considered
  - Using 45 m fiber, monitor spatial resolution of less than 1 m was achieved
- We continue to use and upgrade this method for our facility

Thank you
for your attention