IONIZATION PROFILE MONITORS FOR THE IOTA PROTON BEAM*

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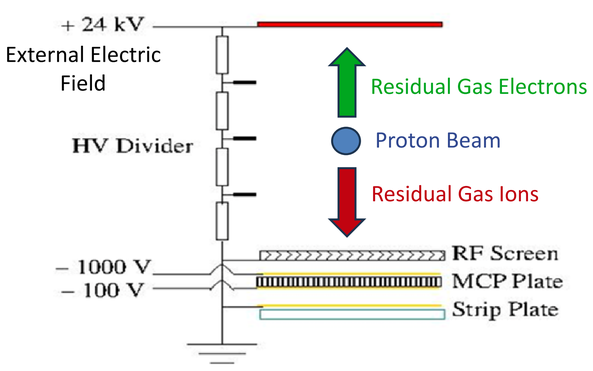
Abstract
Ionization profile monitors (IPMs) are widely used in accelerators for non-destructive and fast diagnostics of high energy particle beams. Two such monitors - one vertical and one horizontal - are being developed for installation in the IOTA storage ring at Fermilab. They will be used for turn-by-turn (microseconds scale) measurements of the 70 MeV/c IOTA proton beam sizes. In this paper we present the IPMs design (largely following the FNAL Booster IPMs which employ no external guiding magnetic fields), their mechanical, vacuum, and electric subsystems and DAQ, and discuss anticipated effects on the beams circulating in IOTA.

Introduction

- Integrable Optics Test Accelerator (IOTA) at Fermilab is a 40-m circumference R&D ring
- Can operate with 100-150 MeV/c electrons and 70 MeV/c protons
- Limited options for measuring proton beam profiles in rings
- IPMs are the primary option
- Residual gas molecules are ionized by the beam and the ions are collected to construct a profile



Response Function

- Space charge forces of the primary beam transversely push the liberated ions altering the measured profile
- Can use a magnet if collecting electrons but not ions
- Effect can be corrected
  - *V. Shiltsev, "Space-charge effects in ionization beam profile monitors", Nucl.Instr.Meth. A, vol. 986, p. 164744, 2021. doi:10.1016/j.nima.2020.164744*

Space-charge potential — Distance from beam to detector

$$\sigma_m = \sigma_0 \cdot h \approx \sigma_0 \cdot \left[1 + \frac{2U_{SC}}{E_{\text{ext}}\sigma_0}\left(\frac{\Gamma(\frac{1}{4})}{3}\sqrt{\frac{d}{\sigma_0}} - \frac{\sqrt{\pi}}{2}\right)\right]$$

External electric field — Beam size

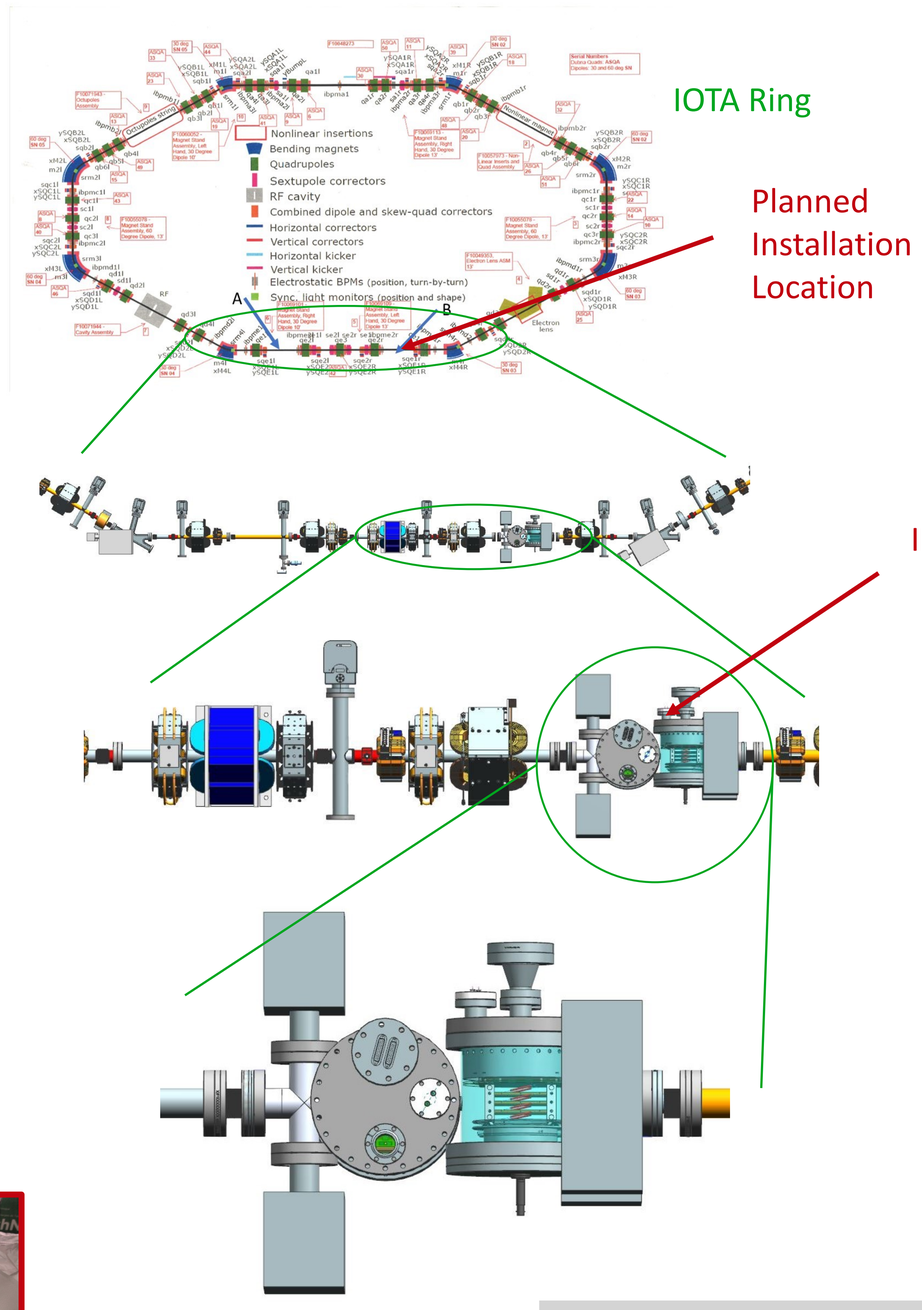
- Using the IOTA beam parameters from above, the expected value of $h - 1$ is between 0.01 and 0.1

Sufficiently small to avoid magnets

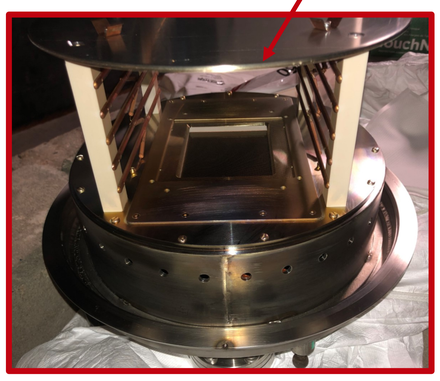
IOTA Beam and IPM Parameters

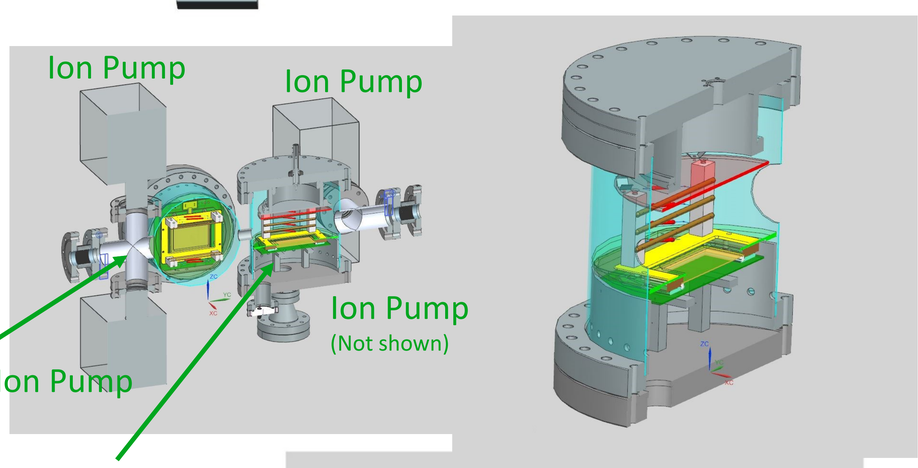
Parameter	Units	Design	Range
IOTA beam			
Proton pc	MeV	68.5	
Number of bunches		4	1-4
Rev. period T_r	μs	1.83	
RF frequency f_{RF}	MHz	2.19	
Avg. current I_b	mA	2	0.5-8
Tr. emitt. geom. $\varepsilon_{x,y}$	μm rms	3	1-4
Rms size at IPM $\sigma_{x,y}$	mm	2.5	1-5
SC potential U_{SC}	V	0.9	0.2-3.5
Mom.spread $\Delta p/p$	rms	$2{\cdot}10^{-3}$	$(1\text{-}2){\cdot}10^{-3}$
Rms bunch length σ_l	m	1.7	1-2
SC tuneshift $-\Delta Q_{SC}$	0.5	0.05-1	
Avg. vacuum P_{IOTA}	Torr	$6{\cdot}10^{-10}$	$10^{-10\ldots-8}$
Nucl. lifetime τ_{vac}	s	300	$20\text{-}10^3$
SC lifetime τ_{SC}	s	<1	10^{-3}-2
IOTA IPMs			
Number of IPMs		2	
Total length	m	0.808	
Min aperture	mm	30	
HV gap D	mm	60	
HV cage length	mm	100	
Strips/IPM		60	
Strip alignment	mrad	±1	
Pitch Δ	mm	0.5	
IPM Voltage V_0	kV	16	4-30
Vacuum P_{IPM}	Torr	$6{\cdot}10^{-9}$	$10^{-9\ldots-7}$
Eff.vac.length	m	0.48	
Integr. time	turns	1	1-10
Ions/turn	10^3	1.8	0.3-30
SC expansion $h - 1$		0.03	0.01-0.1

IPM Installation Location



IOTA IPM based on Booster IPM

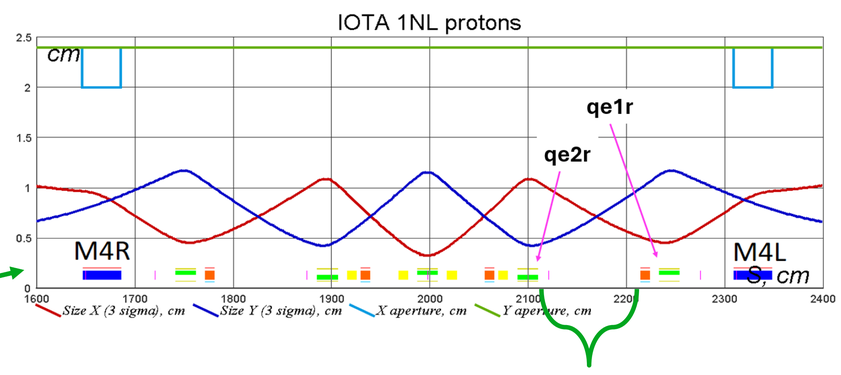




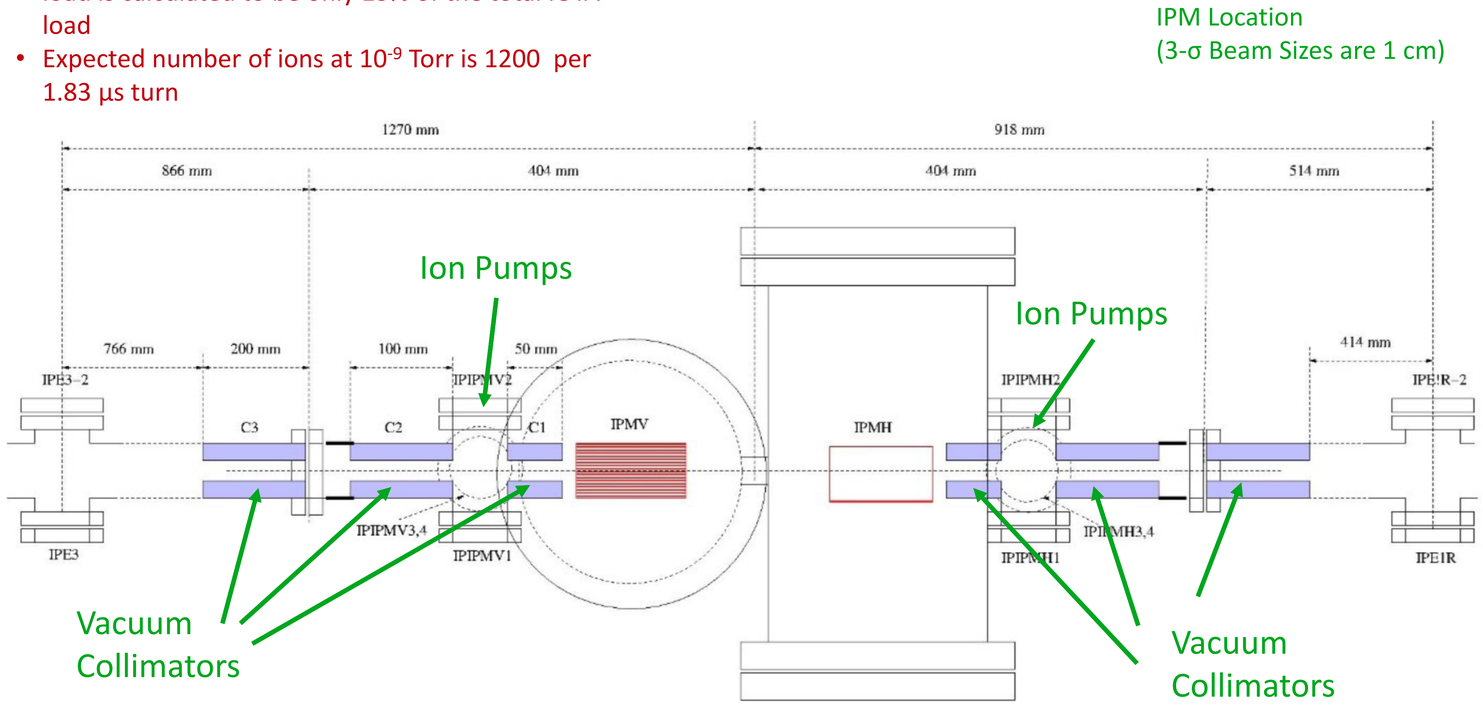
IPM Vacuum

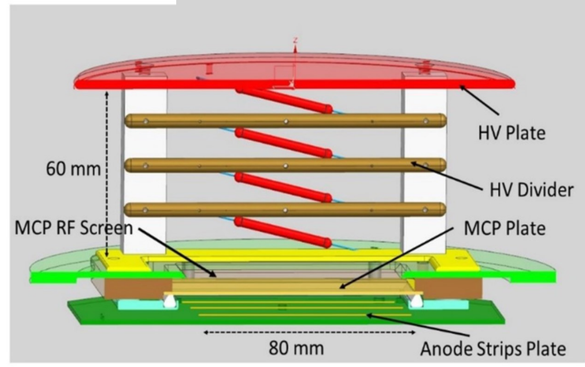
- IOTA beam pipe vacuum pressure can be as low as 10^{-10} Torr
- To obtain a useable signal, the pressure inside the IPM should be 10^{-9}
  - ***Need to have gas leak***
- Plan to install 4 ion pumps (2 on either side of IPMs) plus vacuum collimators to reduce flow rate to the rest of IOTA ring
- The collimator diameter was chosen to be 30 mm based on expected beam size at that location
- With the collimators and ion pumps, the vacuum load is calculated to be only 13% of the total IOTA load
- Expected number of ions at 10^{-9} Torr is 1200 per 1.83 µs turn

IOTA 3-σ Beam Sizes at IPM



IPM Location
(3-σ Beam Sizes are 1 cm)

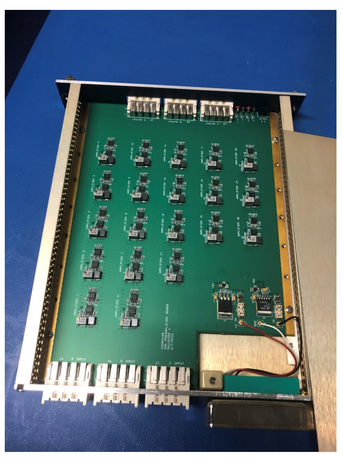




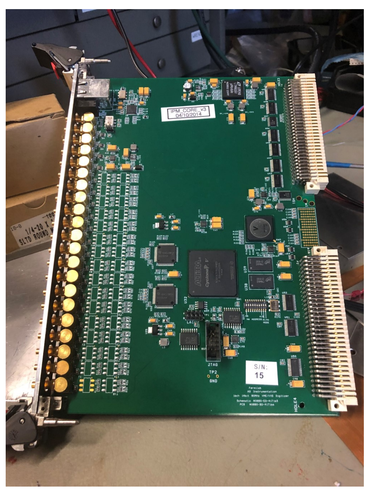
Data Acquisition

- Within the IPM, the ions are amplified by a microchannel plate (MCP; maximum gain of ~1000) before arriving at the anode strips
- From the anode strips, the current signals will be converted with a gain of 0.5 V/µA and a bandwidth of 1 MHz
- The amplified signal is sent out of the enclosure to be digitized

20-channel amplifier (used in Booster IPM)



32-channel digitizer (used in Booster IPM)



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