PAUL SCHERRER INSTITUT

PSI

A. Streun :: on behalf of the SLS-2 project team :: Paul Scherrer Institut

SLS-2 – Ugrade of the Swiss Light Source

25.08.2017 Swiss Physical Society Meeting, Geneva

Outline

- Basics: brightness & emittance
- The Swiss Light Source SLS
- How to minimize storage ring emittance
- Conceptual design of SLS-2

Experiments with synchrotron light

- ***energy range*** UV (10 eV) ... X-ray (100 keV)
- ***brightness***

$$B = \frac{\text{photons}}{(\text{time}) \times (\textbf{area}) \times (\textbf{solid angle}) \times (\text{energy interval})}$$

= 6-dimensional *invariant* photon phase space density

- ***coherence***

$$CF = \frac{\text{phase space (diffraction only)}}{\text{phase space (diffraction } \textbf{+ source}\text{)}}$$

⇨ **requirement for source:** ***small !***

+ stable, reliable, available, reproducible etc....

Brightness, coherent fraction and emittance

$$\left.\begin{matrix} B(\lambda) \\ CF(\lambda) \end{matrix}\right\} = \frac{1}{(\varepsilon_x \otimes \varepsilon_r(\lambda)) \times (\varepsilon_y \otimes \varepsilon_r(\lambda))} \times \left\{\begin{matrix} \dot{N}(\lambda)/\mathrm{BW} \\ (\varepsilon_r(\lambda))^2 \end{matrix}\right.$$

$\dot{N}(\lambda)$ spectral photon flux (dipole or undulator)

BW bandwidth of experiment = wavelength interval (usually 0.1%)

$(\varepsilon_{x/y} \otimes \varepsilon_r)$ = photon beam ***emittance***, horizontal and vertical

$\varepsilon_{x/y}$ electron beam emittance

$\varepsilon_r = \lambda/4\pi$ diffraction emittance

⇨ 10 keV photons → ε_r =10 pm[rad]

"diffraction limited" $\varepsilon_{x/y} \ll \varepsilon_r$

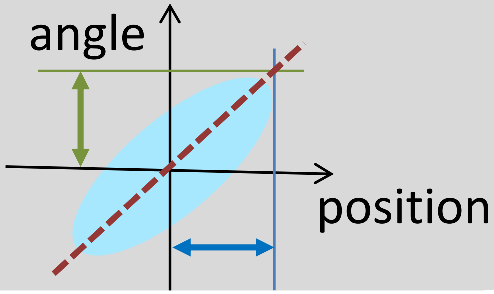
→ Coherent Fraction → 100%

→ Highest possible brightness

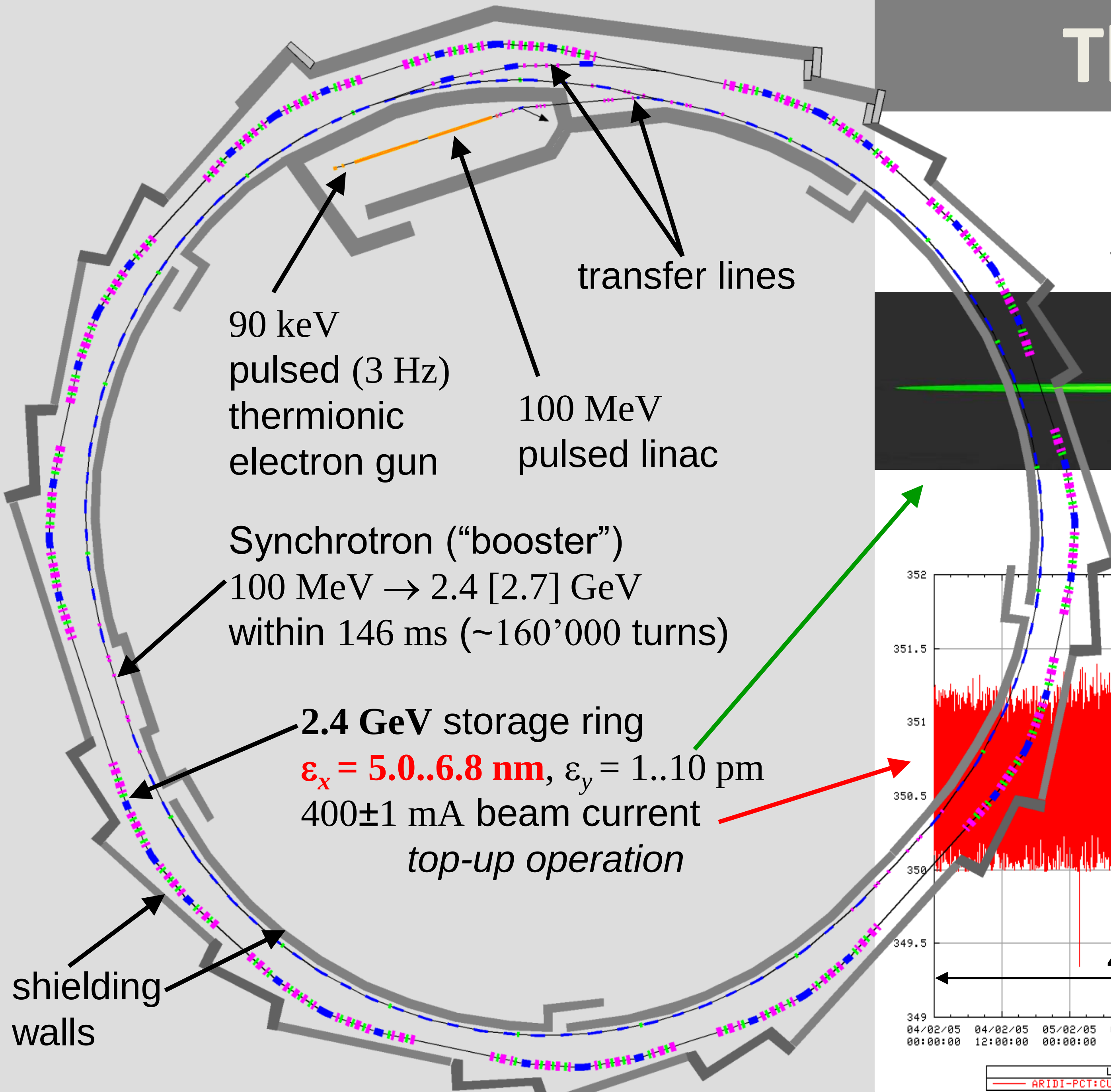
Emittance [m·rad]

= size × divergence – correlation

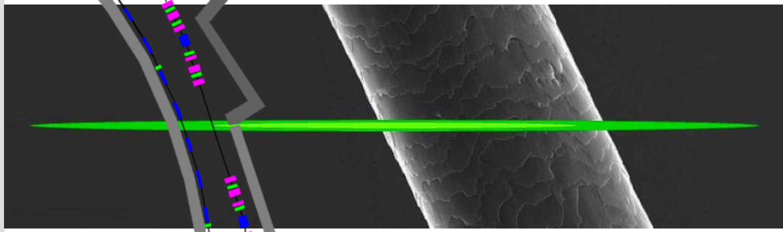
= 2-D phase space area



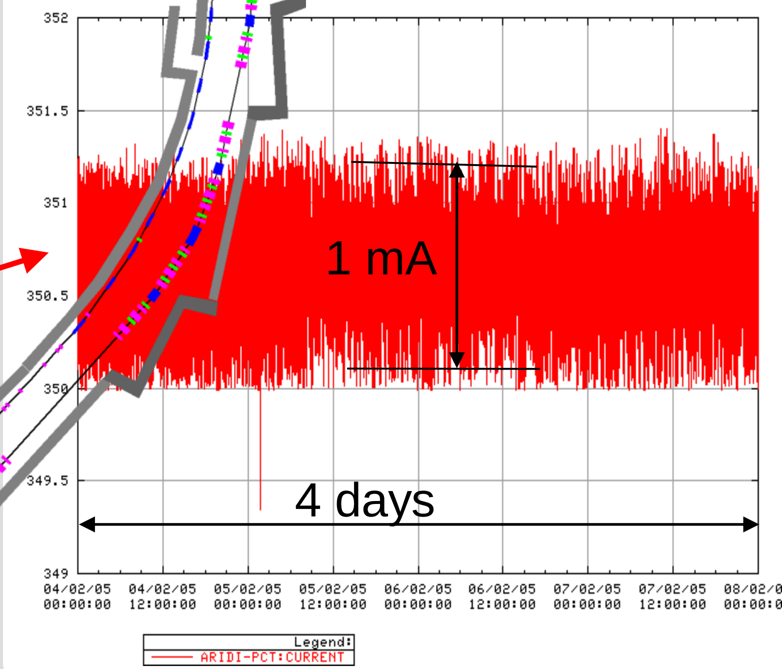
The SLS



Electron beam cross section in comparison to human hair

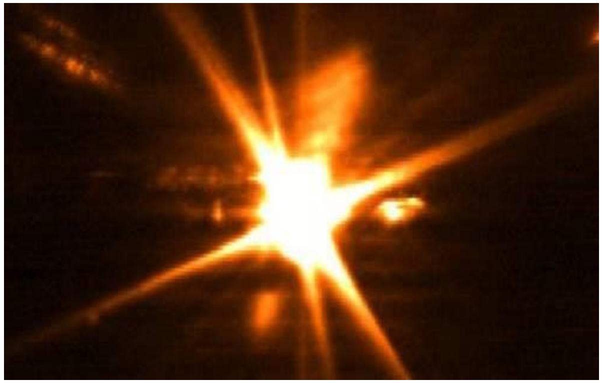


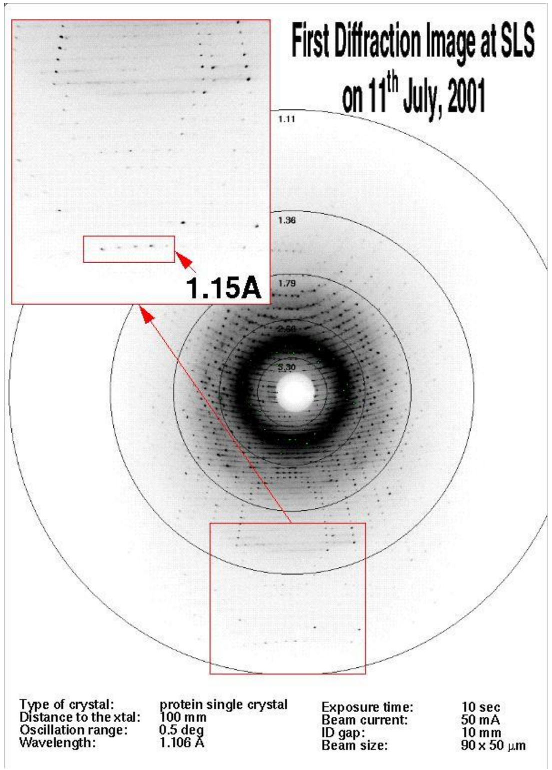
Current vs. time



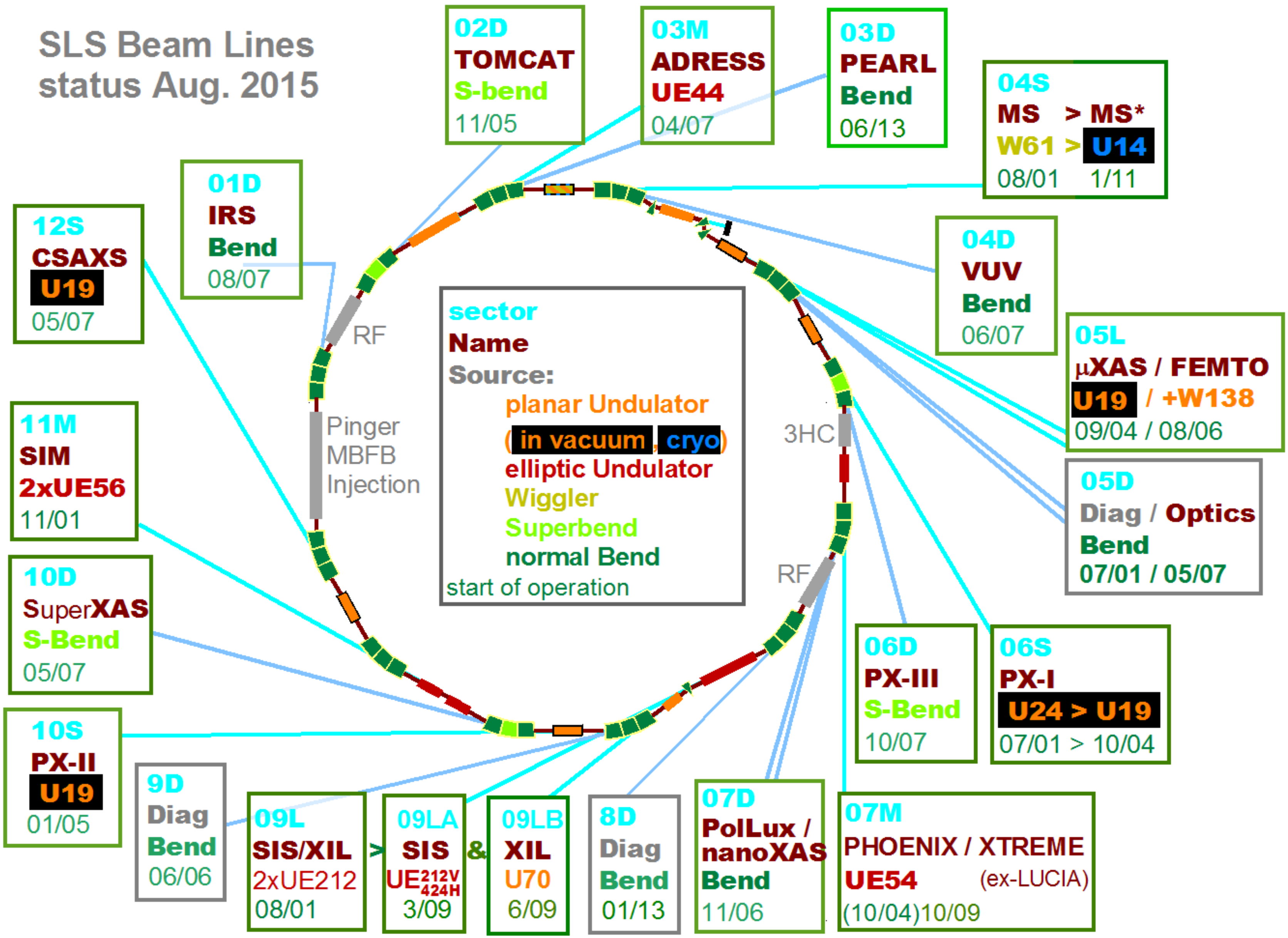
SLS history

	1990	First ideas for a **Swiss Light Source**
	1993	Conceptual **Design** Report
June	**1997**	**Approval** by Swiss Government
June	**1999**	Finalization of **Building**
Dec.	**2000**	First **Stored Beam**
June	**2001**	Design current **400 mA** reached **Top up** operation started
July	**2001**	First **experiments**
Jan.	**2005**	**Laser beam slicing "FEMTO"**
May	**2006**	**3 Tesla super bends**
	2010	**~completion: 18 beamlines**





SLS beam lines



SLS achievements

- **Rich scientific output**
  - > 500 publications in refereed journals/year
- **Reliability**
  - 5000 hrs user beam time per year
  - 97.6% availability (2005-2016 average)
- **Top-up operation since 2001**
  - constant beam current 400-402 mA over many days
- **Photon beam stability $< 1\ \mu m$ rms (at frontends)**
  - fast orbit feedback system (< 100 Hz)
  - undulator feed forward tables, beam based alignment, dynamic girder realignment , photon BPM integration etc...
- **Ultra-low vertical emittance: 0.9 ± 0.4 pm**
  - model based and model independent optics correction
  - high resolution beam size monitor developments
- **150 fs FWHM hard X-ray source FEMTO**
  - laser-modulator-radiator insertion and beam line

SLS and the new light source generation

16 years of successful operation...

... but emittance **5 nm** at 2.4 GeV not competitive in near future

- Flagship applications (CXDI, Ptychography, RIXS etc.) need higher brightness

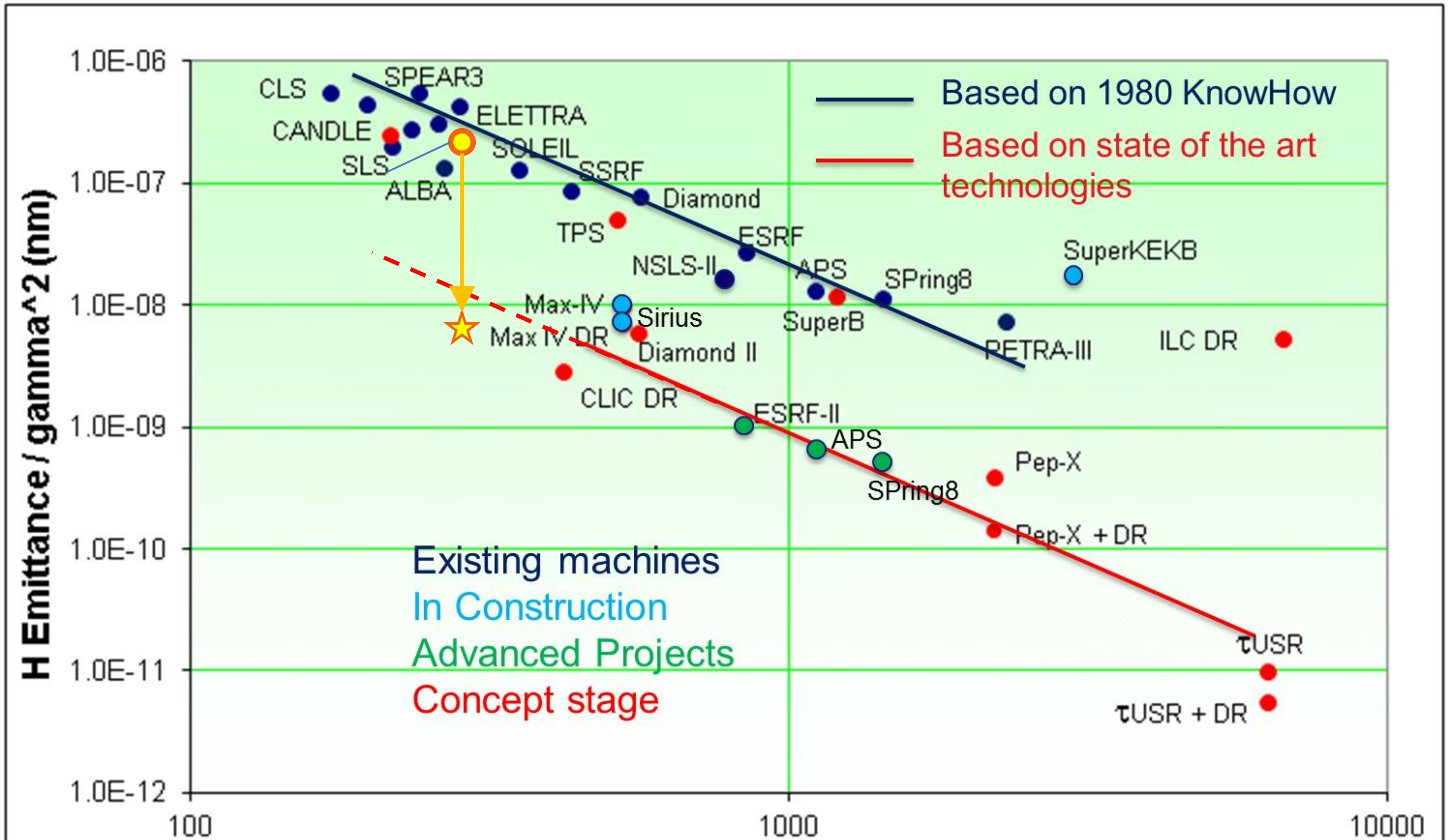


Figure from P. Raimondi, LELD-1 WS, Barcelona, April 2015

SLS

↓

SLS-2

Emittance scaling

$$\varepsilon \propto \gamma^2 C^{-3}$$

→ linear fit

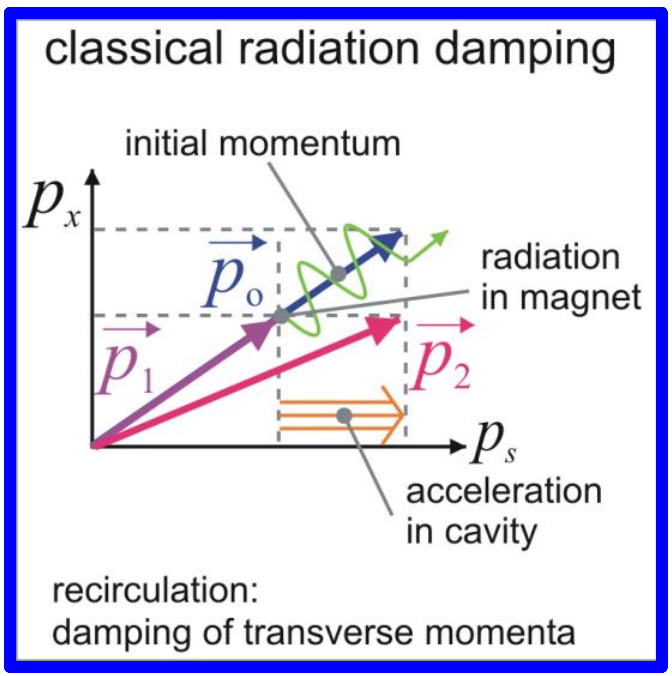
$$\log\frac{\varepsilon}{\gamma^2} = K - 3\cdot\log C$$

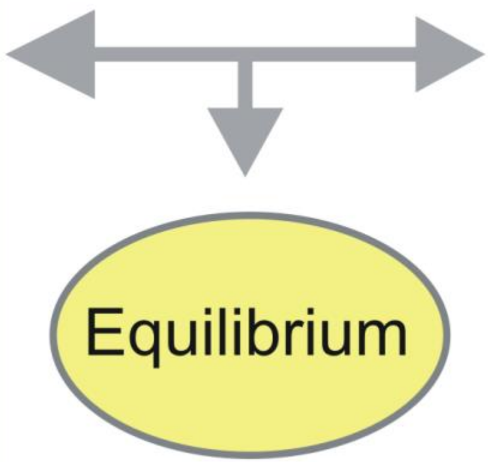
$K \approx 1.5 \rightarrow \approx 0$

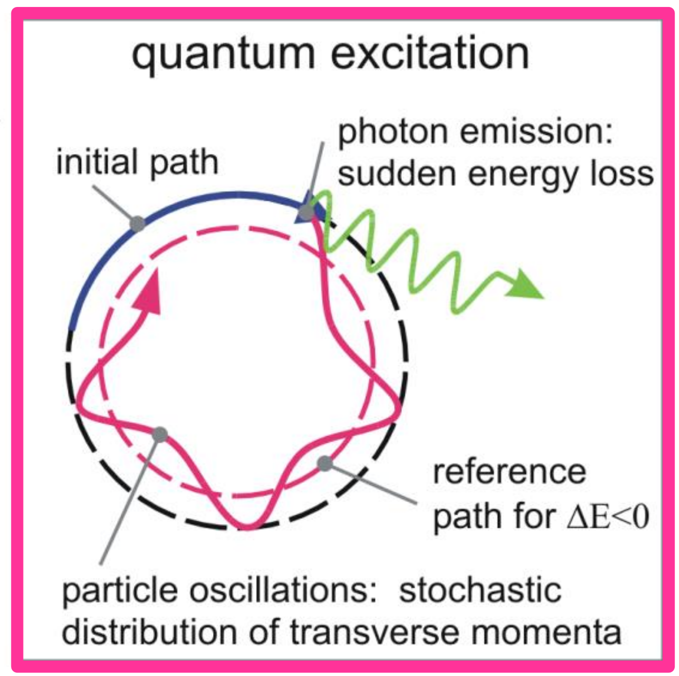
improvement ×30

Horizontal emittance in electron storage ring

- determined by radiation equilibrium
- independent of initial conditions







⇩

how to

⇧ maximize this -- and -- minimize this ⇧

?

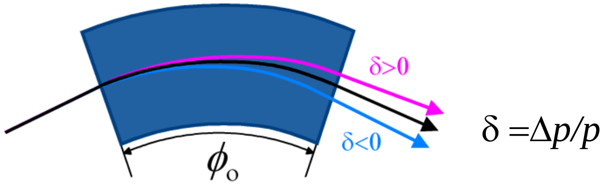
Minimum equilibrium emittance

- Maximum radiation damping
  - increase radiated power ⇨ pay with RF-power

    ⇨ **Damping wigglers**: Σ |deflection angles| > 360°

- Minimum quantum excitation
  - keep off-momentum orbit close to nominal orbit

$$\text{Dispersion} = \frac{\text{orbit}}{\text{momentum}} = \frac{X}{\Delta p / p}$$



⇨ minimize dispersion at locations of radiation (= bending magnets)

- Horizontal focusing into bending magnet to suppress dispersion.
- many short bending magnets (= small deflection angle ϕ) to limit dispersion growth: $\varepsilon \sim \phi^3$

  ⇨ **Multi-Bend Achromat (MBA)** ⇨ Miniaturization of components

Upgrade plan: SLS-2

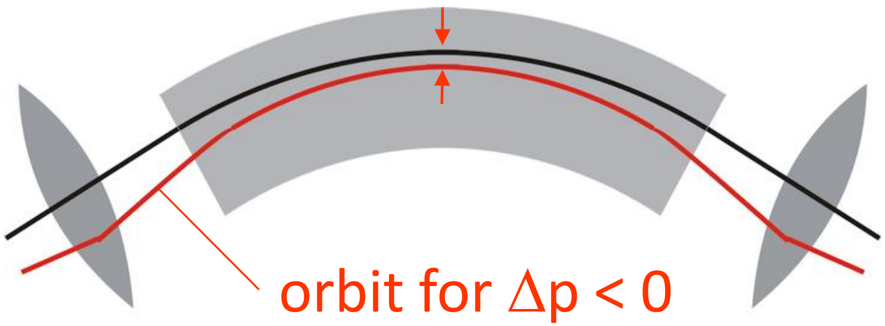
SLS upgrade task: $\varepsilon_x = 5$ nm $\rightarrow \varepsilon_x < 150$ pm

SLS upgrade challenge: small circumference

- Scaling $\varepsilon_x \propto (\text{Energy})^2 / (\text{Circumference})^3$
- Scaling other designs to SLS ⇨ not competitive ✘
  - Scaling MAX-IV, ESRF-EBS, SIRIUS etc. $\rightarrow \varepsilon_x > 500$ pm
- No space for very many lattice cells (MBA)
- No space for damping wigglers

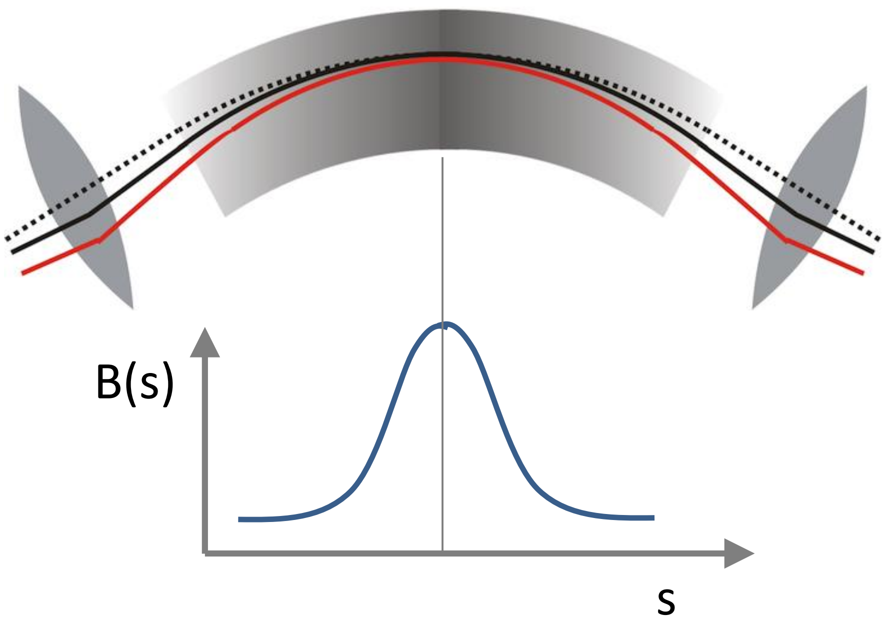
⇨ New lattice concept for SLS-2 $\varepsilon_x \rightarrow$ **125 pm**

SLS-2 lattice cell



Standard MBA cell

- quadrupoles (lenses) to focus dispersion
- dispersion at center > 0 (beam dynamics constraints)



SLS-2 modified MBA cell

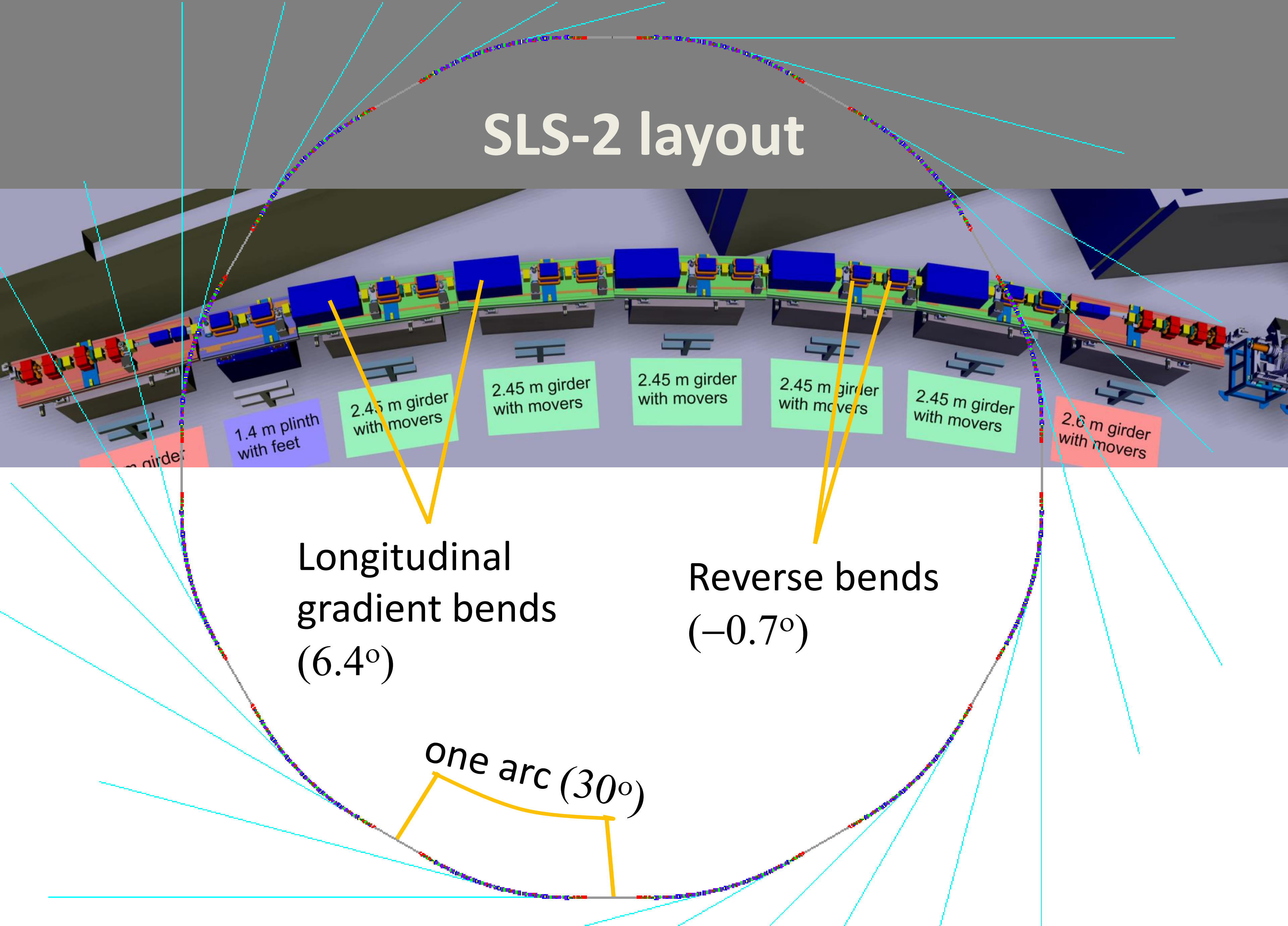
- displaced quadrupoles = reverse bending magnets
- dispersion at centre $\rightarrow 0$
- longitudinal field variation in dipole magnet: max.B at center
- Σ|angles|> 360° integrated “damping wiggler”

⇨ 5× lower emittance than conventional cell

Upgrade summary SLS → SLS-2

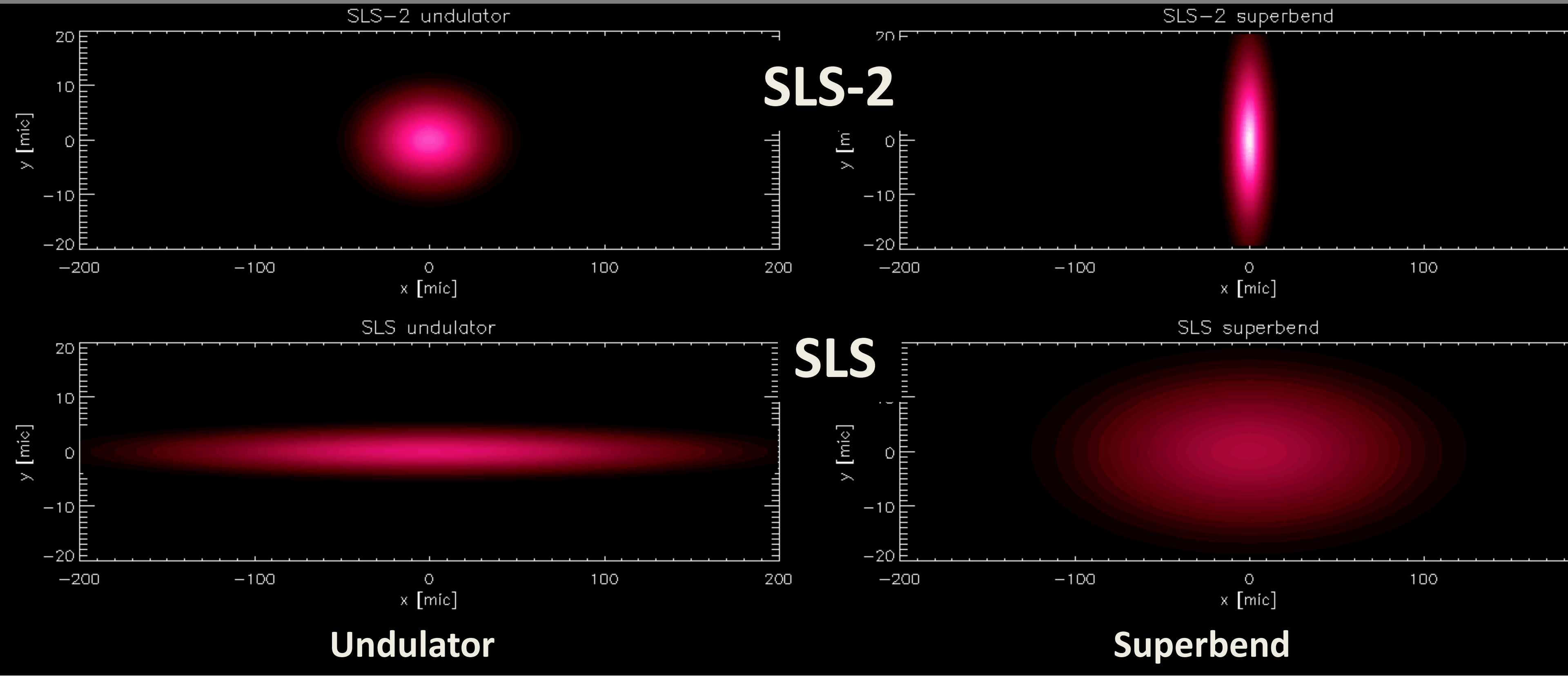
- Lattice type: 12×TBA → 12×**7**-BA
  - longitudinal gradient bend / reverse bend cell
- Emittance: 5.5 nm → **125 pm** (incl. IBS)
- Circumference: 288 m → 290.4 m
- Periodicity: **3** → **12**
- Straight sections:
  3×11 m, 3×7 m, 6×4 m → 12×5½ m
- 3 Superbends: 2.9 T → 6.0 T
- maintained:
  - 2.4 GeV beam energy, 400 mA current
  - off-axis top-up injection

SLS-2 layout



1.4 m plinth with feet
2.45 m girder with movers
2.45 m girder with movers
2.45 m girder with movers
2.45 m girder with movers
2.45 m girder with movers
2.6 m girder with movers
Longitudinal gradient bends (6.4°)
Reverse bends (–0.7°)
one arc (30°)

Beamsize at SLS-2 and SLS



SLS-**2**
emittances 150 / 10 pm, energy spread 1.05e-3
beta-x, beta-y, dispersion: mid straight 2.8 / 2.3 / 0 m, superbend: 0.31 / 8.5 / 3e-4 m

SLS
emittances 5620 / 5 pm, energy spread 0.86e-3
beta-x, beta-y, dispersion: mid S-straight 1.4 / 1.0 / 0 m, superbend: 0.45 / 14.3 / 0.029

SLS-2 budget & schedule

- Budget
  - 2017-20 pre-study budget 2 MCHF
  - 2021-24 project budget 100 MCHF
    - 17 MCHF from PSI budget
  - 2025-29 budget 25 MCHF
- Time schedule
  - Sep 1, 2017: completion of conceptual design report
  - Sep. 26/27, 2017: CDR review meeting
  - < Dec. 31, 2017: submission of proposal
  - 2018-19 technical design
  - 2020-22 construction & preassembly
  - 2023-24 exchange of storage ring