ELENA Beam Instrumentation

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On behalf of G. Tranquille and many other people

AD – ELENA transfer line

Profile & position:	2 * GEM, 2 * uWire 2 * BTV

ELENA ring

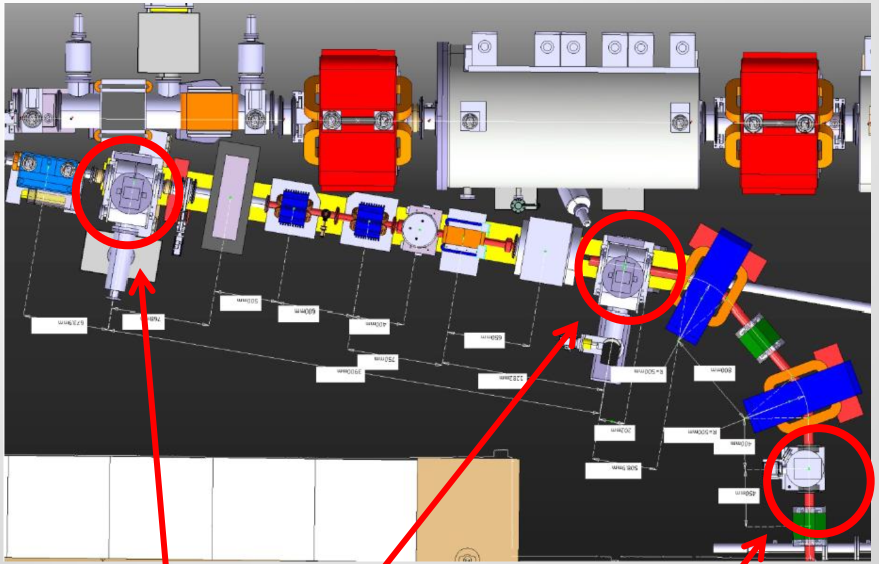
Position:	12 * BPM
Tune:	1* BBQ
Profile:	1 * Scraper +Scintilator
Cooling performance:	1 * Recombination monitor
Intensity + longitudinal:	LF + HF magnetic Schottky Sum of BPM's CCC

Experimental zones

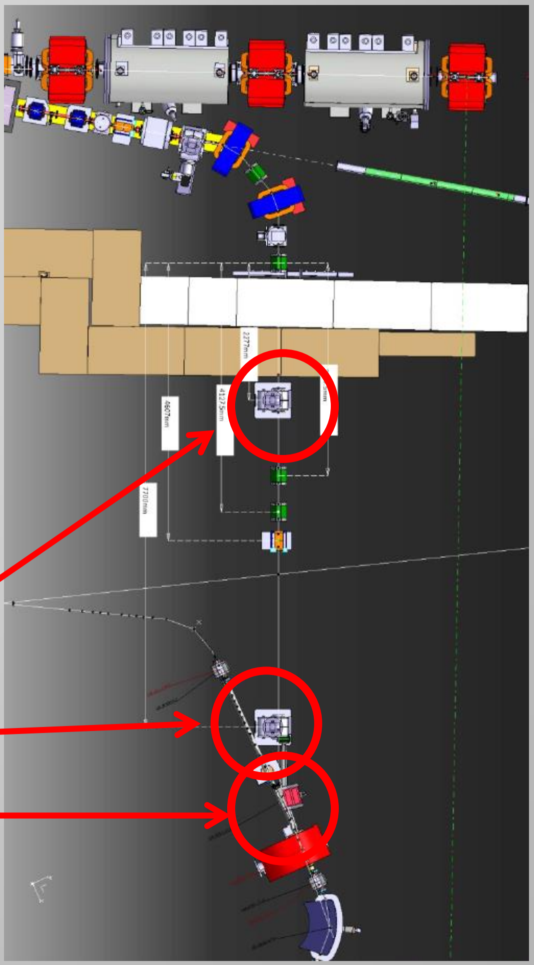
Profile & position:	~ 40* uWire
Intensity	2 * LF magnetic PU

AD-ELENA transfer line

Modification of the existing 7000 line



New line from 7000 line to ELENA



GEM

BTV

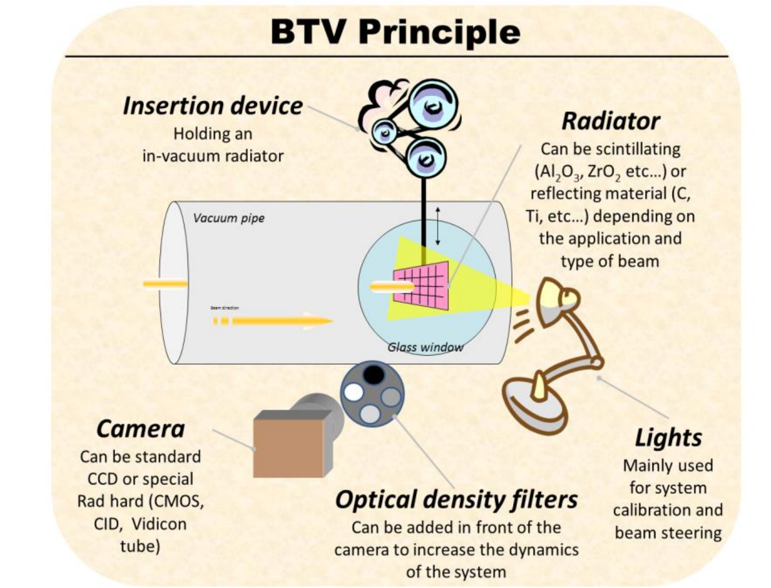
uWire

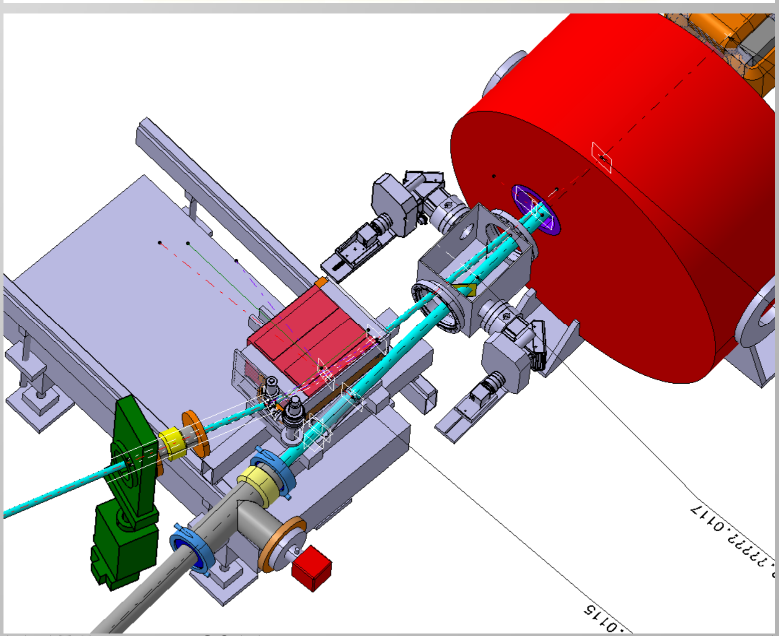
BTV

At present in the AD, Al_2O_3 scintillating screens are installed in the transfer lines. High sensitivity CCD cameras gives sufficient S/N-ratio in the AD extraction lines .

One such device will be moved from its current location in the 7000 line and will be installed after the second bending magnet that will deflect the antiproton beam from the AD to ELENA.

A new system is also being developed that will be capable of measuring just before the injection kicker and at the first turn in the ring. It consists of two distinct systems each incorporating a 6 cm x 4 cm screen. Study ongoing to eliminate bellow.

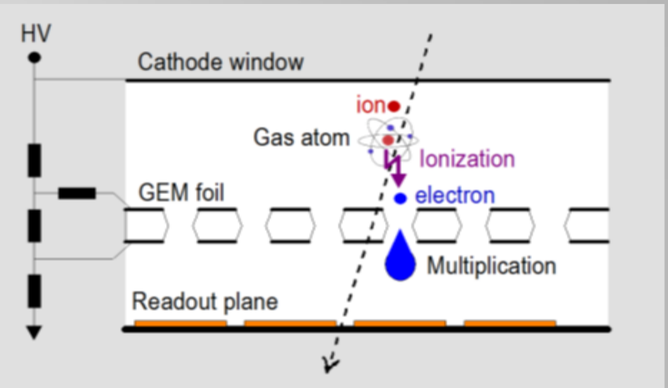


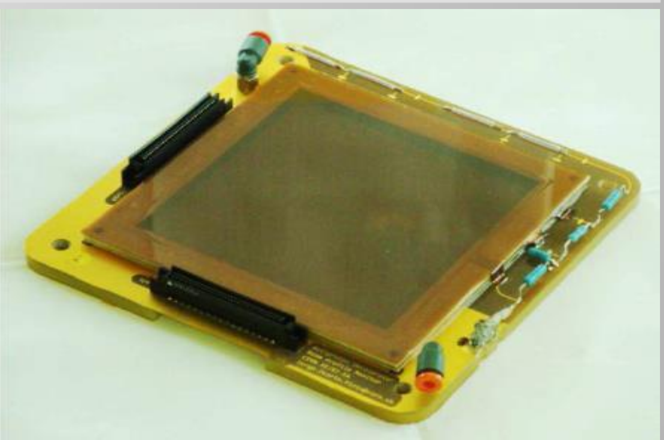


GEM

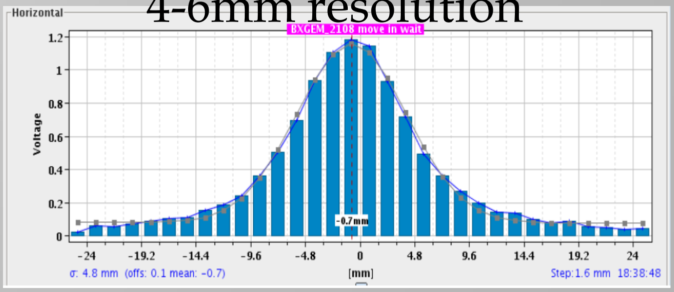
GEMs have been deployed extensively in the present AD experimental areas and give excellent results for both position and profile measurements. **They are destructive.**

- A **GEM** is a 50 µm thick foil of Kapton, copper clad on both sides, pierced with microscopic holes at a high density (our 10×10 cm² foils have about a million holes).
- A voltage of a few hundred volts applied to the top and bottom copper layers causes an electric field that focuses in the centre of these holes.
- Ionization electrons enter the holes from one side, are multiplied inside the holes, and then exit on the other side where they are collected by a strip pattern that integrates the charge and reads out the profile.





4-6mm resolution



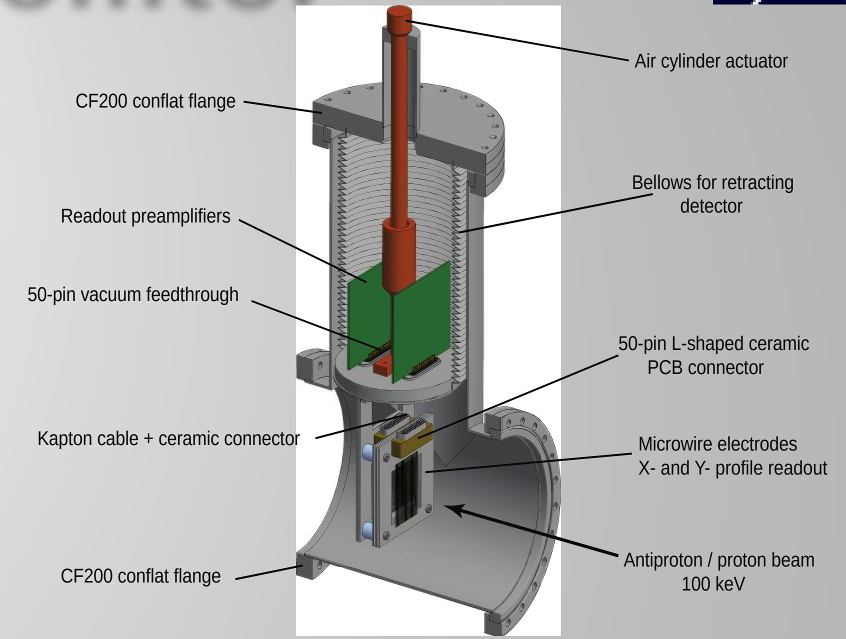
μWire Monitor

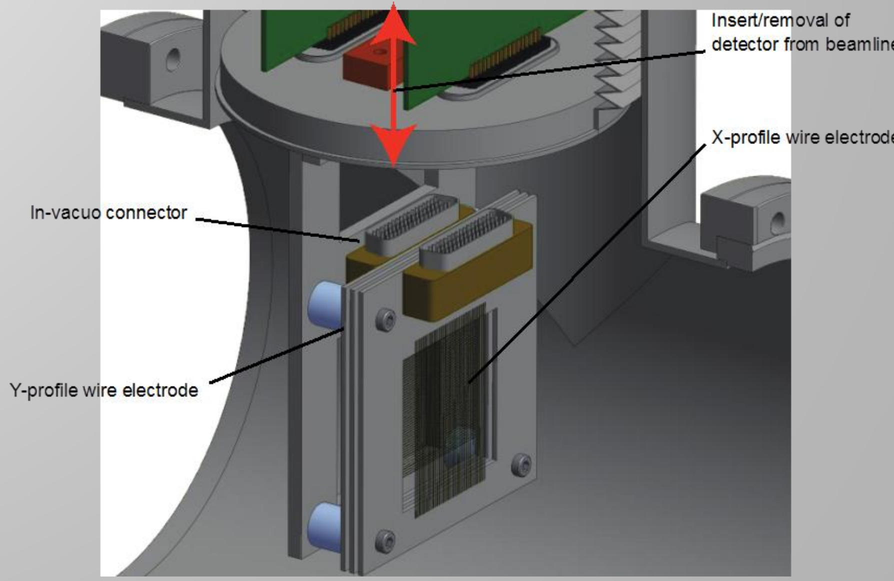
This semi-non destructive monitor is based on the devices used by the ASACUSA collaboration since 1999 to measure 100-keV antiproton beams. The device is sensitive to antiproton, proton, and H^- beams of energies between 10 keV and 5.3 MeV.

It consists of two position-sensitive photocathode grids (GND) providing the X and Y projections of the beam, sandwiched between three anode grids (50V).

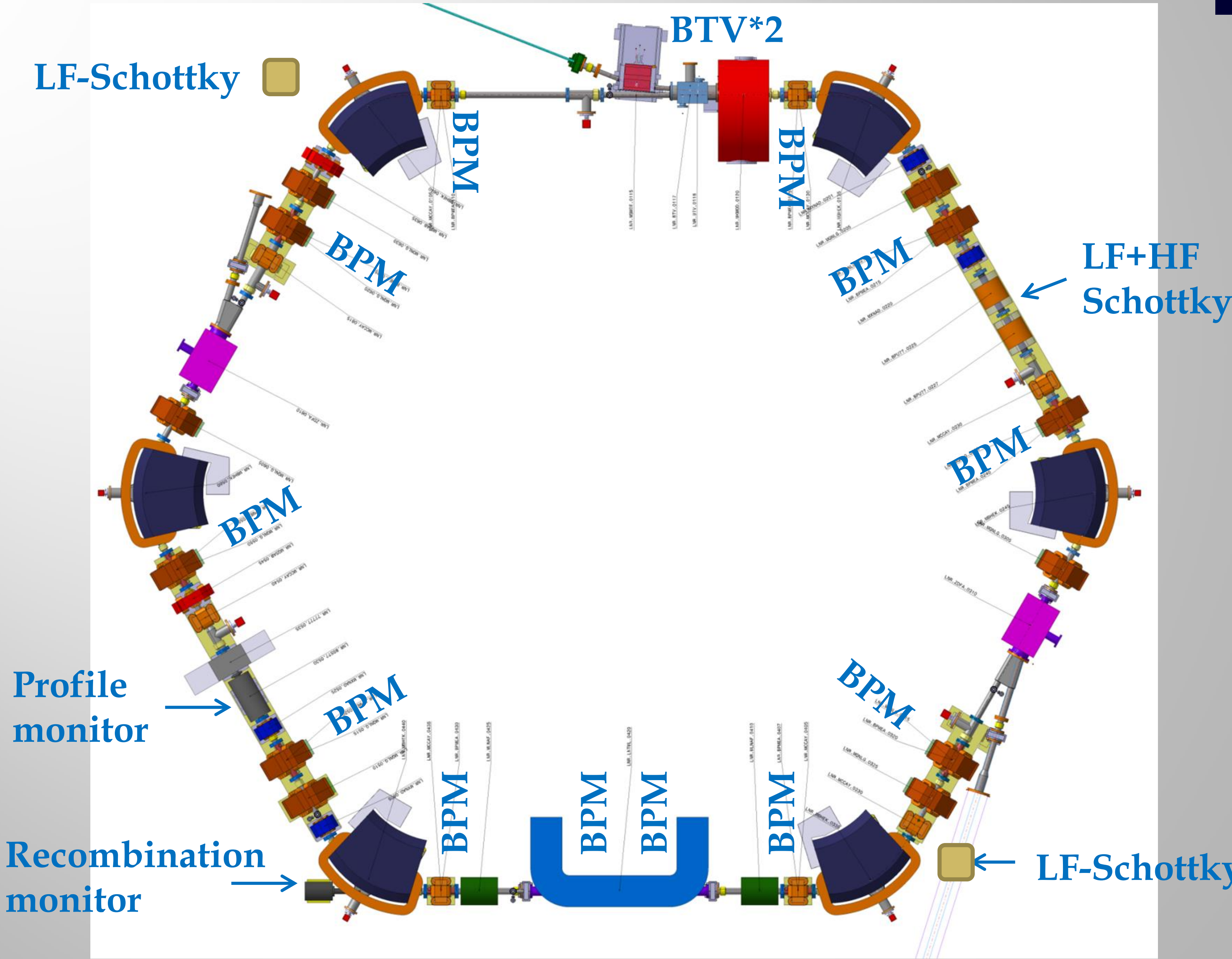
Each grid consisted of between 32 and 48 gold-coated tungsten wires of diameter of 5–20 μm stretched over a ceramic frame, with a pitch 0.5–1.5 mm between neighbouring wires.

The beam profile is obtained by using charge-sensitive preamplifiers to measure the charge Q_i ejected from the cathode wires on the X- and Y-grids with high sensitivity.





ELENA ring



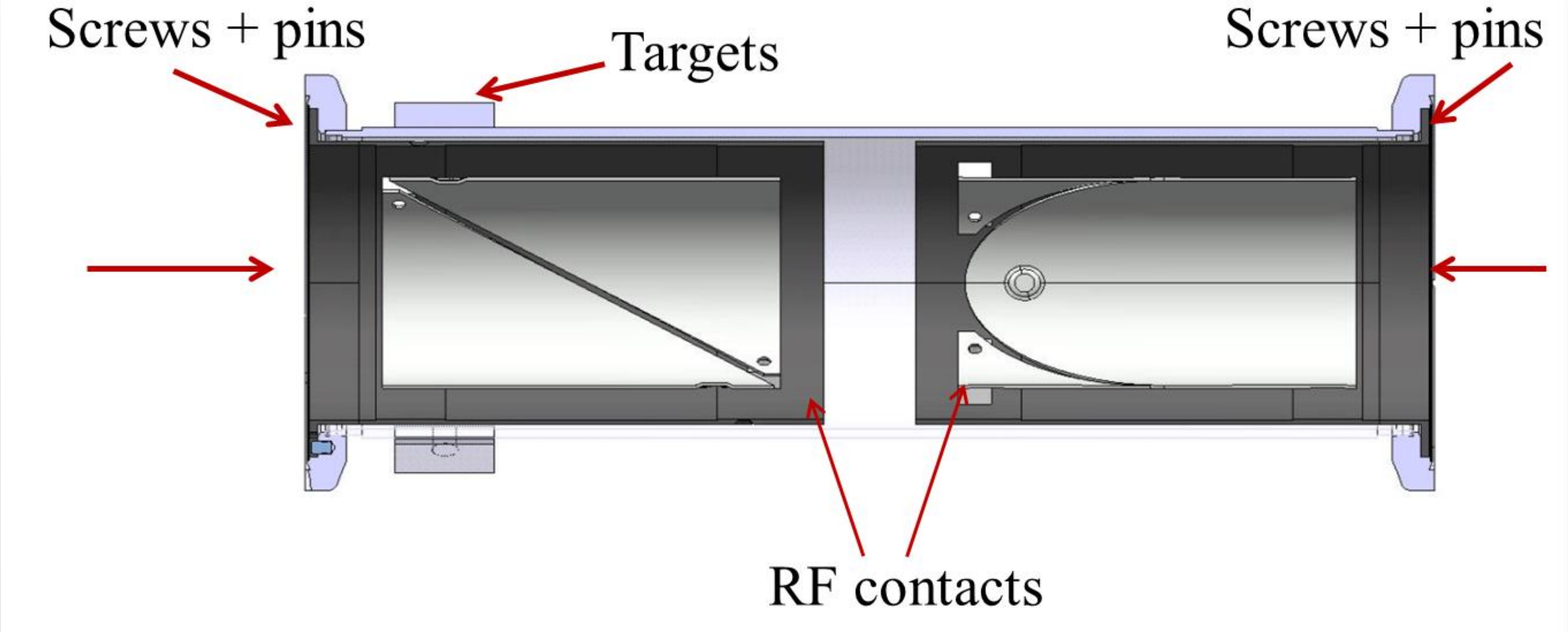
BTV*2
LF-Schottky
BPM
BPM
BPM
LF+HF Schottky
BPM
BPM
BPM
Profile monitor
BPM
BPM
BPM
BPM
BPM
BPM
BPM
Recombination monitor
LF-Schottky

Beam Position

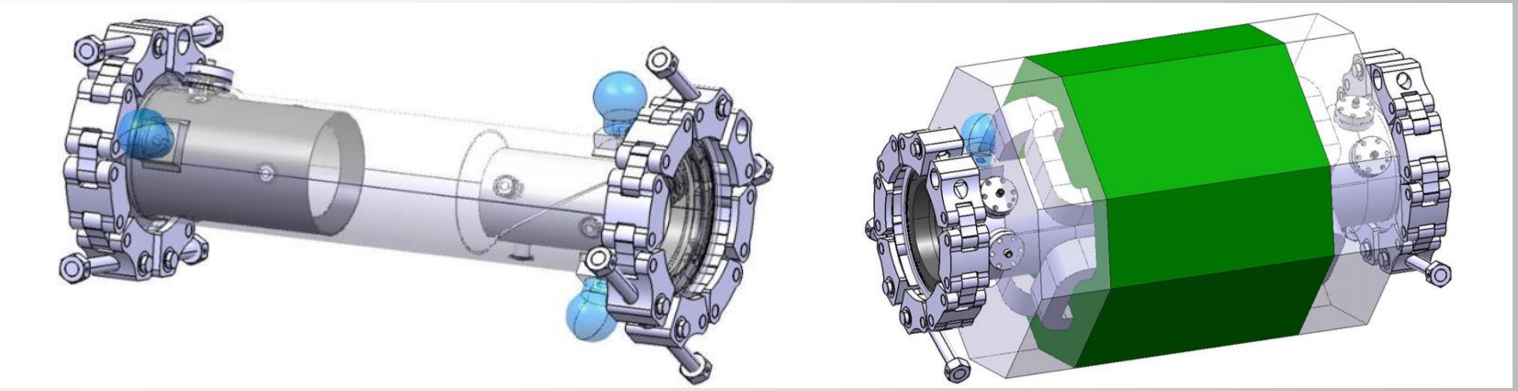
The ELENA orbit measurement system will be based on 24 circular BPMs made out stainless steel with vacuum as dielectric, and mounted inside quadrupoles , dipoles and the electron cooler.

Design of PU, analogue electronics as well as digital acquisition is optimized in view of using the 20 BPMs as one big Schottky PU.

Resolution	0.1mm
Accuracy	0.3-0.5mm
Precision	0.1mm
Max. beam displacement	33mm
Time resolution	~10ms
Overall maximum length	400mm
Inner diameter	66mm
Bake out temperature	250°C
Vacuum	3×10^{-12} Torr



Beam position



H+V PUs

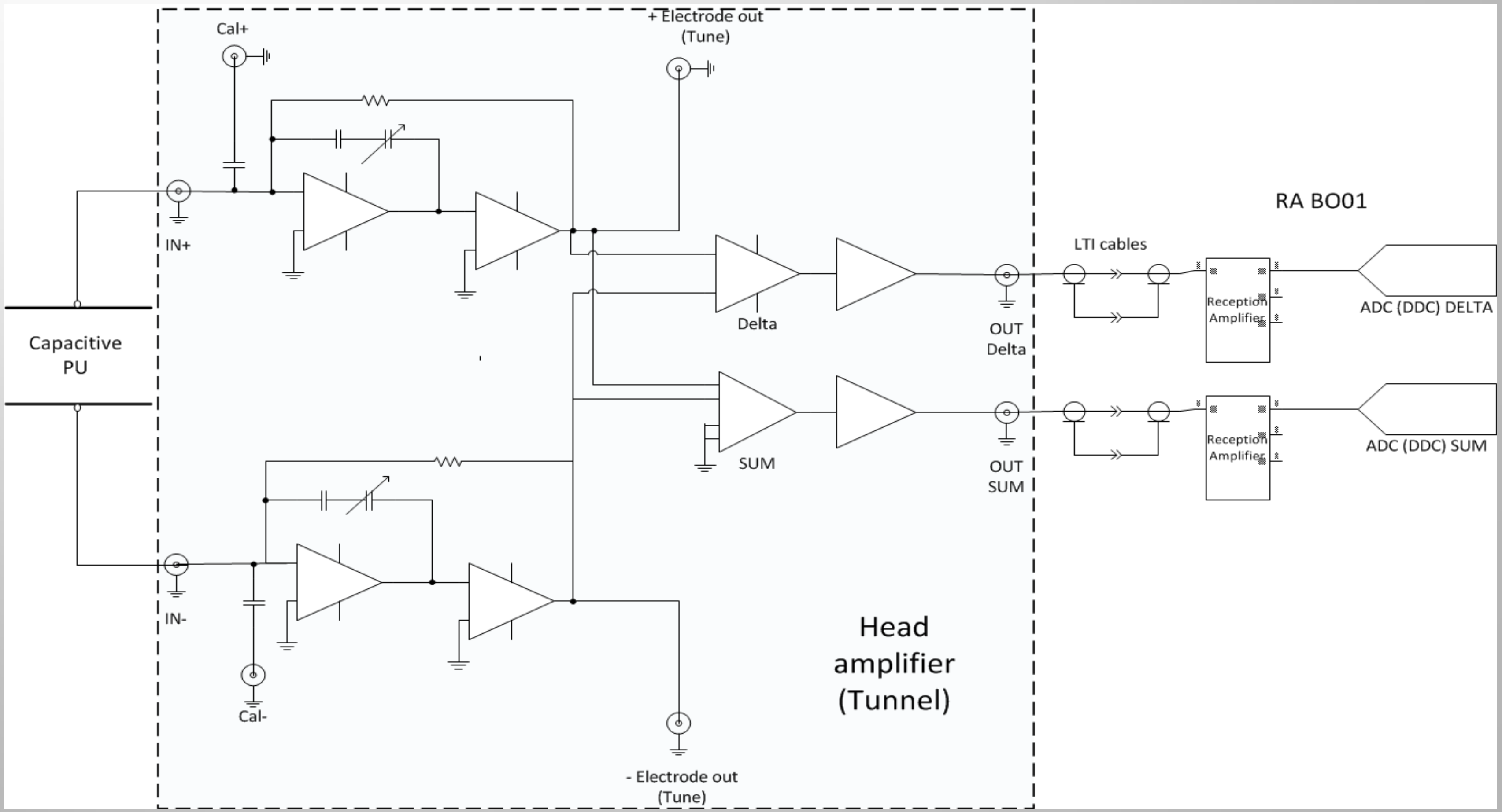
BPM	Magnet	Length	Comments
LNR.BPMEA0110	LNR.MDCAY.0105	340.5mm	Dipole
LNR.BPMEA.0125	LNR.MDCAY.0130	340.5mm	Dipole
LNR.BPMEA.0215	LNR.MQNLD.0210	432.5mm	Quadrupole
LNR.BPMEA.0240	LNR.MQNLD.0235	432.5mm	Quadrupole
LNR.BPMEA.0320	LNR.MQNLD.0315	432.5mm	Quadrupole
LNR.BPMEA.0415	LNR.MDCAY.0405	340.5mm	Dipole
LNR.BPMEA.0430	LNR.MDCAY.0435	340.5mm	Dipole
LNR.BPMEA.0520	LNR.MQNLD.0515	432.5mm	Quadrupole
LNR.BPMEA.0555	LNR.MQNLD.0550	432.5mm	Quadrupole
LNR.BPMEA.0625	LNR.MQNLD.0620	432.5mm	Quadrupole

Electrode length	120mm
Electrode area	1.24E-02 m^2
Electrode capacitance	17pF
Cable capacitance (20cm, 75Ω)	10pF
Amplifier input capacitance	~20pF
Number of charges	1E7
Bunch length	1.5m
Bunching factor	20
Max. input signal amplitude	**3.0mV**
Transverse sensitivity	**~90µV/mm**

Another two PUs to be added inside electron cooler

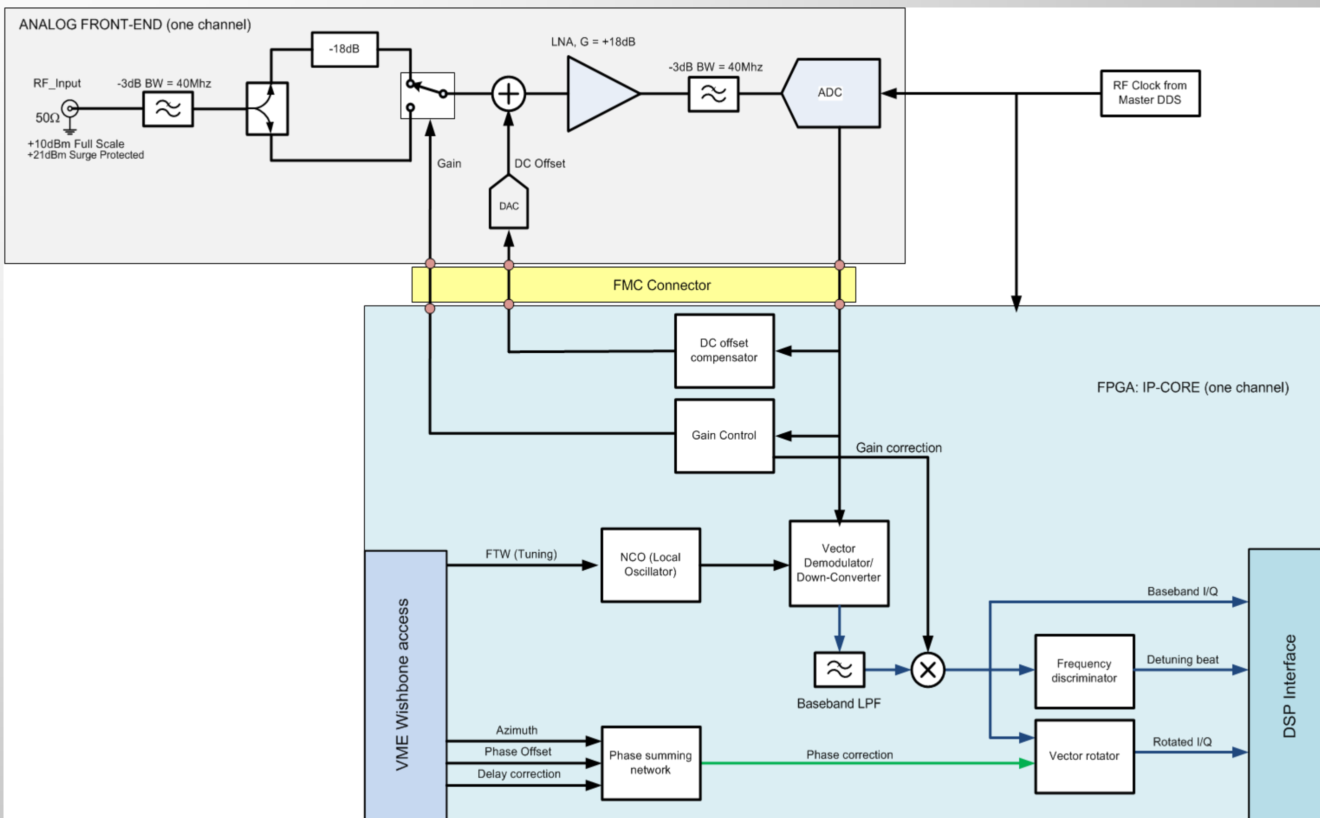
Beam position

- Front-end electronics developed in collaboration with Brescia university.
- First prototype foreseen March 2014



Digital acquisition system

DDC of first or second harmonic, input from RF MDDS
Baseband Δ/Σ- processing, also on ramp



FMC cards + ADC mezzanine developed by BE/RF.
One VXS chassis with switches for inter FMC communication using SUSHI train, for Schottky measurements.

Tune

Base-Band Tune (BBQ) measurement systems are highly sensitive and based on a direct diode detection principle. Can use orbit PU-signals, but dedicated PU preferable.

- Diode detectors, converting beam-induced pulses from electrodes of a position pick-up to slower varying signals.

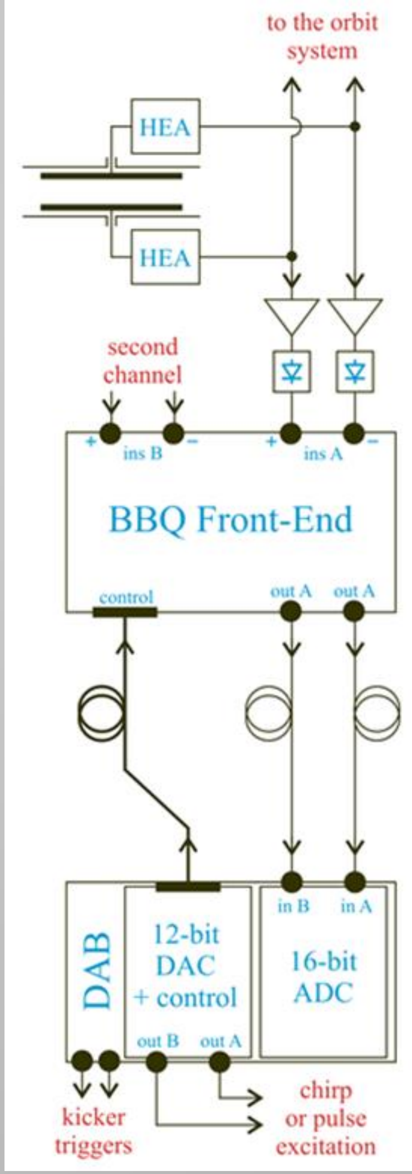
- An analogue front-end amplifying and filtering the detector signals. Digitized by 2 16-bit ADC's

- A VME, FPGA based Digital Acquisition Board (DAB) providing the read-out and processing of the ADC samples.

- Two 12-bit DACs implemented, used to generate signals for beam chirp excitation, independently for horizontal and vertical machine planes.

Dedicated strip line kicker (and PU?) still to be integrated in the layout.

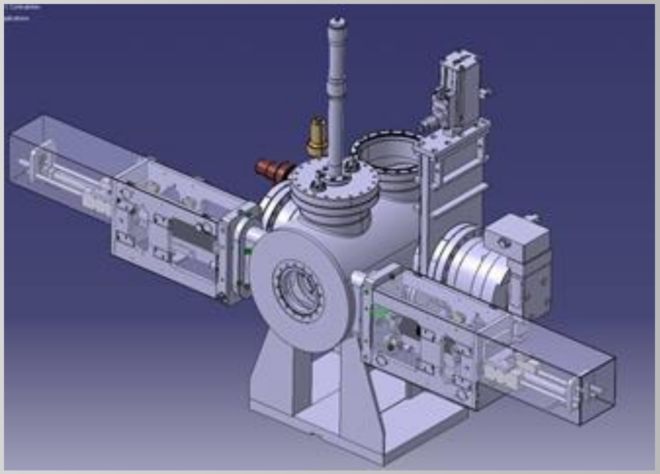
100 turn resolution in the order of 0.3μm is expected



Beam Profile

The profile of the circulating beam will be measured destructively using a scraper + scintillator system.

A simultaneous detection of the intensity of the particle shower outside the vacuum chamber with a scintillator/photomultiplier assembly and the blade position gives an image of the beam profile.

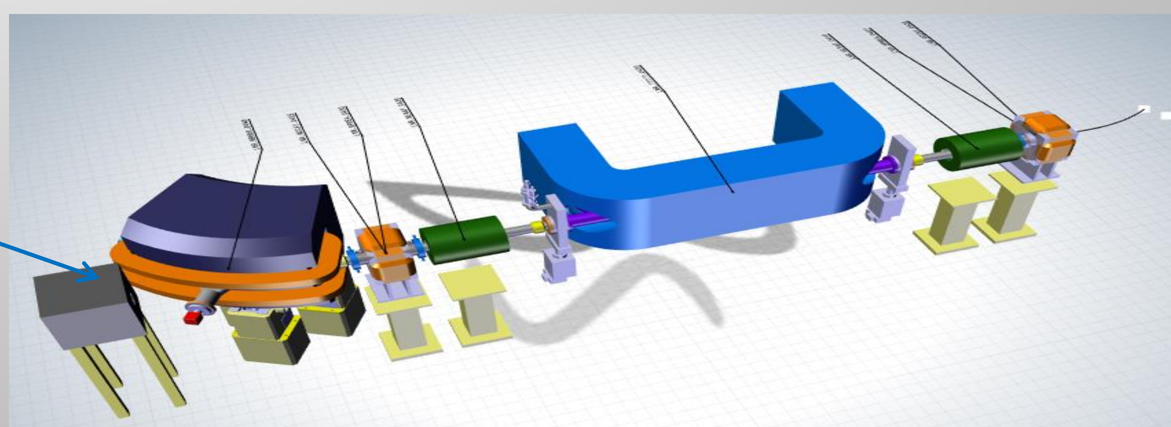


- **For ELENA**, 4 scraper blades (2 horizontal and 2 vertical) will be installed in a vacuum tank in section 5 of the ring .
- Their design is based on the Linac 4 beam stopper and will consist of a 50 mm X 20 mm aluminium plate fixed on a rigid arm which is moved into the beam by a stepping motor or a pneumatic jack.
- The exact position is read via LVDT sensors and end switches. The movement control will be done using standard PLC based controls
- Ionisation Profile Monitor is being studied as well, for non destructive measurements.

Recombination Monitor

- For commissioning at 100 keV with the proton source, optimisation of the electron cooler can be performed by measuring the recombination rate of electrons with the circulating protons **(H_0)**.
- A scintillator coupled to a photomultiplier can be used to measure the recombination rate. A maximum signal is obtained when the beams are correctly aligned.
- Using an imaging monitor (MCP with strip read-out) one can derive the profile and position of the ion beam from the profile and position of the recombined beam.
- The detector will be installed in an extension of the bending magnet vacuum chamber downstream from the electron cooler. It's design will be started soon.

Recombination Monitor (H_0)



Magnets in reverse polarity

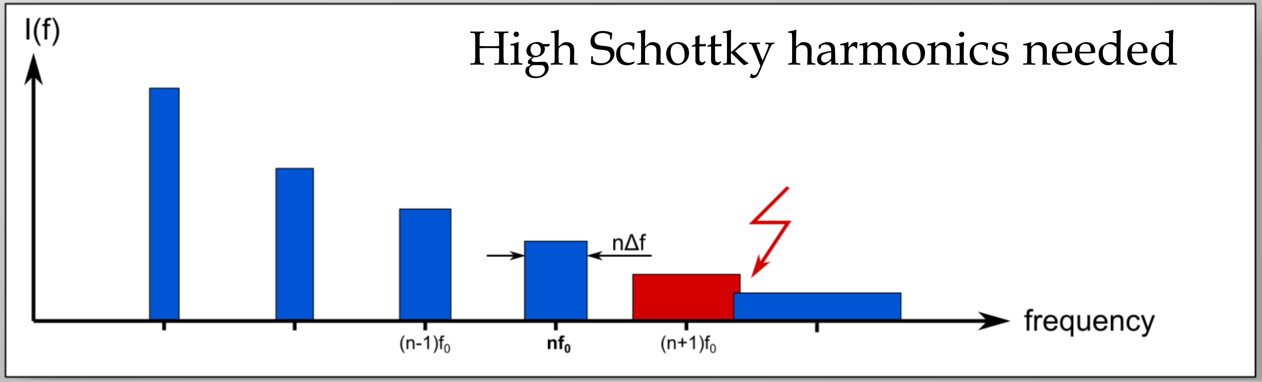
Intensity and longitudinal diagnostics

Three stage implementation:

- Start-up with known (AD design) magnetic Schottky PU (LPU) .
- Use Σ of sum signals of 20 orbit PUs as one Schottky PU. Need continuous phase alignment of signals
- Replace magnetic PU by Cryogenic Current Comparator (CCC).
  - High sensitivity (10nA) and accuracy, can be calibrated

Longitudinal diagnostics:

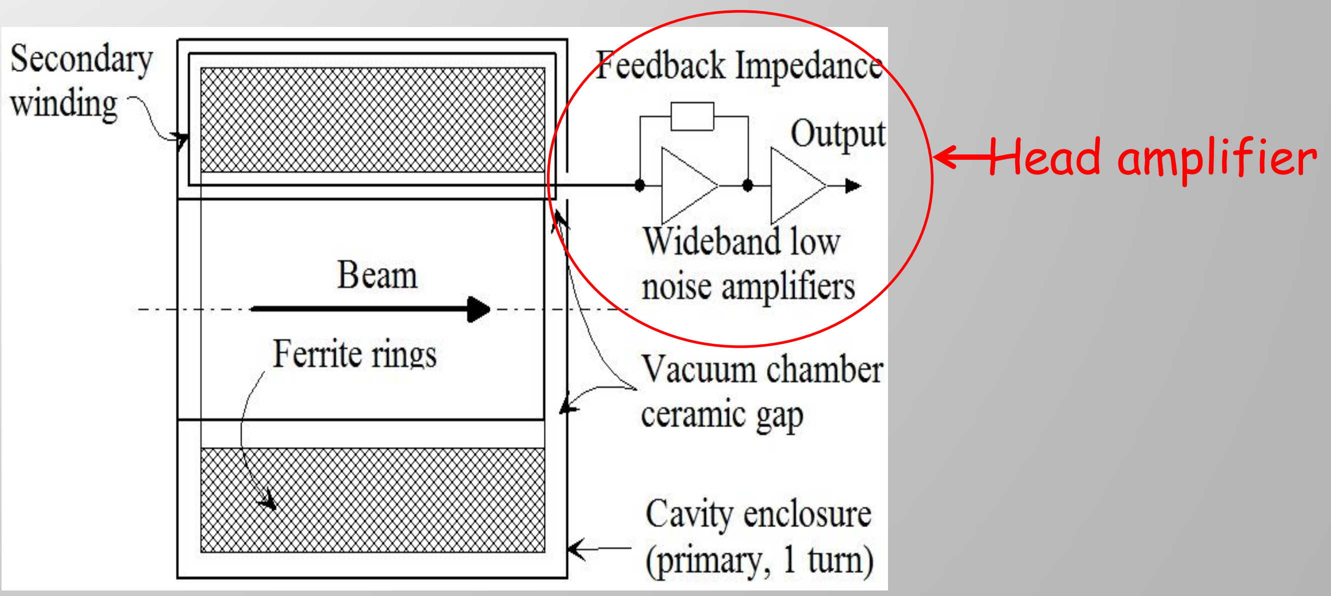
- **Output**: longitudinal beam signal for LLRF
- **Bunched beam**: Intensity,
- **Debunched beam from Schottky scans:**
  - Intensity
  - **Frev**
  - Δp/p (main ecooling diagnostics)
  - <p>
  - Averaged beam spectra



Magnetic LPU: principle

- Make pick-up resonant with high Q to reduce the thermal noise current of the transducer itself.
- Use low noise high impedance amplifier (Si JFET's) and regain broad band properties by strong active feedback without deteriorating the signal to noise ratio .

Schematic view of the high-sensitivity longitudinal beam transformer .

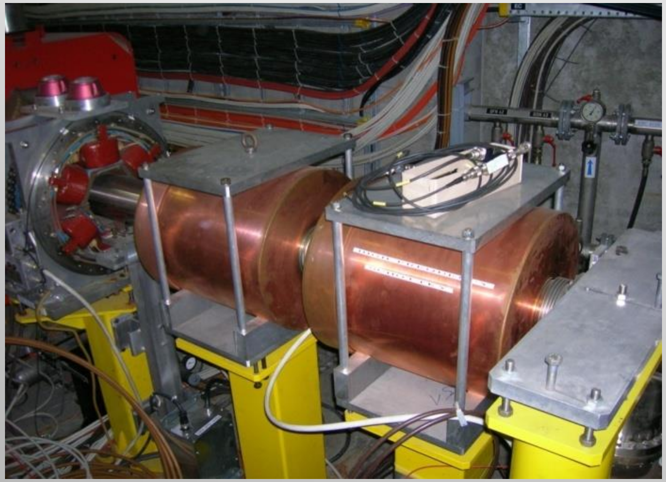


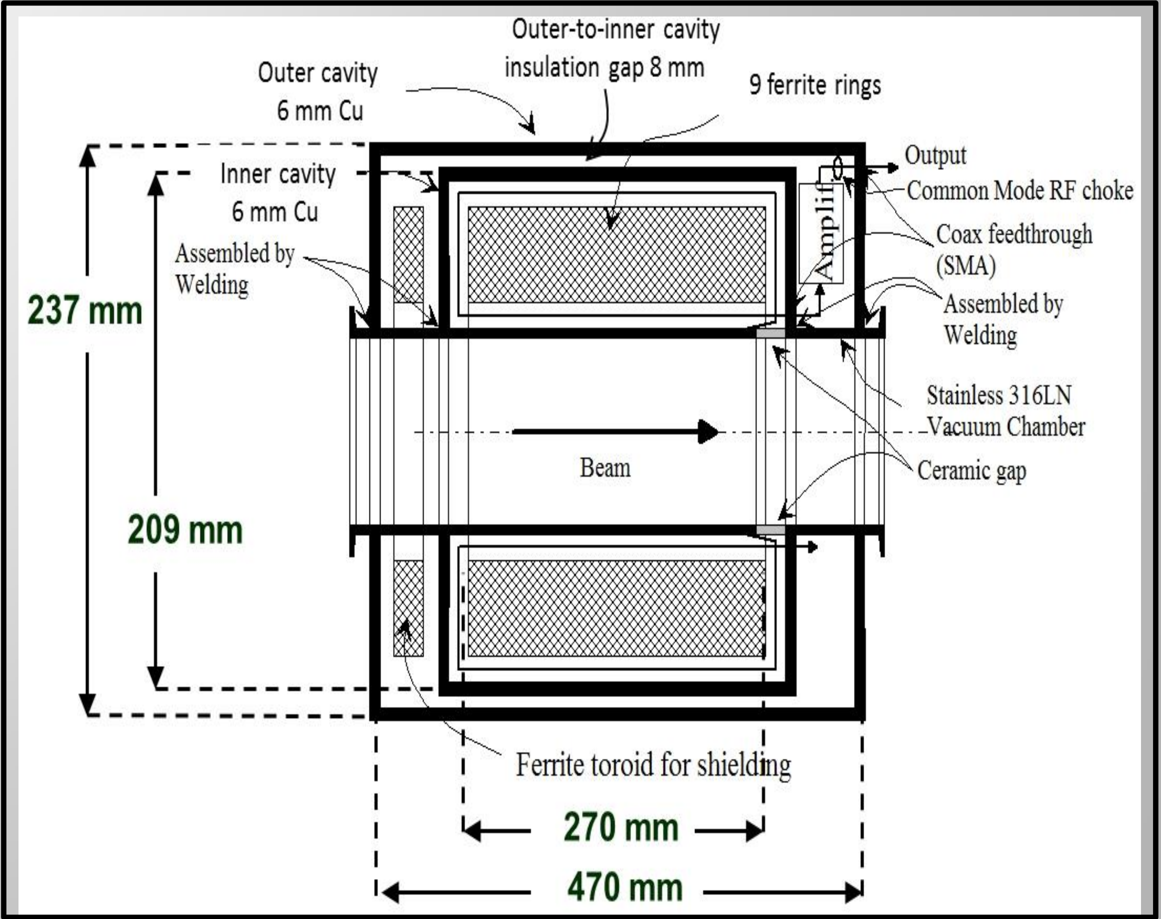
Courtesy M. E . Angoletta

Magnetic LPU: design

- **Modification of AD design** due to:
  - Shorter length allocated (1 m in ring, 50 cm in extraction lines)
  - Smaller vacuum pipe diameter
  - Bake ability (200°).

Double-shielded copper cavity with dimensions





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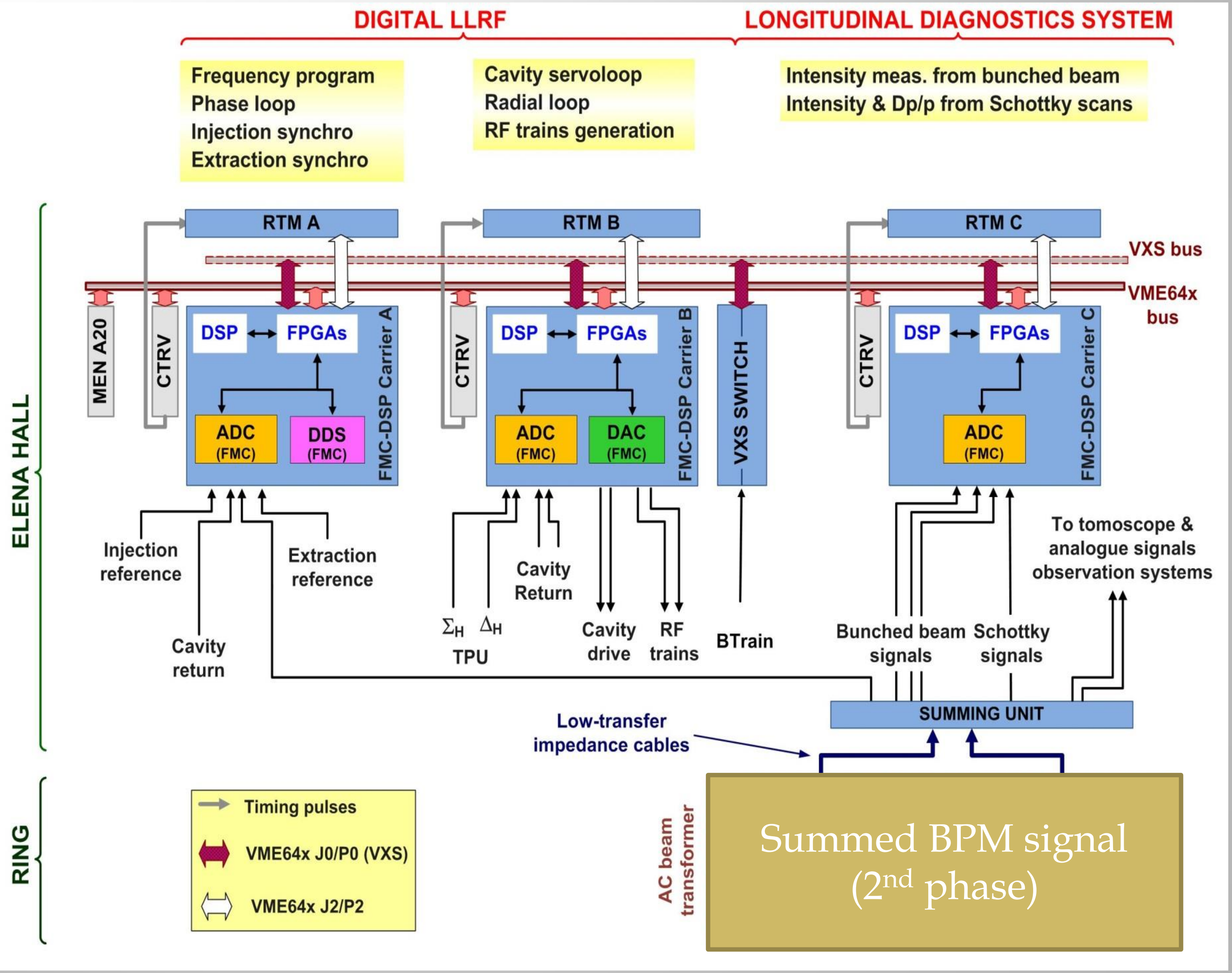
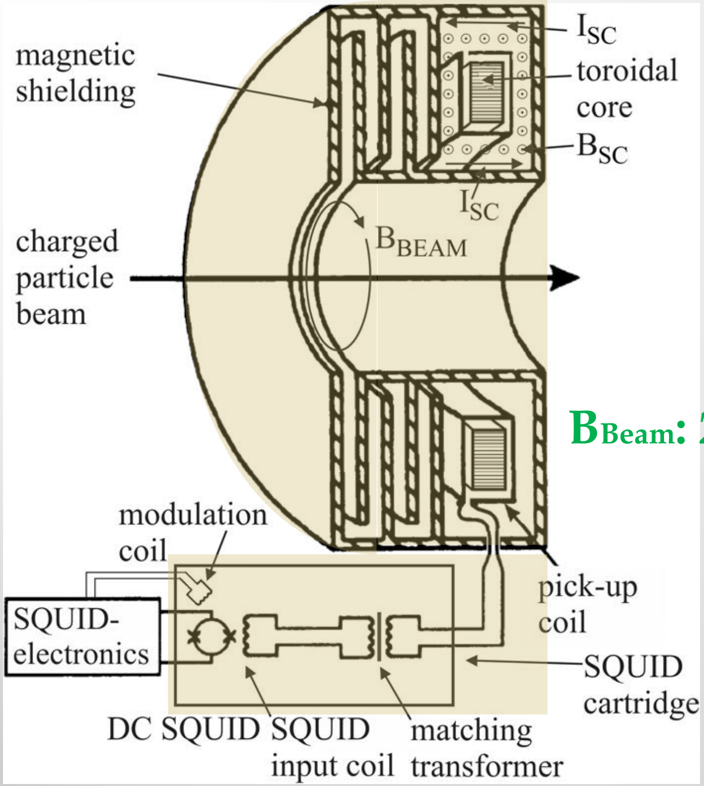
Longitudinal diagnostics



Cryogenic Current Comparator



B_{Beam}: 2-0.5pT

Cold parts, 4.2°k

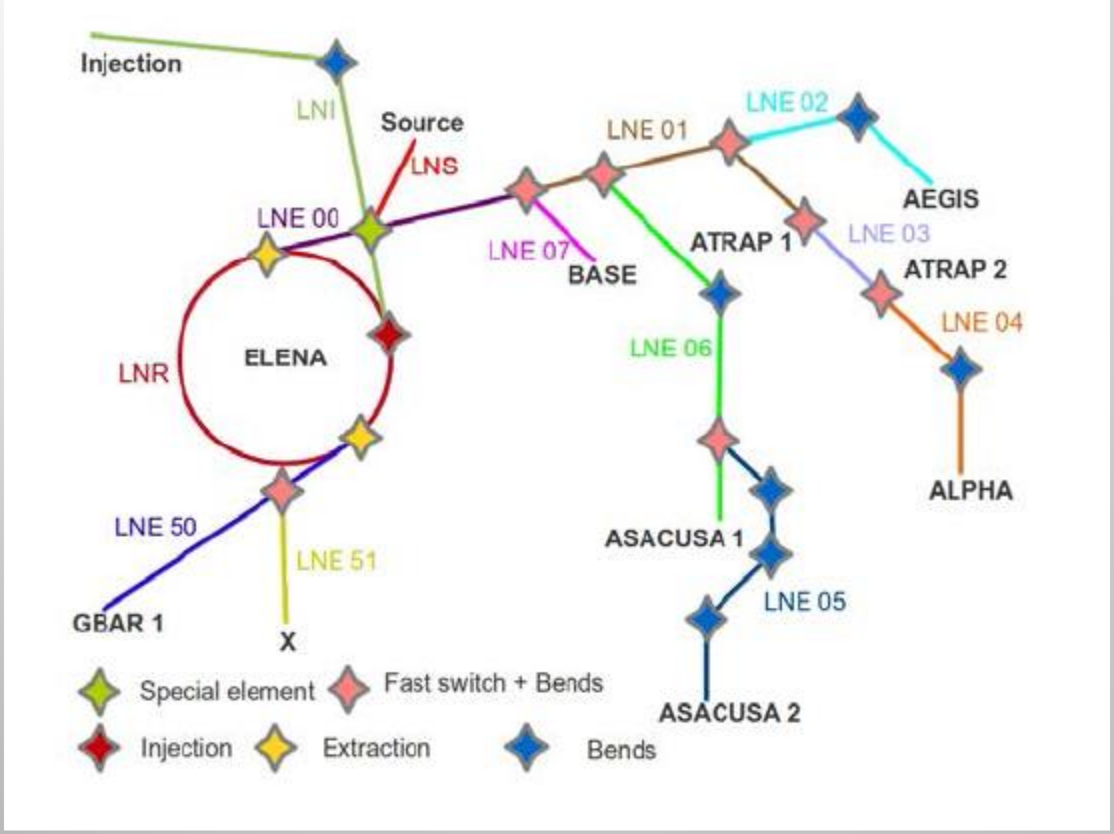
- Working principle similar to that of Beam Current Transformer
- Requires ceramic gaps to let magnetic fields pass.
- Negligible heat load from cold mass
- Geometry:
  - Inner radius: 90 mm
  - Outer radius: 140 mm
  - Length: 180 mm
  - Weight: 43 (Nb) – 50 (Pb) kg

200dB attenuation

Installation and tests of proto type foreseen in AD beginning 2015. Collaboration with GSI, Darmstadt

Experimental Lines

The 100-keV antiproton beam extracted from ELENA will be transported to seven experiments using electrostatic beam lines of total length >100 m. The dipoles and quadrupoles comprising the beam lines must be precisely tuned to focus the antiprotons into the acceptance of the trap experiments.



- **Two low frequency magnetic PUs are foreseen to monitor the extracted intensities.**
- **Around 40 u-Wire grids foreseen to monitor the profiles and position along the lines.**

Consequences for the experiments

- **You will get a nice and well defined beam…. ☺**

	Resolution	Accuracy	Comments
Orbit	0.1mm	0.5mm	1mm single turn
Tune	0.3um		100T
BTV	0.2-0.4mm		Destructive
GEM	4-6mm		Destructive, res can be smaller
uWire	0.5-1.5mm		97-99% transmission
Scraper	< 0.1mm?		
Intensity (Schottky)		5-10%	
Intensity CCC	10nA	1%	Not before 2017-2018

Summery

The main ELENA parameters will be measured with equipment's which we know very well from the AD and believe in:

- Orbit → Electrostatic PUs
- Tune → BBQ
- Profile and positions → BTW, µwire, GEM, Scraper
- Longitudinal diagnostic → Magnetic PU, Schottky

However very interesting and challenging developments are still in front of us:

- Use of BPM PUs for longitudinal Schottky measurements on de-bunched beams as well as intensity and position of bunched beams.
- Cryogenic current comparator (CCC) based on a superconducting quantum interference device (SQUID) for a precise measurement of the circulating beam intensity.
- Investigate the possibility to use residual gas ionisation or luminescence for circulating beam profile measurements.