35th meeting of the

LHC Commissioning Working Group

November 20th, 2006

Status of the LHC Ring Aperture Model

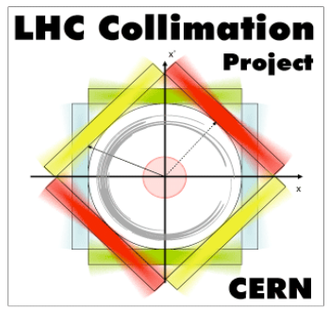
S. Redaelli, AB / OP

and

M. Giovannozzi, AB / ABP

Inputs from: R. Assmann, R. Bailey, S. Chemli, B. Goddard, M. Lamont

Acknowledgments: C. Boccard, S. Chemli, S. Fartoukh, P. Hagen, J.-B. Jeanneret, J. Jowett, P. Le Roux, D. Macina, T. Risselada, J. Uythoven, E. Wildner, AT-MCS, AT-VAC (R. Veness' team, C. Rathjen), work of many people throughout the last years



Agenda of this meeting

- **Requirements for LHC operation** *(Stefano)*
- **Status of ring aperture model** *(Stefano)*
- **Status of the transfer line model** *(Brennan)*
- **Possible implementation in LSA** *(Mike)*
- **What MADX online can offer** *(Frank)*

Aperture requirements for LHC operation

- ☑ Easy access from the CCC to all available information
  - *Design aperture + as-built errors; plotting tools*
  - *Search by element name (ex.: get aperture of the beam screen within a magnet)*
  - *Search by region, by longitudinal coordinate*
- ☑ On-line link to known non-conformities
  - *Obstacles, Fritz' measurements, PIM's, ...*
- ☑ On-line aperture model for beam operation
  - *How big can I make a bump?*
  - *How much space is (supposed to be) left for the beam?*
- ☑ Link to results of beam-based aperture measurements
  - *"As-measured" information on aperture restrictions*
  - *Bumps that optimize the beam clearance*
- ☑ History traceability
  - *Track changes of layout and of aperture measurements*

From Paul's talk on BD requirements + Stefano's on aperture measurements; extended requirements list at:
http://proj-lhc-software-analysis.web.cern.ch/proj-lhc-software-analysis/op-components/aperture-model.htm

“Availability” of the aperture information

Available = defined in paper documentation of the each element

→ *Basically true for all the elements installed in the LHC!*

Available = inserted in some database(s) in electronics format

→ *True for many elements (but not for all)* - *see S. Mallon at the LTC of Aug. 15th, 2007*

→ *Still does not mean that the information is easily accessible...*

Available = organized in a data structure (“Aperture Model”) for higher level usage

→ *All information summarized/collected in a coherent data format*

→ *Get aperture versus longitudinal coordinate*

→ *MADX, SixTrack, PTC, Mathematica, BeamLossPattern, ... can use it!*

Available = “whatever I need to do, a tool exists which can provide without effort from my side the information that I need in the format suitable for the tools that I use”

→ *Difficult to fulfill all the requirements!*

→ *The model is typically tuned to one specific use*

→ *Essential to have one coherent source of information coupled with the machine layout, then each users should tune what is available to their needs.*

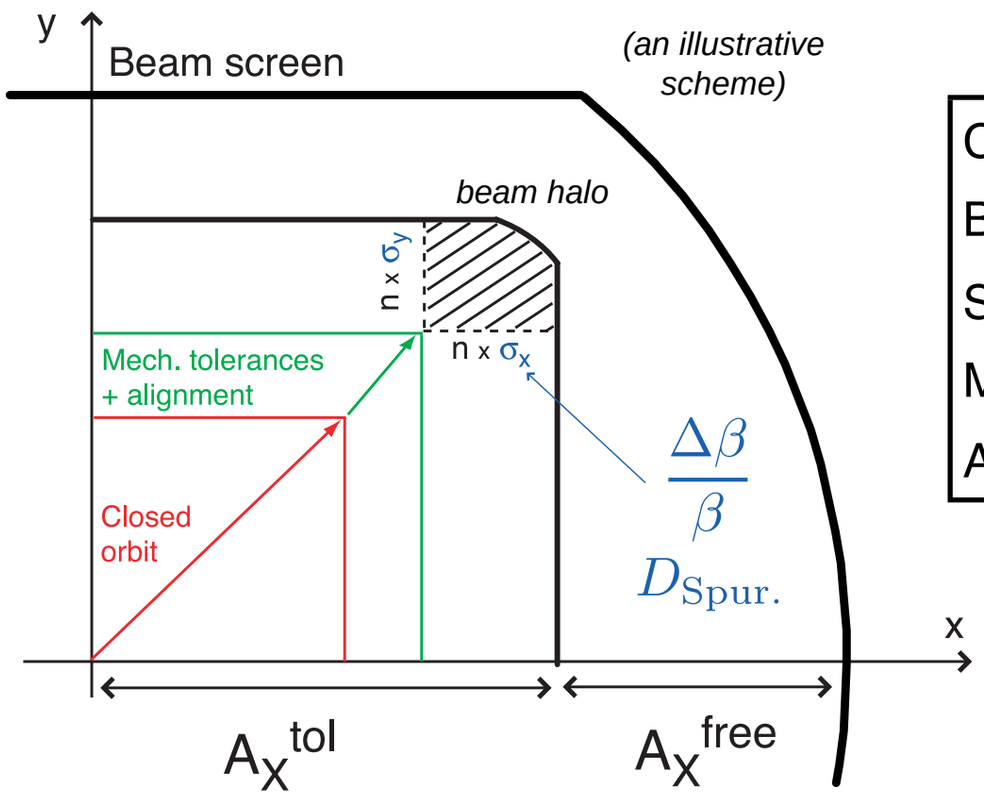
The “beam” aperture model

This talk is mainly about the LHC “Mechanical aperture model”

A “**Beam aperture model**” also exists: it describes expected aperture clearance

The “beam” model includes much more than the bare info on mechanical aperture:

- → *Mechanical aperture of all machine elements!*
- → *Mechanical tolerances (manufacturing + alignment); beam offsets (crossing ...)*
- → *Expected sources of magnetic errors*
- → *Agreed budgets on the beam optics parameters (linear, non-linear)*



Closed orbit	± 4 mm
Beta-beat	± 20 %
Spurious dispersion	27% D_{nom}^{Arc}
Mechanical tolerance	1-2.5 mm
Alignment	1.0.-1.6 mm

$$A_x^{\mathrm{Available}} = \frac{(A_x^{\mathrm{mech}} - A_x^{\mathrm{tol}})}{\sigma_x}$$

$$\sigma_i = \sqrt{\beta_i \epsilon}$$

Available net beam clearance after subtraction of various contributions is typically expressed in “n1” units:

→ $A_{x,y} = 1.22 \times n1$

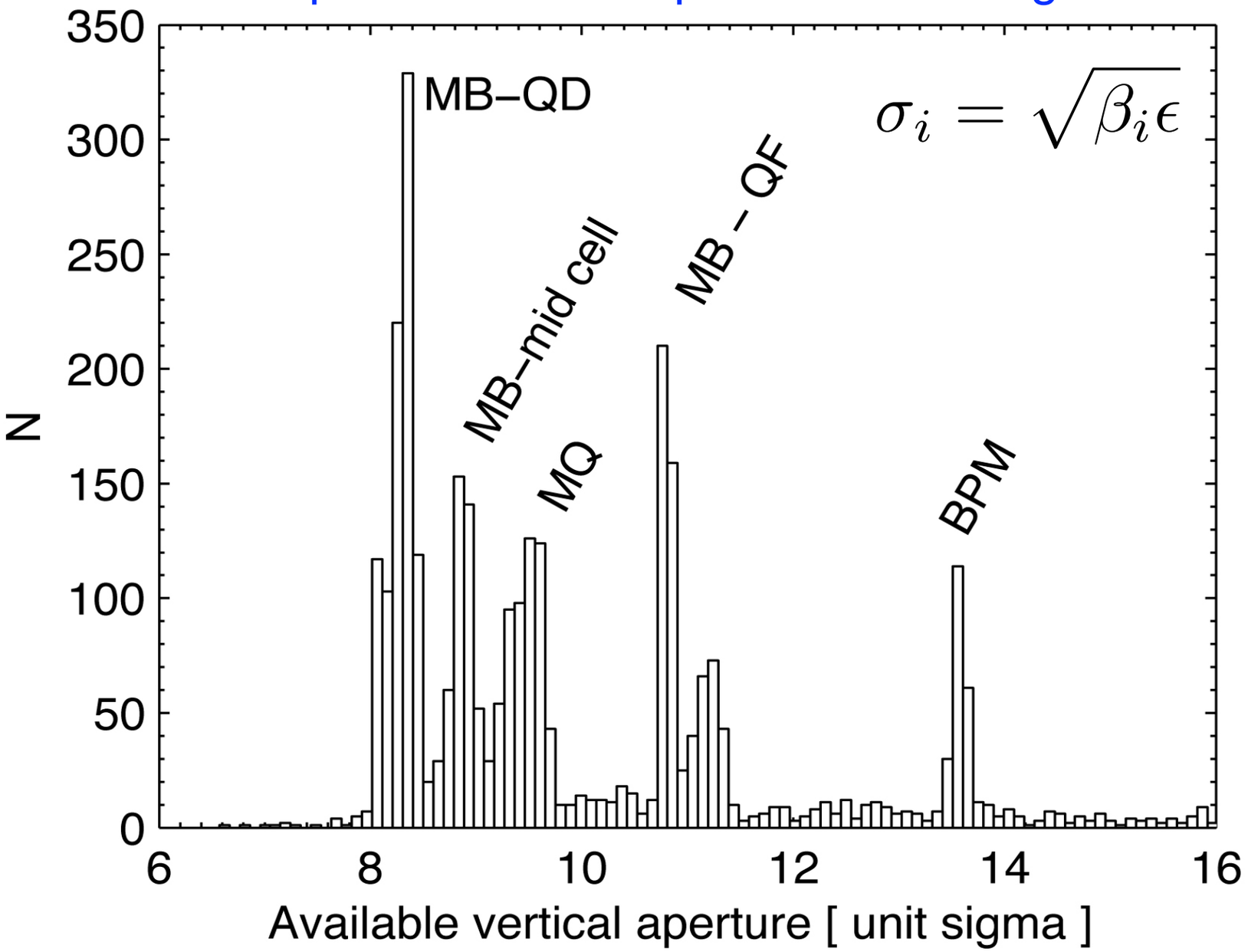
→ $A_{skew} = 1.4 \times n1$

LHC design criterion: n1 > 7

J.B. Jeanneret, LHC-Project-Note 111
Discussed at the LHCCWG by SR (July 26th, 2006)

Expected LHC aperture at injection

Expected vertical aperture in unit sigma



"LHC aperture and commissioning of the collimation system", proceedings of Chamonix 2005

The "beam" aperture model is NOT discussed here, even though this is obviously a primary issue for the LHC commissioning!

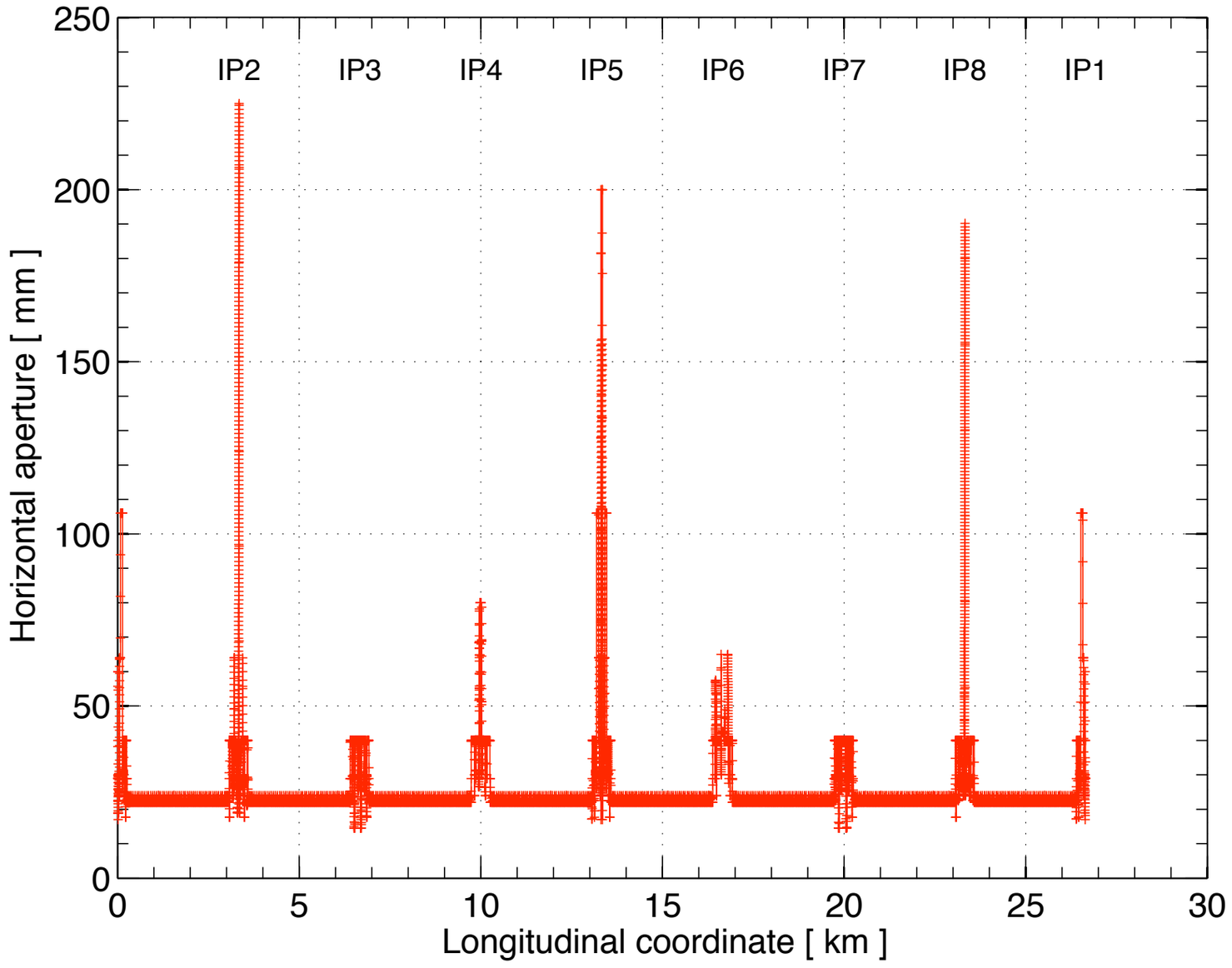
We will have to make sure that the required aperture is achieved! Bring beam parameters within tolerances....

The focus of today's discussion is the availability of the "mechanical" model, which the "beam" model will rely on!

Outline

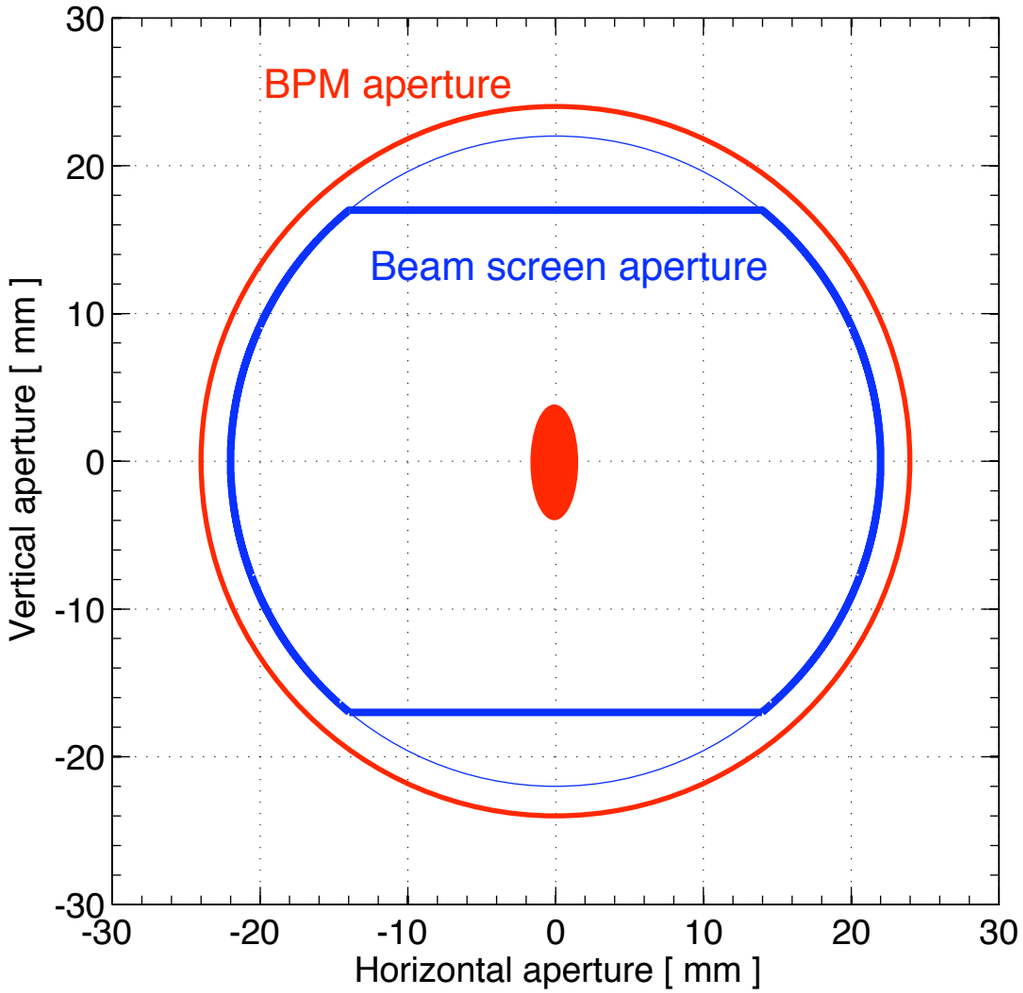
- *Design aperture of the LHC rings*
- *As-built model (magnet align. errors)*
- *Sources of aperture models*
- *Conclusive remarks*

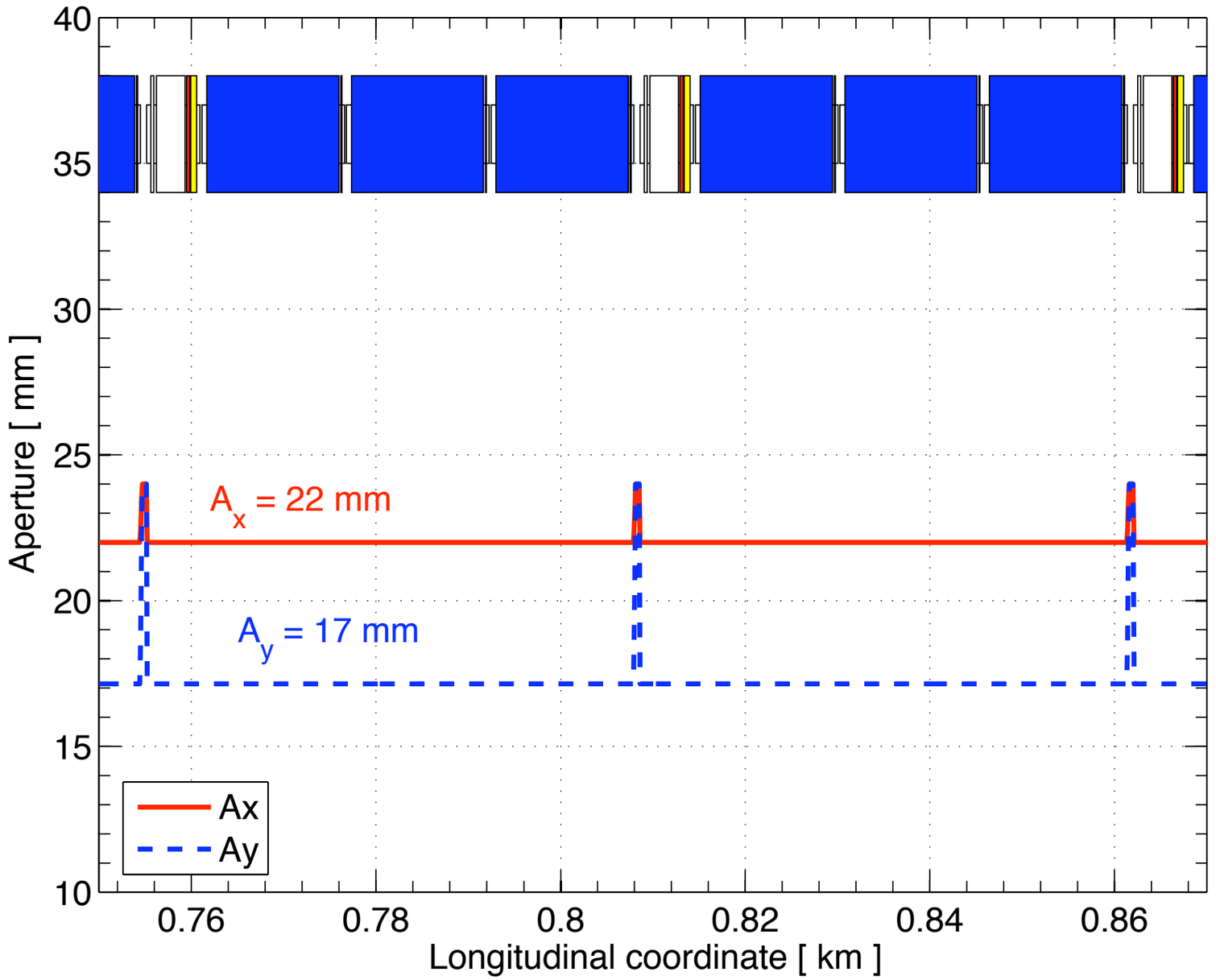
Design ring aperture (i)



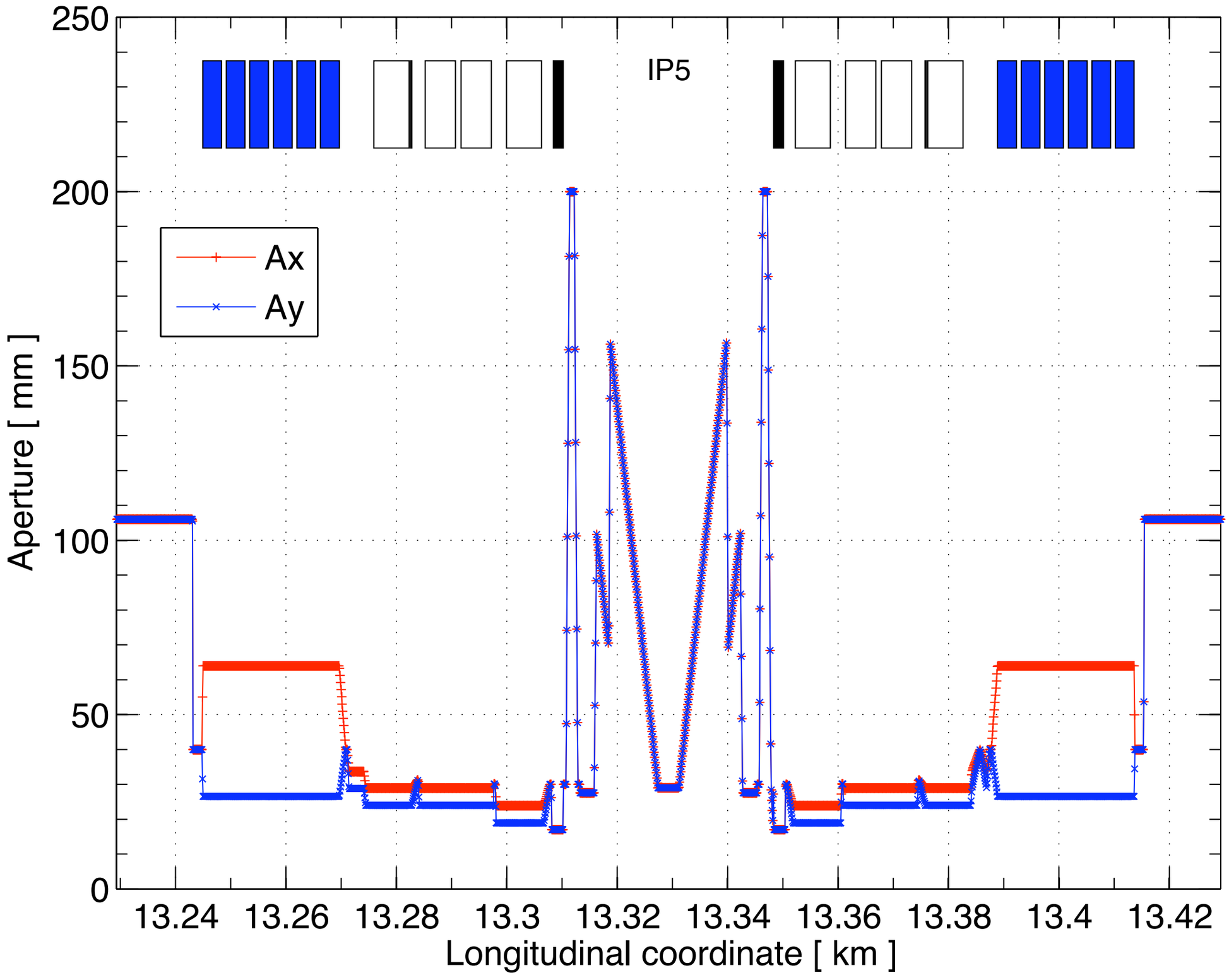
- Continuous aperture model, both rings
- Aperture assignment for all magnetic elements
- “marker” definitions for real beam screen length and to fill the holes
- Layouts of detector regions included
- Model developed within Coll. Team + ABP in collaboration with TS-IC
- A first version available since mid-2004 (collimation team). Evolved since then.

Design ring aperture (ii)

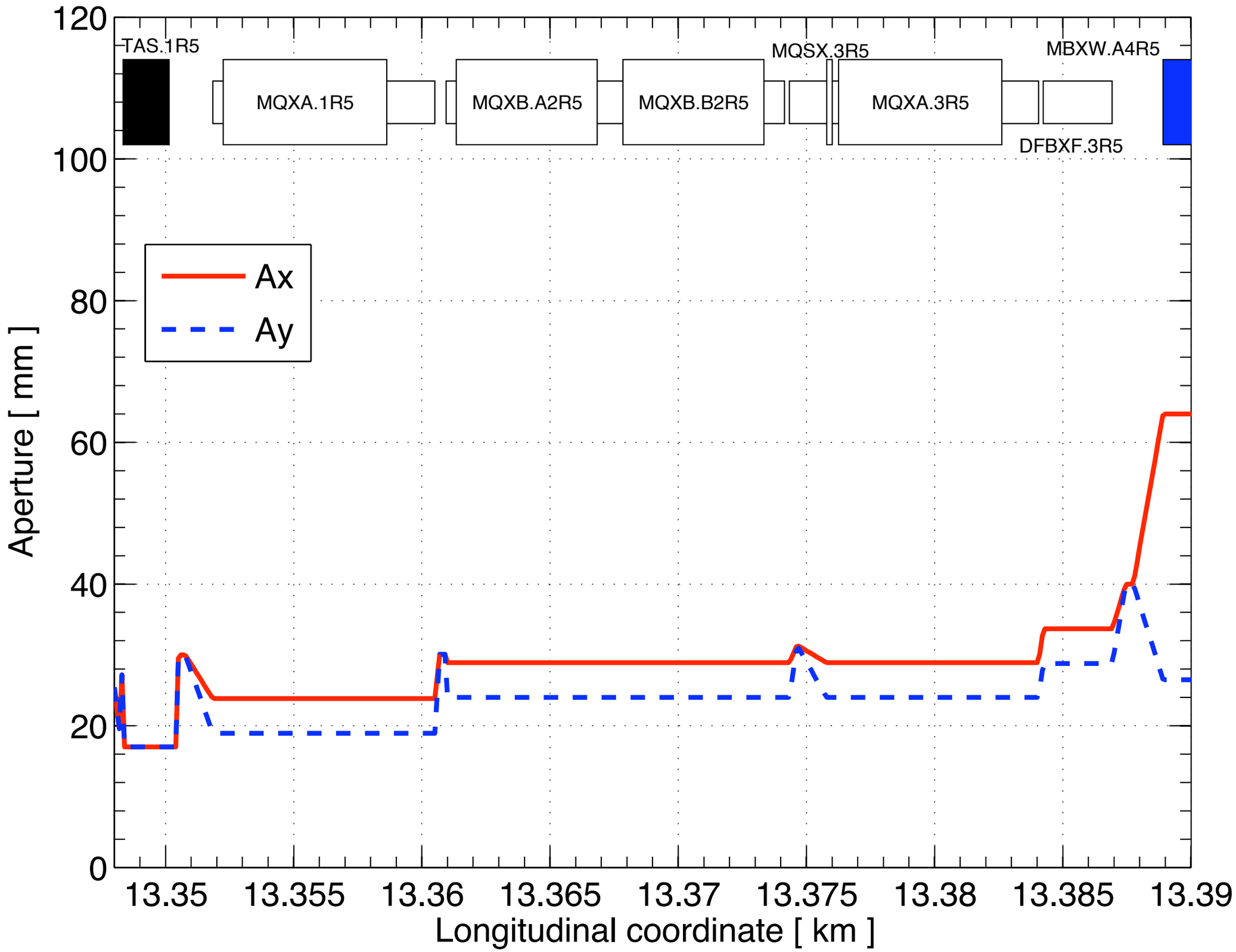




Design ring aperture (iii)

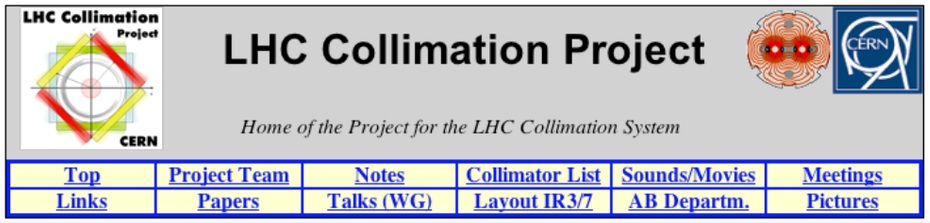


Design ring aperture (iv)



Associated tools

(developed for the collimation performance studies)

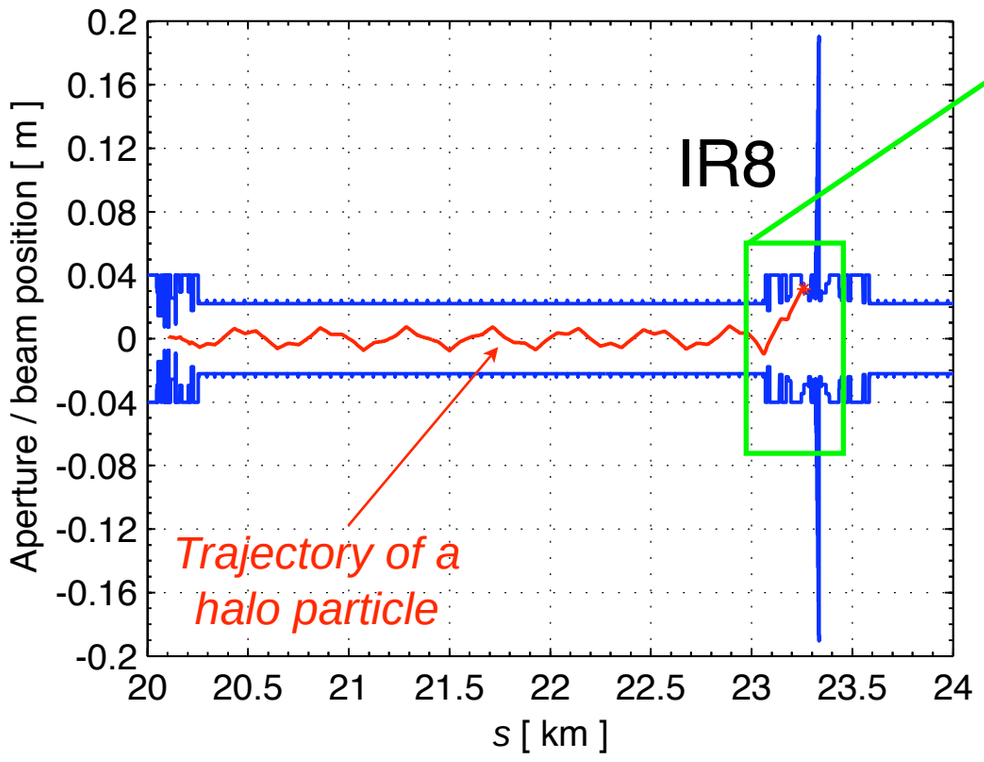


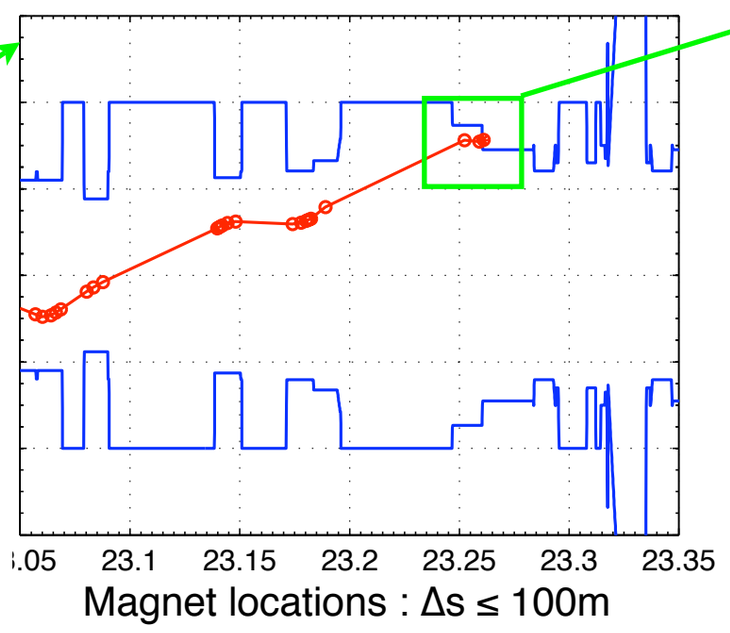
Main motivation: understand the performance of the collimation system.

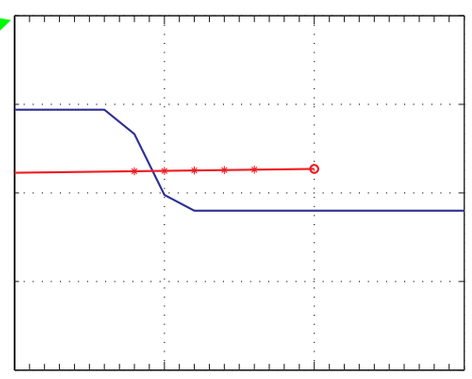
Package of tools developed to determine the loss locations of particles that leak out of the collimators.

See details in the web documentation.

http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/BeamLossPattern.htm



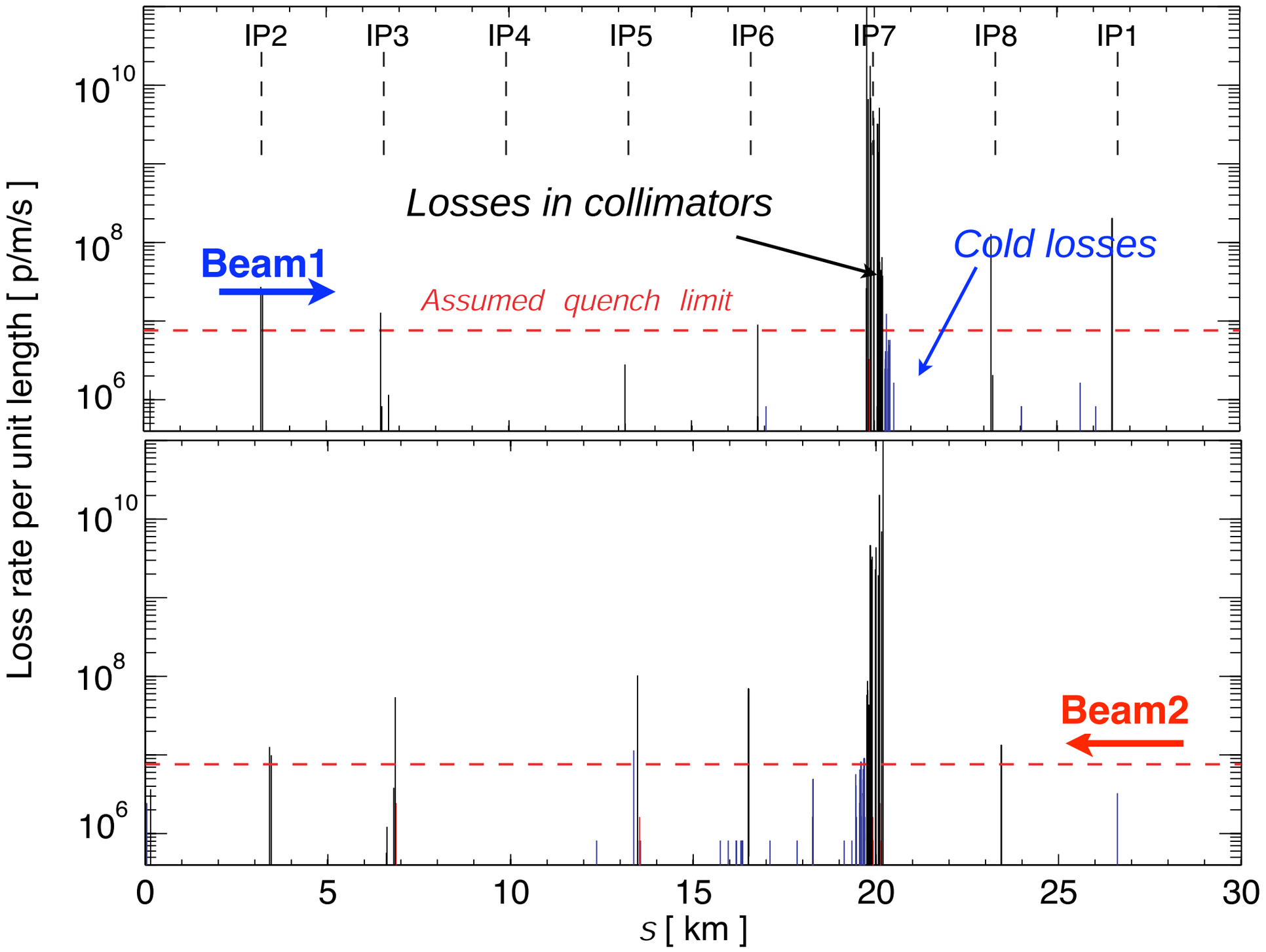




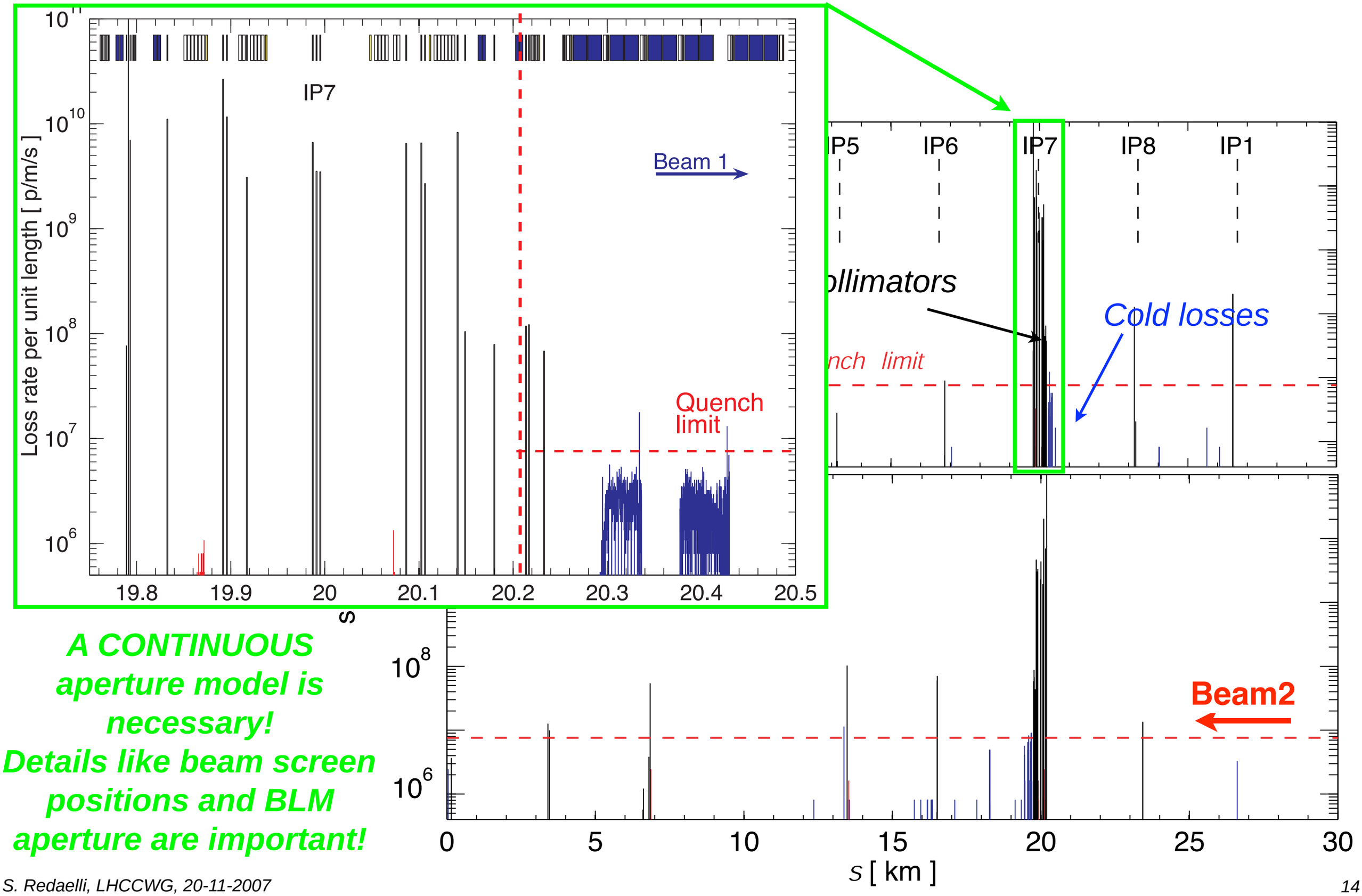
Interpolation: Δs=10cm
(270000 points!)

See Proc. of Chamonix 2005

Example of beam loss studies (i)

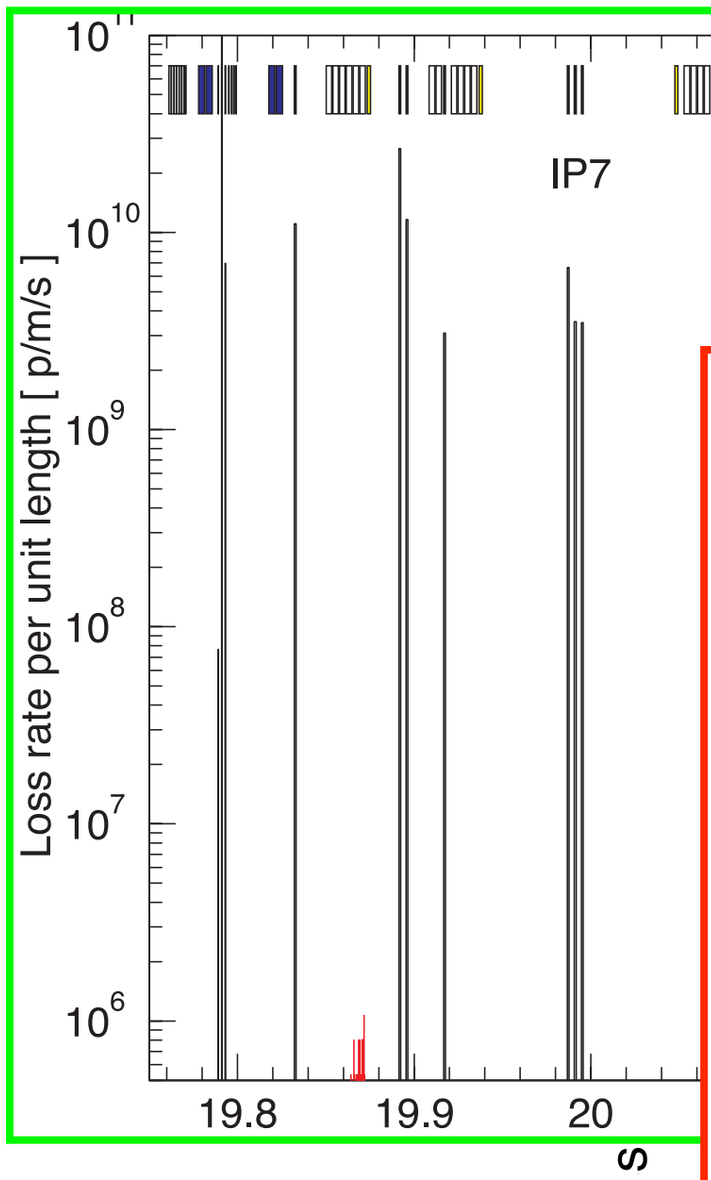


Example of beam loss studies (ii)

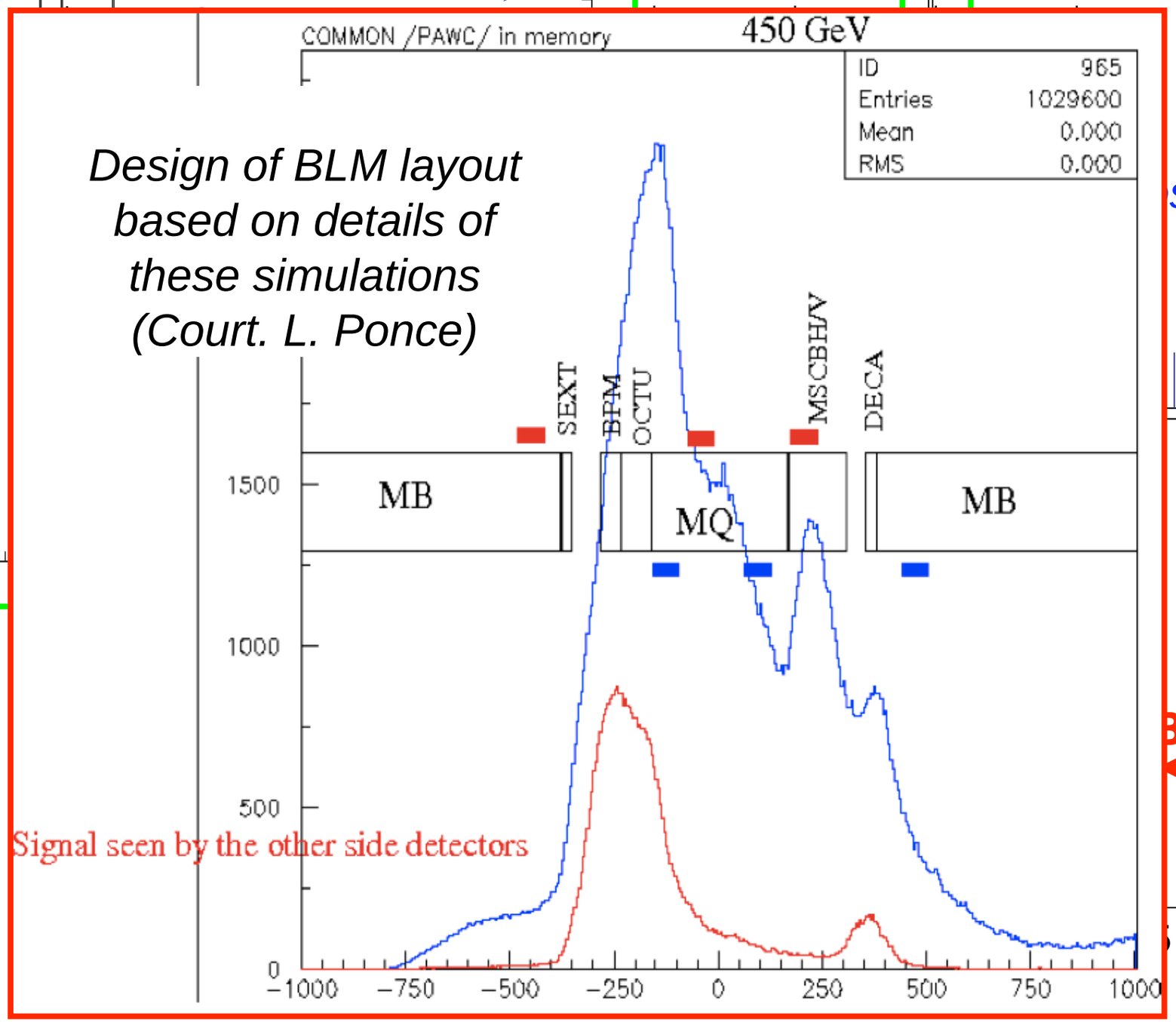


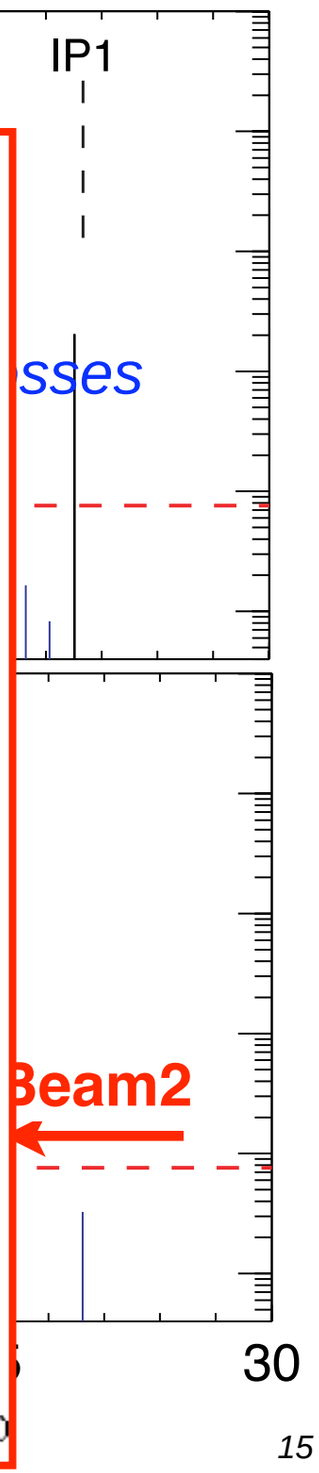
A CONTINUOUS aperture model is necessary!
Details like beam screen positions and BLM aperture are important!

Example of beam loss studies (iii)

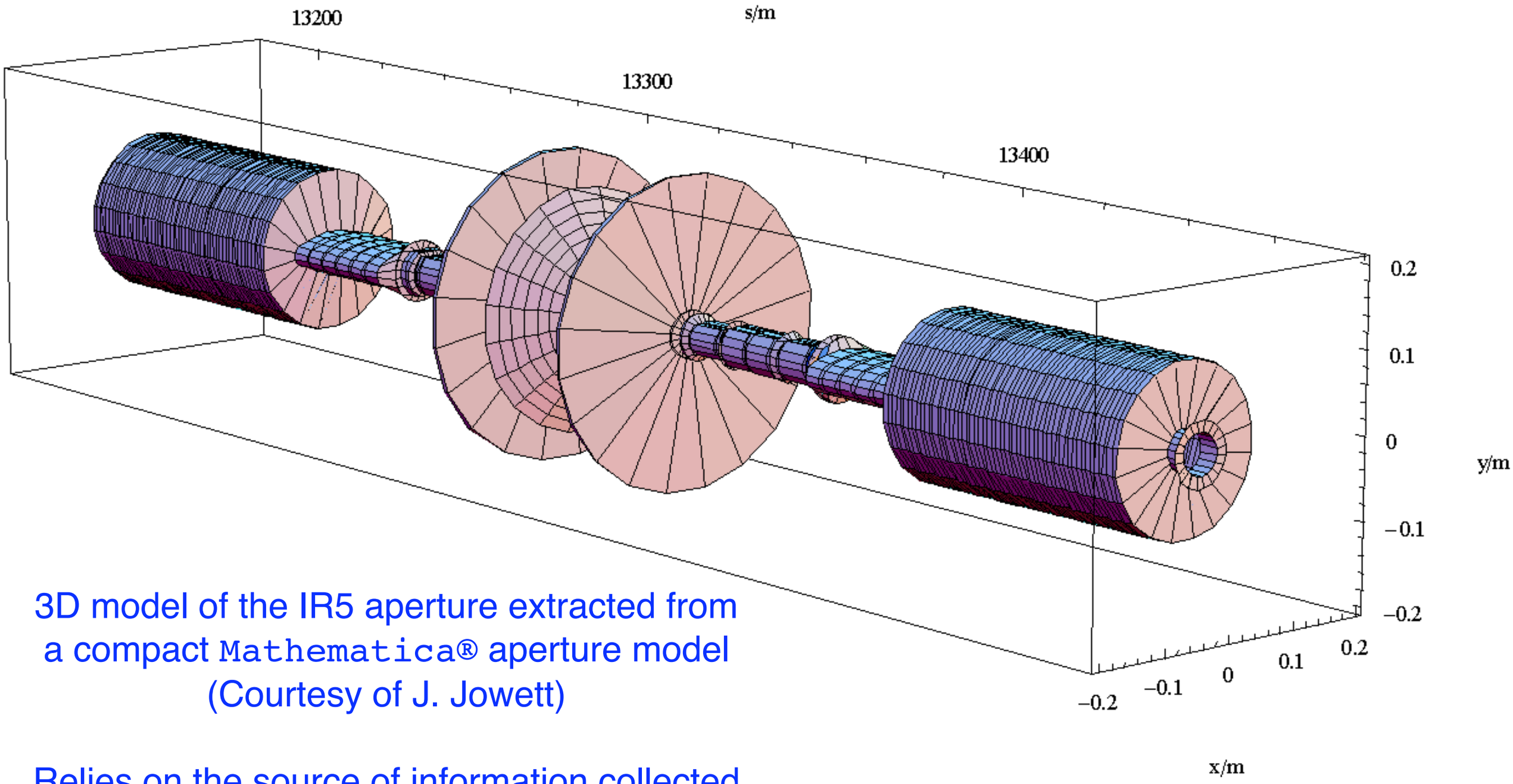


A CONTINUOUS aperture model is necessary!
Details like beam screen positions and BLM aperture are important!





3D view of the aperture



3D model of the IR5 aperture extracted from a compact `Mathematica®` aperture model (Courtesy of J. Jowett)

Relies on the source of information collected for the collimation model.

As-built aperture model

Within the scope of the MEB activity:

Magnet-by-magnet analysis and slot assignment

Slot decided on the basis of:

→ *Magnet geometry*

→ *Slot geometry requirements*

→ *Magnet field quality*

Outcome of the MEB activity:

1. **As-built magnetic model** after slot assignment optimization
2. **As-built aperture model** after slot assignment (cold+warm magnets)

→ The model is manually edited (thanks to T. Risselada who merged the bits and pieces from the ABP magnet team members).

→ It contains specific geometry tolerances instead of generic ones (e.g., "Golden" dipole tolerance).

→ It contains **as-measured alignment information: (Δx,Δy) offset** of the cold-bore measured along the magnet.

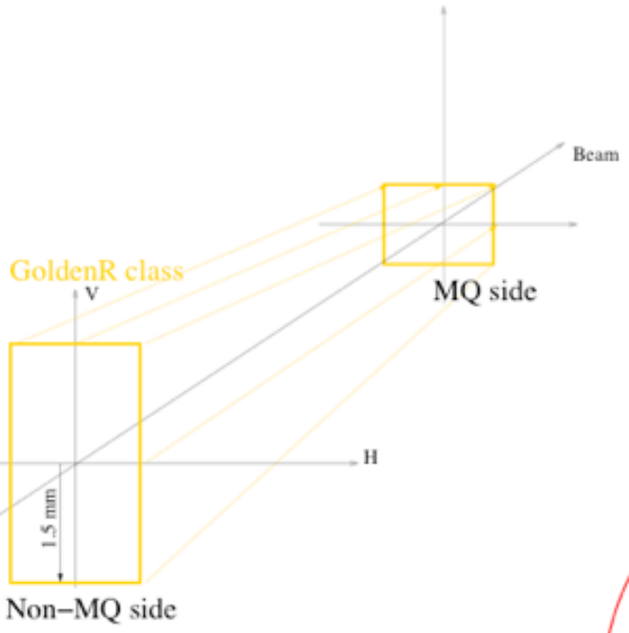
ABP magnet team: S. Fartoukh, J.-B. Jeanneret, F. Schmidt, A. Lombardi (until end 2005), Y. Papaphilippou (from end 2005), M. Giovannozzi

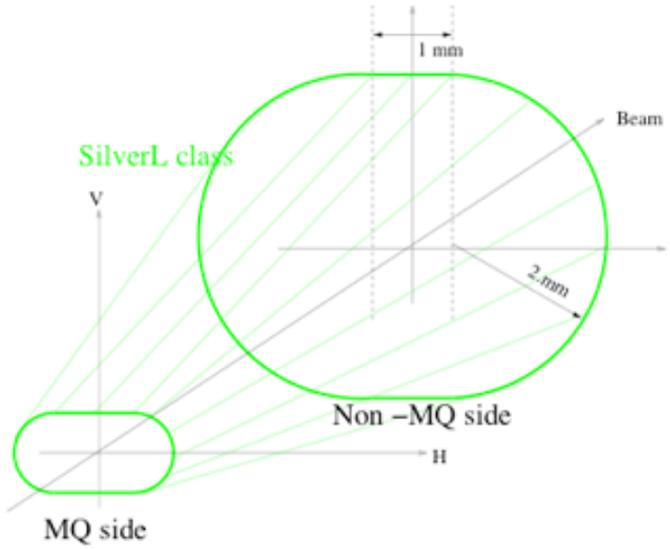
Dipole geometry classes

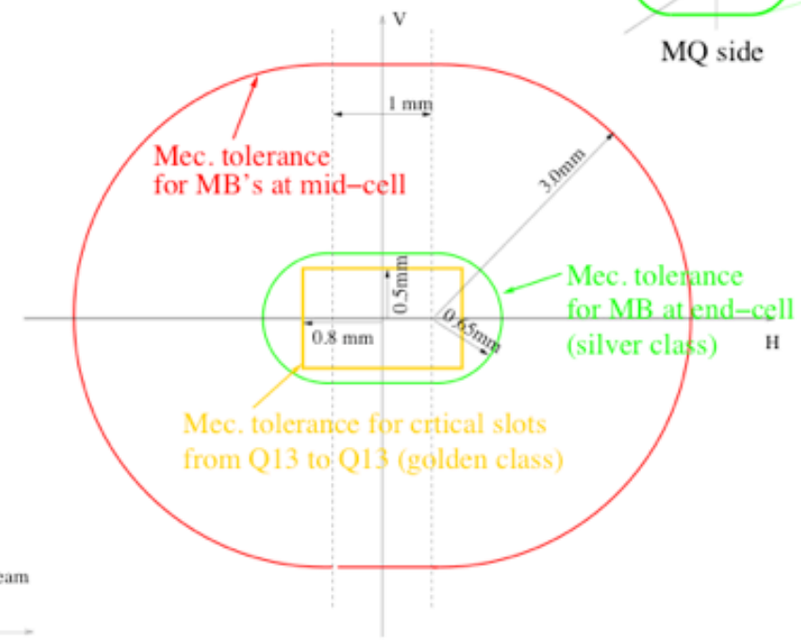
Five main geometry classes for the LHC dipoles

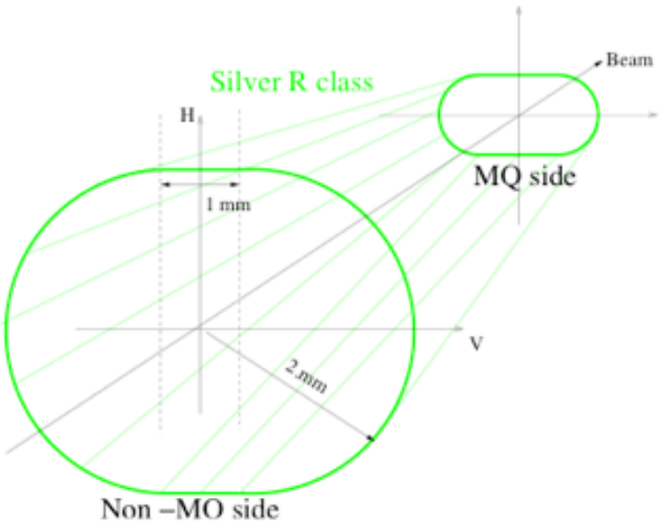
Updated tolerances for "golden" apertures are assigned to the dispersion suppressions magnets (most critical!)

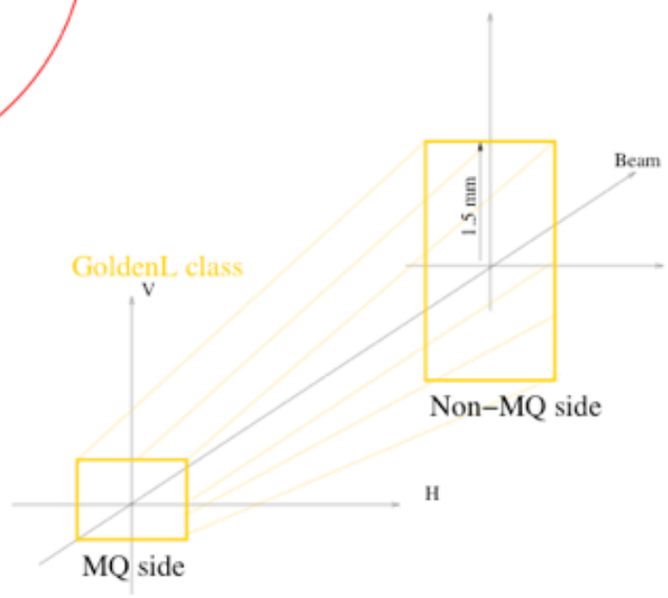
As-built model takes this into account: not only generic tolerances











Courtesy of S. Fartoukh (MEB 107) and also J.-B. Jeanneret, LHC PR 1007 for more details

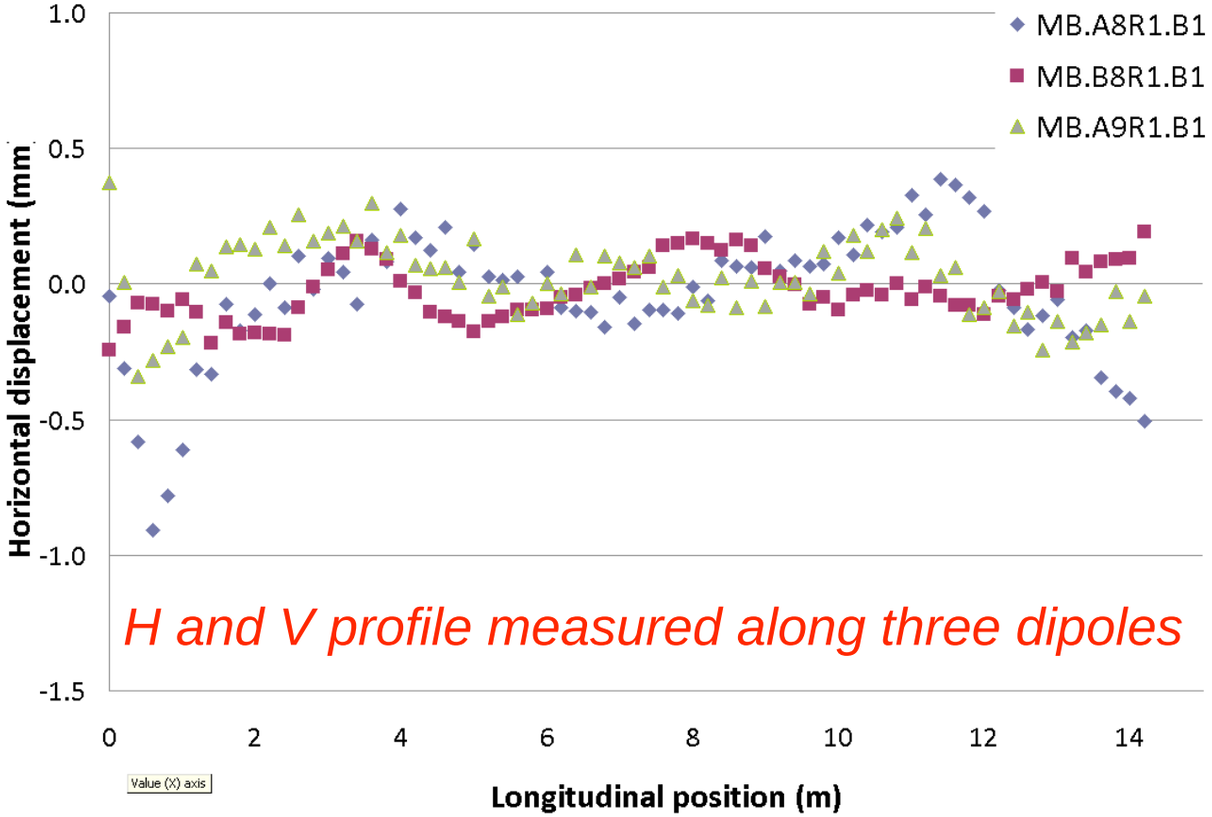
As-built aperture model - cont'd

Following the LHCCWG of February 28th 2007 (WISE talk by E. Todesco), a generalization of the as-built magnetic model was launched (P. Hagen, E. Wildner *et al.*):

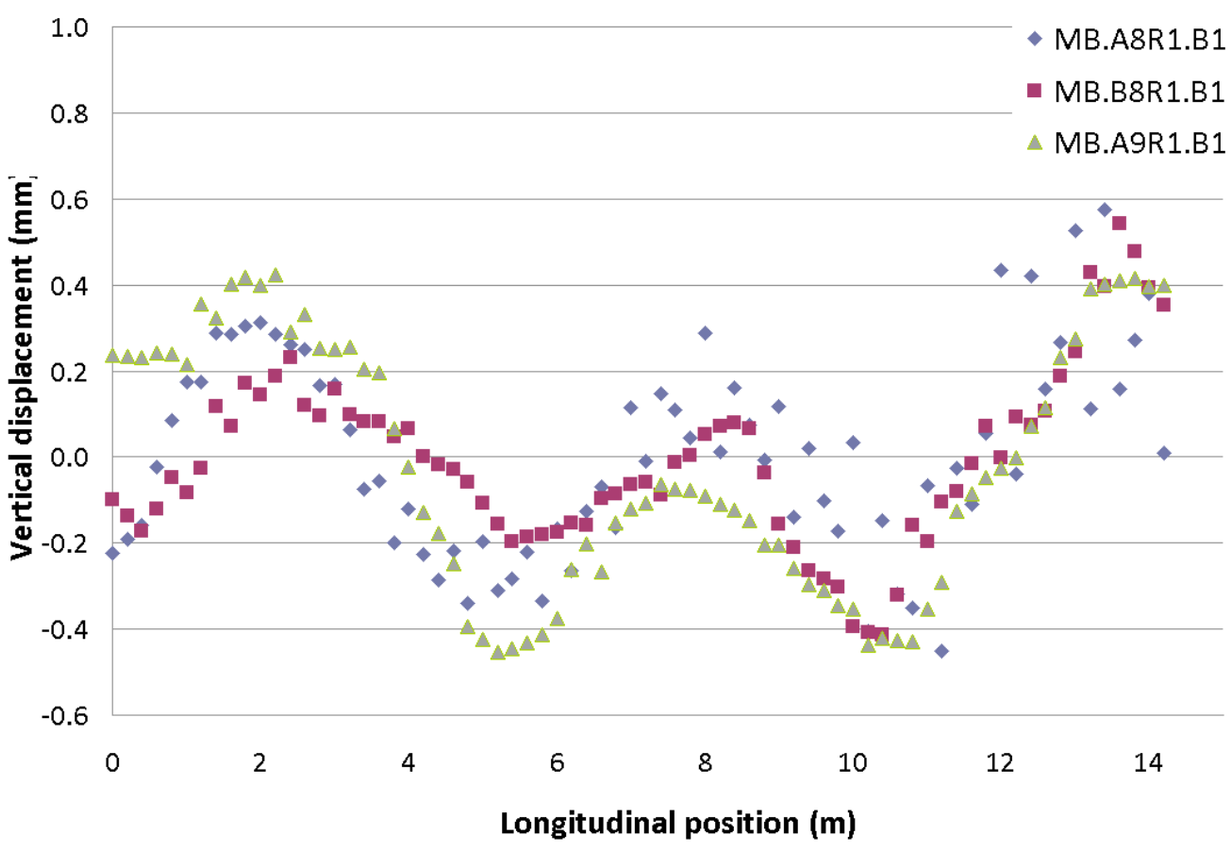
- Alignment information from MEB activity (installation shifts, magnetic axis) was made available for MADX use.
- Detailed measurement of (Δx,Δy) offsets of the cold-bore along the magnet is:

  Data are fitted → Equally spaced points are computed

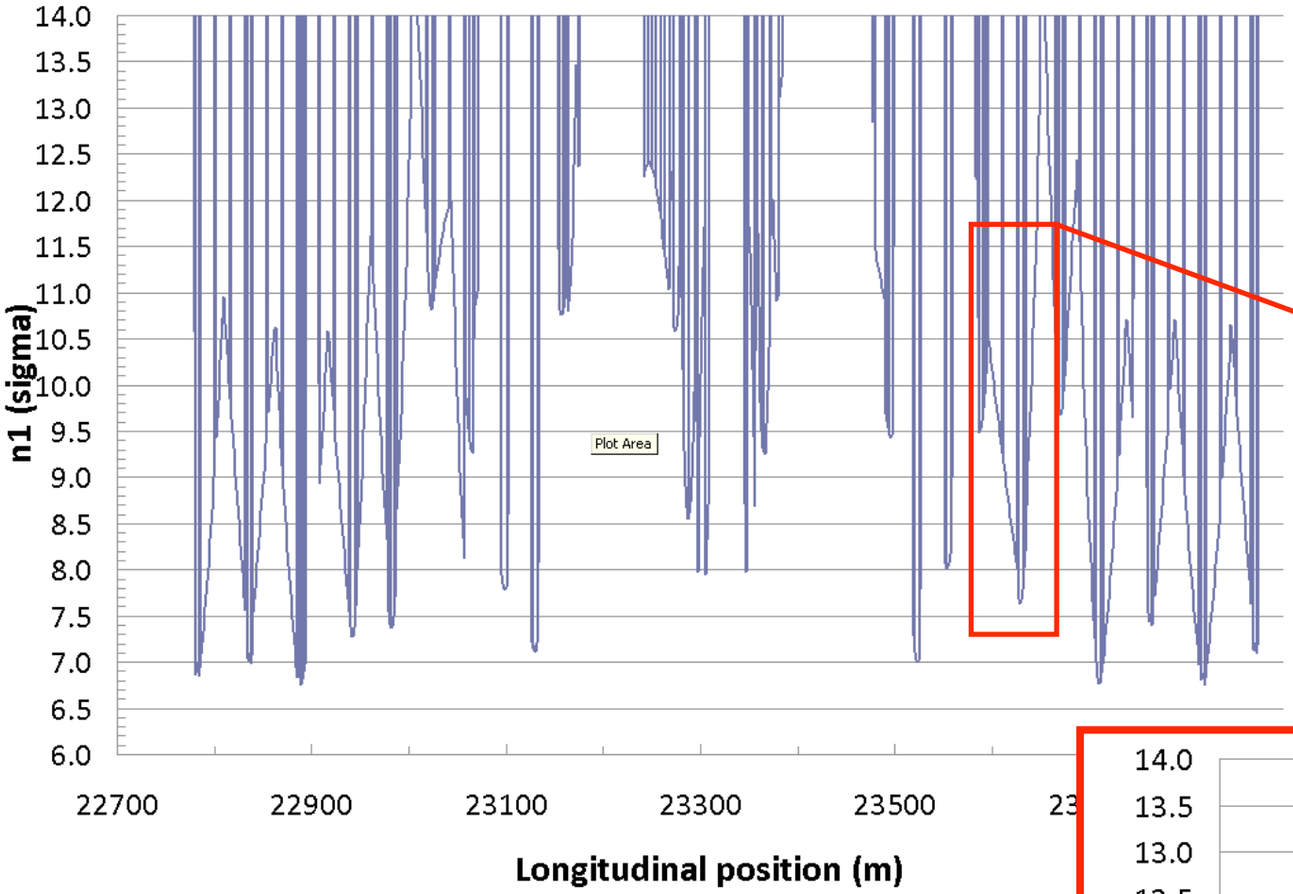
  The resulting profile is output in a file for MADX use



H and V profile measured along three dipoles

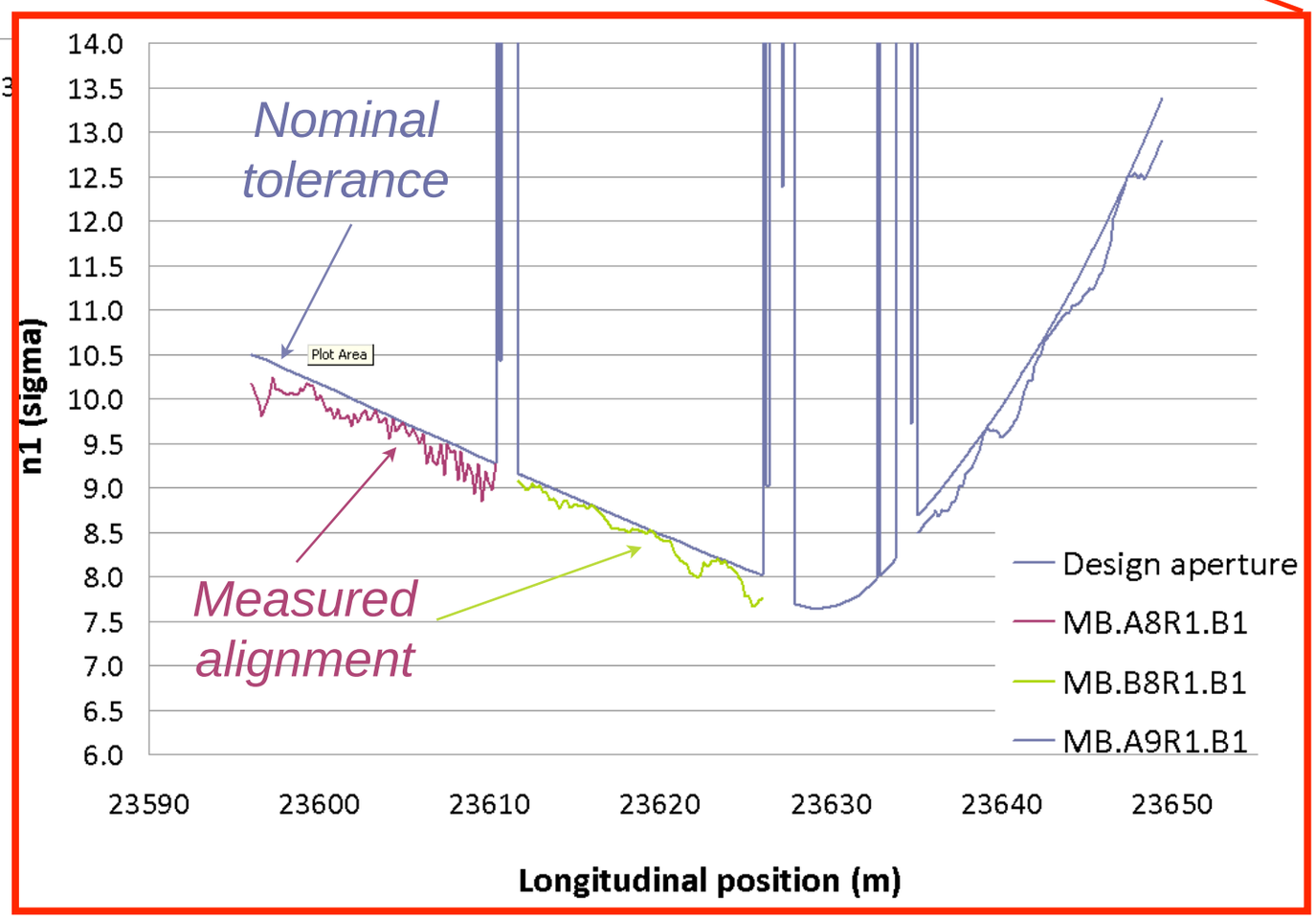


n1 calculation with measured profiles



Work in progress: apply measured alignment error to dipoles in IR1 right

Alignment inputs from P. Hagen



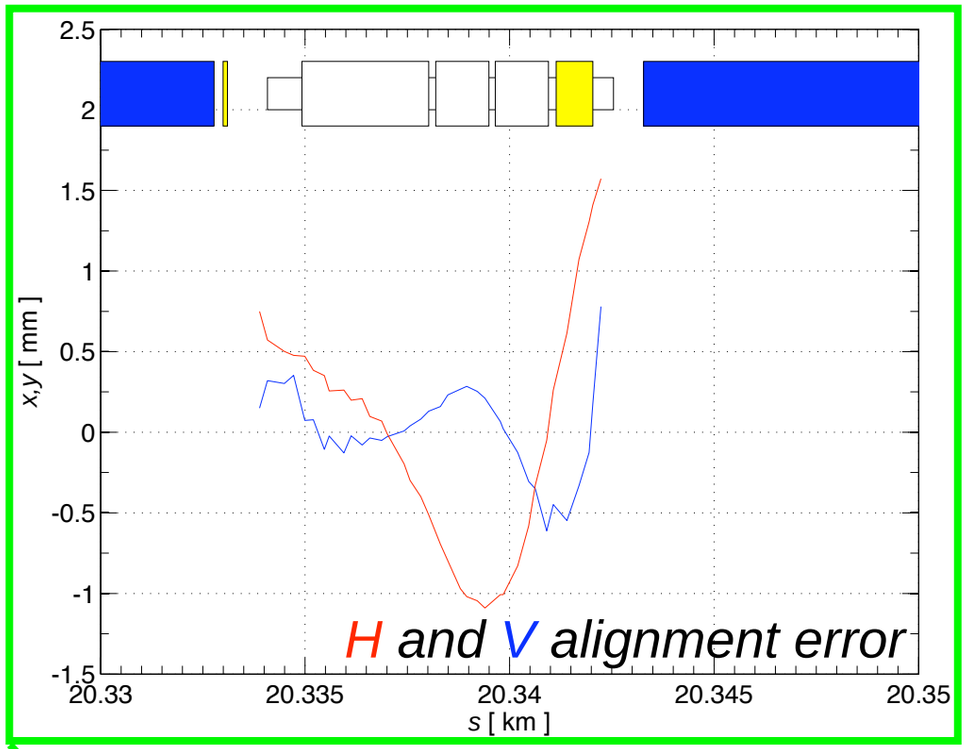
LHC design: n1 > 7

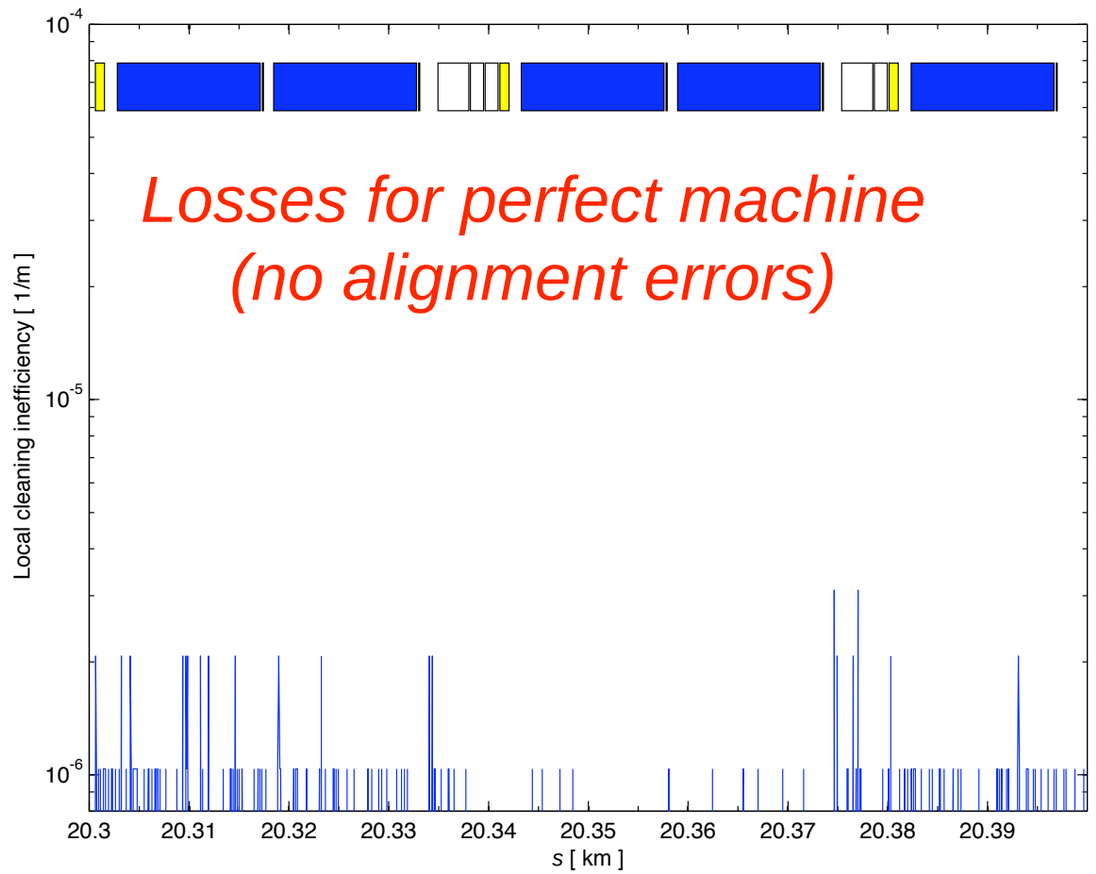
$A_{x,y} = 8.4\ \sigma_{x,y}$

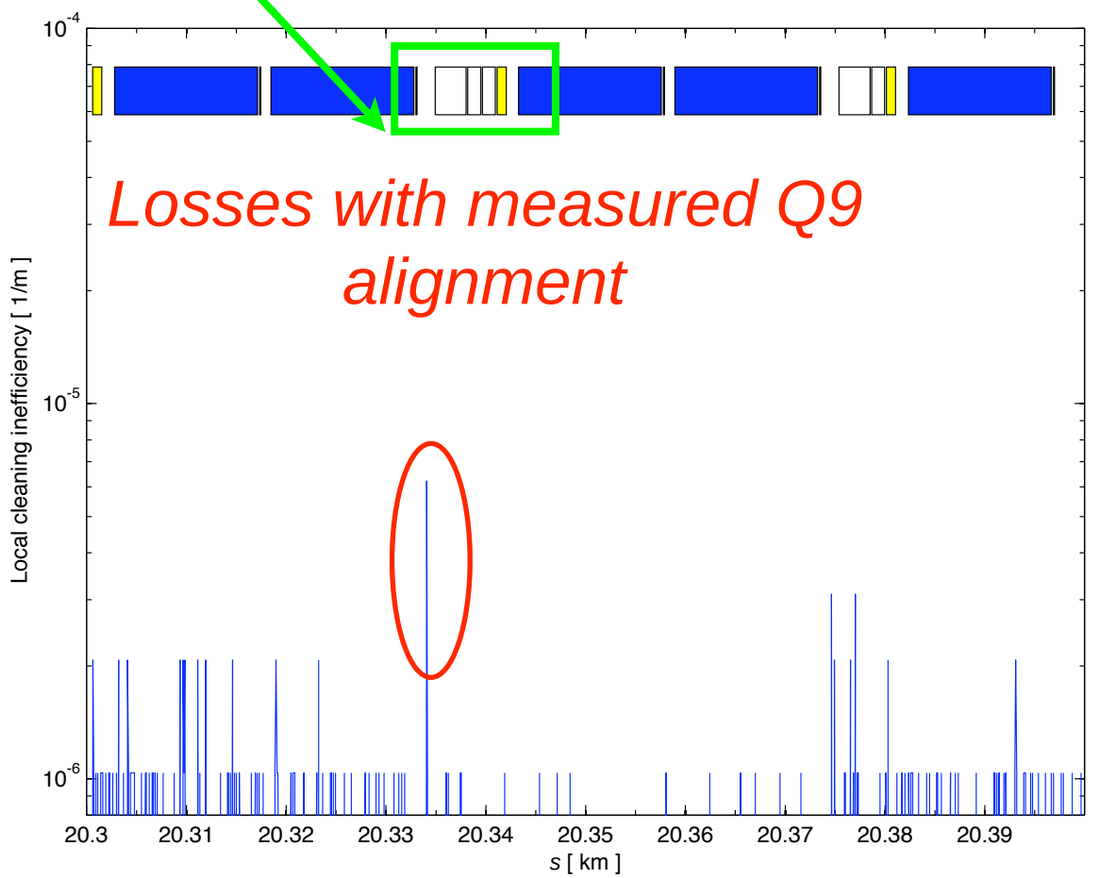
$A_{skew} = 10\ \sigma_{skew}$

Example of beam loss studies

Work in progress: apply measured alignment error along magnet Q9 downstream of IR7.



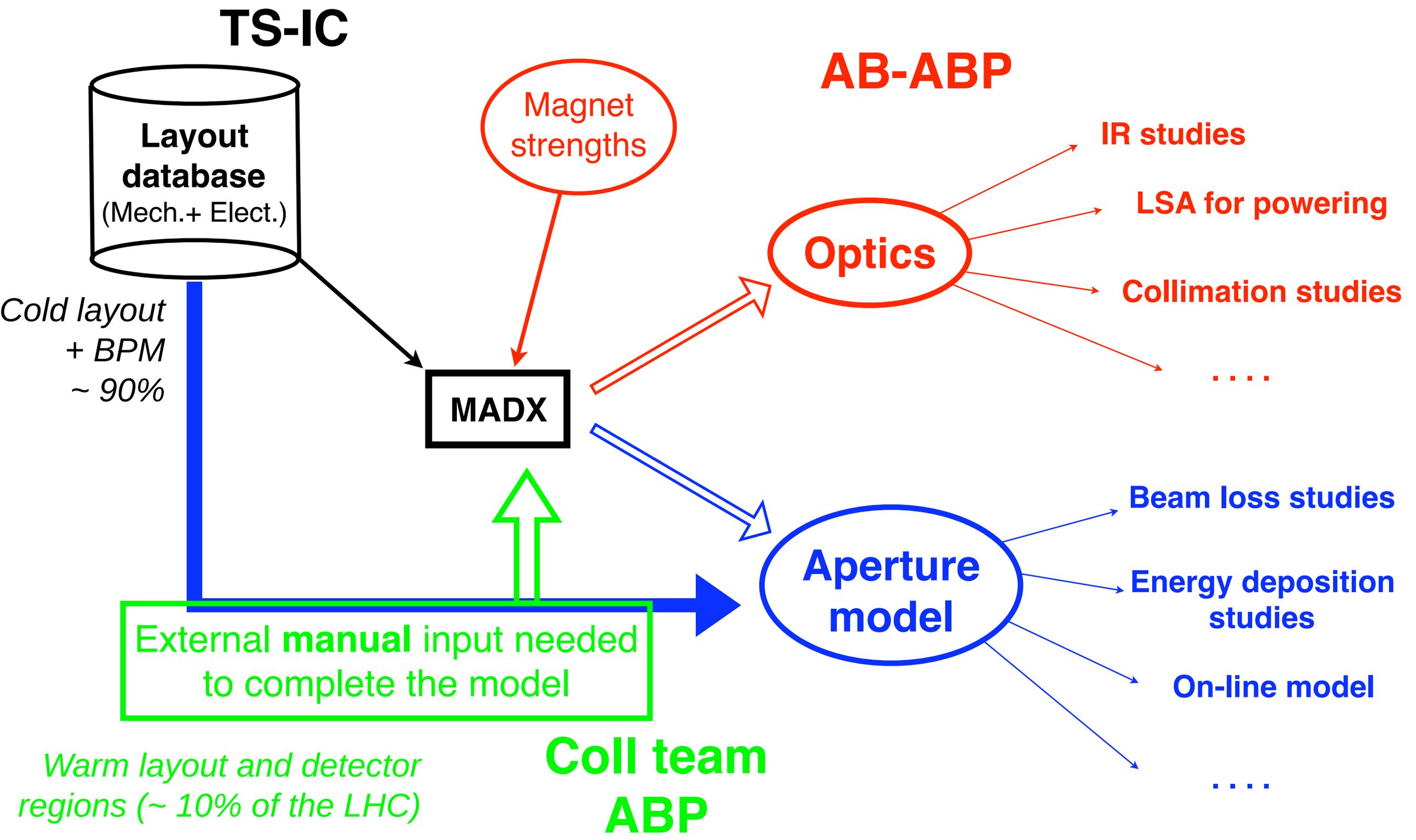




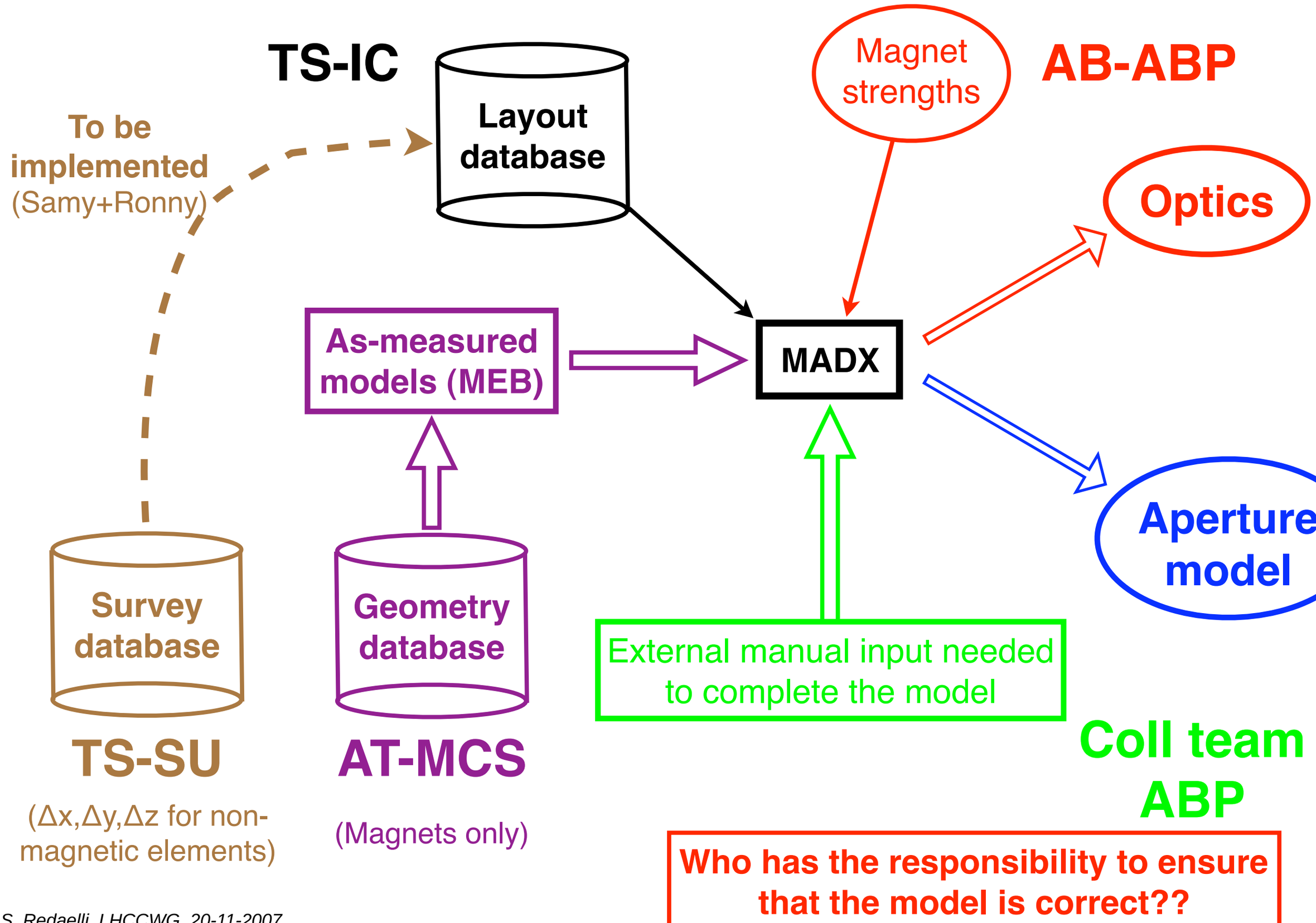
Outline of this talk

- *Design aperture of the LHC rings*
- *As-built model (magnet alignment errors)*
- ***Sources of aperture models***
- *Conclusive remarks*

Sources for aperture model



Sources for as-built model



Conclusive remarks

- ☑ A continuous model of the LHC ring aperture is available (since mid-2004)
  Driving forces: collimation studies, aperture validation, magnet slot assignment
- ☑ Recently the model has been extended to include as-built magnet data
- ☑ The model is appropriate for machine design and performance studies
- ☑ As it stands now, it can be used as an input for the LHC operational require-ments but it does not provide the full required functionality
  MADX should be used as the platform for the aperture information (other options?)
  Possible on-line implementations are discussed in next talks (Frank, Mike)
- ☑ The automatic extraction of the complete model from the layout database is not yet operational (it is successfully implemented only for the magnetic sequence)
  A working implementation was only available for cold sections and BPM's
  The extraction tools used for V6.500 are not yet operational for V6.501 (502, 503...)
  A bottom-to-top approach has been required so far to fill the missing information
  → *Obvious issues of maintenance + time consuming!*
- ☑ All the required aperture information should now be available in the layout DB!
  The automatic extraction of the complete model is promised by end of 2007
  A coherent treatment of the "as-built" data seems necessary to complete the model