Magnet Acceptance and Allocation at the LHC Magnet Evaluation Board

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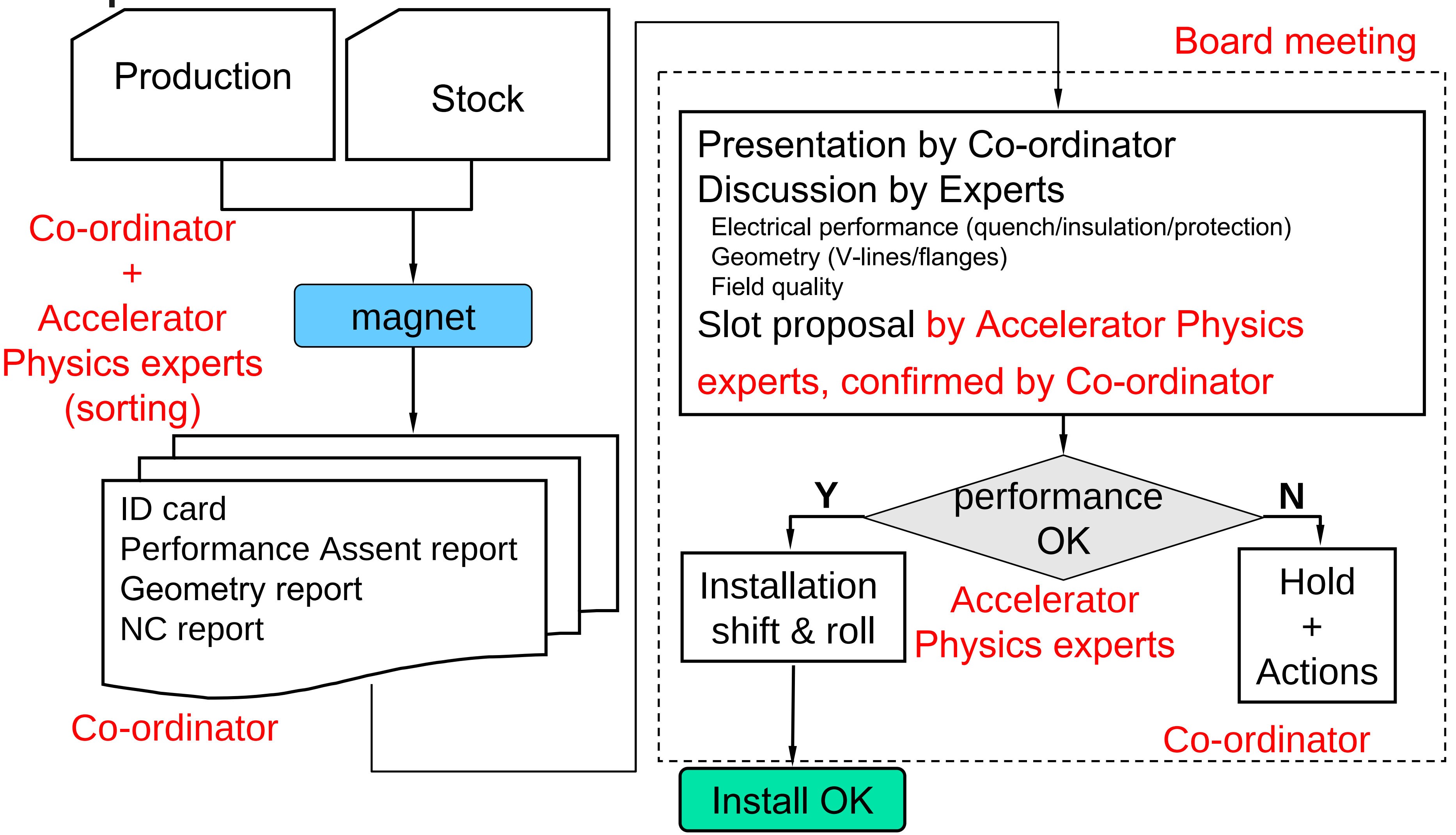
- The Magnet Evaluation Board (MEB) mission
- Sorting results (selection)
  - Arc magnets: main bends (MBs) and short straight sections (SSSs) (Q12-Q12)
  - Insertion quadrupoles (Q4-Q11)
  - Low-beta quadrupoles (Q1-Q3)
- Conclusions
- Acknowledgements

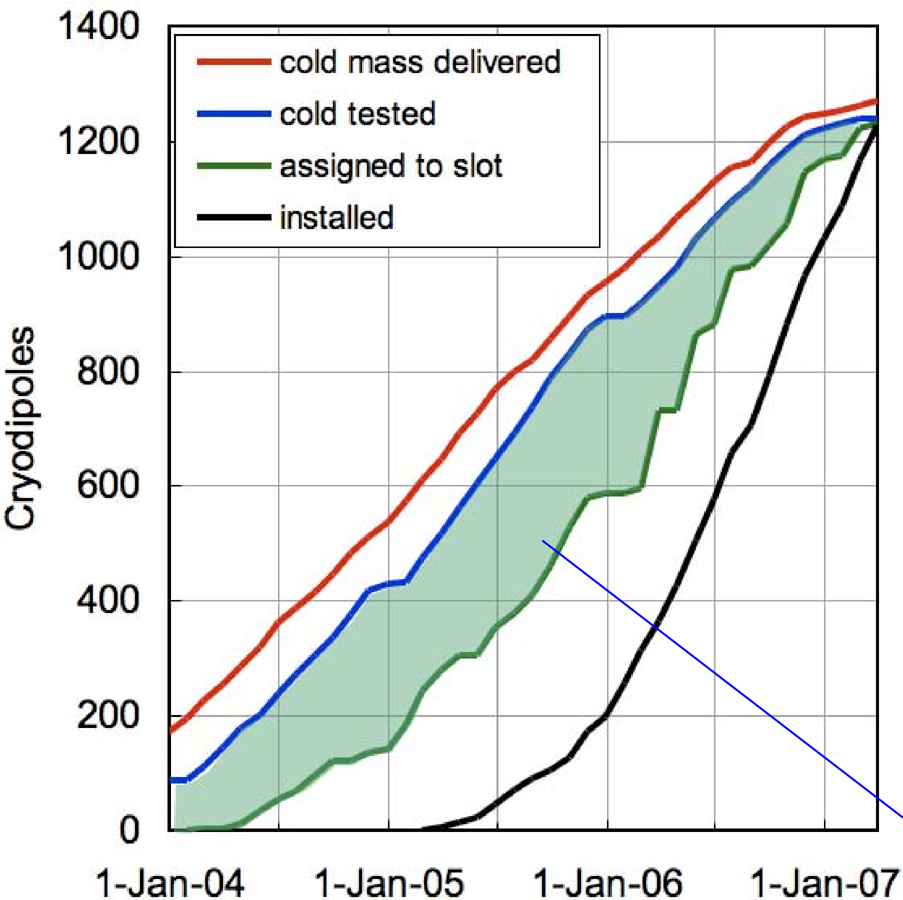
MEB mission statement

- Find suitable places (slots) for the available magnets that perform better than specified, as specified or out-of-tolerance
- Preserve and (if possible) optimize the machine performance
- Include provisions to face day-to-day requirements (faults during processing the magnets, defined as non-conformities- NCs)
- Follow the planned installation schedule with a suitable flow of allocated magnets

MEB Workflow Diagram



Slot allocation for MB's

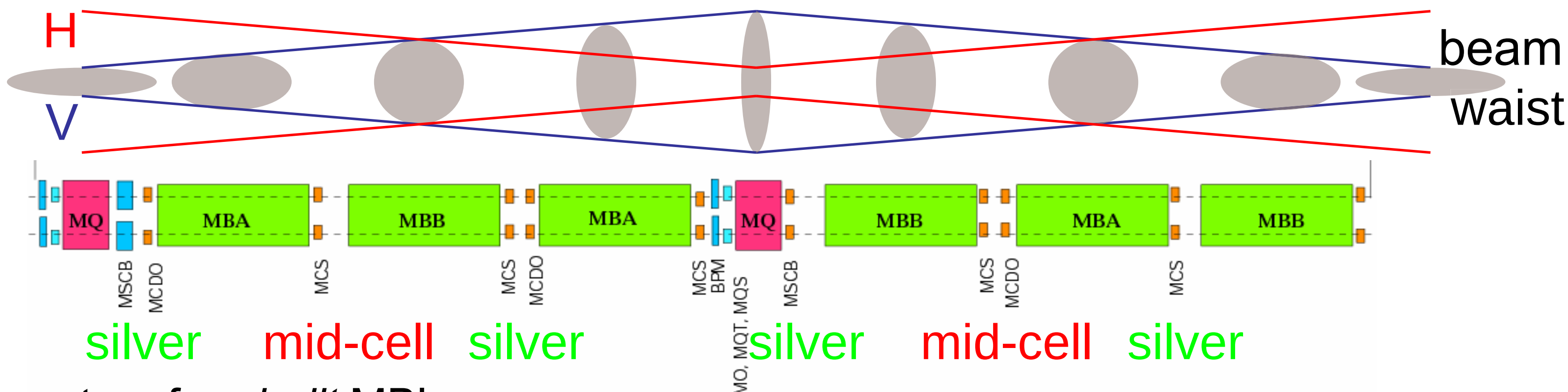


Comfortable stock for sorting: maximum of 300 MB's by end 2005, tapered down in 2006

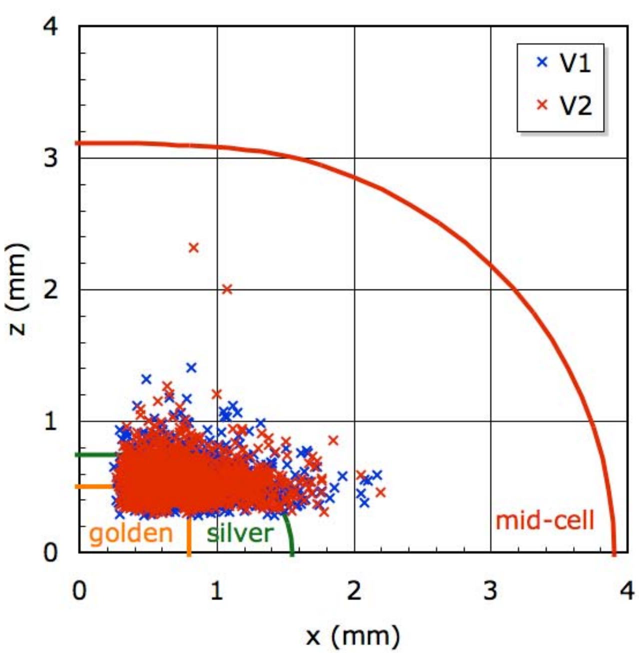
- Most slotting took place in 2 years (2005 and 2006).
- Working mode was drastically modified at the end of 2004 from ***manual assignment*** to ***semi-automatic assignment by batches*** to take profit from magnet production planning and availability on site.
- A stock of 200 to 300 magnets was used for batch selection and local sorting (1 to 2 sectors at a time).
- Sorting figure-of-merits: aperture and field quality.

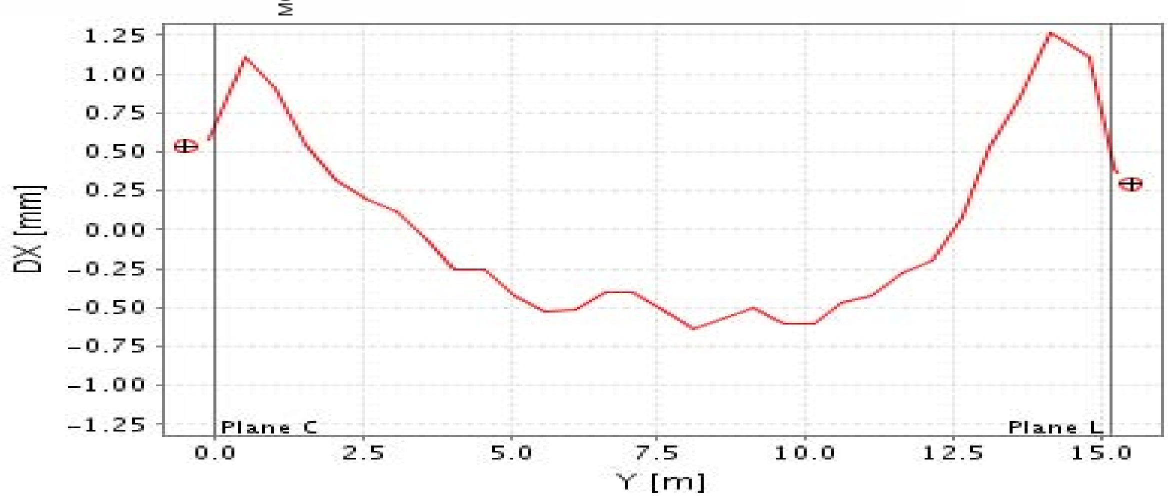
Related contributions: MOPAN086, MOPAN087

MB geometry sorting and gain



Geometry of *as-built* MB's





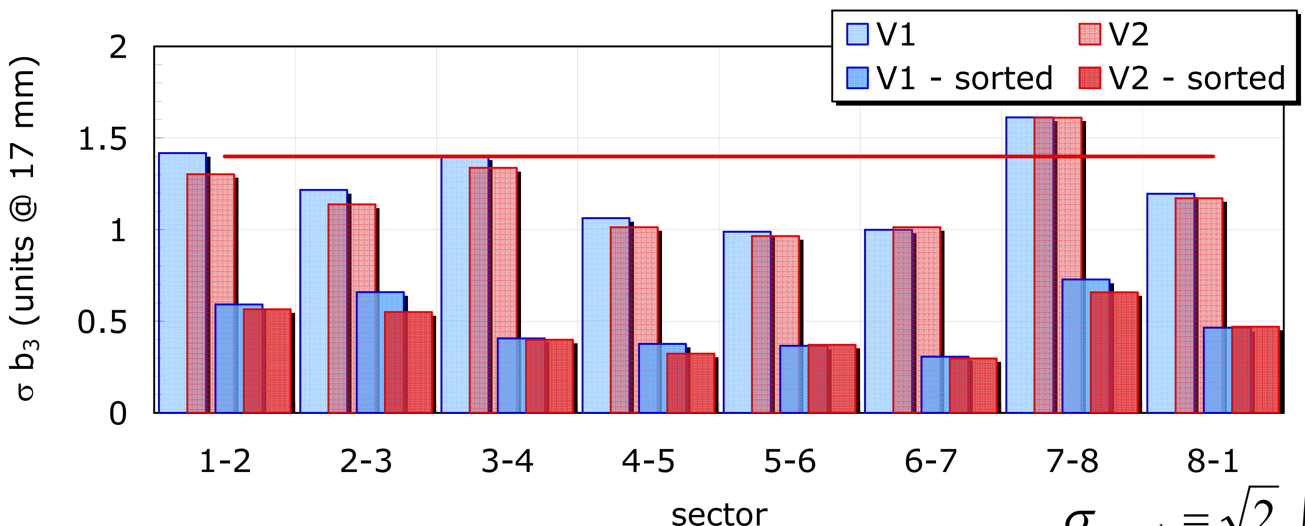
Data courtesy of E. Wildner and P. Hagen

- Approximately 500 MB's required sorting to avoid loss of aperture at 1 mm level.

MB field quality sorting and gain

Local sorting on geometry, TF, b3, a2 w.r.t average value per sector to:

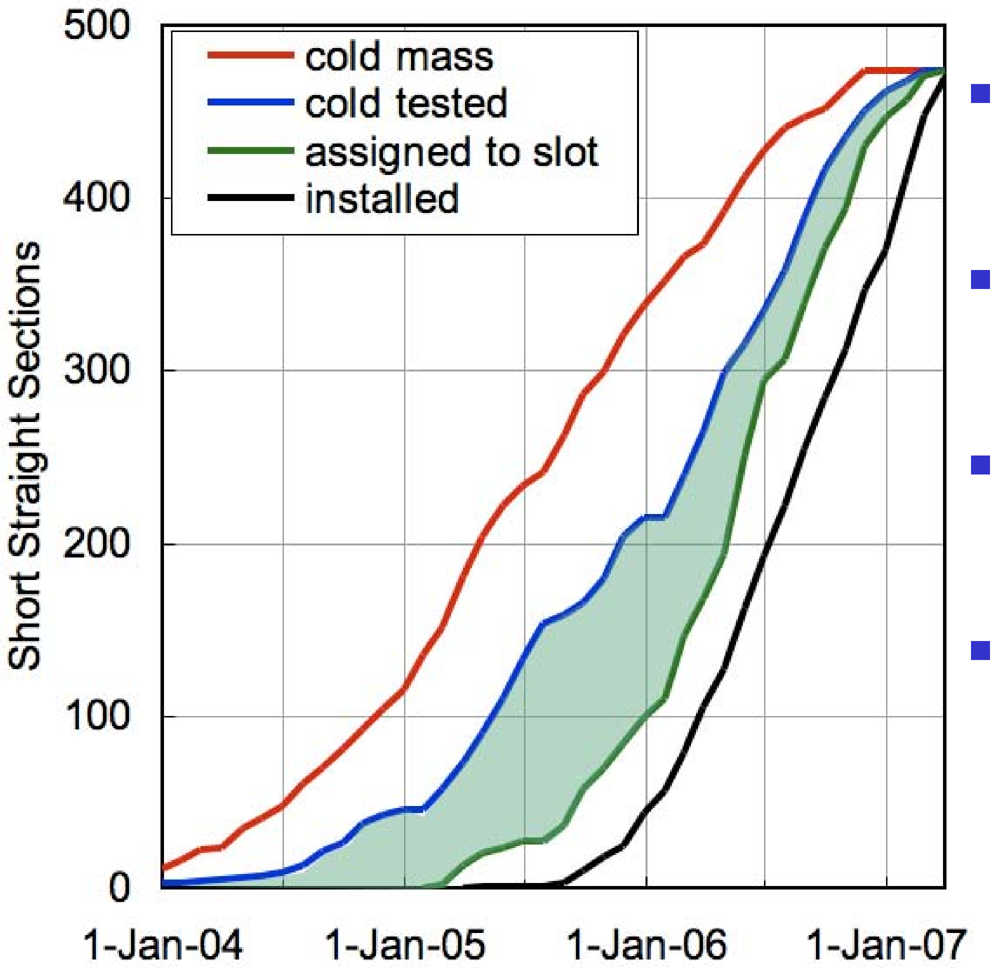
- Ensure that the closed orbit can be corrected with < 30 % of the corrector strength (random b1).
- Control the driving terms of coupling resonance and vertical dispersion (random a2): up-down pairing at 2π.
- Minimize the driving terms of 3rd order resonance (random b3): up-down pairing of consecutive MBs.



Estimated standard deviation of b_3 at start of injection, and effective standard deviation of sorted pairs for each sector batch.

$$\sigma_{b_3^{sorted}} = \sqrt{2}\sqrt{\frac{1}{N-1}\sum_{j=1}^{N/2}\left[\left(\frac{b_3^{2j-1}+b_3^{2j}}{2}\right)-\langle b_3\rangle\right]^2}$$

Slot allocation for SSS's



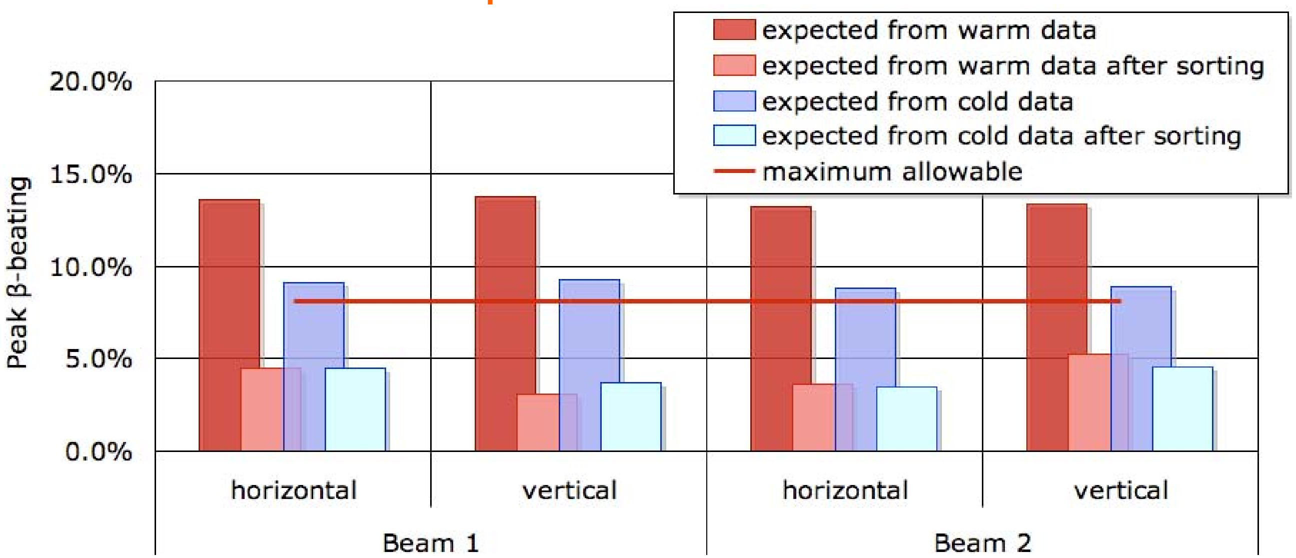
- The slot approval process was driven by the magnet availability after cold test and fiducialisation.
- MEB slotting started about half-way into the production, **reducing the sorting possibility**.
- Approval rate doubled in February 2006, as a result of **global sorting of 4 sectors.**
- Partial re-shuffling of pre-allocated sectors was performed a few times to **cope, e.g., with installation schedule changes.**

Related contribution: MOPAN085

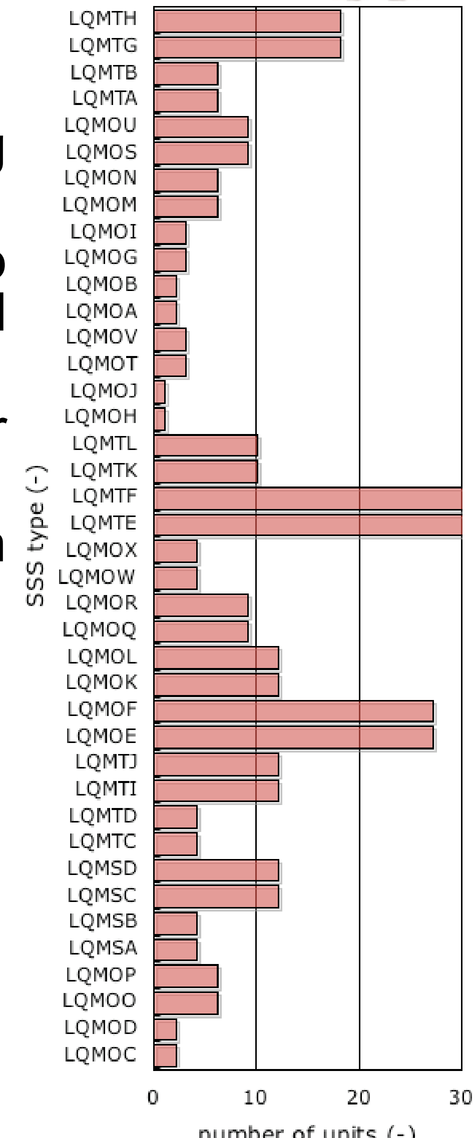
Algorithm devised by A. Lombardi and Y. Papaphilippou
Proceedings of EPAC06, p. 2017

SSS sorting and gain

- SSS come in 61 different types, with **reduced sorting possibility**.
- Batch selection and sorting is performed **in advance to cold test**, based on warm data (cold mass and collared coil): pairing at $\pi/2$ (or at $3\pi/2$) magnets with similar TF.
- The result of sorting was a **pre-allocation**, used for cold mass assembly and cryostating.
- **Installation shifts** were based on geometric data taken after cold test: aperture under control.



Courtesy of Y. Papaphilippou

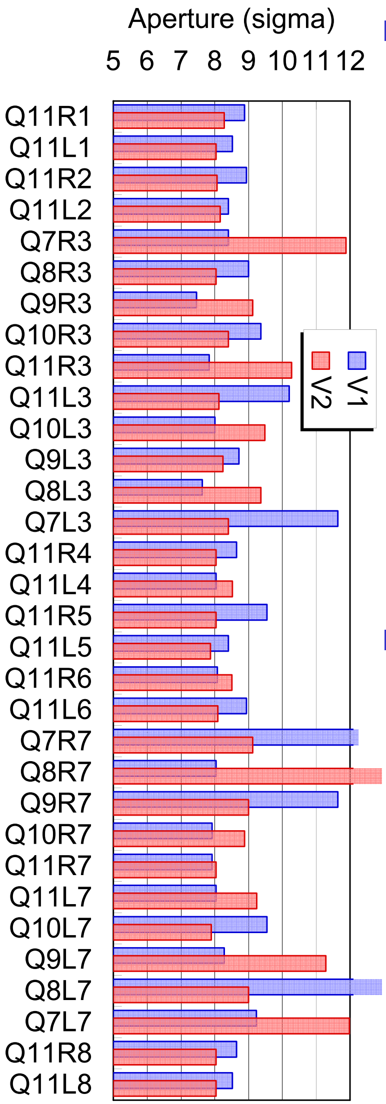


Catalog by courtesy of M. Modena

Slot allocation for insertion quadrupoles

- The discussion of the insertion quadrupoles at MEB was driven by the magnet production and installation schedule.
- The approval was based on a **one-by-one analysis** of performance, aperture and field quality.
- Sorting was very limited, but **crucial**:
  - Current rating of weak magnets vs. required optics.
  - Swapping of magnets based on **aperture considerations.**
  - Local optimization of field quality for assemblies of several magnets.
- Several cases resulted in **requests for additional measurements** (re-training and geometry).
- To be noted:
  - TF and field quality essential for machine performance (beta-beating, squeeze, and dynamic aperture).
  - Extended measurements required to ensure good knowledge of magnetic properties and hence, smooth operation.

Aperture in insertion quadrupoles



- Dispersion suppressor:
  - Limited aperture loss due to the tight optics in IR3 and IR7 (~0.6 σ)

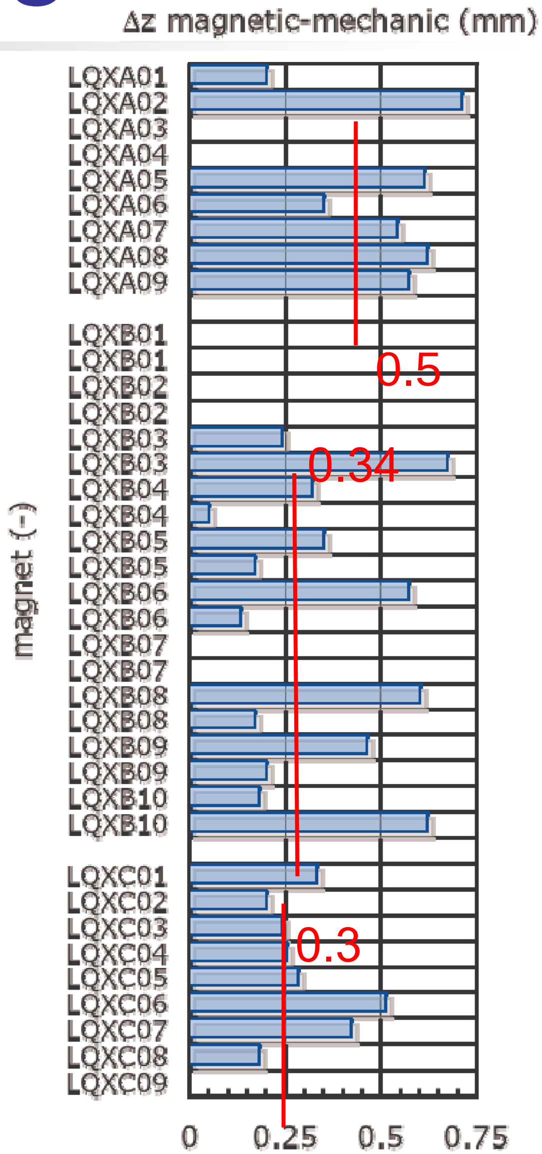
SSS		V1		V2	
			Aperture loss		Aperture loss
SSS508	Q11R7	F	0.48		
SSS504	Q10R7	D	0.12		
SSS528	Q11L5			D	0.17
SSS510	Q10L3	D	0.04		
SSS520	Q8L3	D	0.41		
SSS514	Q9R3	D	0.58		
SSS525	Q11R3	D	0.20		
SSS516	Q10L7			D	0.14

- Matching section:
  - Marginal aperture loss due to the tight optics (~0.3 σ)

SSS		V1		V2	
			Aperture loss		Aperture loss
SSS613	Q9L8			D	0.12
SSS610	Q6R8	F	0.12		
SSS620	Q5L1			F	0.24
SSS626	Q10R4	D	0.12		
SSS678	Q10R2	D	0.05		
SSS665	Q10L2			F	0.12
SSS690	Q7L2	F	0.02	D	0.06
SSS674	Q6R2	F	0.36		

Low-beta quadrupoles

- Sorting (within the constraints of hardware and magnet availability) was used to maximize the aperture.
- Field quality is good, with good compensation between Q2a and Q2b.
- Installation shifts (transverse and longitudinal) were chosen to:
  - Reduce the feed-down and the required dipole corrector strength.
    - Δz ≈ 1 mm magnetic offset at nominal conditions equals the MCBX correction capability.
    - MCBX is quench and force limited.
  - Achieve the required mechanical aperture.
  - Limit the beta-beating induced by longitudinal positioning errors.
- Alignment in all directions remains critical.



Conclusions

- Field quality
  - The magnetic properties are under control (using sorting and compensation), the LHC should be at least as good as expected.
  - The installation sequence was optimized to gain margin (limiting linear imperfections, required corrector strength, and low-order resonance driving terms).
- Aperture
  - The mechanical aperture has been preserved/kept at the target value of 8.4 sigma using sorting and installation shifts/rolls on most magnets as well as other *passive* elements (MKI, MKD, LE, DFB).
  - Exceptions:
    - **Negligible aperture loss in arc quadrupoles (slots: 12/360).**
    - **Modest aperture loss in insertion quadrupoles. A study is in progress to re-match the optics (slots: 8/64).**
    - **Isolated insertion quadrupoles have larger aperture reduction. A study is in progress to re-match the optics (slots: 8/50).**

Acknowledgements

- The Manifacturing and Test Folder database team (T. Pettersson, E. Manola-Poggioli, et al.) for the steady support of tools, reports, views.
- The database responsible's and services for magnetic data and alignment (L. Deniau, et al., P. Hagen, E. Todesco, et al.) for the input to the sorting work.
- The fiducialisation team for their competence and precision.
- The cold test team supporting groups (L. Walckiers, et al.).
- The many engineers, technicians, operators that have entered an overwhelming amount of data that we looked at, and thought we made sense of.

Reserve slide

Other magnets

- Cold D1, D2, D3, D4:
  - Field quality is within specification.
  - Aperture analysis was done on a one-by-one basis, using fiducialisation data measured at CERN.
- Warm magnets:
  - Field quality is in general very good:
    - MBXW (warm D1): sorting on TF (field quality excellent).
    - MBW (warm D3 and D4 in cleaning insertions): sorting on TF (field quality excellent).
    - MQW (warm quadrupoles in cleaning insertions): sorting on b2. Impact on dynamic aperture not negligible, but known.
  - Aperture:
    - Magnets as well as vacuum chambers were sorted on a one-by-one basis to maximize the aperture.
    - Only known *bottlenecks* are in the MQWs of IR3 and IR7 for which additional protections are in place.