Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
IFMIF Goals

International Fusion Materials Irradiation Facility

Characterization of materials envisaged for future fusion reactors.
Study and analysis of the behaviour of materials under a high flux of neutrons ($10^{18}$ n/m$^2$/s).

IFMIF design

Overall facility availability >70%

Accelerator

Deuterons: 40 MeV 2 x cw 125 mA (10 MW)

Target

Irradiation module

Samples

Neutron flux density

Heat extraction by fast liquid Li

Beam footprint at interaction point


I. Podadera- Beam position monitors developments for LIPAC

17 January 2012- DITANET workshop on BPMs
Broader Approach Projects

Contribution: \((50\% + 8\%:\text{EU}) + (10\% + 8\%:\text{JA}) + 10\% \times 4(\text{US,RF,KO,CN})\)

\(100\%:\text{ITER} + 16\%:\text{Broader Approach}\)

ITER

EU

- Contribution: 50%
- Staff: 40%
- Procurement: 40%

JA

- Contribution: 10%
- Staff: 20%
- Procurement: 20%

Remote Center

Simulation

IFMIF-EVEDA

DEMO Design

Satellite Tokamak

Arrangement between EU&JA

M. Seki 2005
EVEDA phase

**Engineering Validation and Engineering Design of the IFMIF project**

LIPAC project

**Linear IFMIF Prototype Accelerator**

**Goals**
- To validate the technical options with the construction of a prototype accelerator.
- Input to produce the detailed integrated design of the future IFMIF accelerator.

**Main specifications**
- Installation in Rokkasho-Japan from 2013.
- Manufacturing and tests of a prototype accelerator (1:1) with 9 MeV final energy.
- Nominal operation: Deuterons, 125 mA cw, 9 MeV.
- Commissioning phase: 10 mA-125 mA, pulsed mode down to >100 μs, 0.1% duty cycle.

I. Podadera - Beam position monitors developments for LIPAC

LIPAC Rokkasho building

Ion species
- $D^+$ (nom. op.)
- $p, H_2^+$ (comm.)

CW current (nominal)
- 125 mA

RFQ output energy
- 5 MeV

SRF output energy
- 9 MeV

RF frequency
- 175 MHz

Bunch width (min/max)
- 0.1-3 ns

Duty factor (min/max)
- 0.1%/CW

Pulse length (min/max)
- ~100 μs/CW

Beam power
- 1.125 MW
Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
Measurement objectives of BPM’s at LIPAC

To detect dipole errors along the beamlines and cryomodule by measuring the position of the transverse beam centroid

To measure the mean energy at the Diagnostics Plate

To tune the cavities with the beam phase
I. Podadera - Beam position monitors developments for LIPAC

**Layout**

<table>
<thead>
<tr>
<th>Region</th>
<th>BPM acronym</th>
<th>Aperture</th>
<th>Number</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEBT</td>
<td>MBPM</td>
<td>48 mm</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SRF</td>
<td>CBPM</td>
<td>50 mm</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Diagnostics plate</td>
<td>DBPM</td>
<td>100 mm</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>HEBT</td>
<td>HBPM</td>
<td>40/130/150 mm</td>
<td>1/2/2</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>20</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Beam dynamics requirements

<table>
<thead>
<tr>
<th>Location</th>
<th>$\beta$ (%)</th>
<th>Transverse size (mm)</th>
<th>Bunch length (mm)</th>
<th>Current (mA)</th>
<th>Aperture (mm)</th>
<th>Measurement type</th>
<th>Range</th>
<th>Precision</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEBT</td>
<td>7</td>
<td>1/5</td>
<td>4/6.5</td>
<td>125</td>
<td>50</td>
<td>Position</td>
<td>0 to 5 mm</td>
<td>0.1 mm</td>
<td>0.01 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.5 mm</td>
<td>0.05 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.25 mm</td>
<td>0.025 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>1.0 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>2 deg</td>
<td>0.3 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.1 mm</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>SRF</td>
<td>7/10</td>
<td>3/3</td>
<td>2.5/2.8</td>
<td>125</td>
<td>49</td>
<td></td>
<td>0 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td>SRF</td>
<td>7/10</td>
<td>3/3</td>
<td>2.5/2.8</td>
<td>125</td>
<td>49</td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Position</td>
<td>0 – 5 mm</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm to BSC/2</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase</td>
<td></td>
<td>1 deg</td>
<td>0.1 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
<td>0.01 to 150 mA</td>
<td>0.001 to 0.1 mA</td>
<td>0.001 to 0.1 mA</td>
</tr>
</tbody>
</table>

*RFQ commissioning*
**Image currents**

- **MEBT**
- **SRF**
- **DP & HEBT**

![Graphs showing beam current over time for MEBT, SRF, and DP & HEBT](image)

*I. Podadera - Beam position monitors developments for LIPAC*
I. Podadera - Beam position monitors developments for LIPAC

17 January 2012- DITANET workshop on BPMs

System description

Accelerator vault

Racks area

40-70 m

~20 m

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

40-70 m

V+

H−

H+

V−

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m

V+

H−

H+

V−

Pickup

Front-end electronics

Control unit

Supervision unit

Racks area

~20 m
Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
BPM’s design

<table>
<thead>
<tr>
<th></th>
<th>Shoe-box (linear capacitive)</th>
<th>Capacitive/Button</th>
<th>(micro)Stripline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linearity</td>
<td>Good</td>
<td>Fair/Poor</td>
<td>Fair</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Phase accuracy</td>
<td>-</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>Space required</td>
<td>Big</td>
<td>Medium/ Small</td>
<td>Small</td>
</tr>
<tr>
<td>Spray particles sensitivity</td>
<td>High</td>
<td>Medium (50 Ω)</td>
<td>Low</td>
</tr>
<tr>
<td>Mechanical complexity</td>
<td>High</td>
<td>Medium/ Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Reliability and maintenance</td>
<td>Bad</td>
<td>Bad/ Good</td>
<td>Medium</td>
</tr>
</tbody>
</table>

MEBT, SRF
Diagnostics plate
I. Podadera - Beam position monitors developments for LIPAC

January 2012 - DITANET workshop on BPMs

---

MBPM design

- Pickups in the middle of each MEBT magnet: electrode connection between poles of the quadrupolar yoke (based on SPIRAL2 design*).
- Welded electrodes are chosen to reduce the transverse PU size.
- Good alignment required with the magnetic quadrupole axis: laser tracker targets in pickup and magnet and separate mechanical supports.
- Non-magnetic materials are used to avoid perturbing the magnetic field of the magnet.
- Capacitive BPMs are the preferred option: high beam current makes signal strength sufficient and the required radial space is smaller.
- The geometry is optimized using a 3D code.
- Results with a realistic simulated beam fit quite well with analytical expectation except some simulation noise.

*P. Ausset, DITANET workshop on High Intensity Proton Beam, 2011

---

EM simulation (long bunch)

- Capacitance optimization
- Length optimization

Comparison of analytical and 3D simulations (real bunch length)

---

EM design permits the use of first harmonic by the electronics in case RF leakage from bunchers@ 175 MHz is too high.
The mechanical design is almost completed.

A prototype will be manufactured in next months for validation of the characterization and the integration in the magnet.
8 BPM's: One pickup in each cavity + solenoid lattice in the sc LINAC

Removable buttons have been chosen to minimize the maintenance impact inside the cryomodule

Use of same buttons than for LHC* (high reliability!); analytical and 3D simulations show the adequance for LIPAC

Sensitivity of each BPM is different (dependance on beam energy)

*see C. Boccard talk
CBPM status

Buttons have been manufactured with the same characteristics than LHC buttons: 24 mm diameter and 49 mm aperture diameter (60° angle).

Helicoflex seals aluminium plated type HN100 for the button flange

Type N connectors for the button feedthroughs: button- male, cable- female.

BPM body is manufactured together with the solenoid flange and welded to the rest of the helium vessel

The buttons have been tested at CERN and a prototype has been manufactured and characterized in CIEMAT (see later)

A prototype of the solenoid + vessel + BPM will be manufactured in the next months
Buttons acceptance tests

Capacitance pairing to obtain better accuracy on the signal strength and position measurement

Complete series tested at CERN (J. Albertone, C. Boccard and I. Podadera)

Test at CERN test bench developed by J. Albertone and C. Boccard

Good agreement with the past results

Few problems detected with a couple of buttons

Four largest capacitance picked for CBPM prototype (more flexibility for pairing later): see results later
DBPM design

3 BPM’s: for beam tracking and measurement of mean energy

Shorted striplines are chosen since they should have less phase dependence for offset positions than other pickups

Geometry is optimized for sum mode impedance operation (dipole or quadrupole modes negligible)

3D simulations confirm the good response but only long bunches simulated

Simulations are being refined to take into account real mechanical geometry

Analytical geometry optimization

Geometry optimization with 3D code

3D simulations (long bunches)
Three BPM’s are better in the diagnostics plate for the TOF measurement.

Good alignment and distance measurement of three BPM’s is required.

~2 keV @ 5/9 MeV

~20 keV @ 5/9 MeV
## DBPM status

The mechanical design is almost completed (similar to SNS or LINAC4)*

A prototype will be manufactured in next months

CF feedthrough: removable for easy maintenance

Bellow for DN100 flange

Reference surfaces for alignment and mechanical support

*see J. Power et al., PAC'03, and J. Tan et al, DIPAC'11

![Diagram of DBPM with labels: Bellow, Aligment plane, RF feedthroughs, CF DN100 flange]
Outline

1. IFMIF and LIPAC
2. BPM’s requirements @ LIPAC
3. Pickups design
4. Test bench
5. Electronics measurements
6. Conclusions & Next steps
Although it is not straightforward to extrapolate the wire method results to low-beta beams...

A test bench has been constructed at CIEMAT to characterize all the IFMIF/EVEDA BPM's before installation in Rokkasho.

It is possible to characterize the following parameters of the BPM’s:

• Electrical center.
• Sensitivity.
• Linearity.
• Resolution.
• Mechanical and electrical stability.

**Setup:**

• Two micromovers (5 μm accuracy, orthogonality 50 μrad)
• BPM support.
• Wire support.

**Characterization of proto CBPM**

Plot of measured $\Delta \Sigma$ in horizontal and vertical and $\Sigma$. Sensitivity 12.8 mm.
Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
The AFE unit is based on two different boards:

1) To measure position: A 4-channel logarithmic amplifier (log amp AD8310, high dynamic range of 95 dB and bandwidth from DC to 440 MHz) and a differential to single-ended converter (AD8130) board connected to each pickup button (central board of the AFE unit).

2) To measure phase: An IQ demodulator (AD8348) board fed by the sum of the 4 button signals of the CIEMAT wire test bench and the same differential to single-ended converter AD8130 (boards on the left).

DU is a Lytech VHS-ADC board, including a high performance cPCI FPGA based on Xilinx Virtex-4 and an Analog to Digital Converters (ADC) → 8 channels, 14 bits resolution sampling up to 105 MHz. Signals linearization and calibration to compensate the errors of the measurements → offset compensation and blocks to obtain the beam phase (arctan(Q/I)) and the position (Δx/Σ algorithm).

Experimental setup used in the CIEMAT tests.
The test bench has been used in order to measure the relation between the variation of measured position signal and real position movement. In the center region of the pickup, the position is related to the measured button signal as:

<table>
<thead>
<tr>
<th></th>
<th>175 MHz</th>
<th>350 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_x$ [mm]</td>
<td>12.58</td>
<td>12.74</td>
</tr>
<tr>
<td>$K_y$ [mm]</td>
<td>12.73</td>
<td>12.79</td>
</tr>
</tbody>
</table>

The obtained results are now very similar to the expected ones and the Libera Single Hadron Pass H measurements (beginning 2011).
The minimum position change that could be detected with the electronic system has been analyzed in two ways:

- Observing the standard deviation of a series of position data acquired at the center position.
- Measuring the long-term stability using long-term data (~1 hour). Results are affected by drifts in the electronics due to the temperature change (8 °C).

The resolution has been measured as function of the input power and also the sensitivity of the BPM electronics at the level of 5-10 µm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>175 MHz</td>
<td>350 MHz</td>
</tr>
<tr>
<td>X position resolution [µm]</td>
<td>4.33</td>
<td>5.48</td>
</tr>
<tr>
<td>Y position resolution [µm]</td>
<td>6.19</td>
<td>6.86</td>
</tr>
<tr>
<td>X position stability [µm]</td>
<td>13.70</td>
<td>-</td>
</tr>
<tr>
<td>Y position stability [µm]</td>
<td>20.78</td>
<td>-</td>
</tr>
<tr>
<td>Phase resolution [°]</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Future developments ESSB

- Work in phase measurements in Bilbao lab.
- Adaptation of test bench to beam bunch-like shapes.
- Test new IQ demodulators.
- Test bench tests of the pulsed measurements.
- Calibration: include precise calibration of log amps, and automatic gain and phase calibration of four channels -> improvement of the absolute accuracy of electronics.
- Final prototype tests.
Libera SPH measurements

M. Znidarcic et al., DIPAC 2011

Libera SPH was tested for first time with a real pickup in the CIEMAT wire test bench using the proto CBPM

Digital electronics based on undersampling scheme

Measurements of CW and pulsed bunch-like signals

Good position and phase resolution

Wire movement measurement. Concatenated results for the displacements over a larger scale (X = +1 mm, -1 mm, +2 mm; Y = 0 mm). Four amplitudes and X, Y positions are plotted.

Wire movement – by 5 um steps in X-direction. Seven steps are seen in position measurement.
Outline

IFMIF and LIPAC

BPM’s requirements @ LIPAC

Pickups design

Test bench

Electronics measurements

Conclusions & Next steps
Conclusions

Electromagnetic pickups are not “ideal” instruments for low beta beams but are essential for LIPAC commissioning and operation.

Signal is degraded due to the low-velocity but we have shown signal from BPM’s is convenient for LIPAC operation.

Capacitive pickups will be used in the MEBT to insert the pickups inside the magnet while keeping their aperture as small as possible.

Buttons are chosen as the main candidate inside the SRF. Reliable LHC buttons are used and has been integrated in the solenoid package. Measurement at 350 MHz might be needed due to RF leakage from the sc cavities.

Shortcut striplines will be used in the diagnostics plate for the TOF measurement. Detail simulation of striplines vs buttons needs to be carried out.

Responses at 5 MeV of the DBPM’s & HBPM’s are to be analyzed with the final transport line design for the RFQ commissioning.

A wire test bench has been constructed and tested for characterization of all the LIPAC BPM’s.

ESS-Bilbao based on log-amps for position measurement and IQ demodulation for phase measurement of the sum signal acquisition electronics has been designed, manufactured and characterized in the test bench. A demo unit of Libera SPH was also tested.

Prototypes of all the BPM’s are being constructed and will be fully characterized this year.
Thanks to...

The ESS-Bilbao team D. Belver, L. Muguira,
The CERN Beam Diagnostics team, especially to C. Boccard, J. Albertone E. Calvo, L. Soby
The Libera team, B. Barucevic, M. Znidarcic, R. Hovratin,
And also to J. Power (LANL), P. Forck (GSI), F. Perez, A. Salom (CELLS) for the good advices during the project
And of course, thanks to all the LIPAC EU-HT
...and for your attention!!

QUESTIONS?
**Particularities of low-β beams**

### Current “density” in A/m for...

- **β=1**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right] = \frac{-I_b(t)}{2\pi b} \left[ \frac{b^2 - r^2}{b^2 + r^2 - 2br \cos (\alpha - \theta)} \right]
\]

- **Any β**

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]

Equivalent expressions for \( g \approx 0 \)

---

**Current “density” in A/m for...**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right]
\]

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]

**Current “density” in A/m for...**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right]
\]

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]

---

**Current “density” in A/m for...**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right]
\]

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]

---

**Current “density” in A/m for...**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right]
\]

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]

---

**Current “density” in A/m for...**

\[
 i_w(b, \alpha, t) = \frac{-I_b(t)}{2\pi b} \left[ 1 + 2 \sum_{m=1}^{\infty} \left( \frac{r}{b} \right)^{m} \cos [m(\alpha - \theta)] \right]
\]

\[
 i_w(\omega, r, \alpha, \theta) = \frac{A_n \langle I_b \rangle}{\sqrt{2\pi b}} \left[ I_0(\text{gr}) + 2 \sum_{m=1}^{\infty} \frac{I_m(\text{gr})}{I_m(\text{gb})} \cos [m(\alpha - \theta)] \right]
\]

\[
 g(\omega) = \frac{\omega}{\beta \gamma c}
\]
Space charge and diffuse beams

High current are dominated by the space charge of the beams. Obviously, high current beams are bigger than low current ones, tending to more diffuse beams.

According to the approximations given in *Comparison of beam-position transfer functions using circular beam-position monitors* (Gilpatrick, PAC97), the sensitivity change can be noticed if the sum of the beam rms transverse width $\sigma$ and the beam offset $(\bar{x}, \bar{y})$ is greater than 65% of the electrode radius $b$.

For example, for a BPM of 150 mm aperture that means the rms width should be greater than 50 mm for this effect to be noticeable. For a 10 mm beam radius, the maximum offset that can accepted is then 40 mm

**Total image current in an electrode created by a diffuse beam**

$$I_T = \sum_{n=-3\sigma}^{+3\sigma} \sum_{m=-3\sigma}^{+3\sigma} \hat{I}_T a_n b_m e^{-\frac{(x_n^2-\bar{x}^2)}{2\sigma^2}} e^{-\frac{(y_n^2-\bar{y}^2)}{2\sigma^2}}$$