

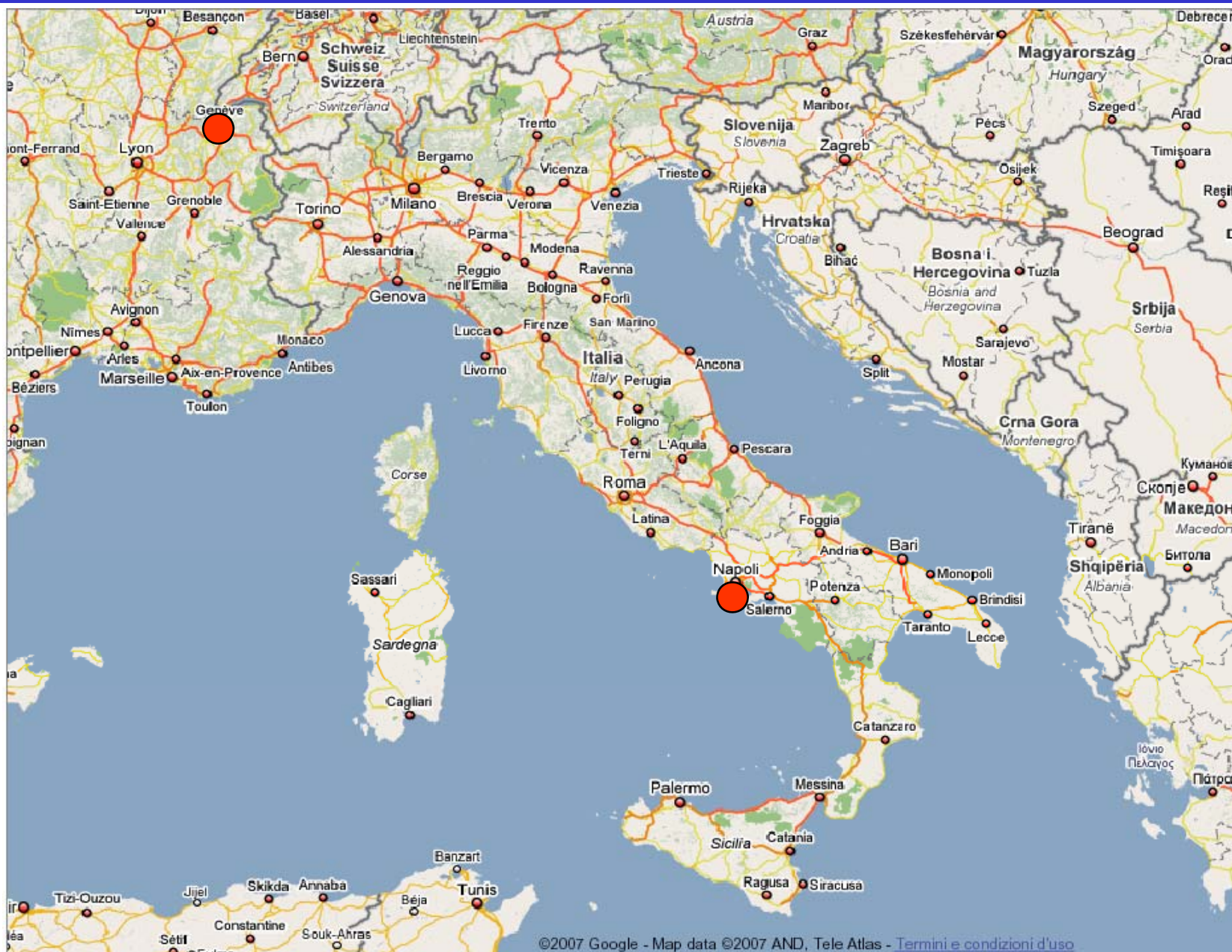
# *Francesco Ruggiero Memorial Symposium*

## *Impedances*

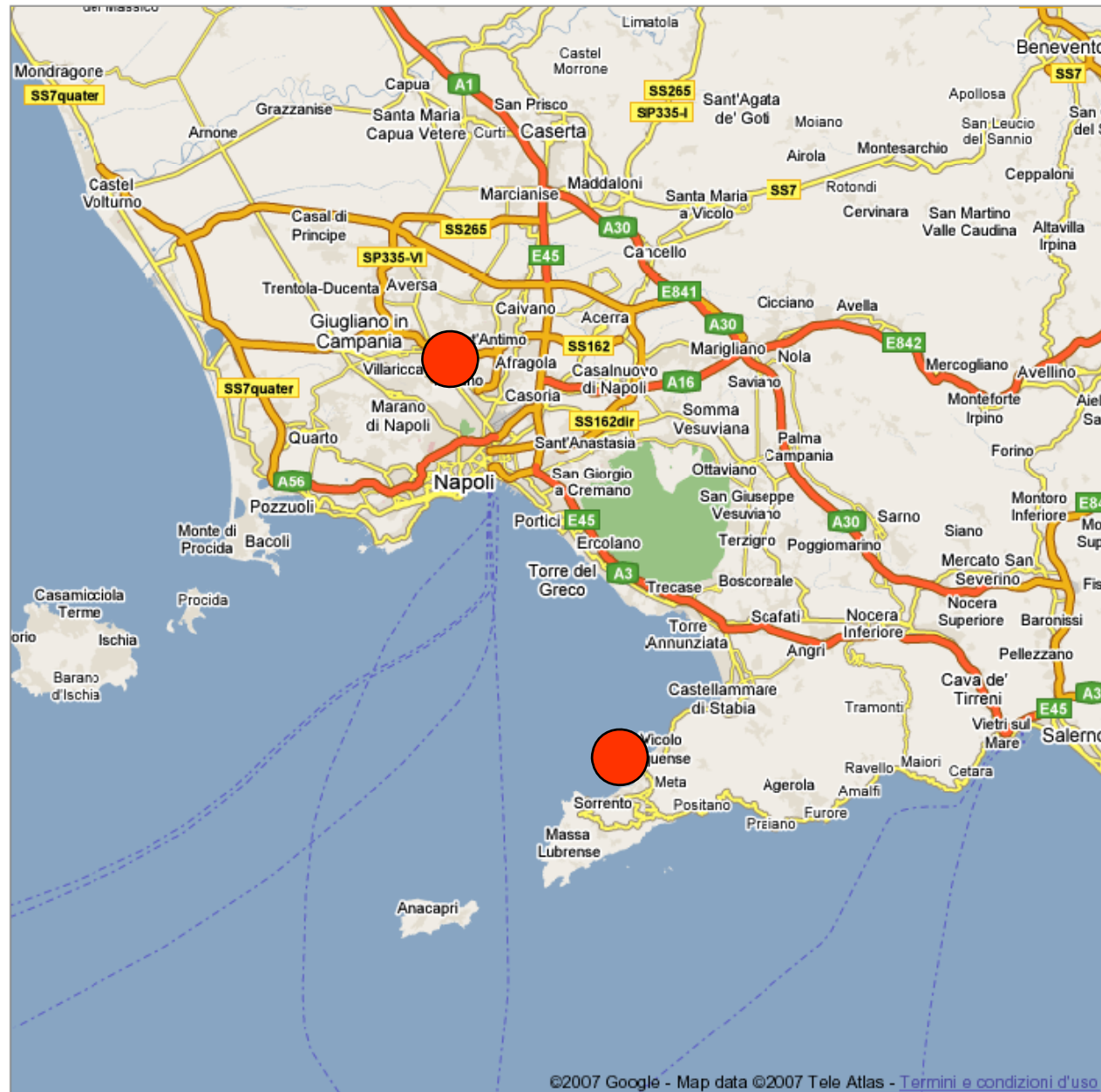
*Luigi Palumbo  
University of Rome "La Sapienza"*

*CERN - October 3rd, 2007*

# Sept. 1982 - LEP Theory Group - fellow - work with B. Zotter



# Several months later .. I met Francesco at CERN ...



## **Two young people from south ....**

**Francesco started his thesis work in the same team: LEP-TH, in the same floor, the 5th of building 30.**

**We shared the habits of people coming from south:**

- late start in the morning**
- late stop in the evening ... often in the night**

**Francesco always won the game ... with the help of coffee, preferably with a good one, from Naples.**

**This was is unforgettable time for me, while I was struggling with the e.m. effects of a discontinuity in the vacuum chamber, Francesco started dealing with beam instabilities.**

**I moved to the University of Rome, never cutting contacts with CERN and with good friends.**

# Collective effects and Impedance budget

## Single-Beam Collective Effects in the LHC

*Francesco Ruggiero*

### ABSTRACT

Single-beam collective effects can limit the current and therefore the performance of the Large Hadron Collider (LHC), unless the impedance of the different vacuum chamber discontinuities seen by the beam is kept below certain limits. Together with parasitic losses considerations, this has an impact on the design of several machine components, such as monitors, kickers, bellows, warm sections, experimental beam pipes, rf-cavities, feedback systems and especially on the thermal beam screen, with its millions of pumping slots. After revising the LHC impedance budget in view of the most recent design options, we compute rise times and thresholds for different instabilities, as well as coherent and incoherent tune shifts and parasitic losses.

Cern SL/95-09 (AP), June 1995



# Impedance-wise design method

Identification of devices mostly affecting the machine impedance, impedance budget estimation: strip-line monitors, kickers, beam screen, ...

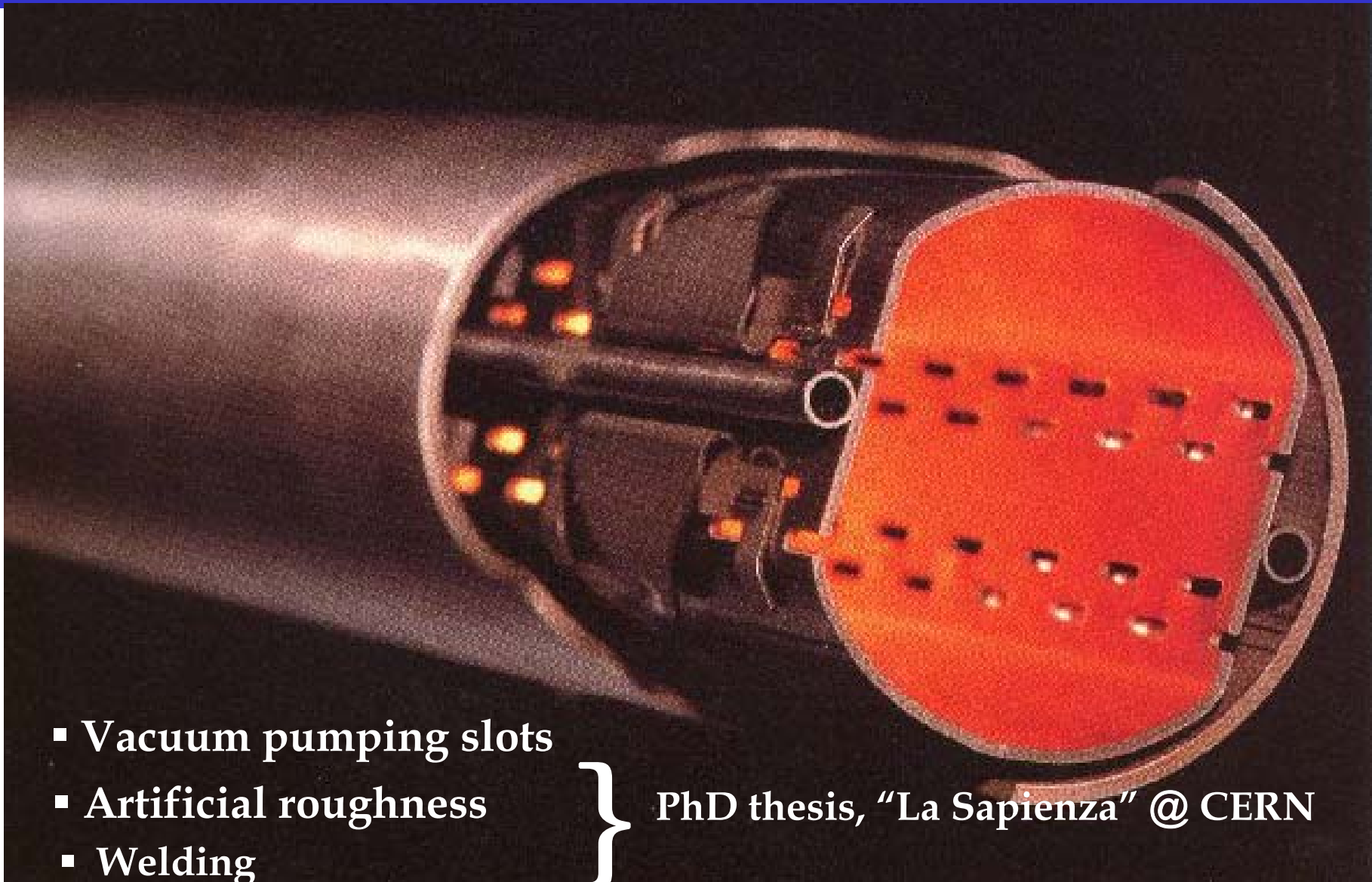
## Impedance-wise design of LHC devices

The Coupling Impedance of each device must be estimated by means of at least two methods among:

- theoretical estimation;
- numerical simulation;
- bench measurements.

Bruno Zotter teaching worked! Similar work was being done for Dafne at LNF

## Few examples: a) LHC beam screen



- Vacuum pumping slots
- Artificial roughness
- Welding

} PhD thesis, "La Sapienza" @ CERN

## b) Resistive wall: anomalous skin effect

*Anomalous skin effect and surface roughness*, surface resistance at different temperatures, frequencies and magnetic field intensities.

Preliminary results *at cryogenic temperatures* indicate a surface resistance of copper about a factor two larger than previously estimated.

W. Chou, F. Ruggiero *Anomalous Skin Effect and Resistive Wall Heating*  
LHC-Project-Note-2, Aug 1995.

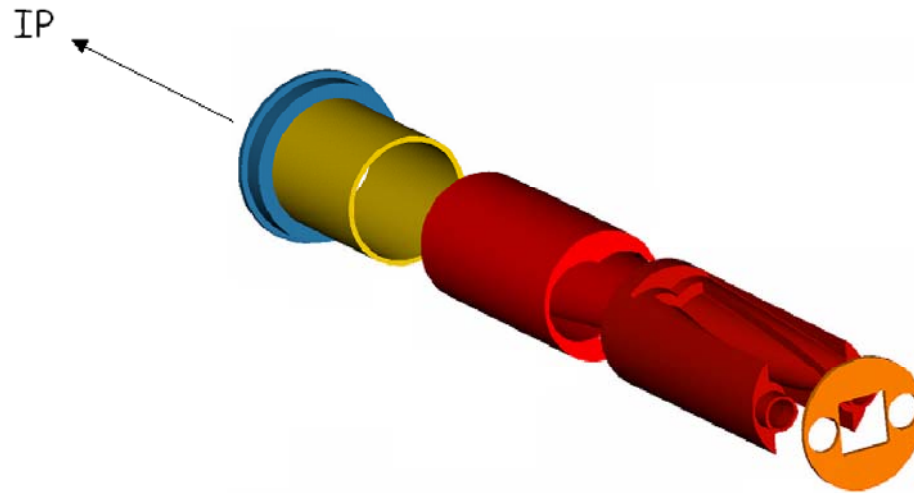
F. Caspers, M. Morvillo, F. Ruggiero *Surface Resistance Measurements for the LHC Beam Screen*  
LHC-Project-Report-115, Jun 1997.

F. Caspers, M. Morvillo, F. Ruggiero, J. Tan *Surface Resistance Measurements and Estimate of the Beam-Induced Resistive Wall Heating of the LHC Dipole Beam Screen*  
LHC-Project-Report-307, Aug 1999.

F. Caspers, M. Morvillo, F. Ruggiero, J. Tan, H. Tsutsui *Surface Resistance Measurements of LHC Dipole Beam Screen Samples*  
LHC-Project-Report-410, Aug 2000.



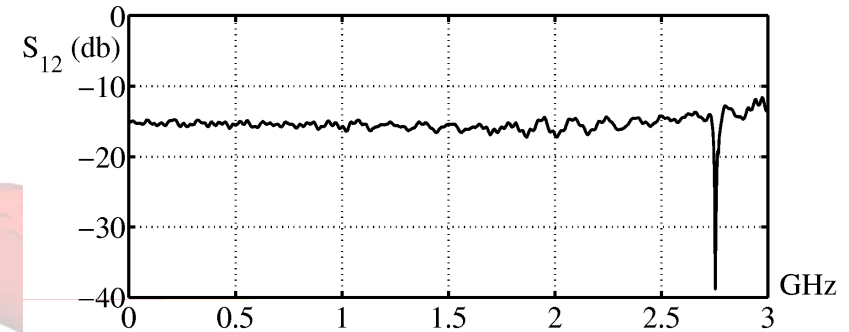
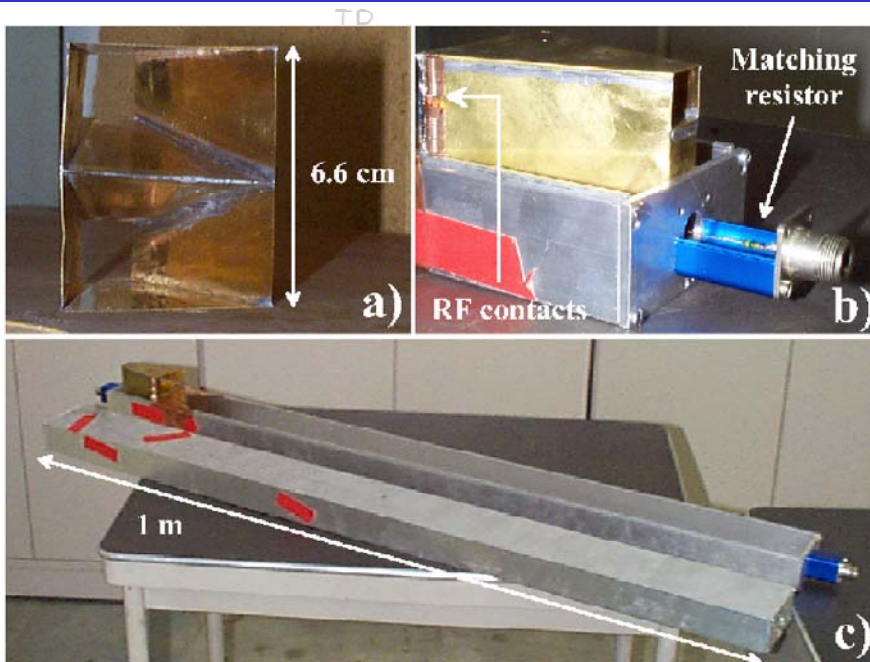
## c) Trapped modes in LHC IR (Y- chamber)



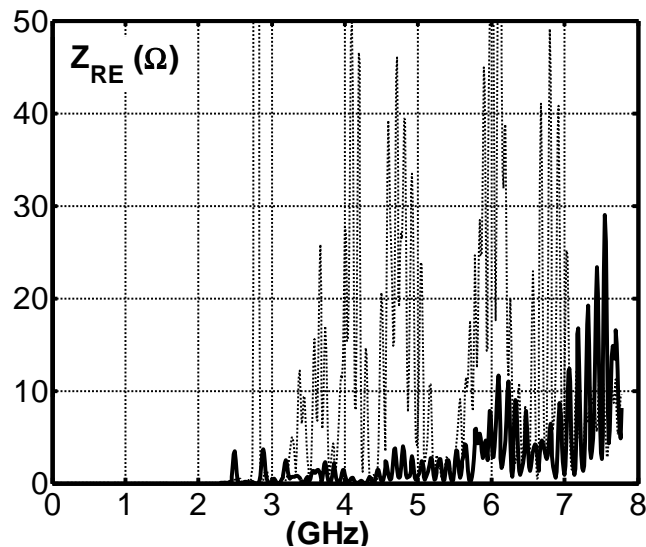
MAFIA simulations showed the importance of *a smooth transitions between the chambers* to avoid unacceptable power deposition due to modes trapped in the structure.

*For the LHC design, the trapped modes are not eliminated, but only damped, need of further study to see whether these modes could be either completely removed or damped to even lower values. ...*

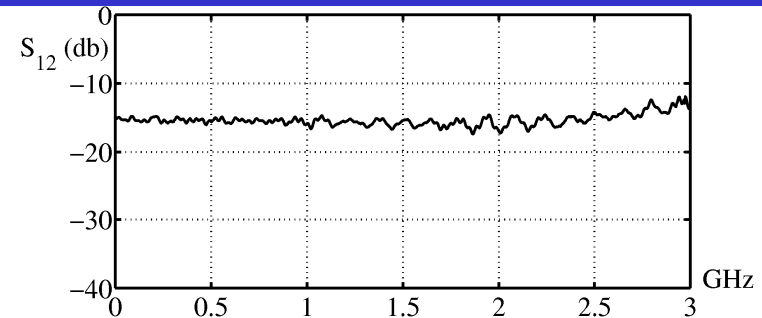
# Rectangular Scaled model measurement



MAFIA	HFSS	Meas.
2.800 GHz	2.753 GHz	2.737 GHz



**Tapering the transition, as in the actual geometry strongly reduces the effect of the trapped mode.**



## Example of a good collaboration ...

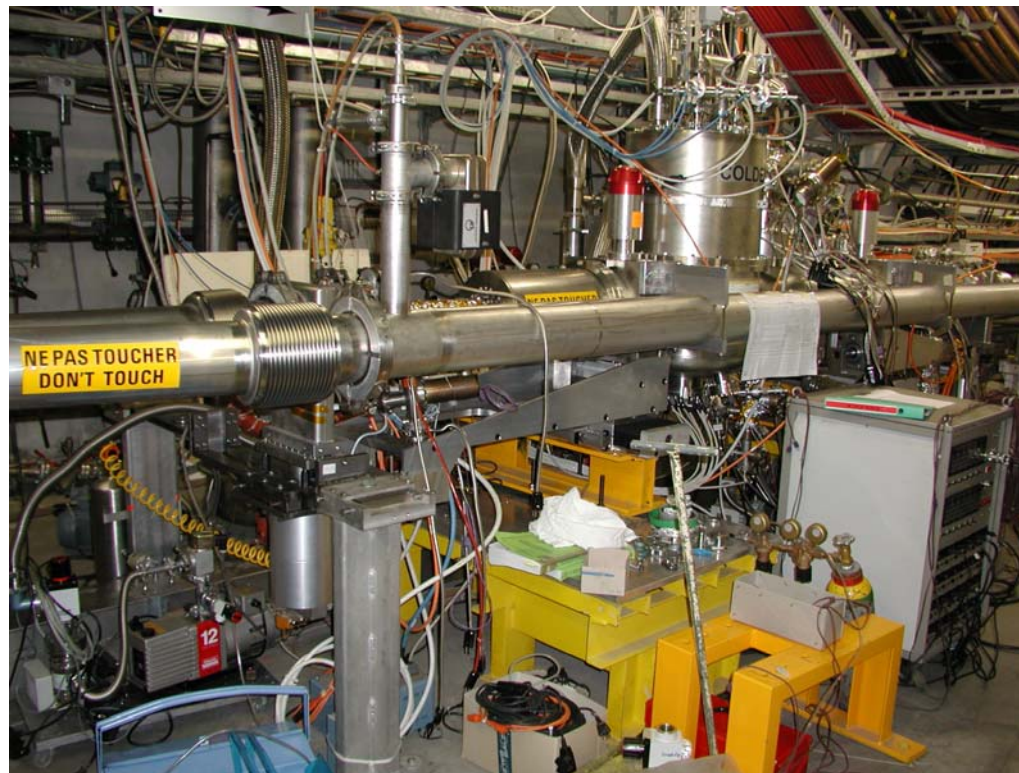
- CERN, LBNL , INFN, La Sapienza Univ.

B. Spataro, F.Ruggiero, D. Brandt, L. Vos, A. Mostacci, M. Migliorati, L. Palumbo, D. Li,  
**On trapped modes in the LHC recombination chambers : numerical and experimental results,**  
Nucl. Instrum. Methods Phys. Res., A 517 19-27, Jan 2004.

B. Spataro, F.Ruggiero, M. Migliorati, A. Mostacci, L. Palumbo  
**Coupling impedances of LHCb recombination chamber (IR8),**  
LHC-PROJECT-NOTE-348, Aug 2004.

## d) COLDEX vacuum chamber impedance

The COLD bore EXperiment (COLDEX) in the SPS machine uses a LHC-like cryogenic vacuum chamber to study the interaction with proton beams, with particular attention to the electron cloud effect.



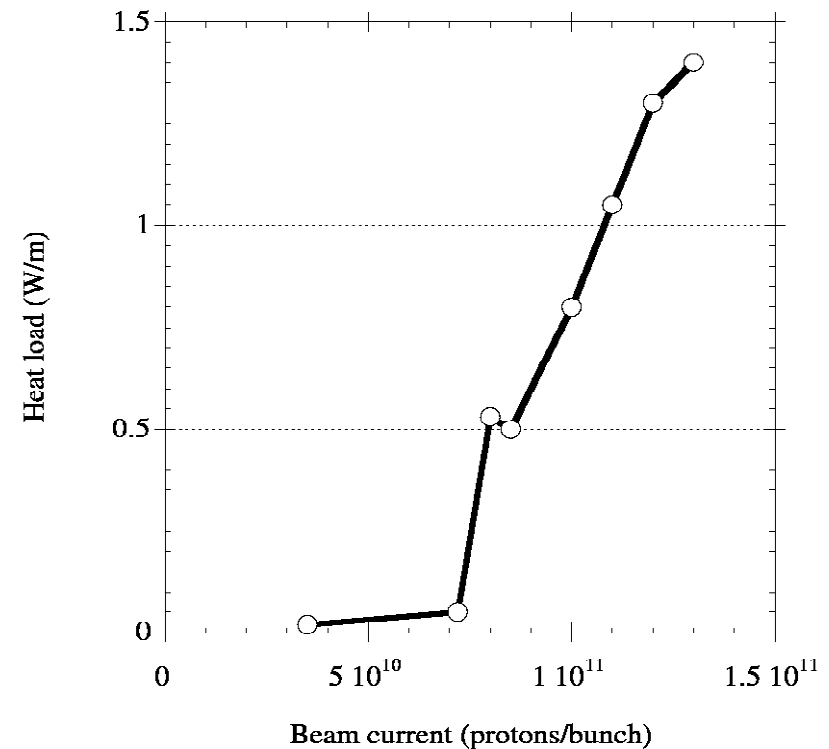
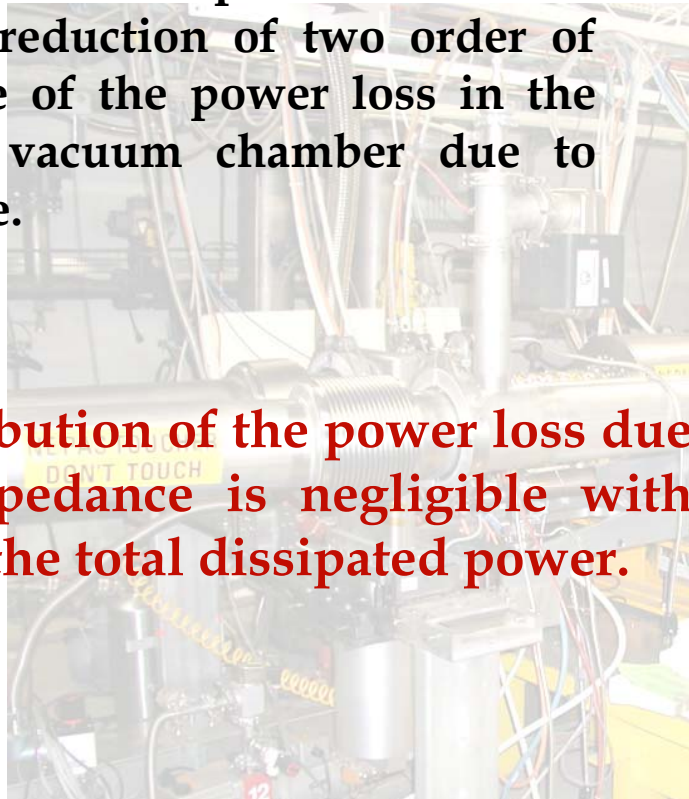
B. Spataro, D. Alesini, M. Migliorati, A. Mostacci, L. Palumbo, V. Baglin, B. Jenninger, F. Ruggiero  
**Impedances of the cold bore experiment, COLDEX, installed in the SPS machine,**  
Nucl. Instrum. Methods Phys. Res., A 564 38-43, Aug 2006.

# COLDEX upgraded vacuum chamber

## COLDEX chamber upgrade

MAFIA based impedance studies proved a reduction of two order of magnitude of the power loss in the COLDEX vacuum chamber due to impedance.

The contribution of the power loss due to the impedance is negligible with respect to the total dissipated power.



B. Spataro, D. Alesini, M. Migliorati, A. Mostacci, L. Palumbo, V. Baglin, B. Jenninger, F. Ruggiero

Coupling impedance studies and power loss measurement of the COLDEX upgraded vacuum chamber, to be published in Nucl. Instrum. Methods Phys. Res., A.

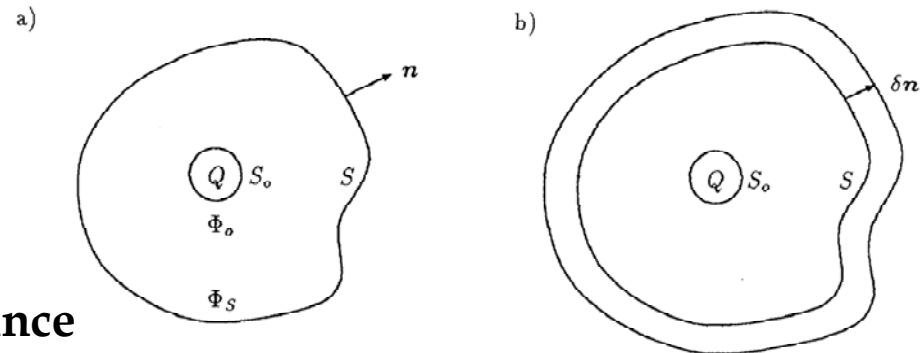


# Theoretical aspects

The longitudinal impedance is proportional to the "normal derivative" of the electrostatic energy stored in the region between the beam and the surrounding beam pipe.

$$\frac{Z_L}{L} = Z_w \frac{\delta}{\delta n} \left( \frac{\epsilon_0}{c} \right)$$

Surface impedance  $\uparrow$   $Z_w$   $\uparrow$  Specific capacitance  $\left( \frac{\epsilon_0}{c} \right)$



For a centered beam pipe and for a given wall resistivity, a square pipe has the longitudinal impedance of the inscribed circular pipe.



# Final thoughts

- **humble and rigorous in the research work,**
- **open minded, ready to listen to any other's opinion,**
- **sower for young bright physicists,**
- **a true gentleman,**

**Francesco was a good friend,  
a great scientist, a lovely person.**