MAX IV 1.5 GeV Storage Ring

Lattice Design and Magnet Requirements

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MAX IV 1.5 GeV Ring Magnet Review Meeting, April 24, 2012

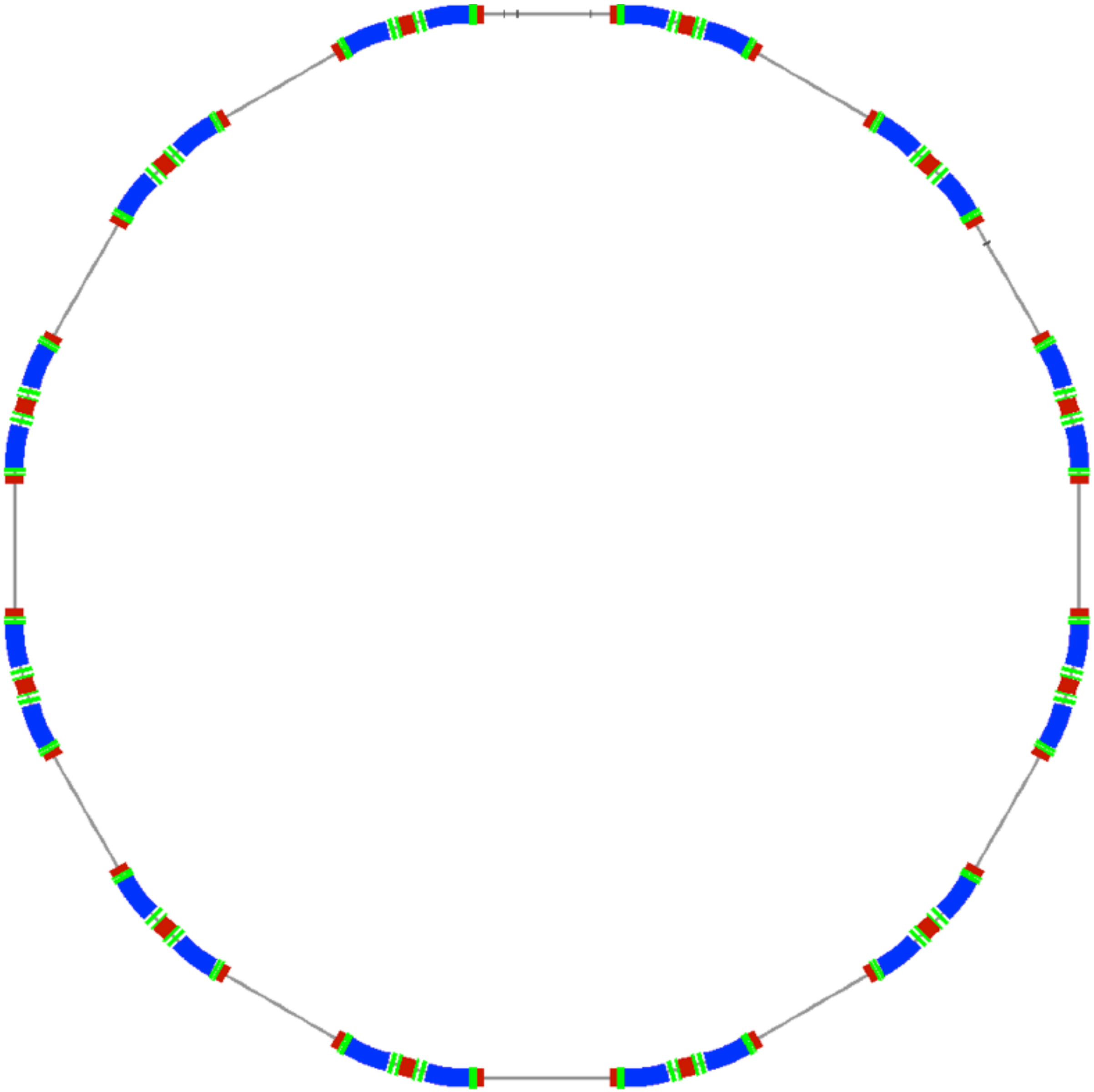
Outline

- Lattice & optics, key parameters
- Benchmarks & performance
- Derived requirements

- References:
  - DDR Chapter 3: “MAX IV 1.5 GeV Storage Ring”
    http://www.maxlab.lu.se/maxlab/max4/DDR_public
  - MAX-lab Internal Note 20120313: “Updates to the MAX IV 1.5 GeV Storage Ring Lattice”
    http://www.maxlab.lu.se/maxlab/max4/max_iv_reports_public
  - Lattice m5-20120313-521-bare.lat & m5-20120313-523-bare.lat
    http://www.maxlab.lu.se/maxlab/max4/max_iv_reports_public

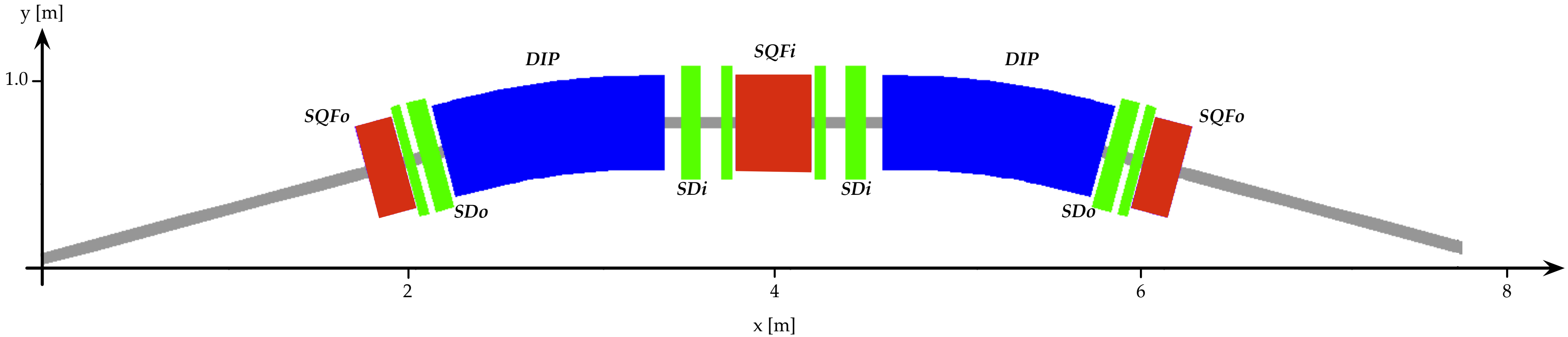
Lattice & Optics

- 1.5 GeV
- 12-fold DBA lattice
- 96 m circumference
- 12 × 3.5 m straights
- 10 straights for ID’s
- ε_0 = 5.982 nm rad

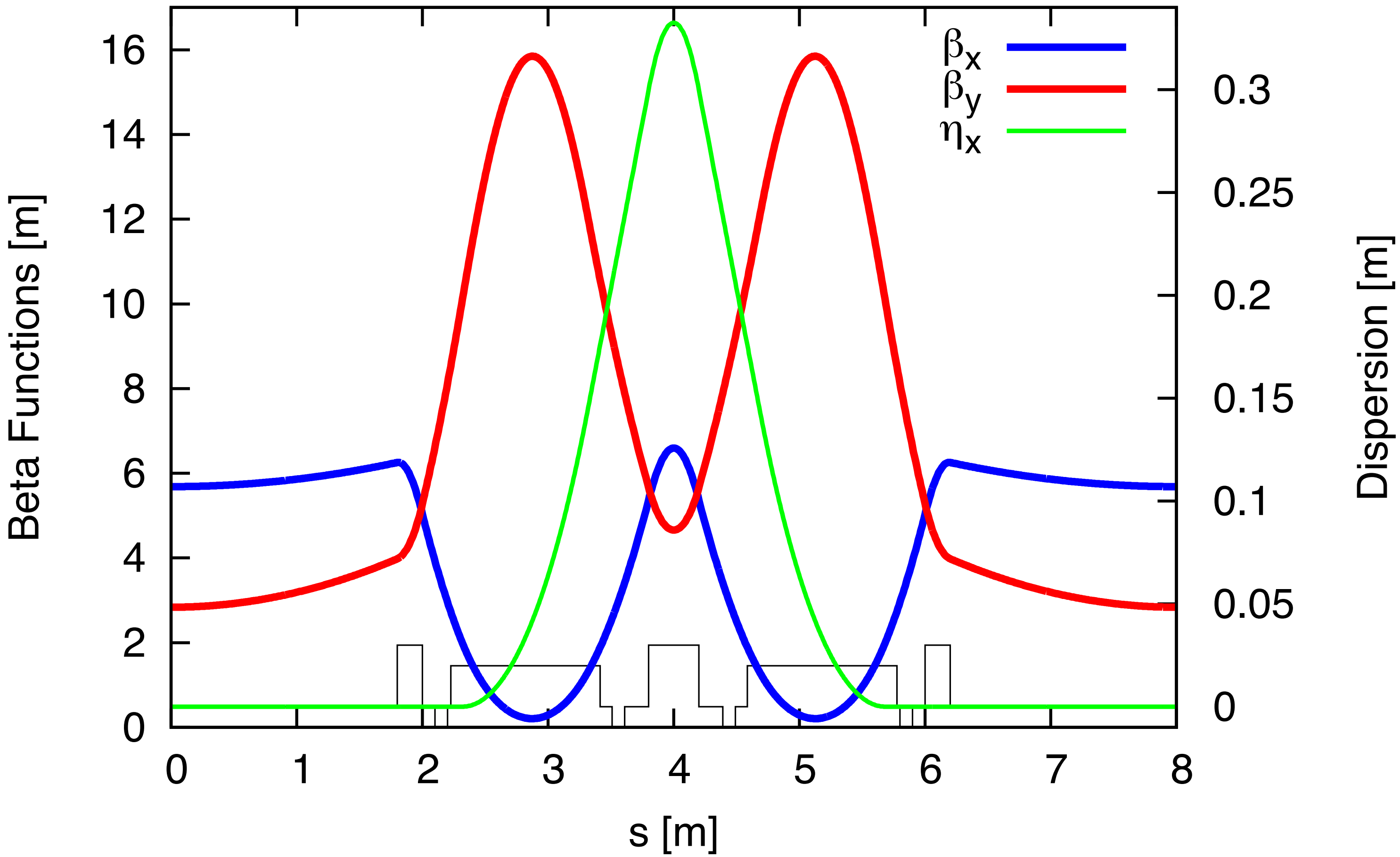


Lattice & Optics

- **Each DBA manufactured as one block → single "girder"**
- **DBA is mirror-symmetric around center**
- **DBA contains:**
  - 2 × 15º sector bends (28 slices in model) with defocusing gradient
  - 3 × focusing quads (3/4 slices in model) with focusing sextupole gradient
  - 4 × defocusing sextupoles (2 chromatic, 2 harmonic)
  - 4 × correction sextupoles (also used as dipole correctors)



Lattice & Optics

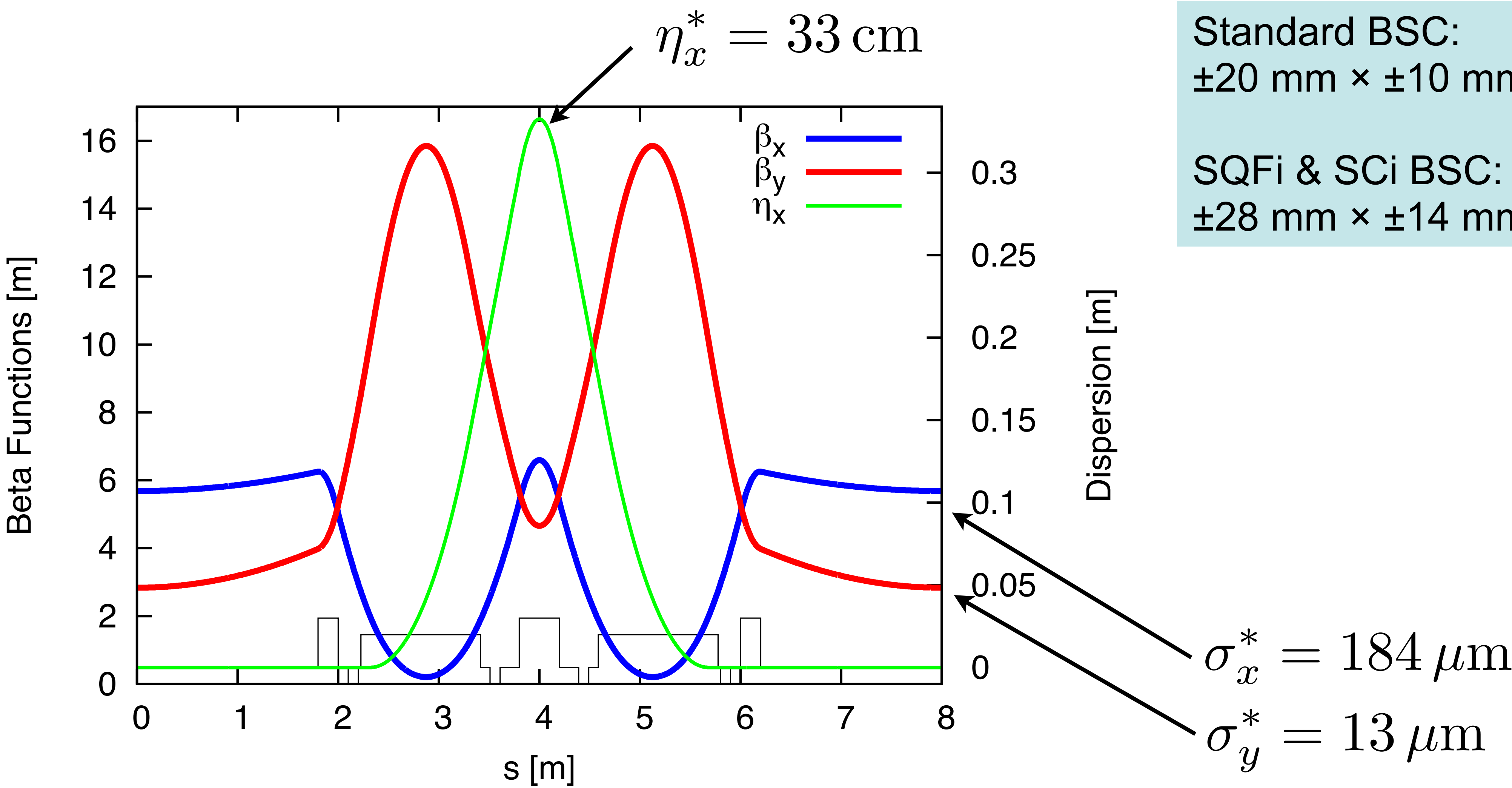


$$\varepsilon_0 = 5.982\,\mathrm{nm\,rad}$$

$$\nu_x = 11.22$$
$$\nu_y = 3.15$$

$$\xi_x = -22.964$$
$$\xi_y = -17.154$$

Lattice & Optics



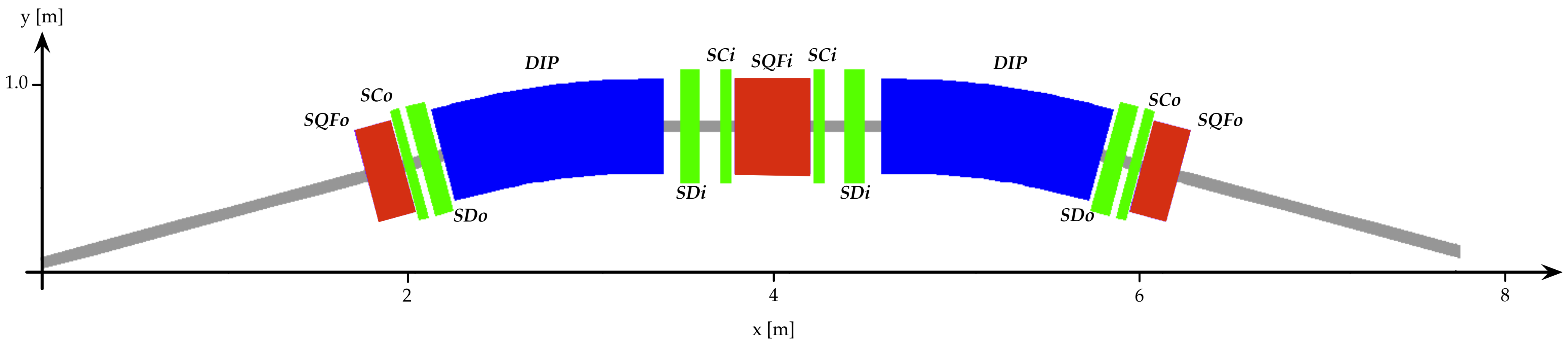
Standard BSC:
±20 mm × ±10 mm

SQFi & SCi BSC:
±28 mm × ±14 mm

Lattice & Optics

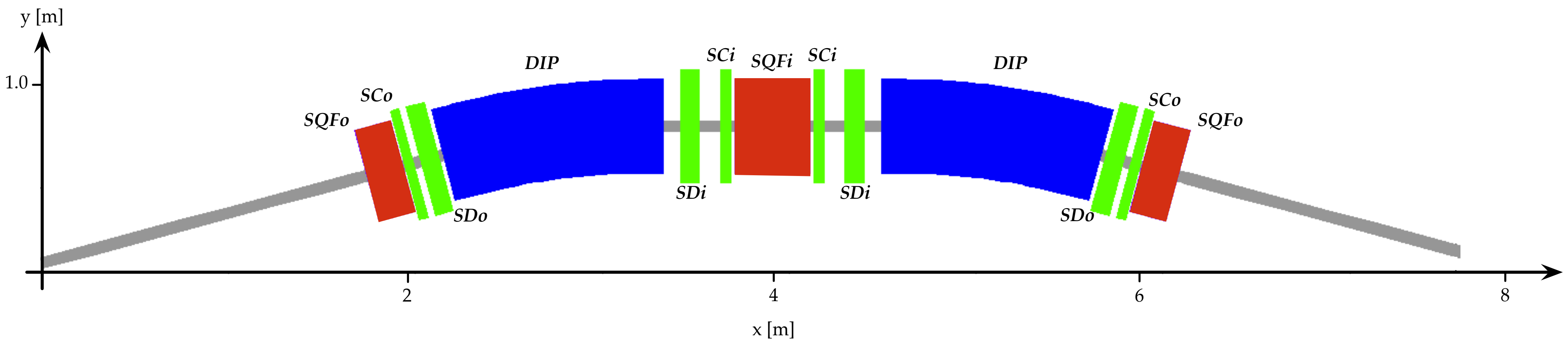
- **Dedicated sextupoles and sextupole gradients in quads:**
  - SQFi, SDi: chromatic sextupoles to correct neg. natural chromaticity to +2
  - SQFo, SDo: harmonic sextupoles for nonlinear optics optimization

- **Beyond nonlinear optics “in iron” (521):**
  - SCi adjusts focusing sextupole component in SQFi
  - SCo adjusts focusing sextupole component in SQFo
  - 523 nonlinear optics uses SCi/o (and SDi/o) to adjust chromaticity to +1



Lattice & Optics

- **Other corrections:**
  - Dipole gradient correction: pole-face strips in dipoles
  - Dipole correctors: pair (H/V) of secondary windings on SQFo & SCi
  - Skew quads & aux. sextupoles: secondary windings on SQFi/o, SDi/o, SCi/o
    (the same winding can be used as either upright quad [BBC], skew quad, or aux. sextupole depending on how it's powered)



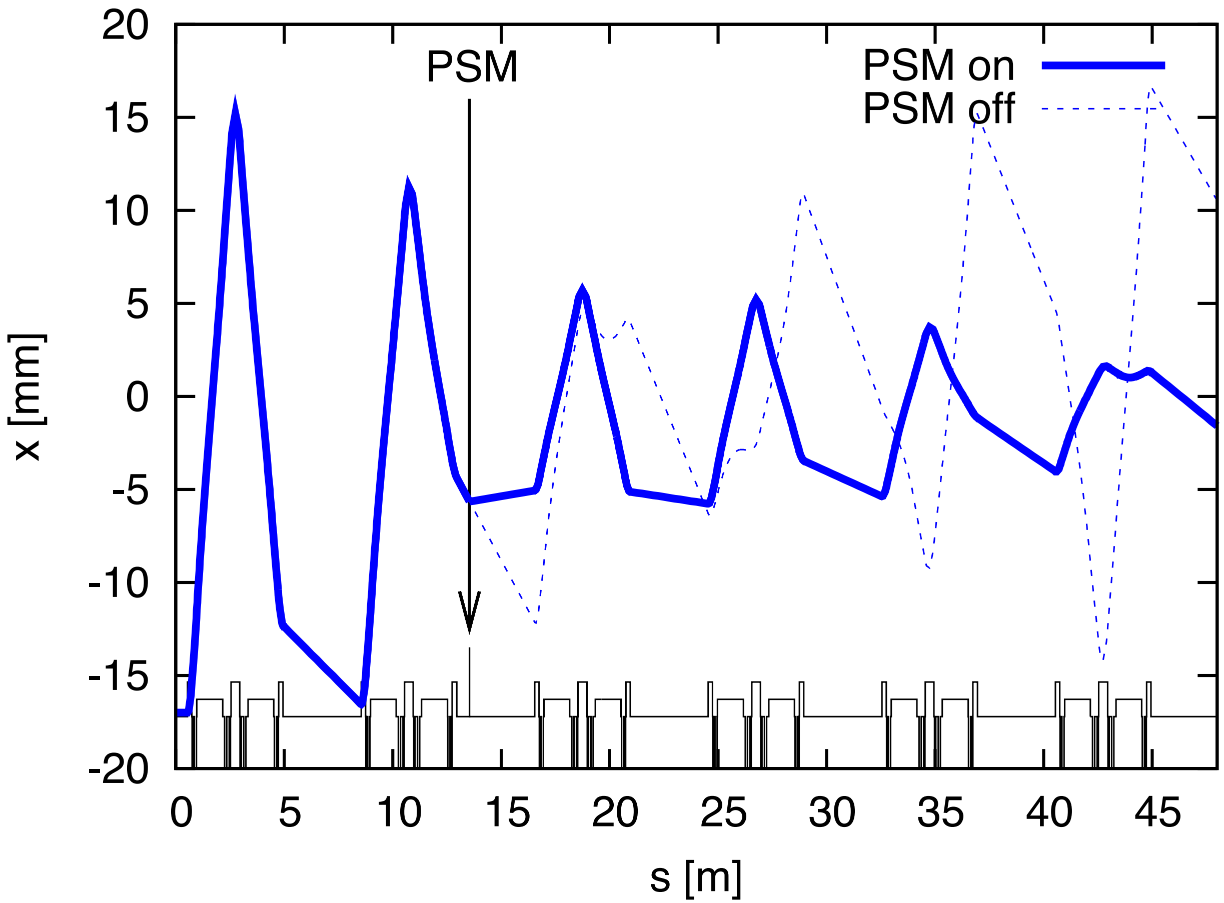
Benchmarks & Performance

- **Beam dynamics requirements:**
  - Sufficient DA for injection (H) and lifetime (coupling, V)
  - Sufficient MA for lifetime

- **Targets:**
  - Roughly 100% capture efficiency with both injection schemes (PSM and KI)
  - Roughly 10 h overall lifetime @ 500 mA
    - ➡ translates to roughly 21 h Touschek lifetime
    - ➡ translates to MA >3.5% (if LC's tuned in to stretch bunches to 60 mm)

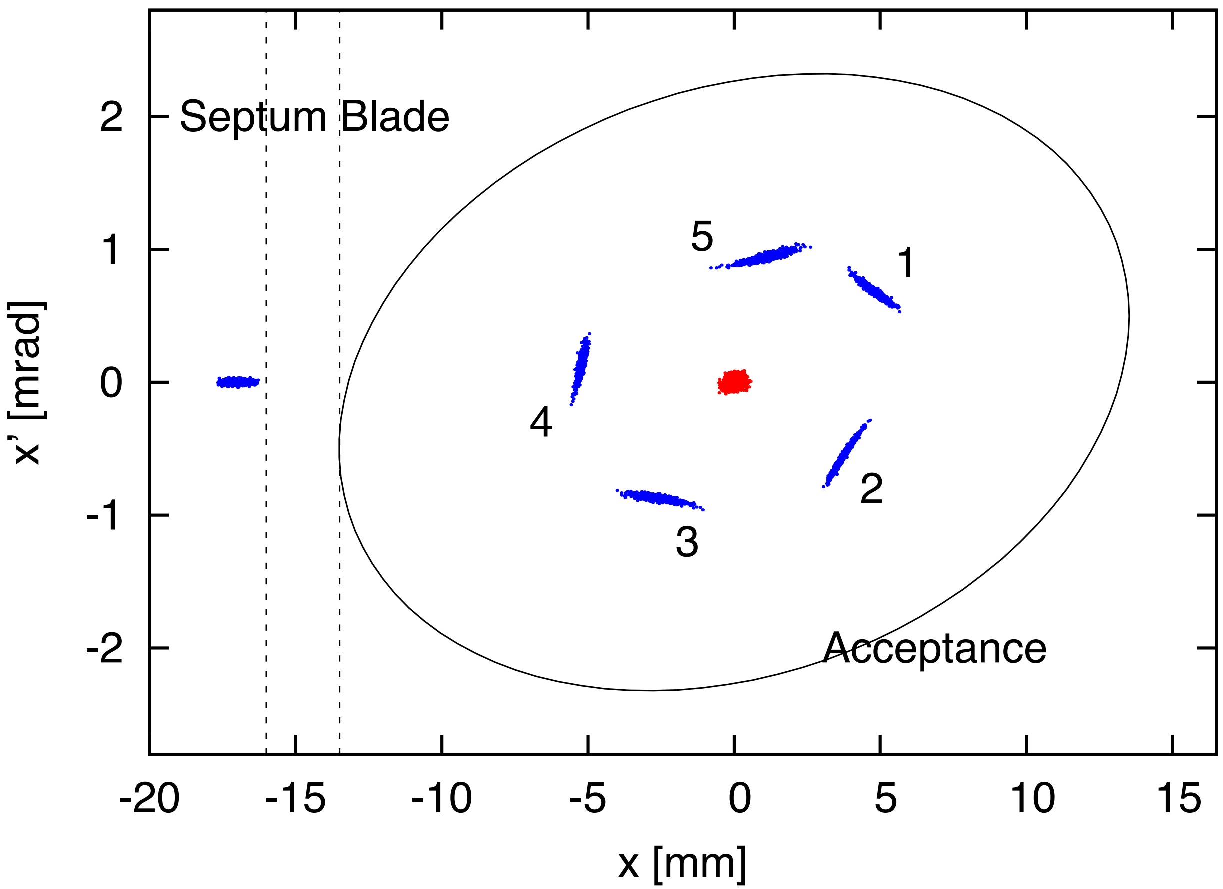
Benchmarks & Performance

- **Illustration: PSM injection process (1)**



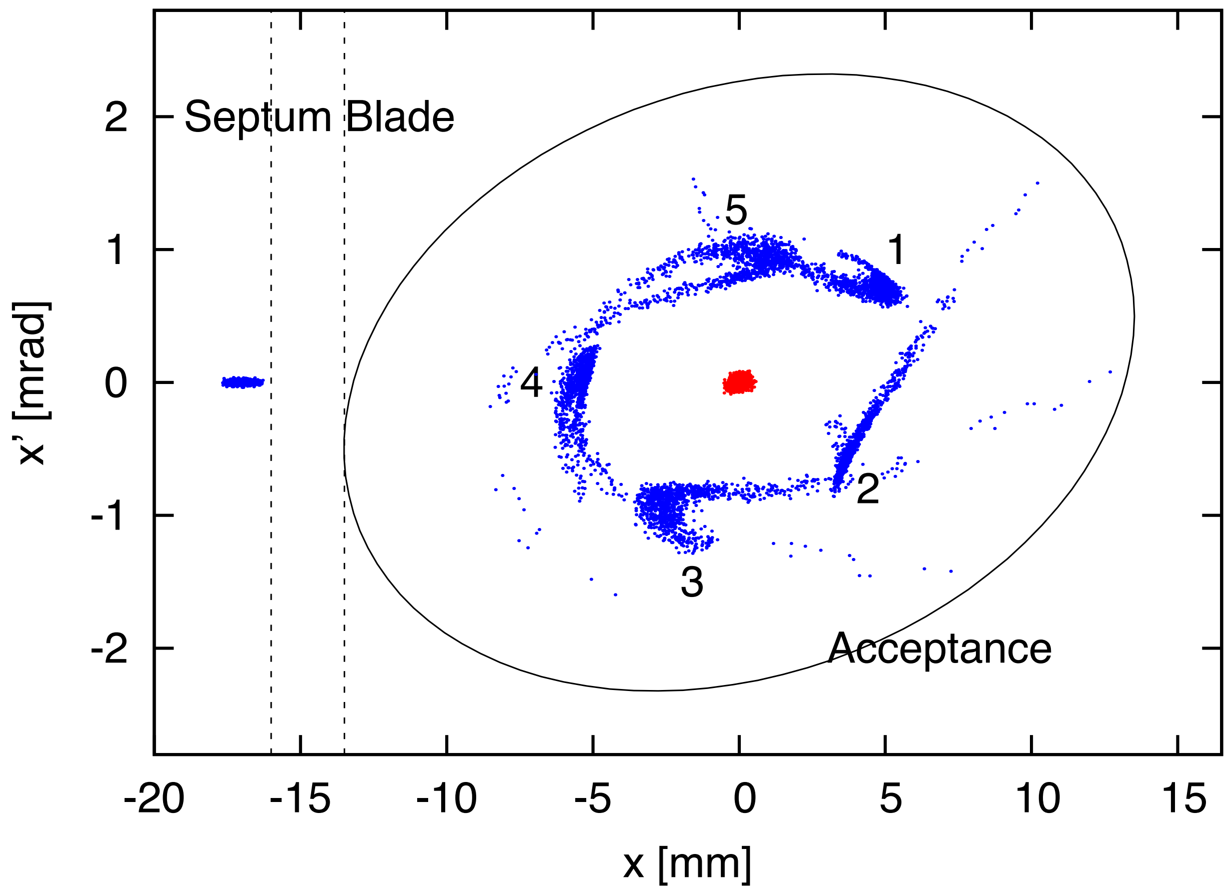
Benchmarks & Performance

- **Illustration: PSM injection process (2)**



Benchmarks & Performance

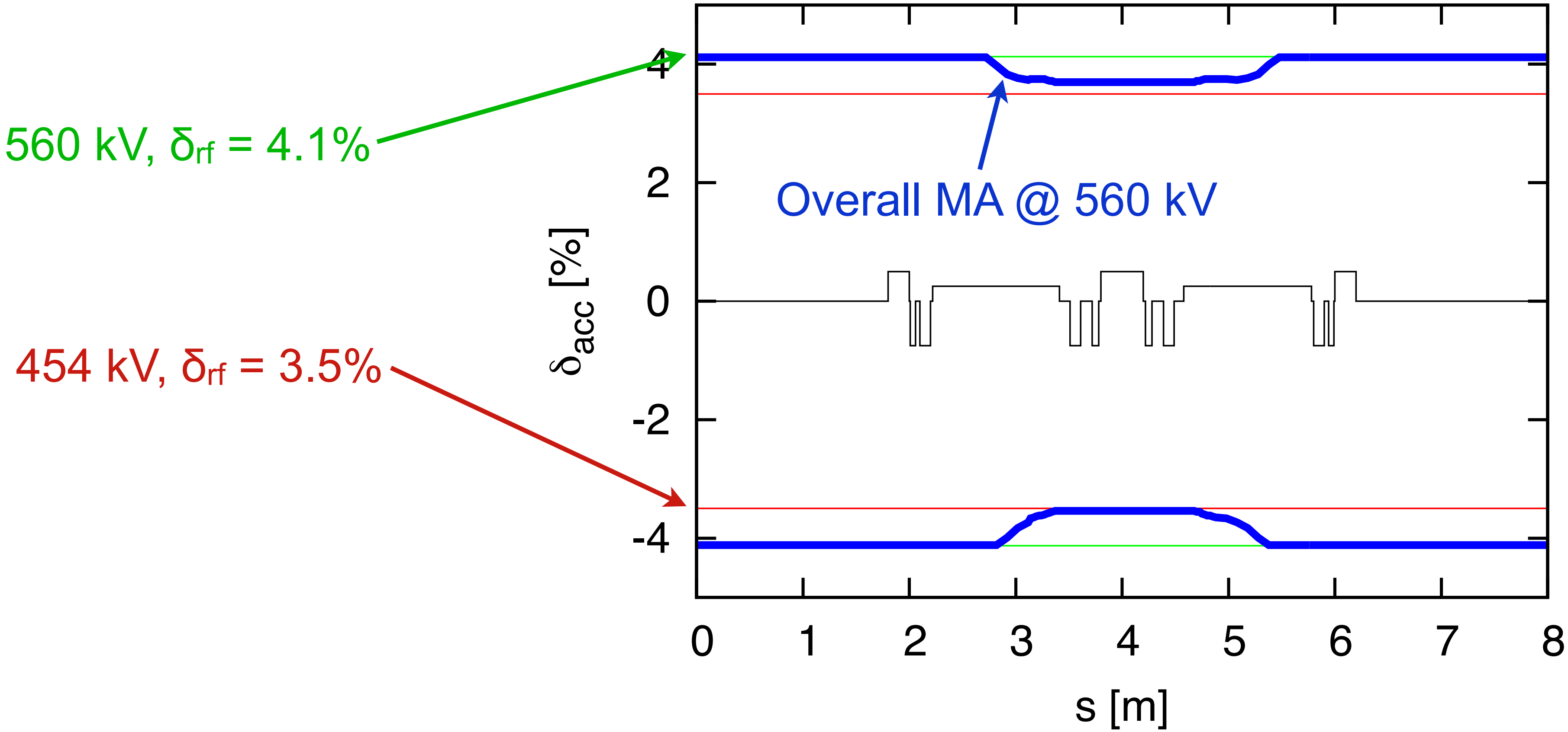
- **Illustration: PSM injection process (3)**



Benchmarks & Performance

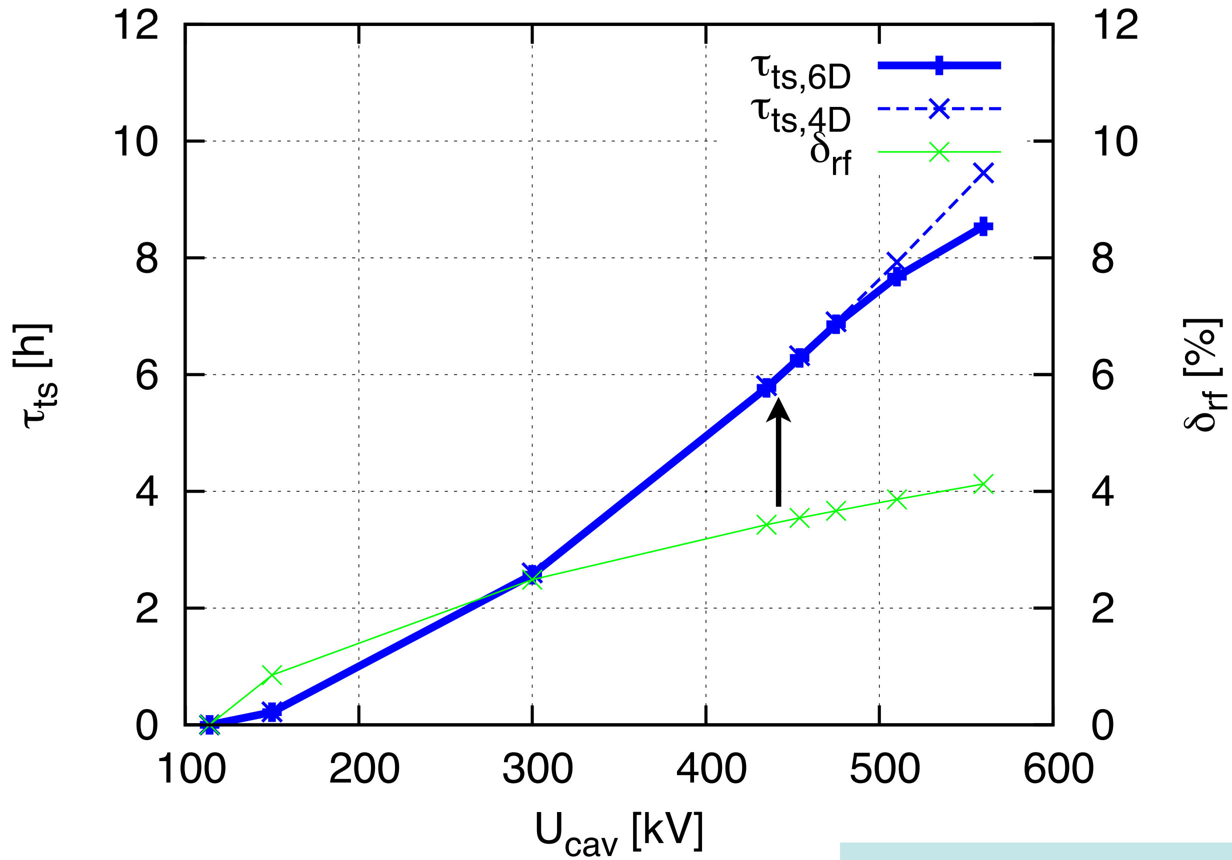
• Illustration: momentum acceptance (1)

- 500 mA → 5 nC/bunch, IBS included (minute effect at 1% coupling)
- 2×280 kV max. main cavities → RF acceptance
- Design apertures (20×10, 28×14, septum included) → lattice acceptance



Benchmarks & Performance

- **Illustration: momentum acceptance (2)**



3.5% → ~ 6 h → ~ 22 h with LCs

Benchmarks & Performance

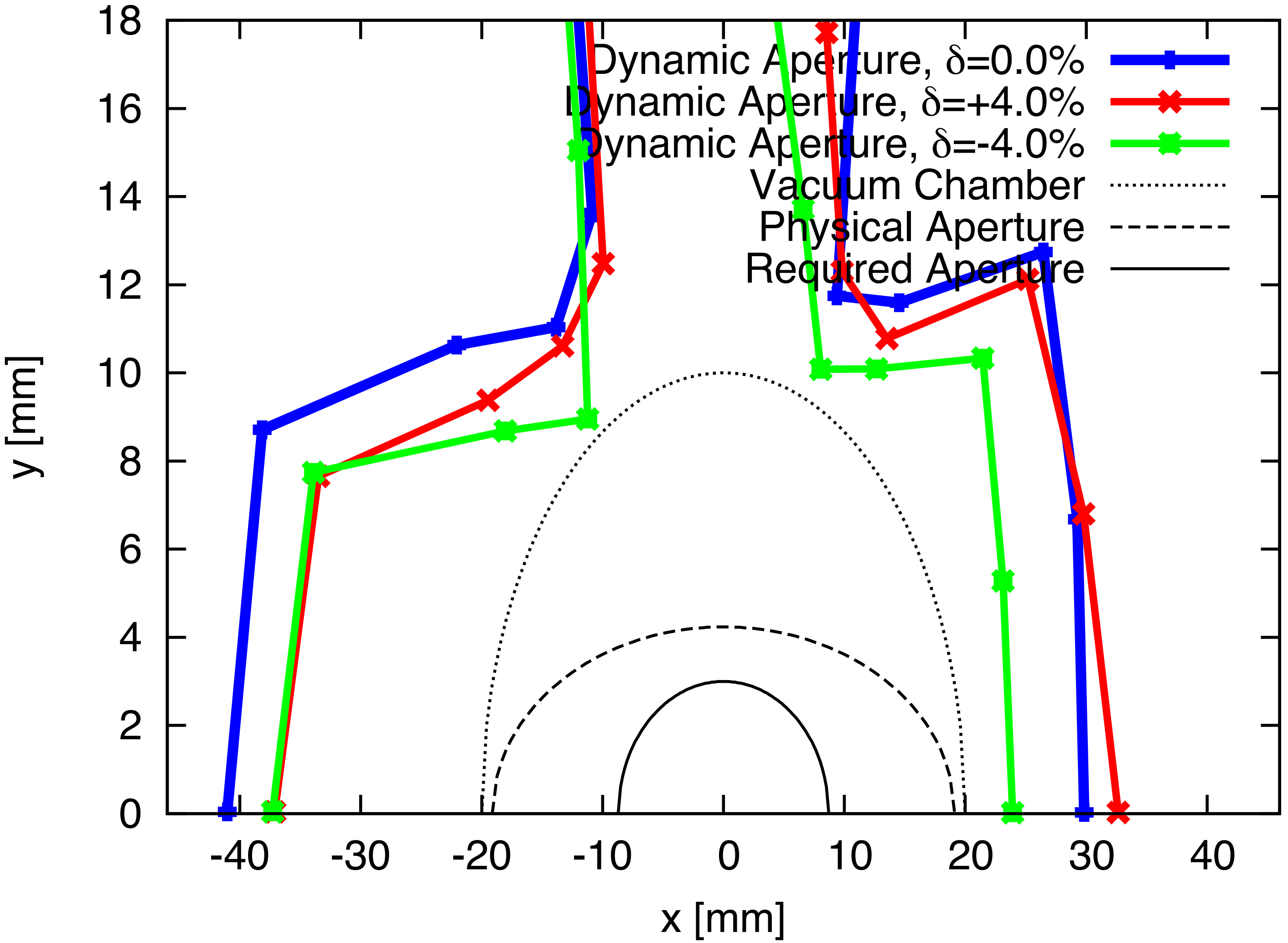
- **Ultimately, DA is the benchmark:**

  – Required DA off energy:
    - Verify finite DA available at $\delta \cong \pm 4\%$

  – Required DA on energy:
    - Injection process: ~7 mm maximum amplitude after PSM kick
    - Margin for error (misalignments, injection tuning): ~ 1.5 mm
      ➡ ± 8.5 mm @ straight center
    - Vertical DA should (at least) cover narrow-gap ID chamber acceptance
      ➡ ± 3 mm @ straight center (working assumption)

Benchmarks & Performance

- **Design DA (523 nonlinear optics):**



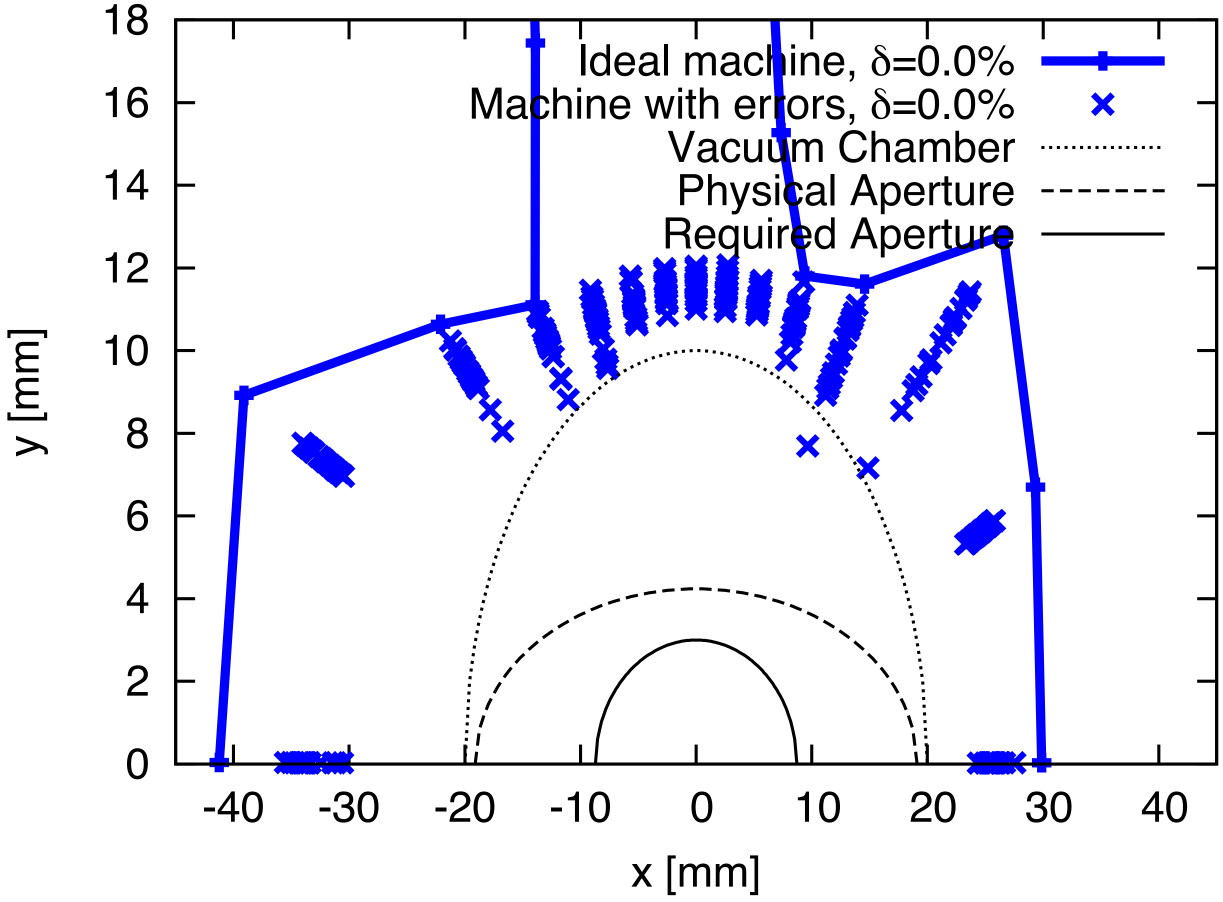
Benchmarks & Performance

- **Real DA derived from:**
  - Misaligned machine (using orbit correction)
  - Magnets with multipole errors
  - Magnets with field errors (after shunting within families)

- **Find acceptable DA for the above cases → guidelines for:**
  - Magnetic alignment (alignment <u>within</u> the magnet block)
  - Magnet field quality
  - Power supply stability (using analytic estimates)

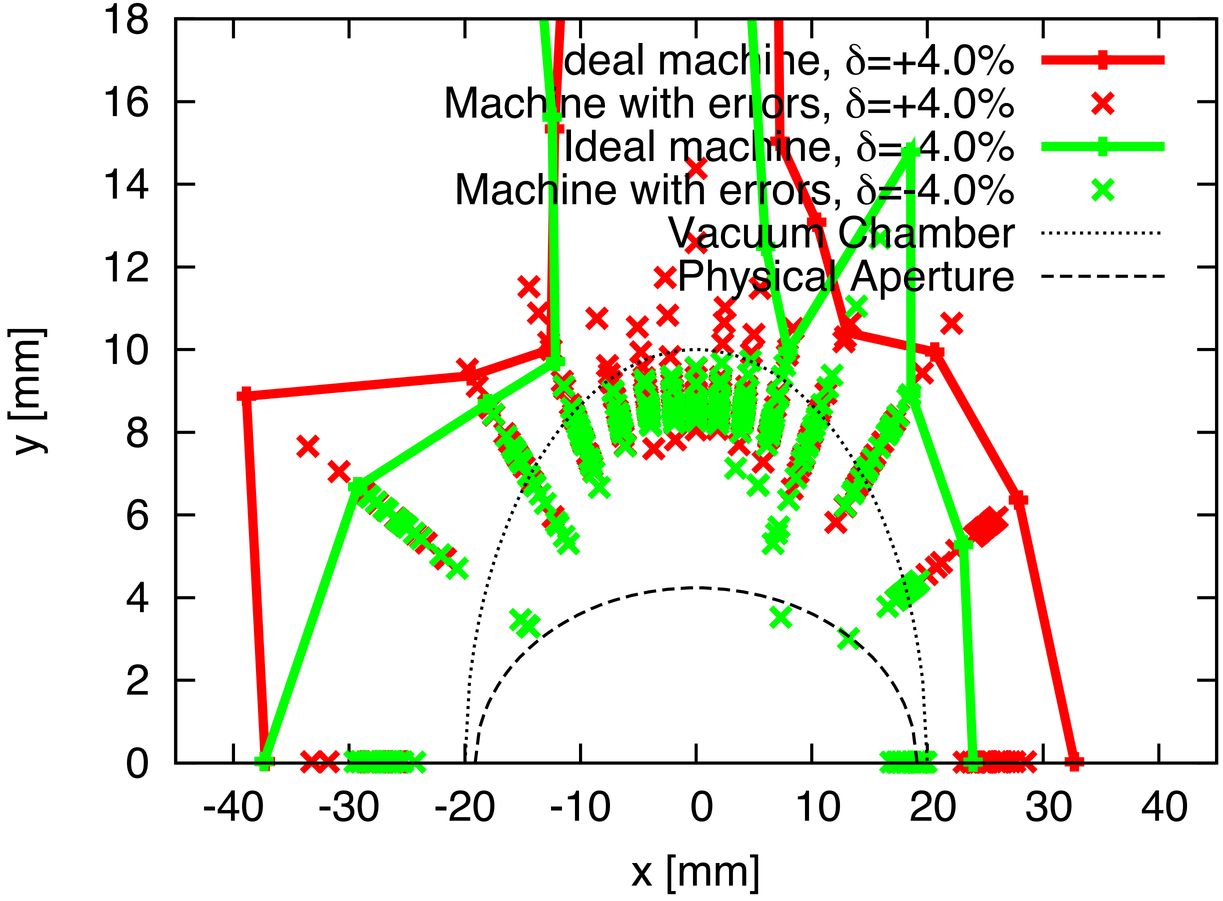
Derived Requirements

- **Real DA (523 nonlinear optics with all errors)**



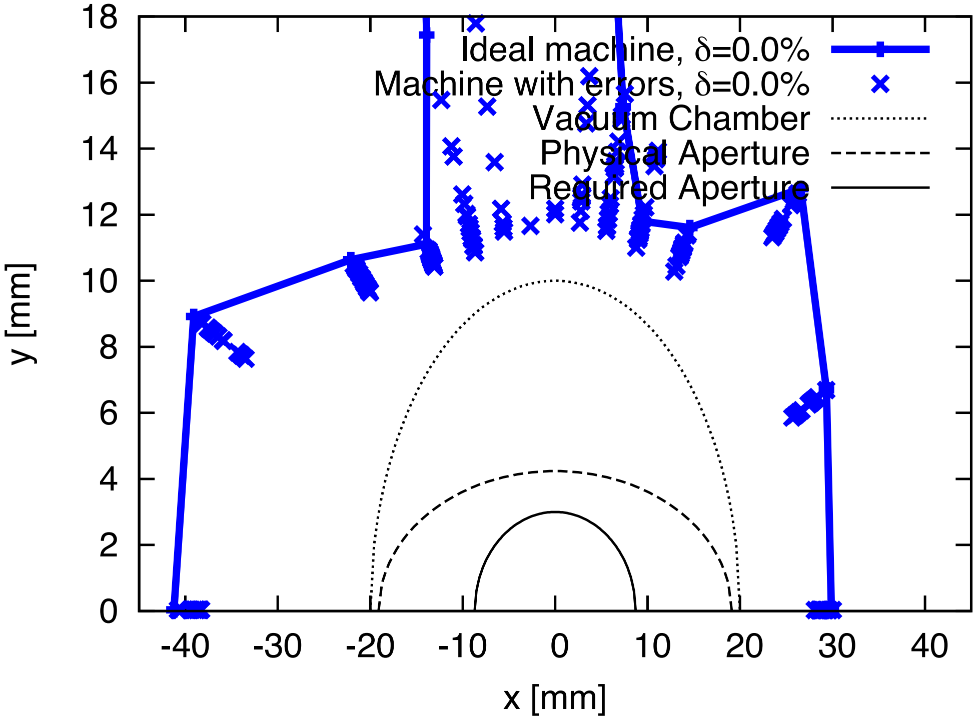
Derived Requirements

- Real DA (523 nonlinear optics with all errors)

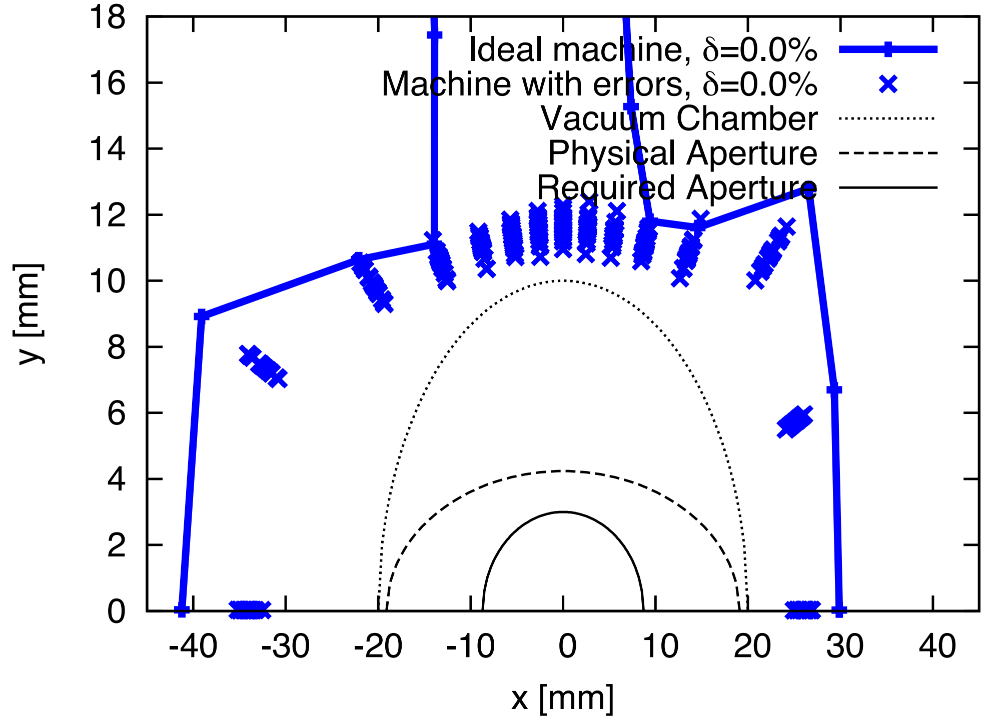


Derived Requirements

- **Which errors contribute most to DA reduction?**



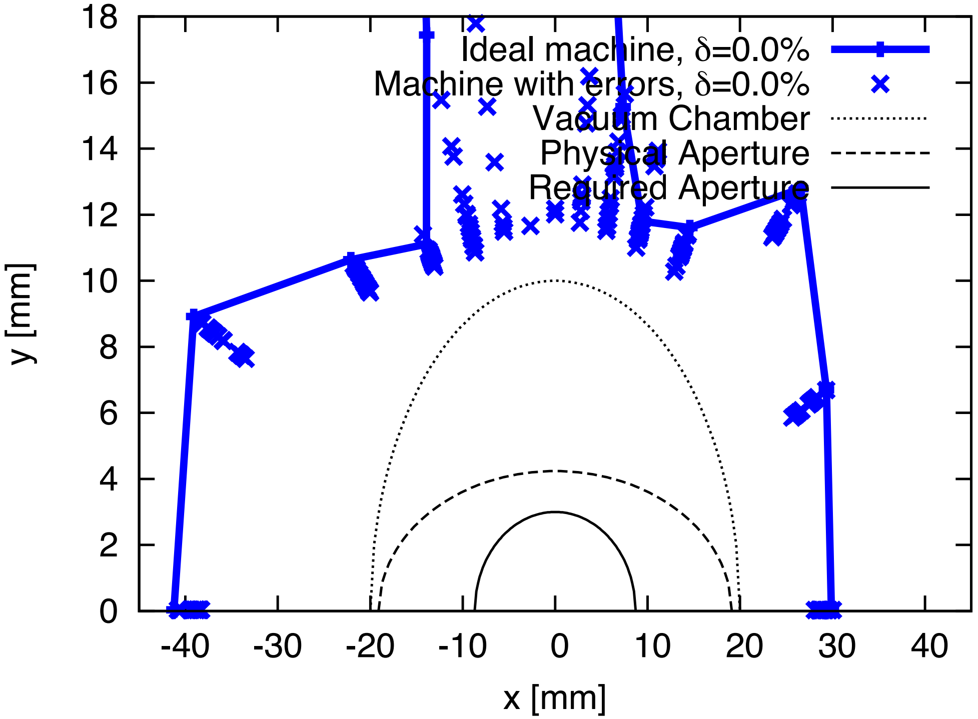
Alignment errors
("reasonable")



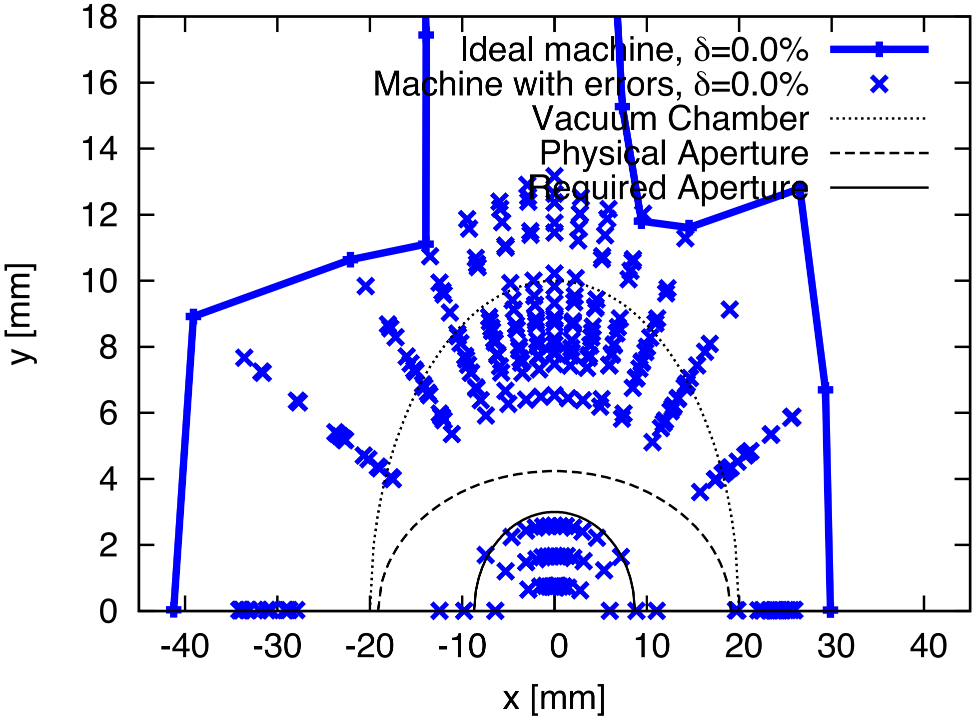
Field & multipole errors
("tough")

Derived Requirements

- **Which errors contribute most to DA reduction?**



Alignment errors
(“reasonable”)



Field & multipole errors
(“relaxed”)

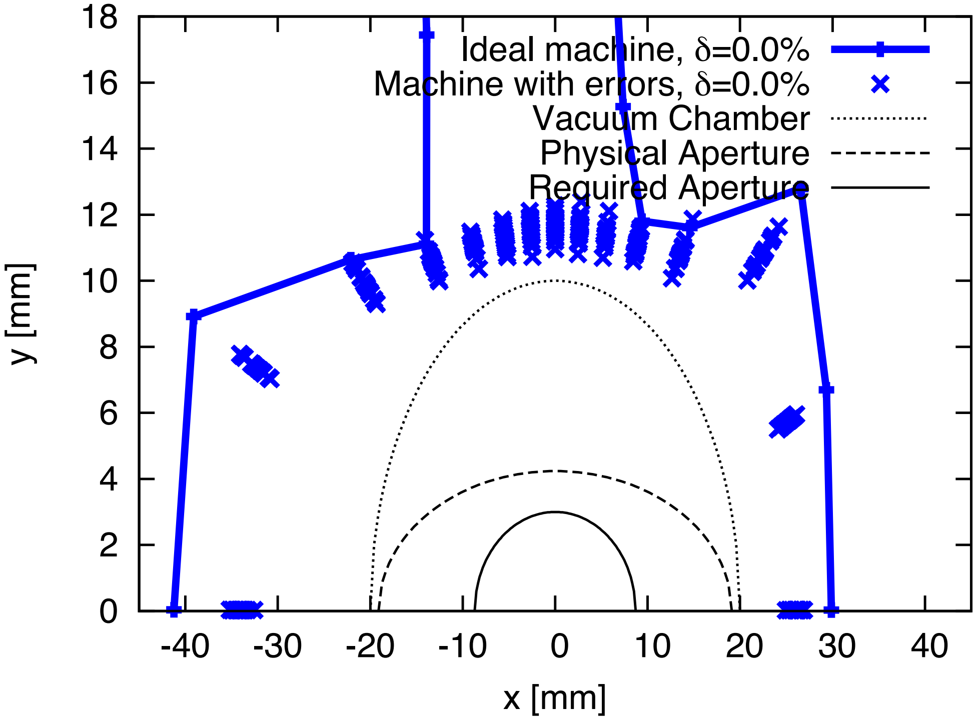
Derived Requirements

- Alignment error model: Gaussian, cut-off @ ± 2σ

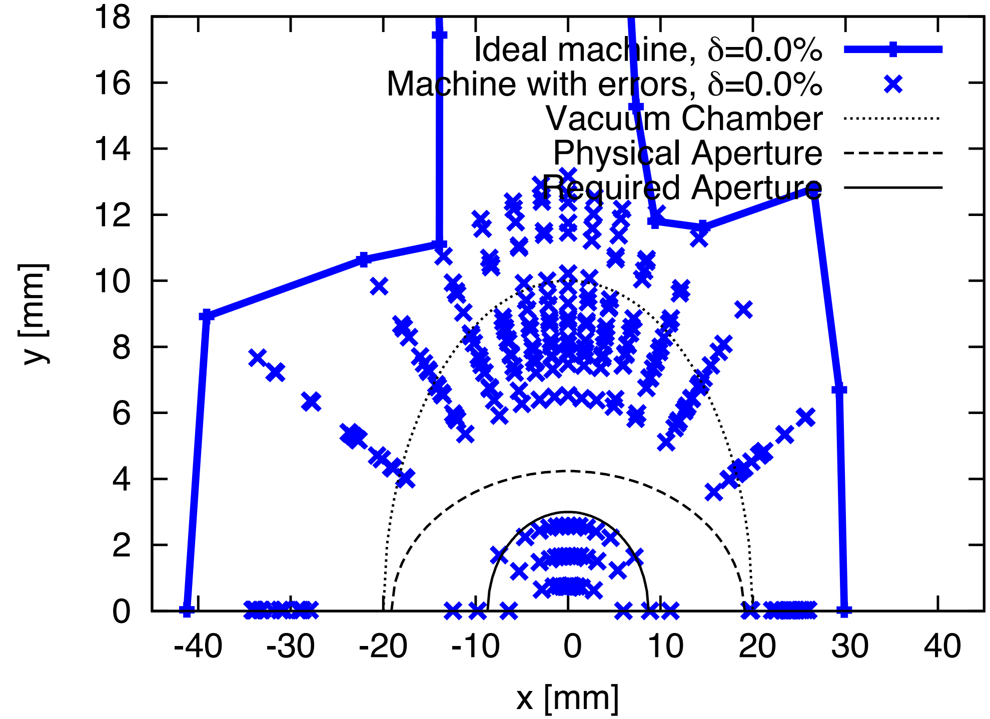
	Transverse displacements	Roll error
Girders (magnet blocks)	50 micron rms	0.2 mrad rms
Dipole slices (!)	25 micron rms	0.2 mrad rms
Quadrupole slices (!)	25 micron rms	0.2 mrad rms
Sextupoles	25 micron rms	0.2 mrad rms
Correctors	25 micron rms	0.2 mrad rms
BPM calibration	3 micron rms	0.1 mrad rms

Derived Requirements

- Field errors cause much more damage than multipoles



Multipole errors &
0.02% rms gradient variation



Multipole errors &
0.2% rms gradient variation

Derived Requirements

- **Multipole error model:**
  - APAC 2001, THP017, Antokhin et al.
  - SLS quadrupoles and sextupoles measured at BINP
  - Systematic and random errors
  - Upright and skew errors
  - Random errors modeled as Gaussian with cut-off @ ± 2 σ

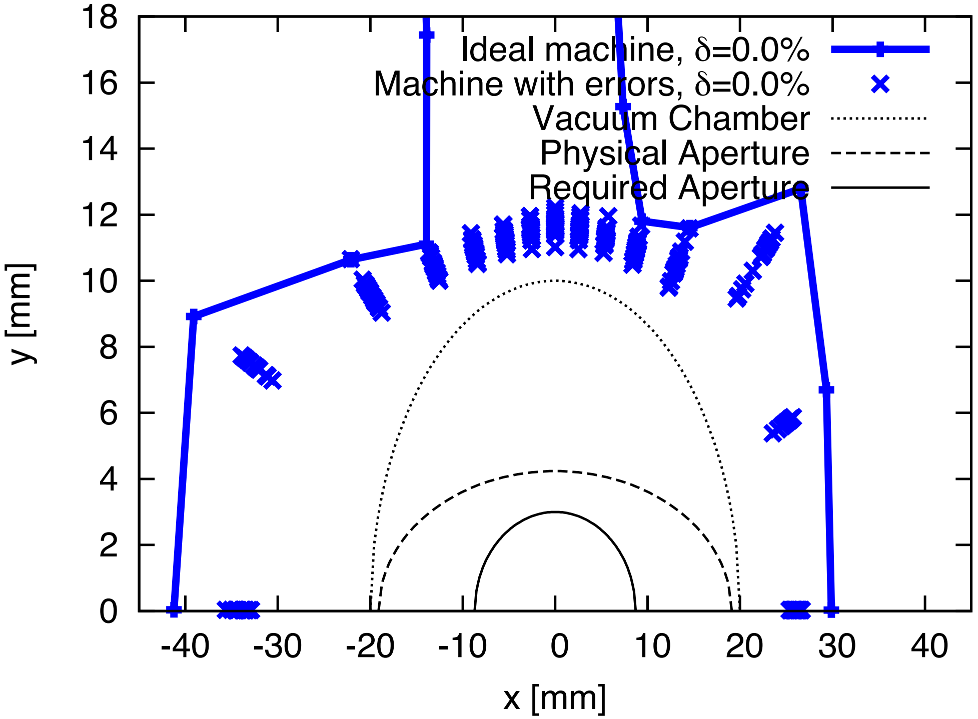
Table 3.7: Multipole errors used in the MAX IV error model. The data has been taken from magnet measurements of the SLS storage ring magnets [6]. The order column refers to the multipole order defined by 2 = quadrupole, 3 = sextupole, etc.

Magnet family	Error type	Order	Maximum multipole component (relative to main field component) Upright	Skew
Quadrupoles	Systematic	6	0.5×10^{-4}	—
		10	0.5×10^{-4}	—
		14	0.1×10^{-4}	—
Sextupoles	Systematic	9	0.5×10^{-4}	—
		15	0.5×10^{-4}	—
		21	0.5×10^{-4}	—
Quadrupoles	Random (rms)	2	2.5×10^{-4}	—
		3	2.8×10^{-4}	2.9×10^{-4}
		4	1.9×10^{-4}	1.4×10^{-4}
		6	1.3×10^{-4}	—
		10	3.0×10^{-5}	—
Sextupoles	Random (rms)	3	5.0×10^{-4}	—
		4	5.2×10^{-4}	4.9×10^{-4}
		5	3.5×10^{-4}	—
		9	8.0×10^{-5}	—
		15	5.0×10^{-5}	—

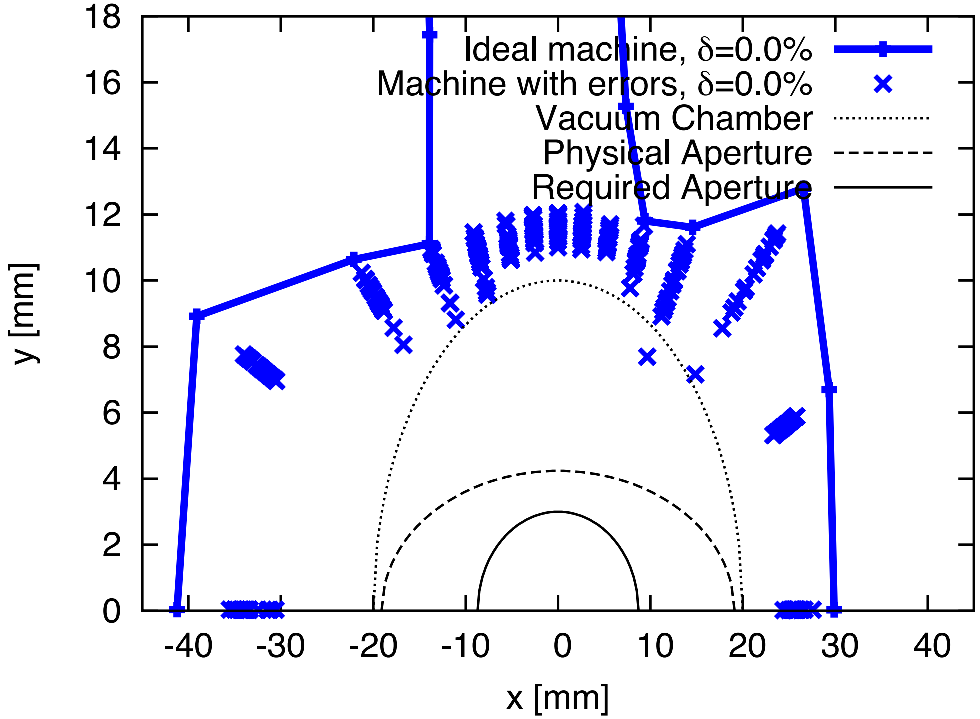
from DDR Chapter 3

Derived Requirements

- Dipole gradient errors actually cause most damage



Misalignments, multipole errors & 0.02% rms gradient variation



Misalignments, multipole errors & 0.2% rms gradient variation, 0.02% rms for dipole gradients

Derived Requirements

- **Field error model: Gaussian, cut-off @ ± 2σ**
  – Dipole gradients: 0.02% rms
  – Quadrupole and sextupole gradients: 0.2% rms

- **Reduce dipole gradient variations by:**
  – Shunting dipoles to gradients rather than bending angles (offload bending angle errors to orbit correctors)
  – Power PFS's individually

Derived Requirements

- **Systematic field errors from power supply drift or jitter**
  - Dipoles → orbit correction / orbit feedback, tune measurement
  - PFS's and quadrupoles → tune measurement / tune feedback
  - Sextupoles → chromaticity measurement

  - Quadrupole gradients:
    - 1 PS for PFS's, SQFi, and SQFo
    - 10^{-4} jitter on PS will lead to tune jitter of roughly 1×10^{-3} (H/V)

  - Sextupole gradients:
    - 1 PS for SQFi, SQFo, SDi, and SDo
    - 10^{-4} jitter on PS will lead to chromaticity jitter below 0.01 (H/V)