# Overview of Magnet design issues

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The ESRF ASD

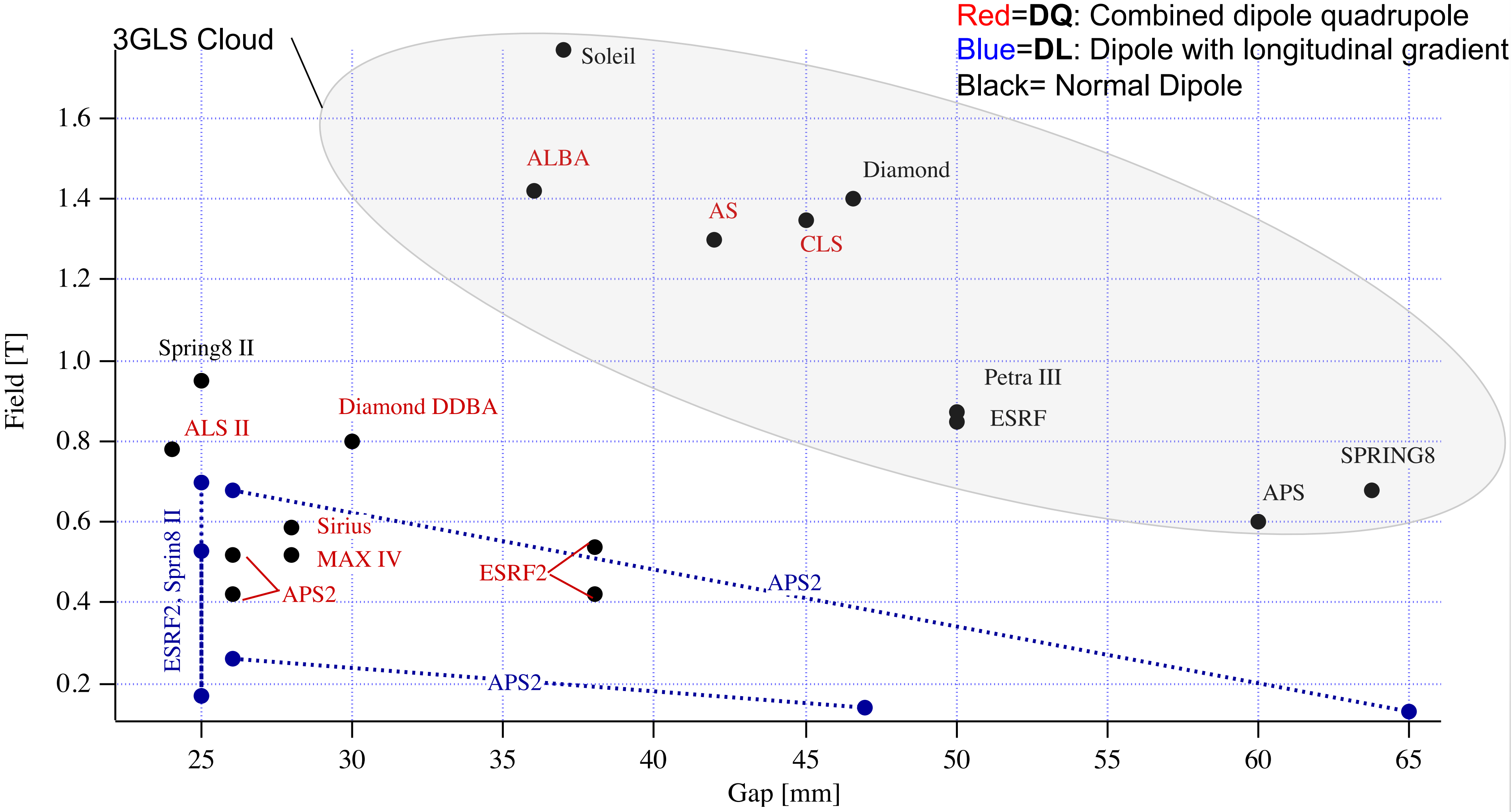
# OUTLINE

1. **Magnets in DLSRs**

2. **Magnetic design**

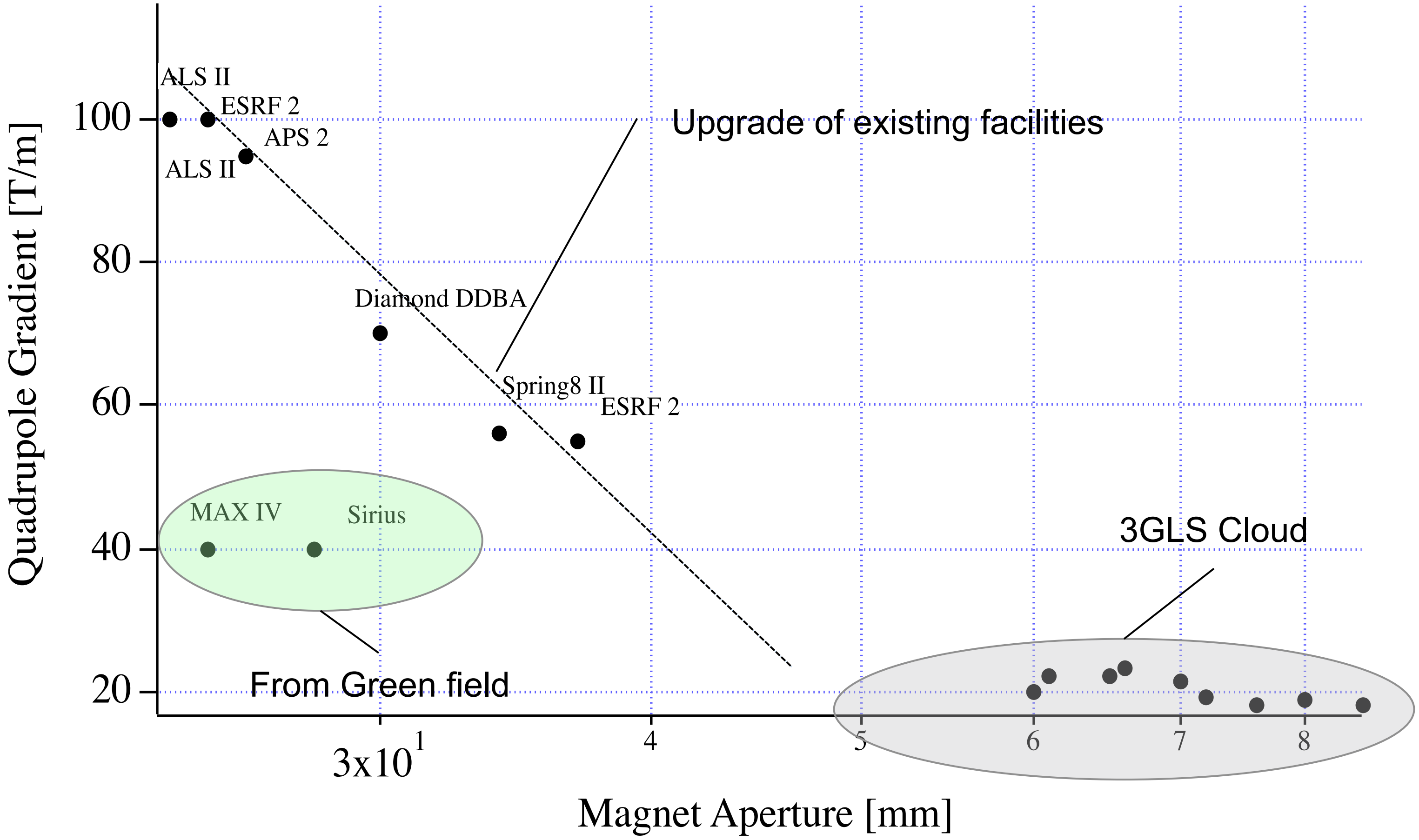
3. **Magnetic measurements/alignment**

# Bending Magnets



No more standard dipoles in DLSRs

# Quadrupole magnets



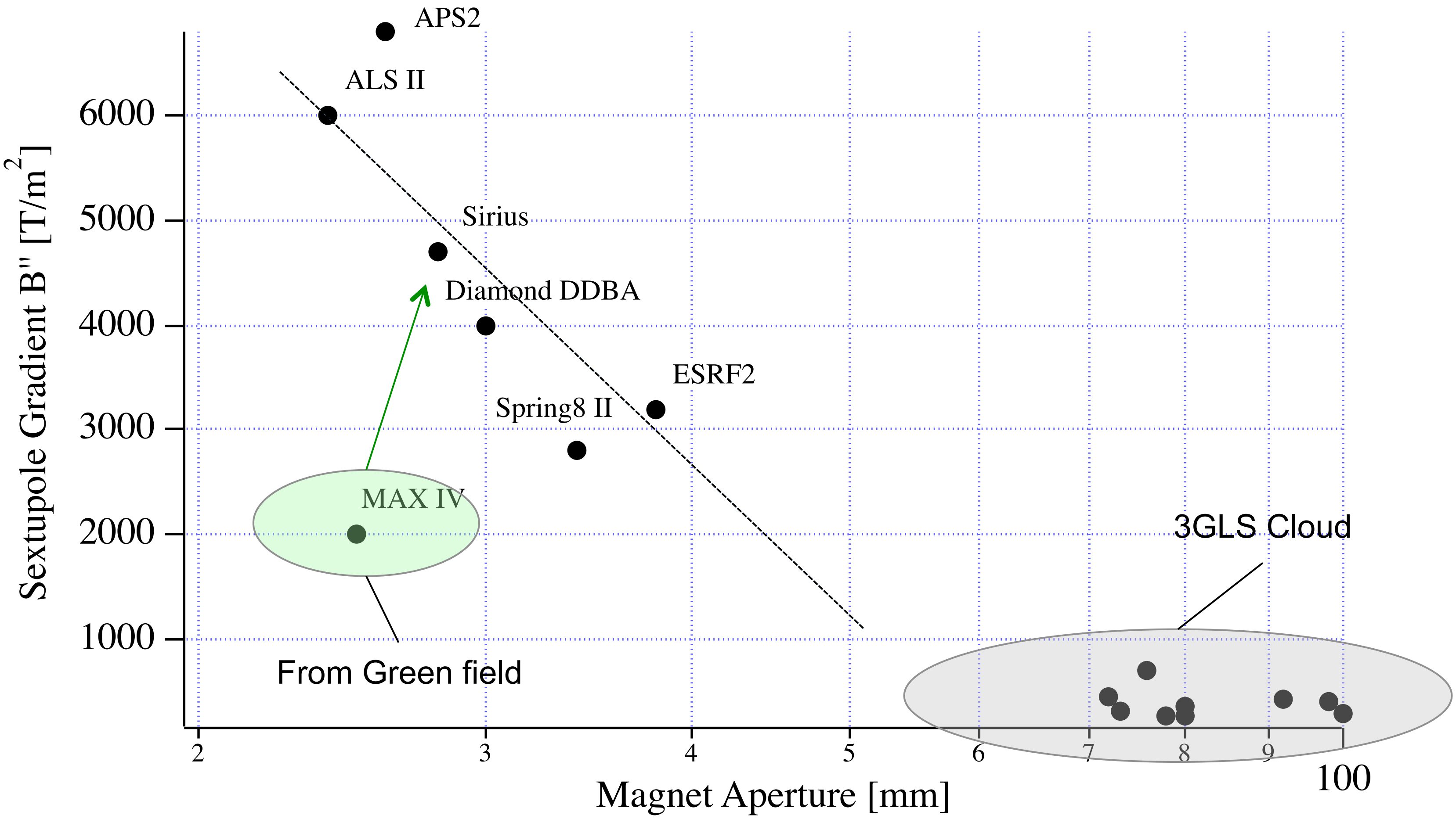
Upgrade of existing facilities

3GLS Cloud

From Green field

Quadrupole gradient primarily increased with reduction of aperture
Mostly demanding for upgrade projects ( has to cope with existing cell length)

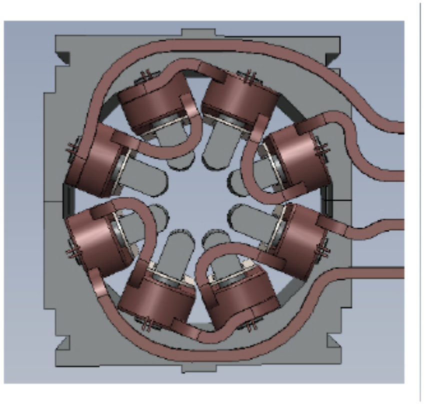
# Sextupole magnets



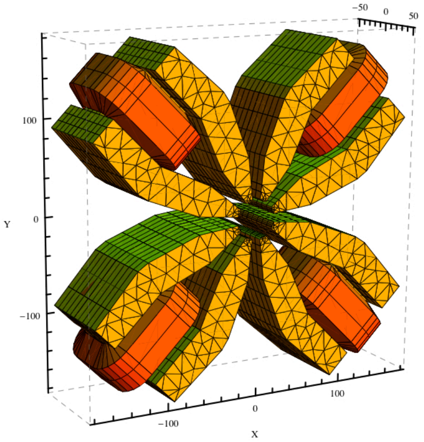
Sextupole gradient ~ same observation as for quadrupoles

# Octupoles

. Emerge as lattice components in some projects



- MAX IV:
  - 65 000 T/m$^3$
  - Bore radius 12.5 mm



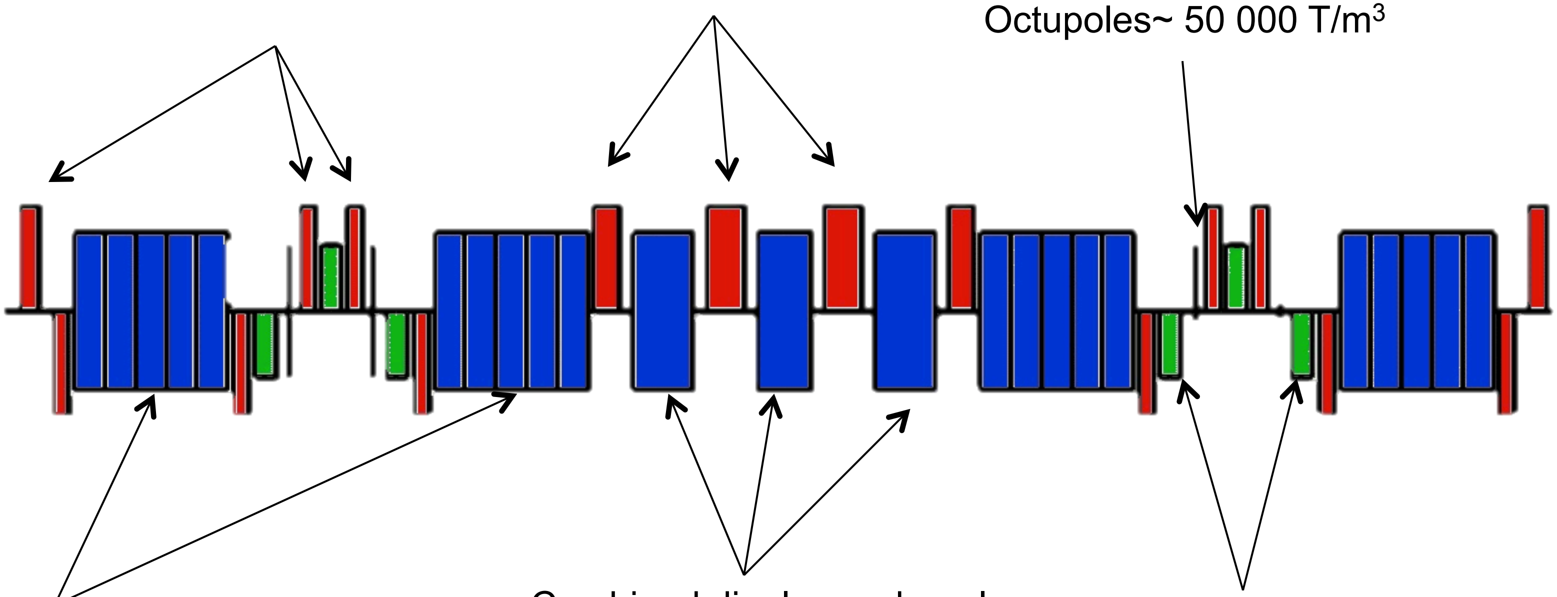
- ESRF 2
  - 50 000 T/m$^3$
  - Bore radius 20 mm
- OTHERS …..

# Few comments

1. Magnet apertures need (must) be dramatically reduced
    - Conventional magnet technology ( “a la 3GLS”)
    - Reasonable magnet size & wall plug power

2. Distinction between “ Green Field” projects and upgrade projects
    - Upgrade projects have additional constraints
        - Use exiting ring
        - Same cell length , same source points for Insertion Devices
        - Compact magnet lattice smaller integrated drift space/cell ( 9 m -> 3m @ ESRF)

# S28 Lattice @ ESRF



Quadrupole
49 to 55 $Tm^{-1}$

High gradient quadrupoles
100 $Tm^{-1}$

Octupoles~ 50 000 $T/m^3$

Dipoles with
longitudinal gradient
0.18 -> 0.53 T

Combined dipole quadrupoles
0.54 T / 34 $Tm^{-1}$
and 0.44 T / 37 $Tm^{-1}$

Sextupoles
1600 to 3200 $Tm^{-2}$

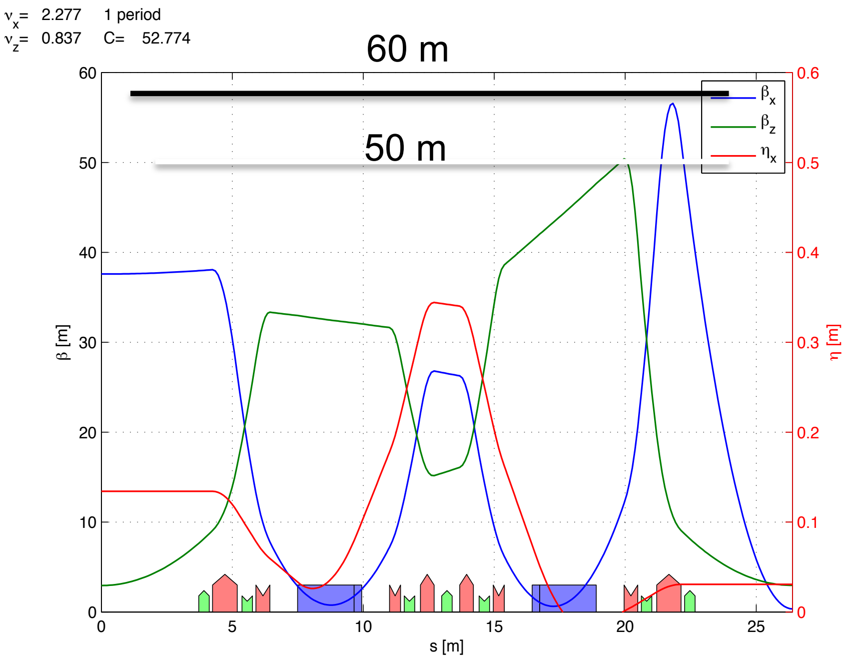
# Field Quality

**Definition of Good Field Region (GFR) is important for magnet design**

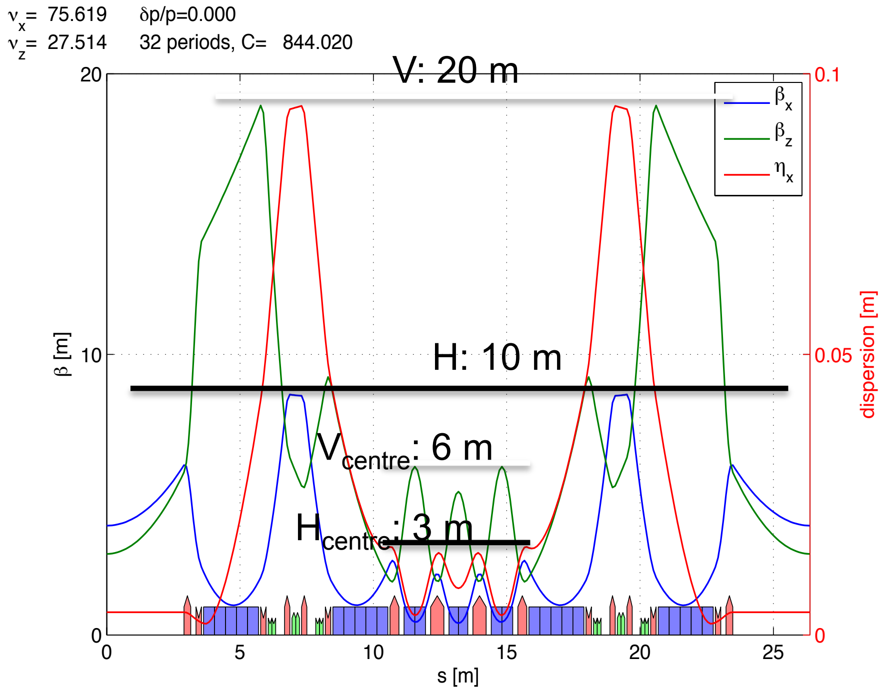
- Small magnet aperture
- GFR size mostly defined by injection requirements (efficiency)
  - Emittance in booster
  - On axis/off axis injection
- Smaller beta function in MBAs is helping in this context ->smaller GFR
- Magnets may need to include pole shaping in some cases
- Vertical gap between poles/coils for photon beam extraction
- Systematic Beam tracking analysis definitely crucial
  - Error allowance
  - Sensitivity to different multipoles
  - Relevance of optimizations …
  - etc

# Beam stay clear & GFR @ ESRF

## Beam stay clear derived from beta $^{1/2}$ scaling

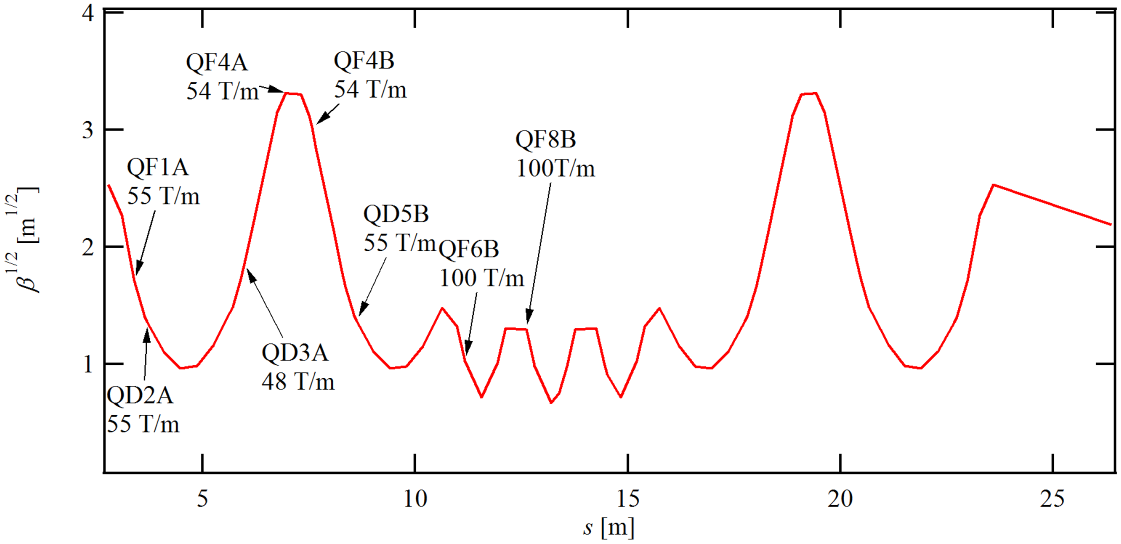


Present lattice



New 7BA Lattice

# S28 Lattice



Starting point

| Magnet | Tolerance in GFR |
|---|---|
| 2-poles | $DB/B < 10^{-4}$ |
| 4-poles | $DG/G < 10^{-3}$ |
| 6-poles | $DH/H < 10^{-2}$ |

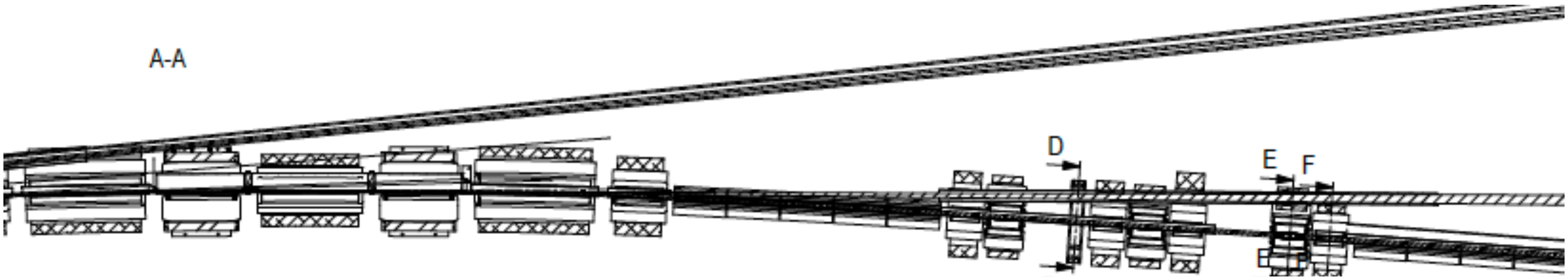
Field quality specs to be refined

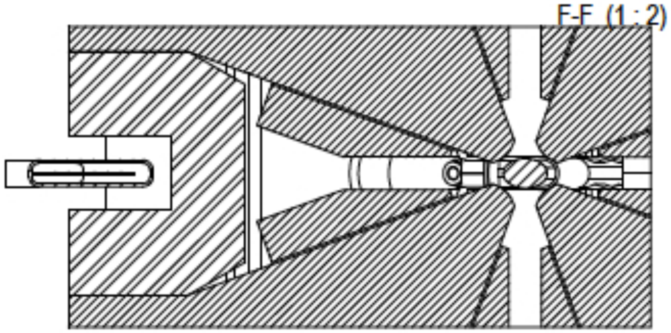
| Zone 1 | Horizontal [mm] | Vertical [mm] |
|---|---|---|
| Vacuum chamber aperture (radius) | 15 | 10 |
| Good field region (radius) | 13 | 9 |

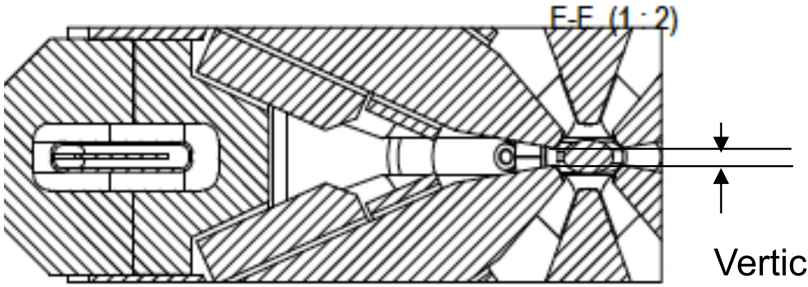
| Zone 2 (high gradient) | Horizontal [mm] | Vertical [mm] |
|---|---|---|
| Vacuum chamber aperture (radius) | 8.3 | 5.5 |
| Good field region (radius) | 7 | 5 |

# Photon beam stay clear

## Photon beam path to beamline







Vertical pole gap

Vertical pole gap important impact on magnet design

- Field strength
- field quality
- More difficult for high order multipole magnets

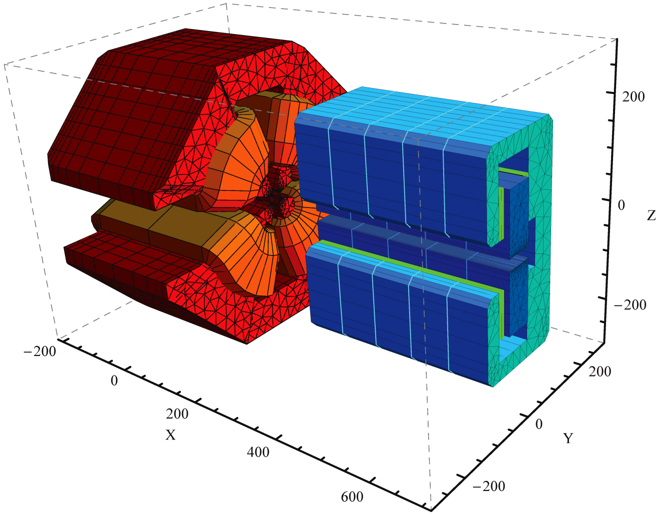
# Magnet design

## Tools

- 3D magnetic simulation & magnetic tracking in magnet (Radia)
- Optimization toolbox

## Design methods & studies

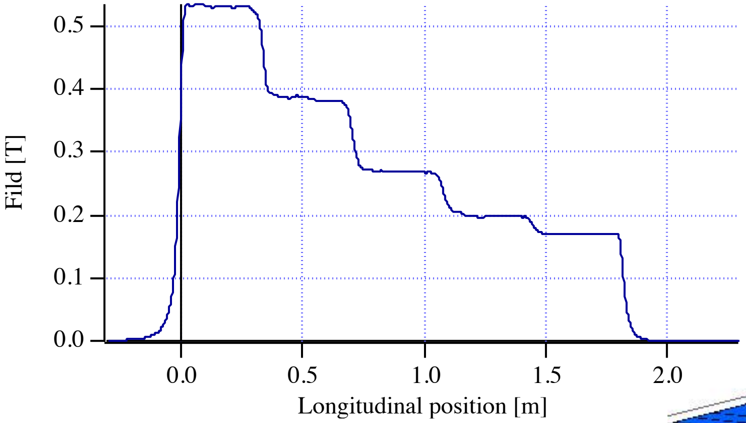
- Shape optimization (can be helpful)
- Energy efficiency
- Sensitivity analysis (small aperture)
- Interaction between magnets (compact lattice)

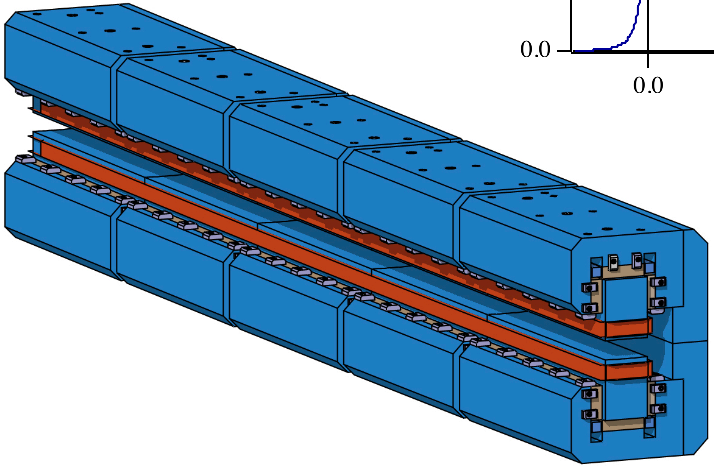


# DL magnets

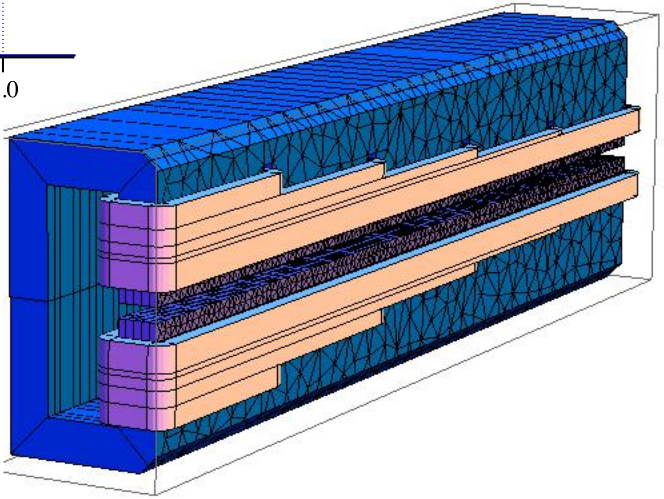
Coming on the scene for emittance reduction (ESRF2, APS 2)

- Significant L gradient: 0.5 T -> 0.15 T over ~ 2m





Example: ESRF DLS
Under study



Permanent Magnet based Dl magnet
0.53 T-0.18 T, constant gapl
Iron weight 575 kg, Pm weight 30 kg
± 2% Filed tuning with small coil

Resistive DL magnets
0.53 T – 0.18 T constant gap
1.5 kW. 1600 kg Iron +coils

# DQ magnets (1)

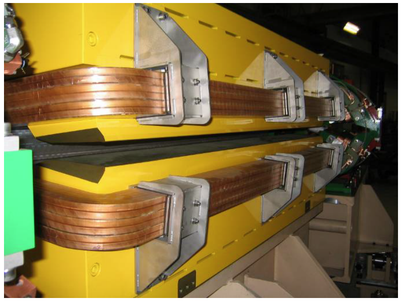
## Two families of DQs

Low to moderate gradient

| | B at beam [T] | Gradient [T/m] | Aperture [mm] |
|---|---|---|---|
| MAX IV | 0.52 | 8.6 | 28 |
| Sirius | 0.584 | 7.8 | 28 |
| Diamond DDBA | 0.8 | 14.4 | 30 |
| ESRF2 DQ1 | 0.54 | 37 | 38 |
| ESRF2 DQ2 | 0.42 | 48 | 38 |
| APS 2 | 0.5 | 38 | 26 |
| ALS II | 0.78 | 50 | 24 |

High gradient

# DQ magnets (2)

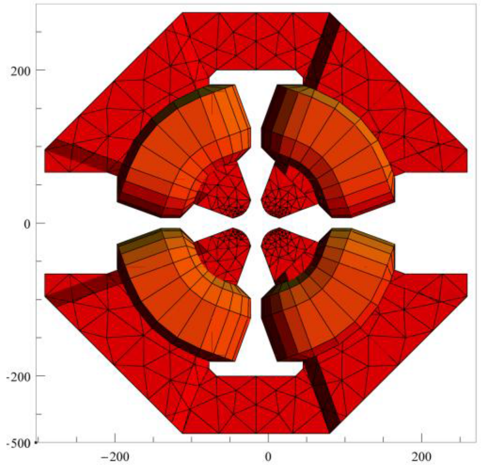


Low gradient DQs: magnet derived from modified dipole

- Pole shaping
- In use in some 3GLS facilities (ex : ALBA, AS, CLS, SPEAR 3)

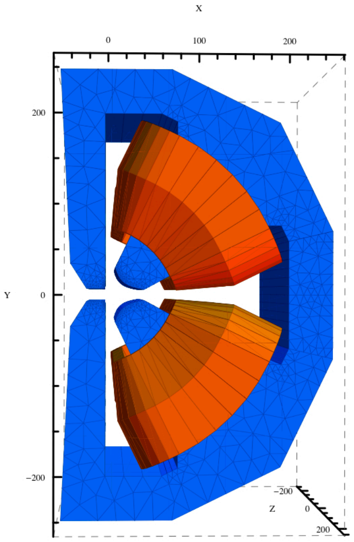
High gradient DQs: magnet derived from quadrupole

- Pole shaping may be necessary
- Different designs
- High field on beam= large offset -> difficult GFR



Quadrupole offset
ESRF DQ 0.57 T-35 T/m 38mm aperture

Or



Concept used for a septum quadrupole at Hera

Can be adapted for DQs
Easier Vacuum chamber engineering

Half quadrupole
ESRF DQ 0.57 T-35 T/m 20 mm bore radius

# Bending magnets: X-ray sources

- Many Hard X-ray users on BM beamline in present high energy facilities

- General trend in MBAs is (obviously) to reduce the BM field

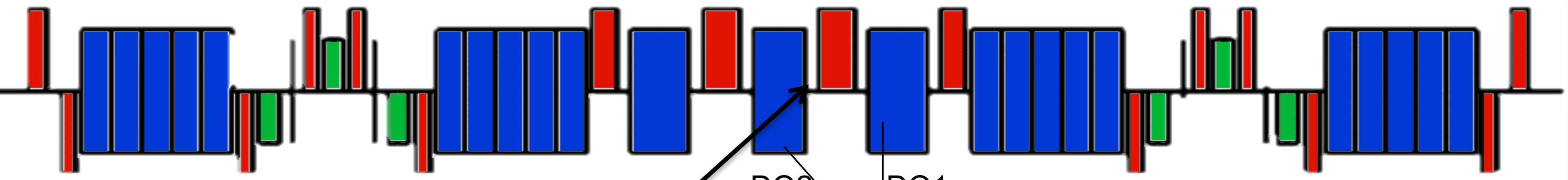
- DQs used as BM source points (ESRF, APS) with reduced field

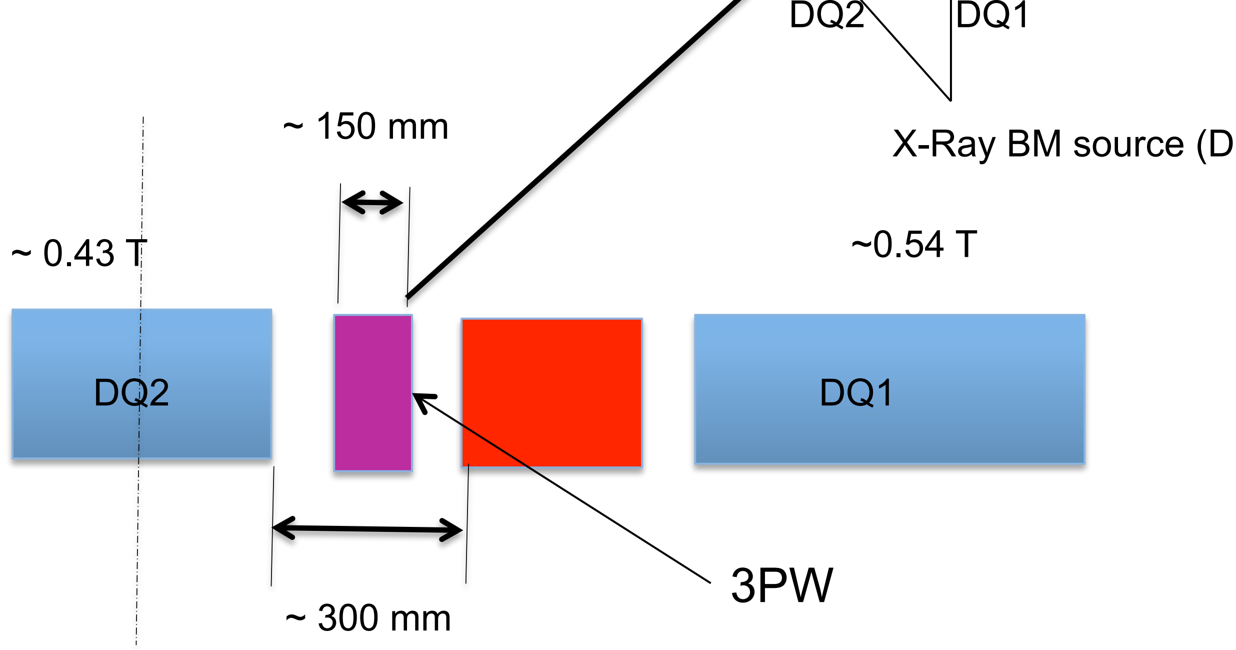
  - easier engineering
  - Lower wall plug power

- Clearly conflicting with hard X-ray demand from BM beamlines

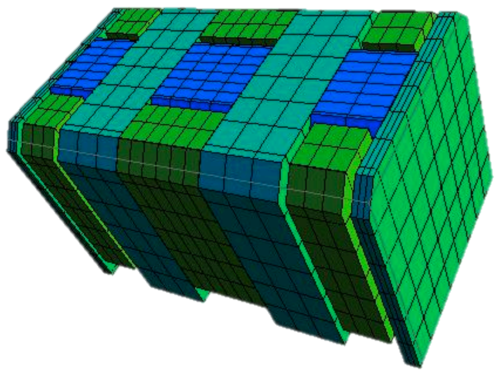
- ESRF has presently 0.85 T BM (+0.4 T short soft ends)

# Mini Wiggler insertion



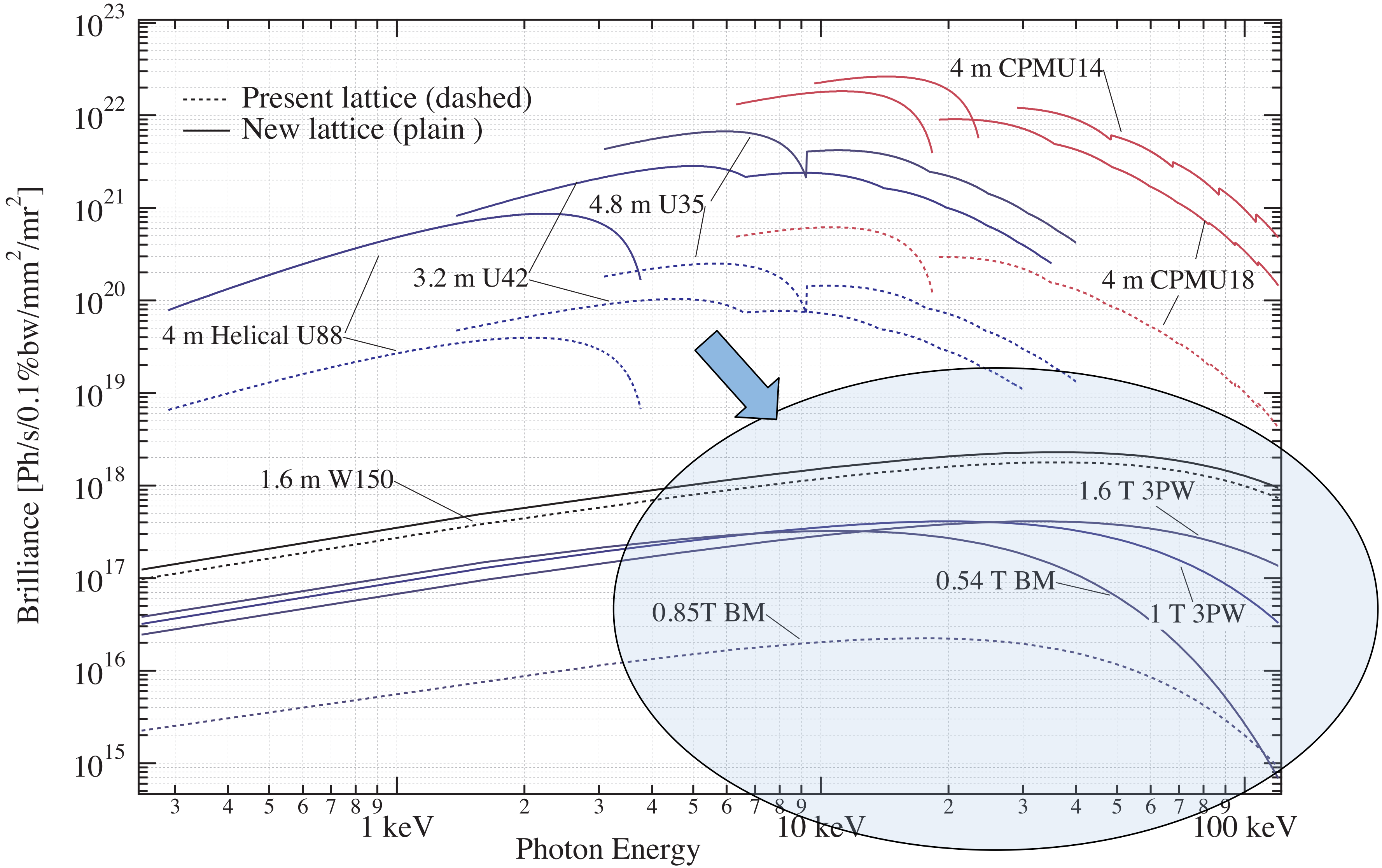


3PW magnetic structure



Mini-wiggler or 3 poles wiggler (3PW) or wavelength shifter
Beamline not anymore linked to BM field
More flexibility to BL, ( Mini Insertion Device source)

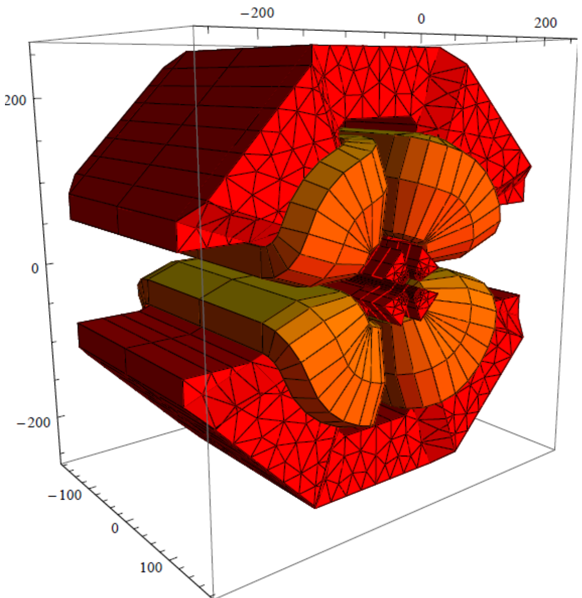
# Mini Wiggler insertion

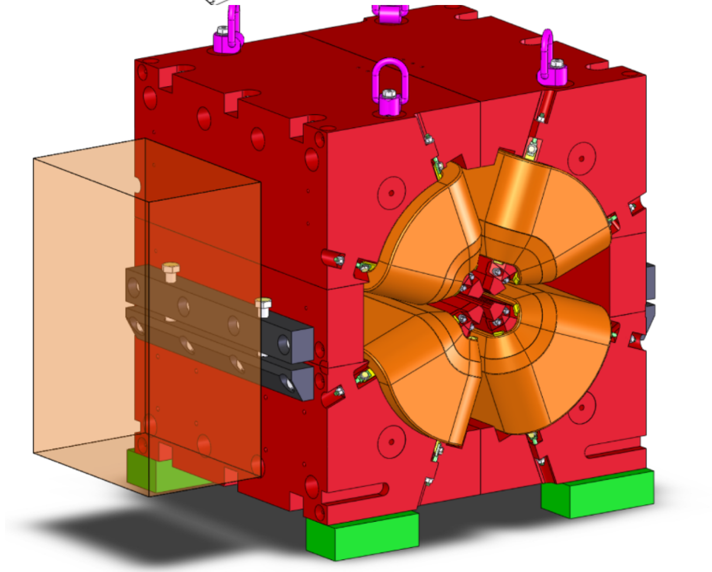


# High gradient quadrupole

## ESRF Quadrupole prototype

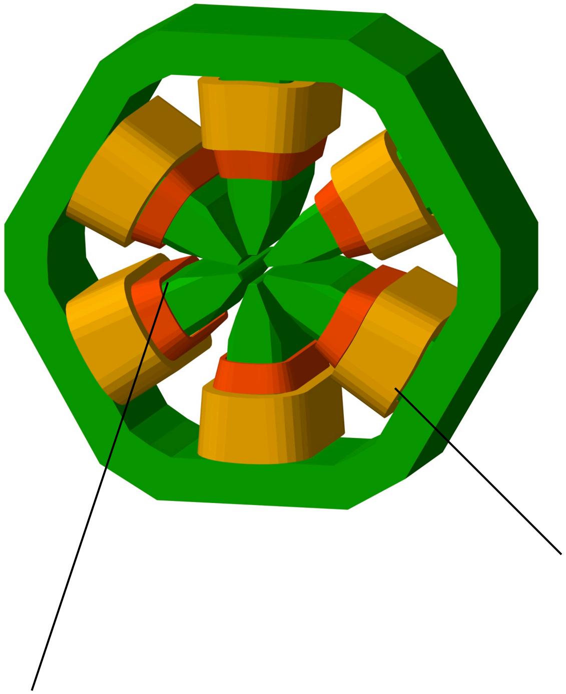
- High gradient QF8B
- 100 T/m
- 500 mm long
- Massive iron (ARMCO type)
- 12.5 mm bore radius
- 1.85 kW
- Close to saturation @ 100 T/m





**Engineering design of QF8B quadrupole prototype**

# Sextupoles



## Sextupole Parameters

- Bore radius : 19 mm
- B''=3200 T/mm$^2$ nominal, 4900 max.
- Iron Length: 200mm
- Outer diameter: 430mm
- Total length (iron+coils): 262 mm
- Power: 430 W @ nominal field
- Min. Vertical gap between poles: 10 mm
- Laminated iron (Fast Orbit Correction)

Main sextupole coil

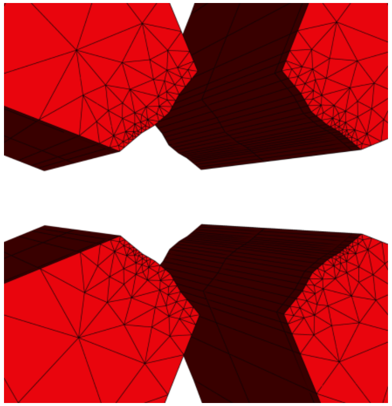
Corrector coil; Horizontal and vertical orbit correction, skew quadrupole correction

Additional version with dedicated modified yoke for photon beam stay clear (BM X-Ray source)

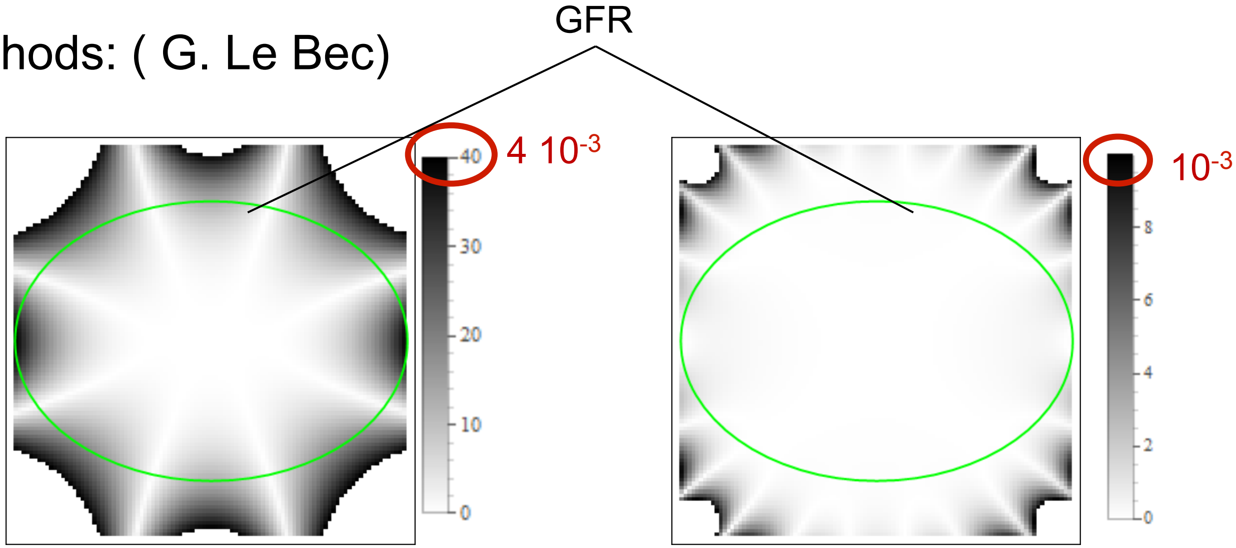
# Pole shapes

Improve field quality in GFR

Different (iterative) methods: ( G. Le Bec)



Optimized poles for high gradient quadrupole



GFR

$4\ 10^{-3}$

$10^{-3}$

Hyperbolic profile

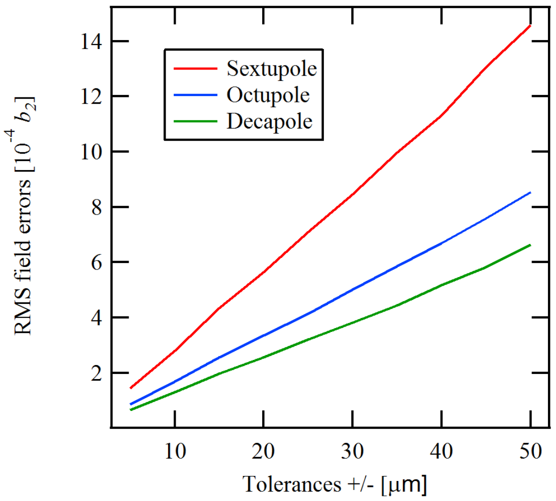
Modified profile

**Gradient error plots (D*g*/*g*)**

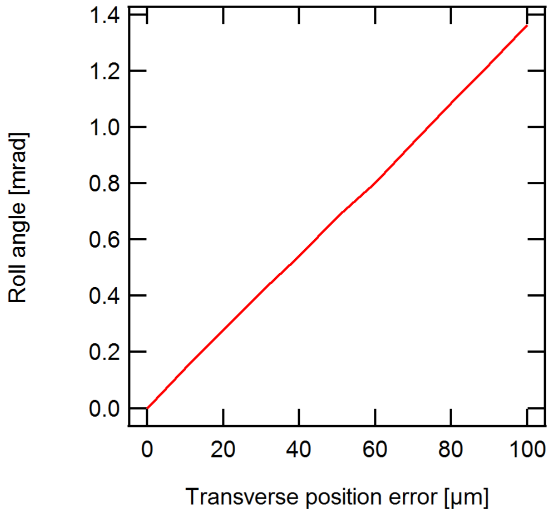
Quadrupole magnet Gradient: 100 T/m
Bore radius: 12.5 mm

# Mechanical errors

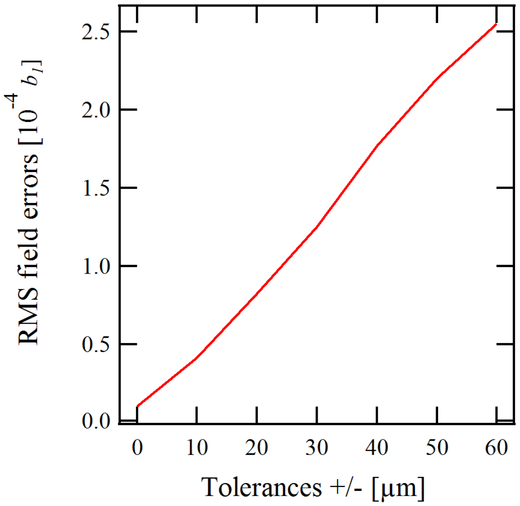
## Sensitivity to random mechanical errors



**Mechanical tolerances. (Quadrupole, 100 T/m, 12.5 mm bore radius, at $r_0$=7 mm.)**



**Transverse misalignment. (Quadrupole, 100 T/m, 12.5 mm bore radius, at $r_0$=7 mm.)**



**Mechanical tolerances. (Dipole, 0.5T, 25 mm gap.)**

# Magnetic Measurements/ alignment

## 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

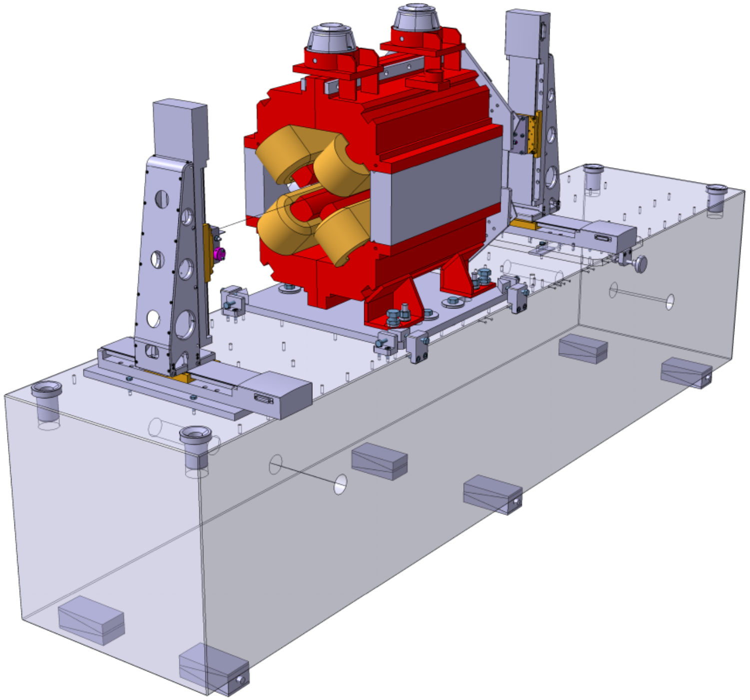
Expect outcomes very soon

MAX IV open girder

# Magnetic Measurements/ alignment

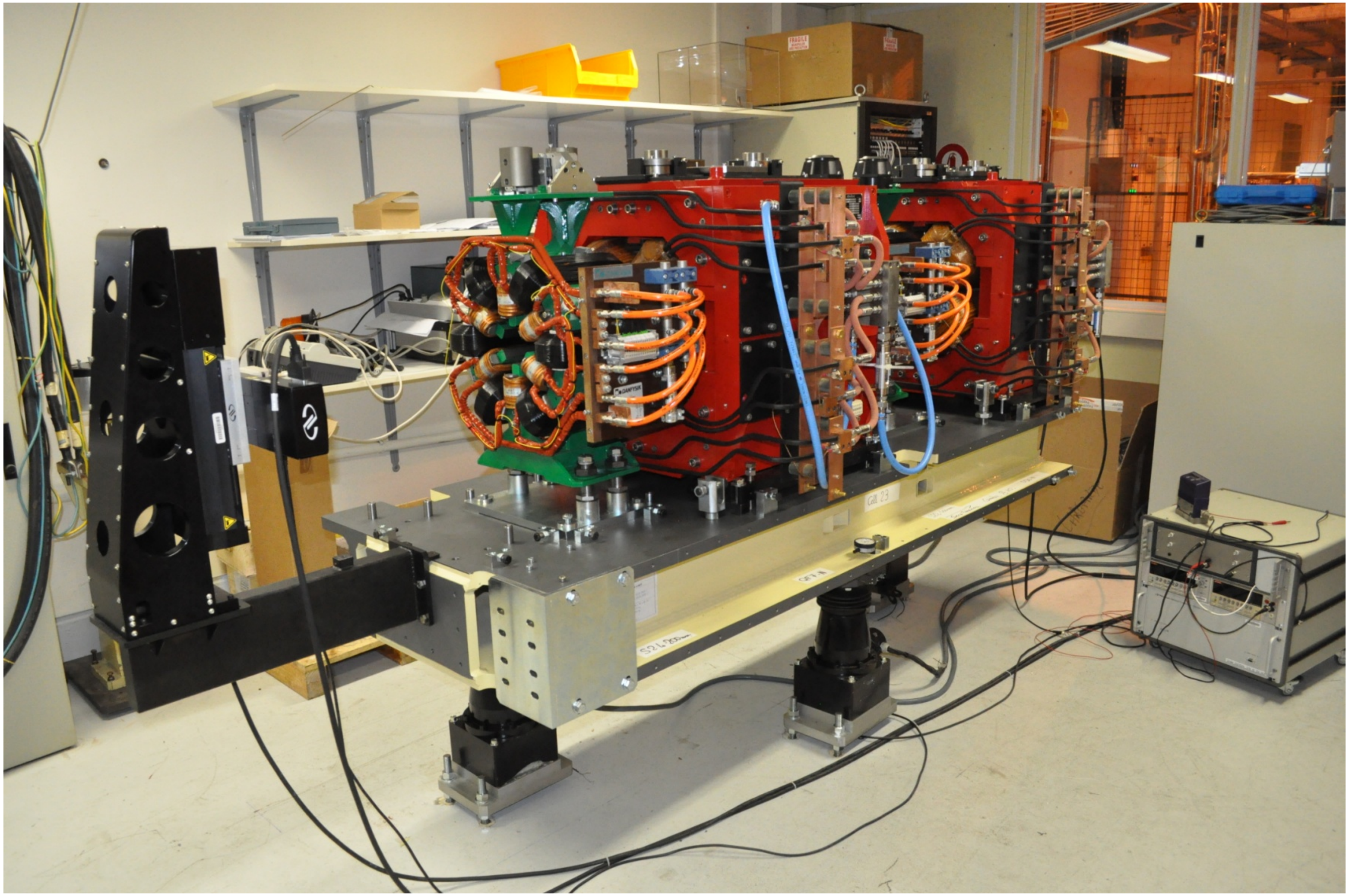
## 2- Individual magnet approach

- 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**

# Magnet alignment on girder



**G10 girder (cell30) equipped with the *in situ* measurement bench.**

# Magnetic measurements

## Alignment approaches (G. Le Bec)

### *In situ alignment*

- All the magnets are aligned on a wire

$$\sigma \approx 20\ \mu\text{m}$$

- Transfer to the survey monuments

$$\sigma \approx 50\ \mu\text{m}$$

### *Classical alignment*

- Magnets are measured in lab
- Survey monuments are adjusted

$$\sigma \approx 50\ \mu\text{m}$$

- The magnets are aligned using the survey monuments

$$\sigma > 50\ \mu\text{m}$$

- Similar results with precise spacers

**Better alignment with the *in situ* method**

- Alignment errors driven by the magnet position adjustment
- Will be mandatory for the future lattice high gradient magnets

# Summary

## 1 Magnet Design

- **Aggressive quadrupoles & sextupoles in DLSRs**

    - Small magnet aperture
    - Field quality seems reachable
    - Quadrupoles~ close to saturation, still some margin on sextupoles
    - Vertical pole gap can be a limiting factor for field quality
    - Required mechanical tolerances may be difficult to reach (cost)

- **New types of Bending Magnets**

    - DLs
        - Feasible without doubt
    - High gradient DQs
        - X-ray source points for BM beamlines
        - Trade off between high gradient & high field

- **Prototyping will be essential**
- **No show stopper for the time being**

# Summary (2)

## 2 Magnetic measurements/alignments

- Recent R&D in magnetic measurements definitely helpful
    - Stretched wire
    - Vibrating wire
- Further work needed for curved magnets
- Alignment
    - Rely on machining tolerance (Max IV)
    - In situ alignment on girder using wire