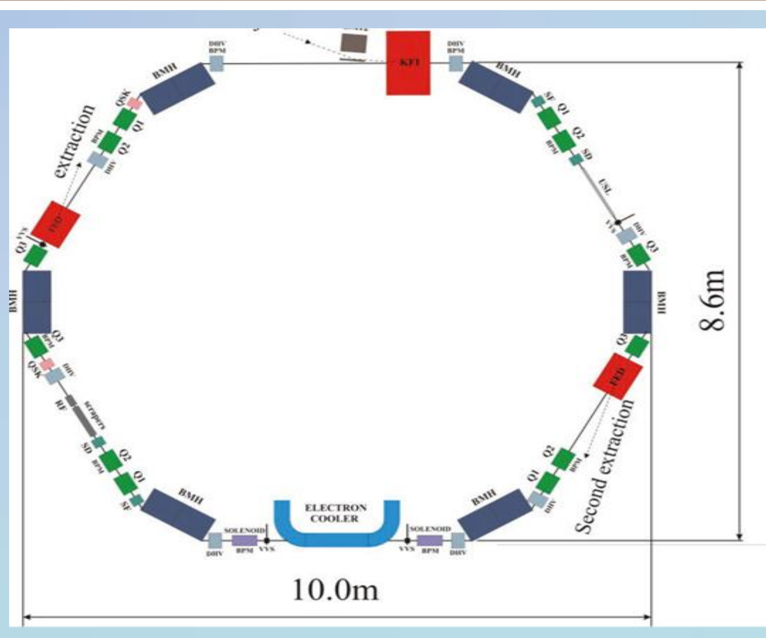
Modeling & Simulation Studies of ELENA BPM based on Multilevel Fast Multipole Method (MLFMM)

S.Naveed#, C.P.Welsch, Cockcroft Institute and University of Liverpool, UK
Andriy Nosych, ALBA CELLS, Barcelona, Spain
O.Ergul, Middle East Technical University Ankara, Turkey

Abstract

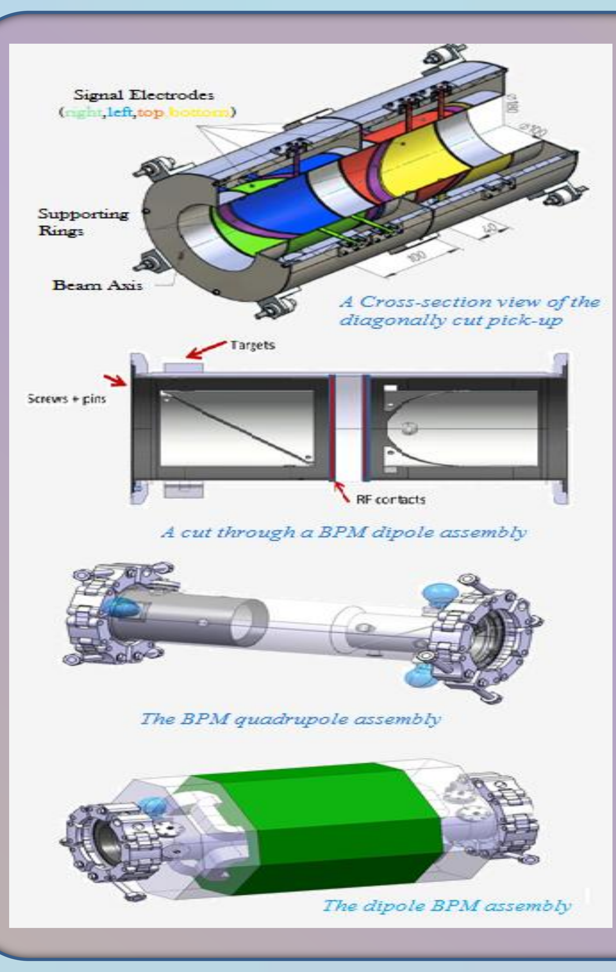
Beams of cooled antiprotons at keV energies shall be provided by the Ultra-low energy Storage Ring (USR) at the Facility for Low energy Antiproton and Ion Research (FLAIR) and the Extra Low Energy Antiproton ring (ELENA) at CERN's Antiproton Decelerator (AD) facility. Both storage rings put challenging demands on the beam position monitoring (BPM) system as their capacitive pick-ups should be capable of determining the beam position of beams at low intensities and low velocities, close to the noise level of state-of-the-art electronics. Here, we describe the design and anticipated performance of BPMs for low-energy ion beams with a focus on the ELENA orbit measurement systems. We also present the particular challenges encountered in the numerical simulation of pickup response at very low beta values. Finally, we provide an outlook on how the implementation of faster algorithms for the simulation of BPM characteristics could potentially help speed up such studies considerably.

Design & Specifications



A schematic view of the layout of the ELENA ring

ELENA is a compact storage ring, which shall slow down antiprotons up to to 100 keV. The total number of extracted antiprotons is estimated to be ~2.107.



- The ELENA BPM system is based on 20 cylindrical diagonally cut electrodes.
- The electrodes are mounted inside quadrupole and dipole magnets by ceramic supports.
- Difference and sum signals read from the electrodes will be digitized and provide beam position information along the ELENA ring.

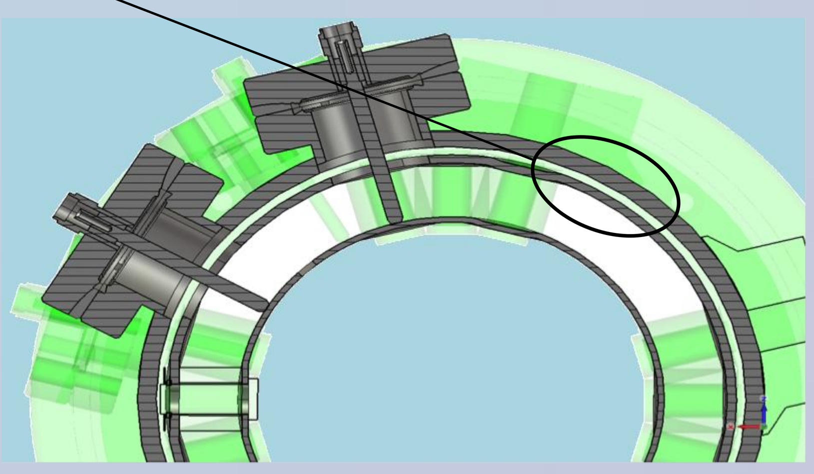
BPM Mechanical Dimension		BPM Requirements	
Electrode inner diameter	66mm	Resolution	0.1mm
Electrode thickness	1mm	Accuracy	0.3-0.5mm
Electrode to support tube gap	10mm	Precision	0.1mm
Support tube inner diameter	88mm	Max. Beam displacement	33mm
Support tube thickness	1mm	Time Resolution	~10ms
Vacuum tube thickness	1.5mm	Revolution Frequencies	1k-145kHz
Feed through flanges	DN16CF	Overall maximum length	400mm
Electrode length	120mm	Inner diameter	66mm
Overall length, Dipole	340.5mm	Bake out temperature	250C
Overall length, qudrupole	432.5	Vacuum	3x10-12Torr

Electromagnetic Simulations & Challenges

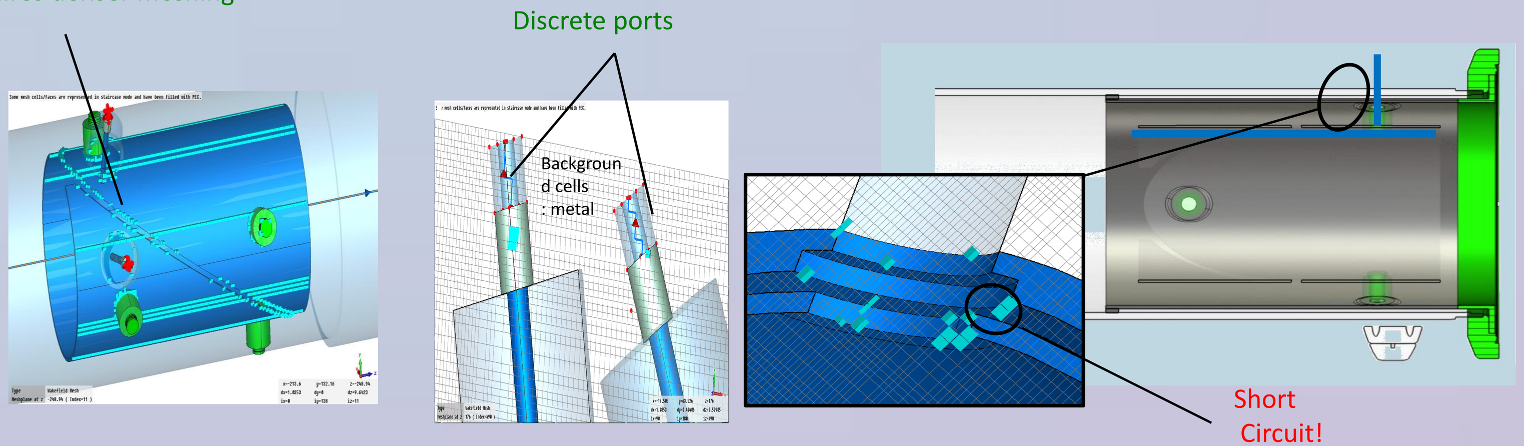
Ultimate Aim

To achieve convergence for different mesh counts for non relativistic beams.

The structure contains a very thin interlayer of vacuum (1.5 mm)

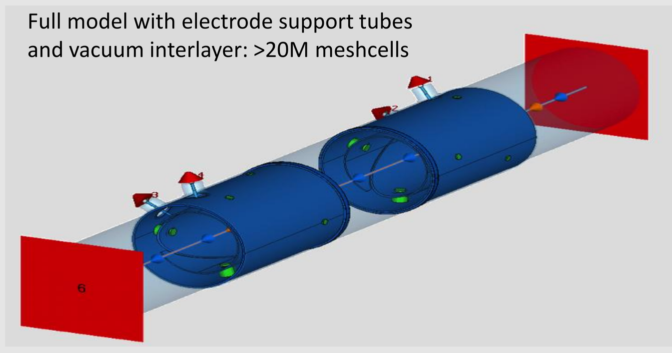


- This interlayer is important to simulate correctly as it can cause trapped modes and thus reflections in the transmission line.

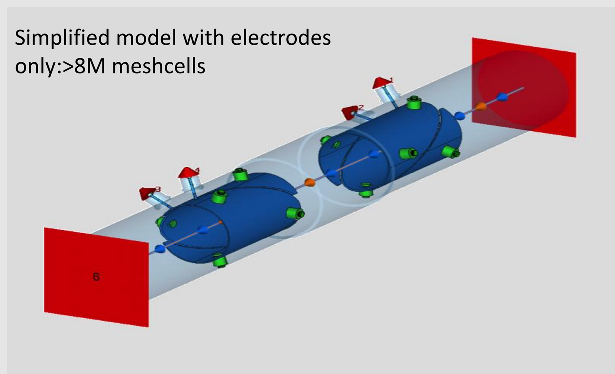


- It requires **very dense meshing** to avoid short-circuits within cubical mesh cells.

Simplified EM versions of the mechanical model: NO CONVERGENCE!

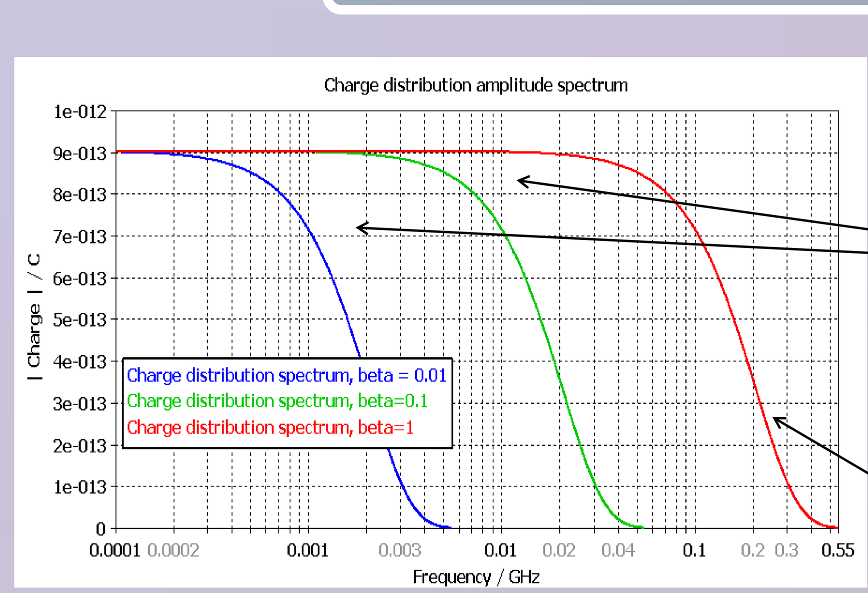


19h of computation time on 32 cores.
Wake-Loss-Factor: 5.3e-001 V/pC
Correct Feedthrough readings
ERROR in wake calculation!



8h of computation on 2 cores
Wake-Loss-Factor: 7.13e-004 V/pC
Short-circuited Feedthrough (bad mesh)
REALISTIC wake calculation

Single Bunch Excitation



Requirement:

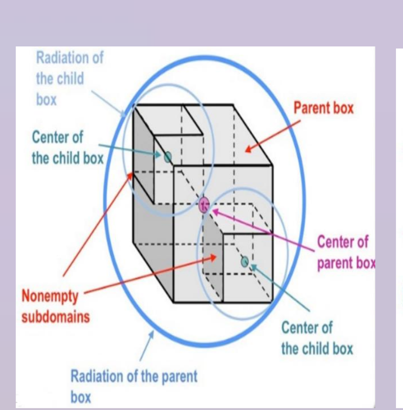
- Charge: 1E7 p- = -1.6E-12 C
- Length: truncated gaussian [-2s, 2s] or 1.3 m for s = 325 mm
- Velocity: b = between 0.01 and 0.1

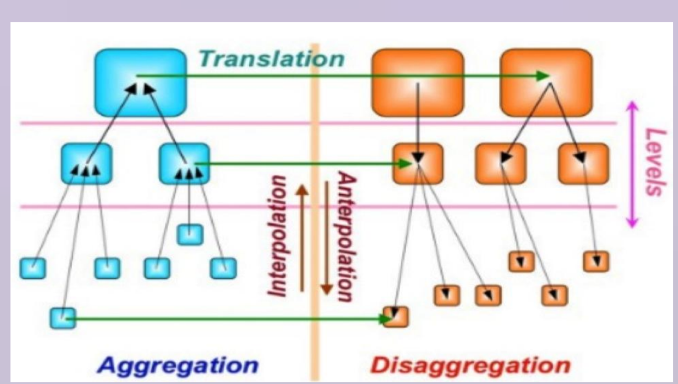
Possible simulation with CST PS:

- Charge: 1E7 p- = -1.6E-12 C
- Length: gaussian shape [-5s, 5s] or 11 ns,or 3.25 m, for s = 325 mm
- Velocity: b = 1

Simulation Environment based on MLFMA

◆MLFMA enables the solution of large problems by reducing the complexity of MVMs from $O(N^2)$ to $O(N\log N)$ or $O(N\log^2 N)$.





- The algorithm is Based on a hierarchical decomposition of a cube named as the oct-tree grouping.
- Group center to center distances are fixed at each level.
- One set of translation operators need to be cached, dramatically reducing memory.

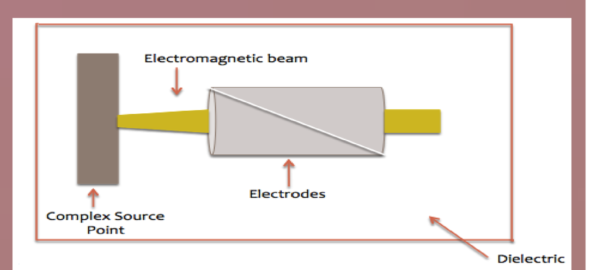
Challenges with MLFMA
➢ MLFMA works with models based on WAVES.
➢ MLFMA works for waves travelling with speed of light.
➢ In MLFMA dielectrics are used instead of vacuum.
➢ MLFMA suffers from low frequency breakdown.
➢ MLFMA could also become ill conditioned for small geometrical shaped objects.

Mathematical Modeling

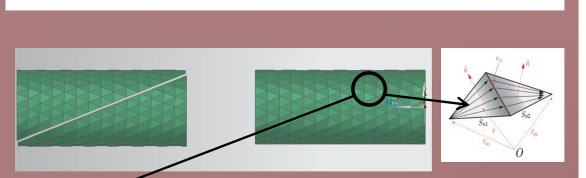
- In order to obtain an electromagnetiic beam, which satisfies Maxwell's equations exactly, an ideal dipole can be located at

$$r_d = r_{d,R} + i r_{d,I}$$

In Comples Coordinates.

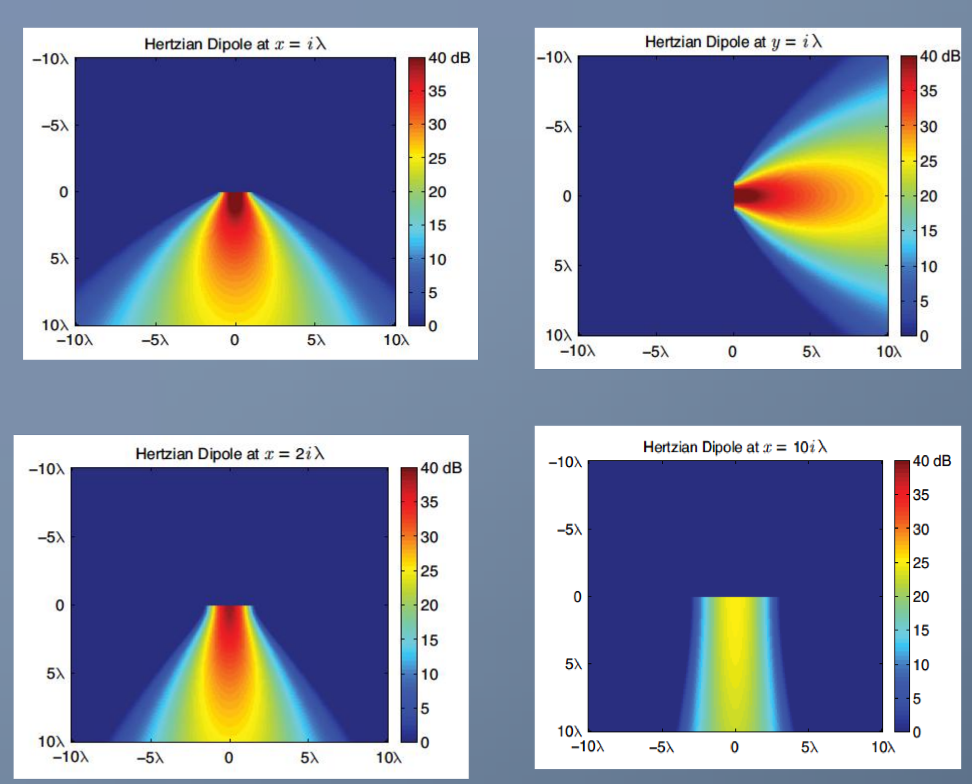


Then the electromagnetic fields can be found at any point r



Triangular mesh

Experiments with Hertzian Dipole to obtain the required beam width



References

[1] O.Ergul, "The Multilevel Fast Multipole Algorithm for Solving Large-Scale Computational Electromagnetics Problems, Whiley Blackwell (2014).
[2]M. F. Gyure and M. A. Stalzer, "A prescription for the multilevel Helmholtz FMM," IEEE Comput.Sci.Eng., vol. 5, no. 3, pp. 39–47, Jul.-Sep. 1998.
[3]W. C. Chew, J.-M.Jin, E. Michielssen, and J. Song, Fast and Efficient Algorithms in Computational Electromagnetics.Boston: Artech House, 2001.
[4] W. C. Chew, S. Koc, J. M. Song, C. C. Lu, and E. Michielssen, "A succinct way to diagonalize the translation matrix in three dimensions," Microw. Opt. Technol. Lett., vol. 15, no. 3, pp. 144–147, Jun. 1997.
[5] M. Burton and S. Kashyap, "A study of a recent moment-method algorithm that is accurate to very low frequencies," ACES J., vol. 10, no. 3, pp. 58–68, Nov. 1995.

Acknowledgements

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under contract PITN-GA-2011-289485 and by STFC under the Cockcroft Institute Core Grant No. ST/G008248/1.

http://www.cockcroft.ac.uk
http://www.quasar-group.org
sehar.naveed@liverpool.ac.uk