# Beam Instrumentation For Linear Accelerator Of SKIF Synchrotron Light Source

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## Introduction

A new synchrotron light source SKIF of the 4th generation is under construction at BINP SB RAS (Novosibirsk, Russia) [1] . The linear accelerator is SKIF's injector to provide 200 MeV electron beam. The set of diagnostics will be applied for tuning of the linear accelerator and measurements of beam parameters from electron RF gun to output of the accelerator. The diagnostics complex includes 8 fluorescent screens for the beam transverse dimensions measurement, 2 Cherenkov probes for the beam duration measurement, magnetic spectrometer with range from 0.6 to 200 MeV, Faraday cup and FCT for beam charge measurement. The set of BPM along linear accelerator will be applied for beam alignment. Numerical simulations of diagnostics elements and results of beam dynamics simulations are presented in the paper. Brief description of the design and parameters of each diagnostics system is presented. Possible scenarios of linear accelerator tuning are also discussed.

# Linear accelerator of SKIF

- E = 200 MeV
- Beam charge = 0.3 – 1 nc
- Repetition rate 1Hz
- Energy spread with 200 MeV ≤ 1% (rms)
- Geometric emittance with 200 MeV: 80 nm · rad

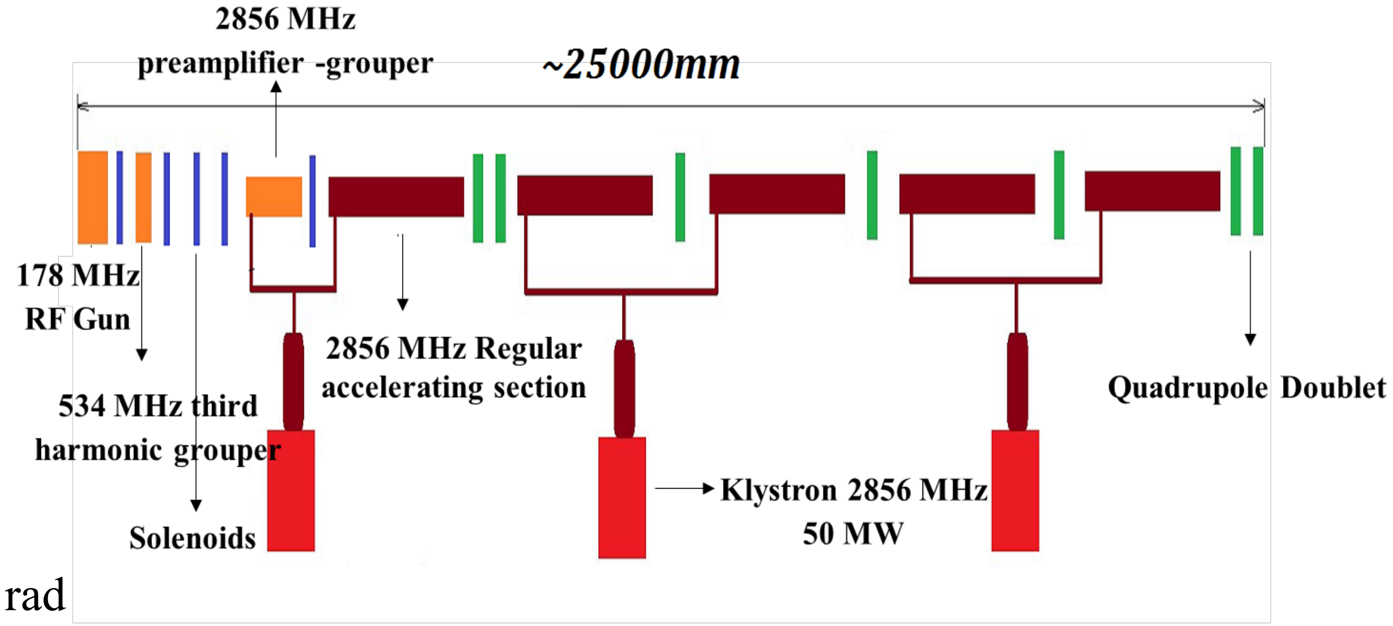


Figure 1. Layout of the linear accelerator.

Table 1: Parameters of the SKIF linear accelerator.

| LINAC | after the electron RF gun | in the bunching channel | after the pre-accelerator | after the first accelerating section | in the end of the linac |
|---|---|---|---|---|---|
| **E** | 0.65 MeV | 0.65 MeV | 3.2 MeV | 50 MeV | 200 MeV |
| **Beam transverse dimensions** | $\sigma_x$= 2 mm, $\sigma_y$=2 mm | $\sigma_x$= 2 mm, $\sigma_y$=2 mm | $\sigma_x$= 2 mm, $\sigma_y$=2 mm | $\sigma_x$=2.2 mm, $\sigma_y$=0.6 mm | $\sigma_x$= 1 mm, $\sigma_y$=0.4 mm |
| **Beam duration (FWHM)** | 140 ps | 80 ps | 8 ps | 8 ps | 5 ps |

## Fluorescent screen

Fluorescent screens are used to measure the transverse distribution of beam particles. Reasonable spatial resolution **is 0.05 $\sigma_{x, y} \approx$ 0.15 mm**.

The totally eight screens are used in the linac.


Figure 3. MANTA G-158

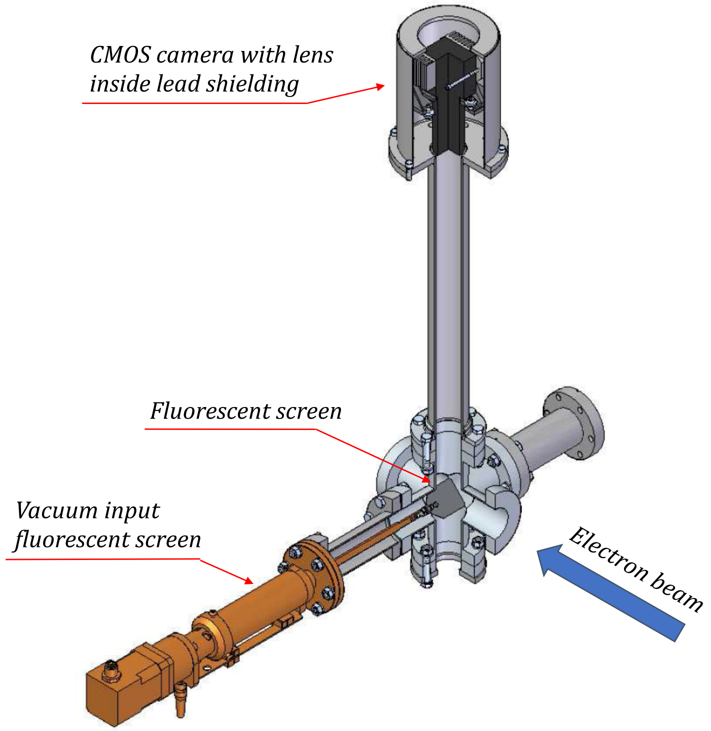


Figure 2. Scheme of fluorescent sensor in SKIF linac. The totally eight screens are used in the linac.

- Screens: CHROMOX[4]
  - at 694nm (Decay Time: 3.4ms)
  - at 691nm (Decay Time: 6.7ms)
  - High photon yield: 5 x $10^4$ photons/MeV
- CMOS digital camera: MANTA G-158 [5]
- Linear actuator: CAHB-10 [6]

## Cherenkov sensor

An image of the beam must be focused on a photocathode of streak-camera with a size of less than 0.2 mm to obtain a temporal resolution at **picoseconds** level.

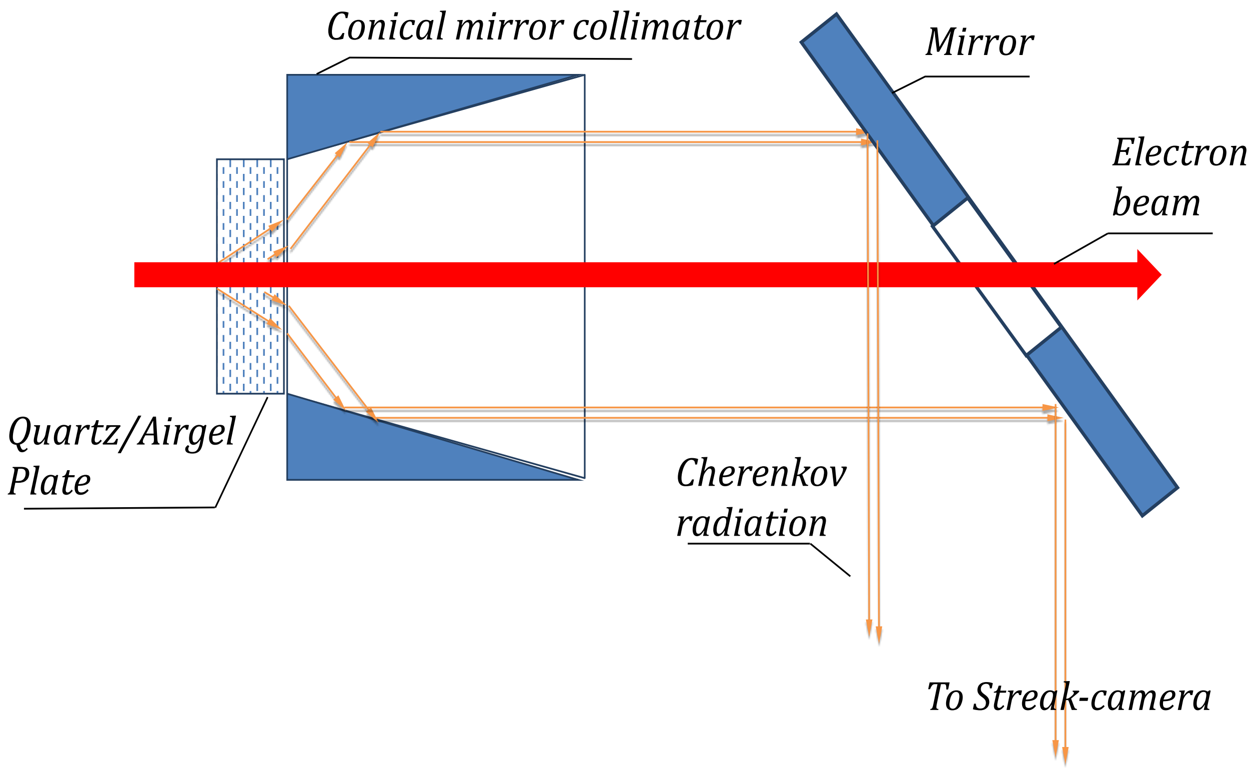


Figure 4. Layout of Cherenkov sensor for measuring longitudinal beam profiler.

$$cos\theta_C = \frac{1}{n\beta}$$

$$\frac{dN}{dx} = \int_{\lambda_1}^{\lambda_2} d\lambda \frac{d^2N}{dxd\lambda} = 490z^2\alpha sin^2\theta$$

$$\Delta t = \frac{ndsin\theta}{c} = \frac{d}{c}\sqrt{n^2 - \frac{1}{\beta^2}}$$

# FLUKA Simulation

- Aerogel (n=1.05)
- Quartz (n=1.46)

**For 0.6 MeV:**

- ➢ Quartz could be used as radiator.
- ➢ The thickness of quartz plate needs to be limited to the millimeter level.
- ➢ Optimal thickness of the quartz plate does not exceed 0.4-0.5 mm.
- ➢ The reduction rate of optical system should be 5 times or greater.
- ➢ Temporal resolution is about **3 ps**.

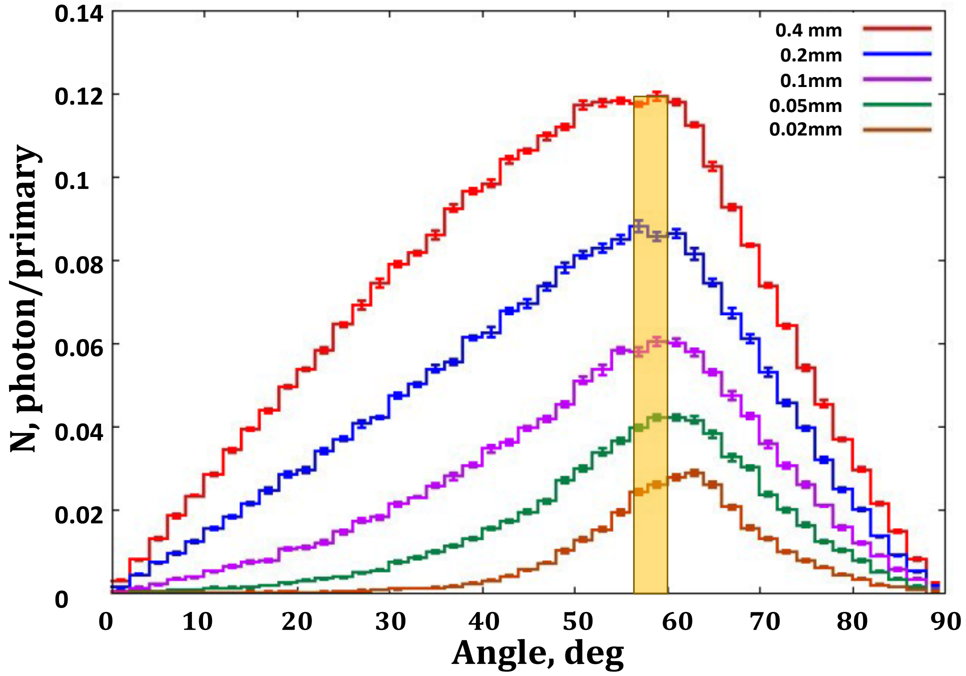


Figure 5. Cherenkov radiation angular distribution of 0.6MeV electrons beam through different quartz plate thicknesses.

**For 3 MeV and 50 MeV:**

- ➢ Aerogel could be used as radiator.
- ➢ The divergence angle of Cherenkov radiation is greatly decreased in comparison with 0.6 MeV.
- ➢ About 90% of the total emitted photons was included in the range ±1.5° of the peak.
- ➢ Temporal resolution is about **2 - 3 ps**.

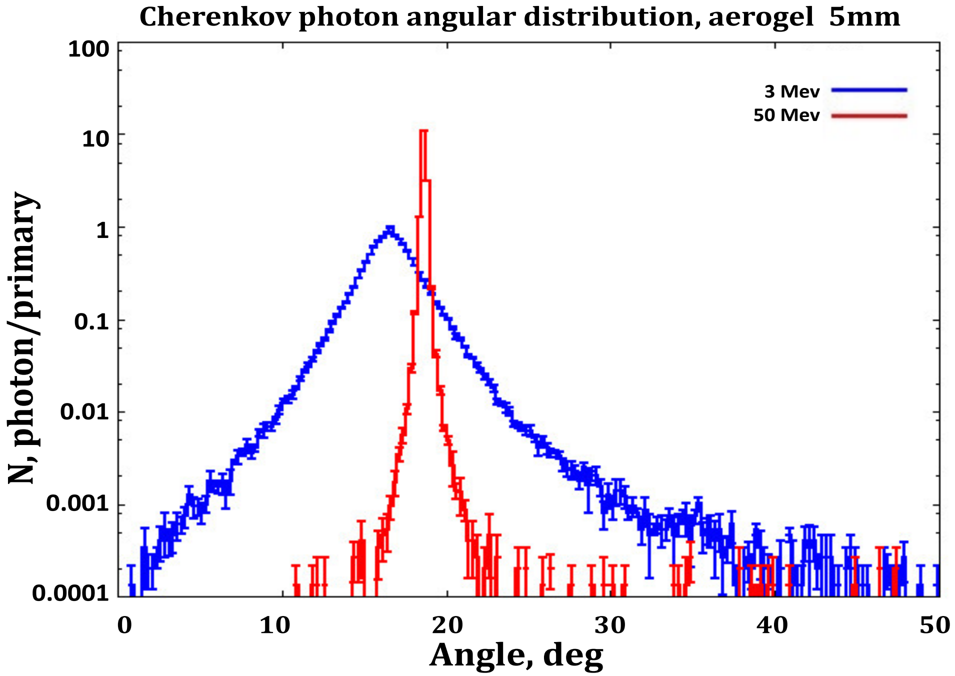


Figure 6. The angular distributions of Cherenkov photons emitted by 3 MeV and 50 MeV electron beam passing through 5mm aerogel.

## Spectrometer

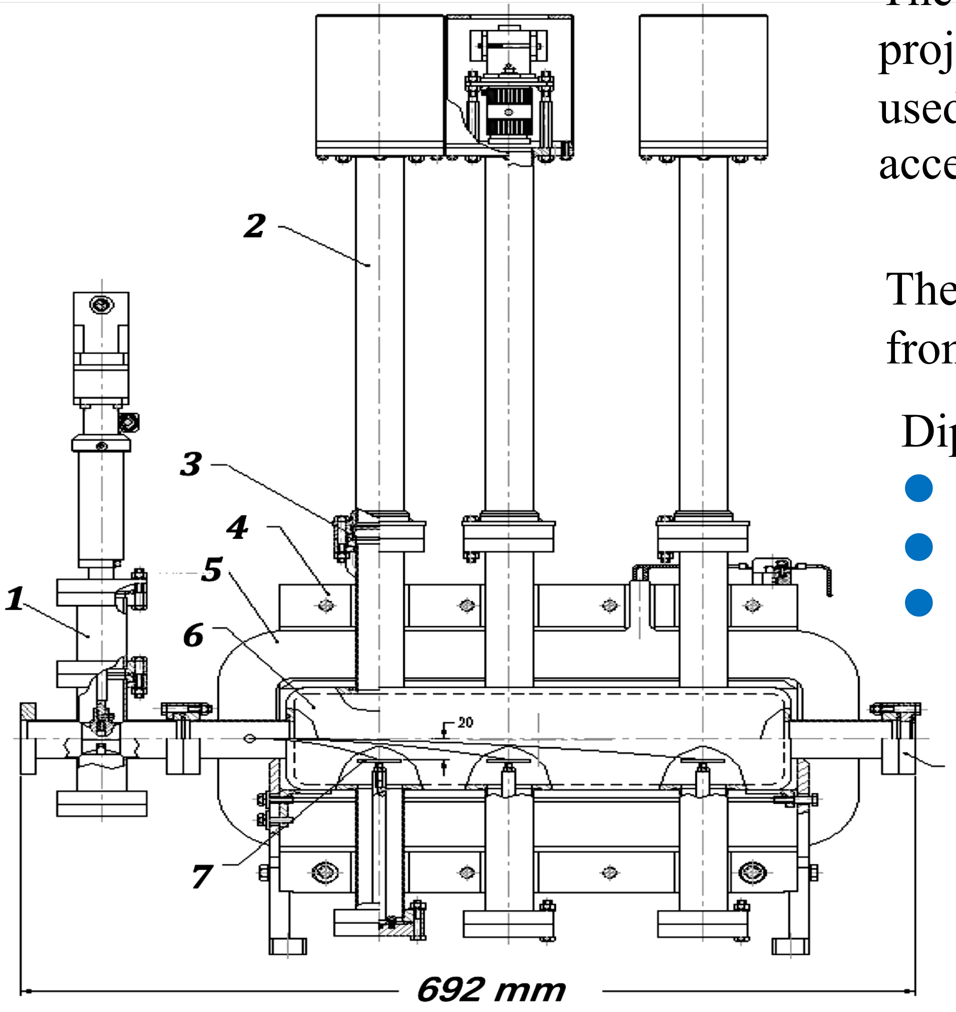


Figure 7. Layout of spectrometer: 1 - collimator with electric I/O, 2 - digital camera assembly, 3 -vacuum window, 4 - magnetic core, 5 - coils, 6 - vacuum chamber, 7 – fluorescent screen, 8 – titanium outlet window.

The spectrometer consisting of a dipole magnet, fluorescent screens, projection optics and CMOS digital cameras. The device will be used to measure the energy and energy spread of beam along linear accelerator (from 0.6 MeV to 200 MeV).

The positions of fluorescent screens are 100mm, 200mm, and 350mm from the magnet entrance.

Dipole magnet:

- Dimensions: 330×180×450 *mm*
- Good field area has a cross-section of 50 (*x*) x 30mm (*y*)
- Total current: 2kA (for a field of 1.31 kGs)

Table 2: Calculated parameters of the fluorescent screens of the magnetic spectrometer (ASTRA)

| Fluorescent screen: Position; Energy; | $E_{min}$, MeV | $E_{max}$, MeV | B, Gs | dE/dx, keV/mm |
|---|---|---|---|---|
| L = 100 mm $E_k$ = 0.6 MeV | 0.40 | 0.83 | 77.86 | 17.24 |
| L =200 mm $E_k$ = 6 MeV | 5.22 | 6.83 | 129.45 | 64.47 |
| L = 350 mm $E_k$ = 50 MeV | 45.91 | 53.67 | 329.73 | 287.44 |
| L = 350 mm $E_k$ = 200 MeV | 183.5 | 214.2 | 1307 | 1228 |

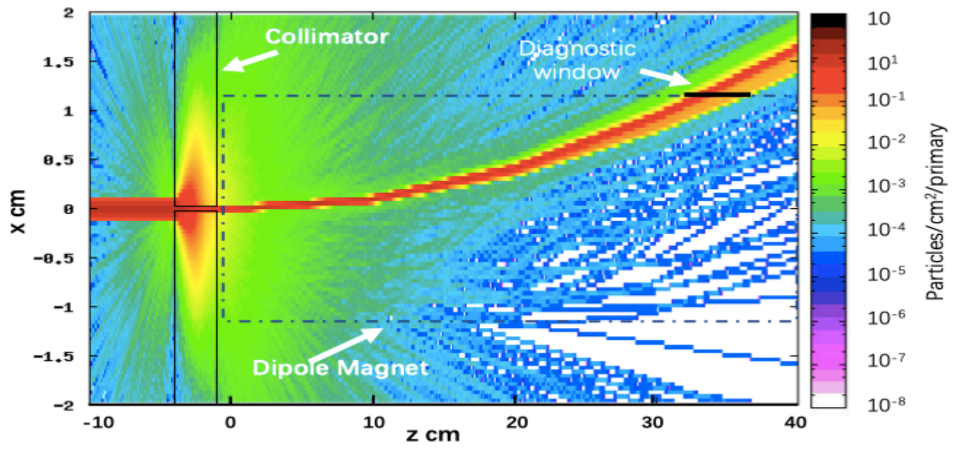


Figure 8. Typical beam trajectory simulation.

# FLUKA Simulation

The FLUKA simulation results are consistent with the ASTRA calculation results.

The spectrometer measure energy and energy spread of the beam with **1 -3%** accuracy in a wide energy range **from 0.6 MeV up to 200 MeV**.

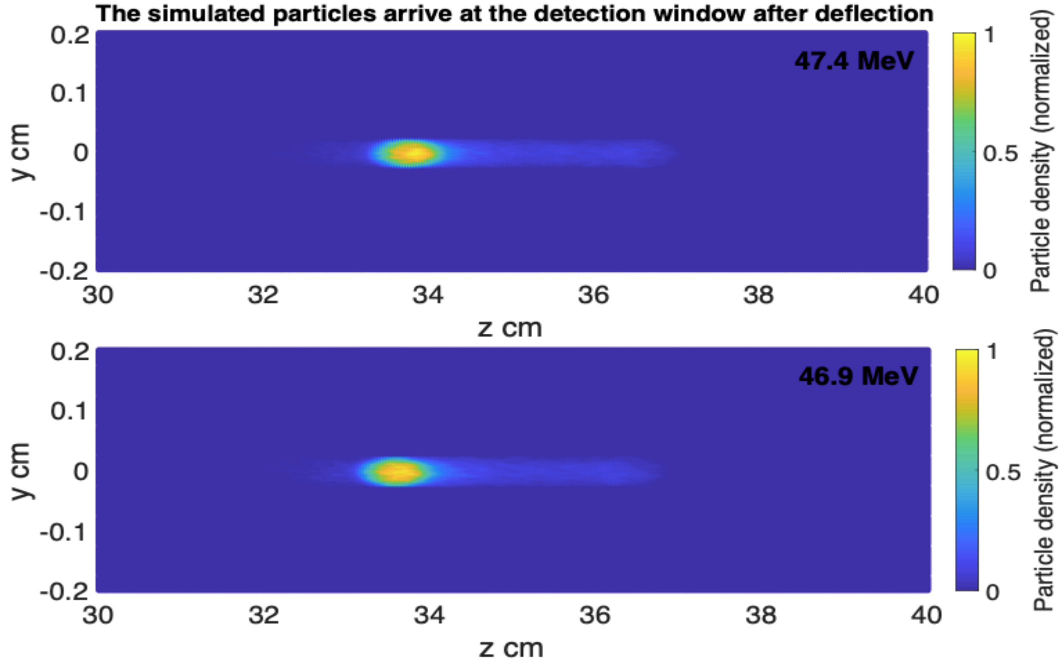


Figure 9. The simulated longitudinal profile of the beam.

**47.4 MeV**

**46.9 MeV**

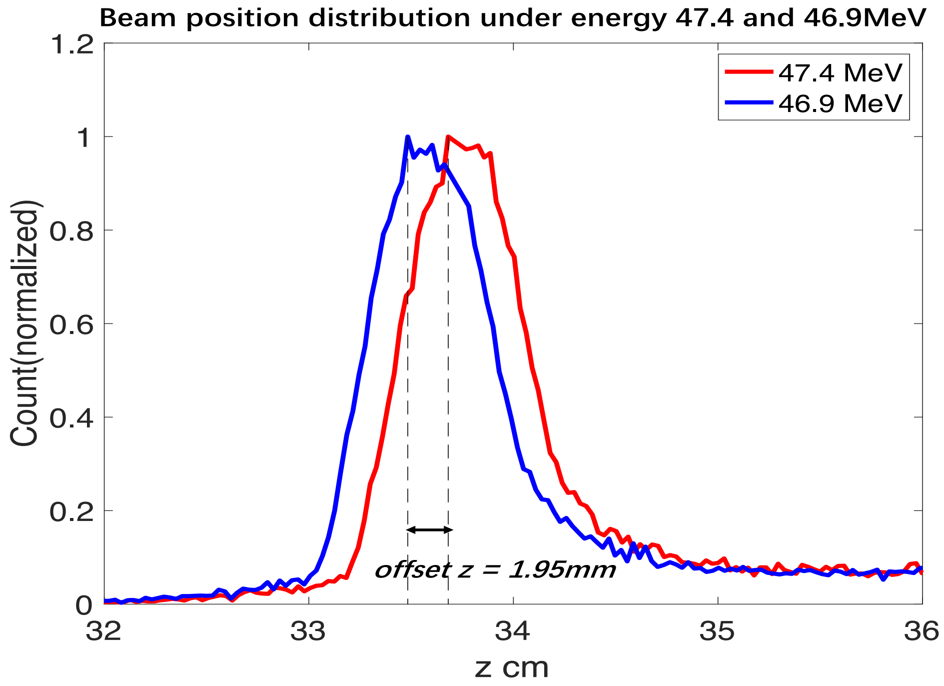


Figure 10. Comparison of the simulated longitudinal distribution of beams of 47.4 MeV and 46.9 MeV.

# Beam charge measurements —Faraday cup

The Faraday cup is applied for measurement of beam charge and use lead as absorbing material.
It could measure 200 MeV, **0-3.1nC beam with 5% accuracy**.

Simulation at 200MeV beam energy made with FLUKA. Copper and lead were compared as the material of absorber. Using lead as the absorbing material, the volume and weight of Faraday cup are 3.5 times and 2.765 times smaller than for copper absorber.

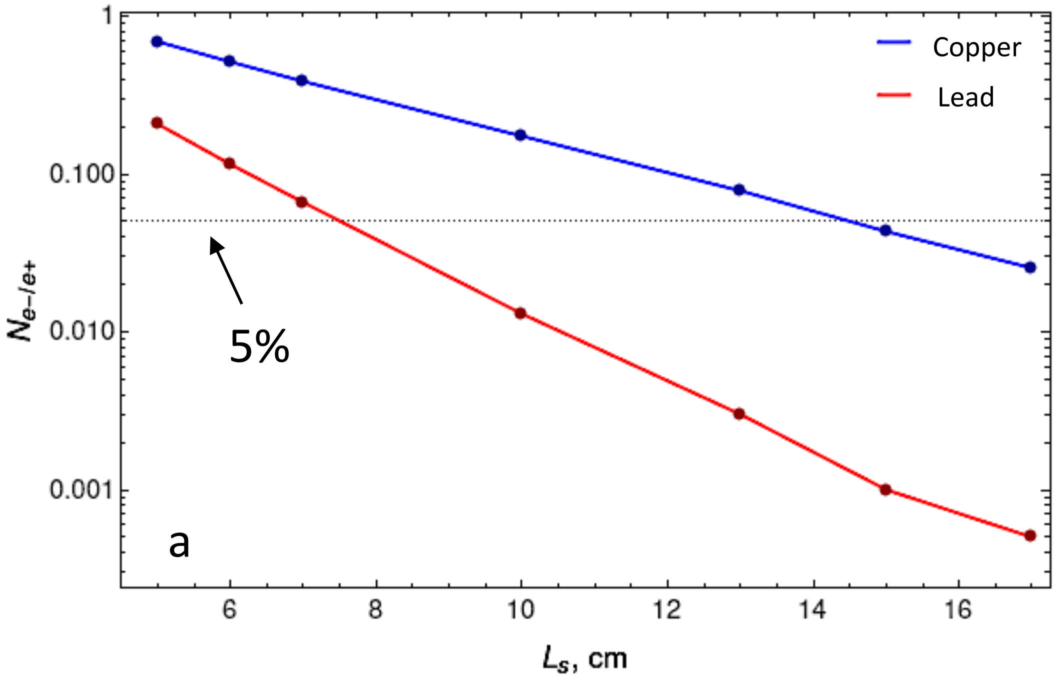


Figure 11. a) The ratio of primary and secondary electrons escaped from the exit of Faraday cup with different thickness (Radius is much larger than Moliere radius);

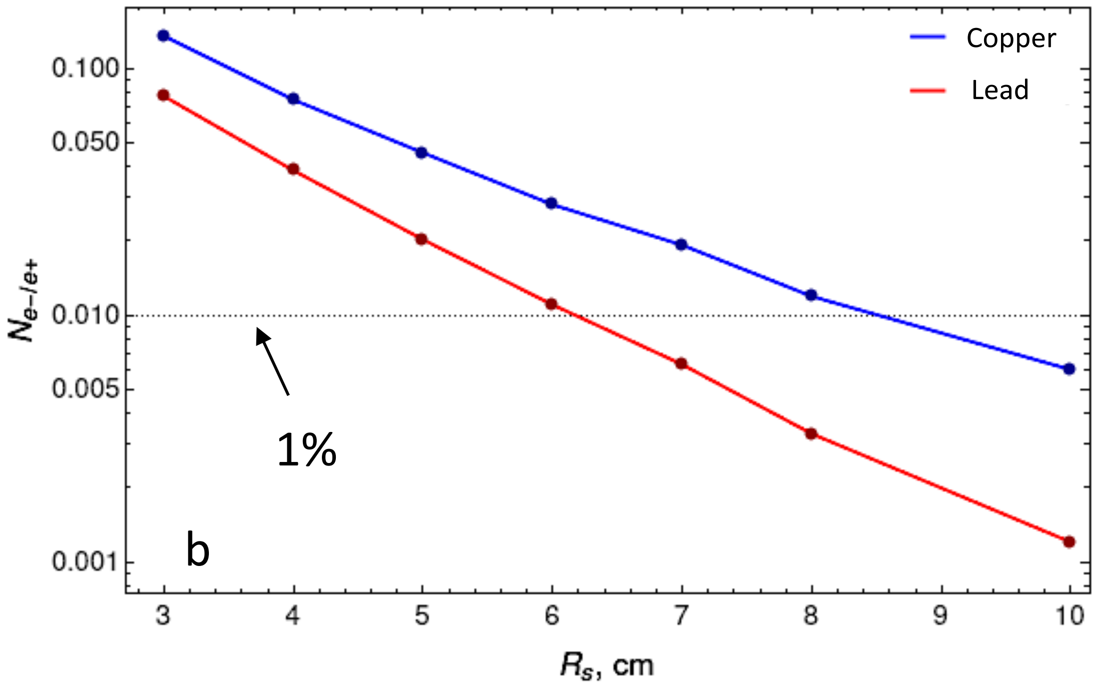


Figure 11. b) The number of primary and secondary electrons escaped from surface of Faraday cup with different radius (Thickness is much larger than shower length). $10^4$ particles were simulated

# Beam charge measurements —Fast Current Transformers (FCT)

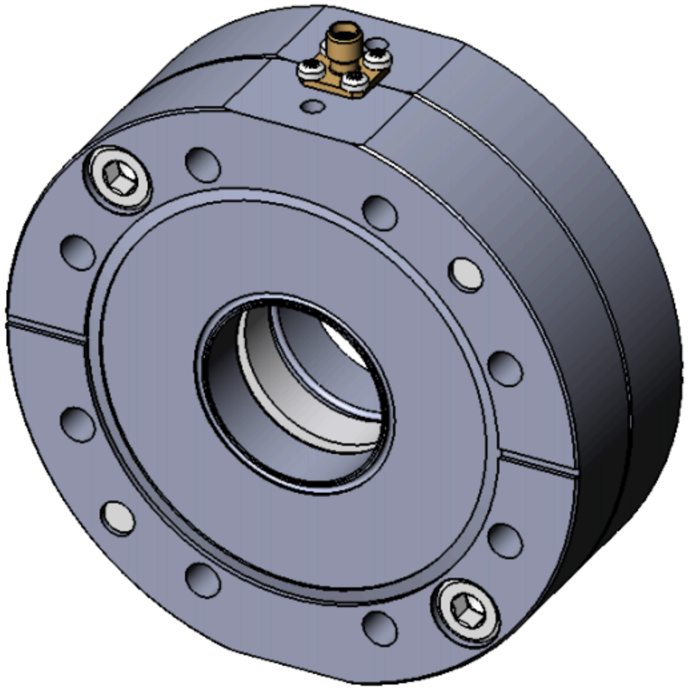

Figure 12. Bergoz® FCT-CF4“1/2-34.9-40-10:1-UHV.

Expected absolute accuracy of beam charge measurements is **~5%** for beam charge range 1-15 nC, expected related accuracy (or repeatability) of measurements **1-2 %**.

For beam charge measurements at different parts of Linear accelerator four FCT will be installed.

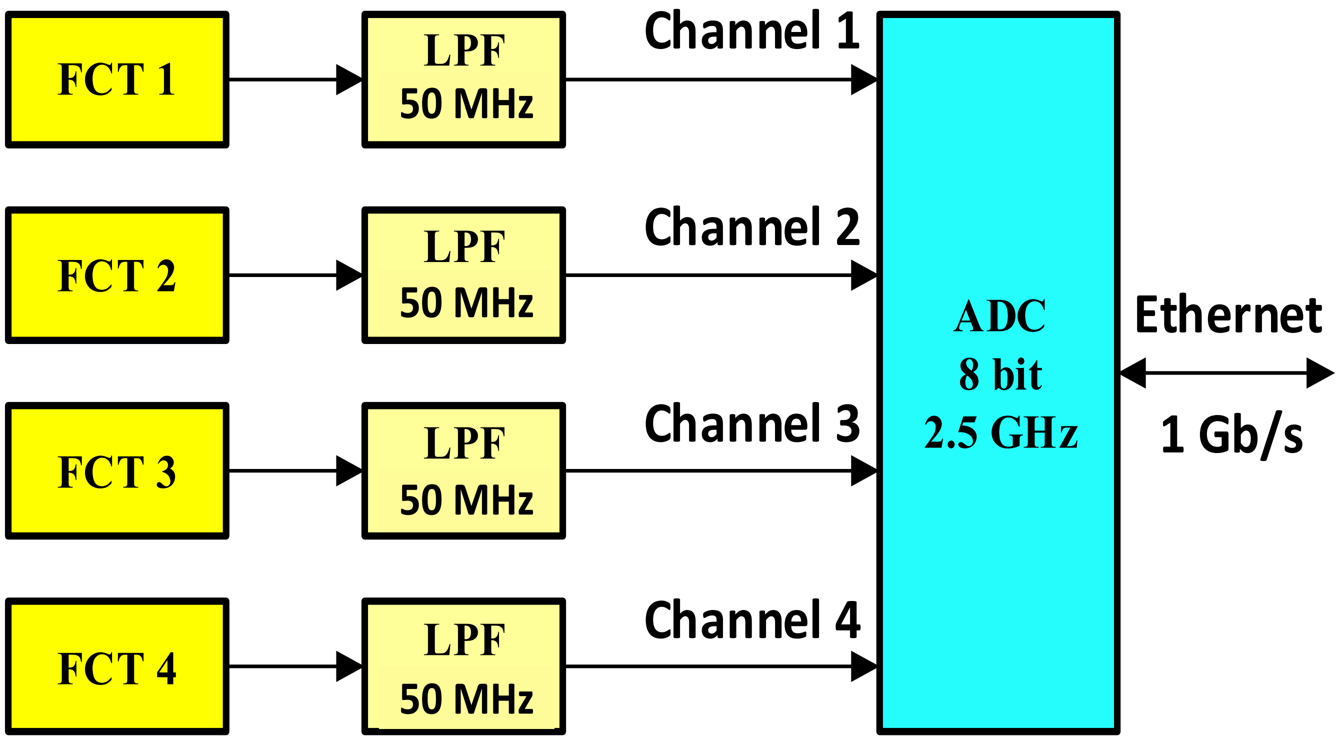


Figure 13. Block diagram of beam charge measurements.

## Beam Position Monitor

The BPM system allows measuring the beam trajectory after each beam "shot" with **accuracy of 10-20 µm**.

Stripline type BPMs will be used in the linear accelerator of SKIF (Fig.14).

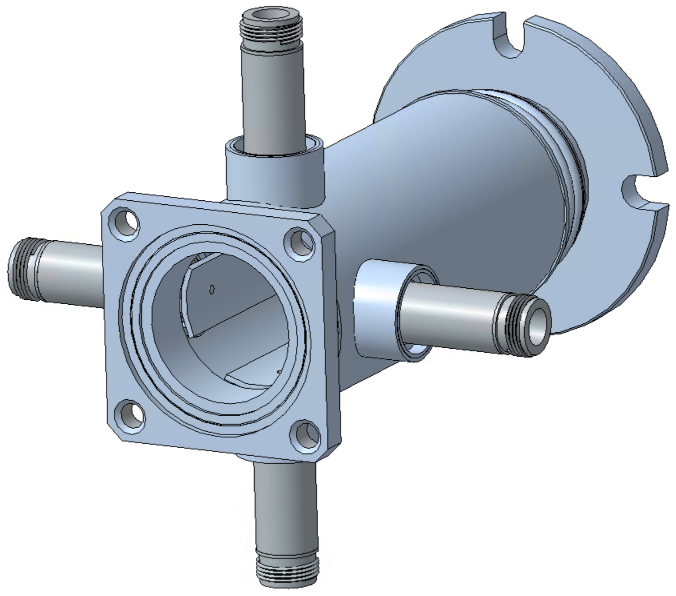

Figure. 14. Stripline type BPM.

BPM consists of 4 short-circuited at one end striplines with 50-Ohm and 4 vacuum N-type welded connectors.

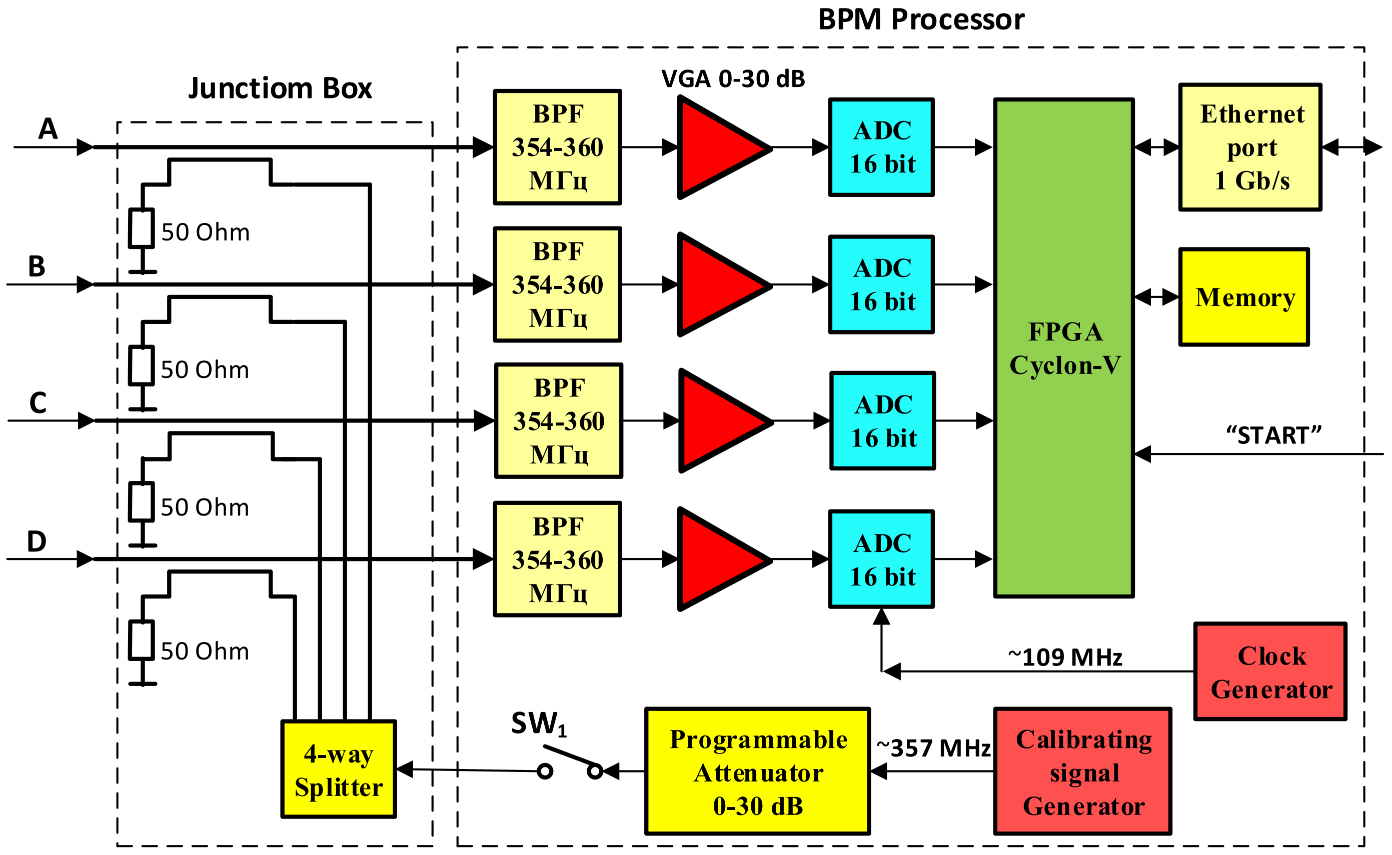


Figure. 15. A functional diagram of electronics for one BPM.

## Conclusion

The diagnostics complex of SKIF linac include fluorescent screens for meaasurements of the transverse dimensions, a Cherenkov sensors for measuring of longitudinal beam size, magnet spectrometer for measuring beam energy, Faraday cup and FCT for charge measurement, and BPM for measuring the position of the beam. The set of diagnostics which will applied on different satge of linac comissioning will depend on the expermental demants

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