WEPP002

DEVELOPMENT OF A LOW-BETA BPM FOR MYRTE PROJECT

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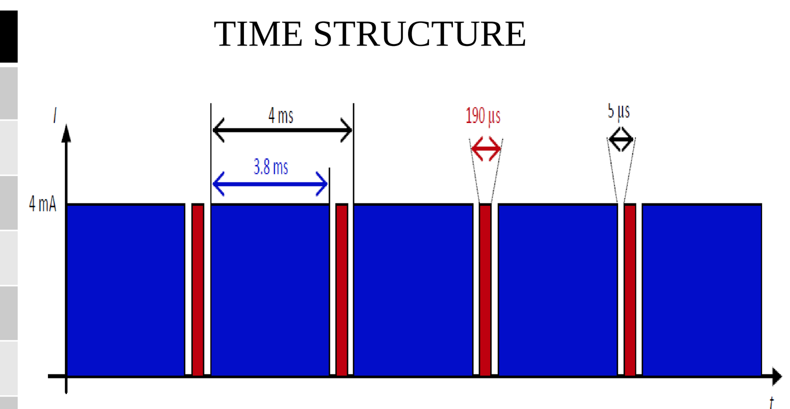
ABSTRACT

MYRTE (MYRRHA Research Transmutation Endeavour) performs research to support the development of the MYRRHA (Multi-Purpose Hybrid Research Reactor for High-Tech Applications) research facility, which aims to demonstrate the feasibility of high-level nuclear waste transmutation at industrial scale. MYRRHA Facility aims to accelerate 4mA proton beam up to 100 MeV. The accurate tuning of LINAC is essential for the operation of MYRRHA and requires measurement of the beam transverse position and shape, the phase of the beam with respect to the radiofrequency voltage with the help of Beam Position Monitor (BPM) system. MYRTE aims to qualify beam operation at 1.5MeV. Two BPMs were realized for MYRTE operation. This paper addresses the design, realization, and calibration of these two BPMs and their associated electronics. The characterization of the beam shape is performed by means of a test bench allowing a position mapping with a resolution of 0.02mm.

MYRTE PROJECT

MYRTE BEAM PARAMETERS	
Operation modes	CW, pulsed (down to 100µs pulse length)
Beam Energy	1.5MeV
Beam particle	Proton
Beam Current	100µA-4mA
β	0.0565
Bunch Length	40°
Beam pipe radius	28mm
Bunch Frequency F_{acc}	176.1MHz

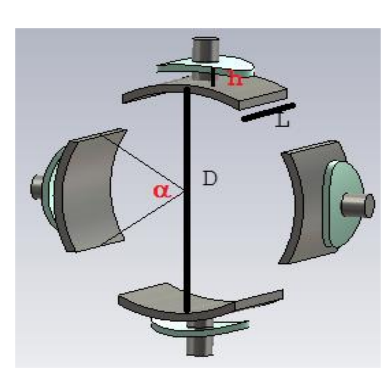
TIME STRUCTURE



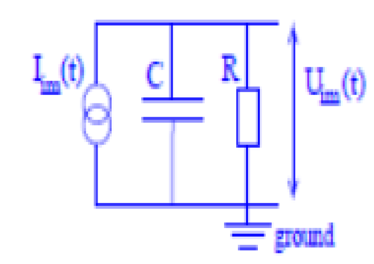
BPM SPECIFICATIONS AND DESIGN

SPECIFICATIONS	
Operation mode	CW, (down to 100µs pulse in commissionning phase)
Position	±10 mm
Phase	360degrees
Quadrupole moment	±5mm

BPM CHOICE: 4 CAPACITIVE PROBES



CST MODEL



ELECTRICAL MODEL

ELECTRICAL FIELD (centered beam)

$$E_r(D,z) \approx \frac{Q}{3\pi\varepsilon_0 D^2} e^{-\frac{z^2}{2\sigma^2}}$$

BPM OUTPUT VOLTAGE (centered beam)

$$U(t) \approx \frac{Q}{\sqrt{2\pi}} \frac{R}{\sqrt{1+(2\pi RCf)^2}} \frac{\alpha}{2\pi}\left(e^{-\frac{t^2}{2\tau^2}} - e^{-\frac{(t-t_b)^2}{2\tau^2}}\right) \quad ; \quad \tau = \frac{\sigma}{\beta c} \quad ; \quad t_b = \frac{L}{\beta c}$$

R= Probe Resistance
C= Probe Capacitance

Beam position measurement formulas

$$\left(\frac{R}{L}\right)_{dB} = \left(1 + G(\beta,f)\right)S_x(f) * \left(X - \Delta_x(f)\right)$$

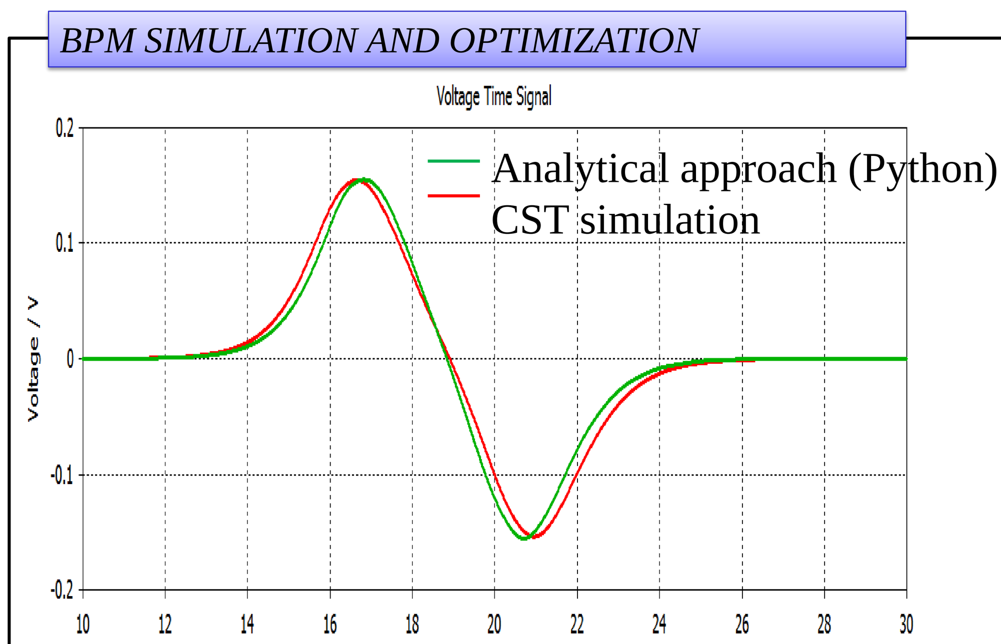
$$\left(\frac{T}{B}\right)_{dB} = \left(1 + G(\beta,f)\right)S_y(f) * \left(Y - \Delta_y(f)\right)$$

Beam quadrupole moment measurement formula

$$\left(\frac{R*L}{T*B}\right)_{dB} = \left(1 + G_Q(\beta,f)\right) * S_Q(f) * \left(E + X^2 - Y^2 - \Delta_Q(f)\right)$$

(X, Y) are the beam position coordinates.
β the beam relative velocity.
f the electrodes output signal acquisition frequency.
(S_x, S_y) is the position sensitivity at β=1.
(Δ_x ,Δ_y) are the position offset coordinates at β=1.
G(β,f) is a correction factor set by Shafer [2].
S_Q and Δ_Q are respectively the quadrupole moment offset and sensitivity at β=1. G_Q(β,f) is a correction factor mentioned in [3]

BPM SIMULATION AND OPTIMIZATION



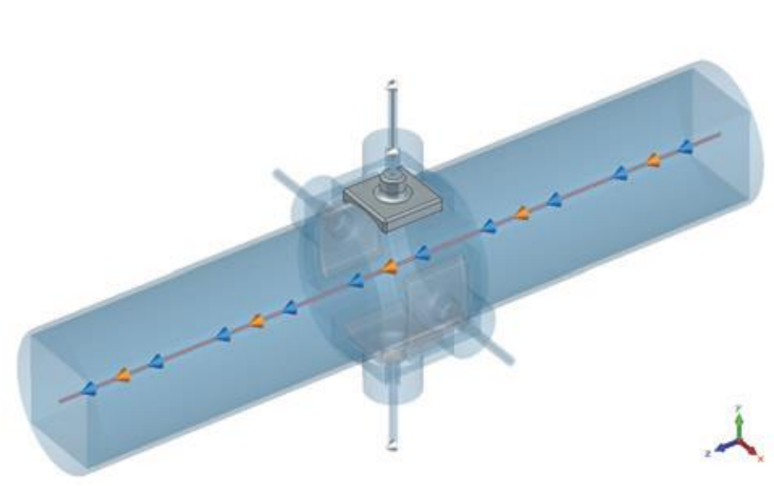
BPM output voltage for the optimized solution (β =0.0565, 1nC bunch)

OPTIMIZATION GOALS	
Output voltage V	High
Robustness	High
Position sensitivity S_P	High
Quadrupole moment sensitivity S_Q	High

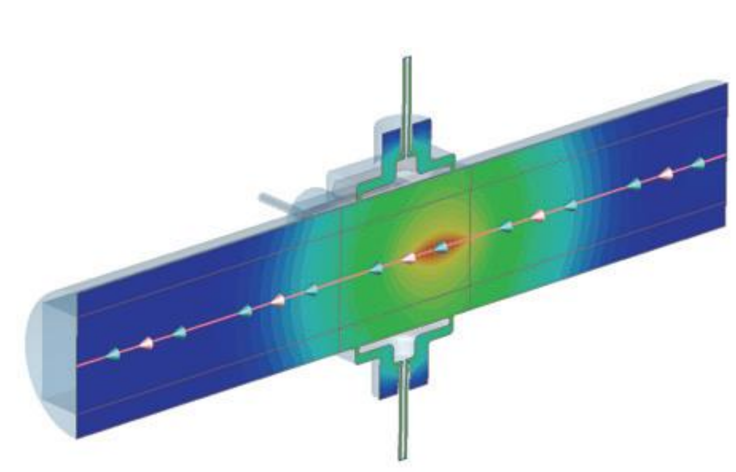
OPTIMIZATION PARAMETERS	
Angular aperture α ↗	V ↗ , Robustness ↘ , S_P S_Q →
Probe length L ↗	V ↗ , Robustness ↘ , S_P S_Q →
Electrode gap h ↗	V ↗ , Robustness ↘ , S_P S_Q →

Trade off between different parameters gives: L=62mm, α=60° and h=2,9mm

EXPECTED RESULTS			
Relative velocity	Output voltage	Position sensitivity S_P	Quadrupole moment sensitivity S_Q
β=1		1,16dB/mm	0,031dB/mm
β=0,0565	150mV	1,59dB/mm	0,05dB/mm



CST MODEL



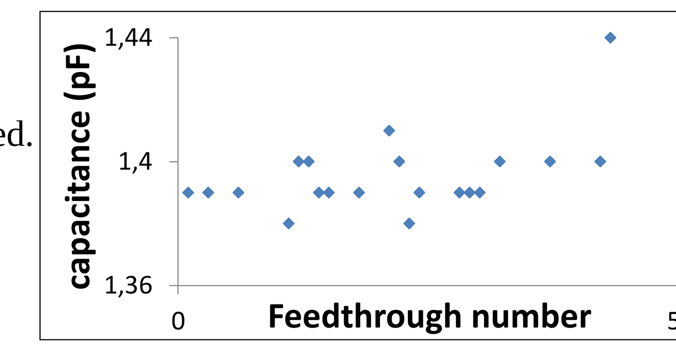
Instant Electric Field (β =0.0565, 1nC bunch)

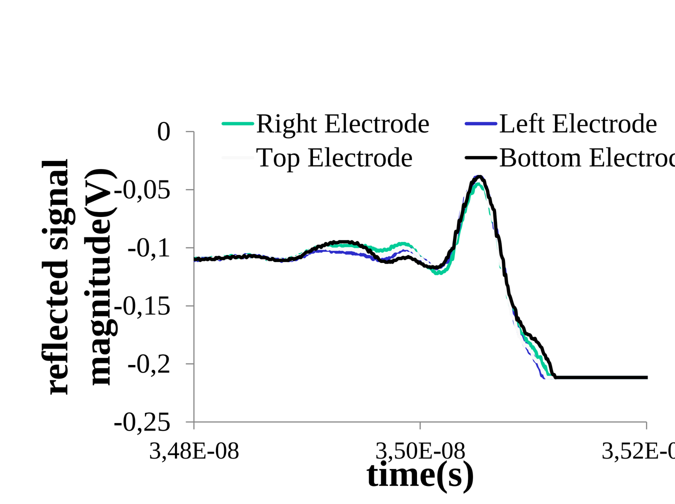
BPM FABRICATION

Using ceramic barrettes in BPM fabrication [1] eases electrodes positioning and offers a robust and reproducible BPM.

BPM realization steps:

- Feedthrough fabrication:
  - 20 reverse polarity feedthroughs fabricated.
  - Electrical isolation verified
  - Capacitance measurement
  - TDR response measurement
  - 4 feedthrough are chosen per BPM
- Block realization:
  - Electrical isolation verified
  - Capacitance measurement
  - TDR response measurement
- BPM realization:
  - Electrical isolation verified
  - Capacitance measurement

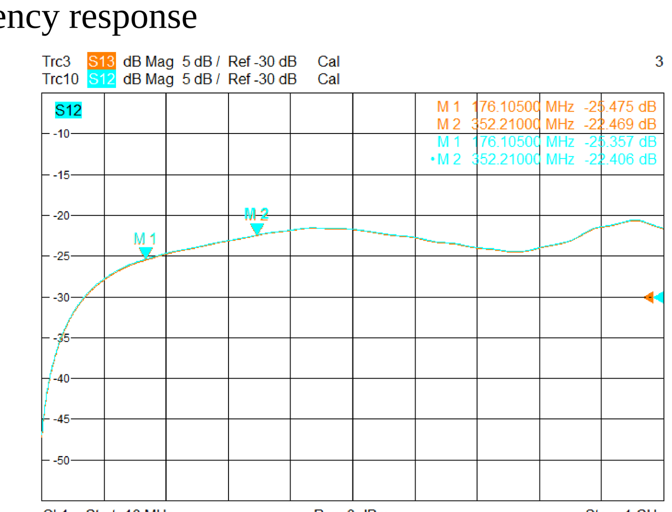




BPM CHARACTERIZATION

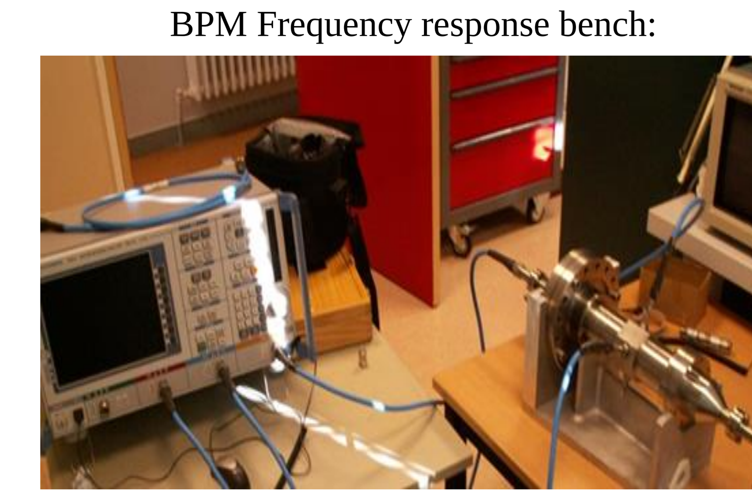
Goals:

- Frequency response

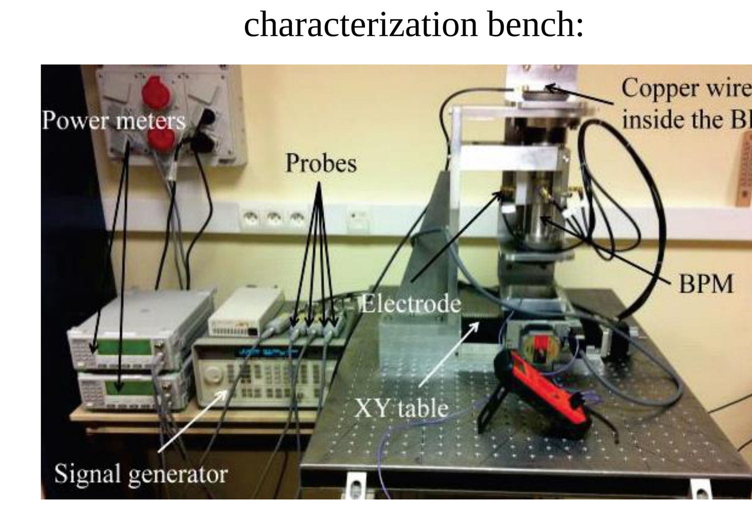


High pass filter feature is confirmed
Electrode responses are similar

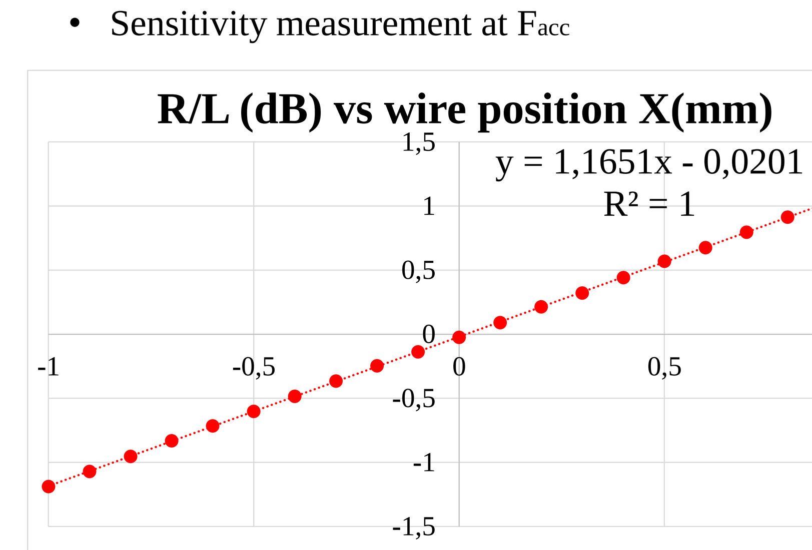
BPM Frequency response bench:



BPM Position and Quadrupole moment characterization bench:



- BPM position parameters:
  - Electrical centre localization: Electrical centre corresponds to the position where the amplitudes of opposite electrodes received signals are equal.
  - Offset measurement at F_{acc}: position offset coordinates are the algebraic differences between BPM mechanical centre and electrical centre.
  - Sensitivity measurement at F_{acc}

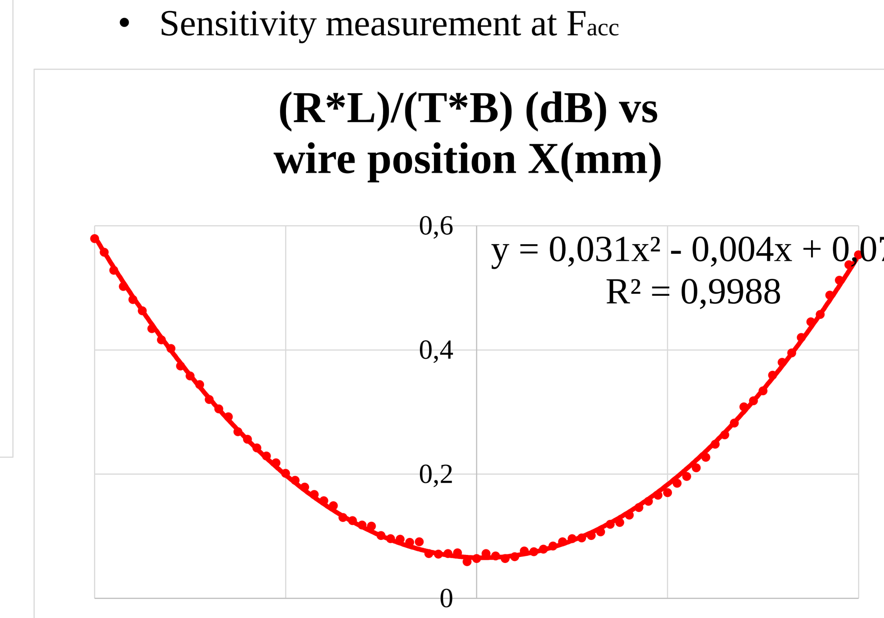


BPM	Sensitivity S_P(dB/mm)	Offset coordinates (Δ_x ,Δ_y) (µm)
1	1.165	(36;-166)
2	1.163	(-49;123)

BPM	Sensitivity S_Q(dB/mm)	Offset Δ_Q (mm²)
1	0,0313	4.09
2	0,0317	-3.97

Goals:

- BPM quadrupole moment parameters:
  - Sensitivity measurement at F_{acc}



- Offset measurement at F_{acc}: With the wire placed at the BPM electrical centre, the amplitudes at the electrodes outputs at F_{acc} are measured and the quadrupole moment offset is calculated.

CONCLUSION

MYRTE BPMs are presented in this paper. The mechanical fabrication is offering stable and reproducible BPMs. BPM Characterization shows a good agreement to expected position and quadrupole moment parameters.
For low-level beam (100µA), BPM electrodes output levels (-50dBm) could be processed by off the shelf acquisition systems as LIBERA single pass H. however, limitations occur for beam quadrupole moment measurement at these levels.

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REFERENCES

[1] M. Ben abdillah, "Novel electrostatic beam position monitors with enhanced sensitivity", in Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16), Barcelona, Spain, September 2016, paper TUPG09, pp. 335-337.
[2] R.E. Shafer, "Beam position monitor sensitivity for low β beams", in Proc. Int. Linac Conf, pp. 905-907.
[3] M. Ben Abdillah et al, "Results of SPIRAL2 Beam Position Monitors on the Test Bench of the RFQ", in Proc. 7th Int. Beam Instrumentation Conf. (IBIC'18), Shanghai, China, September 2018, paper TUPB03, pp.261-264.