SLAC DLSR Workshop
Accelerator Session Close-Out

December 11, 2013

Accelerator Physics: J. Safranek (SLAC) for R. Bartolini (DLS)

Magnets: M. Eriksson MAX-IV

Vacuum System: G. Decker (APS)

Injection: R. Walker (DLS)

Accelerator Session 1:
AP aspects of component design

J. Safranek for R. Bartolini

The accelerator session reviewed

- the main accelerator physics problems met in the design of diffraction limited storage rings
- the strategies and tools used
- the implications in the design of components (magnets, vacuum chamber, RF mostly)

Presentations

D. Robin: Review of AP issues for DLSR lattice and component design

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M. Eriksson: MAX IV 3 GeV storage ring

M. Borland: Optimisation of an ESRF-II style lattice fro APS

P. Raimondi: ESRF upgrade phase II optics

L. Liu: Sirius

H.Tanaka – AP issues at Spriing8 II

A. Kling: Low emittance studies at Petra III

J. Byrd: AP issues for Harmonic Cavities for ALS II

Accelerator lattice

MBA lattices: two designs are emerging

- MBA with sextupoles throughout – (a la Max IV)
- hybrid MBA (with dispersion bump; a la ESRF)

Hybrid MBA helps significantly the accelerator design by reducing the sextuple strength required for chromaticity correction

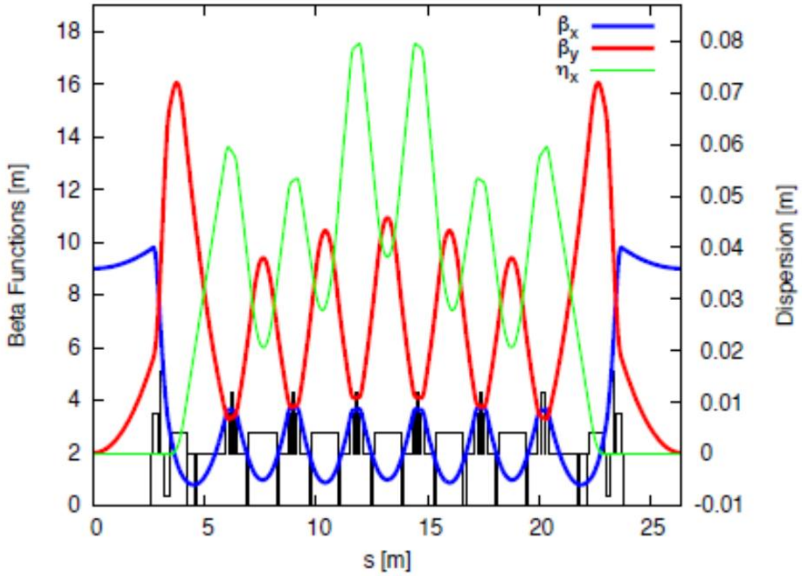
MBA lattice with M = 5, 7, 9 were shown

- M = 5 Sirius, SPRrng8 II
- M = 7 APS ESRF, MAX IV
- M = 9 ALS II

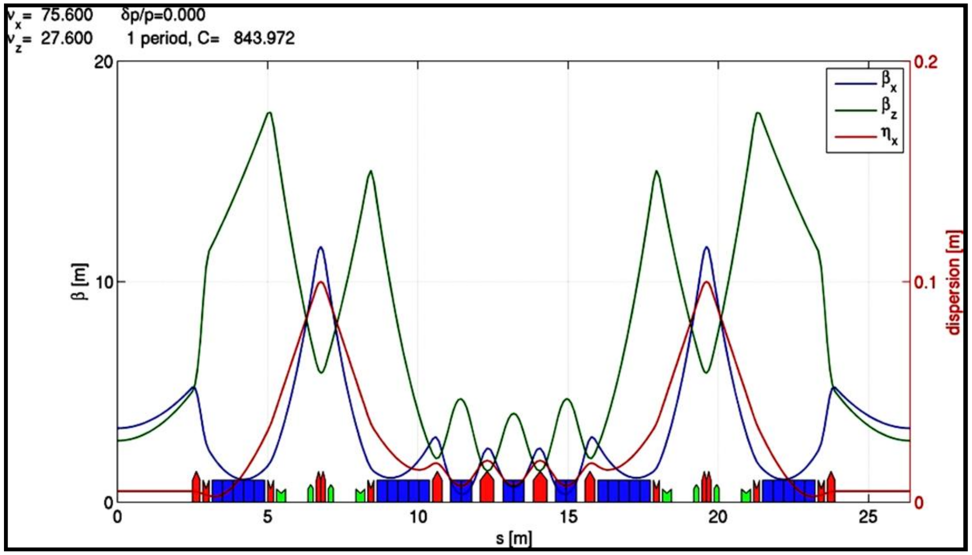
They provide lattice with emittance in the range 50 – 300 pm

Accelerator lattices

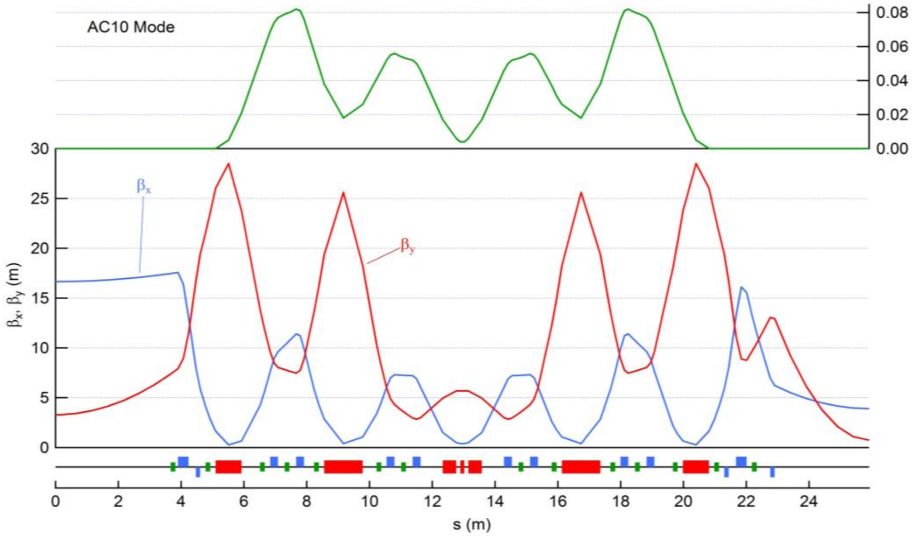
MAX IV



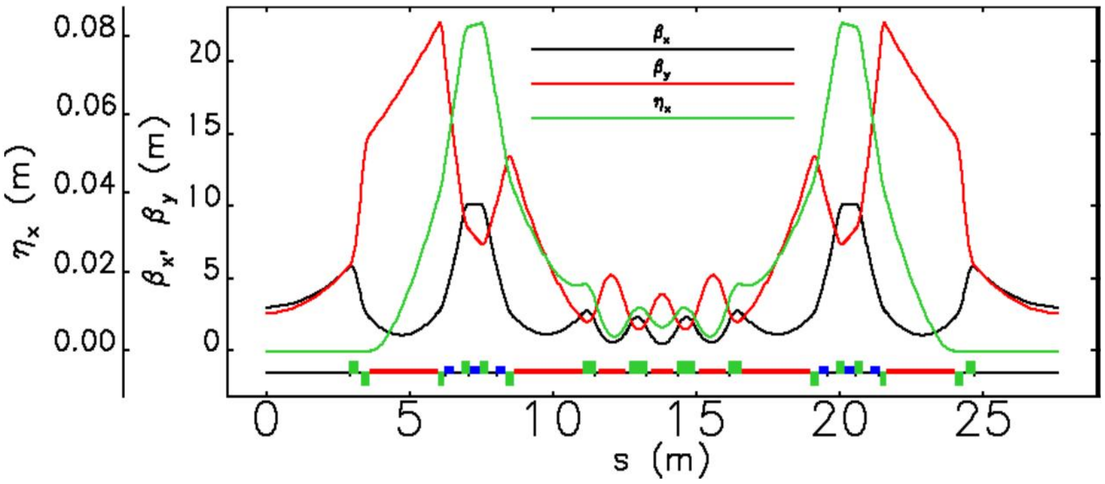
ESRF II



SIRIUS



APS-U



Accelerator optimisation

Linear optics matching of TME-like lattices should take into account

- matching to photon beam size and divergence at straight sections
- symmetry preservation is still advisable but not necessary
- operation with round beams should be considered (e.g. RIXS ALS-II)

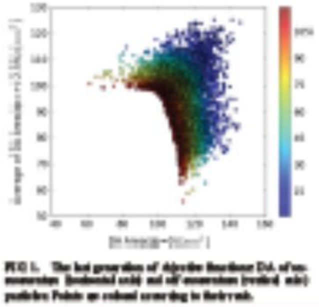
Nonlinear optics; dynamic aperture (DA), momentum aperture (MA)

- driving term compensation per cell (ESRF) or per N cell (PEP-X)
- Frequency map analysis (FMA) well established tool
- MOGA-type of algorithms for direct DA and MA optimisation

AP optimisation must be coupled with Accelerator engineering

- Magnets, Vacuum, Engineering integration, ….

Development of accelerator simulation tools



Symplectic Tracking based methods

DA, MA separated

DA, MA together

SOLEIL SYNCHROTRON

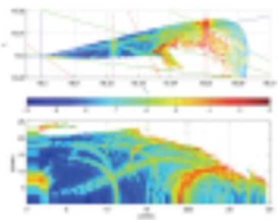
from L. Nadolski,
ICFA LowEring,
Oxford 7/13

Direct tracking based optimization

GLASS

Analytical based method

Genetic Algorithm
MOGA



Lie Algebra/Differential Algebra

Frequency Maps
FMA
Diffusion factor

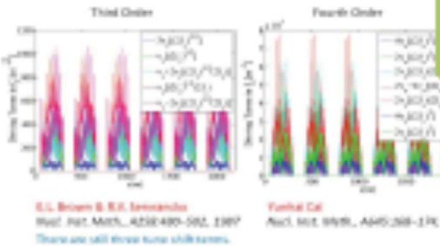
Nonlinear
“LOCO”

Resonance Driving Terms
RDT minimization

Amplitude Tuneshift
minimization

Resonance identification

Canceling
Sextupole
Resonances



E.L. Brown & R.V. Servranckx
Nucl. Inst. Meth., A258:480-502, 1987
There are still three tune shift terms.

Yunhai Cai
Nucl. Inst. Meth., A645:168-174, 2011

Phase advances

Interleaved
sextupoles

Robustness to magnetic, alignment errors

Robustness ID configurations

Tracking codes: **PTC MADX TRACY AT LEGO OPA ELEGANT**

Main AP issues (I)

Dynamic aperture

- >~5 mm for off axis injection
- >~1 mm for swap out injection

Lifetime

- large variation in the nominal required lifetime among projects
- limits on lifetime should be set considering,
    - Top-Up frequency,
    - loss rate, loss distribution and shielding
- few % momentum aperture is anyway required

Main AP issues (II)

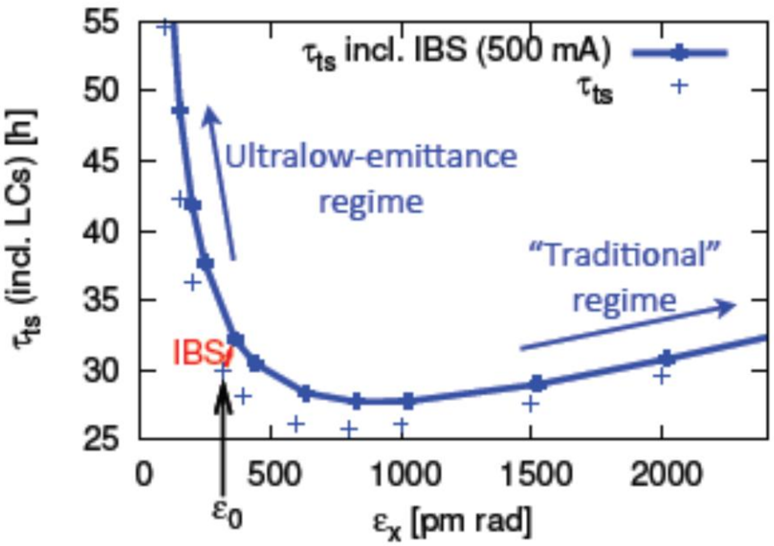
- Collective effects
  - long bunch length are preferable. They can be achieved with
    - long RF wavelenght e.g. 100 MHz a la MAX IV
    - Harmonic cavities for bunch lengthening

IBS is the main limiting factor for the brightness

Other forms of impedance were not discussed (see 1/2014 workshop)

Some projects operate in the regime where Touschek lifetime is increased with lowering the emittance

IBS experiments at PETRA-III and other facilities



Implications on magnets

Dipoles:

Most lattices design use gradient dipoles. Gradients are getting large - - offset quadrupoles being used. Longitudinal tapered dipole are also proposed.

Quadrupoles

gradients required are large up to 100 T/m

Bore radius is small 15 mm or less

implication of small apertures (vacuum, magnet measurements, …)

AP studies define the tolerances

error analysis of harmonic and misalignments, assembly, …

implication on tolerances of pole profile (is 50 um enough?)

implications on alignment (are 50-70 um enough?)

Are beam-based correction technique sufficient? (BBA, LOCO, dispersion free steering…, low V emittance achieved on existing rings is sufficient)

Tolerances on alignment and field quality

Over-specifying tolerances can be very expensive

There was a general consensus that the tolerances assigned to magnet alignment in the field quality are computed with a pessimistic approach. **The possibility of beam based correction should be considered in specifying the tolerances.**

This is true for alignment errors both for orbit and for optics corrections. Beam based correction tools like BBA, LOCO, coupling free steering can significantly relax the tolerances. It as suggested to set tolerances based on **first-turn** just to store the beam.

Swap out injection allows operating with small dynamic aperture and might help likewise to relax also the tolerances on harmonics

Some implications on RF

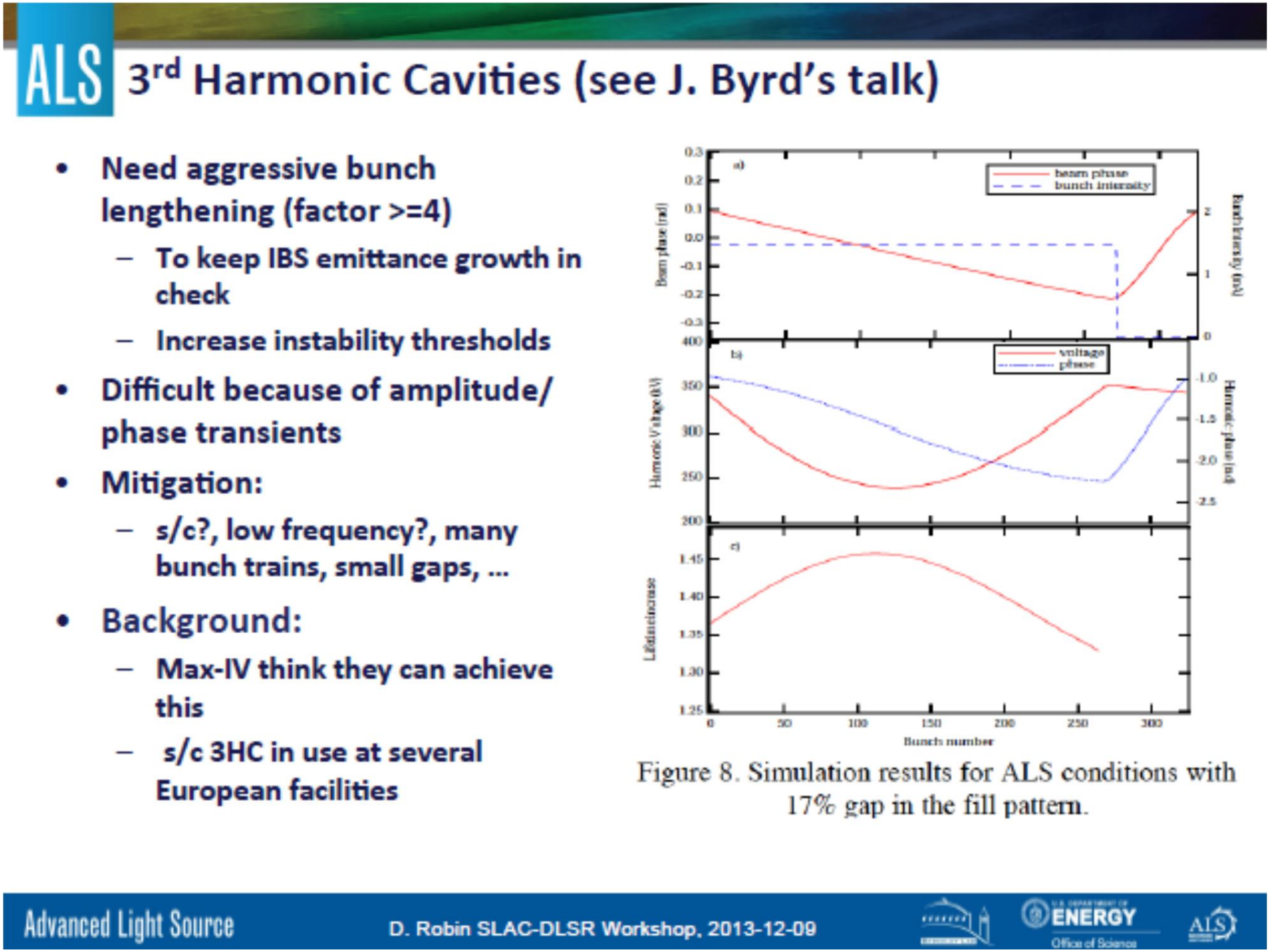
Long bunches are beneficial to

- damping collective instabilities
- reduce RF heating
- increase lifetime (via bunch lengthening and control of IBS emittance blow up)

Main technical solutions are

- use lower RF frequency (e.g. max IV - 100 MHz)
- use high harmonic cavities

Transient beam loading should be looked at. It can prevent an effective bunch lengthening over the bunch train.



3rd Harmonic Cavities (see J. Byrd's talk)

- Need aggressive bunch lengthening (factor >=4)
  - To keep IBS emittance growth in check
  - Increase instability thresholds
- Difficult because of amplitude/ phase transients
- Mitigation:
  - s/c?, low frequency?, many bunch trains, small gaps, …
- Background:
  - Max-IV think they can achieve this
  - s/c 3HC in use at several European facilities

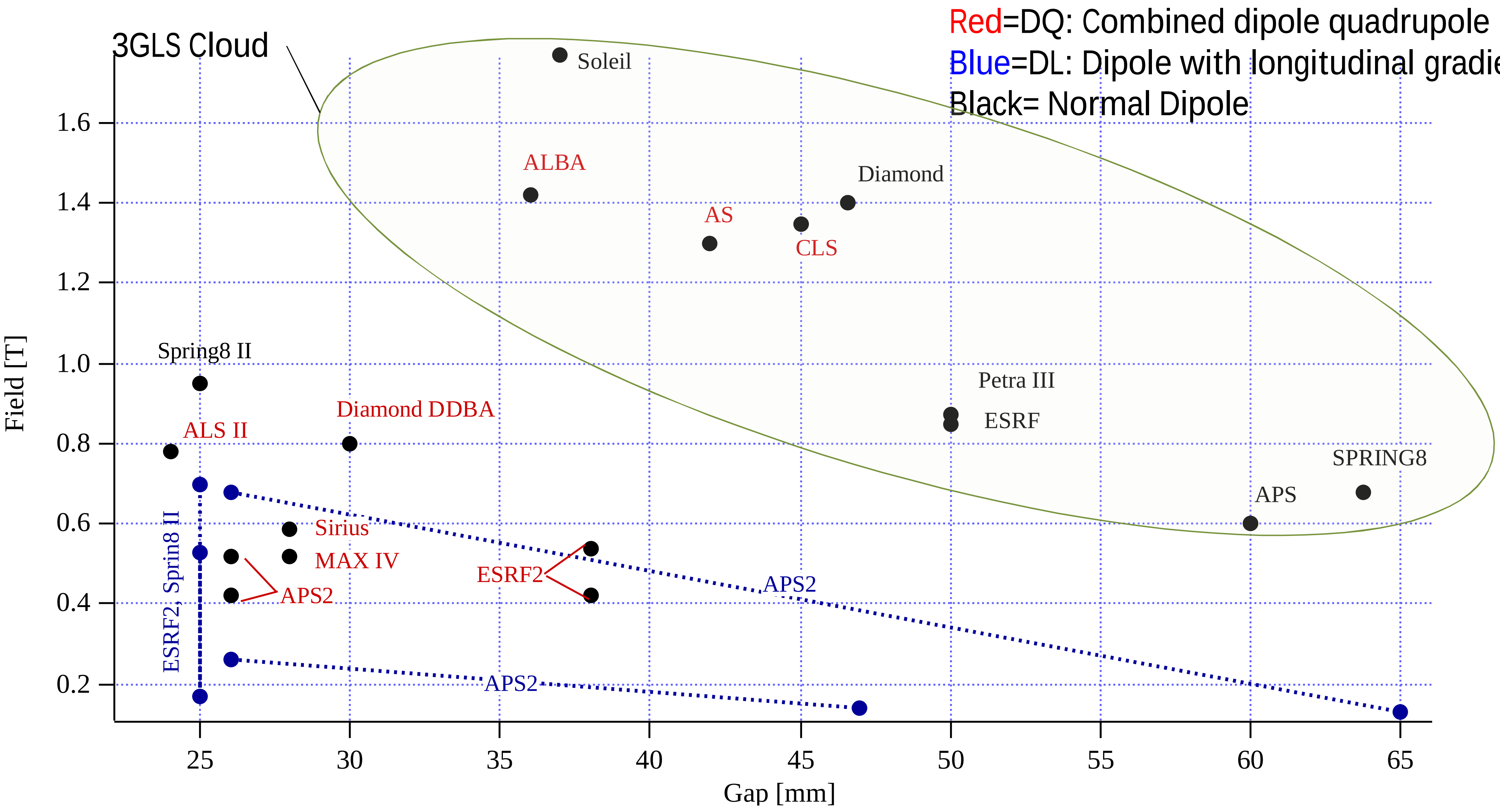
Figure 8. Simulation results for ALS conditions with 17% gap in the fill pattern.

x4 lengthening has technical challenges

DLSR Magnets

Some conclusions from magnet presentations:

- DLSRs call for a large number of magnet items.
- It’s necessary as well as an opportunity to develop new types (smaller) magnets with smaller apertures for DLSRs.
- Opportunities: Stronger multipole (MP) magnets, magnet integration in blocks, smaller machine functions => miniaturization. On axis injection=>relaxed magnet tolerances, new types of IDs…
- Challenges: Stronger MP magnets, magnet integration in blocks, smaller machine functions => miniaturization. On axis injection (=>relaxed magnet tolerances, new types of IDs…). Photon beam extraction from small vacuum chambers and magnets.
- Increasing demand for system integration (injection, vacuum, RF, diagnostics, close orbit correction etc)
- Modeling tools improved as well as diagnostics
- Green field versus upgrades projects =>different solutions



No more standard dipoles in DLSRs

Different strategies:

1- “A la MAX IV”

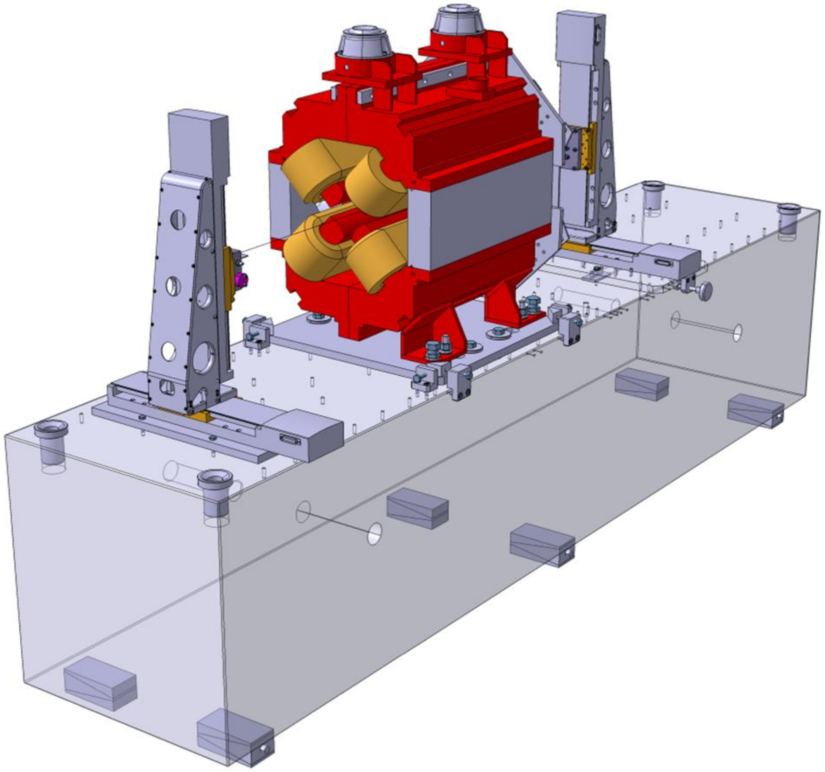
- Common yoke for magnets on girder
- Massive iron yoke
- Rely on precise girder machining
- Magnet alignment = mechanical alignment
- Limited effort on magnetic measurements

Expect outcomes very soon

MAX IV open girder

2- Individual magnet approach

- Separated magnets
- Individual magnetic characterization
  - Multipoles analysis
  - Magnetic center
- Relative magnet alignment on girder done using stretched/vibrating wire
- Applicable to straight magnets only
- Positive experience from NSLS II & ESRF



ESRF stretched wire bench

Discussion in Magnet session

Q: Are our alignment tolerances too tight?
A: Might be so. CO correction schemes and designs should then take preservation of DA in account. Commissioning should be planned in detail.
Examples: BBA could focus on getting the beam through sextupole centers, LINAC algorithms used for first turn, initial injection on axis (then off-axis), corrector strengths used for re-alignment etc.

Q: Can magnet fields tolerances be relaxed?
A: Sometimes. Especially for on-axis injection.

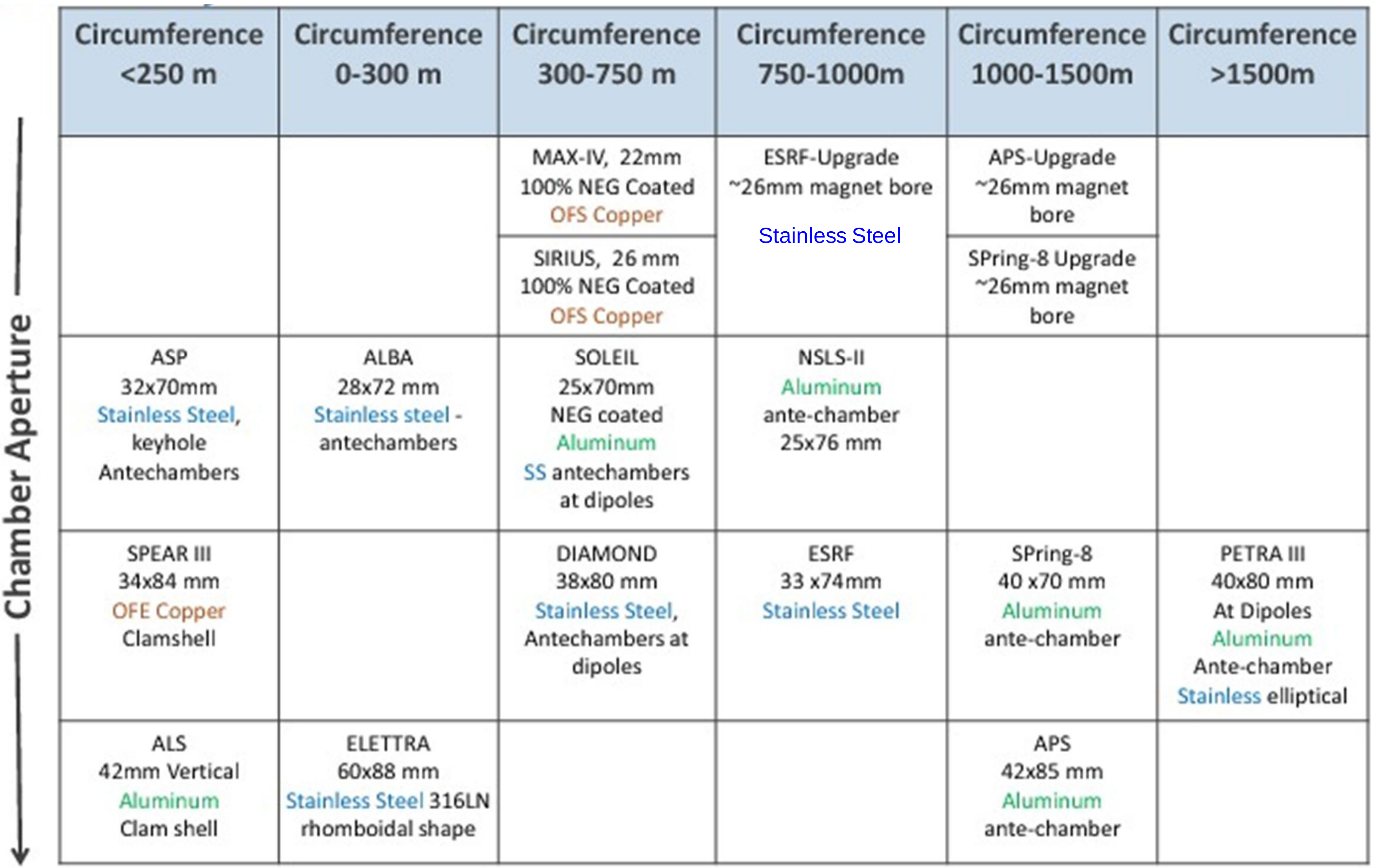
Q: Can mechanical alignment and precision machining replace the need for magnetic measurement?
A: An open question whose answer depends on the magnet design. For high magnet counts there is a trend towards relying on mechanical alignment with verification by magnetic measurement.

Q: Vibrations?
A: Beam line optics may be more susceptible to vibrations than the accelerator. Integrated accelerator-beamline stabilizing systems are probably needed.

Vacuum Working Group Summary

Vacuum System Design Choices

- Material
  - Copper – high conductivity, higher temperature activation is possible, 180 to 250 deg. C
  - Steel – High strength, low conductivity, shields hard X-rays
  - Aluminum – low-temperature bake, loses strength above ~180 deg. C, not as strong as OFS Cu or SS, transparent to hard X-rays
- Philosophies:
  - NEG coatings
    - Best solution for low-conductance chambers with no space for antechambers
    - In-situ vs. ex-situ activation
  - Antechambers
    - Distributed pumping e.g. NEG strips
    - Lumped pumping
  - Hybrid solutions



Chamber Aperture ↓

Circumference <250 m	Circumference 0-300 m	Circumference 300-750 m	Circumference 750-1000m	Circumference 1000-1500m	Circumference >1500m
		MAX-IV, 22mm 100% NEG Coated OFS Copper	ESRF-Upgrade ~26mm magnet bore Stainless Steel	APS-Upgrade ~26mm magnet bore	
		SIRIUS, 26 mm 100% NEG Coated OFS Copper		SPring-8 Upgrade ~26mm magnet bore	
ASP 32x70mm Stainless Steel, keyhole Antechambers	ALBA 28x72 mm Stainless steel - antechambers	SOLEIL 25x70mm NEG coated Aluminum SS antechambers at dipoles	NSLS-II Aluminum ante-chamber 25x76 mm		
SPEAR III 34x84 mm OFE Copper Clamshell		DIAMOND 38x80 mm Stainless Steel, Antechambers at dipoles	ESRF 33 x74mm Stainless Steel	SPring-8 40 x70 mm Aluminum ante-chamber	PETRA III 40x80 mm At Dipoles Aluminum Ante-chamber Stainless elliptical
ALS 42mm Vertical Aluminum Clam shell	ELETTRA 60x88 mm Stainless Steel 316LN rhomboidal shape			APS 42x85 mm Aluminum ante-chamber	

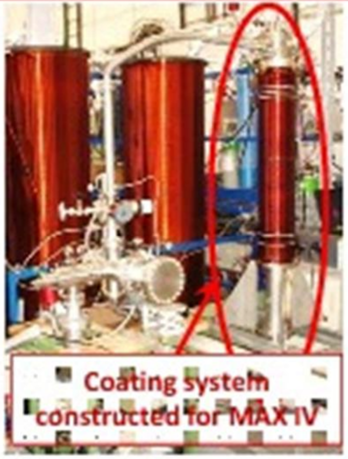
Herman Cease, APS

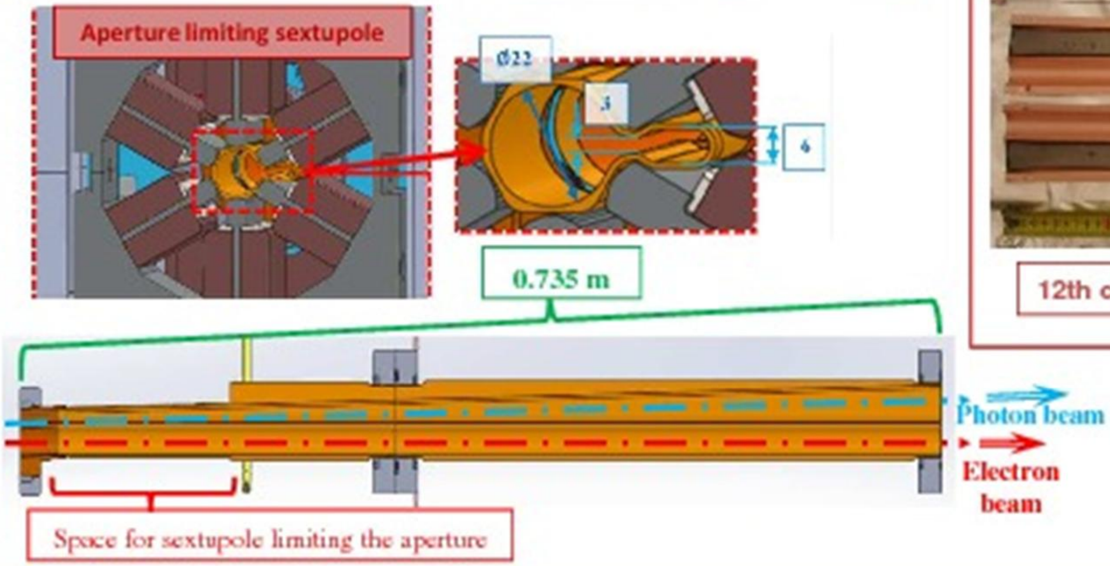
MAX IV LABORATORY

NEG coating R&D at CERN

Aim: to develop coating procedure for chambers with small antechamber (minimum vertical aperture 5 mm),

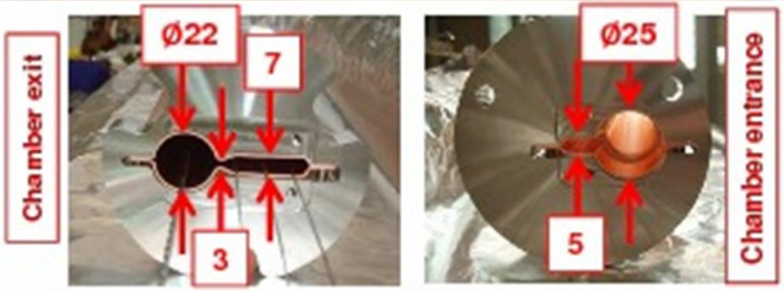

Coating facility at CERN used for LHC and MAX IV chambers


Coating system constructed for MAX IV

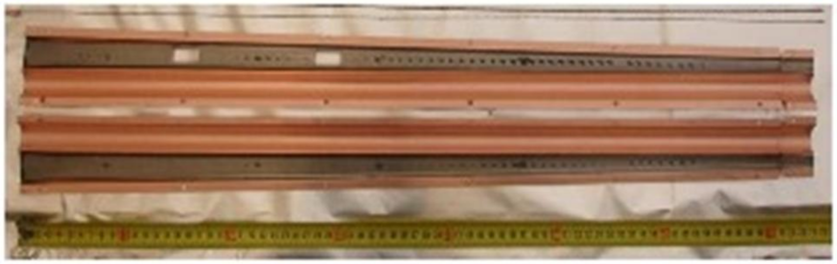


Space for sextupole limiting the aperture

Prototype made in two halves to facilitate inspection of the coating.



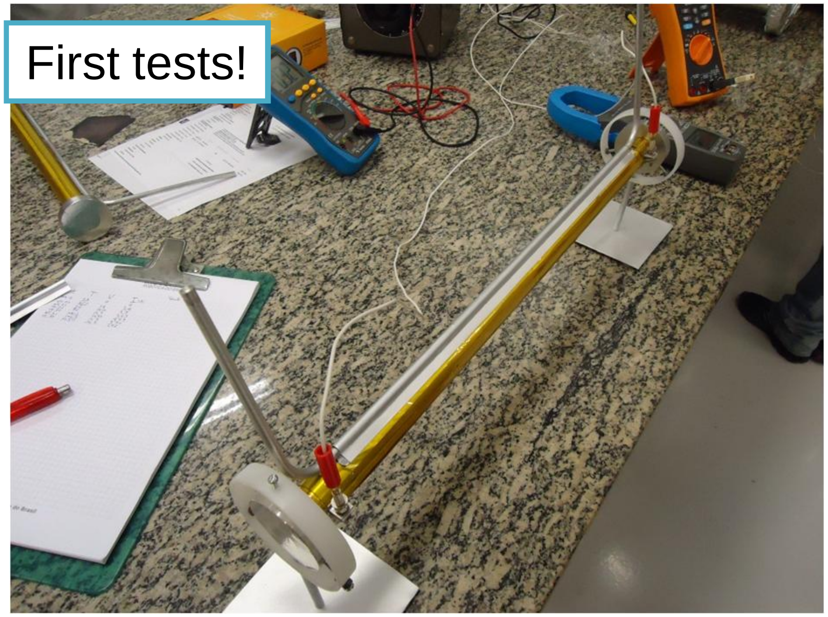
Example: coating trial results for magnetic field of 360 - 270


12th coating - 1 cathode (3.6e-1 mbar, 650V, 0.04A, 26W)

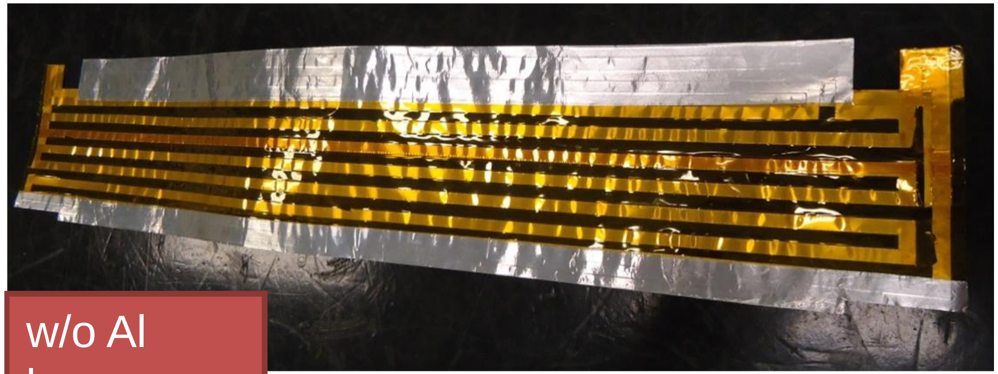
Eshraq Al-Dmour Maxlab, Dieter Einfeld

Storage ring:
Installation and Bake-out

1. After NEG coating, the chambers will be filled with N_2 and stored
2. *In-situ* assembling the chambers with half of the magnets in place
3. Make all electrical and hydraulic connections
4. Close magnets
5. *In-situ* bake-out for NEG activation (200 ^{0}C @ 24h):
    - An thin polyimide heating tape will be used:
        - Thickness < 0.4 mm
        - Max. tested temperature 250 ºC

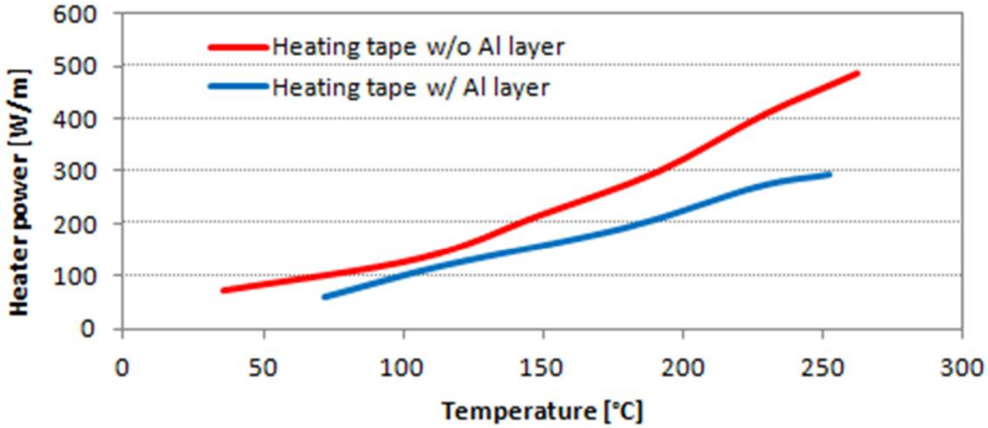


First tests!



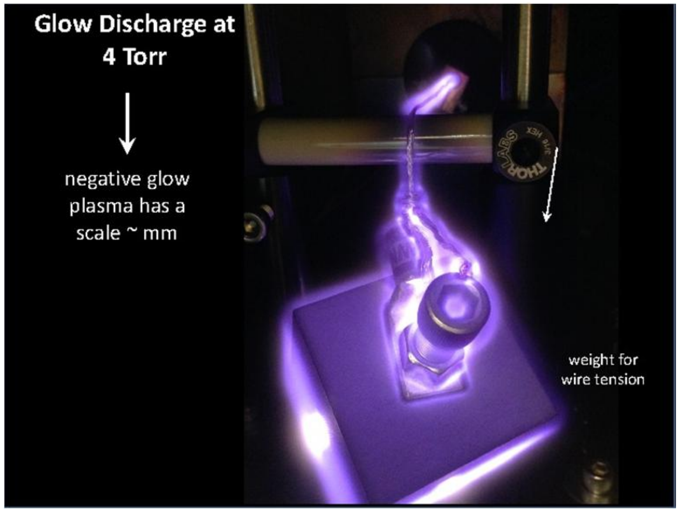
w/o Al layer

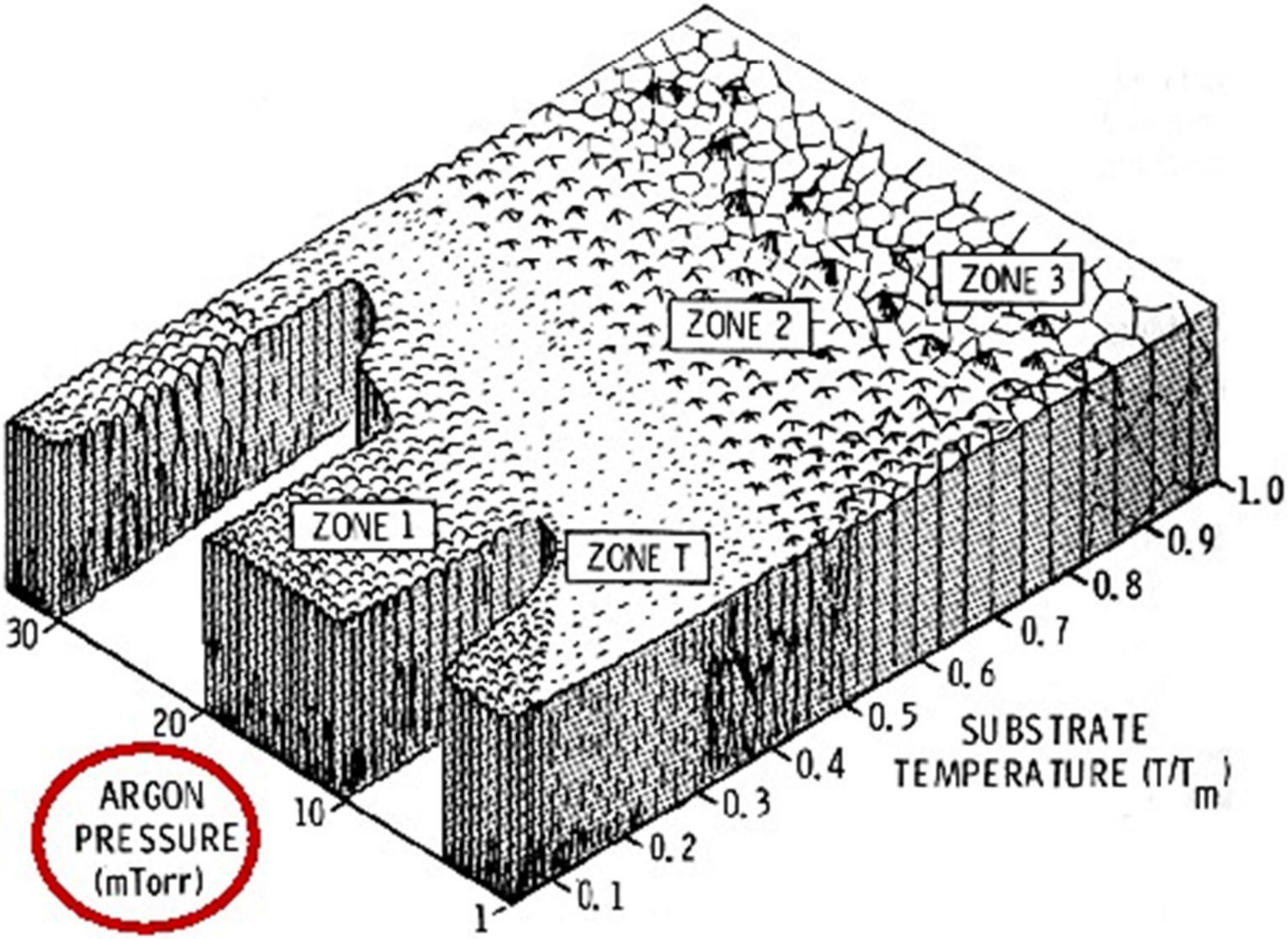
w/ Al layer



R. M. Seraphim, R. Neuenschwander LNLS

Thorton’s Structure Zone Diagram of Film Microstructure for Sputtering





Contains the effects of energetic particle bombardment, and more precisely, it should be pd

Courtesy A. Anders, LBNL

J. A. Thornton, *J. Vac. Sci. Technol.* **11** (1974) 666

Vacuum Challenges

- In-situ bake out / activation procedures:
  - Minimum gap needed between chamber and magnet poles.
  - Chamber heating methods, how to apply thin radiation resistant heat films.

- NEG Coatings:
  - Coating very narrow gap and small <10 mm chambers.
  - Surface roughness
  - Photon extraction ports:
  - Coating key hole geometry is challenging.
  - Fabrication methods compatibility with coating processes.
  - Coating development in industry. Very limited industrial capability – a possible risk.
  - NEG impedance might become a problem for very short bunches.

- Photon absorbers:
  - Compact geometry with adequate cooling and minimized radiation scattering.
  - Radiation shielding with aluminum chambers.

- Impedance: More gentle transitions, round chambers improve geometric impedance; smaller cross sections, NEG coatings challenging.

- Simulations:
  - Useful tool, may be a necessity for ray tracing and multiple mis-steering cases.

- Alignment:
  - Low vibration mounts, stable chamber and BPM position, low impedance bellows.

Injection Design Issues

1) Off-axis, with accumulation

- MAX-IV
- SIRIUS
- ESRF Upgrade (special high βx section at injection to increase inj. efficiency)
- SPring-8-II

Use of Pulsed Multipole Magnet to reduce disturbance to the stored beam:

- MAX-IV (in addition to single dipole kicker; copying BESSY design)
- SIRIUS (in addition to conventional four dipole kickers, in the same straight)
- BAPS

2) On-axis, no accumulation → "swap-out" injection

"*If you need off-axis injection, your lattice is not pushed enough* …"
(similar statements from M. Borland/B. Hettel)

- APS-U: swap-out and dump

- ALS-II: swap-out and "recycle" via additional Accumulator Ring

- single bunches (APS-U) or bunch trains (ALS-II)
(APS-U: requires 15 nC bunch for 48-bunch timing mode .. seems do-able)

- kicker technology is critical:
.. very fast rise/fall times (esp. for single bunch)
.. more relaxed for bunch trains, but limits possible fill-patterns
.. in all cases stability & reliability will be crucial

- injection transients will be inevitable at some level:
.. calculate the average brightness from the bunches
… gating/timing/post-processing might be needed

Advantages of on-axis swap-out injection:

- possibility of narrow horizontal ID gaps
  (e.g. for elliptically/variably polarized undulators)
- smaller good field regions for magnets
  i.e. more relaxed errors tolerances
- smaller injection losses

Increasing confidence in swap-out injection …

“*The more we think about it, the less scary it seems …*” (D. Robin)

But is swap-out an absolute requirement ? ..
… is off-axis injection possible at least as a fall-back ?
… or in cases of less “aggressive” dynamic aperture ?

- high βx section at injection
- share residual kick between injected beam and stored beam
- still will require a very thin septum, very close to the beam …

Might be worth thinking a bit more about.