IC128-25LC

Ionization Chamber

User Manual

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3 Safety Information

This unit is designed for compliance with harmonized electrical safety standard EN61010-1:2000. It must be used in accordance with its specifications and operating instructions. Operators of the unit are expected to be qualified personnel who are aware of electrical safety issues. The customer's Responsible Body, as defined in the standard, must ensure that operators are provided with the appropriate equipment and training.

The unit is designed to make measurements in **Measurement Category I** as defined in the standard.

CAUTION. High voltage.
High voltage must be provided to this device for correct operation.
The high voltage is not exposed in the correctly assembled unit. Two independent voltages of up to +2000 V DC at 500 µA maximum can be supplied to the IC128-25LC via the SHV connectors. The are not accessible or hazardous live under the definitions of EN61010 but may nevertheless give a noticeable shock if misuse were to lead you to come into contact with them. The user must therefore exercise appropriate caution when servicing the device and when connecting cables. Power should be turned off before making any connections.

The body of the IC128-25LC should be grounded via its connection to the customer's beamline and/or mounting.

CAUTION. Radiation

After use in a high-energy particle accelerator beamline, the IC128-25LC may become activated. Do not work on the device, or move the device from a controlled area until it has been surveyed and declared safe by a qualified radiation supervisor.

Only Service Personnel, as defined in EN61010-1, should attempt to work on the disassembled unit, and then only under specific instruction from Pyramid Technical Consultants, Inc.

Some of the following symbols may be displayed on the unit, and have the indicated meanings.

--- ---	Direct current
(earth symbol)	Earth (ground) terminal
(protective conductor symbol)	Protective conductor terminal
(frame/chassis symbol)	Frame or chassis terminal
(equipotentiality symbol)	Equipotentiality
|	Supply ON
◯	Supply OFF
(electric shock triangle)	CAUTION – RISK OF ELECTRIC SHOCK
(warning triangle)	CAUTION – RISK OF DANGER – REFER TO MANUAL
(entrapment triangle)	CAUTION – ENTRAPMENT HAZARD

4 Models

IC128-25LC	Transmission ionization chamber with two orthogonal 128-strip readout electrodes and one integral dual gap dose plane section.
-AU	Gold coated readout electrodes instead of aluminium.
-2I	Additional independent dual gap integral plane electrode section. Refer to the IC128-25LC-2I datasheet for more information.
-SG	Small gap variant for higher beam current operation. Refer to the IC128-25SG datasheet for more information.

4.1 Differences from IC128-25

The IC128-25LC replaces prior model IC128-25. The IC128-25LC provides reduced noise on the integral plane due to reduced capacitance, and faster response from integral plane and strips due to smaller gaps. There is no change to readout strip geometry, external dimensions, beam path length or connector details.

Primary changes are as follows

	IC128-25	IC128-25LC
Integral section	One gap, 10 mm	Dual gaps 5mm each, connected to provide one combined signal.
		Reduced capacitance on integral electrode.
Strip readout sections	10 mm gaps	7 mm gaps
Spare Lemo 0B connector	Shorting plug required to ground an internal electrode plane.	No electrode connection to the spare connector.

5 Scope of Supply

I128-25LC model as specified in your order.

Lemo 0B four pin blanking plug.

USB memory stick containing:
IC128-25LC Data sheet
IC128-25LC User manual
Test data

High quality re-usable shipping case

Optional items as specified in your order.

6 Optional Items and Consumables

6.1 Readout electronics

I128-XP20 128-channel electrometer with integral plane readout channel and +2kV bias supply. Two required to read out one IC128-25LC.

6.2 Signal cables and cable accessories

6.2.1 Individual cables

CAB-D44F-25-D44M   Cable, 44-way screened, DSub 44-pin female to DSub 44-pin male, 25' (7.6 m). Eight needed per IC128-25LC. Other lengths available.

CAB-D44F-25LN-D44M   Cable, 44-way screened with anti-triboelectric layer, DSub 44-pin female to DSub 44-pin male, 25' (6.1 m). Alternative to standard cable, eight needed per IC128-25LC. Other lengths available.

CAB-L304M-25LN-L304M   Cable, 4-way screened with anti-triboelectric layer, Lemo 304 4-pin male to Lemo 4-pin male, 25' (7.6 m). One needed per IC128-25LC (single integral plane version). Other lengths available.

CAB-SHV-25-SHV Cable, coaxial HV, SHV to SHV, 25' (7.6 m).   Two or four (loopback configuration) needed per IC128-25LC. Other lengths available.

CAB-D9M-25-D9F Cable, multiway, DSub 9 pin male to DSub 9 way female, 25' (7.6 m). One or two (redundant sensor readout configuration) needed per IC128-25LC.

PLG-L304M-IC128 Shorting plug, Lemo 304 4-pin male.

6.2.2 Cable sets

CAB-SET-ICA-25 Cable set 25' comprising qty 4 CAB-D44F-25-D44M , qty 2 CAB-SHV-25-SHV, qty 1 CAB-D9M-25-D9F.

CAB-SET-ICB-25 Cable set 25' comprising qty 4 CAB-D44F-25-D44M , qty 1 CAB-L304M-25LN-L304M , qty 2 CAB-SHV-25-SHV, qty 1 CAB-D9M-25-D9F.

CAB-SET-ICALN-6.6   Cable set 6.6' low-noise comprising qty 4 CAB-D44F-6.6LN-D44M , qty 2 CAB-SHV-6.6-SHV, qty 1 CAB-D9M-6-D9F.

CAB-SET-ICBLN-6.6 Cable set 6.6' low-noise comprising qty 4 CAB-D44F-6.6LN-D44M , qty 1 CAB-L304M-6.6LN-L304M , qty 2 CAB-SHV-6.6-SHV, qty 1 CAB-D9M-6-D9F.

One each of set A and set B is required to connect one IC128-25LC to two I128-XN20 electronics units.

6.3   Consumables

DES_PK_IC128   Pack of four desiccant sachets (sufficient for one desiccant replacement cycle).

7 Intended Use and Key Features

7.1 Intended Use

The IC128-25LC is intended to provide position, shape and intensity readout of high-energy ion beams, nominally proton beams in the energy range 30 to 350 MeV and typical beam current range 100 pA to 100 nA. It will form a part of a complete beam dosimetry suite in a particle accelerator system, and will generally form part of the treatment room nozzle in a particle therapy system. It is designed to be read out by a pair of the matching I128 electronics units, however any electronics able to measure very small currents on multiple channels can be used.

The IC128-25LC performs an almost non-invasive measurement of the ion beam due to its use of very thin film electrode and window materials. The ion beam passes through the device leaving measureable amounts of ionized gas in the electrode gaps, but the total energy deposited is tiny compared to the beam energy. The amount of scattering the beam receives is very small and can be neglected for most purposes.

A particle therapy dosimetry system requires two independent integral plane measurements of the dose delivered by the ion beam. Typically a pair of IC128-25LC is used to provide this redundancy, and it also provides redundancy in position readout. The duplicate position readouts, together with a knowledge of the geometry allow the trajectory of the ion beam to be reconstructed. The IC128-25LC-2I includes a second integral plane section within the same body which provides a single unit dosimetry solution. Refer to the IC128-25LC-2I datasheet and user manual for more details.

The operating environment should be clean and free of vibration and electrical interference. Users should be familiar with low current measurement and the general handling of sensitive equipment.

7.2 Key Features

- Large active area and high position resolution. Two axis position and integral dose in a single unit.

- Dual gap integral plane sections combine good sensitivity with fast, linear response over a wide beam current range.

- Very low scattering.

- Operation with atmospheric air or flow-through gas.

- Bias voltage up to 2 kV.

- Bias voltage loopback

- Hermetically sealed with built-in desiccant.

- Air or flow gas filling.

- Integrated redundant sensors for temperature, pressure and humidity.

- Compatible with the I128 electrometer.

8 Specification

Beam compatibility		
	Species	Protons, deuterons, helium ions, carbon ions
	Energy range	30 MeV/nucleon to 500 MeV / nucleon
	Beam current density	Up to 30 nA cm^{-2}, protons. The limit is not fixed but depends upon how much recombination is tolerated. The amount of recombination can be modified by selection of high voltage setting and gas fill.
Sensor		
	Type	Parallel plate dual ionization chamber with two multistrip cathodes and integral plane (dose) cathode.
	Sensitive area	250 mm by 250 mm
	Sensitive volumes	Integral plane section two 5 mm gaps (10 mm effective total)
		Strip cathode Y section 7.0 mm gap.
		Strip cathode X section 7.0 mm gap.
	Readout strip geometry	128 strips, equal width 1.89 mm on 2.00 mm pitch.
	HV bias range	Up to 2000 V.
	HV configuration	Two independent bias voltage inputs, each with loopback of voltage for validation
Beampath materials		
	Layers	1. 12.5 μm polyimide window with 0.1 μm Al both sides 11.9 mm fill gas 2. 12.5 μm polyimide HV electrode with 0.1 μm Al both sides 5.0 mm fill gas (active gap dose) 3. 25 μm polyimide strip electrode with 0.1 μm Al both sides 5.0 mm fill gas (active gap dose) 4. 12.5 μm polyimide HV electrode with 0.1 μm Al both sides 7.0 mm fill gas (active gap position) 5. 25 μm polyimide cathode electrode with 0.1 μm Al both sides 7.0 mm fill gas 6. 12.5 μm polyimide window with 0.1 μm Al both sides 8.0 mm fill gas 7. 12.5 μm polyimide window with 0.1 μm Al both sides
	Water-equivalent thickness (protons)	200 μm including windows and atmospheric air filling.

	Gas fill	Humidity-free air (semi-sealed operation) or flow gas.
Environmental sensors		
	Sensors	Two redundant sensor circuits monitor internal environment.
	Measured parameters	Temperature, pressure and humidity of internal gas filling.
Consumables		
	Desiccant	Four desiccant sacs, field replaceable.
Mechanical		
	Insertion length	44.0 mm window to window, 50.4 mm body face to body face.
	Orientation	Operable in any orientation, and with beam entering in either direction.
	Gas connections	Push-fit self-sealing to suit 1/8" plastic tube.
	Weight	5 kg (11 lb)
	Operating environment	Clean and dust-free 5 to 35 C (15 to 25 C recommended), < 70% humidity, non-condensing Vibration should be minimized. Ambient sound should be minimized below 300 Hz to prevent microphonic pickup.
	Shipping and storage environment	Special transport case must be used. 5 to 40 C < 80% humidity, non-condensing Vibration < 1g all axes, 0.1 to 100 Hz.
	Dimensions	See figures 1 to 3 for dimensions
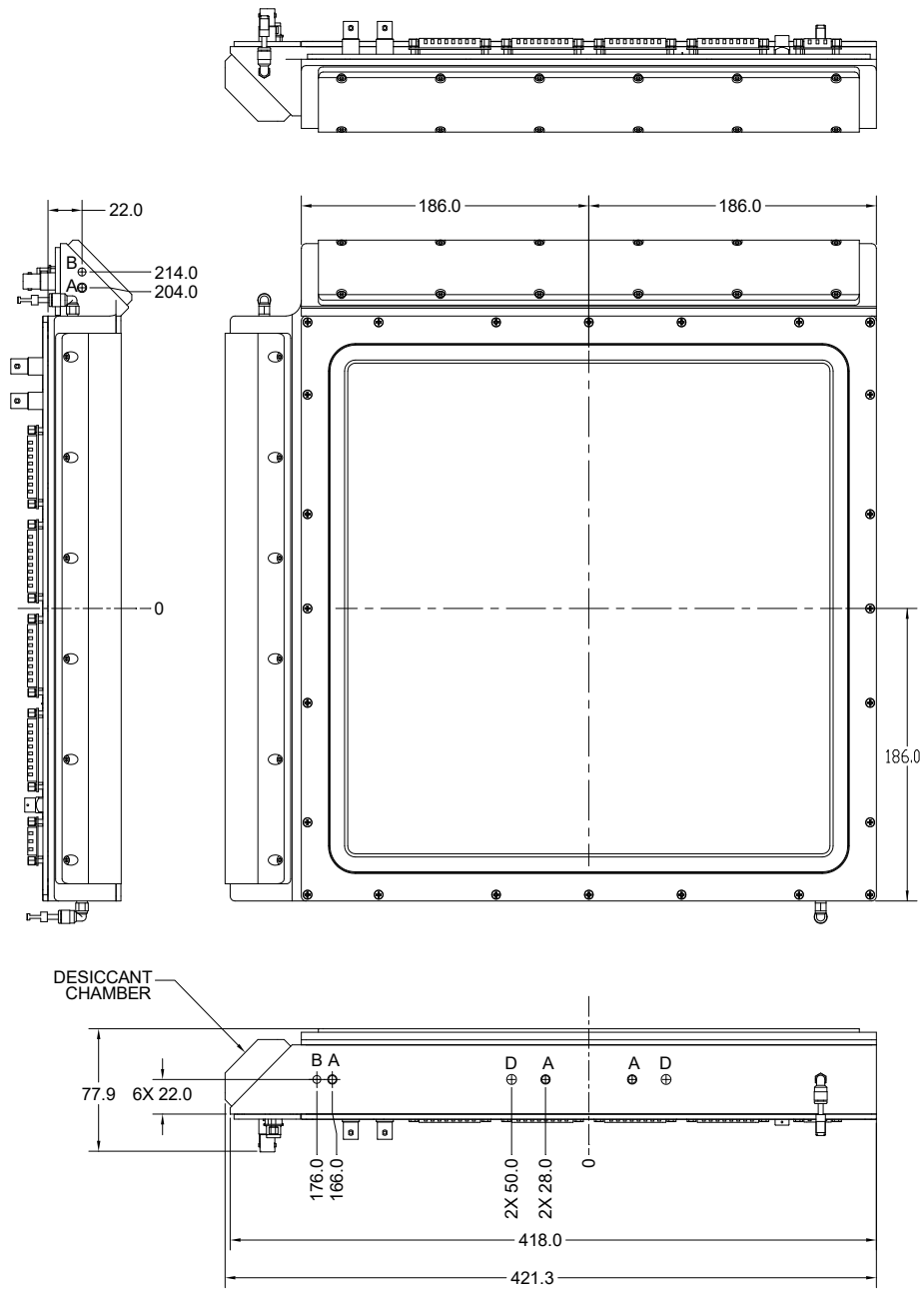
Figure 1. IC128-25LC dimensions (mm) and mounting face 1.

10X 22.0

2X 165.0 ⊕ C
2X 150.0 ⊕ A

2X 80.0 ⊕ A
2X 65.0 ⊕ B
2X 50.0 ⊕ D

420.3

418.0

6.40
4X Ø6.35 x 10
FIDUCIAL
MARKED "D"
⊕ D

4X Ø5.05 x 6
LOCATING HOLE ⊕ B
MARKED "B"
⊕ A

8X M6X1.0 x 10
MOUNTING HOLE
MARKED "A"
⊕ A

2X 5.05x 6 ⊕ C
LOCATING SLOT
MARKED "C"

44.0
BETWEEN
ENTRY & EXIT WINDOWS

50.4
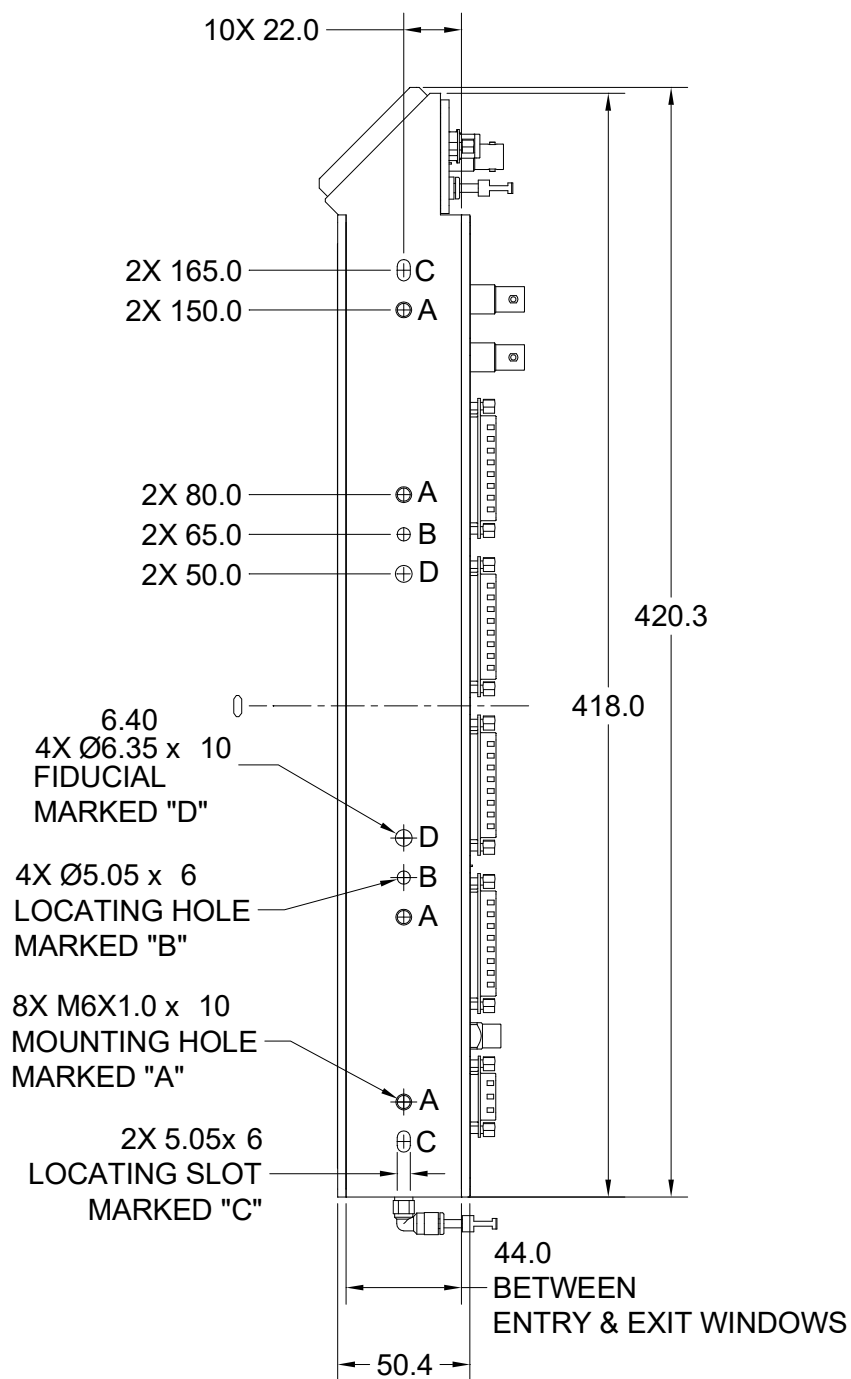
Figure 2. IC128-25LC mounting face 2.

372.0 SQ

312.0 SQ

GAS FITTING
1/8" TUBE
ROTATABLE
SHOWN WITH PLUG

HV INPUT & MONITOR
(SHV)

STRIP OUTPUT
128 CHANNELS/AXIS
(DSub 44 HD)

DOSE OUTPUT
(LEMO 0B)

ENVIRONMENT CONTROL
& OUTPUT
(DSub 9)

GAS FITTING
1/8" TUBE
ROTATABLE
SHOWN WITH PLUG
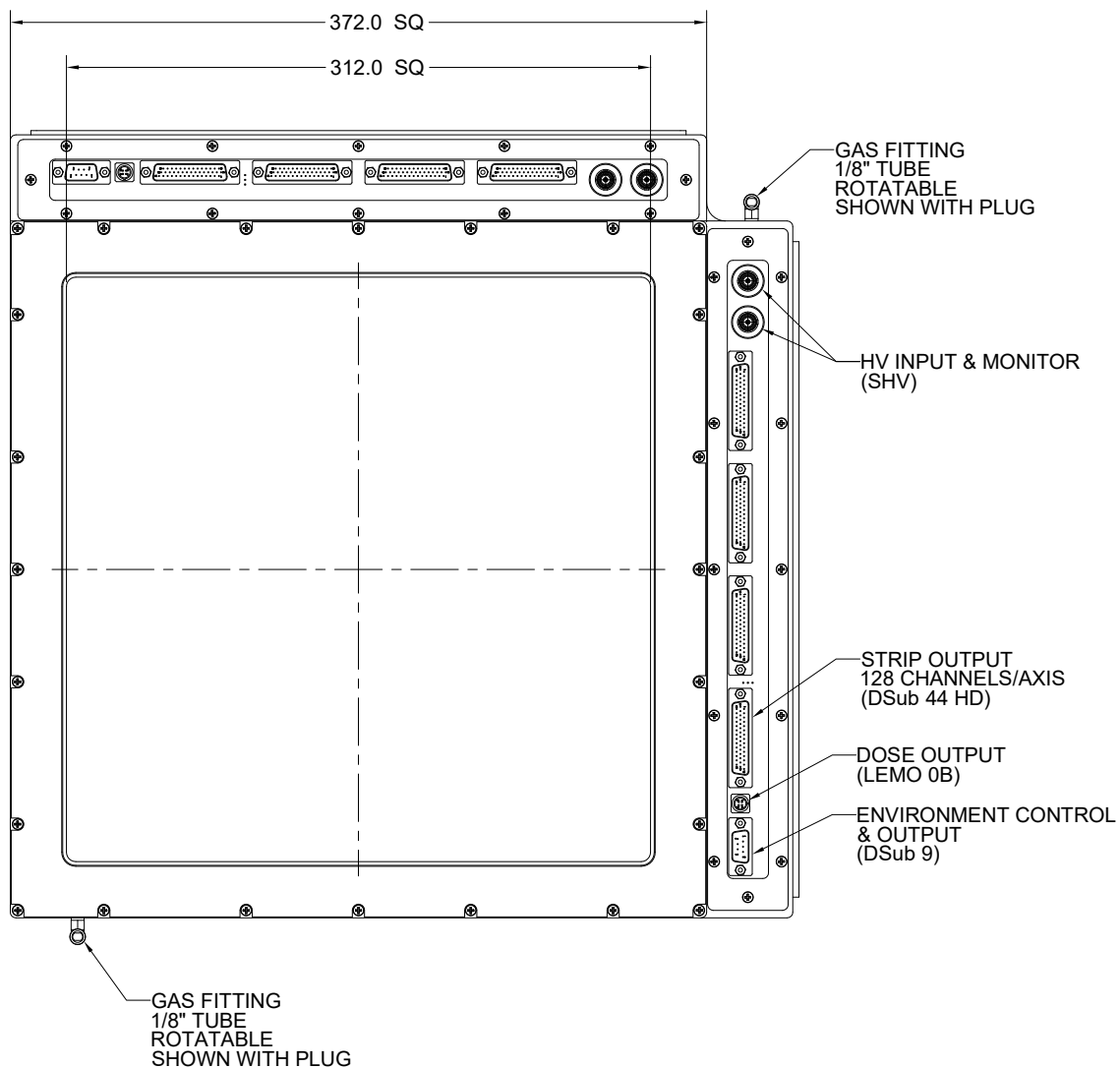
Figure 3. IC128-25LC connectors face (nominal beam entry face)

9 Installation

9.1 Preparation and handling

The IC128-25LC is shipped in a special protective transport case with plastic covers protecting the film windows.

Figure 4. Shipping case

The interior gas volume of the IC is hermetically sealed, and maintained at near zero humidity by the built-in desiccant. Open the case and check the IC on receipt, but leave it in the case for protection until you are ready to use it. Remove the unit carefully from the case, taking care not to strain the gas connectors. Leave the covers that protect the windows in place. The IC is not heavy, but it is delicate, and must be handled carefully.

CAUTION – Delicate equipment

We recommend keeping the window covers on until the IC128-25LC is installed in its operating position in a clean, dry area. The windows can resist moderate pressure from fingers, but could be punctured by sharp objects like hand tools. Excessive inward pressure on the windows may allow the window to push on the active electrodes inside, which may degrade gain uniformity.

Any service work must be carried out in a clean, dry environment.

9.2 Mounting

9.2.1 Standard mounting arrangement

The IC128-25LC should be mounted with its electrode planes orthogonal to the particle beam direction. The beam may enter on either face, and the IC may be mounted in any rotational orientation relative to the beam axis. In most particle beam systems, there are relatively independent "X" and "Y" axes orthogonal to the beam direction defined by the ion optical elements like dipole magnets, and the IC will be positioned so that its two sensing directions align with X and Y. The mounting must be aligned accurately with the beamline ion optical elements that define X and Y, be rigid and not subject to vibration. You may require that the mount provides position adjustment in the two transverse axes, so that the IC transverse position can be adjusted to remove physically any offsets. However, a simple arithmetic offset correction by software is generally sufficient. It is simpler to make a fixed mount that is compact and rigid.

Mounting face 1
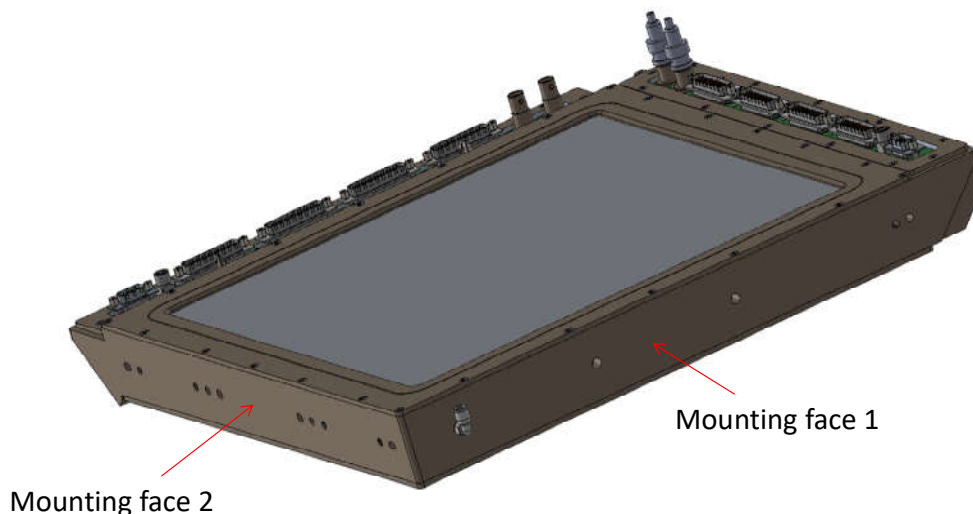
Mounting face 2

Figure 5. IC128-25LC mounting faces.

The standard arrangement involves fixings to the two mounting faces, leaving a clearance as necessary for the gas fitting. A stabilizing attachment can be made to the features at the opposite corner. There are M6 tapped holes, 5mm dowel holes and fiducials on the IC128-25LC housing, as shown in figures 1 and 2. Figure 6 shows an example mounting.
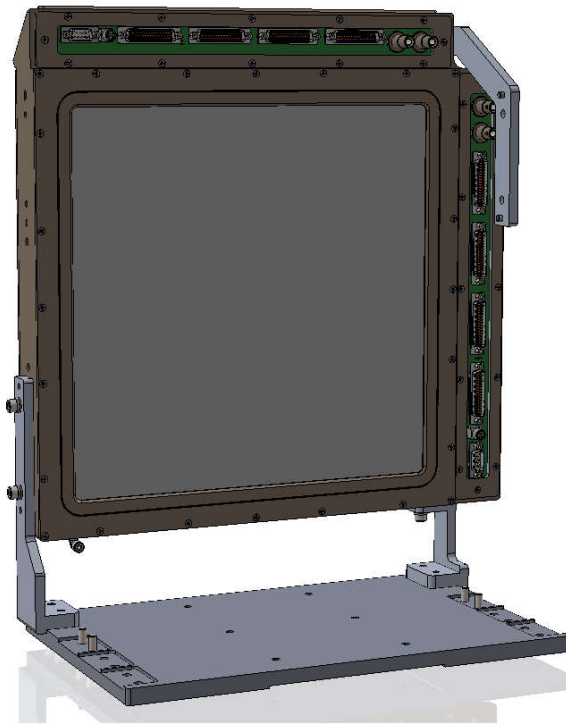
Figure 6. Example mounting scheme.

If the IC is being used in a particle therapy nozzle, then the beam exit needs to be kept clear, so the beam should enter on the connectors face, so that the cables can route naturally back along the beamline. Figure 7 shows the beam's view on the entrance face of the IC for this arrangement. Assuming that mounting face 1 is at the bottom as shown, the right hand connectors read out the vertical sensing axis (horizontal electrode strips), and increasing strip number corresponds to increasing vertical position. The top connectors read out the horizontal sensing axis (vertical electrode strips) and increasing strip number corresponds to increasing distance to the right. The strip numbering assumes readout by I128 electrometers with strip 1 connected to channel 1 and so on.
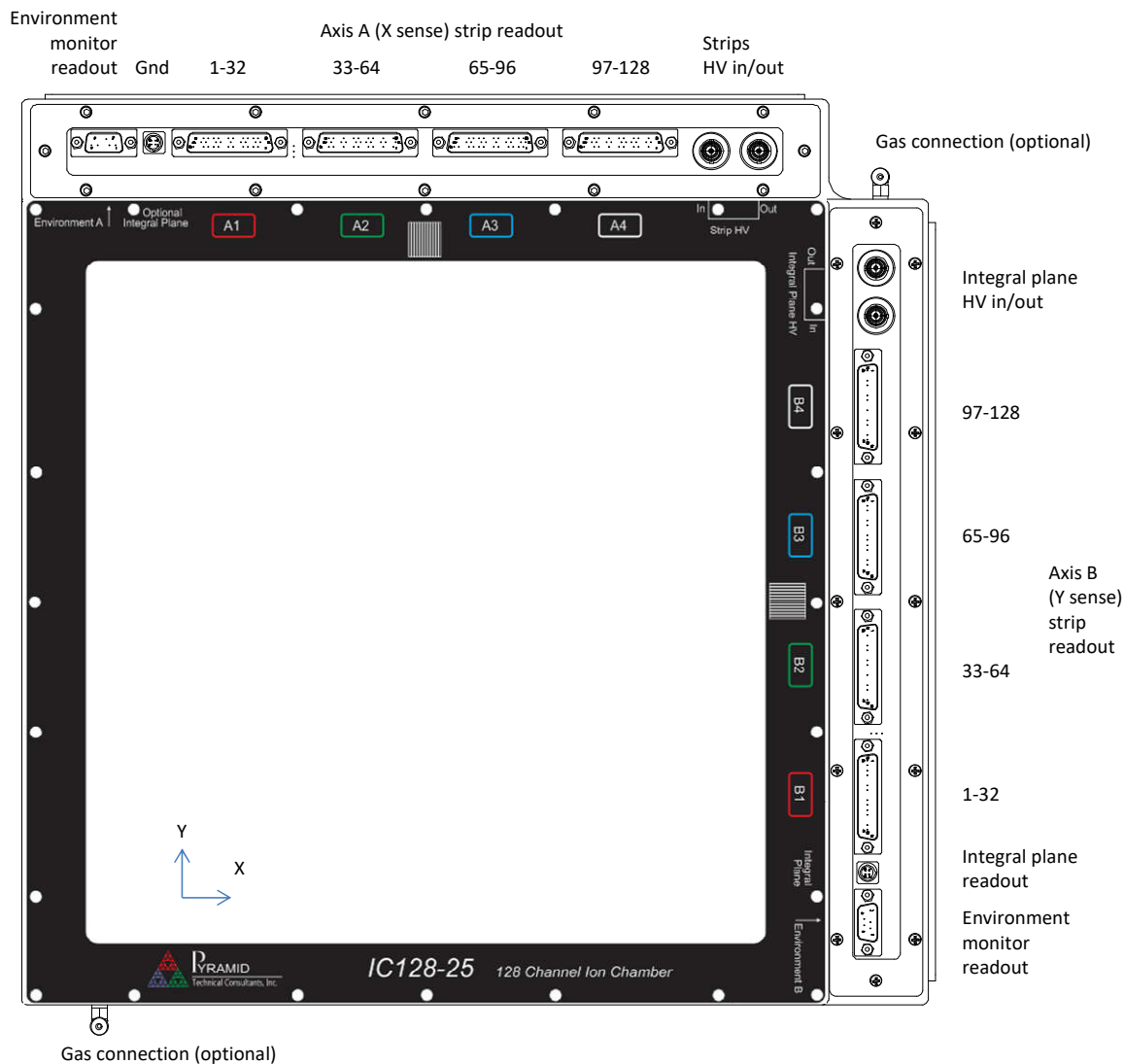
Figure 7. Beam entrance face in the standard orientation showing connection points.

Note that the sense of "X" and "Y" shown here is only illustrative and local. X and Y would typically be defined in beamline coordinates; the correspondence between readout in IC128-25LC strip units and beamline coordinates depends on the mounting of the chamber, and any offsets discovered during physical surveys.

When the beam enters through the face shown in figure 7, the sequence of electrodes that the beam passes through is as shown in the following figure.
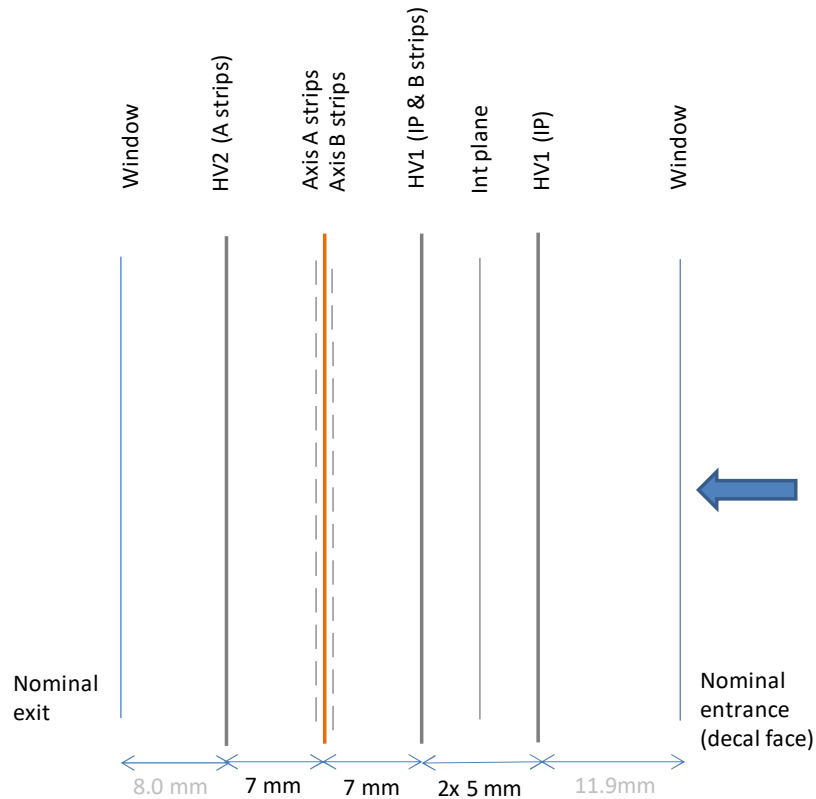
Figure 8. Sequence of electrode foils for nominal beam direction.

9.2.2   Dual IC mounting

The very beam low scattering produced by the IC128-25LC allows you to use two chambers in series. This provides redundancy in the position and intensity measurements, and if the chambers are spaced apart by about 100 mm or more, the beam trajectory and divergence can be recovered with good precision. The two IC128-25LCs can to be rotated 180 degrees about the nominal beam axis relative to each other as shown in the following figure, to reduce cable interference.
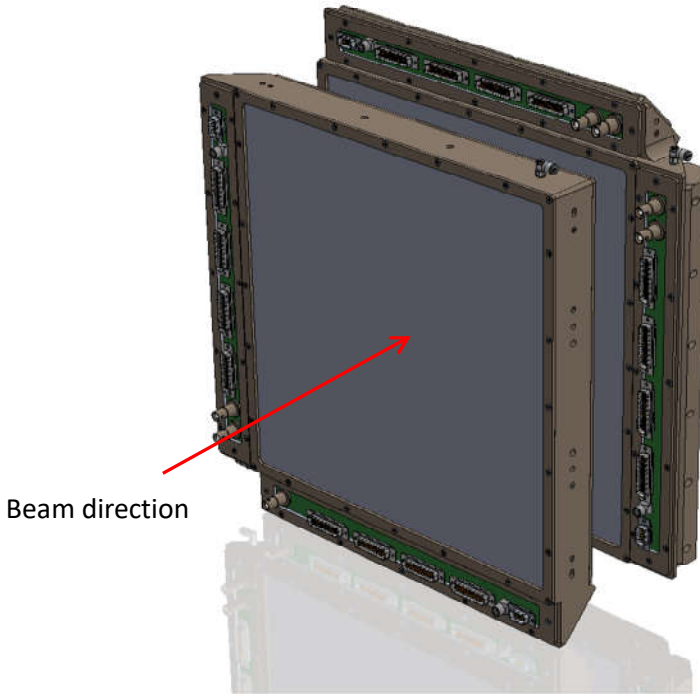
Beam direction

Figure 9. Two IC128-25LC in series.

The mapping of readout direction sense to strip number will of course be reversed in the upstream IC, and this must be accounted for in the conversion of strip number to absolute position.

9.2.3   Beamline coordinate conventions

In the conventional beamline optics convention, z is always directed along the beam forward direction (thus tangent to beam trajectory when in a dipole field), the horizontal (X axis) is defined as orthogonal to z and outwards along the radius of curvature of local dipole magnets, and vertical (Y axis) being the orthogonal direction to Z and X (and thus the non-dispersion direction of dipole magnets. This is illustrated in figure 9. Note that this convention makes the X direction sense opposite to that shown in figure 7. Check carefully to ensure you know how the IC orientation you use relates to your coordinate system convention.
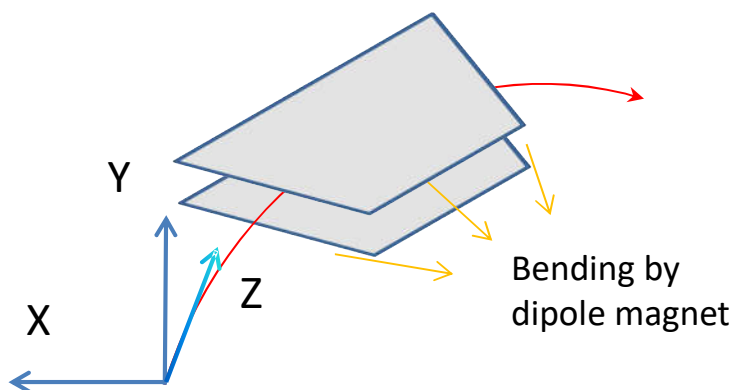
Figure 10. Ion optics standard coordinate convention (Transport code).

9.3   Cabling and services

9.3.1   Electrical connections

The following cable connections are required:

Function	*Connector on the IC128-25LC*
Axis A readout	Four DSub HD 44-pin male
Axis B readout	Four DSub HD 44- pin male
Bias voltage input – strips	SHV receptacle
Bias voltage readback – strips (optional)	SHV receptacle
Bias voltage input – integral	SHV receptacle
Bias voltage readback – integral (optional)	SHV receptacle
Environment sensors (second optional)	Two Dsub 9- pin male
Integral plane readout	Lemo 0B 4-pin female
Optional integral plane (short with grounding plug provided)	Lemo 0B 4-pin female

The bias voltage readback outputs are intended for systems that can provide independent monitoring of the voltage delivered and the voltage returned. If this is not available, then the readback SHV connectors can be left unconnected.

If independent biasing of the integral plane readout and the strip readout is not required, then a single bias input voltage can be connected, and the corresponding output can be connected to the other input using a short link cable.

The IC128-25LC has an unused four-pin Lemo connector on the axis A connector block labeled "Optional Integral Plane". This connector is used on the IC128-25LC-2I but not on the IC128-

25LC. Although there is little risk if no connector is fitted, we recommend fitting the shorting connector provided to avoid confusion.

⚠️

CAUTION – Risk of arcing damage

All electrodes within the IC128-25LC must be connected to electrometer inputs, HV power supplies or ground. Any electrode left floating could charge up over time from beam-created ionization of the fill gas, and internal arcing may result. This may damage the electrode surfaces and readout traces. Ensure all connections are made. Any electrode connectors that are not being read out or biased should be fitted with shorting plugs.

9.3.2   Readout with the I128 electrometer

Any suitable electronics system can be used to read out the IC128-25LC. The Pyramid I128 electrometer is specifically intended to read out the IC128-25LC, however. Two I128-XP20 are required per IC128. This provides 256 channels of signal processing for the strips, two integral plane readouts (only one is necessary for the normal IC128-25LC configuration), two high voltage bias supplies giving up to 2 kV, high voltage readback sensing and readout of both sets of environment monitors. The I128 can perform various real-time computations on the data, and it has a set of digital and analog I/O and interlock relays that can be used to control a beam delivery system.
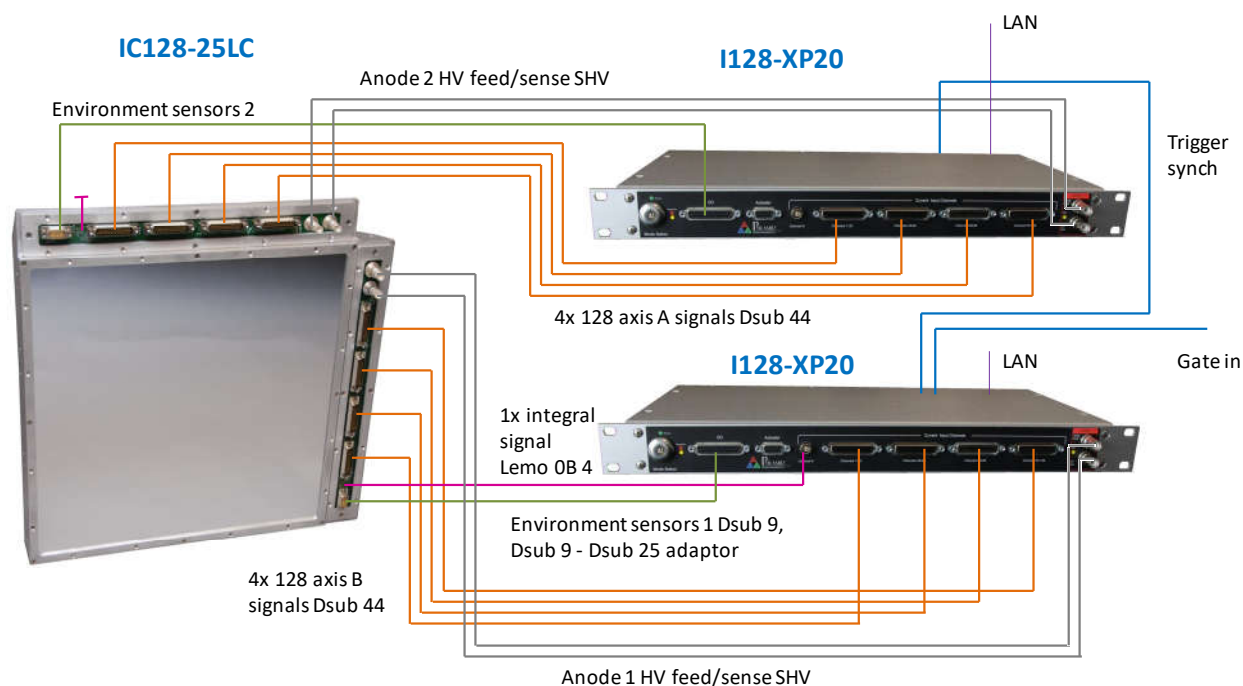

Figure 11. Schematic connection arrangement to two I128-XP20 electrometers.

The location of the I128 must reconcile the conflicting requirements to keep the signal cables short for best noise performance, but keep the electronics out of the radiation field. A maximum cable length of 10 m (33') is recommended. Longer cables will still function, but signal to noise performance will degrade. Low-noise signal cables with special anti-triboelectric noise coatings are recommended to minimize noise due to cable movement and vibration, although good-quality conventional screened cables may suffice in some cases. Low-noise cables are available to special order from Pyramid Technical Consultants, Inc.

9.3.3   Cable routing

Ionization chambers create very small current signals, so you must give careful attention to screening, grounding and routing of cables. Good grounding practice and the use of good quality screened cables will minimize noise injection by electrical coupling. However it is possible to pick up interference from AC magnetic fields. These may be present if the ionization chamber is operated in the vicinity of fast beam scan magnets or switching magnets. The fields can induce small currents in the cables between the IC and the electrometer. Because the ionization chamber appears as a capacitance between the signal lines and the ground return path, the resulting interference on the signal appears as a differentiated version of the changing field, multiplied by a gain term related to the absolute field level. This gain factor arises from yoke saturation in the source magnet(s) leading to a non-linear increase in their stray fields.

If you observe interference like this, you should re-route the cables away from regions where a high stray magnetic field is present. As a further measure, the cables should be run in ducting that provides magnetic shielding, made of a high permeability material like soft iron or mu-metal.

9.3.4   Gas connections

The following service connections are required if you plan to use flow gas filling:

Function	*Connector on the IC128-25LC*
Fill gas in (optional)	Push fit connector for 1/8" flexible tubing
Fill gas out (optional)	Push fit connector for 1/8" flexible tubing

The IC128-25LC can be operated with dry air filling, in which case the plugs in the two gas connectors must be kept in place. If you wish to use flow gas, then one connector will be the input and the other the output. The gas in and out ports are interchangeable. Use clean 1/8" OD flexible pipe. There should be sufficient length on the return line to inhibit migration of atmospheric air back into the IC body.

CAUTION. Risk of damage by overpressure

The required flow rate for flow gas operation is very small. Take great care not to overpressure the IC128-25LC, which could damage or rupture the windows. The return line can be temporarily disconnected for initial flushing out atmospheric air, to reduce backpressure.

10 An Overview of the IC128-25LC

10.1 Ionization chambers

10.1.1   Signal formation

High energy ions pass through matter with relatively small lateral scattering and energy loss, but nevertheless leave a trail of ionization behind. In the ionization chamber the free charge that is created is separated by the applied bias voltage, with the positive air ions moving to the cathodes, which are grounded at the virtual earths of the readout preamplifiers, and the electrons (or negative ions formed by electron capture) moving to the anode. The resulting small current is measured by the readout electronics. The current from an individual ion is too small to measure, but for beam currents of a few 10's of pA or more, the aggregate current can be measured by sensitive electrometer electronics.
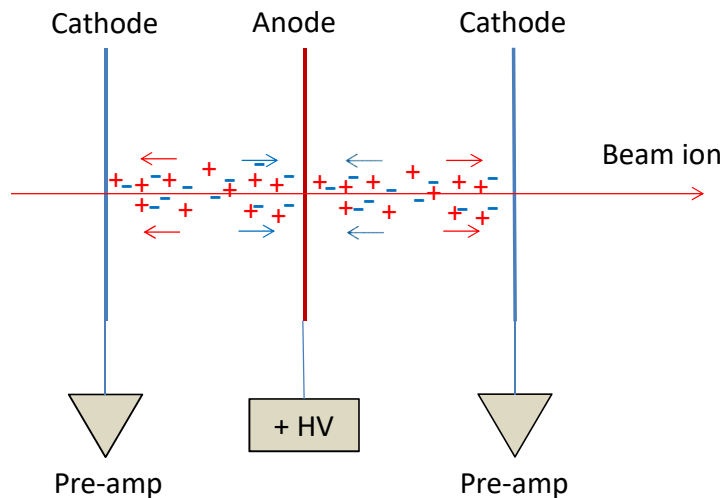
Figure 12. Ionization chamber signal formation.

The ionization chamber uses a parallel plate geometry to provide uniform gain over its active area. At higher applied bias voltages and with field intensifying geometry such as thin wires or points, the chamber would start operate in the proportional regime, where the signal is increased greatly by electron avalanching. This regime is generally avoided in high energy ion beamlines, because it is less stable, and the chamber is more prone to degradation from beam exposure.

The integral plane electrode (sometimes called the dose plane) collects charge over the whole active area of the IC and delivers it to a single readout channel. The strip electrodes partition the measured charge according to where it is formed across the readout area. The partitioning is linear and direct because the field is uniform in the gap. Although the readout strips on the cathodes are separated by very small gaps, all the induced signal and charge eventually arriving at

the cathodes is routed by the electric field onto the strips. Therefore you can safely assume that the effective strip width is the same as the strip pitch, and the conversion to physical units is given by multiplying a result in strips by the strip pitch.
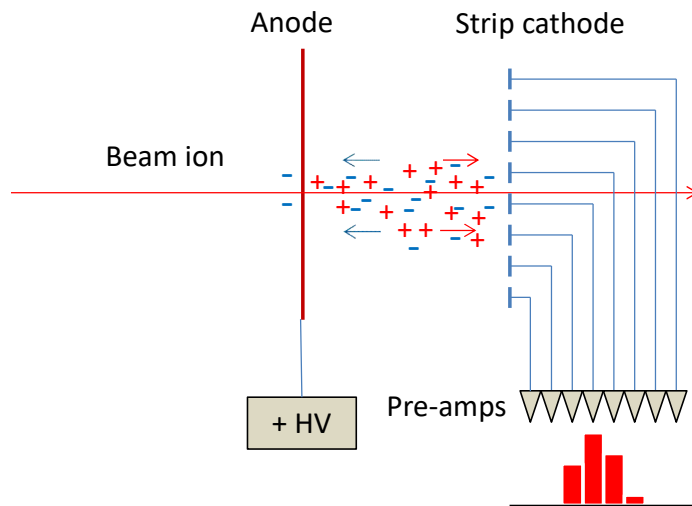
Figure 13. Signal partition on strip cathodes.

10.1.2 Pulsed beams

For DC or slowly varying ion beams, the signal measured on the cathodes will simply track the beam current, related by a gain factor. If your particle accelerator is a type such as a linac or synchrocyclotron that produces a series of shorts pulses, then the time response of the ionization chamber becomes important. The cloud of ion-electron pairs is produced essentially instantaneously by the passage of the high energy beam particle, but signal development only starts as the ions and electrons start to drift in opposite directions in the constant applied electric field.

The mobility of ions in air in the chamber electric field is about 30 m s-1 at 1000 V bias and 1 atmosphere pressure, and it varies directly with electric field and inversely with gas pressure. The mobility of free electrons is hundreds of times higher; electrons are generally collected in less than 1 µsec. The variation of electron mobility with field and pressure is more complex than for ions, but higher fields and lower pressures again increase mobility. Most electronics processing methods integrate the ion motion so that all the available signal is used. However some applications such as timing or fast control loops use fast processing which is sensitive to the initial electron movement. In this case it is necessary to prevent too many electrons being captured to form slower moving negative ions. Other gas mixtures than air can have much higher mobilities. Hydrogen and helium give high mobilities for example; while water vapour reduces ion mobility significantly.

Some typical ion and electron gap crossing times for dry air filling at one atmosphere pressure and for the IC128-25LC gaps are as follows:

Gap (mm)	Bias voltage (V)	Ion collection time (µs)	Electron collection time (µs)
5.0	1000	140	0.26
	1500	95	0.20
	2000	70	0.16
7.0	1000	270	0.43
	1500	180	0.34
	2000	135	0.29

The motion of the electrons and ions in the chamber field induces changing charges on the electrodes, which are the detectable signal. If electrons remain free, then 50% of the signal should appear very quickly, with the other 50% developing until all the ions are collected. However some fraction of the electrons will be captured by electronegative gas molecules such as O_2. The resulting negative charge carriers move at similar speed to the positive ions.

Overall, a time-resolved measurement of the IC signal shows a sharp initial spike due to electron movement, varying from 50% to 0% of the whole depending on the electron capture fraction, plus a slow tail due to the ion drift. The simulated example in figure 13 shows a case where the beam pulse is less than one microsecond, and two-thirds of the electrons are converted to negative ions.
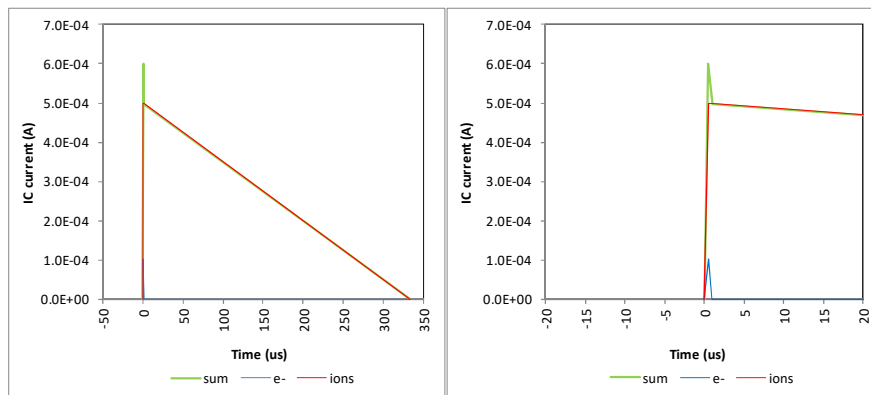
Figure 14. Example pulsed beam response.

Generally you require the total charge measured by the ion chamber for dosimetry purposes, so the electronics should be set up to trigger prior to the start of the pulse, and to integrate until all the ions have been collected.

Note that even if you are making measurements on DC beams, the ion collection time limits the speed of response to changes, for example to the particle beam being suddenly turned off.

10.1.3 Gain calibration

The energy to produce an ion-electron pair in the gas filling is almost constant for a given target species, and very small compared to the energy carried by the ion, hence the minimal effect on the beam.

Air	34.0 eV
Nitrogen gas	36.4 eV
Oxygen gas	32.2 eV
Argon gas	26.3 eV
Helium gas	42.7 eV

The amount of ionization per ion in the gas filling of the ionization chamber depends upon the gas composition (essentially constant if atmospheric air is used), the distance travelled through the gas, the pressure of the gas, the energy of the ion and its charge state. If the factors mentioned above are fixed by control or by calibration, for example against a Faraday cup collector, then the effective gain of the ionization chamber, (= chamber signal / ion beam current) is known at the particular energy, and the chamber can be used to give a good indication of beam current.

The approximate gain curves for the IC128-25LC with 5 mm and 7 mm electrode spacings, as a function of beam energy for protons in air at standard ambient temperature and pressure, is as shown in figure 15 below. Note that the 5 mm curve is the combined signals from the two halves of the integral plane section; in other words the section has the gain of a 10 mm gap combined with the response speed of a 5 mm gap.

⚠ CAUTION

If the IC128-25LC is used for critical dosimetry applications, then you must use accurate gain values referenced to traceable standards, and regularly validated.

If the IC is only being used to measure the position and shape of the beam, then we don't need to know the gain accurately, only that it is consistent across the chamber.
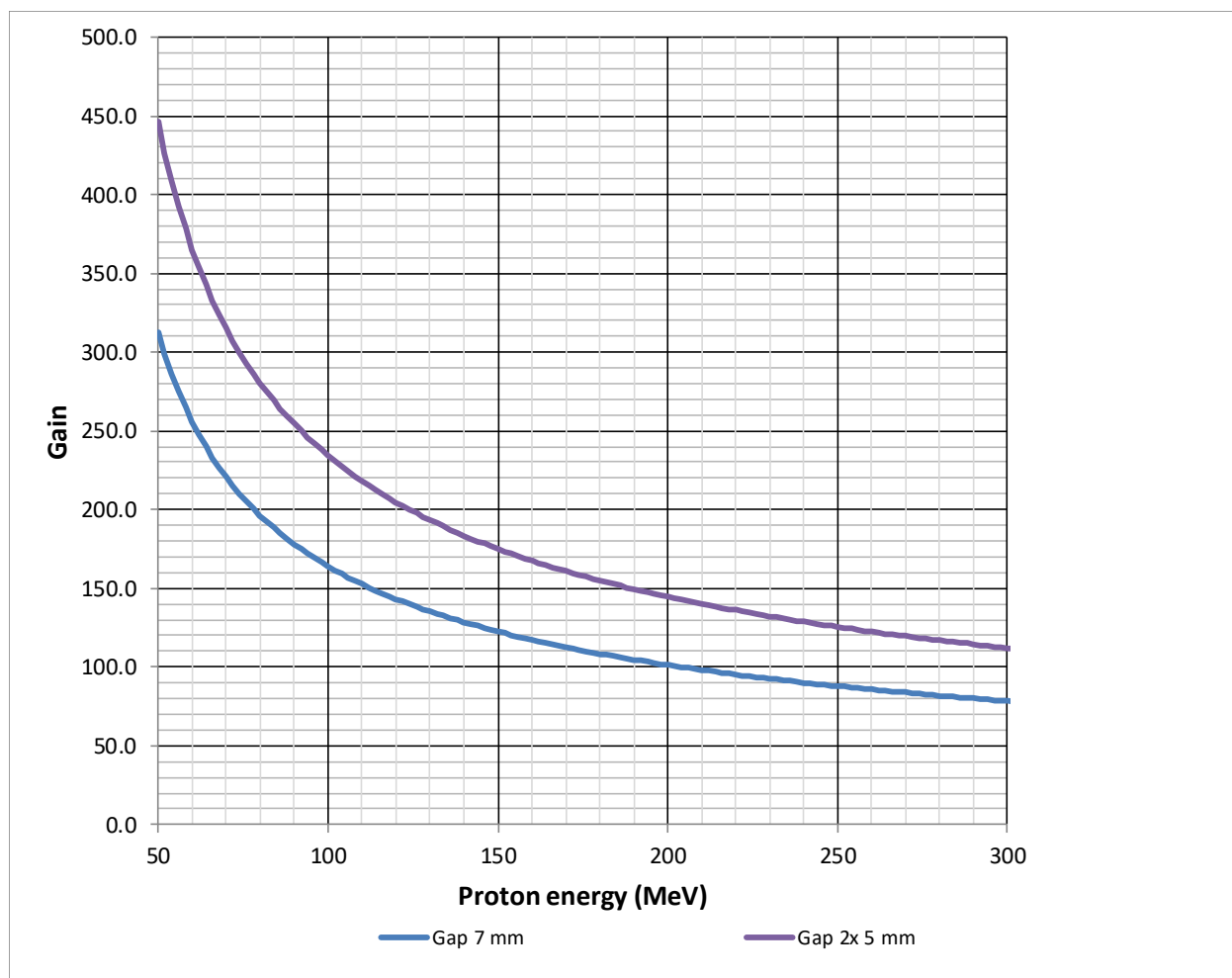
Figure 15. Approximate gain curves for the IC128-25LC, protons in air at SATP.

Since the gain at any beam energy is a function of the gas density in the electrode gaps, it has to be corrected for variation in pressure and temperature, relative to the gain at some reference pressure and temperature where it is known. For example, if you know the gain at standard atmospheric temperature and pressure (SATP; Temperature$_{SATP}$ = 298.15 K, Pressure$_{SATP}$ = 100000 Pa), then the actual gain for another air pressure and temperature is given by

Gain$_{ACTUAL}$ = Gain$_{SATP}$ *1/[(Pressure$_{SATP}$ / Pressure$_{ACTUAL}$) * (Temperature$_{ACTUAL}$ /

Temperature$_{SATP}$)]

Temperatures must be in Kelvin, pressures can be in any convenient absolute unit.

10.1.4 Effect of beam trajectory

The gain parameter assumes that the beam passes through the detector orthogonal to the electrode planes. If the beam passes through at an angle, then the ionized gas path is longer and thus a higher signal is produced. The strip readout will also see a broadened peak.
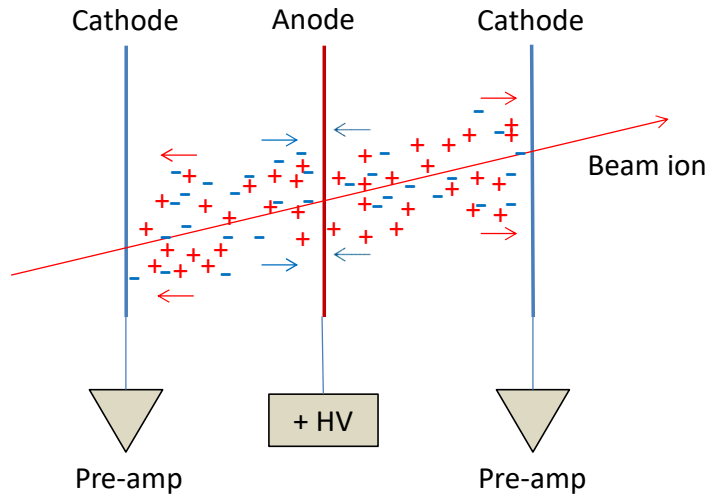
Figure 16. Increased path length and ionization from an inclined trajectory.

The chamber gain increases by a factor $\sqrt{1 + (\tan\alpha_X)^2 + \tan(\alpha_Y)^2}$ where α_X and α_Y are the angles of the beam in the two transverse axes to the normal to the electrode planes. For beam deflection angles used in high energy particle beam deflection systems, typically less than 7 degrees, the gain correction is small, less than 1.5%, and can often be ignored.

10.1.5 Recombination

The upper beam current measurement limit of the ionization chamber is set by recombination of the ions and electrons before they can be collected on the electrodes, which reduces the measured current. Recombination is a function of the local beam current density, the electric field strength, the gas composition and pressure. Very high current density may also initiate arcing in the chamber which may damage the electrodes.

Pulsed beam systems present the greatest challenges, because the peak beam current in the pulse maybe high. Using a higher bias voltage to increase the ion and electron drift velocities is the simplest mitigation. A smaller anode-cathode gap is also a good mitigation, but comes at the cost of lower chamber gain, and it becomes harder to achieve excellent gain flatness and highly stable operation. The 5 mm and 7 mm gaps of the IC128-25LC are a good compromise and are suited to most quasi-DC or moderate pulsed beam measurements.

At low current densities, corresponding to typical ion beam current densities up to around 10 nA cm^{-2}, recombination is negligible and can be safely ignored. The standard method to quantify the amount of moderate recombination is to run the same beam current at a range of IC bias voltages. A plot of the reciprocal of the measured signal against the reciprocal of the bias voltage is called a Jaffe plot. The value 0 on the 1/V axis corresponds to infinite electric field, when there would be no recombination. The reciprocal of the 1/signal as it crosses the vertical axis at 1/V = 0 is thus the signal level without recombination, and the levels of recombination at practical operating voltages can be estimated.
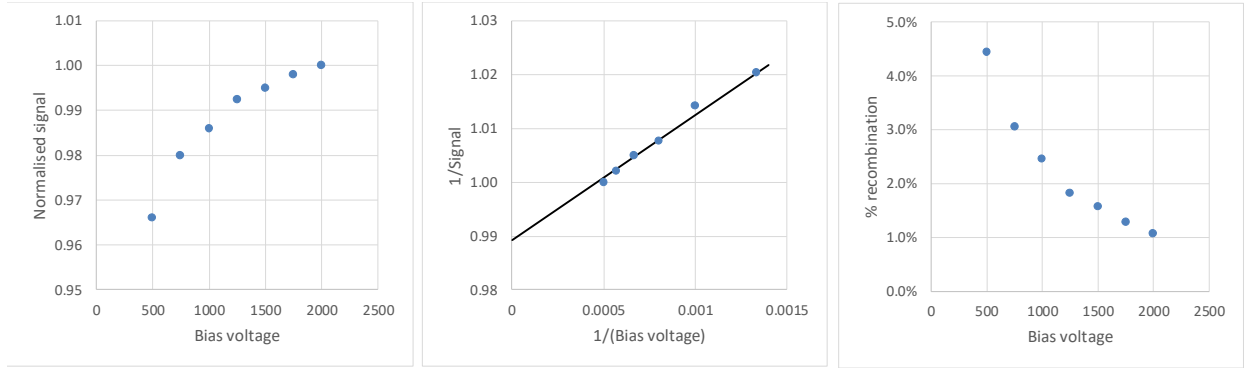
Figure 17. Illustration of Jaffe plot for recombination estimation (simulated data).

Even at higher current densities, the effect on the measurement of the beam centroid and width is comparatively little affected. The following plots show beam profile measurements for 228 MeV protons at beam current 2.7 nA and 18.4 nA with a 10 mm gap, a less favorable geometry than the IC128-25LC. The bias voltage setting was 2 kV. The approximate beam current density at the peak was 12 and 80 nA cm^{-2}. The peak channel response is suppressed by 10% due to recombination, but the centroid determination altered by only 0.02 mm, and the width determination by 0.09 mm.
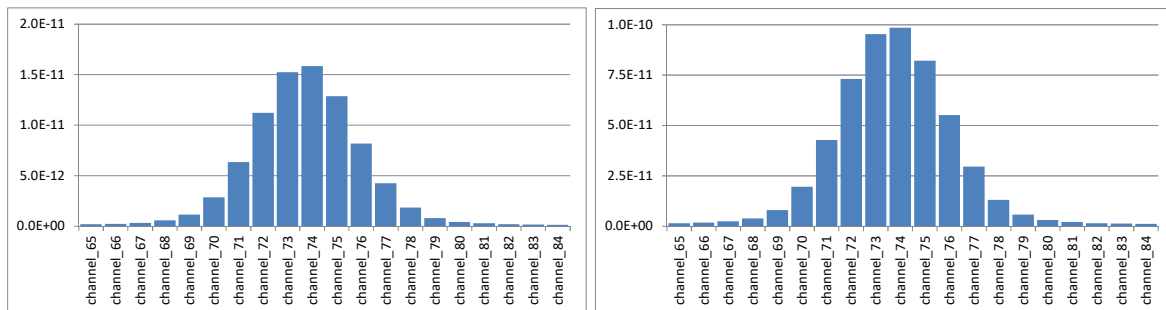
Figure 18. Example of minimal effect of recombination on peak measurement

Because the peak shape determination remains robust, it is possible to make a first-order correction of the measured current or charge for moderate recombination amounts using knowledge of the beam dimensions to estimate the local current density.

10.2 Position readout

The strip pitch of the IC128-25LC, S = 2.00 mm, is relatively small compared to the beam width for the intended application, so that you will see signal on three strips at least. You can then use peak fitting or centre of mass calculation to determine the position of the peak to much less than one strip width, typically 10% of the strip width or less for normal beam currents and noise levels.

A centre of mass calculation (CoG) is simple to calculate and makes no assumptions about the shape of the peak. However it is unreliable if the whole peak is not included, or if excess background noise or offset is included. A fit to a Gaussian is often the best solution. Pyramid real time controller products include fast algorithms for Gaussian peak fitting and centroid finding.

10.2.1   Beam centroid

The sensor strip geometry is controlled to high accuracy by the use of precision electrode machining techniques. The centre of the pattern is between the 64th and 65th strips in each axis. Thus in a perfect system with no offsets, a perfectly centred beam would give a centroid reading of 64.500 strips in X and in Y, which you would typically translate as a physical position of (0.000, 0.000) mm.

If you determine a peak position, (P_X, P_Y) expressed in strips, then the position in physical units in the nominal IC128-25LC coordinate system (figure 7) is given by

$$X_S = (P_X - 64.5) * S$$

$$Y_S = (P_Y - 64.5) * S$$

Ionization chambers like the IC128-25LC are usually required to return absolute positions in an external coordinate system. This may be the beamline coordinate system, or the coordinate system of a patient imager (the patient coordinate system) in the case of the particle therapy application. To translate to the beamline coordinate system we must first allow for any rotations of the IC relative to the beamline coordinate system due to the way it is mounted. There will also be a series of small offsets which combine to give an overall offset between the position measured by the IC in its own strip electrode coordinate system, and the corresponding position in the external coordinates. The components of this series include the very small offset between the IC electrodes and the IC body, the position of the IC relative to something that it is mounted to, typically the accelerator beamline magnets, determined by survey, and position of the target of beam delivery relative to the beamline.

Offsets of the IC body relative to its ideal position in the external coordinate system will be determined during commissioning and/or survey.

The following example, with grossly exaggerated offsets, shows how a measured X position in strip electrode coordinates is translated to the beamline coordinate system. Firstly, the raw centroid, X_S, is found in the sensor coordinate system from the cathode strip signals, using a suitable centroid calculation.
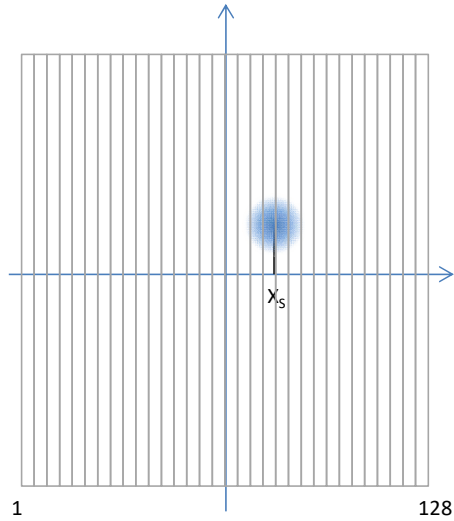
Figure 19. Beam position in IC128-25LC strip electrode coordinates (blue)

The residual offsets between the strip electrodes and the body of the IC128-25LC are controlled to less than 0.1 mm by the manufacturing process. However, if we know, and wish to make adjustment for, the small offset ΔX_0 between the strip electrode and the IC body, then the beam position relative to IC body must be adjusted by this offset.
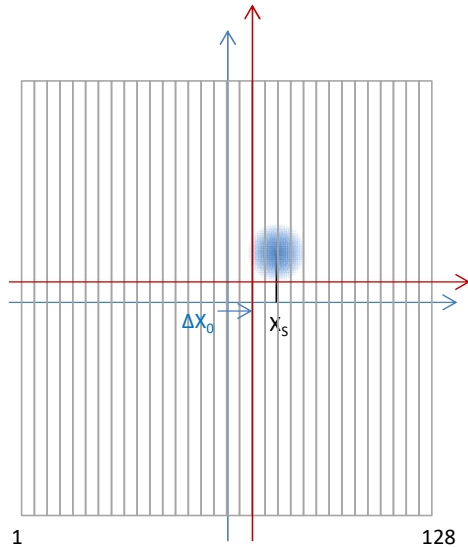
Figure 20. Displacement of IC body coordinates(red) from IC strip electrode coordinates (blue)

Finally we change to external coordinates. For the example we assume this involves a change in the X axis direction, and a further measured residual offset, ΔX_1, of the IC body relative to the external coordinate system, stated in the external coordinate system.
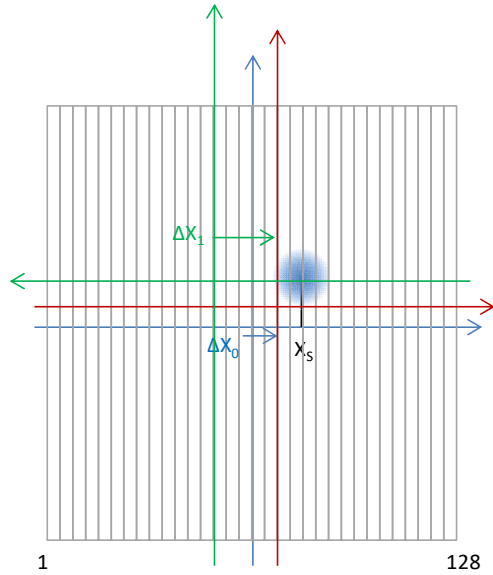
Figure 21. Change to external coordinates (green)

Thus the beam position in external coordinates is

$$X_E = \lambda(X_S - \Delta X_0) + \Delta X_1$$

where $\lambda=1$ if the IC X axis is in the same direction as the external X axis, and $\lambda=-1$ if it is in the opposed direction.

10.2.2 Beam width

Conversion of computed beam width to physical units is simply a matter of multiplying the width computed in strips to mm by multiplying by the strip pitch.

11 Environment sensors

11.1 Readout

The IC128-25LC includes two identical circuit boards that route signals to the external connectors. Each also includes sensors for the temperature, pressure and humidity of the gas filling. A redundant measurement of each is therefore available. The signals are read out as voltages by external electronics such as the I128 electrometer, and converted to physical units using the calibrations given in the next section. All three voltages plus the reference voltage provided by the external electronics are connected to a single analog channel via an on-board multiplex switch. The switch is controlled by a pair of digital lines.

Bit 1 (pin 3)	*Bit 0 (pin 7)*	*Switch selection*
0	0	Temperature (V_{measT})
0	1	Pressure (V_{measP})
1	0	Relative humidity (V_{measH})
1	1	Reference voltage (V_{ref})

The signals change only slowly. The readout electronics can and should use long averaging periods (>0.1 second recommended) to give good signal to noise ratio.

11.2 Calibrations

11.2.1 Temperature

Convert the raw voltage V_{measT} from the sensor to temperature as follows:

Temperature(centigrade) = 100 * V_{measT}

Temperature(Kelvin) = Temperature(centigrade) + 273.2

11.2.2 Pressure

Convert the raw voltage V_{measP} from the sensor to pressure as follows:

Pressure(psi) = 18.75 * (V_{measP} / V_{ref} - 0.1)

Pressure(mbar) = Pressure(psi) * 68.95

Pressure(Pa) = Pressure(psi) * 6895

V_{ref} is the reference voltage supplied by the external electronics, and is 5V nominal. The voltage supplied by the I128 electrometer is 5 V.

11.2.3 Humidity

Convert the raw voltage V_{measH} from the sensor to % relative humidity as follows:

Relative humidity (%) = $157 * (V_{measH} / V_{ref}) - 23.8$

12 Connectors

12.1 Electrical

12.1.1 Integral plane readout

Lemo four-way female type 0B (EPG.0B.304.HLN). To mate with Lemo FGG.0B.304.CLAD52Z or similar,
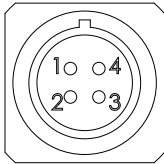
(External view on connector / solder side of mating plug)

1	Signal current	3	Aux signal current
2	AGnd	4	Chassis

1 and 3 are connected internally.

12.1.2 Unused integral plane connector

Lemo four-way female type 0B (EPG.0B.304.HLN).

In the IC128-25LC-2I this connector is used for the second integral plane electrode.

12.1.3 Axis A and B signal outputs

Two sets of four DSub 44 pin male, colour-coded.

Pin 1   Pin 15

Pin 16   Pin 30

Pin 31   Pin 44
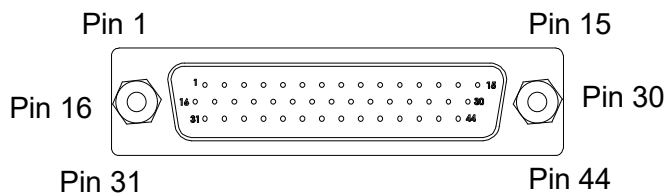
(External view on connector / solder side of mating plug)

Strip numbering assumes connection to the corresponding channel inputs of I128 electrometers via pin to pin cables. Note that electrical schematics for the IC128 and the I128 number the strips and channels starting from 0 instead of 1. These references are shown as I_xx in the connector tables below.

12.1.3.1 Strips 1-32 (colour code red) connectors A1 and B1

1	Strip 29 (I_28)	16	Strip 31 (I_30)	31	Strip 32 (I_31)
2	Strip 28 (I_27)	17	Strip 30 (I_29)	32	KGnd
3	Strip 26 (I_25)	18	Strip 27 (I_26)	33	KGnd
4	Strip 24 (I_23)	19	Strip 25 (I_24)	34	KGnd
5	Strip 22 (I_21)	20	Strip 23 (I_22)	35	KGnd
6	Strip 20 (I_19)	21	Strip 21 (I_20)	36	KGnd
7	Strip 18 (I_17)	22	Strip 19 (I_18)	37	KGnd
8	Strip 16 (I_15)	23	Strip 17 (I_16)	38	KGnd
9	Strip 14 (I_13)	24	Strip 15 (I_14)	39	KGnd
10	Strip 12 (I_11)	25	Strip 13 (I_12)	40	KGnd
11	Strip 10 (I_9)	26	Strip 11 (I_11)	41	KGnd
12	Strip 08 (I_7)	27	Strip 09 (I_8)	42	KGnd
13	Strip 06 (I_5)	28	Strip 07 (I_6)	43	Shield
14	Strip 04 (I_3)	29	Strip 05 (I_4)	44	Strip 03 (I_2)
15	Strip 02 (I_1)	30	Strip 01 (I_0)		

12.1.3.2 Strips 33-64 (colour code green) connectors A2 and B2

1	Strip 61 (I_60)	16	Strip 63 (I_62)	31	Strip 64 (I_63)
2	Strip 60 (I_59)	17	Strip 62 (I_61)	32	KGnd
3	Strip 58 (I_57)	18	Strip 59 (I_58)	33	KGnd
4	Strip 56 (I_55)	19	Strip 57 (I_56)	34	KGnd
5	Strip 54 (I_53)	20	Strip 55 (I_54)	35	KGnd
6	Strip 52 (I_51)	21	Strip 53 (I_52)	36	KGnd
7	Strip 50 (I_49)	22	Strip 51 (I_50)	37	KGnd
8	Strip 48 (I_47)	23	Strip 49 (I_48)	38	KGnd
9	Strip 46 (I_45)	24	Strip 47 (I_46)	39	KGnd
10	Strip 44 (I_43)	25	Strip 45 (I_44)	40	KGnd
11	Strip 42 (I_41)	26	Strip 43 (I_42)	41	KGnd
12	Strip 40 (I_39)	27	Strip 41 (I_40)	42	KGnd
13	Strip 38 (I_37)	28	Strip 39 (I_38)	43	Shield
14	Strip 36 (I_35)	29	Strip 37 (I_36)	44	Strip 35 (I_34)
15	Strip 34 (I_33)	30	Strip 33 (I_32)		

12.1.3.3 Strips 65-96 (colour code blue) connectors A3 and B3

1	Strip 93 (I_92)	16	Strip 95 (I_94)	31	Strip 96 (I_95)
2	Strip 92 (I_91)	17	Strip 94 (I_93)	32	KGnd
3	Strip 90 (I_89)	18	Strip 91 (I_90)	33	KGnd
4	Strip 88 (I_87)	19	Strip 89 (I_88)	34	KGnd
5	Strip 86 (I_85)	20	Strip 87 (I_86)	35	KGnd
6	Strip 84 (I_83)	21	Strip 85 (I_84)	36	KGnd
7	Strip 82 (I_81)	22	Strip 83 (I_82)	37	KGnd
8	Strip 80 (I_79)	23	Strip 81 (I_80)	38	KGnd
9	Strip 78 (I_77)	24	Strip 79 (I_78)	39	KGnd
10	Strip 76 (I_75)	25	Strip 77 (I_76)	40	KGnd
11	Strip 74 (I_73)	26	Strip 75 (I_74)	41	KGnd
12	Strip 72 (I_71)	27	Strip 73 (I_72)	42	KGnd
13	Strip 70 (I_69)	28	Strip 71 (I_70)	43	Shield
14	Strip 68 (I_67)	29	Strip 69 (I_68)	44	Strip 67 (I_66)
15	Strip 66 (I_65)	30	Strip 65 (I_64)		

12.1.3.4 Strips 97-128 (colour code white) connectors A4 and B4

1	Strip 125 (I_124)	16	Strip 127 (I_126)	31	Strip 128 (I_127)
2	Strip 124 (I_123)	17	Strip 126 (I_125)	32	KGnd
3	Strip 122 (I_121)	18	Strip 123 (I_122)	33	KGnd
4	Strip 120 (I_119)	19	Strip 121 (I_120)	34	KGnd
5	Strip 118 (I_117)	20	Strip 119 (I_118)	35	KGnd
6	Strip 116 (I_115)	21	Strip 117 (I_116)	36	KGnd
7	Strip 114 (I_113)	22	Strip 115 (I_114)	37	KGnd
8	Strip 112 (I_111)	23	Strip 113 (I_112)	38	KGnd
9	Strip 110 (I_109)	24	Strip 111 (I_110)	39	KGnd
10	Strip 108 (I_107)	25	Strip 109 (I_108)	40	KGnd
11	Strip 106 (I_105)	26	Strip 107 (I_106)	41	KGnd
12	Strip 104 (I_103)	27	Strip 105 (I_104)	42	KGnd
13	Strip 102 (I_101)	28	Strip 103 (I_102)	43	Shield
14	Strip 100 (I_99)	29	Strip 101 (I_100)	44	Strip 99 (I_98)
15	Strip 98 (I_97)	30	Strip 97 (I_96)		

12.1.4 Environment sensors

Two DSub 9 pin male

Pin 1   Pin 5

Pin 6   Pin 9
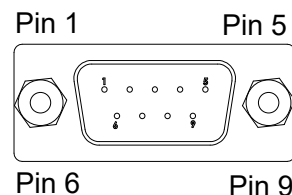
(External view on connector / solder side of mating plug)

1	Chassis	6	Analog out +
2	Analog out –	7	Digital in 1 (switch control bit 0)
3	Digital in 2 (switch control bit 1)	8	Digital out 2 (ID bit 2)
4	Digital out 1 (ID bit 1)	9	Vref in
5	DGnd		

Pin 2 is connected internally to DGnd by the signal selection switch. Pins 4,8 allow the external electronics to identify the configuration of the ionization chamber. Internal links pull them to ground to set the ID bit.

12.1.5 High voltage inputs and outputs

Four SHV receptacles. To mate with standard SHV connector. Inputs and outputs both connect to the relevant HV electrodes internally, at independent points.

12.2 Fill gas

Push fit fittings are installed for 1/8" flexible tubing. Gas in and out are not distinguished and are interchangeable. If using the chamber with air filling, the plugs must be fitted to seal the chamber.

Figure 22. Plugging flow gas port for operation with dry atmospheric air

13 Maintenance

CAUTION. Radiation.

Do not work in the beamline area, or on the IC128-25LC, until a survey has been completed by a qualified radiation supervisor and the radiation is known to be at acceptable levels.

We do not recommend that you attempt to disassemble the IC128-25LC. There are no routine service parts inside, and the risk of damage to delicate electrode structures is high. Pyramid Technical Consultants offers a complete factory refurbishment service.

13.1 Preventative maintenance schedule .

Exact details will depend on the nature of your application. If the IC128-25LC is being used in a critical dosimetry application, then validation against external traceable standards will be required on a regular basis.

Action	Recommended frequency	Nominal duration	Details
Check dose calibration against QA standard	Daily	(1 hr)	Follow procedures defined your facility.
Check response to HV enable pulse	Daily	2 min	Record signals on all channels as HV is enabled. All channels should respond. Look for any trends.
Check offset currents	Daily	5 min	Record background offset on all channels with HV on, beam off, no known electrical noise sources active. Look for any trends.
Replace desiccant	Annually	30 min + dehumidification time	Replace desiccant packs (four per chamber).

13.1.1 HV enable response check

This is a powerful diagnostic of all readouts that can be performed quickly and regularly. When the HV bias is applied to the chamber, the capacitances of the electrode stack are charged up, and current flows while this is taking place giving a characteristic pulse response on all channels.

Acquire data on all channels while the HV is being enabled. Every channel should show a transient response, and the individual strip responses should be similar.
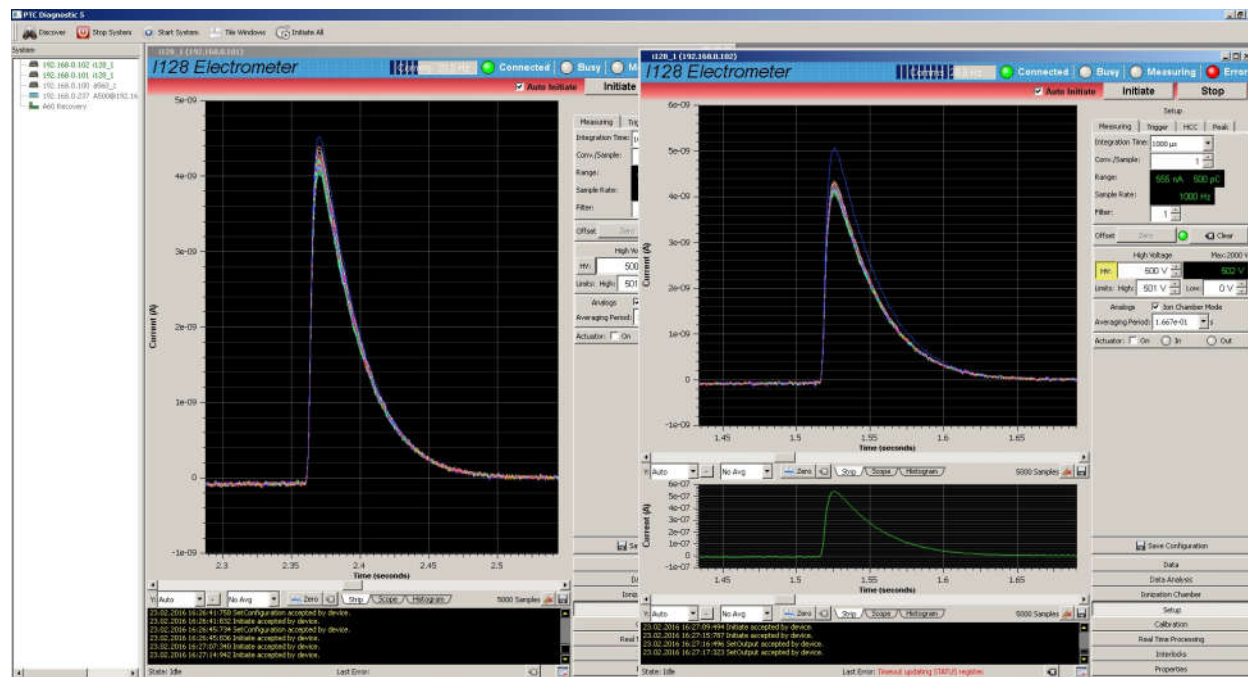

Figure 23. High voltage turn on pulse captured on all strip channels and the integral channel

If any channel that does not respond, or has an anomalous response, generally slower, that can indicate that it has become disconnected or has a poor connection. Check that the electrometer and external wiring is good before suspecting a break inside the chamber.

13.1.2 Offset currents

In the absence of a particle beam or any electromagnetic or triboelectric noise sources, there will a characteristic pattern of small background currents which you can see clearly using a long integration or averaging period in the electronics. If you keep a record of those currents, you can spot any trends or discontinuities which may indicate an emerging problem. Two adjacent strip channels that start to show diverging offset currents can indicate a high resistance short between them. A sudden change or a trend on one channel can indicate an open circuit or high resistance has developed somewhere in the connection of the electrode to the electrometer.

13.2 Desiccant replacement

The desiccant should be replaced if the reading from the internal humidity sensor starts shows greater than a few percent relative humidity. 10% is the upper limit for reliable operation.

The procedure can be carried out with the IC128-25LC mounted on the beamline or removed to a clean working location.

13.2.1 Procedure

1) Perform a radiation survey to confirm that it is safe to work on the ionization chamber.

2) Fit protective covers over the IC windows if they are liable to be touched while you are working on the IC.

3) Locate the desiccant chamber.
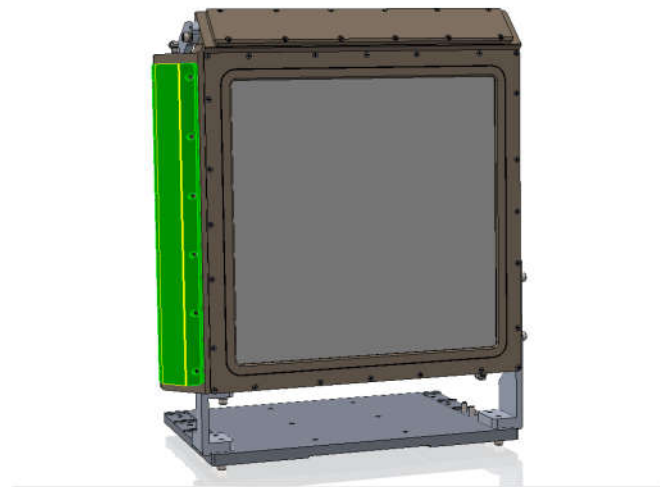
Figure 24. Desiccant chamber location (view from nominal beam exit side)

4) Remove the 12 M3x8 screws and take the desiccant chamber to a clean working area.

5) Remove the 10 M2.5x4 screws and washers that hold the wire grille to access the desiccant sacs. Remove the four old desiccant sacs. Remove the new desiccant from its sealed packaging ensure the replacement sacs are clean and free of dust. Install as shown in the figure below.

Figure 25. Installation of the desiccant sacs

6) Refit the grille using the 10 M2.5x4 screws and washers and ensure that the O ring (not shown in the photograph) is clean and correctly positioned.
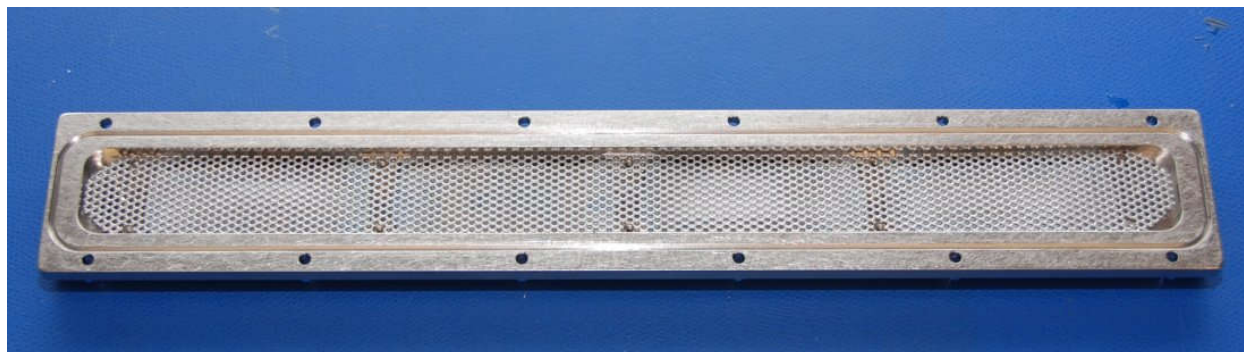

Figure 26. Grille in place.

7) Check that the O ring sealing surface on the IC body is clean and refit the cavity to the IC body with the 12 M3x8 screws, tightening the screws evenly to ensure the seal is well made.

8) Remove protective window covers if you fitted them at the start of the process.

9) Monitor the two humidity readbacks from the IC. One of the sensors is close to the desiccant, and its reading should drop below 10% relative humidity in less than one hour. Allow 12 hours for the second sensor to also drop below 10%. If this does not happen, then the replacement desiccant was already saturated, or there is a break in in the hermetic seal of the IC.

13.3 Consumables and spares

Item	*Part number*	*Supplier*
Serive kit including desiccant sachets, O ring seal and replacement fasteners	SK-IC128	Pyramid Technical Consultants, Inc.
Desiccant replacement set (four sachets Tri-Sorb 5G 4A G2 27X70 (Matl 4286))	SK-DES4	Pyramid Technical Consultants, Inc.
O-ring 9" id for desiccant chamber cover.		Pyramid Technical Consultants, Inc.

14 Fault-finding

The IC128-25LC is designed to give you trouble-free service. We expect that a simple replacement policy will be followed for any units that fail on a beamline, and that failed units will be returned to Pyramid for refurbishment. However the following fault-finding is provided to help decide whether an IC should be exchanged, and to guide repairs for customers who do not have a service arrangement.

Symptom	Possible Cause	Confirmation	Solution
Beam position peaks distorted and change discontinuously with beam position	Connections from IC to electronics are mixed up.	Check connections carefully.	Correct cabling, use colour coding to simplify installation.
	Cables do not connect each strip to corresponding electronics channel.	Check cables and drawings carefully.	Use correct cables. Use electronics that allows pin to pin cables as this is simpler to diagnose.
Beam position peak moves in wrong direction when the beam moves.	IC is rotated so that axis direction sense is altered.	Check IC orientation.	Change orientation or make sign correction in position calibration.
	Position calibration gain has the wrong sign	Check IC orientation and calibration factors.	Use correct factor.
Small or no signal	HV is not enabled or connected.	Check power supply and cabling.	Correct as necessary.
	HV bias not reaching the relevant anode.	Check loopback HV if this is used. Check HV supply. Check cable integrity.	Correct as necessary. If the lost connection is inside the IC, contact Pyramid Technical Consultants.
No signal from integral plane	Cable is plugged into the wrong Lemo connector.	Check connections.	Correct the connections and ensure grounding plug is connected to the unused Lemo connector.
Unstable signal	Internal electrode is	Check external	Correct any

	floating	connections to electrometer inputs and HV bias supplies are in place. Perform HV bias enable pulse check.	connection errors. If you suspect an internal break, contact Pyramid Technical Consultants.
	HV arcing due to high humidity.	Check humidity sensor. Check enclosure is sealed (desiccant chamber O ring, gas flow plugs).	Change desiccant if required. Remake any seals as necessary and check that internal humidity drops below 10%.
	HV arcing due to very high local beam intensity	Check beam current and IC signal level.	Operate within the beam current density limits of the IC. Reduce the bias voltage.
	Triboelectric noise in signal cables.	Ensure cables are not moving or vibrating, wait and recheck.	Remove source of vibration or movement, and/or use low-noise cables. Do not use data from immediately after any movement of cables.
Noise in readout in the 20 – 300 Hz range	IC is responding to loud audio noise in the environment.	Turn off noise source and recheck.	Move noise source away. Filter out problematic frequencies.
Noise pulses on signals	Interference from external electrical equipment such as motors.	Turn of potential noise sources and recheck.	Shut down noise sources when making measurements.
	AC magnetic field pickup	Disable AC electromagnets and recheck.	Route cables well-clear of stray magnetic fields. Route cables through magnetic shielding ducts.

15 Returns procedure

Damaged or faulty units cannot be returned unless a Returns Material Authorization (RMA) number has been issued by Pyramid Technical Consultants, Inc. If you need to return a unit, contact Pyramid Technical Consultants at support@ptcusa.com, stating

> - model

> - serial number

> - nature of fault

CAUTION. Radiation.

The unit cannot be shipped until it is certified to be below legal limits for radiation, and that it is clear of any chemical contamination.

An RMA will be issued, including details of which service center to return the unit to. The unit must be returned in its shipping case to avoid damage.

16 Support

Manual and other documentation updates are available for download from the Pyramid Technical Consultants website at **www.ptcusa.com**.   Technical support is available by email from support@ptcusa.com.   Please provide the model number and serial number of your unit, plus relevant details of your application.

17 Disposal

We hope that the IC128-25LC gives you long and reliable service. The IC128-25LC is manufactured to be compliance with the European Union RoHS Directive 2002/95/EC, and as such should not present any health hazard, once any activation has decayed.

CAUTION. Radiation.

The IC must not be released from a radiation controlled area until it has been surveyed and declared safe by a qualified Radiation Supervisor.

When your IC128-25LC has reached the end of its working life, you must dispose of it in accordance with local regulations in force. If you are disposing of the product in the European Union, this includes compliance with the Waste Electrical and Electronic Equipment Directive (WEEE) 2002/96/EC. Please contact Pyramid Technical Consultants, Inc. for instructions when you wish to dispose of the device.

18 Revision History

The release date of a Pyramid Technical Consultants, Inc. user manual can be determined from the document file name, where it is encoded yymmdd. For example, B10_UM_080105 would be a B10 manual released on 5 January 2008.

Version	Changes
IC128-25_UM_140820	First general release
IC128-25_UM_140830	Updated photograph
IC128-25LC_UM_180625	New version created for IC128-25LC which replaces IC128-25.