High Power Wire Scanner Development at TRIUMF Laboratory

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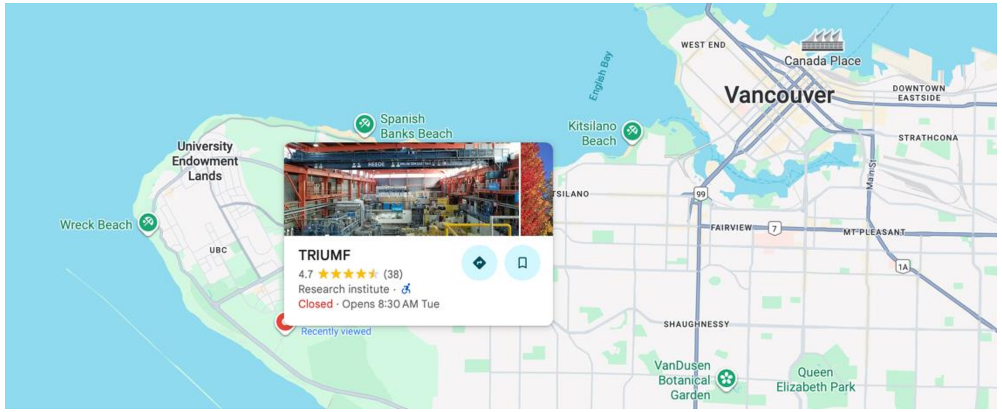
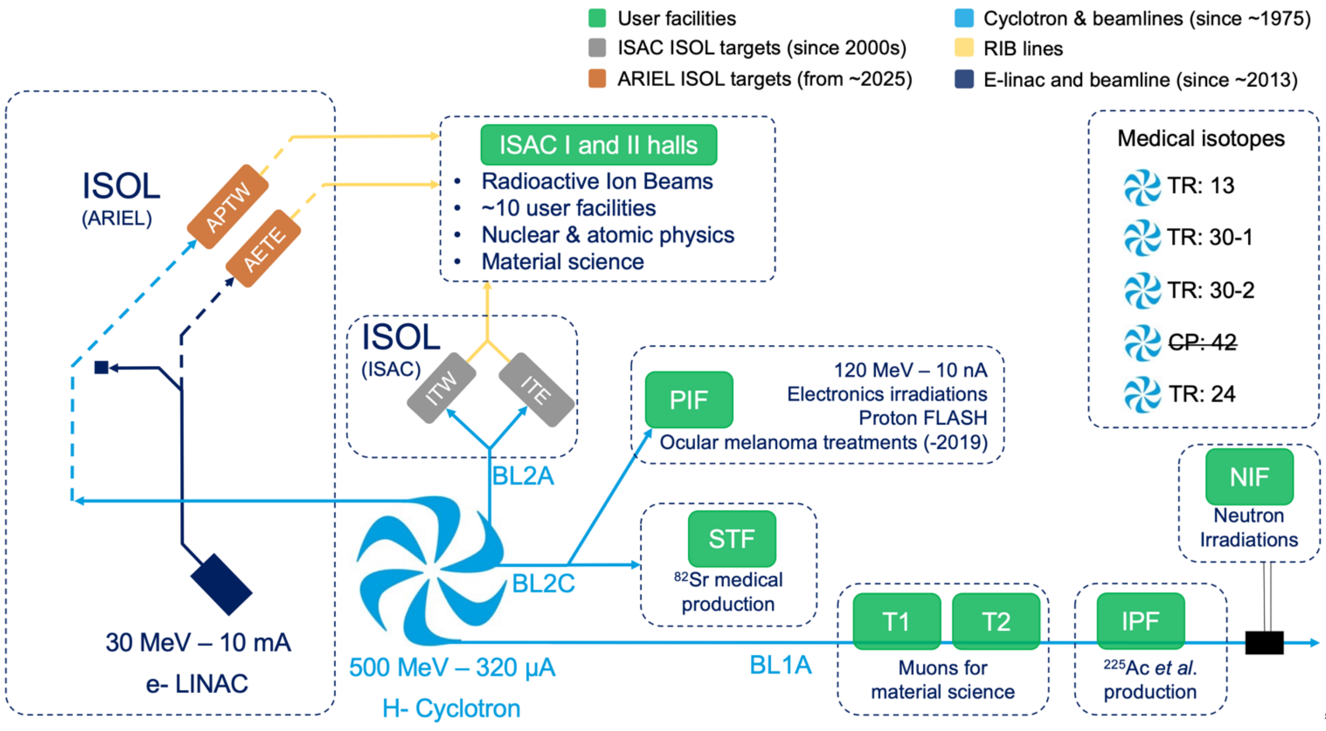
TRIUMF: Canada's Particle Accelerator



Overview
- Biggest particle accelerator laboratory in Canada.
- Founded in 1968 by a collaboration of universities.
- Centred on accelerator technology, detector development and isotope research.

Facilities
- Cyclotron
- Isotope accelerator
- Recoil mass spectrometer
- Gamma ray infrastructure

TRIUMF's Beam Properties



Overview of accelerator facilities in TRIUMF
(Update on TRIUMF, Nigel Smith, CINP-IPP Joint Session)

30 MeV Electron Beam

- To produce rale isotope beam by colliding it to ion source.
- Operate at a high current of 10 mA to generate an intense electron beam.
- Designed to reach 500 kW of beam power based on the superconducting RF.

500 MeV Proton Beam

- Proton beams for rare isotope production and other subatomic physics applications.
- Spirally accelerated H^- ion and stripped into proton by a thin carbon foil.
- Delivers an approximately 150 kW proton beam to several beam lines.

Concpet of a Wire Scanner

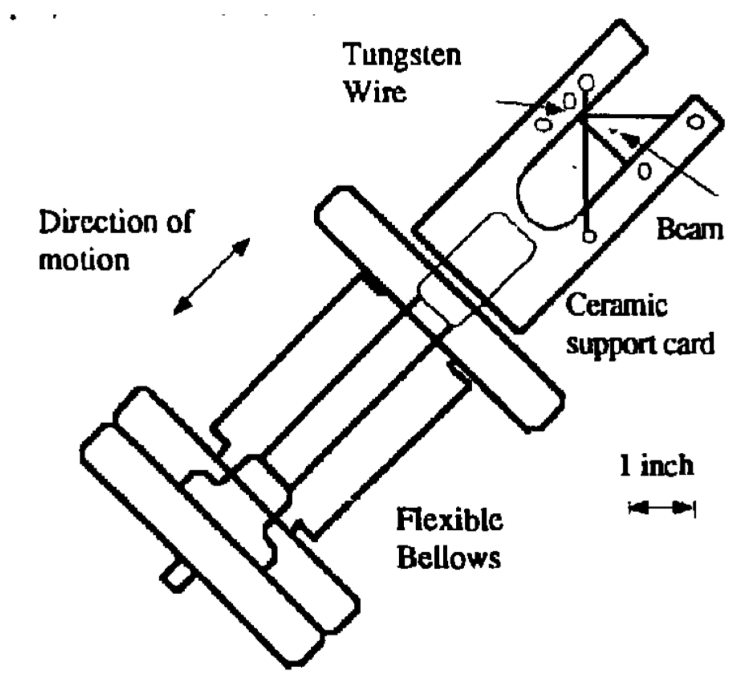


Figure 1: SLC wire scanner wire support card viewed in the beam direction. The translation stage and vacuum chamber are not shown.

Overview

- Thin solid wire sweeps the beam to measure the transverse beam size, position and intensity.
- Reconstruct the beam profile based on the wire position and signal readout.

Structure

- Wire: μm-scale diameter made of Carbon, Titanium, Tungsten.
- Fork: Support the wire in high tension inside the vacuum chamber.
- Bellow: Control the motion depending on the type of the beam.

Features

- Intuitive and low-cost buildability.
- Adjustable resolution by the wire diameter.

Drawbacks of a Wire Scanner

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Heat

Calculations show that when traveling at a speed of 3 m/s through a 10 mA and 50 MeV electron beam with a size of about 0.5 mm (FWHM) the temperature of a carbon wire, for example, can locally reach approximately $\boxed{2000^\circ\ \mathrm{C}\ \text{in just}\ 160\ \mu\mathrm{s}.}$

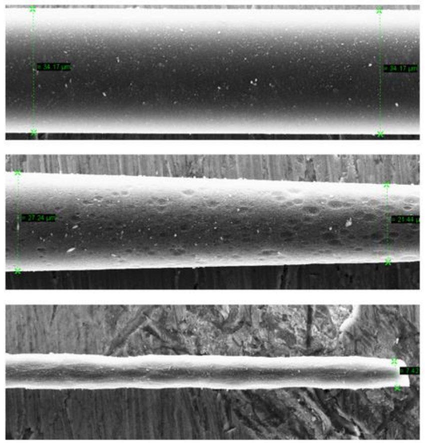

Figure 2: Fiber fracture at three distances from the beam impact location: 1 mm (upper plot), 0.5 mm (middle plot) and at beam center location (bottom plot). The presented wire has been installed in the vertical scanner.

Carbon Fiber Damage in Particle Beam
(M. Sapinski, et al, HB2010)

Vibration

- Wire vibration occurred at high scanning speed.

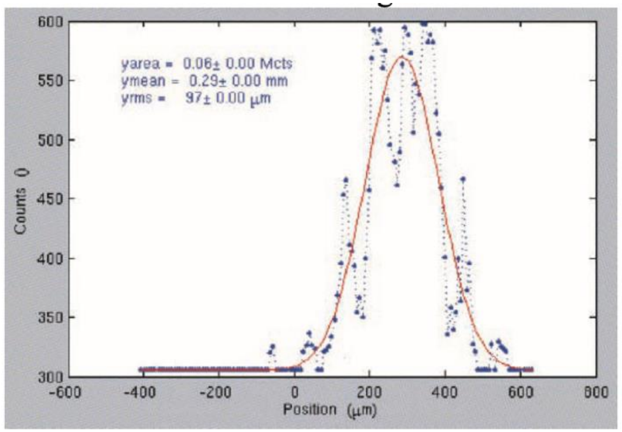

Figure 7. Wire scan at 135MeV

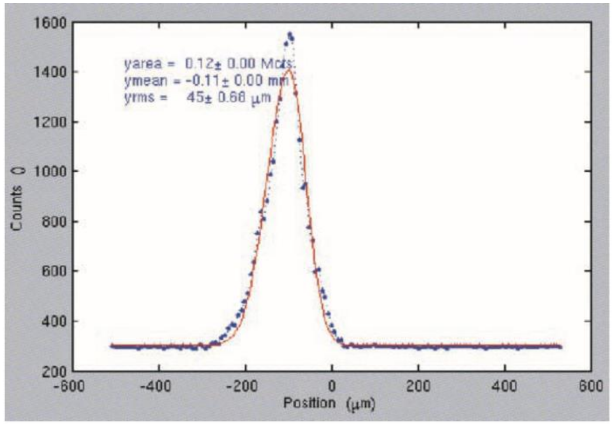

Figure 8. Wire scan at 135 MeV with 10X gear reducer added.

Beam Measurements at LCLS
(J. Frisch,et al, SLAC-PUB-15018, BIW08)

Fast Wire Scanner

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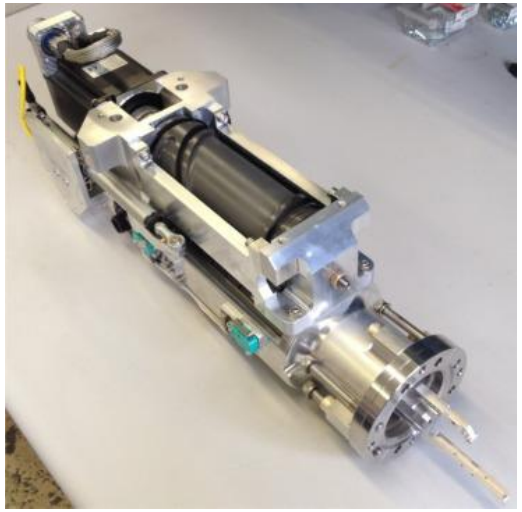
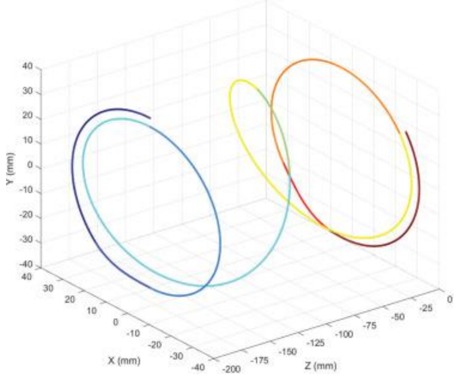
Objective
- To reduce the interaction time between the beam and the wire material.
- Wire can be damaged in 100 kW class electron beam.

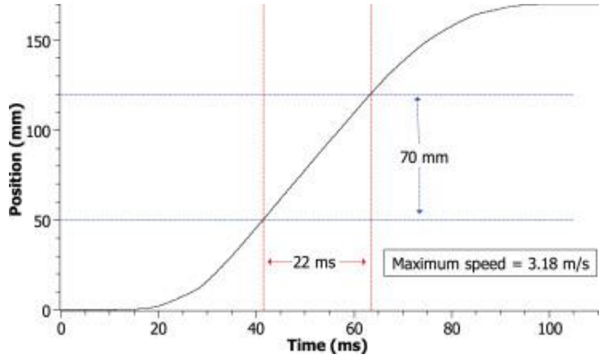
Motion
- Helical cam linearly moves the wire fork back and forth.
- Sinusoidal velocity to minimize a jerking motion.
- For a speed of 3 m/s in 70 mm range, maximum 3.25 m/s is required.



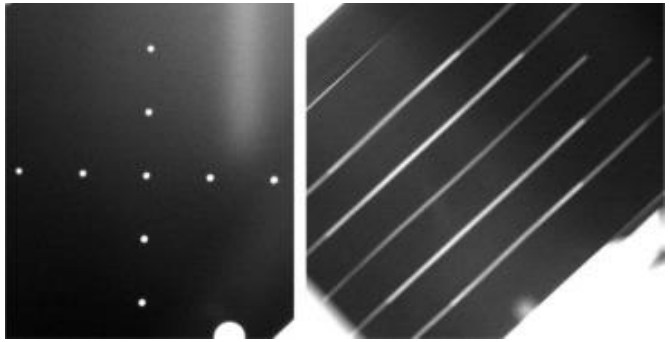
TRIUMF fast wire scanner assembly



3D cam motion curve



Fast wire scanner position versus time



a linear path and no visible non-linear deviations

Fast Wire Scanner

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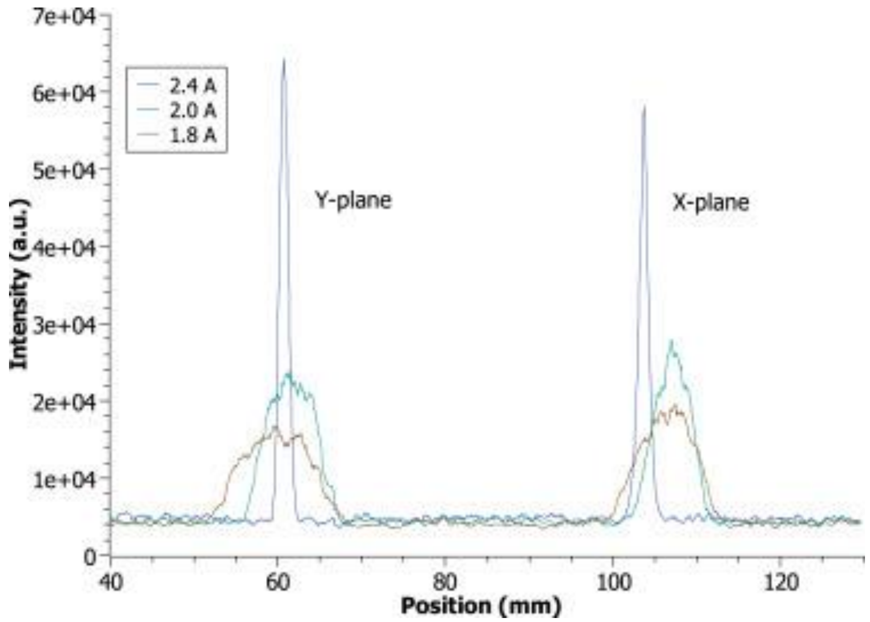
Test environment

- Beam: 300 KeV electron
- Wire scanner speed: slow mode (0.075 m/s)
- Change the beam focusing strength by the magnet current.



Scans of a 300 keV beam for several strengths of a focusing solenoid. The solenoid current was 2.4 A, 2.0 A and 1.8 A, respectively.

Measurement result

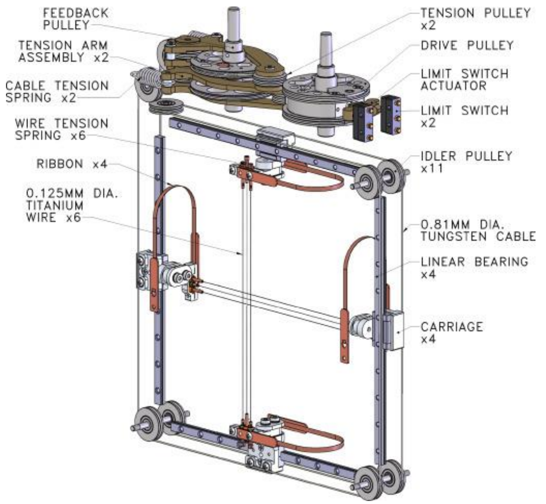
- Beam size is proportionally changed to 1/focusing current.
- As the beam focuses, the peak increases.

Reliability considerations

- The reliability under high beam power will be limited by the structural failures of scanning wires due to thermal stress.
- Data provided by manufacturers relate to “normal’’ operating conditions.

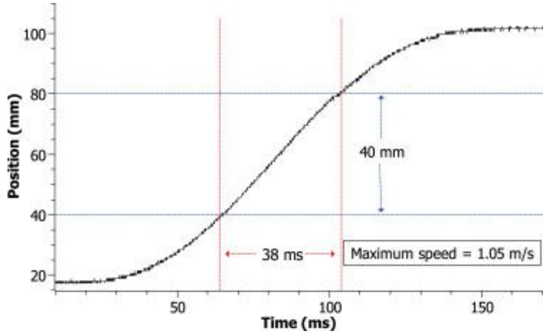
Wide Dynamic Range Wire Scanner

Objective
- To cover the proton beam current of 1 nA - 100 μA.
- To actively adjusts the scanning speed based on beam energy.

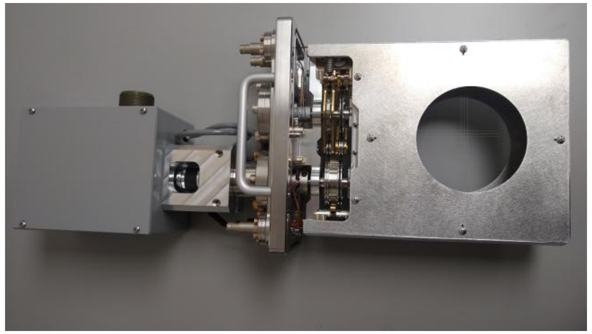


Cable drive mechanism

Measurement
- Rotary motion is converted to linear one connected by a wire.
- Each axis consists of three wires, and electrons radiated from the center are processed in the form of current signal in the wires at both ends.
- Monitor the beam position by time-integrating current value.



Wire scanner position versus time



Proton wire scanner assembly

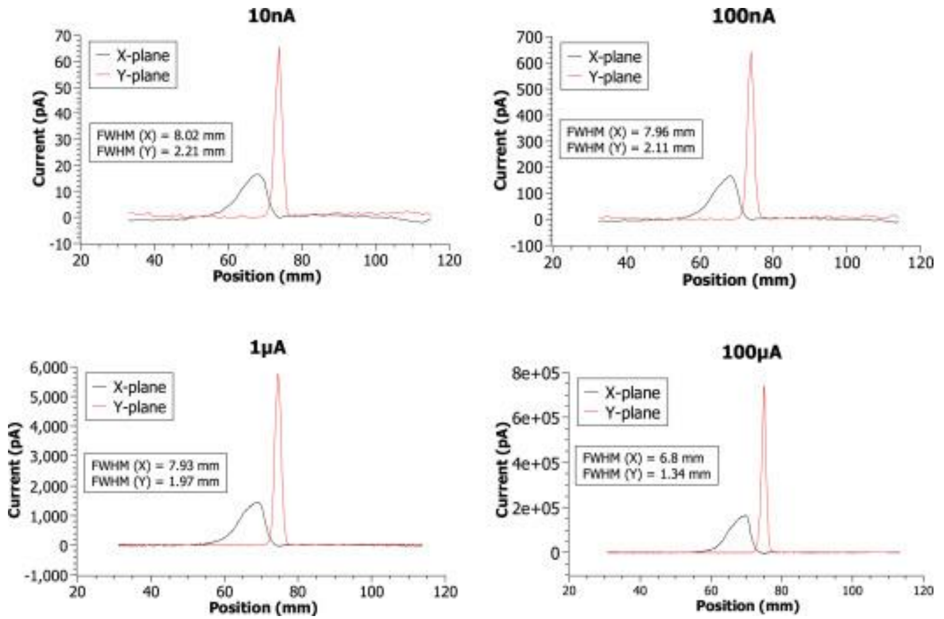
Wide Dynamic Range Wire Scanner

Test environment

- Beam: 500 MeV proton → 1 nA - 100 μA
- Wire scanner speed: 5 mm/s - 180 mm/s
- Signal integration time: 200 ms - 0.444 ms

Measurement result

- Beam size and position are consistent in all the currents.
- As the current becomes high, the peak increases.



Measured beam profiles at several beam currents of 10 nA, 100 nA, 1 μA and 100 μA.

Dynamic range

- A substantial number of beam measurements were performed with wire scanners in a wide range of beam intensities from 1 nA to 100 μA.
- High measurement versatility by adjusting the DAQ time and scanning speed.

Conclusion and Summary

Wire scanner for beam profile monitors
- Scan the charged beams measuring the beam position, size, and intensity.
- Requires precise structure and minimum assembly tolerance.
- Sensitive to wire damages and Signal-to-Noise Ratio.

Significance
- Measure the profile of high-power electron beam.
- Cover the wide range of proton beam current.
- Newly developed mechanical design is reliable.

Future research
- Carbon wire instead of Titanium.
- High speed scanning for high energy electron beam.

Thank You

QnA

Appendix

빔에 따른 Wire 종류 차이

- 전자빔은 충돌 radiation 커서 하나의 wire로 충분 (전자 속력: 0.99c)
- 양성자는 secondary electron emission 작아서 세 개의 wire로 signal 처리 (양성자 속력: 0.75c)
- 여러 wire 사이에 전압을 걸어서 방출 전자를 수집하여 current signal로 변환
- 전자빔은 신호가 강하지만 발열 문제, 양성자는 약하지만 넓은 동적 범위 요구

물리량	단위	의미	논문에서의 예
빔 에너지	MeV	입자 1개가 가진 에너지	Electron beam: 300 keV → 50–500 MeVProton beam: 500 MeV
빔 전류	nA, μA, mA	입자 흐름량(초당 입자 수)	Proton beam: 10 nA ~ 100 μAElectron beam: up to 10 mA
빔 파워	kW	에너지 × 전류	500 MeV × 1 mA = 500 kW (E-linac)
솔레노이드 전류	A	focusing strength을 결정	Fig. 7: 1.8 A, 2.0 A, 2.4 A
Bias voltage	V	SEE 전자 수집 전압	100–300 V

Appendix

구분	Electron beam	Proton beam
질량	매우 작음, 자기장에 매우 민감	매우 큼
Wire 충돌 시 신호	고에너지 radiation → 강력한 신호	SEE 전자만 발생 → 매우 약한 신호
기본 검출 원리	Photon detection (scintillator)	Current measurement (SEE electron current)
Wire damage 위험	매우 큼 (고전력에서 wire instantly vaporized)	상대적으로 더 낮음
beam current typical	mA range	nA–μA range
빔의 상호작용 범위	전자기적 영향 강함	주로 핵반응·Coulomb scattering
진단 난이도	신호가 매우 강해 검출은 쉽지만 heating 발생	신호가 약해 검출이 어려움

- Recoil mass spectrometer: 입자 충돌 실험에서 나오는 생성물 분리하고 비전하 측정
- Subatomic physics: 표준 모형, 검출기, 렙톤 붕괴 같은 핵실험
- 빔 전류 조절: source에서 통제, collimator(halo 제거), beam 일부를 dump