PYRAMID
Technical Consultants, Inc.

Pyramid Technical Consultants was founded in 1986 and is an established supplier of instrument control systems for the medical, semiconductor, physics and biological research markets. The systems typically involve specialized electronic hardware, embedded real-time software, and host system software drivers and applications. We have particular expertise in ion chamber development and low-current measurement which is central to PBS dosimetry.

Pyramid has been active in particle therapy since 2006 and is now known as a leading supplier of pencil beam scanning equipment and software. We work closely with our customers to provide solutions ranging from individual components up to complete integrated nozzle systems, using field-proven products and innovative new technologies. Pencil beam scanning offers exciting opportunities to treat conditions that may be difficult or impossible to handle by other methods, with the promise of improved patient outcomes. Let Pyramid work with you to create a pencil beam scanning solution that is cost-effective, on-time and brings benefits to your product, your hospital, your practitioners and most of all,
to your patients.

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Pyramid Products and Services

A rapid start to your new system development, advanced technology for your system upgrade

The process of developing or enhancing a particle therapy system requires a wide range of sophisticated technologies. Many of the required hardware components are available from Pyramid, either as standard parts or as customized products. Pyramid hardware and support software is designed to work together to simplify the creation of streamlined systems without a substantial investment in research and development by the system developer.

Hardware

Fully engineered and custom products from Pyramid include:

- Complete dose delivery nozzles with high performance scan systems and redundant dose monitoring. A flexible platform that can be highly customized to suit different accelerators.
- Beamline controls and diagnostics including beam position monitors, magnet power supply controllers, Hall probe systems and general controls.
- Commissioning and Q/A instrumentation specifically focused on pencil beam scanning.
- Dosimetry safety and interlock components

Software

All the way from embedded real-time code that controls and monitors dose delivery to software that interfaces to session management, treatment planning and parameter verification, using the latest DICOM, IHE-RO and UPS standards. Don't let software delays disrupt your project. Let Pyramid streamline the process.

- The Pyramid Scan/Dose platform provides a flexible, customizable platform to control all aspects of real time beam delivery, scanning, dosimetry, and interface to associated systems.
- The Pyramid Scan/Dose Diagnostic host software provides direct control and testing capability during development, and can be a key part of final engineering control and monitoring.
- The Pyramid Nozzle Simulator provides a comprehensive simulation and analysis capability, essential for rapid development, fault finding and verification

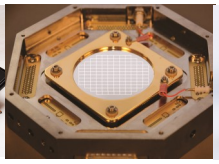
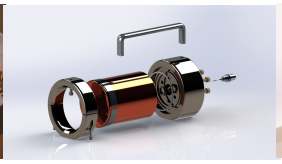
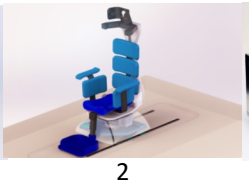
Documentation

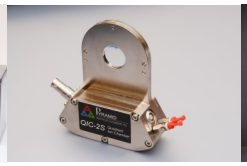
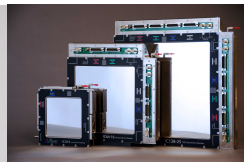
Pyramid is accredited for ISO-13485 and ISO-9001. We are familiar with IEC 60601-2-64 and can provide full documentation for existing and new products including manuals, failure-mode analysis, and training modules.

Consulting

Pyramid has years of experience in bringing full systems to completion, and can bring our experience to bear on new facility designs as well as system upgrades. We can help with:

- Dose delivery systems
- Transitioning to Pencil Beam Scanning
- Products and design services for ionization chambers, electromagnets and patient positioners

Scan/Dose Software

A comprehensive solution for beam delivery and dose control, drastically reducing time-to-market.

Scan-Dose software is a reconfigurable product platform designed to integrate the specific nozzle embodiment with the overall Particle Therapy system. The software product incorporates the different delivery techniques, such as PBS, and it offers streamlined control of the beam delivery (patient treatment), along with integration with hospital systems through DICOM or IHE-RO profiles by performing the role of the TDD (Treatment Delivery Device)

The Scan-Dose software provides the following high-level functionality:

- Device configuration and version management
- Calibration data configuration management
- All aspects of IMPT beam delivery, control and interlocking
- Performs more than 60 tolerance parameters (safety) checks in 1ms
- Built-in data recovery under abnormal crash conditions (power failures etc.)
- Conversion algorithms from DICOM RT Ion Plan to device units

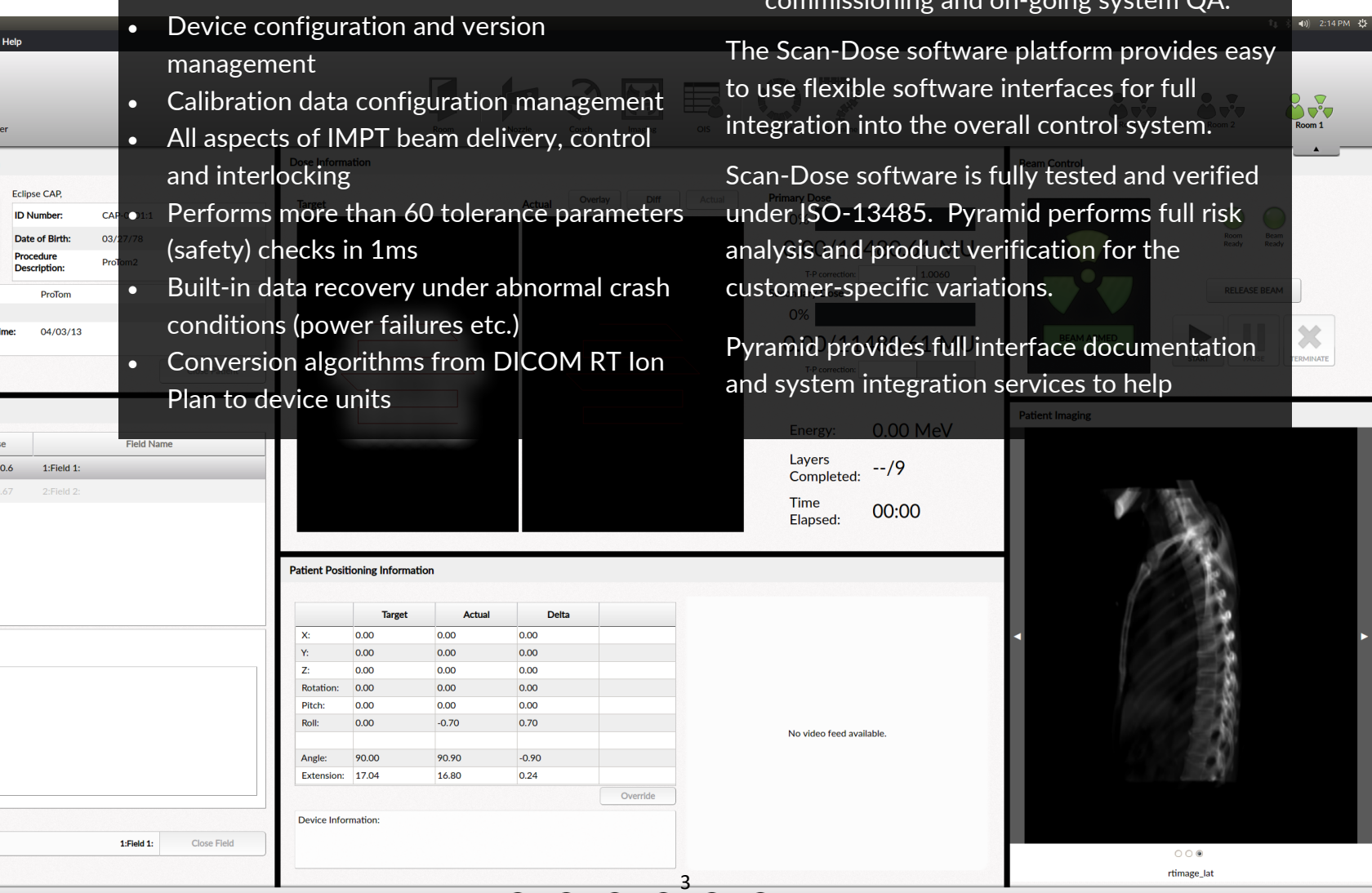
> "The Scan-Dose software platform provides easy to use flexible software interfaces for full integration into the overall control system."

- Data logs/records of all parameters measured and/or computed at 1msec resolution
- Complete diagnostics/analysis/service GUIs with automation useful of system commissioning and on-going system QA.

The Scan-Dose software platform provides easy to use flexible software interfaces for full integration into the overall control system.

Scan-Dose software is fully tested and verified under ISO-13485. Pyramid performs full risk analysis and product verification for the customer-specific variations.

Pyramid provides full interface documentation and system integration services to help



CM100 Charge Monitoring Unit

Control and Charge Monitoring Unit for Particle Therapy Treatment Control Rooms

The CM100 was designed to meet the requirements of IEC 60601-2-64:2014. Its primary purpose is to provide a redundant means of recording total delivered charge, and making that data available in the event of a power outage. The CM100 accomplishes this though a battery-backed display and nonvolatile storage. The device includes the capability of counting individual spots so that it can satisfy the particular needs of PBS in spot-scanning mode.

The charge collection function is combined with a flexible set of switches that can be configured to satisfy IEC 60601-2-64:2014 with respect to hard-wired and relay-driven interfaces to arm, start, pause and stop the treatment process. Addition functions are available through the graphic touch-screen, allowing the device to be updated as new requirements arise

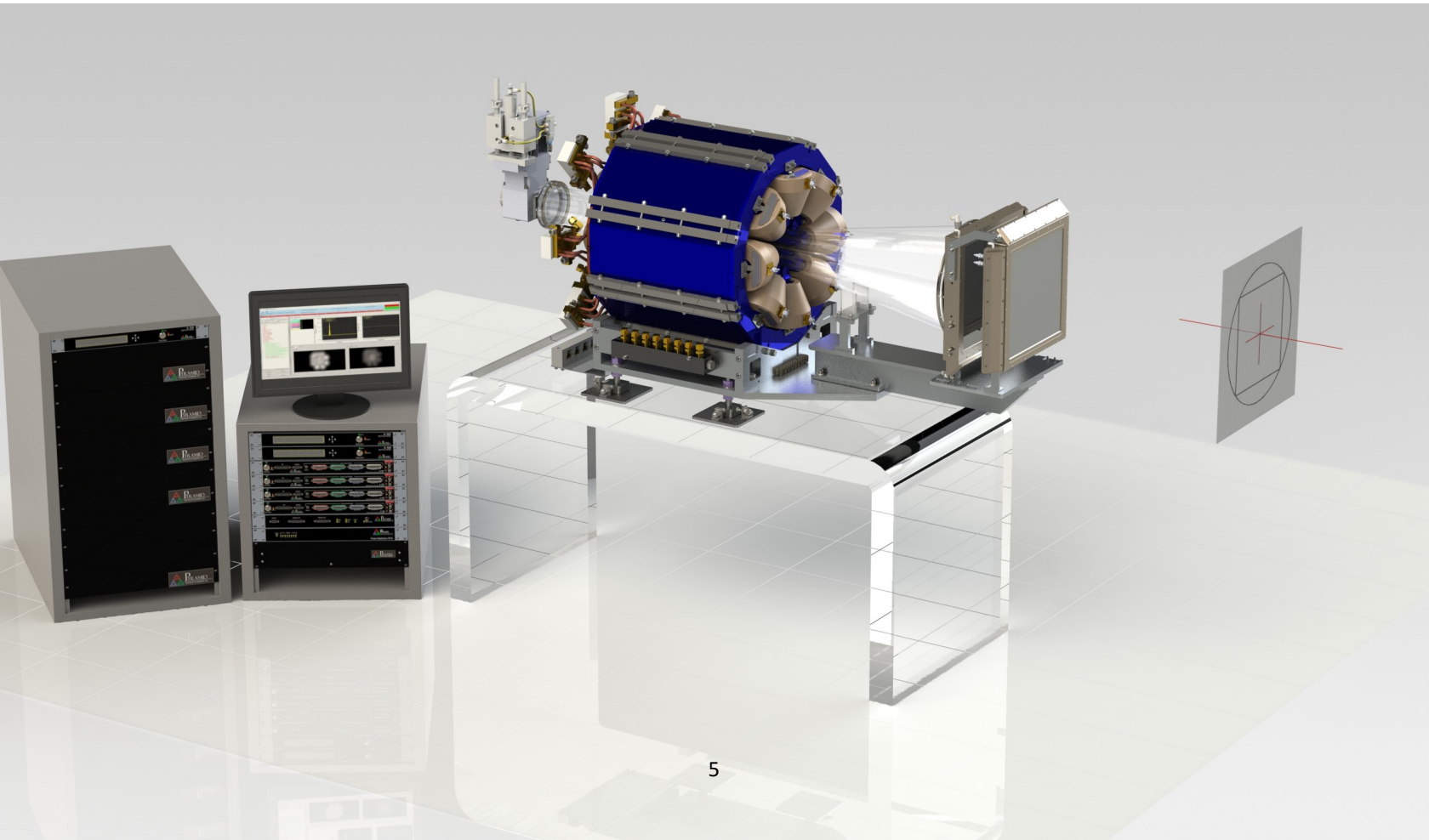
- Designed to meet the requirements of IEC 60601-2-64:2014.
- Non-volatile charge recorder (> 30 minutes duration)
- Key switch access for preparing and enabling irradiation
- Illuminated physical switches to start and pause irradiation
- Audible signal for dose being delivered
- Latching emergency stop button with direct connection to rear panel connector
- Relay to stop irradiation if total dose exceeds target plus allowed tolerance
- 7” color LCD touch screen for real-time display of dose delivered, dose target and system state
- Maintains a record of pencil beam spot number when used with compatible dosimetry systems

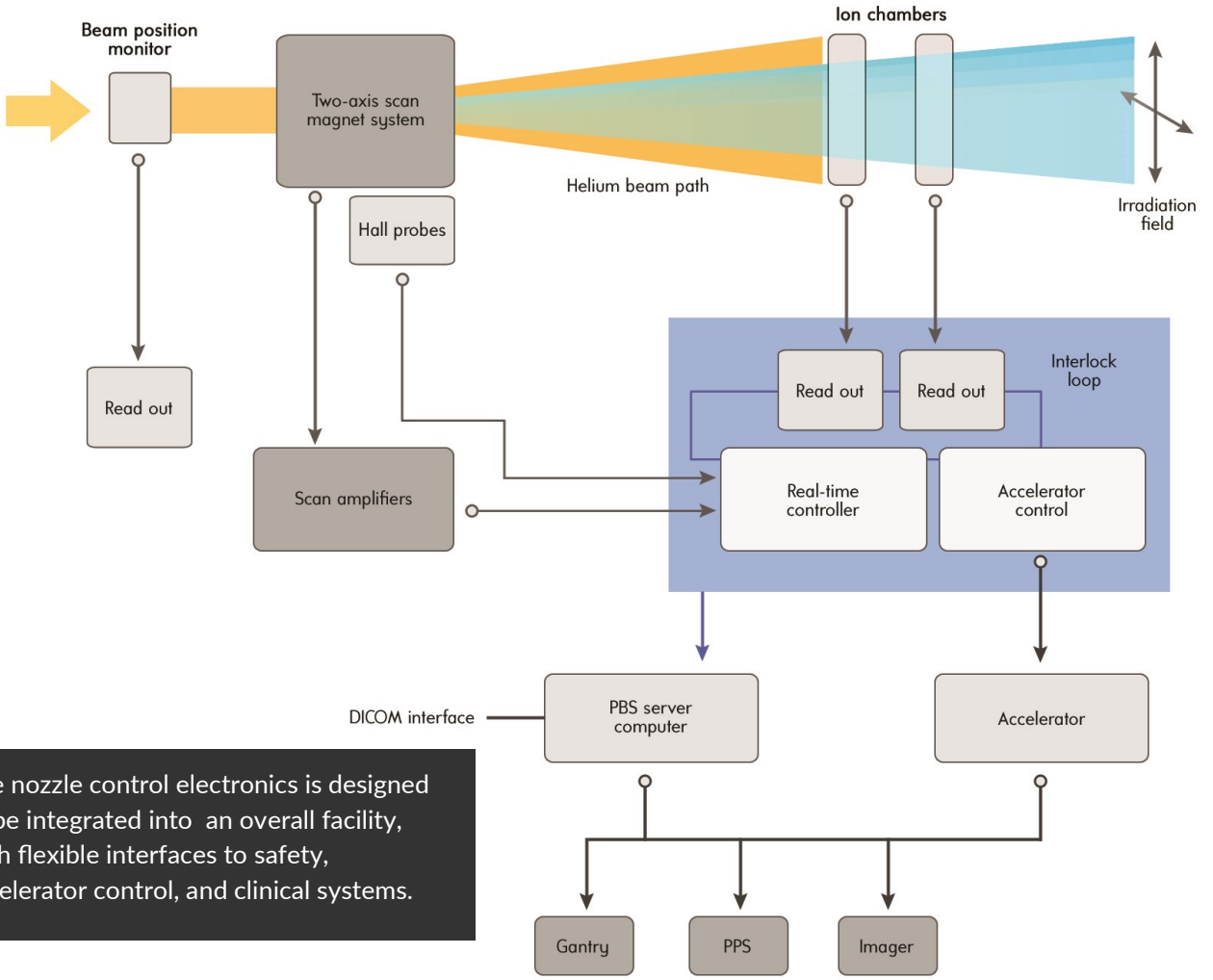
Beam Delivery Nozzle

The key to providing an accurate dose distribution to the patient

The last section of the beam path before the patient is referred to as the beam delivery nozzle. The nozzle is where the beam spot is positioned and carefully measured before the beam is delivered to the patient. Pyramid provides complete beam delivery nozzle systems that are customizable to specific customer requirements that include the following components:

- Designed for easy integration with the Pyramid Scan/Dose software platform, with well-defined interfaces to oncology information systems, treatment planning, patient imaging and others, using standard DICOM format
- Vacuum and helium windows
- Ionization chamber beam position monitors, both in-line and retractable
- Scan magnets and amplifiers
- Helium-filled beam path
- Dose and position-sensing ionization chambers with readout
- Redundant real-time controllers for map execution and interlocking





The nozzle control electronics is designed to be integrated into an overall facility, with flexible interfaces to safety, accelerator control, and clinical systems.

The illustration and the simplified chart above show the components of a typical nozzle system. However, each facility has special requirements, and any particular nozzle may differ significantly from what is shown.

On the left you see a MPM8-500 multipole combination scan magnet with four high performance amplifiers. A helium beam path reduces scattering as the beam passes through the magnet and on to the ionization chambers. The illustrations show a pair of IC128-25 ionization chambers that provide redundant readout of beam current, position, shape and trajectory for every delivered spot. I128 readout electronics compute the beam properties in real time and checks for deviations from the treatment map. The system communicates with the accelerator to control beam energy and current, coordinating with the movement of the beam spot.

> *"Any of the multiple real-time controllers have the capability to suspend the irradiation if there are fault conditions, providing a high degree of redundancy and safety"*

Any of the multiple real-time controllers have the capability to suspend the irradiation if there are fault conditions, providing a high degree of redundancy and safety. In addition to the beam gating control used during the irradiation, a shutdown escalation can be commanded through two separate hardware relay circuits. One circuit is room-specific, and is used typically for map tolerance violations. The other circuit is system-wide and is used for hardware failures, access violations and similar events.

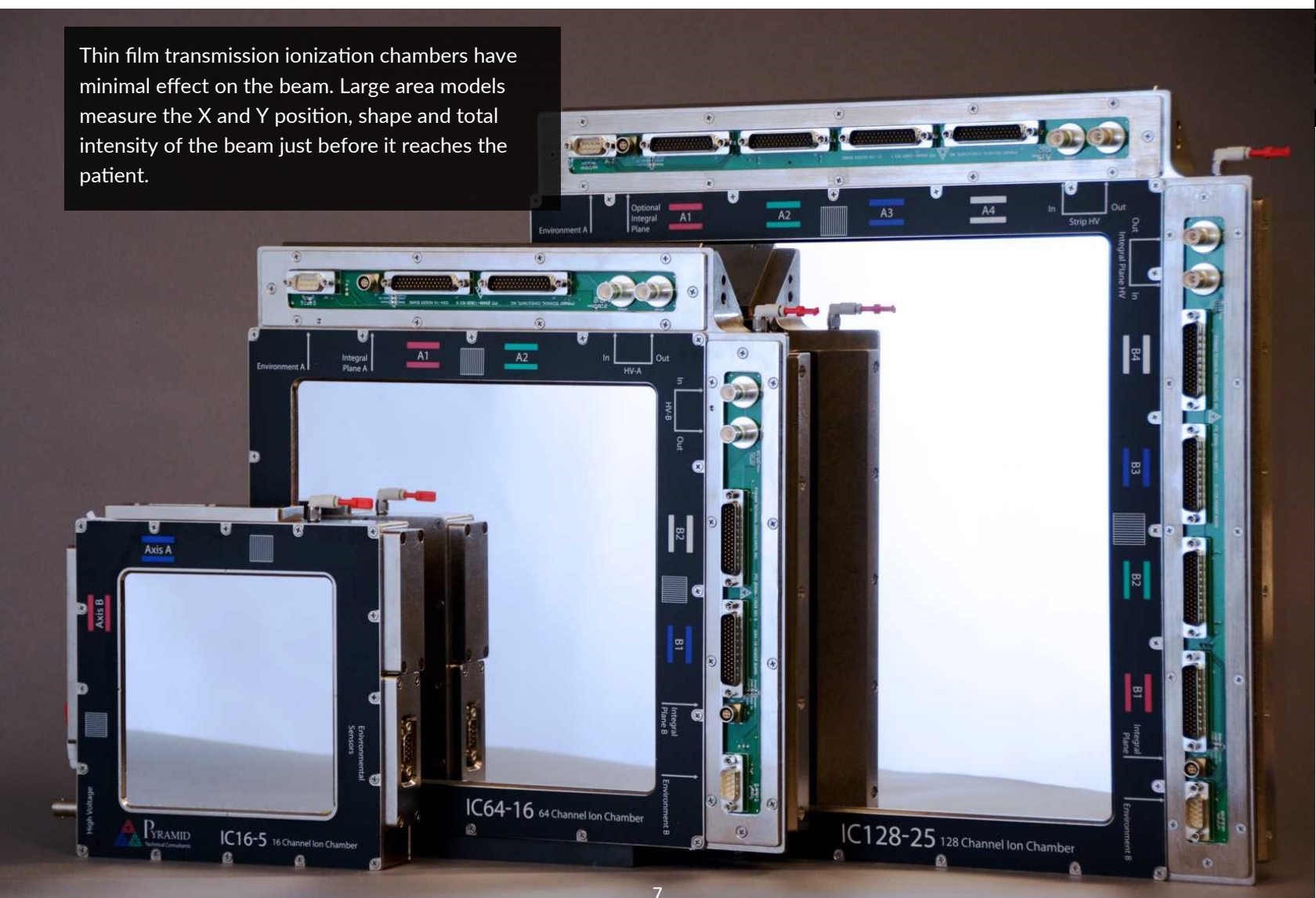
Ionization Chambers

Transmission ionization chambers: the proven solution for on-line measurement of dose, spot position, and beam shape

Ionization chambers are the heart of an effective pencil-beam delivery system. They must provide fast, accurate information with high reliability, while having as little influence on the beam as possible. The Pyramid range of chambers provides different configurations to suit customer requirements of:

- Linear dimensions to suit the scan area
- Spatial resolution to match beam spot size
- Enhanced field strength and gap dimensions to maintain linearity with pulsed beams
- Redundant sensors to maintain a desired level of redundancy

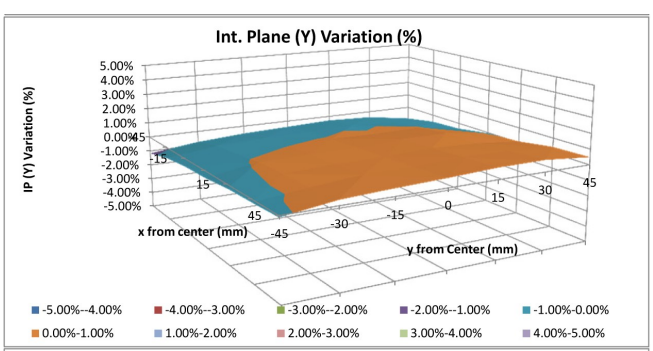
Key features include ultra-thin electrode substrates for minimal beam scattering, highly precise and stable electrode patterns for accurate position determination, built-in pressure and temperature sensors for gain compensation and desiccant cartridges for fill gas dehumidification. Reduced gap chambers are available to handle high instantaneous beam current.

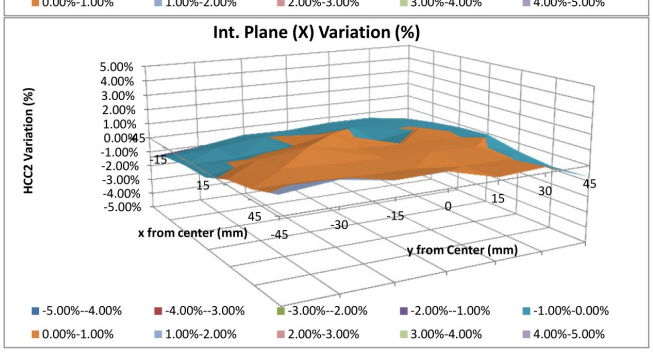


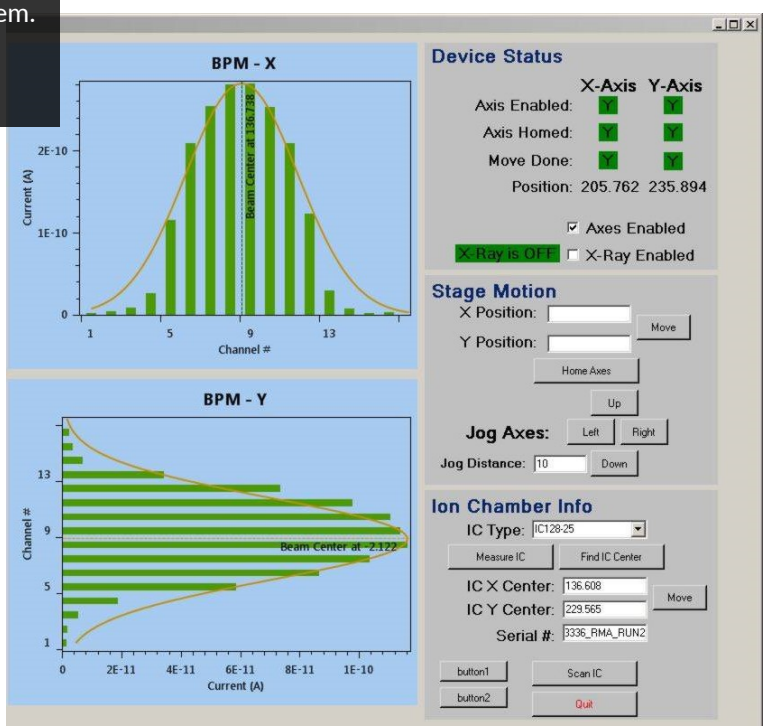
Thin film transmission ionization chambers have minimal effect on the beam. Large area models measure the X and Y position, shape and total intensity of the beam just before it reaches the patient.

Pyramid has developed highly optimized laser patterning equipment to produce the thinnest, most dimensionally accurate ion chamber structures available. In-house manufacturing means customized electrode structures can be quickly designed and tested.

Every completed ionization chamber is tested for position readout linearity and gain flatness with an X-ray test system. This ensures that devices are accurately interchangeable without significant on-site calibration.







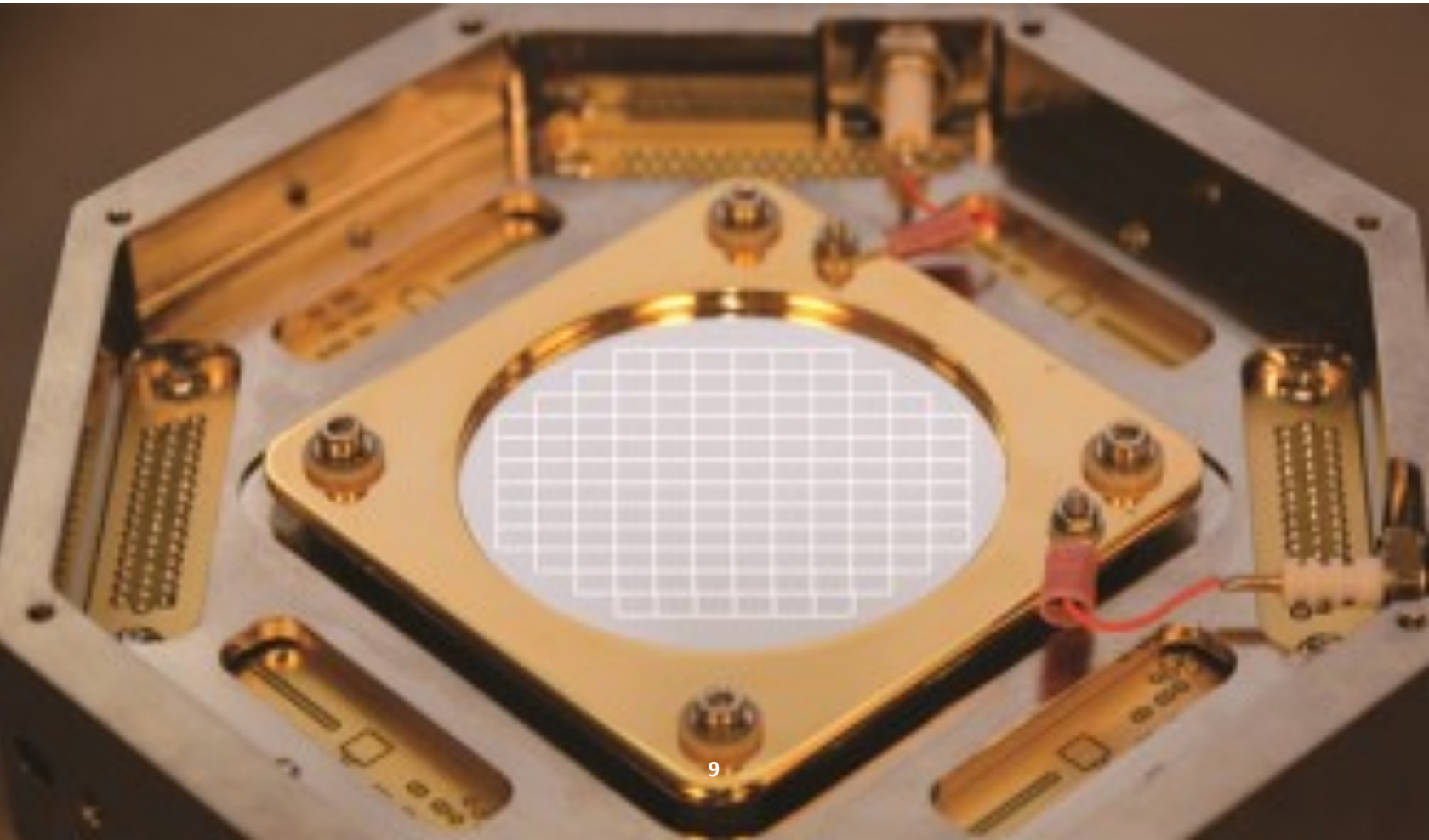
Ionization Chambers (continued)

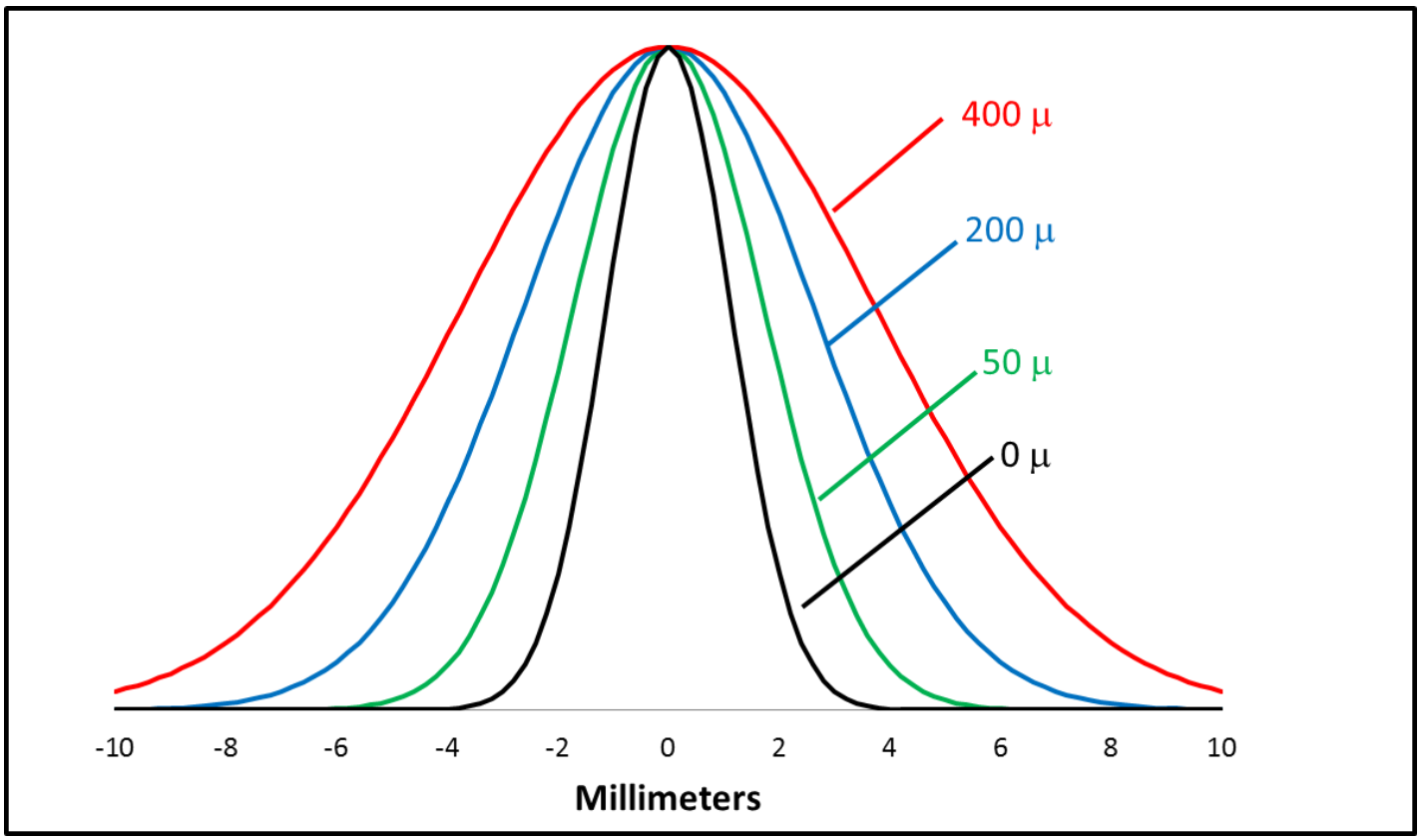
Low-scattering, highly customizable configurations to suit every application

The range of ionization chamber products includes large-area detectors with strip readout and integral dose planes, for use in the scanned beam. Small-area detectors with strip readout or pixel readout are for use upstream of the beam scan magnets, for measurement of beam trajectory and shape. In this application, a construction with absolute minimal beam energy degradation and scattering is vital.

Chambers like the PX-2 with pixelated readout provide significant extra information about the beam. Treatment plans typically assume symmetric beams with Gaussian-like profiles. If beamline setups are incorrect, the actual beams may be elliptical and inclined, or have extended halos, multiple peaks or other undesirable pathological conditions. The Pyramid pixelated imagers reveal these cases and allow the user to trace and eliminate the underlying problem. Pixelated chambers also allow the ultimate low scattering designs to be created. The water equivalent thickness of the electrodes in the Pyramid PX-3 chamber is less than 100 µm.

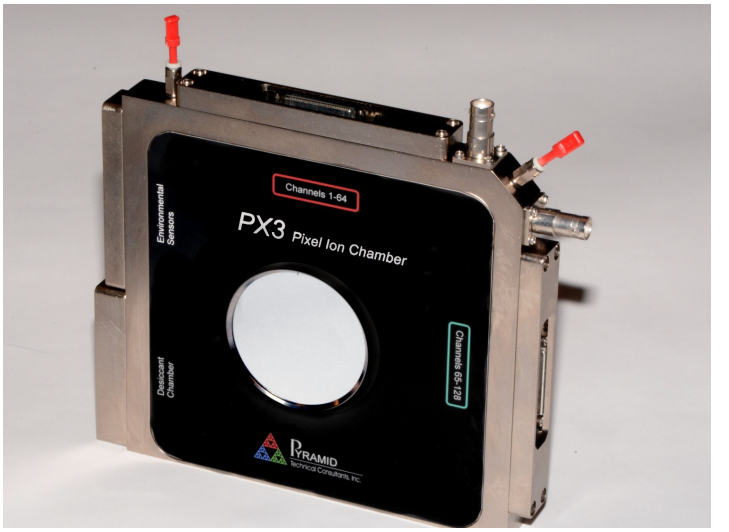
This ion chamber combines multiple strip detectors and dose planes in a sealed and electronically monitored module. The unit was developed as a functionally equivalent retrofit to an existing system and has been in service for 2 years.





Detectors with lower water equivalent thickness (WET) will have a smaller effect on the beam spot size. This graph shows the effect, assuming an initial beam spot size of zero. To simulate the use of a detector before the scanning magnet, a 250 cm path length is assumed, with the first 200 centimeters in helium, and the last 50 cm in air.

The PX-3 ionization chamber shown on the right, represents the state of the art for low-scattering ionization chambers for particle therapy, with a water-equivalent thickness of only 100 µm including its air filling. Its face to face thickness is only 20 mm. The PX-3's pixelated readout provides a comprehensive 2-D image of the beam.



Due to the extremely thin design, the PX-3 is ideal for in-line beam position monitoring at the end of a beam transport line, for example at the entrance of the treatment nozzle. The position and shape of the beam can be tracked continuously, including during patient irradiation. Effects such as shifts in the beam trajectory entering the scanning magnets can be detected directly.

IC Summary Specifications

The Pyramid ionization chamber designs listed here cover many customer requirements. However, if you need something a little different, we are happy to propose a new design which can be created as necessary using our in-house facilities.

Device	Sensor Active Area	Readout Elements	Active Gap Types	# of Gaps	Active Gap Size (mm)
IC128-25	25 cm sq	128 by 128 strips Dose plane (f)	Strip Dose	2 1	10.00 10.00
IC32-20	20 cm sq	32 by 32 strips Dose planes (f) with density pad (g)	Strip Dose/Dose density	2 2	10.00 10.00
IC64-16	16 cm sq	64 by 64 strips Dose plane (f)	Strip Dose	2 2	5.00 3.00
IC64-13	13 cm sq	64 strips Dose plane (f)	Strip Dose	1 1	3.80 3.80
IC32-6	6.4 cm sq	32 by 32 strips	Strip	2	3.00
IC16-5	4.8 cm dia	16 by 16 strips	Strip	2	3.00
PX-2	4.2 cm dia	120 pixels	Pixel	1	6.25
PX-3	4.2 cm dia	120 pixels	Pixel	1	5.00
QIC-2	1.9 cm dia	4 quadrants	Quadrant	1	3.20
QIC-2S	1.9 cm dia	4 quadrants	Quadrant	1	3.20
BPM16-38	3.8cm sq	16 by 16 strips	Strip	2	6.00

Notes

(f) Also known as integral plane

(g) Dose density pad used for double scattering

Insertion Length (mm)	Gas Fill	Water equ. Thickness (µm) (e)	Environment Sensors?	Desiccant?	Materials in Beam Path	Other Features
44.0 (b) 50.4 (c)	Atm or flow	180	✓	✓	Polyimide, Al	
56.6 (b) 63.0 (c)	Atm or flow	210	✓	✓	Polyimide, Al	Compatible with IBA IC2+IC3
44.0 (b) 50.4 (c)	Atm or flow	195	✓	✓	Polyimide, Al	
22.0 (b) 28.4 (c)	Atm or flow	110	✓	✓	Polyimide, Al	Design allows two devices to be mounted orthogonally for two-axis sensing
32.0 (b) 37.0 (c)	Atm or flow	150	✓	✓	Polyimide, Al	In-line monitor
32.0 (b) 37.0 (c)	Atm or flow	150	✓	✓	Polyimide, Al	In-line monitor
32.0 (b) 36.6 (c)	Atm	390			Polyimide, Al, FR4, Cu	Isocenter diagnostic application
14.6 (b) 20.0 (c)	Atm or flow	100	✓	✓	Polyimide, Au Ni	In-line monitor
7.6 (b) 3.7 (c)	Atm or flow	70		✓	Polyimide, Al	
7.6 (b) 3.7 (c)	Atm or flow	70		✓	Polyimide, Al	
34.2 (b) 152.4 (d)	Atm or flow	1030 (0 if out)			FR4, CU, St. Stl	Pneumatic actuator Vacuum housing

Notes

(b) Window to window

(c) Face to face

(d) Flange to flange

(e) Calculated equivalent proton energy degradation including all electrodes, windows, and air gaps

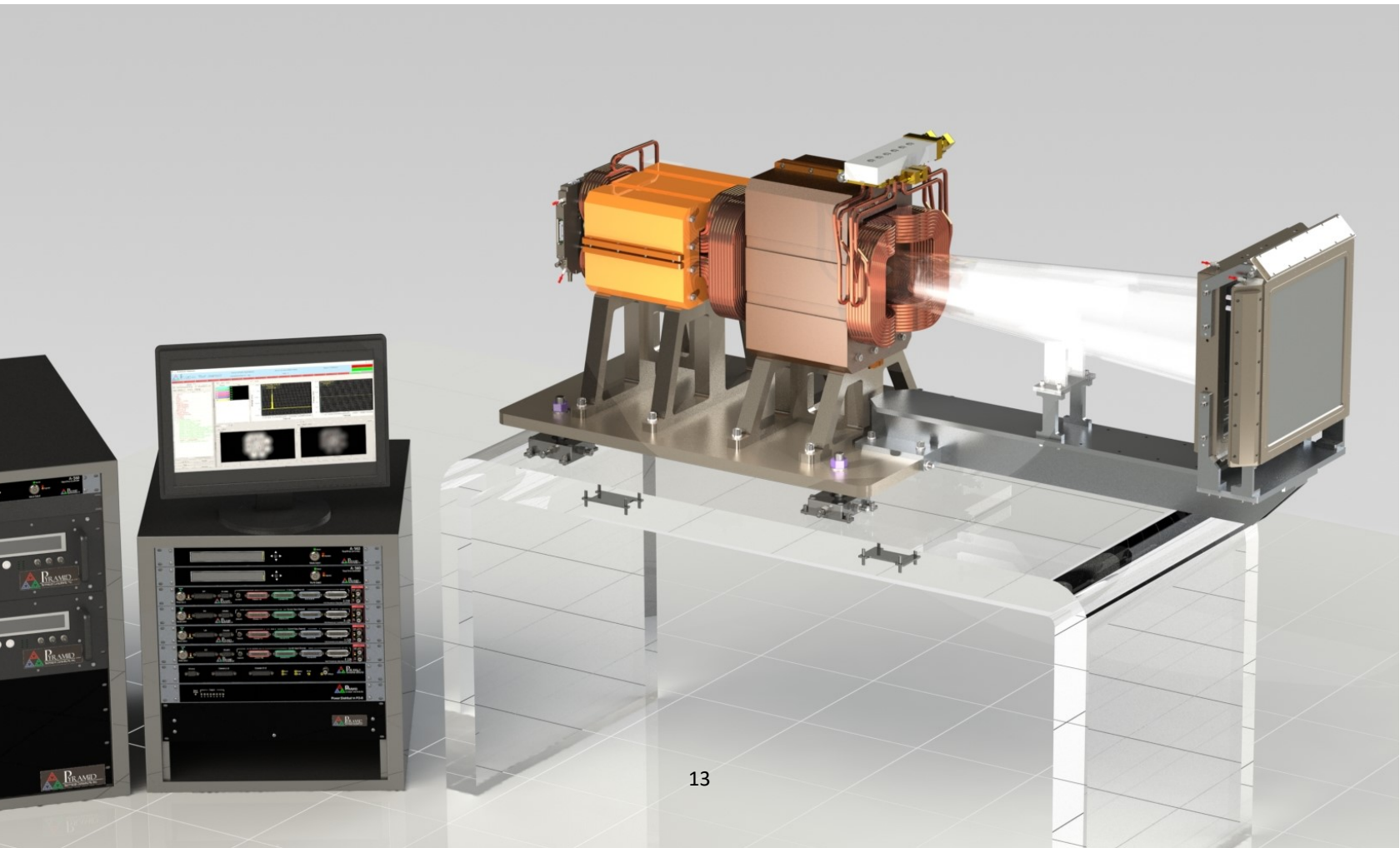
Scanning Magnet Systems

Optimized ion optics for rapid, precise positioning of the beam

The Pyramid D2-650 dipole scan system is a compact, cost-effective scanning magnet system with separate X and Y laminated deflection magnets. It provides a combination of deflection angle and low inductances which allow for fast spot placement over a large scan field.

Combined with the high-performance amplifiers and the H20 Hall probe system, the result is a highly-integrated system with direct control and monitoring of the magnetic fields.

The scanning magnet system allows the beam to reach any point in the scan field at the isocenter plane at the highest specified beam energy. It moves quickly between spot positions, and occupies as little space as possible in the beam path. The matching scan amplifier system provides the current to maintain the beam spot precisely in position, then drive the magnet load to the next spot position at high slew rate with minimal settle time.

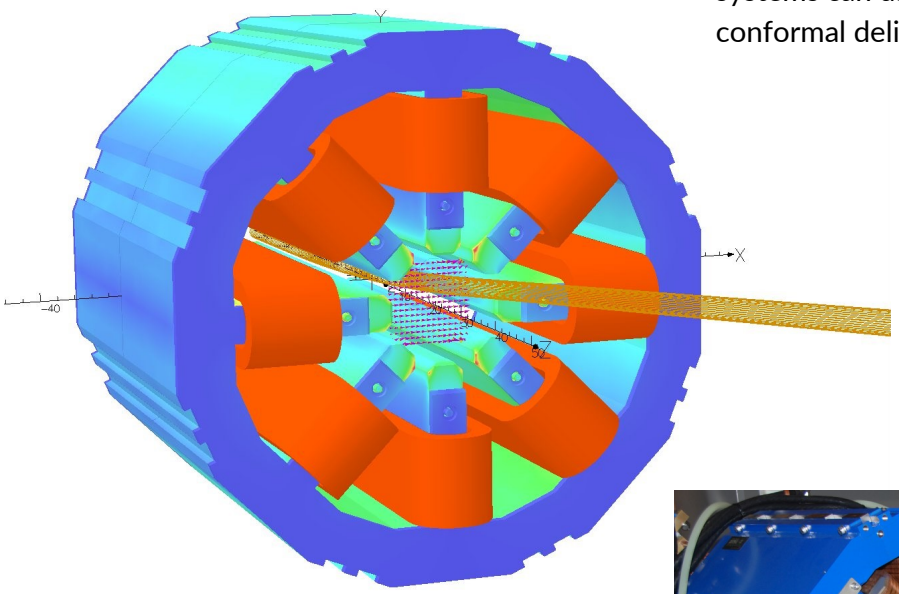


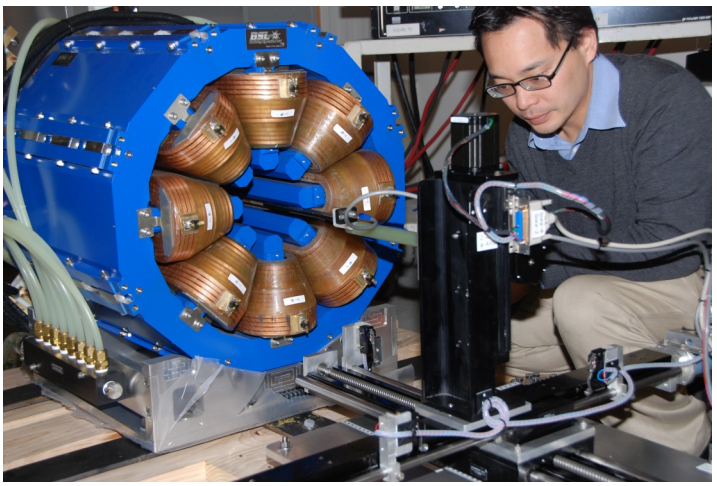
Innovative designs for specialized requirements

The Pyramid MPM8-500 is a compact scan magnet with unique capabilities. Combined together with the high-performance amplifiers, Pyramid has created a patented solution for pencil beam scanning. The unique octopole structure allows a dipole magnetic field to be rotated to any angle. In the standard configuration of the octopole, the maximum deflection angle is 6 degrees in any direction at proton energies up to 230 MeV. The result is a scanning magnet system that has no preferred axis, so the patient does not have to be rotated to align a physiological feature with the magnet scan direction. This creates convenience to the patients and the radiologists alike.

> *"A compact scanning magnet with unique capabilities"*

As pencil beam scanning continues to evolve there is an increasing desire to have the smallest spot size as possible. With excellent dipole field quality, the beam shape is maintained over the scan field. Pyramid offers a compact system, the complete magnet is 500 mm long, less than most conventional scan magnet solutions. When driven with eight individual amplifiers, the octopole magnet also has the ability to alter the beam spot shape as fast as it moves from spot to spot. Future treatment planning systems can use this unique feature to improve conformal delivery of dose.

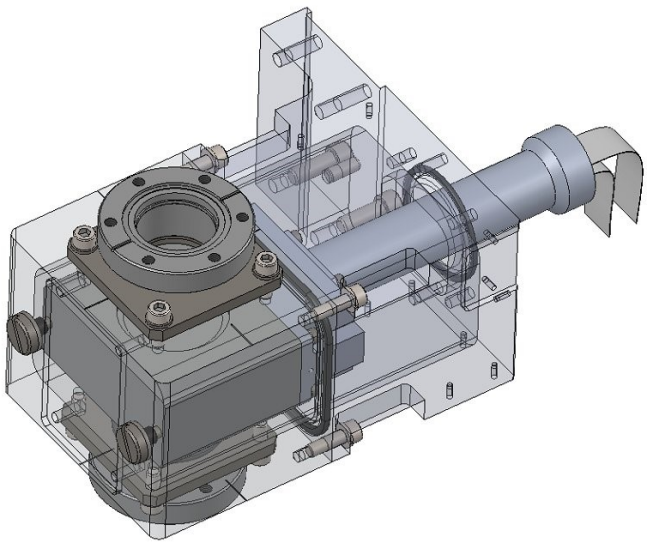


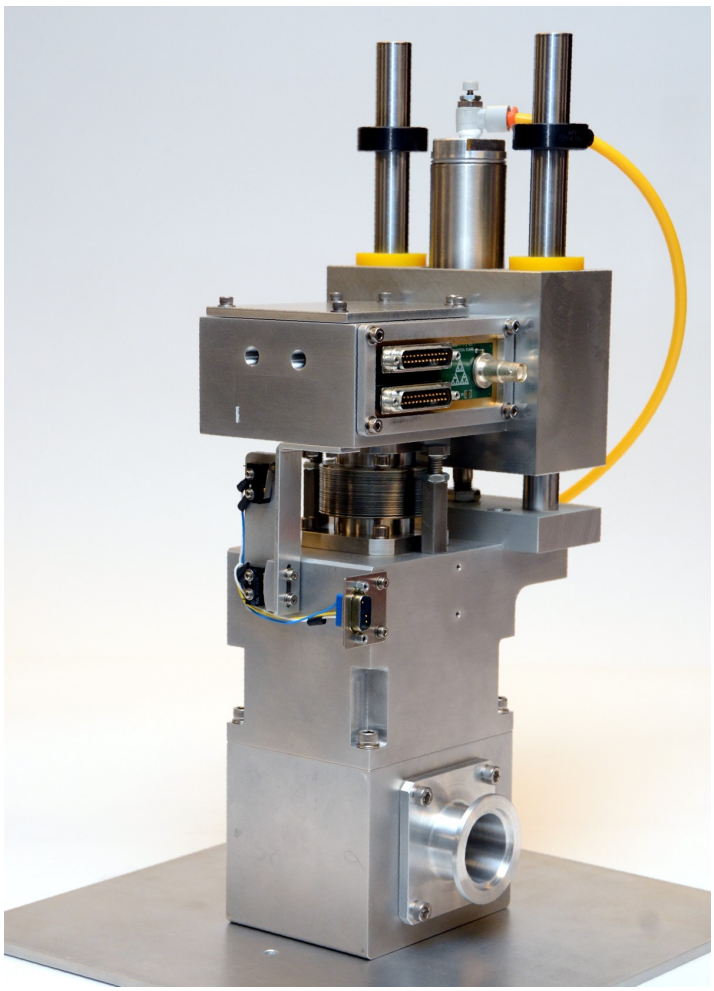


Beam Position Monitors

Accurate beam position, shape, and intensity monitoring within the beamline

The BPM16-38 beam position monitor comprises a robust, small ionization chamber with two-axis strip readout integrated with a pneumatic actuator that can move the chamber completely clear of the beam when it is not being used. It may be used for beam trajectory checking before the scan magnets in a nozzle system, and also generally along a high-energy beam transport line to aid beam tuning. The whole assembly is high-vacuum compatible, and is available with alternative vacuum flanges. It can operate in any orientation.





Fixed-position BPM's for continuous monitoring

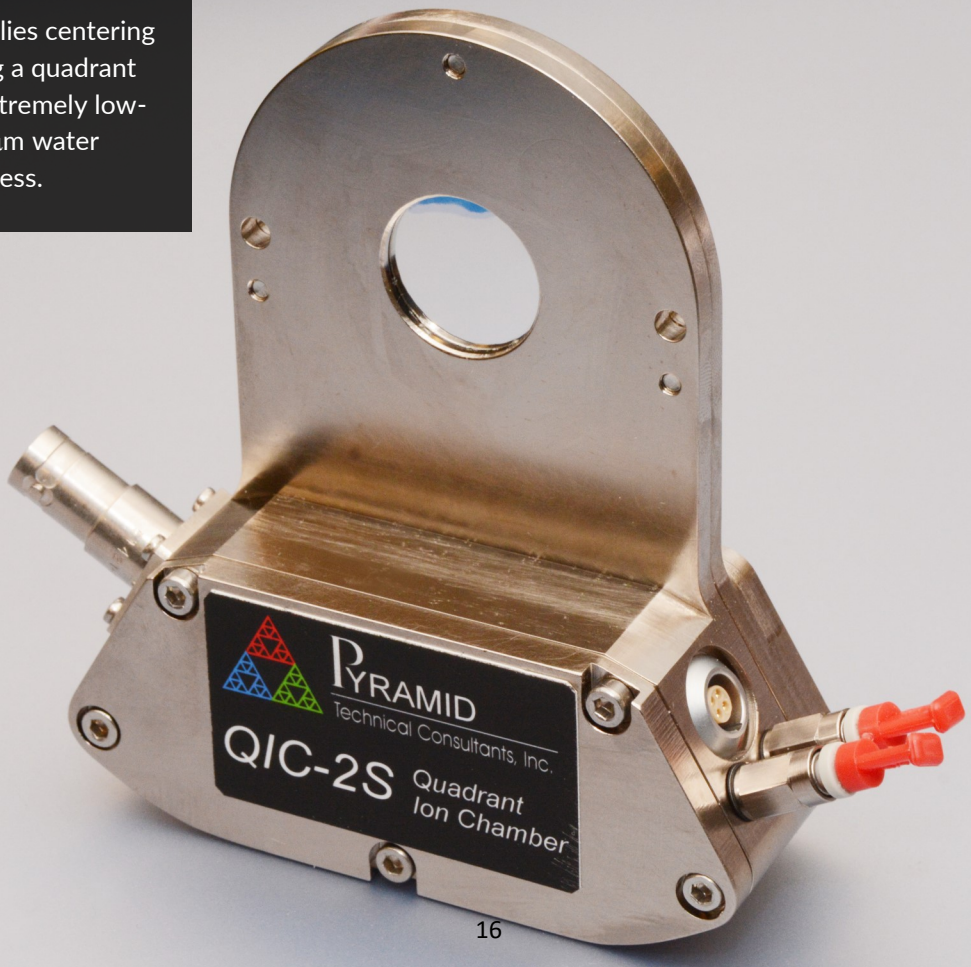
When continuous monitoring of the beam position is required, beam scatter must be reduced to the lowest practical value. Total water-equivalent thicknesses of less than 100 μm allow selected detectors to remain in the beam during treatment.

Our PX-3 ionization chamber is ideal for use as a fixed beam position monitor, providing continuous monitoring of the beam as it enters the scanning nozzle.

The QIC-2S is a very thin quadrant detector well-suited for monitoring small beams, such as those as the accelerator output.

The PX-3 provides continuous monitoring of position, as well as 2-dimensional shape information.

The QIC-2S supplies centering information using a quadrant electrode. It is extremely low-scattering at 70 μm water equivalent thickness.



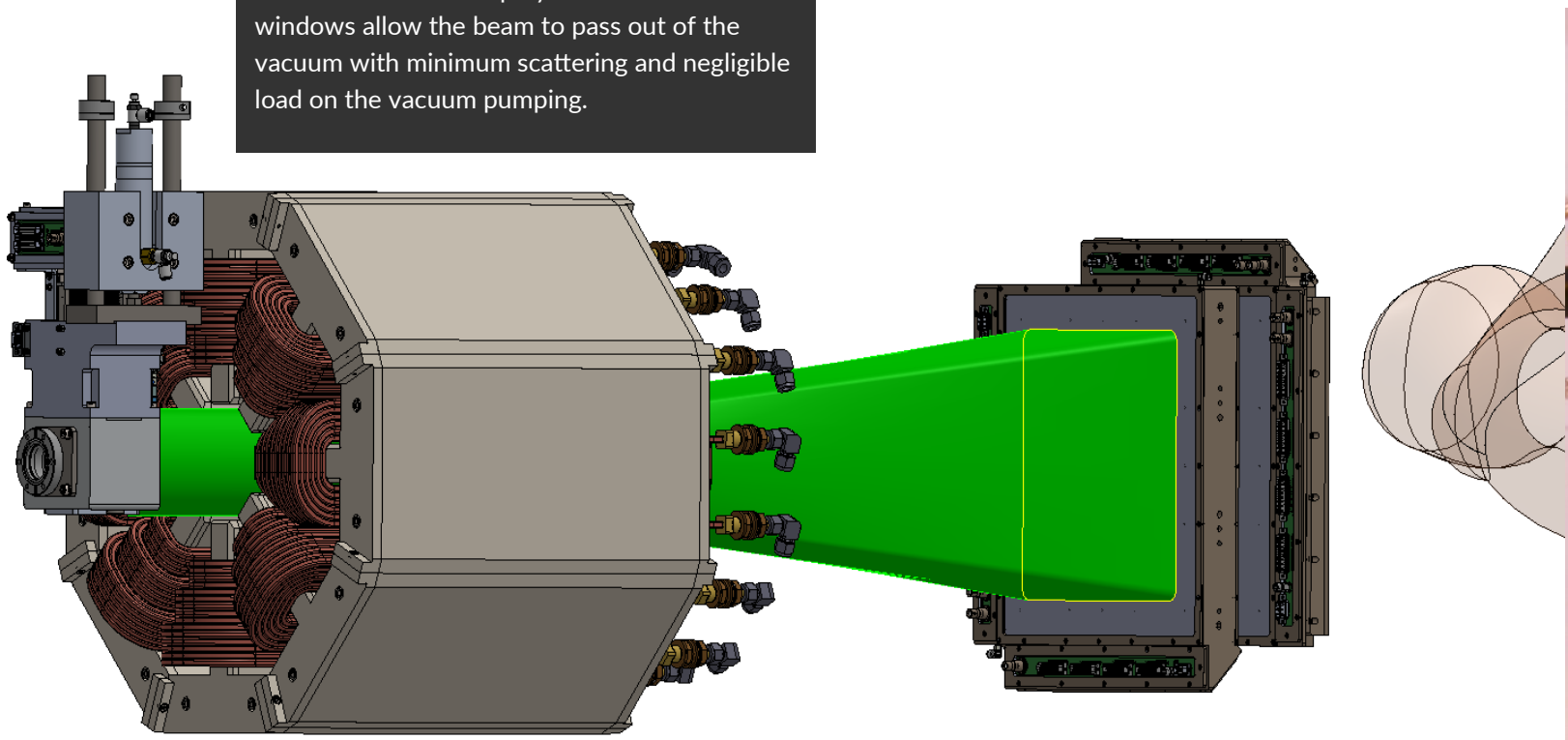
Helium Beamline Envelopes and Controllers

Maintaining minimum spot size by reducing scatter in the nozzle

In order to reduce the scattering of the beam in the nozzle, a helium-filled beam pipe takes the beam through the scanning system up to the final dosimetry and beam tracking ionization chambers. The scattering and energy degradation due to helium is less than one-fifth of that due to the same distance in air. The Pyramid helium beam path system comprises a transparent PVC flared beam pipe with replaceable thin polyimide windows.

A mass-flow controller-based gas control system provides automatic control of input flow rates and uses a sensor to confirm that helium has displaced all the air from the chamber.

Robust nickel-coated polyimide vacuum windows allow the beam to pass out of the vacuum with minimum scattering and negligible load on the vacuum pumping.

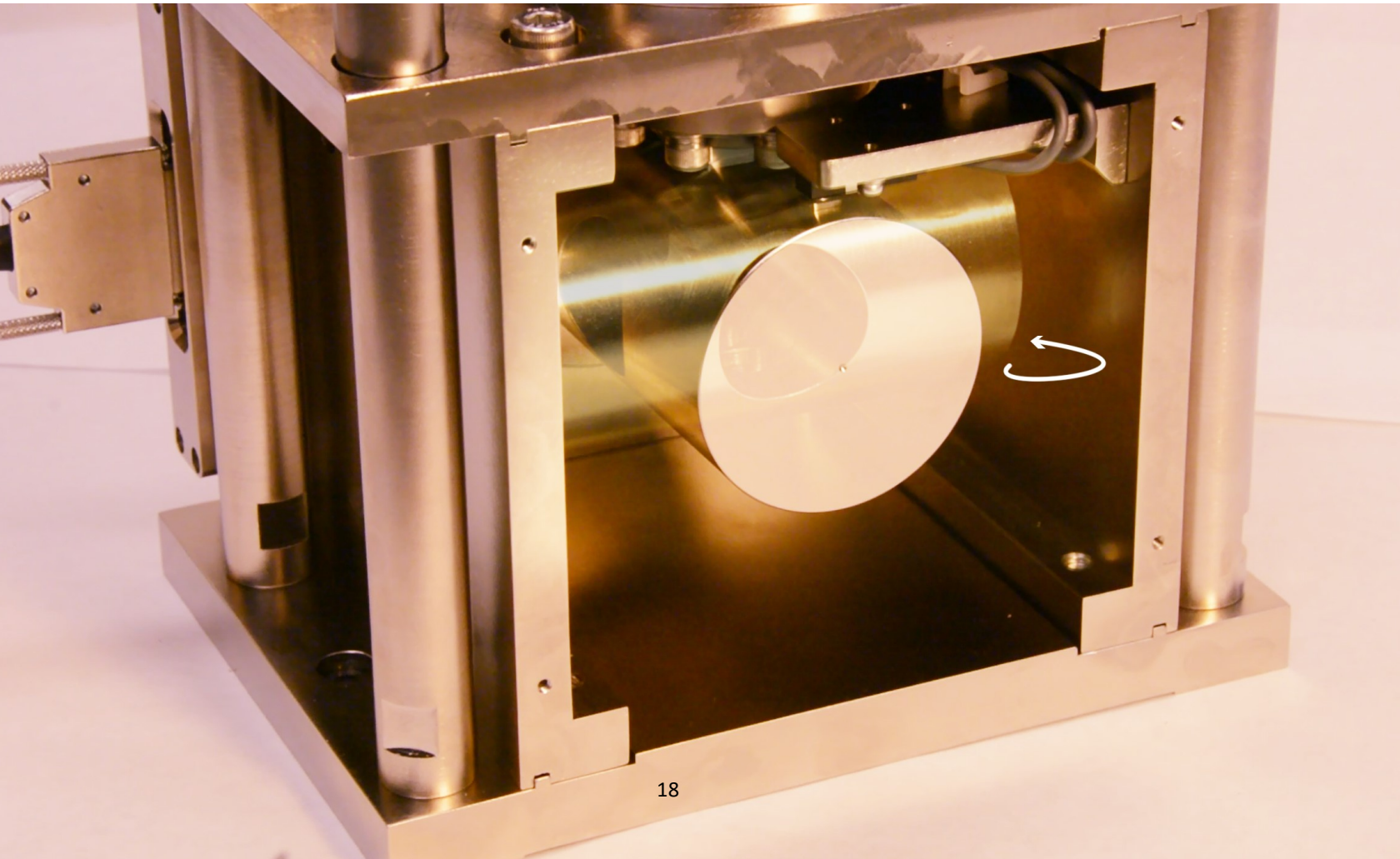


Combined Beam Stop / Monitor

Combining interlock functions with beam positioning capability

The unique fast rotary beam stop allows the beam to be blocked in less than 100 milliseconds. This can be used as part of a full safety interlock system. The beam stop can be combined with the PX3 thin beam position monitor to provide a powerful feedback capability, which can stabilize the beam as it enters the nozzle with high speed and accuracy. In many cases, this will eliminate the need for test pulses during patient treatment.

The beam stop is shown here in the closed (no beam) position with an overlay of the open position on top. The beam stop actuates in <100 milliseconds.



Isocenter Diagnostics

Reduced commissioning time, rapid quality assurance and automation software that links to your existing system

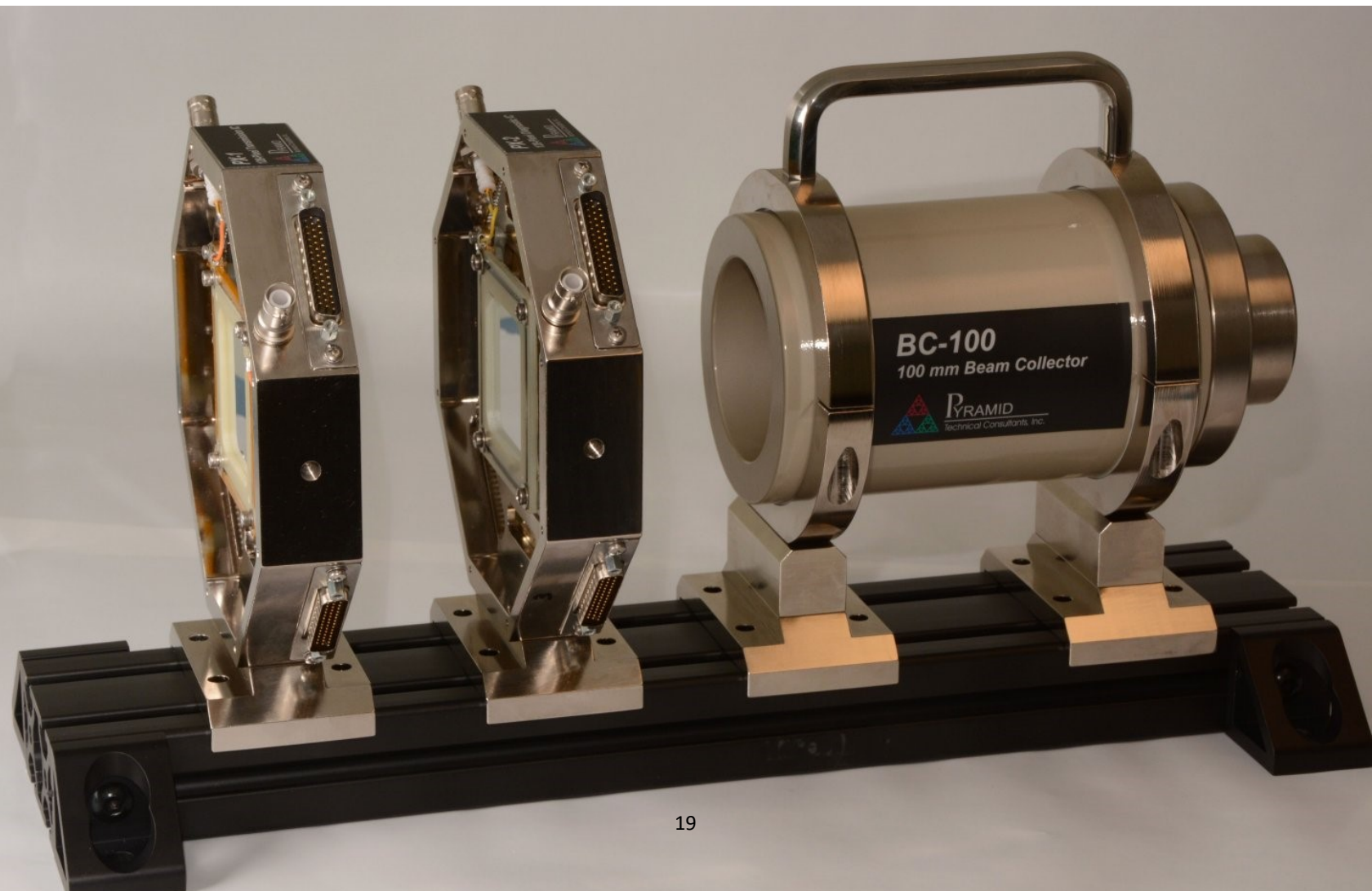
Pencil beam scanning raises needs for new approaches to commissioning and quality assurance. Pyramid isocenter diagnostic systems enable automated QA sequences, independent verification of scan geometry and rapid periodic calibration.

The isocenter diagnostic systems are independent of the main therapy system so that they can make independent measurements, but can be interfaced to it, so that measurement sequences can be automated, saving time and resources.

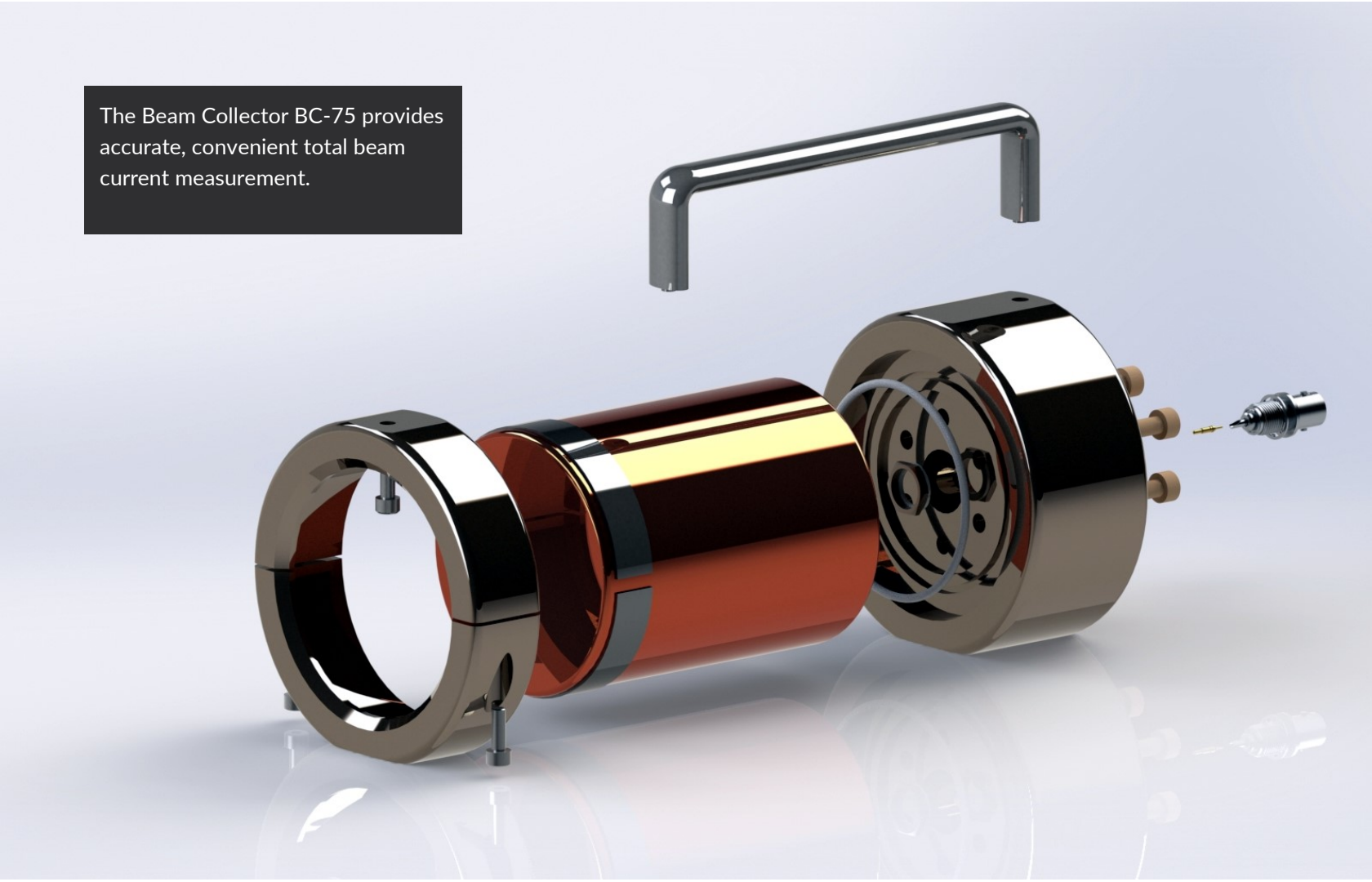
Pyramid offers a range of devices, which can be integrated in a variety of configurations using Pyramid support software

Isocenter Telescope for rapid and comprehensive characterization of the pencil beam

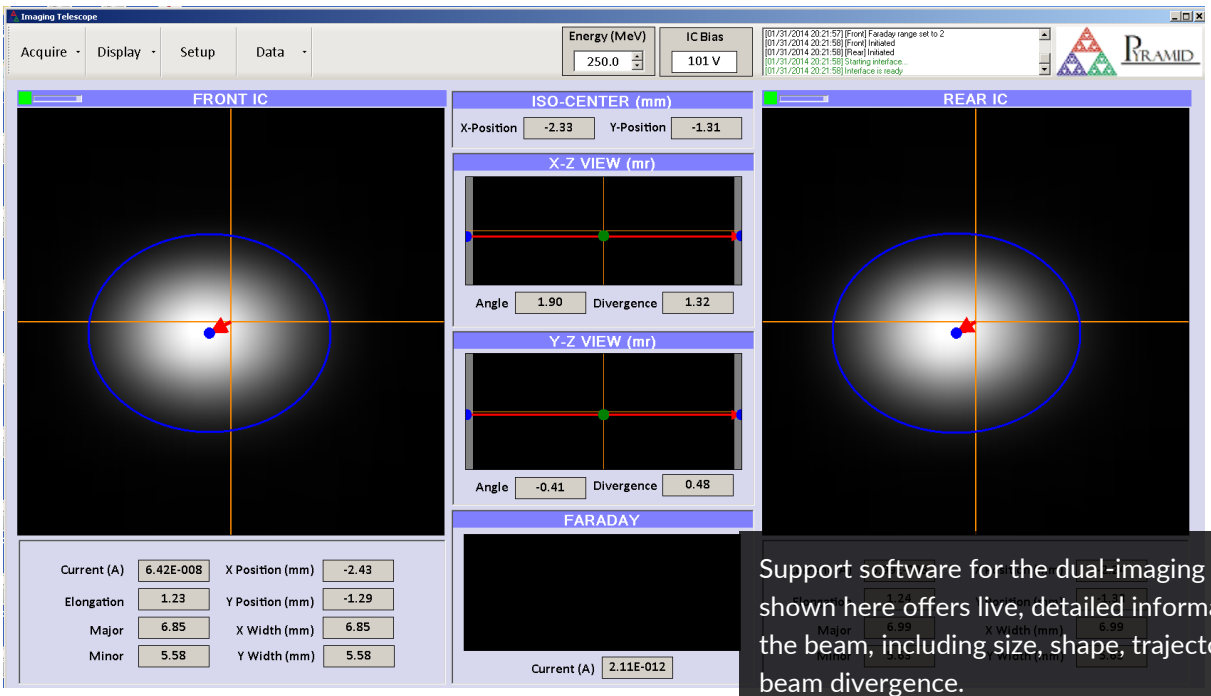
The isocenter telescope is a customizable module that combines one or more Pyramid devices into a single unit. The configuration shown below is made up of two 2-dimensional imaging detectors and a current-measuring beam collector. Combined with the Telescope software, this combination will accurately measure total beam current, position trajectory angles and beam divergence. The beam spot is analyzed to provide x and Y sigmas, beam symmetry and spot rotation. Readout is rapid, and can be combined with beam tuning software to optimize beam characteristics.



The Beam Collector BC-75 provides accurate, convenient total beam current measurement.



The beam collector BC-75 gives a direct measurement of beam current and delivered charge that is independent of energy, environment, or any calibration factors. With an absolute accuracy of about 1-2%. It is comparable to far more complex vacuum-based systems, and requires only a simple connection to a charge measurement device.



Support software for the dual-imaging system shown here offers live, detailed information about the beam, including size, shape, trajectory and beam divergence.

Multi-Layer Range Verifier

High-resolution multi-layer range verifier for rapid, convenient and absolute beam energy validation

The standard for determining depth-dose profiles is through the use of water tank/ion chamber systems. These are inconvenient, being heavy and slow.

The MLRV measures a similar beam characteristic: the beam energy profile. The depth/dose and energy profile are related, and can in fact be transformed into each other in single-energy conditions that exist in PBS delivery systems.

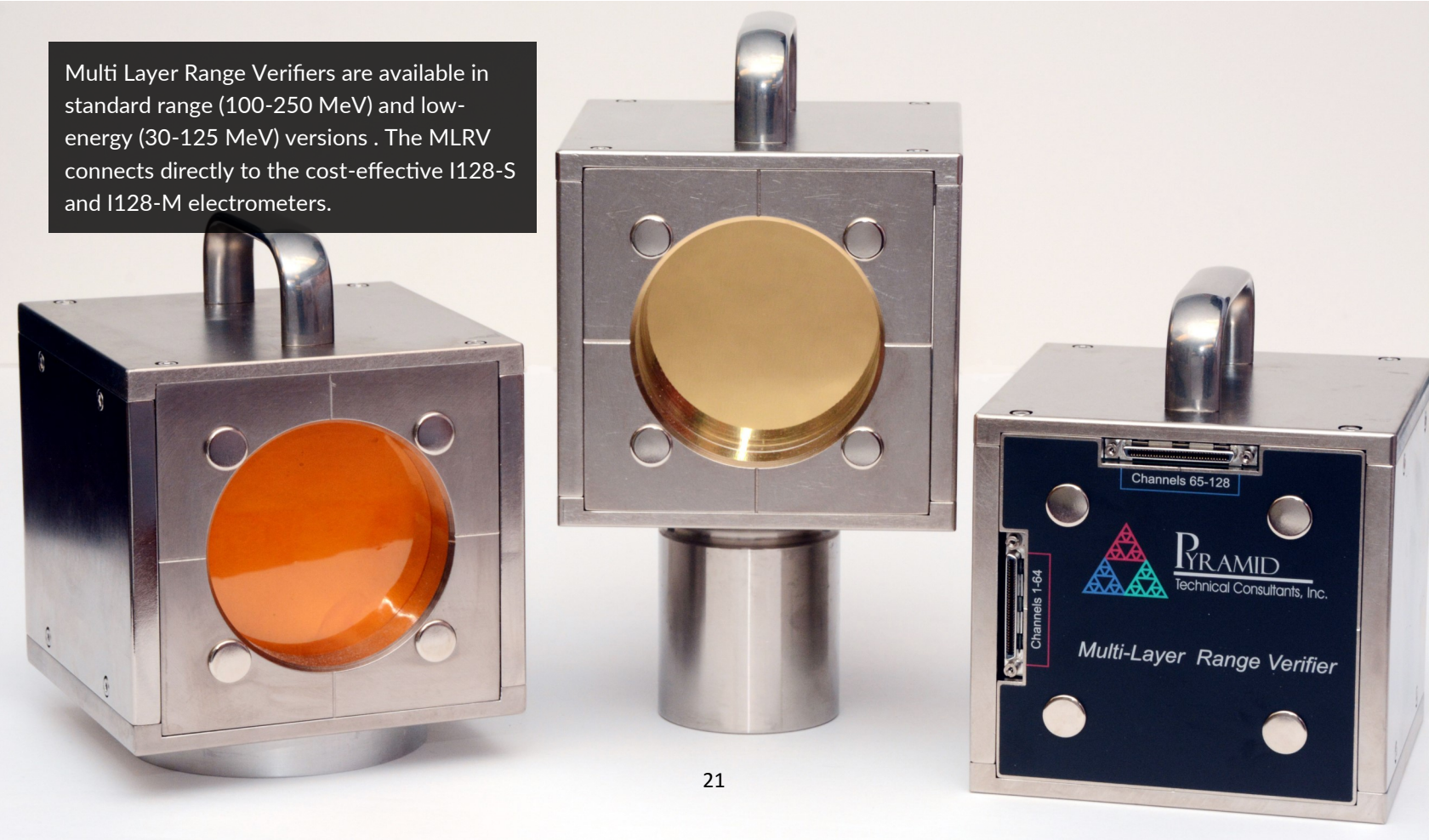
The MLRV can be used to monitor changes in beam characteristics between full calibrations, having the ability to detect extremely small changes in the beam. It can also be used to establish consistency between different beamlines and facilities.

Combined with the MLRV support software are readout electronics, the MLRV will match and measure a number of key beam characteristics including:

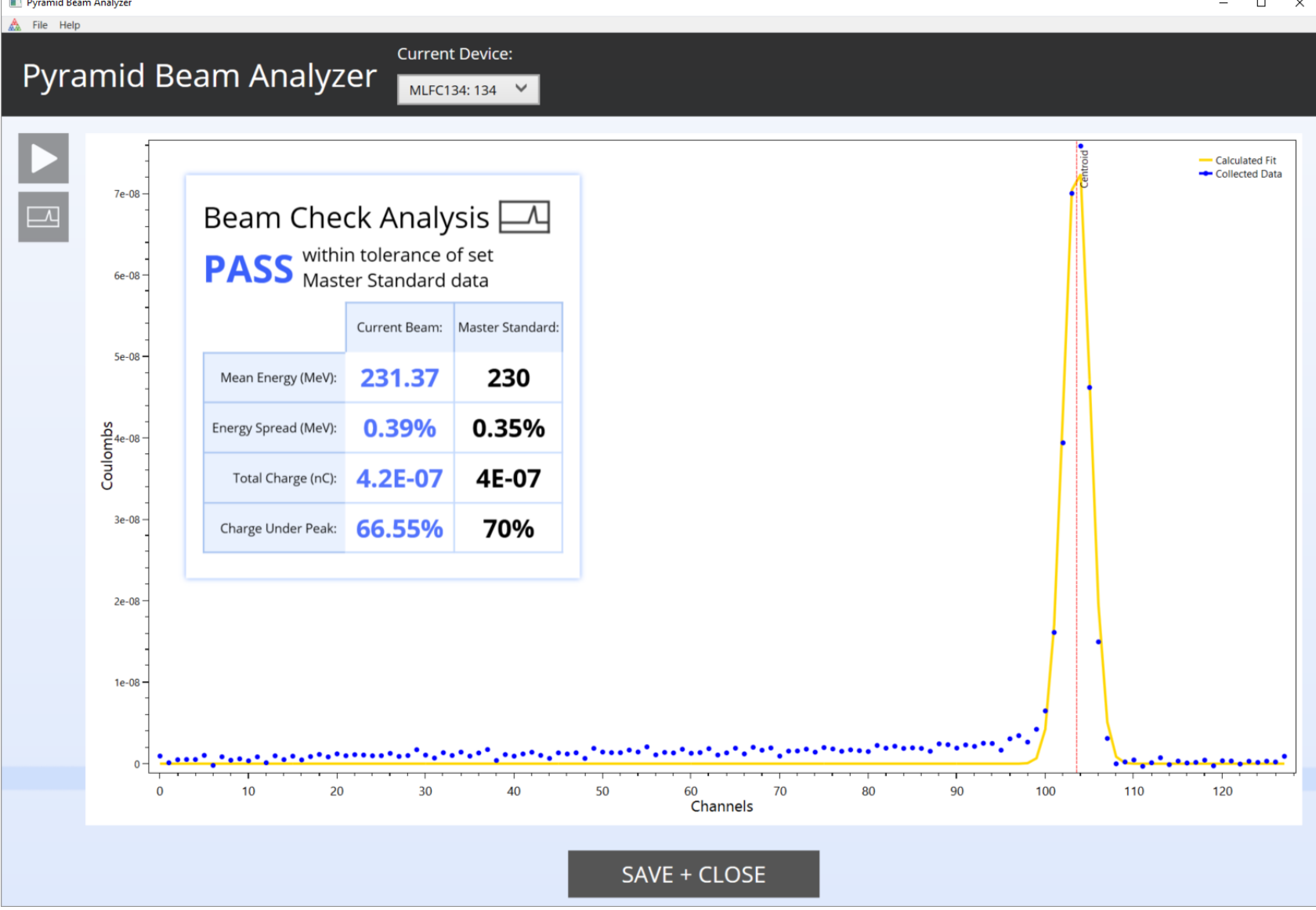
- Mean Beam Energy
- Energy Spread
- Peak/Background
- Total Delivered Charge

The characteristics of the device are very stable over time, and are independent of local temperature and pressure.

The MLRV concept was pioneered by Bernard Gottschalk at the Harvard Cyclotron Laboratory. The Pyramid MLRV is constructed using 128 precisely-characterized layers, provide very accurate beam characterization over a wide energy range.



Multi Layer Range Verifiers are available in standard range (100-250 MeV) and low-energy (30-125 MeV) versions . The MLRV connects directly to the cost-effective I128-S and I128-M electrometers.



Rapid beam characterization for PBS quality assurance

The Pyramid Beam Analyzer (PBA) software, used in tandem with the Multi-Layer Range Verifier (MLRV) is a fast and convenient tool for beam QA. With one step, the PBA software acquires, stores, and visualizes data while extracting key parameters for easy comparison with reference measurements. The system requires only seconds to collect a full range of beam energies, and can detect very small deviations from nominal. The tool accurately characterizes changes in mean energy, energy spread, and the peak/background ratio.

The MLRV can also measure delivered charge with high accuracy, providing an additional check on dose delivery.

> *"With one step, the PBA software acquires, stores, and visualizes data while extracting key parameters for easy comparison"*

When used in combination with a comprehensive QA program,. The PBA/MLRV tool allows daily verification of beam characteristics with minimal effort

16K Pixel Dose Imager

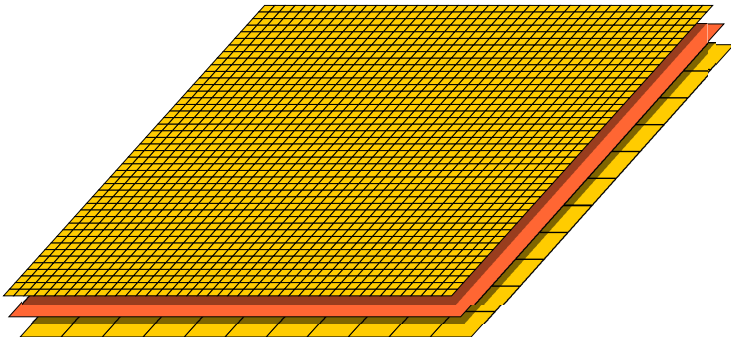
High resolution detector for verification of PBS dose patterns

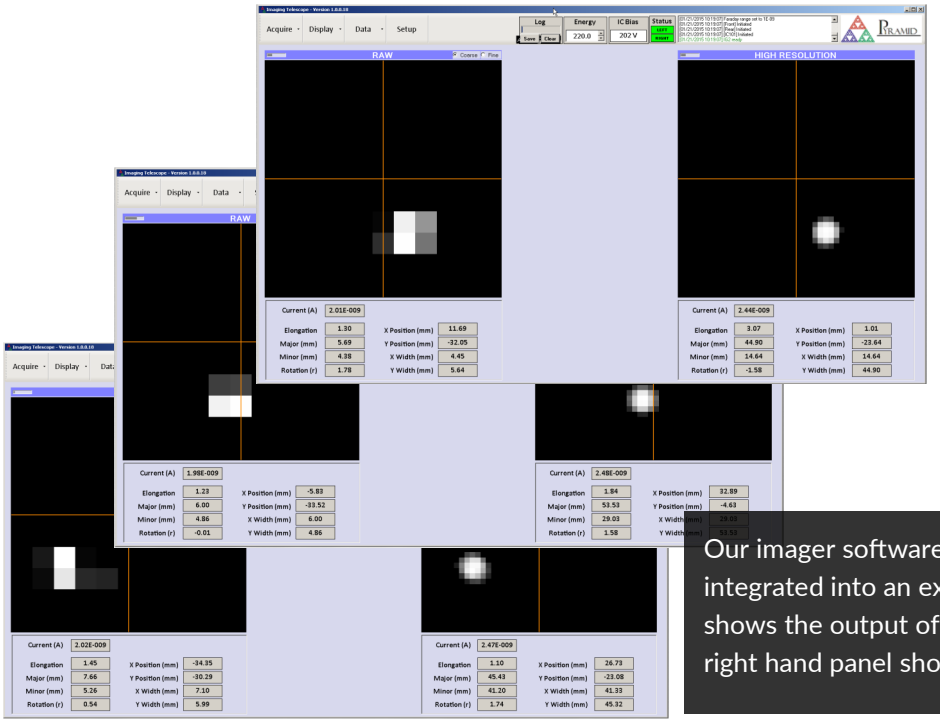
Comprehensive quality assurance means knowing the position and shape of the beam spot during an irradiation sequence, spot by spot. This requires a sensor with large area placed at the isocenter plane. A pixilated readout is preferred as this can reveal problems with the shape of the beam that are not visible using strip readout devices. The new generation of small PBS beam spots means that high spatial resolution is required.

The combination of large active area and high resolution can result in a high cost, complex system with limitations on frame readout rate.

The new PX16K-25 solves this problem for PBS by combining a multiplexed high resolution sensing electrode with 2 mm pixels and a low resolution sensing electrode with 8 mm pixels into the same device. The result is high resolution 2-D sensing over a large area with good resolution, readout rates of 1 kHz or more, at an affordable cost.

The dual-resolution detector integrates two image planes to generate high-resolution output with the speed of a much lower resolution device.





Our imager software can be used directly, or integrated into an existing system. The left hand panel shows the output of the 7.8 mm detector plane. The right hand panel shows the output of the 2 mm plane.

Robotics/Patient Positioning

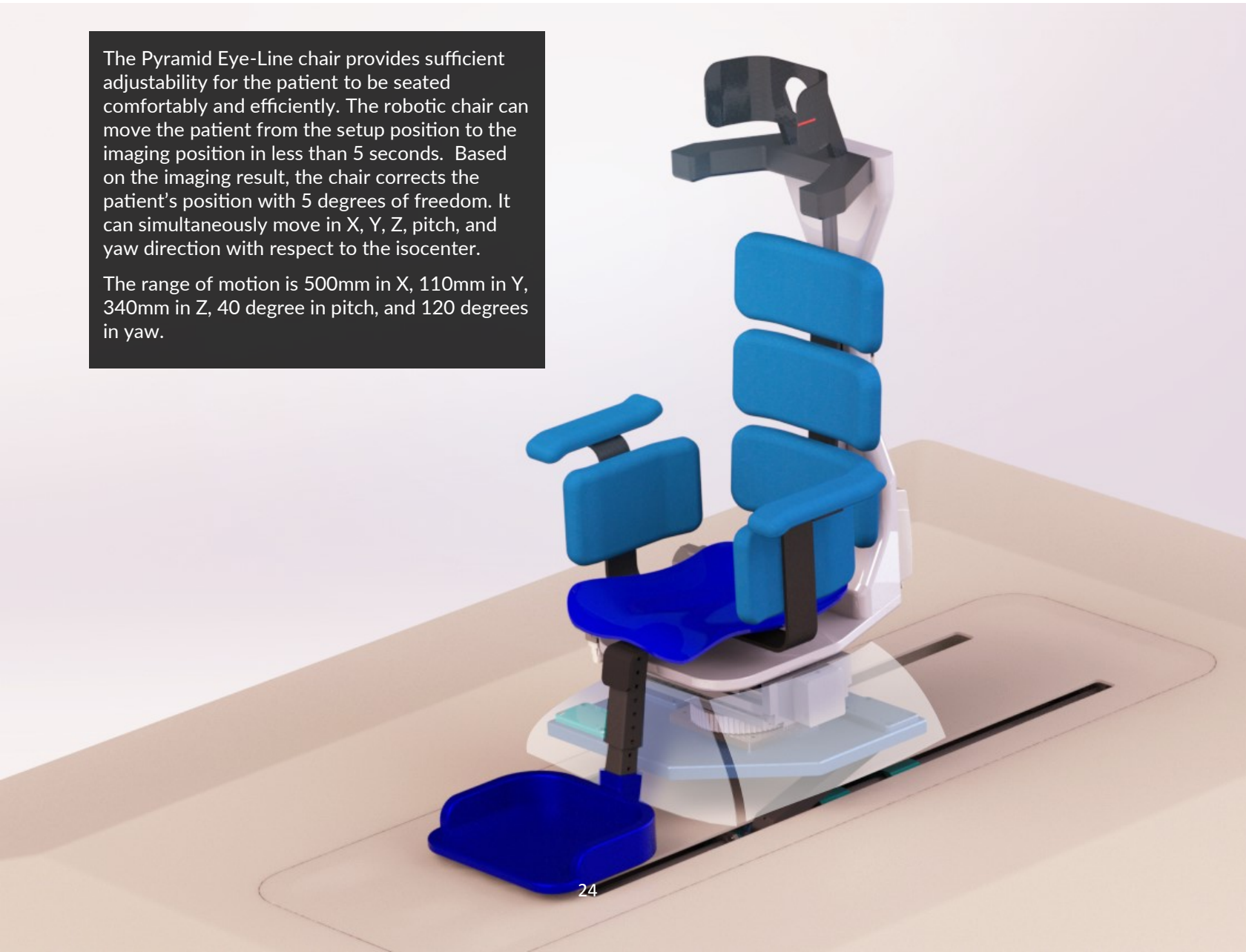
Efficient robotic solutions for accurate patient positioning

PBS is well suited to work with fixed beamlines, and the elimination of the complex gantry system helps to reduce system cost. The fixed beamline does require an increased emphasis on the patient positioning system (PPS). Pyramid has substantial expertise in the design of robotic subsystems, and can assist in the development of customized PPS solutions.

Pyramid has developed a dedicated positioner for the eye-line at Massachusetts General Hospital. This robotic chair allows rapid and convenient initial positioning of the patient, and then provide precise 5-axis fine positioning based on data from the imaging system. This basic design can be customized to specific needs.

The Pyramid Eye-Line chair provides sufficient adjustability for the patient to be seated comfortably and efficiently. The robotic chair can move the patient from the setup position to the imaging position in less than 5 seconds. Based on the imaging result, the chair corrects the patient's position with 5 degrees of freedom. It can simultaneously move in X, Y, Z, pitch, and yaw direction with respect to the isocenter.

The range of motion is 500mm in X, 110mm in Y, 340mm in Z, 40 degree in pitch, and 120 degrees in yaw.



Electronic Solutions

The Pyramid product range includes multi-channel electrometers for ionization chamber readout, interface units for scan magnet control and general applications and real-time controllers for map execution and interlocking. They can be used with Pyramid ionization chambers, magnet systems and other nozzle equipment, or with devices from other suppliers.

Multichannel electrometers	
	**I3200** The most successful multi-channel electrometer on the market, with over four hundred units sold. Thirty-two parallel gated integrator channels. Dynamic range from 100 µA down to 100 fA. Multiple integration modes, external trigger input, precision internal calibration current source. External continuity test signal. Pneumatic actuator control output. HV bias output. *PT applications: ionization chamber readout, profile grid readout, multilayer Faraday collector readout.*
	**I6400** Sixty-four parallel gated integrator channels plus separate dose plane input. Dynamic range from 100 µA down to 100 fA. Multiple integration modes, external trigger input, precision internal calibration current sources. Pneumatic actuator control output. I/O port for environmental sensors or other uses. HV bias output with loopback check. Full real-time controller capability including map execution, slave device control and interlocking. *PT applications: ionization chamber readout, profile grid readout, multilayer Faraday collector readout, treatment map real-time processing.*
	**I128/I128M** One-hundred and twenty eight parallel integrator channels plus separate dose plane input. Dynamic range from 550 nA down to 1 pA. Multiple integration modes, external trigger input, precision internal calibration current sources. Pneumatic actuator control output. I/O port for environmental sensors or other uses. HV bias output with loopback check. Full real-time controller capability including map execution, slave device control and interlocking. *PT applications: ionization chamber readout, profile grid readout, multilayer Faraday collector readout. treatment map real-time processing.*

I128S

A reduced function version of the I128, the I128S is ideal for diagnostic applications that require 128 channels of integration, but do not require the interlocking and dose plane functions of the I128.

PT applications: MLRV , PX2, telescope applications.

F3200E

Thirty-two parallel fast I-V converter channels. Dynamic range from 10 mA down to 100 pA. Time resolution down to 4 µsec. Multiple integration modes, external trigger input, precision internal calibration current source. Pneumatic actuator control output. HV bias output.

PT applications: fast ionization chamber readout, profile grid readout.

Other electrometers

IC101

Single channel gated integrator. Dynamic range from 200 µA down to 1 pA. Multiple integration modes, external trigger input, precision internal calibration current source. HV bias output.

PT applications: beam collector and beam stop readout.

I400

Four channel gated integrator with biased inputs. Dynamic range from 100 µA down to 100 fA. Multiple integration modes, external trigger input, internal calibration current source. Pressure and temperature compensation inputs.

PT applications: miniature ion chamber readout, quadrant BPM readout.

F460

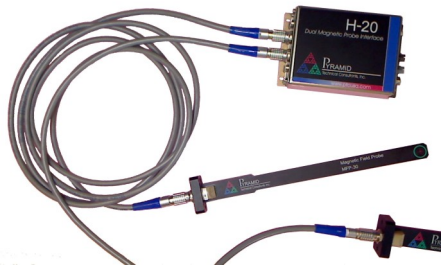
Four-channel current to voltage converter with four independently adjustable current ranges on each channel, 1 mA, 100 µA, 10 µA, 1 µA). Dynamic range 1 mA to 100 pA. 250 kHz digitization. Precision internal calibration current sources. Optional bias high voltage output. Optional servo controller.

PT applications: fast ion chamber readout, quadrant BPM readout, general fast current measurement .

Electronic Solutions (continued)

Pulse counting	
	**C400** Four-channel detector controller, suitable for fast scintillation detectors. 150 MHz bandwidth window discriminators, 100 MHz counters, HV and pre-amp power supplies. Gate input and output, monitor outputs and encoder input. Automated pulse height distribution measurement. *PT applications: beam loss monitor readout.*

Real-time controllers	
	**A560** Real time controller with ten fiber optic loop ports, each supporting up to fifteen slave devices. High throughput Ethernet interface supporting TCP/IP and UDP. Peer to peer connection capability. Built-in interlocking. *PT applications: system integration, map execution and*
	**A360** Cost-effective loop controller. Two fiber optic loop ports, each supporting up to fifteen slave devices. High throughput Ethernet interface supporting TCP/IP and UDP. *PT applications: small system integration, servicing, development.*

Magnetic field measurement	
	**H20** Two-channel Hall probe system with high precision +/-2.8T MFP-30 probe. Fast monitor analog outputs and field control option. *PT applications: scan magnet field measurement, general beamline magnet measurement, field control for hysteresis compensation.*

General I/O

M10

General-purpose precision I/O interface. M10C version with programmable 20 mA current source.

PT applications: accelerator current control, scan amplifier control, general magnet power supply control, helium supply control, general distributed control purposes.

M40

General-purpose high-density precision I/O interface.

PT applications: accelerator current control, scan amplifier control, general magnet power supply control including multiple channel supplies, general distributed control purposes.

X32

Interface to two-channel IECO scan amplifier and LEM current sensors.

PT applications: scan amplifier control.

Other products

HV1-4

Four-channel hardware comparator system for confirmation that high voltage bias is being delivered to an ionization chamber. Selectable threshold voltages. Safety relay outputs, and monitor port suitable for an M40.

PT applications: ionization chamber interlocking.

N2400

Twenty-four channel actuator driver (suitable for 24 VDC solenoid-driven pneumatic actuators) with full front-panel manual override capability.

PT applications: beamline automation.

Useful constants

Speed of light	299792458	m s-1
Proton charge	1.6021766E-19	C
Proton mass	1.6726218E-27	kg

Properties of proton beams

Proton Energy (MeV)	Beta (v/c)	Magnetic Rigidity (Tm)	Range in water (cm)	Typical IC gain (mm-1 air gap)
30	0.2470	0.7977	0.884	61.2
40	0.2830	0.9236	1.486	47.7
50	0.3140	1.0353	2.224	40.3
60	0.3415	1.1370	3.089	34.5
70	0.3661	1.2313	4.075	30.8
80	0.3885	1.3197	5.176	27.8
90	0.4091	1.4033	6.389	25.2
100	0.4282	1.4830	7.707	23.5
110	0.4459	1.5593	9.128	21.9
120	0.4625	1.6327	10.65	20.5
130	0.4781	1.7036	12.26	19.4
140	0.4928	1.7723	13.96	18.5
150	0.5066	1.8391	15.76	17.5
160	0.5198	1.9041	17.63	16.8
170	0.5322	1.9675	19.59	16.2
180	0.5441	2.0295	21.63	15.4
190	0.5554	2.0902	23.74	14.8
200	0.5662	2.1496	25.93	14.4
210	0.5765	2.2080	28.19	14.2
220	0.5863	2.2654	30.52	13.6
230	0.5958	2.3218	32.91	13.5
240	0.6049	2.3774	35.37	12.9
250	0.6136	2.4321	37.90	12.5

NOTES: