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BEAM LOSS DIAGNOSTICS SYSTEM FOR SKIF SYNCHROTRON LIGHT SOURCE

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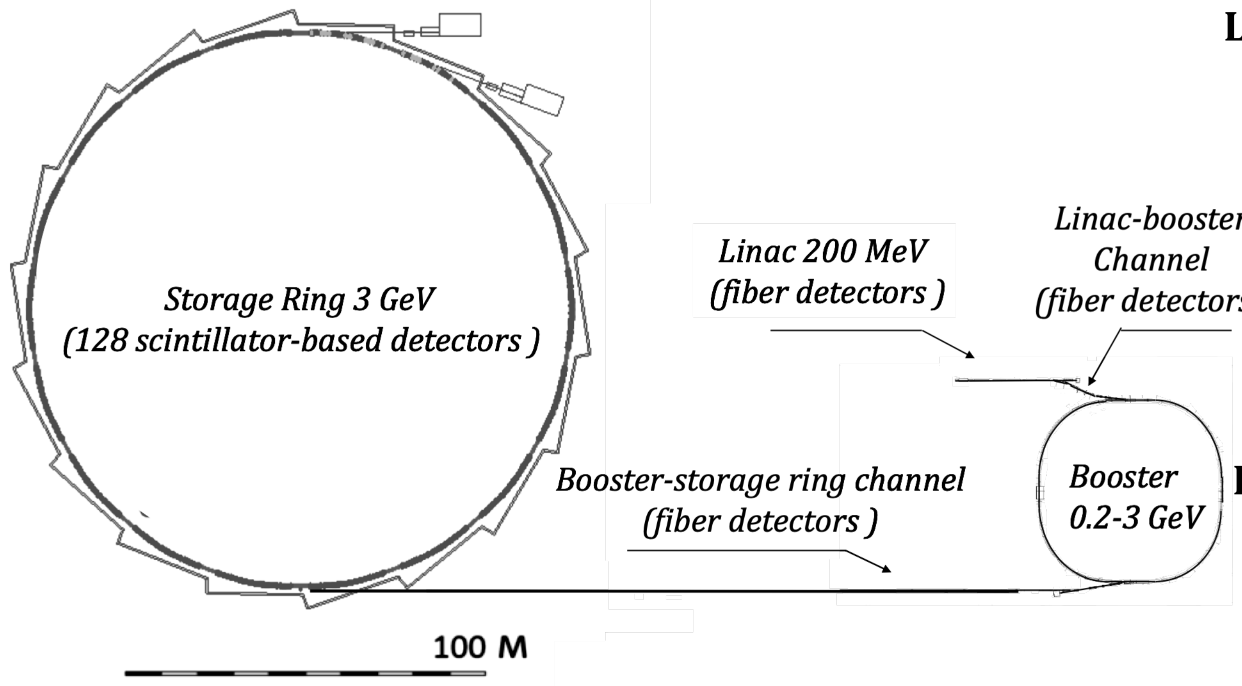
Siberian ring photon source (SKIF)

- 4th Generations synchrotron light sources
- 3 GeV Energy
- Low-emittance
- 2023/2024



SKIF layout.

Injector: linear accelerator

Max. energy =200 MeV
Operating frequency= 1Hz
Geometric emittance at 200 MeV = 150 nm rad
Energy spread at 200 MeV = No more 1% (rms)

Linac-to-booster transfer line(LBTL) 8 m

Booster

Max. energy = 3 GeV
Operating frequency = 1Hz
RF Frequency = 350 MHz
C = 158.7 m
Maximum beam charge = 15 nC
Injection/ extraction charge transmittance efficiency=>75% (reached 93%)

Booster-to-storage ring transfer line (BSTL) 200 m

Storage ring

Energy = 3 GeV
C = 476 m
ε_x = 75 pm (0 mA, no IDs)
I_{max} = 400 mA
16-fold symmetry

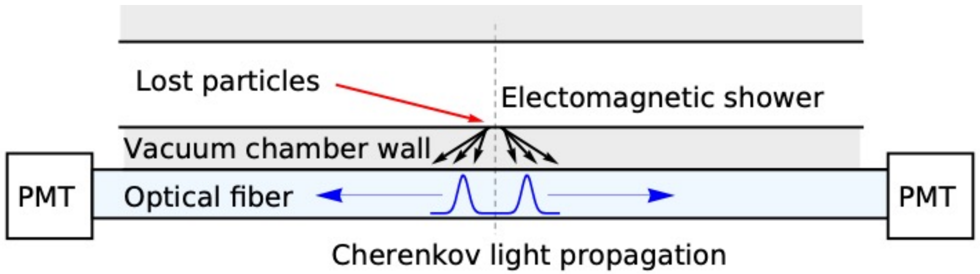
Types of beam loss monitor (BLM) for SKIF

- To eventually improve machine performance and operation stability, **beam diagnostics with BLM system is required**.
- BLMs are useful for real time beam loss monitoring during both beam routing and storage ring operation.

Linac, LBTL and BSTL ➢ **Cherenkov -BLM**

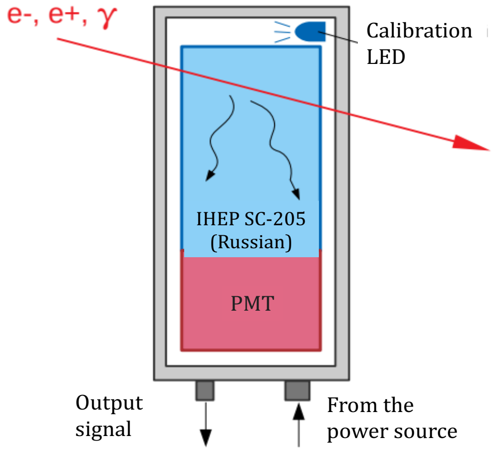
Storage ring ➢ **Scintillator-BLM**

Fiber-based Cherenkov beam loss monitor (CBLM)



CBLM principle.

Scintillator-based beam loss monitor (SBLM)



SBLM scheme.

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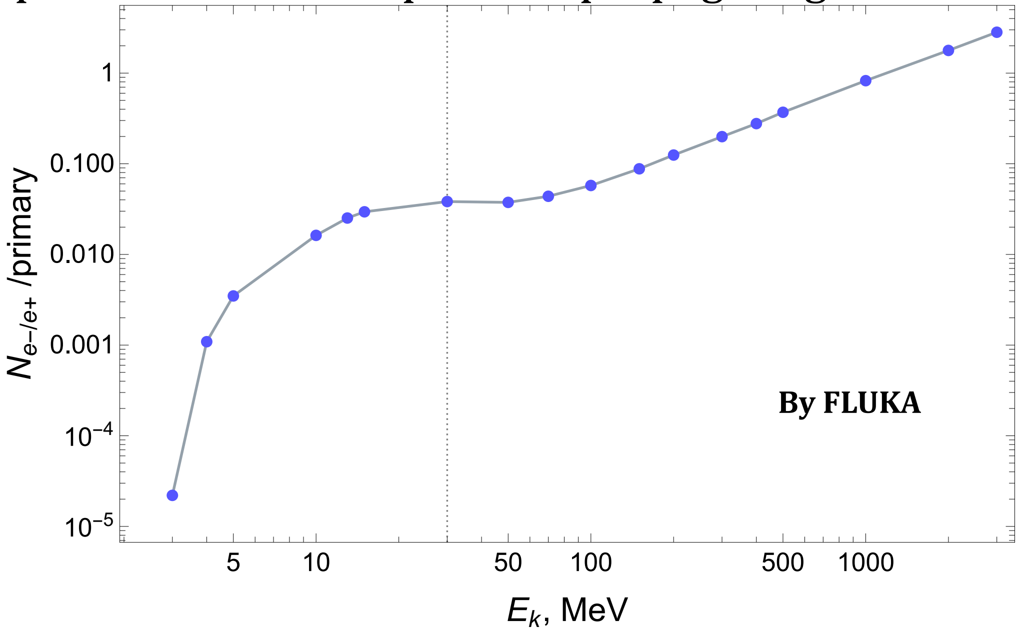
The operation principle of the CBLM is based on the acquisition of the Cherenkov radiation (CR) generated in the optical fiber attached to the vacuum chamber by secondary charged particles.

Cherenkov BLM:

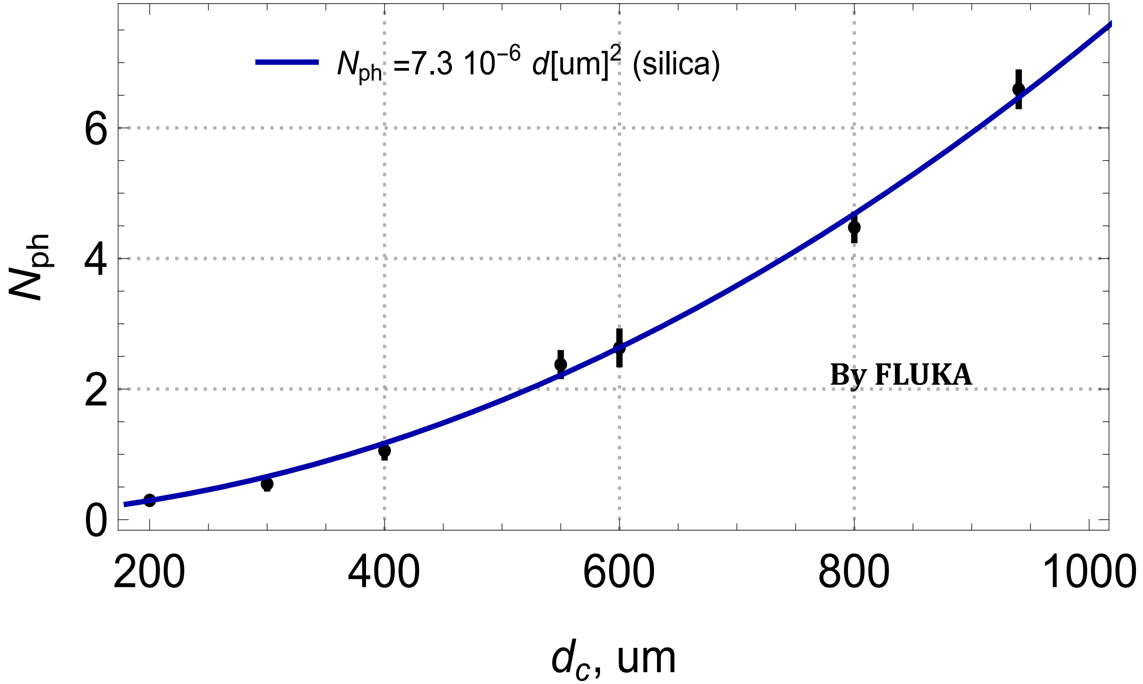
Simulation studies for SKIF

The contributions of secondary particles passing through the optical fiber and CR photons propagating in the fiber.



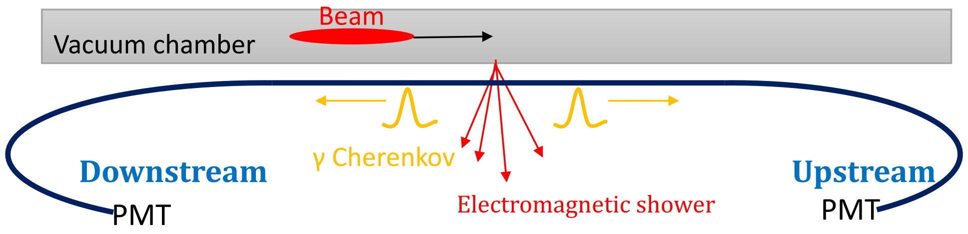
- Above 30 MeV bremsstrahlung is predominate and above 100 MeV an electromagnetic shower (EMS) appears.
- BLM can be used for beam with energy **greater than 3 MeV**, but for energies up to 5 MeV number of particles is 10^{-4}-10^{-2} per primary.

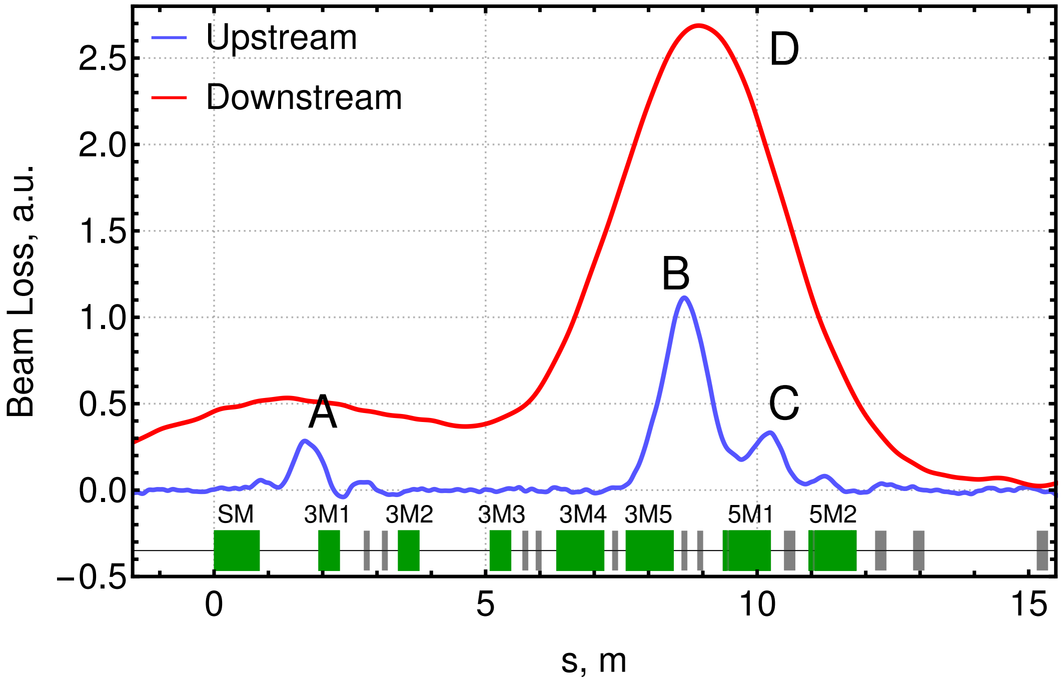
BLM sensitivity depends quadratically on fiber core diameter.



- The signal sensitivity at the upstream end of the fiber is about **10 times** lower than downstream one
- For silica fiber only about **5%** of the generated CR are able to be trapped in optical fiber and exit fiber end.

Cherenkov BLM: Prototype test at operating accelerator at the BINP





Upstream (blue) and downstream (red) loss distributions of the electron beam at the injection complex.

- **Upstream** signal:
  loss B and C were intentionally generated using dipole magnet.
- **Downstream** signal:
  loss D is a combination of losses B and C due to intersymbol interference.

✓ Although loss B is almost equidistant from both fiber ends, FWHM of the second signal corresponds to 0.96 m (@19m) and 3.8 m (@31m) for the upstream and downstream measurements, respectively. Which leads to **4 times** better spatial resolution at the upstream fiber end.

✓ Taking into account the difference between Photomultiplier Tube (PMT) gains, downstream signal sensitivity is about **10 times** higher than upstream one.

✓ Taking into consideration the intensity of the light signal and its duration, the optimal length of the fiber was found to be about **40 m**.

Cherenkov BLM: CBLM parameters for SKIF

For SKIF, both fiber ends will be used simultaneously:

- **Upstream:** better monitor spatial resolution
- **Downstream:** better monitor sensitivity

Optimal fiber type (preliminary selected):

Multimode silica fiber with step-index profile manufactured by Thorlabs (FG550UEC)

- 500 μm core diameter
- High OH–, F-doped silica cladding
- Measured dispersion was obtained to be 0.17±0.01 ns/m.

CBLM system layout:

Linac and LBTL: ✓ Single 30 m long fiber

BSTL(200 m long): ✓ 5 BLMs with 45 m long fibers each

Photodetector: Detecting beam losses of ~1 pC

MCP-PMT with a maximum of photocathode spectral sensitivity range	300–600 nm
The front rise time	0.5 ns
The duration (FWHM) of the anode current pulse	at least 1.5 ns
Gain	over 10^6
Dark current	less than 1 nA

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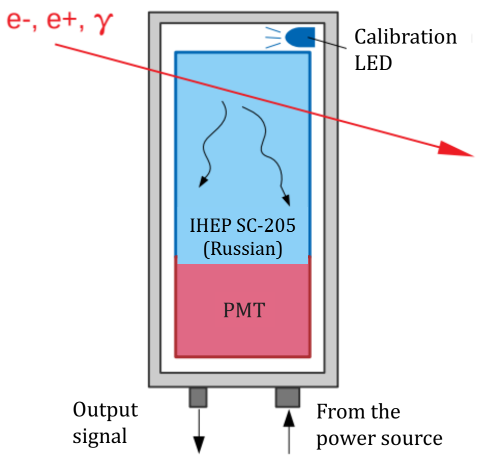
Scintillator BLM: Element selection



➢ Plastic scintillator

- The scintillator is planned to be SC-205 produced by the Institute of High Energy Physics (Russia). (Decay time = 2.4 ns, Max.spectrum @ 420 nm)

➢ PMT

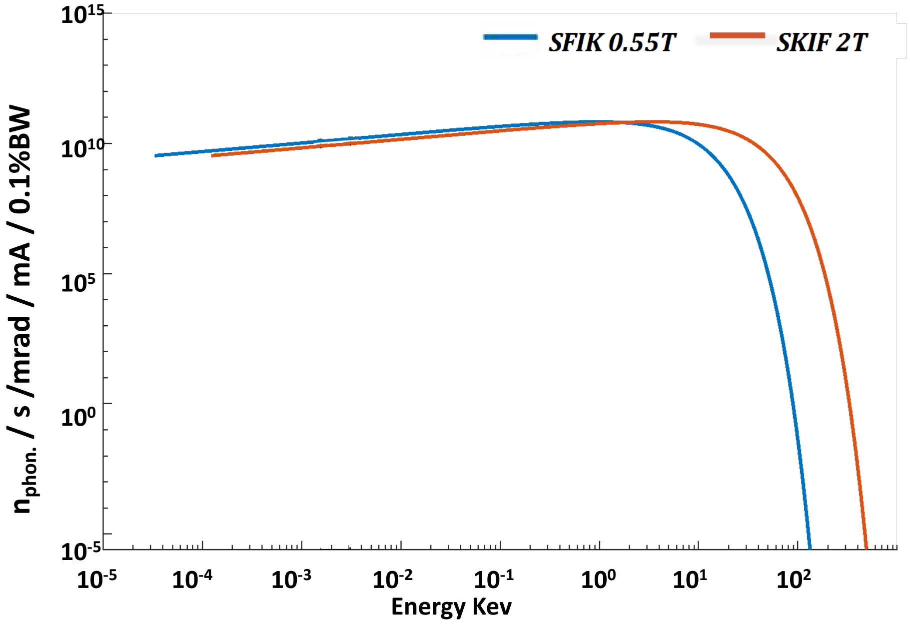
- An ET Enterprises® 9107B photomultiplier tube with a 2.5 cm diameter cathode will be used to acquire the CR light in the spectrum range. (Max.Gain = 30x 10^6)

➢ Reflector

- The reflective Tyvek® paper is wrapped around the scintillator to maximize light output. (Refl.Coeff.@440mm = 0.97)

➢ Lead shielding

- The photon energy generated by synchrotron radiation is low ~100 keV, which is not enough to affect the sensitivity of the BLM detector. Lead shielding may **not be required**, that can reduce the size of the BLM and a higher degree of freedom of installation can be obtained.



Spectrum of synchrotron radiation SKIF with H = 5.5 kG (blue) and 20.5 kG (red) for 3GeV beam energy.

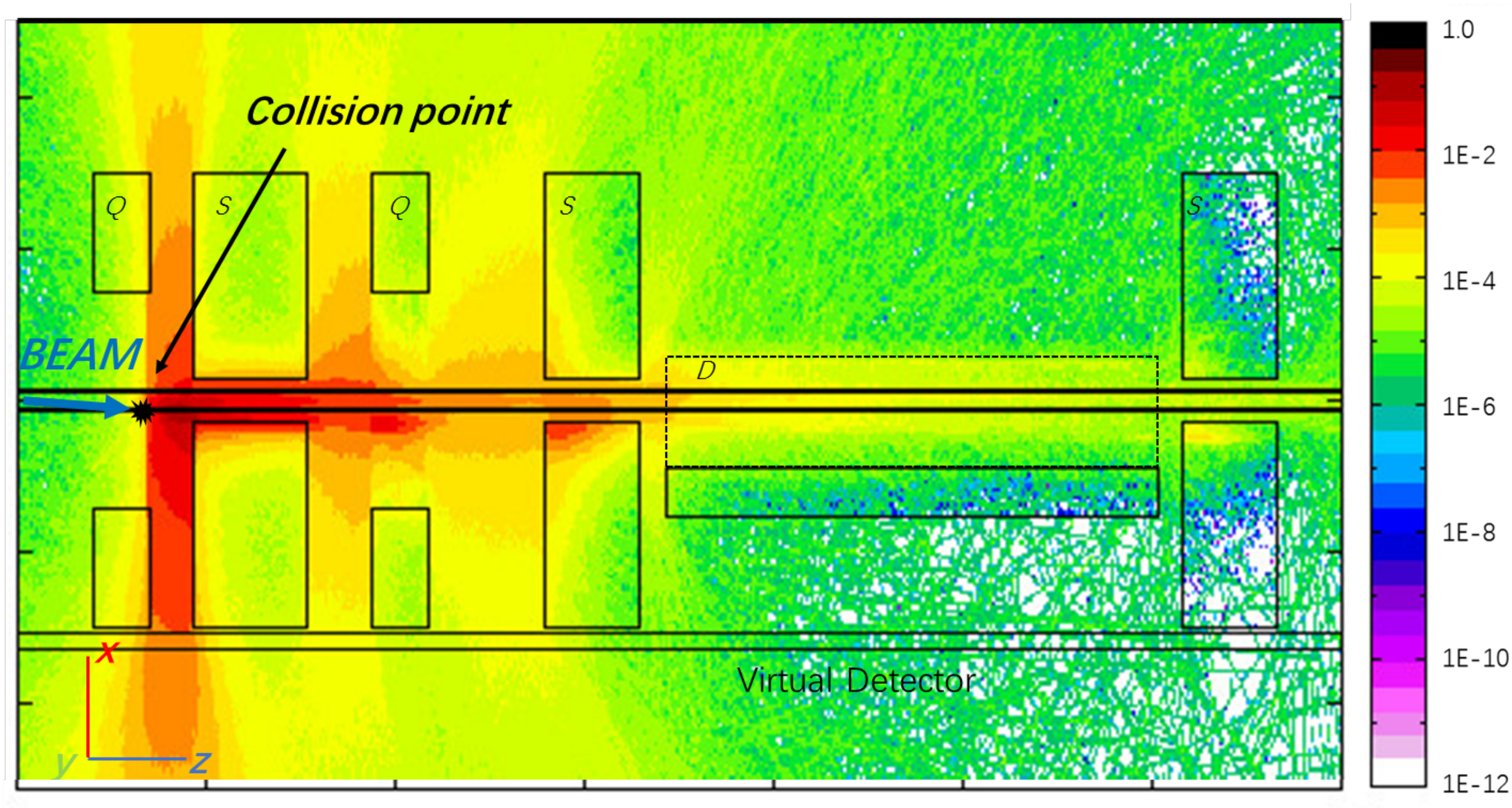
Scintillator BLM: FLUKA simulation and results

Electromagnetic shower simulation conditions:

- 3 GeV electron beam
- 15000 initial electrons particles
- Vacuum tube: 1.5 mm thickness
- 1 °incident angle relative to equilibrium orbit
- 5000 photons (optical, not γ) from 1 x-ray photon; 200 photons from 1 γ- ray.

Beam losses are likely to occur at places with maximum value of the:

- β-function
- dispersion function



The typical distribution of secondary particles calculated by FLUKA. The collision takes place on the outer radius of vacuum chamber at the maximum value of the β function.

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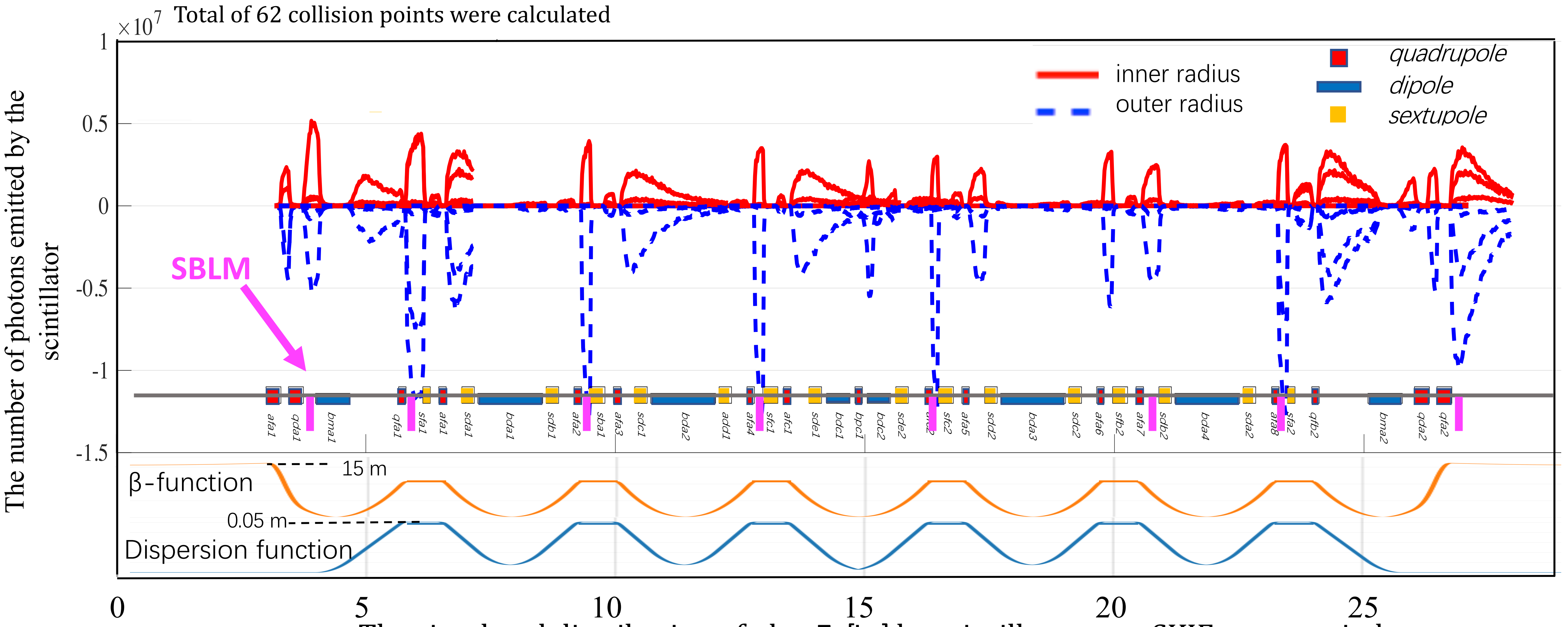
Scintillator BLM

8 SBLMs per superperiod are decided to be used.
Total number around the SKIF storage ring is 128 SBLMs

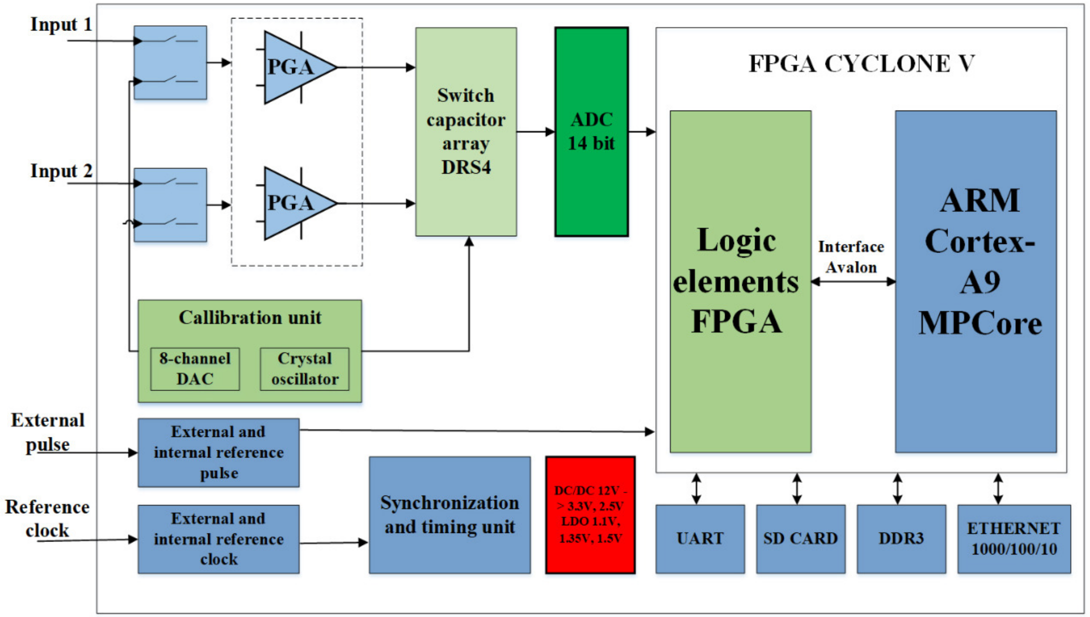


The simulated distribution of photon in the scintillator over SKIF superperiod.

Electronics:

Electronics for CBLM

- Programmable gain input amplifiers (PGA);
- DRS4 chip in the configuration with two lines of capacitive storage arrays up to 4096 elementary cells for everyone;
- A unit that generates signals for carrying out amplitude and time calibration for DRS4 chip;
- ADC of the megahertz range;
- Node of synchronization and timing, linking DRS4 data recording cycles to external events;
- Digital node based on Intel Cyclone V SoC FPGA.



Simplified diagram of the measurement module for CBLM.

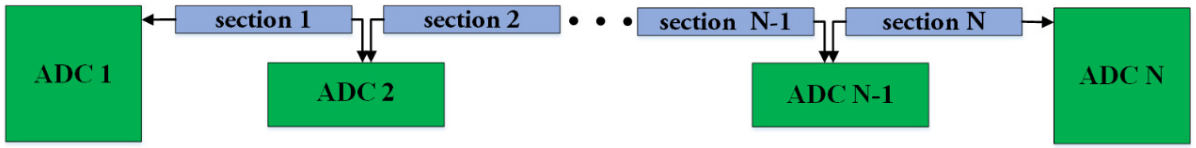
Two modes of operation:

- Unilateral signal registration mode

  Each sensor has its own measuring module operating in the single-channel mode.

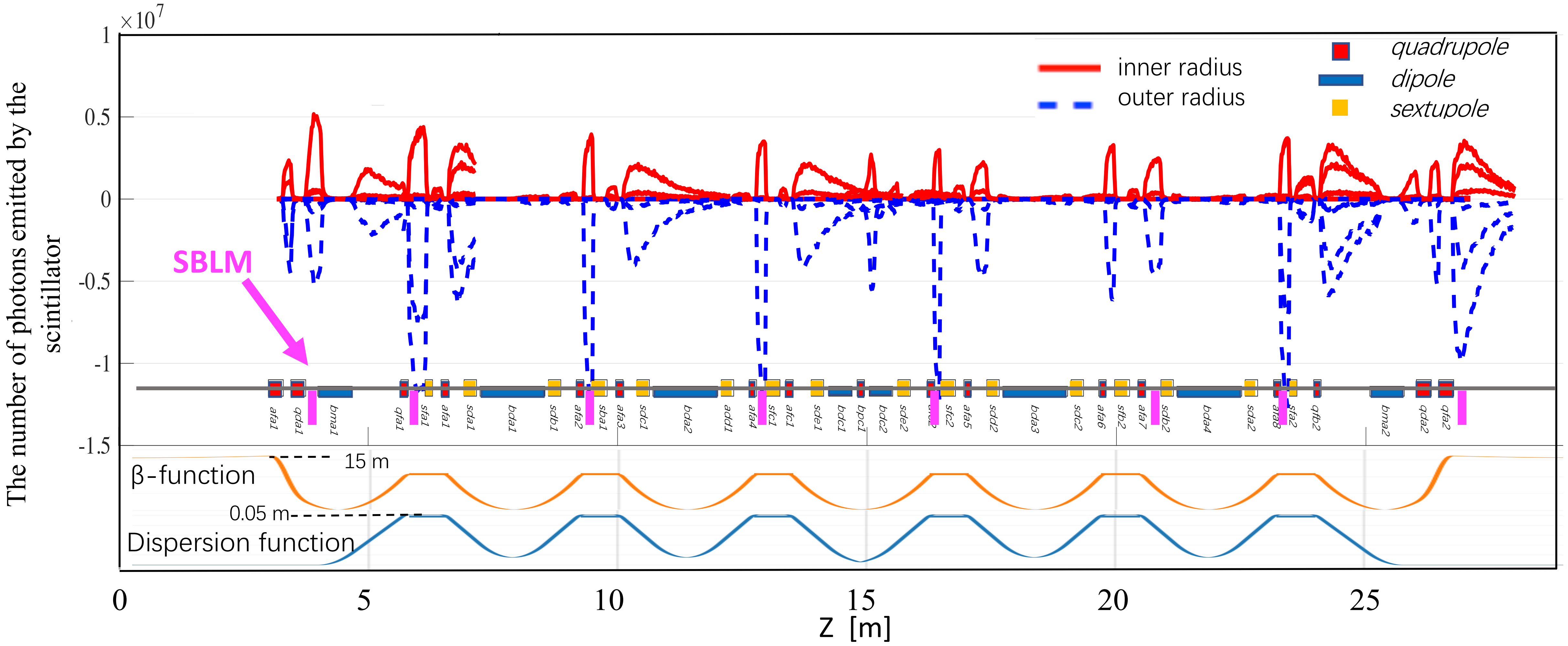
- Bilateral signal registration mode

  The measuring modules placed between the segments of the magnetic structure operate in a two-channel mode.



Where ADC 1, ADC 2, ADC N-1, ADC N – 2-channel ADC. ADC 1 and ADC N – 1-channel ADC.

System for loss level measuring in successive segments of the magnetic structure .



×10^7
1
0.5
0
-0.5
-1
-1.5
The number of photons emitted by the scintillator
inner radius
outer radius
quadrupole
dipole
sextupole
SBLM
β-function
15 m
0.05 m
Dispersion function
0
5
10
15
20
25
Z [m]

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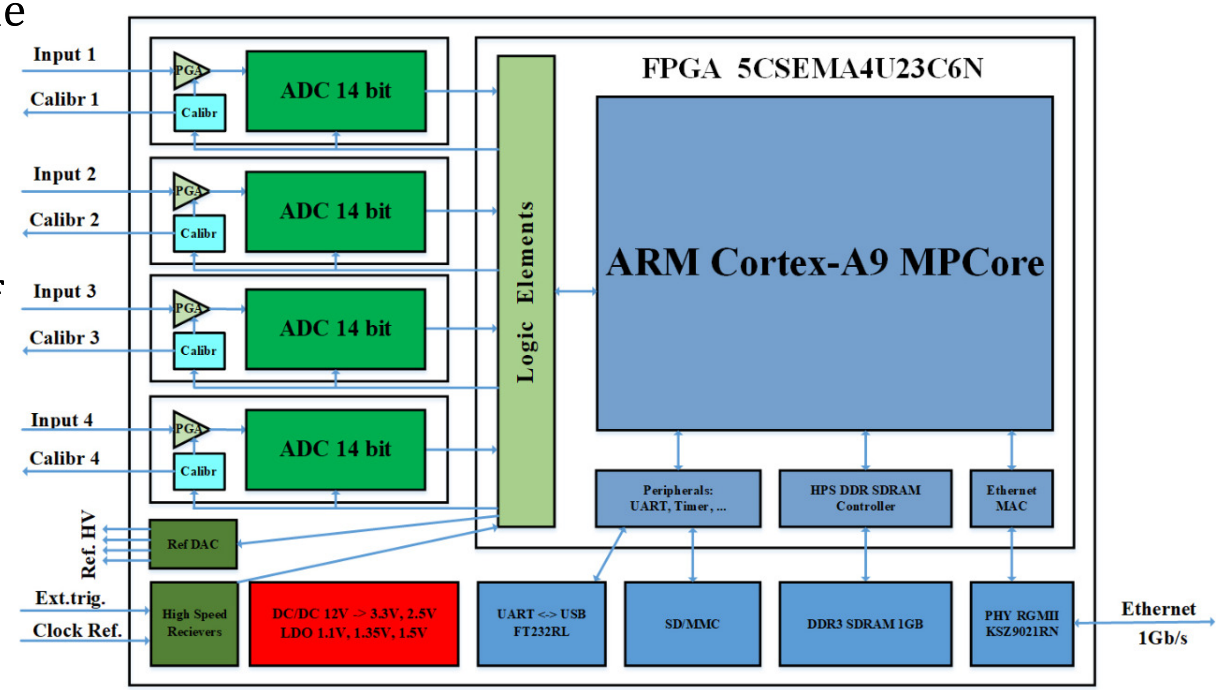
Electronics:

Electronics for SBLM

- Wideband input amplifier (0 - 100MHz) with programmable gain;
- 14-bit ADC with sampling rate up to 250 MHz;
- Synchronization and timing node, built on the basis of PLL (generator with a phase-locked loop) and FPGA elements;
- The generator of the test signal for amplitude calibration of SBLM;
- The photomultiplier supply voltage controller for gain adjusting when changing the operating mode of the measuring tracts (from oscillographic to counting and vice versa).



Measuring module of scintillation sensors

Two modes of operation:

- **Oscillosope mode** allowing to record the shape of the detector signals in a sequence of time windows with a duration set by the operator;
- **Counting mode** allowing to fix signals in a sequence of successive time windows, the duration of which is set in software.

Conclusion

- The beam loss diagnostics system of the synchrotron radiation source SKIF is basically completed.
- The experience of using a Cherenkov BLM at operating accelerator allows us to select BLM elements with optimal parameters that meet the requirements for beam loss diagnostics at SKIF.
- By using Monte Carlo simulation of the electron beam shower, the best Scintillator BLM installation position on the SKIF storage ring was obtained. It is expected that the desired dynamic range 10^6 will be achieved.
- Measuring modules of the Cherenkov and scintillation BLMs are combined into the general data acquisition system by the cable synchronization lines that ensure the binding of data acquisition cycles to external events. They interface with a PC-based operator console using a standard switch over Ethernet-1000 communication channels.

Thank You!