Accelerators for Research with Photons

Quo Vadis Large Scale Research Facilities

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1913, Enrico Guazzoni, Italy
First blockbuster in
history of cinema!

Perspectives in Accelerator Physics and Technologies
TU Darmstadt, 17.02.2017

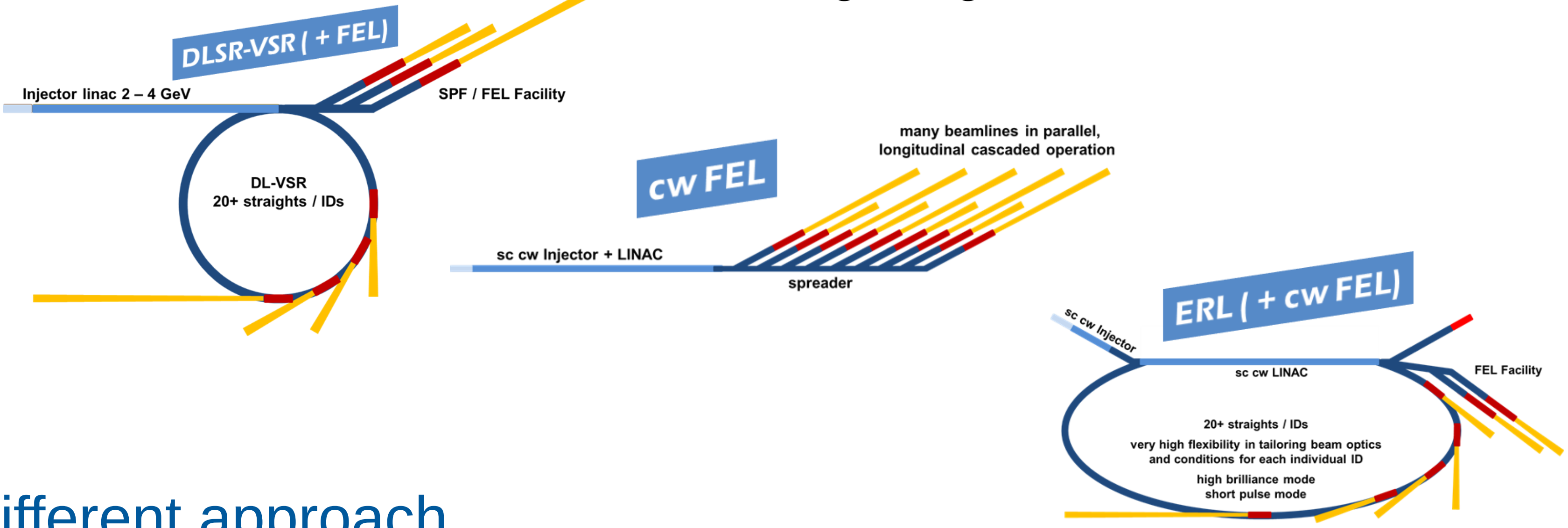
The menu

- Synchrotron radiation

  why, how, history

- Different kind of facilities

  state of the art and future for storage rings, FEL, ERL



- Different approach

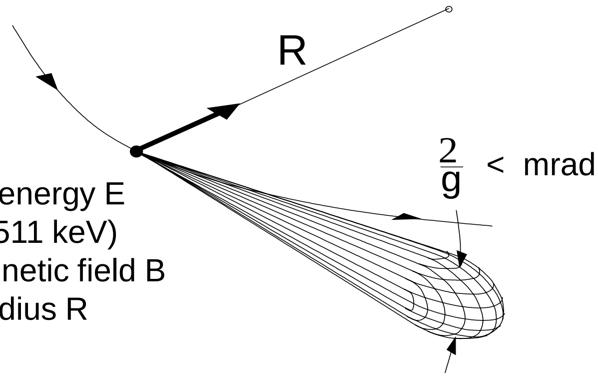
  novel accelerator concepts, PWA driven light source

- Conclusion

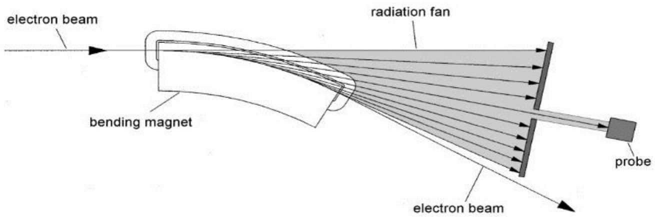
Synchrotron radiation

accelerated charges loose energy by emitting electromagnetic radiation

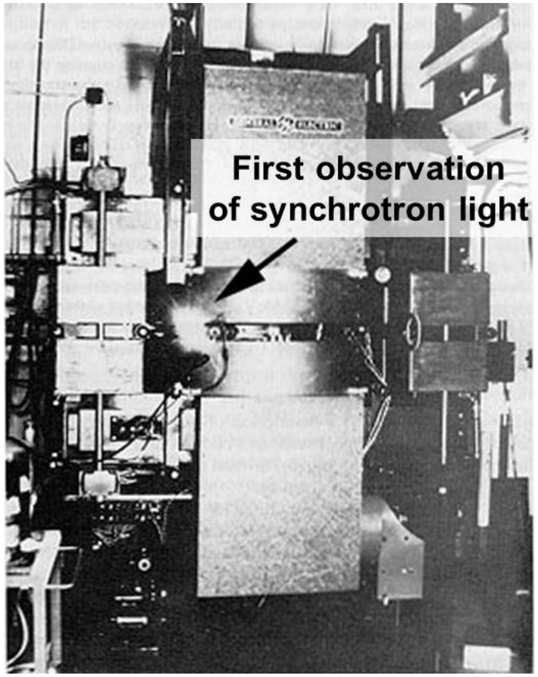
(Maxwell, Larmor, Liénard, Schwinger, …)



electron, energy E
(γ = E / 511 keV)
bend in magnetic field B
with radius R



$$P_{SR}(kW) = 88.5 \cdot \frac{E^3[GeV^3]}{R[m]} \cdot I[A] \qquad \lambda_c = \frac{4\pi \cdot R}{3\gamma^3}$$



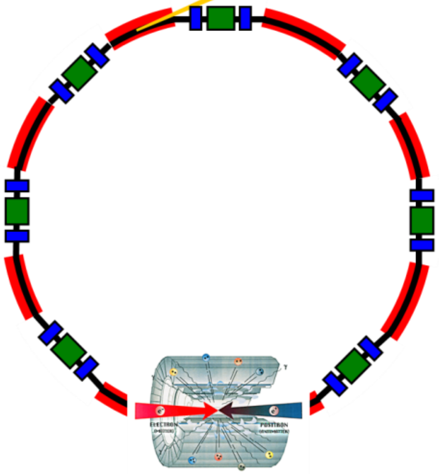
G.E. Synchrotron, 70MeV, 1947

- high intensity from a small source point (electron beam)
- broad, tuneable spectrum
- photon energy up to many keV
- short pulses, depending on electron bunch length
- polarized radiation

The genealogy of storage ring based SR sources

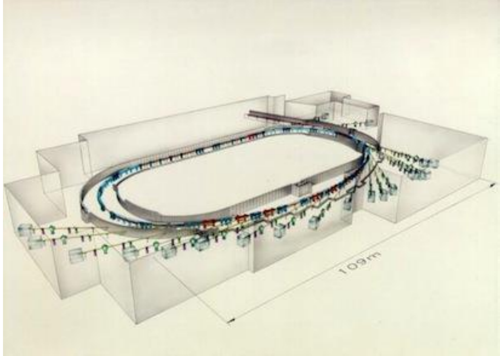
1st Generation

“parasitic use”
of a “by-product”



1970ies: SPEAR, SLAC

1970/80ies: DORIS, DESY



2nd Generation

“dedicated sources”
bendings, some IDs

1980ies: SRS, Daresbury

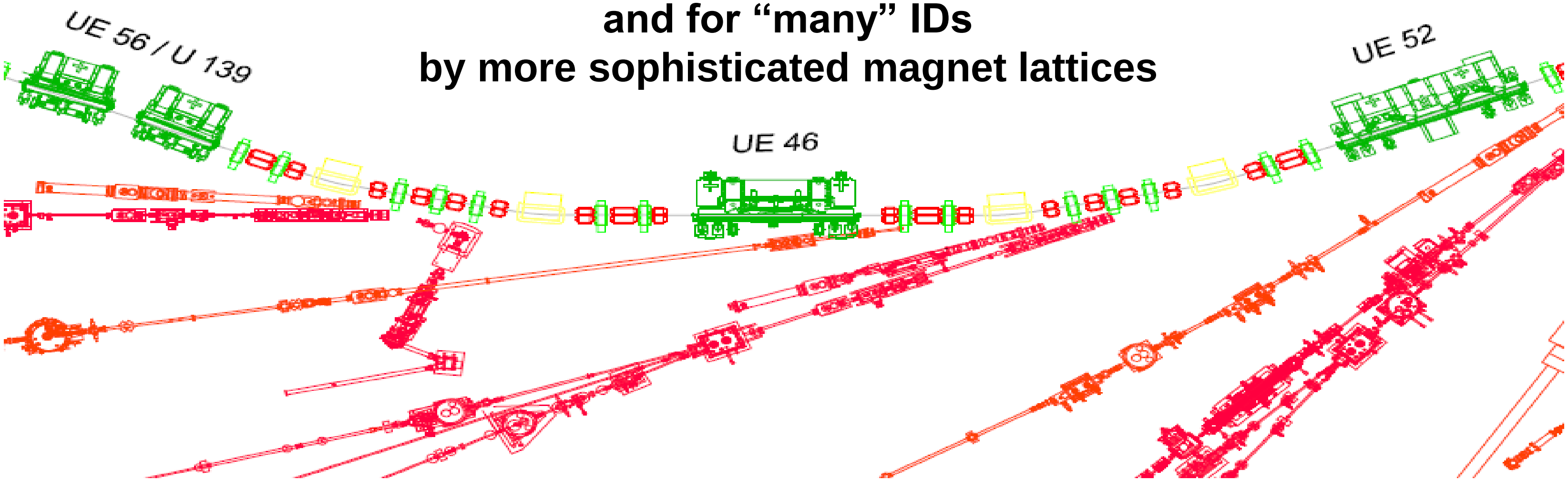
1980ies: BESSY, Berlin

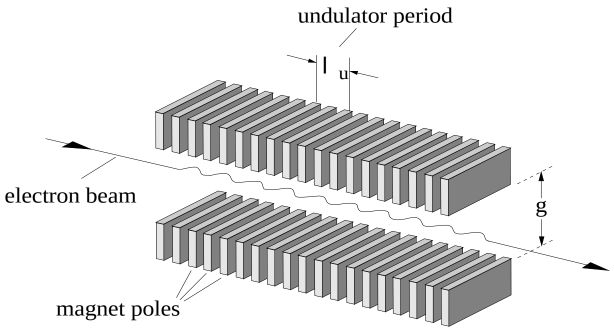
The genealogy of storage ring based SR sources

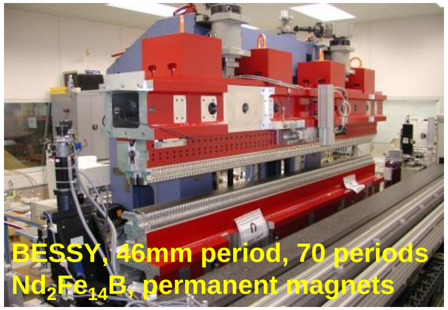
Appetite comes with eating!

3^{rd} Generation

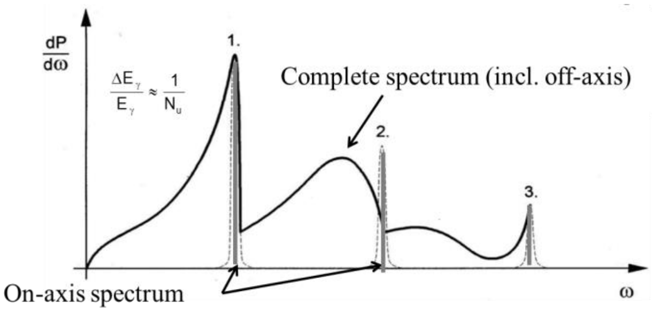
optimized in brightness (smaller emittance ~ nm rad)
and for "many" IDs
by more sophisticated magnet lattices







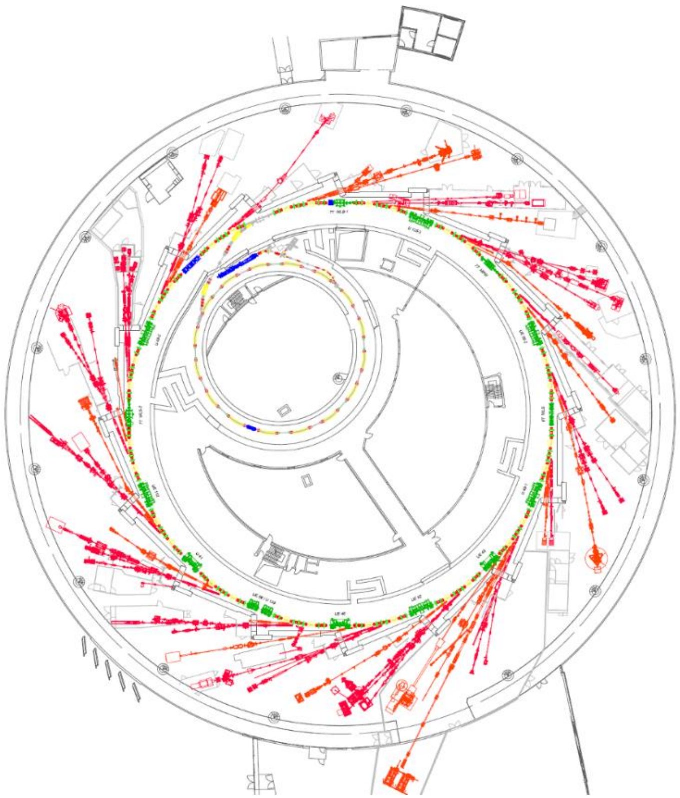
BESSY, 46mm period, 70 periods
$Nd_2Fe_{14}B$, permanent magnets



line spectrum, small line width,
res. 100000, elliptic polarisation

3^{rd} generation storage ring light source – e.g. BESSY II

Energy/current	1.7GeV / 300mA
Emittance	5 nm rad
Pulse length	15 ps (rms)
Circumference	240 m
Straight sections	16
Undulators / MPW+WLS	12 / 1+2
Beamlines	46

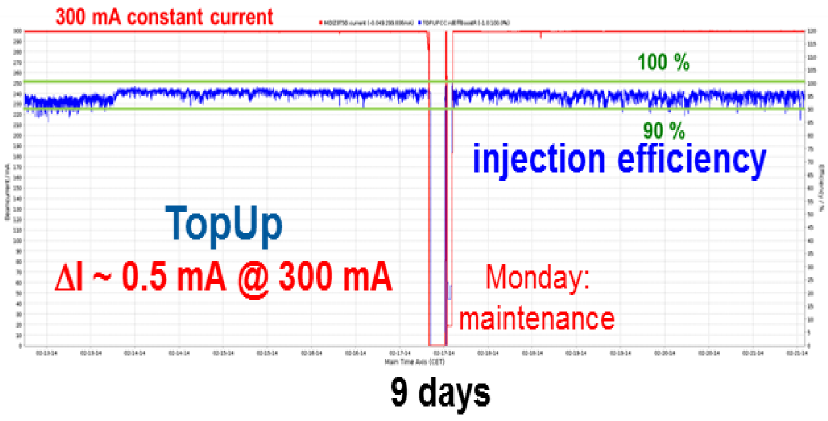


5000 h user operation, 3000 user visits / a

specialties

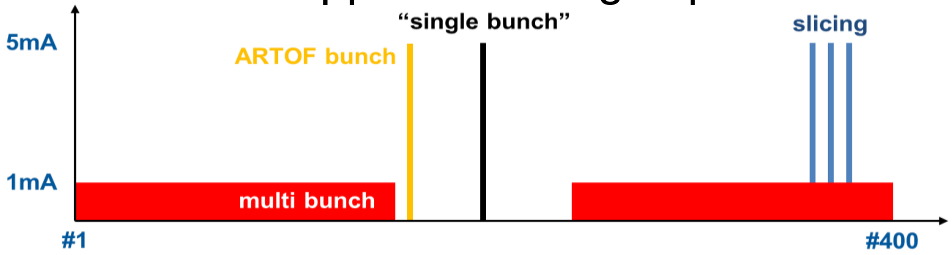
low-α operation, femto slicing

ps beams, CSR, THz, 100 fs, polarised x-rays



standard mode = 4 in 1

excellent support of timing experiments



3rd generation storage ring light sources – the 90ies ++


P.GINTER/ES

ESRF / France, 1993


ALS / USA, 1993


ELETTRA / Italy, 1994


APS / USA, 1996


©RIKEN/JASR

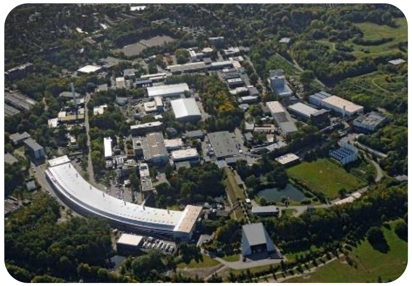
SPring-8 / Japan, 1997


BESSY II / D, 1998


SLS / Switzerland, 2001


SOLEIL / France, 2006


DIAMOND / UK, 2007


PETRA III / D, 2010


ALBA / Spain, 2010


TPS / Taiwan, 2014

Energy: 1.7 GeV – 8 GeV
Beam Current: 100 mA – 500 mA
Natural Emittance: 1 nm rad – 20 nm rad (coupling down to << 0.1% = 5 pm rad vertical)
Pulse Length: ~ 30 ps (~ ps in low-α and 100 fs slicing @ strongly reduced current)

The phase space of parameters

Brilliance

$$B_{average}(\lambda) \sim \frac{N_{photon}(\lambda)}{\varepsilon_x \cdot \varepsilon_y}$$

Photons on Sample

Advanced IDs,
tailored beam optics,
efficient photon optics

Diffraction limit, coherence

$$\varepsilon_{x,y} \sim \frac{\lambda}{4\pi}$$

Light Source

Repetition Rate & Pulse Structure

pulses, pulse trains, cw

Timing Resolution

electron / photon pulse length

Longitudinal Coherence

SASE, seeded radiation, stability,
“monochromatic” photons

Peak Brilliance

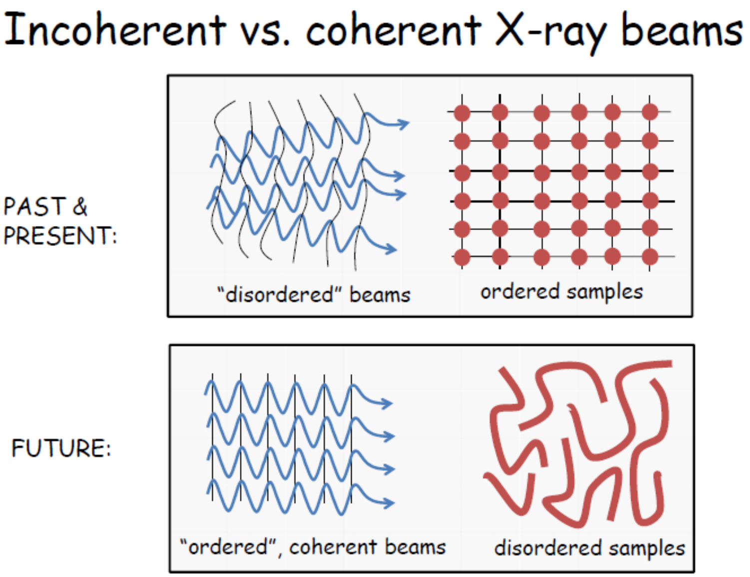
$$B_{peak} \sim \frac{N_e}{\sigma_t}$$

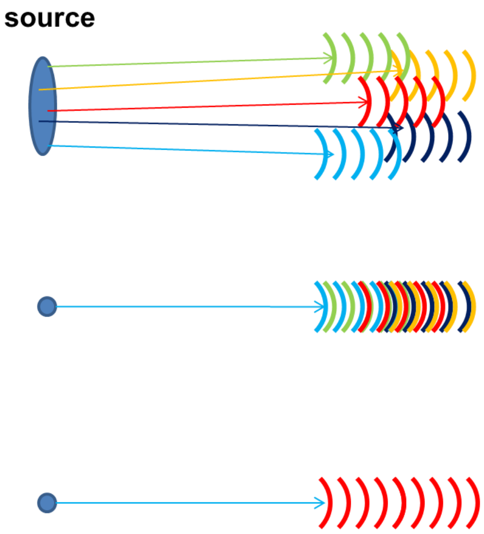
incoh.

$$B_{peak} \sim \frac{N_e^{\,2}}{\sigma_t}$$

coh.

The challenge in pictures





Case1: Currently …
e.g. **3rd gen. synchrotron sources**

Case2: Near Future …
Diffraction-limit light source

Case3: Ultimately …
Fourier transform-limit light source

http://erl.chess.cornell.edu/gatherings/2011_Workshops/talks/WS1Shpyrko.pdf

One driving factor – increase in brilliance and coherence

Brilliance

$$B_{\text{average}}(\lambda) = \frac{N_{\text{photon}}(\lambda)}{4\pi^2 \cdot \left(\varepsilon_x \oplus \varepsilon_{\text{photon}}(\lambda)\right) \cdot \left(\varepsilon_y \oplus \varepsilon_{\text{photon}}(\lambda)\right)\left(s \cdot 0.1\%\text{BW} \cdot A\right)}$$

defined by lattice=“beam optics”, beam energy

$$\varepsilon_{\text{photon}}(\lambda) = \frac{\lambda}{4\pi}\ \text{(Gaussian)},\ \frac{\lambda}{2\pi}\ \text{(undulator)} \quad : \text{photon beam emittance}$$

Electron beam emittance for diffraction limited radiation:

$$\boxed{\varepsilon_{x,y}(\lambda) = \frac{\lambda}{4\pi}} \qquad f_{\text{coh}}(\lambda) = \frac{\varepsilon_{\text{photon}}(\lambda)}{\varepsilon_x \oplus \varepsilon_{\text{photon}}(\lambda)} \cdot \frac{\varepsilon_{\text{photon}}(\lambda)}{\varepsilon_y \oplus \varepsilon_{\text{photon}}(\lambda)}$$

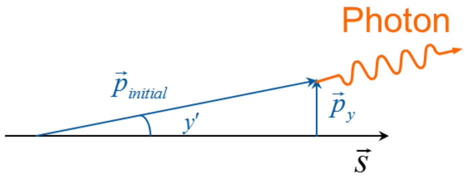
ε = 1 nm rad → λ = 13 nm (95 eV)

λ = 10 nm (124 eV) → ε = 800 pm rad

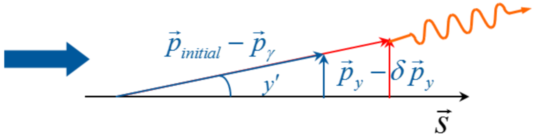
λ = 1 nm (1.240 keV) → ε = 80 pm rad

λ = 1 A (12.4 keV) → ε = 8 pm rad

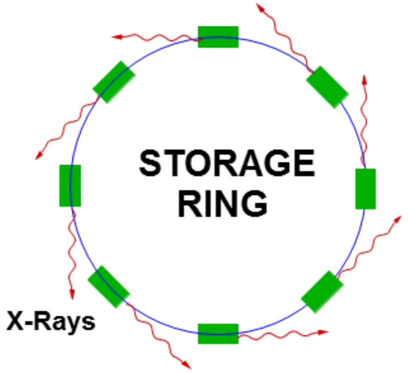
Storage ring – governed by equilibrium processes

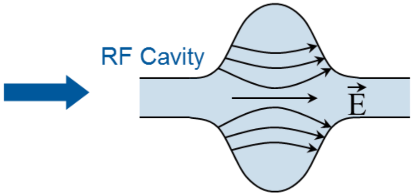


electron emits photon

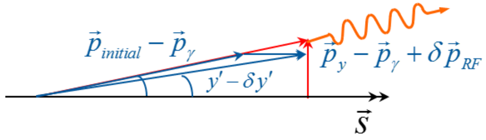


looses momentum (also transversal)





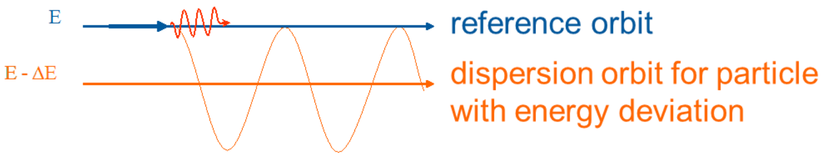
longitudinal momentum restored in acceleration cavity



angle and displacement reduces
→ emittance shrinks

“damping”

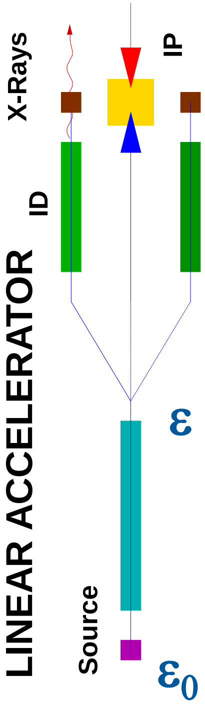
emission of photon at position with dispersion
(e.g. in dipole, where transversal position
is energy dependent)
electron oscillates around reference orbit
→ emittance increase

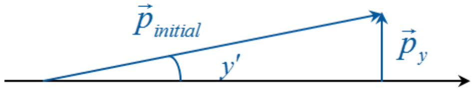


“heating”

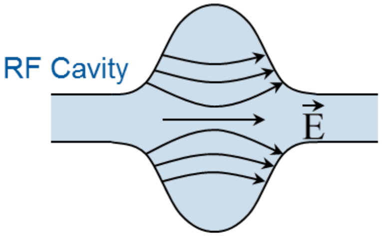
emittance is defined by an equilibrium between these
two processes (damping and heating)
similar process defined energy-spread and pulse length

Linac – governed by adiabatic damping and control

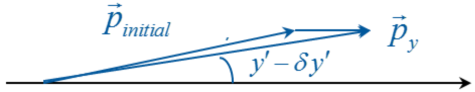




electron has transversal momentum



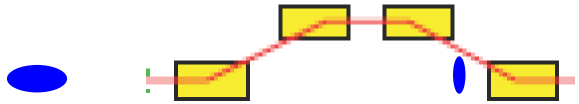
longitudinal component increases during acceleration



angle reduces with acceleration, emittance shrinks $\varepsilon = \dfrac{\varepsilon_0}{\gamma}$

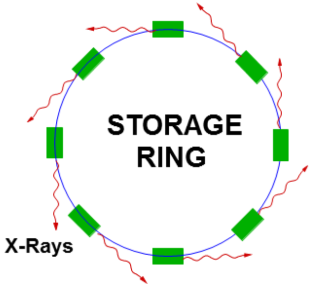
„adiabatic“ damping

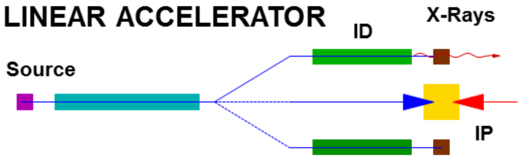
additional: bunch-length control by applying correlated energy chirp (off crest) and magnetic chicane with longitudinal dispersion



The quality of the beam is defined by the source, the rest is proper acceleration and phase space control !
(taking into account CSR, wakes, …)

Storage ring versus Linac





equilibrium beam dimensions	adiabatic damping + control
$\varepsilon_x = C_\gamma \cdot \frac{\gamma^2}{J_x} \cdot \frac{\left\langle \frac{1}{R^3} H(s) \right\rangle}{\left\langle \frac{1}{R^2} \right\rangle} \sim \frac{\gamma^2}{N^3}, \varepsilon_y = \kappa \cdot \varepsilon_x$	$\varepsilon_{x,y} = \frac{\varepsilon_0}{\gamma}$
$\frac{\sigma_E}{E} \sim \frac{\gamma}{\sqrt{\rho}}$	$\left(\frac{\sigma_E}{E}\right)_0 \sim \frac{1}{\gamma}$
$\sigma_s \sim \sqrt{\frac{\alpha}{V'}} \cdot \sigma_E$	$\sigma_s = f(\sigma_0)$ plus bunch manipulation

“virtual” (internal) power

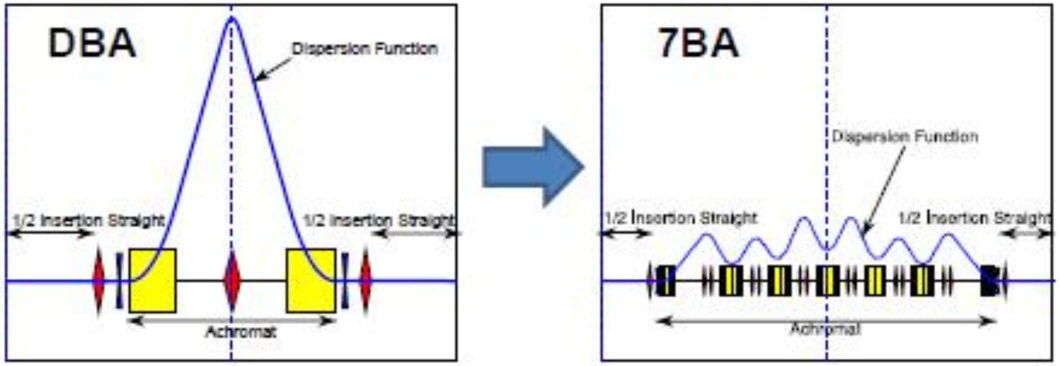
real (external) power

Quo vadis storage rings? – The diffraction limit challenge

Lattice design evolution from double- and triple-bend achromats (DBA, TBA) to multi-bend achromats: increase N_D.

$$\varepsilon_x = C_L \frac{E^2}{N_D^3}, \quad \varepsilon_x \underbrace{\propto}_{\text{Fixed E}} \frac{1}{C^3}$$

C_L = lattice constant
N_D = # dipoles
C = Circumference



Strong Focusing and Low Dispersion

First used for MAX-IV.

D. Einfeld *et al.*, Proc. PAC 95, Dallas TX

Multi-bend lattices are becoming a reality:

- MAX IV (Sweden) is in operation (~ 300 pm rad)
- Sirius (Brazil) just started construction
- ESRF MBA upgrade on the way (France)
- APS-U (US), ALS-U (US), SPRING-8 (Japan), PETRA IV (D), SLS2 (Switzerland), DIAMOND2 (UK), SOLEIL2 (F), … planning

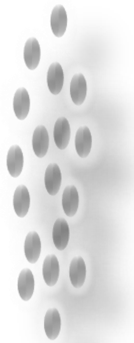
Full energy, low emittance injector
usefull as "short pulse" or even FEL source

DLSR compared to 3G SR:

Emittance reduction < 1/10 (~ 100 pm), even down to < 1/100 (~ 10pm)

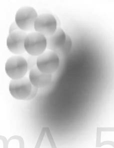
but:

- lattices with very strong quadrupoles (and multipoles)
- reduced dynamic aperture makes injection complicated
  "If you can inject in your lattice, your emittance is still too large"
  → new concepts for injection, e.g. "swap-out injection"
- careful control of Intra Beam Scattering and Touschek lifetime

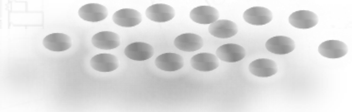


3G, 20ps

MAX IV
3 GeV, 500mA, 528m, 320 pm (200 pm with IDs)



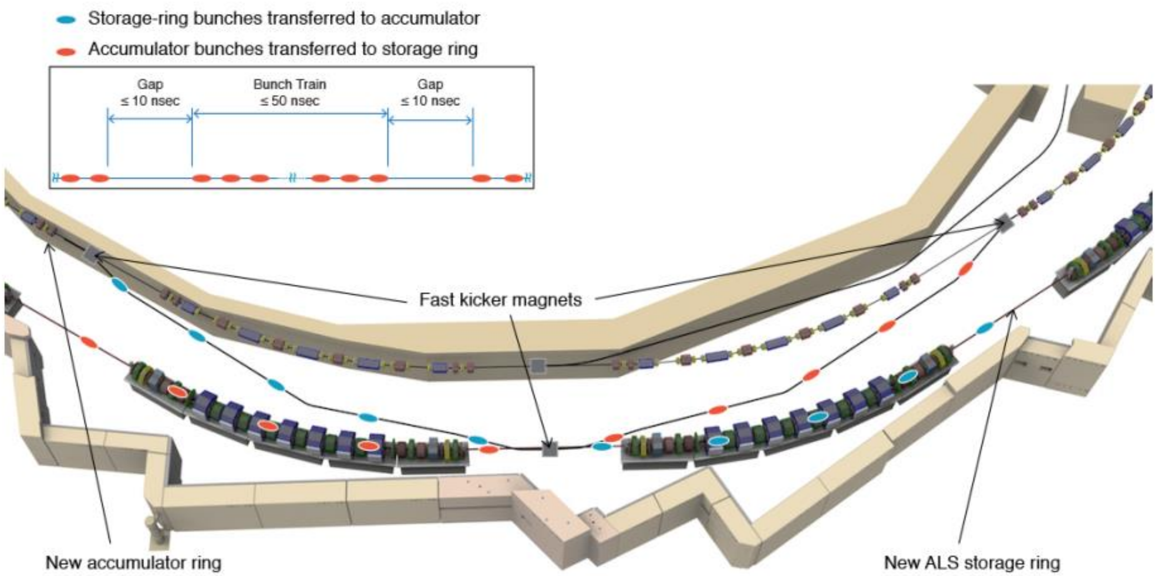
DLSR, 20ps
- high phase space density
- many scattering processes
- low lifetime, emit. increase



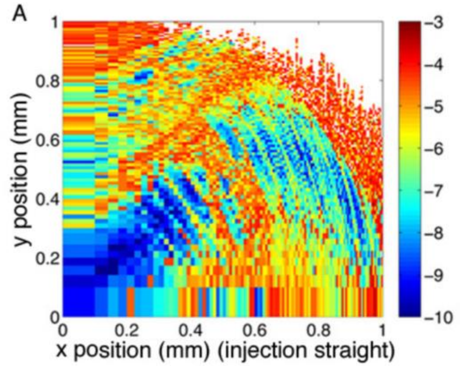
work around
- increase bunch length, 75 – 200 ps
- transfer hor. emittance to vert.
  "round beams"

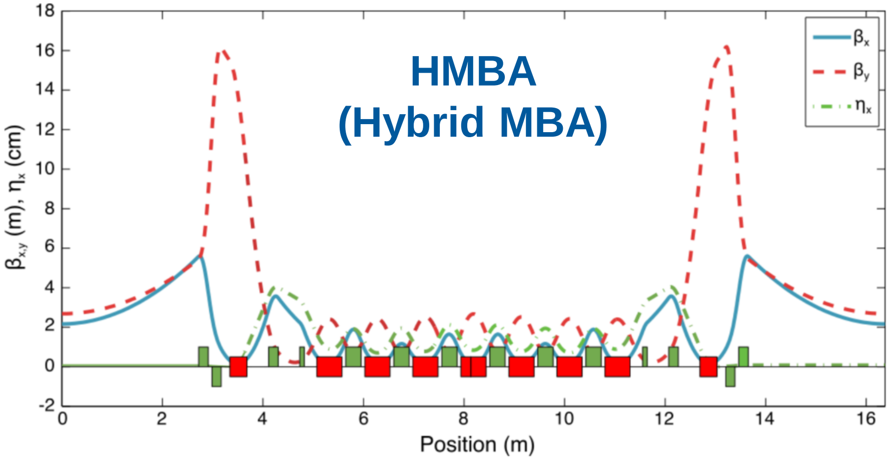
2 examples of new designs – ALS U (short, low energy)

ALS-U: 2 GeV, C = 200 m, 50 pm rad (round beam), 500 mA, ~ 200 ps



very low dynamic apperture

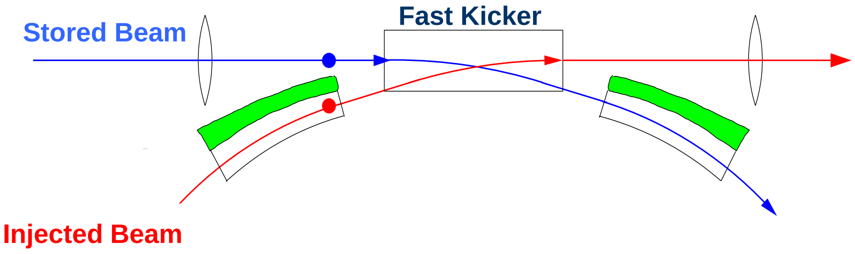




HMBA (Hybrid MBA)

On-axis swap-out injection

(initially proposed by M. Borland)



Stored Beam

Fast Kicker

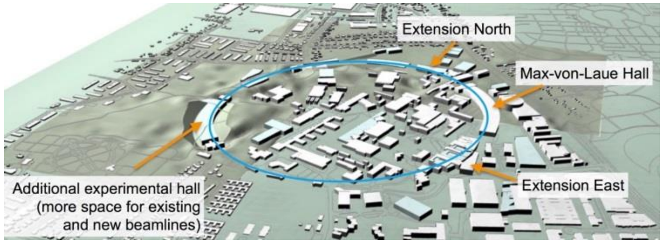
Injected Beam

(need additional accumulator ring)

ALS-U proposal, April 2016

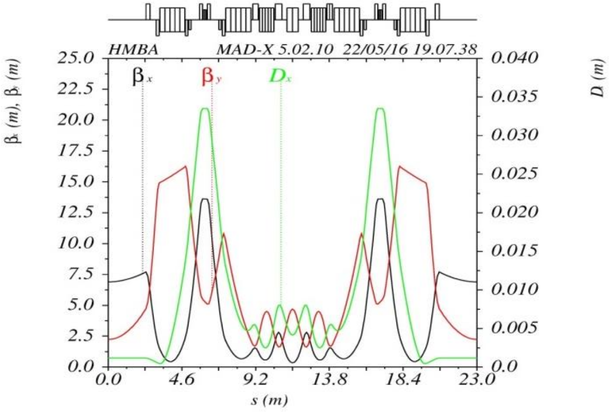
2 examples of new designs – PETRA IV (long, high energy)

PETRA IV: 6 GeV, C = 2300 m, ~ 10 pm rad (round beam), 100 mA, 100 ps



1. Lattice based on HMBA Cells

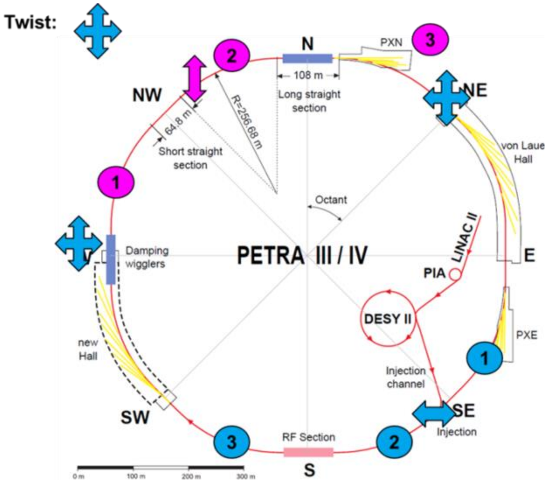
- Arcs: 9 HMBAs cells to build a 45° arc
- 8 identical arcs
- Straight sections: FODO cells

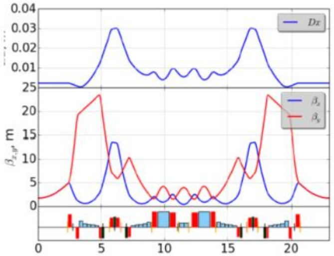


Horz. emittance of HMBA-based ring is 12 pm·rad at 6 GeV ✓
Cell not yet optimized,
(small dynamic aperture) ✗

2. 4D-phase space exchange and MBAs

- arc cells with non interleaved sextupoles
- Undulator section, preliminary version with HMBA



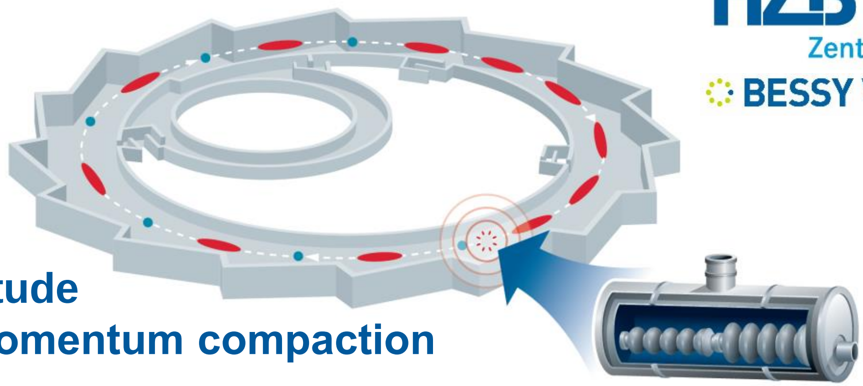


Emittance ~ 20/20 pm ✓
(5 GeV, wigglers not yet included)
Undulator cell not yet optimized ✗

R. Wanzenberg,
R. Brinkmann, et al.

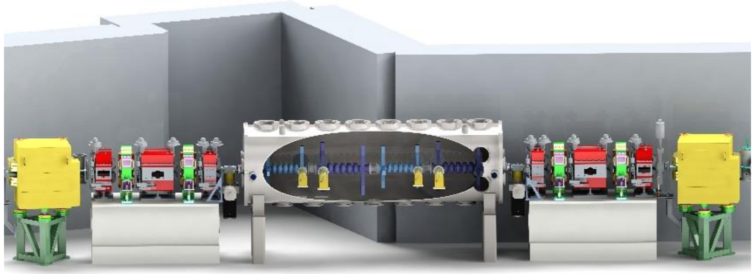
Alternative approach - variable pulse length storage ring

$$\sigma \propto \delta_0 \sqrt{\frac{E_0}{f_0} \cdot \frac{\alpha}{\dot{V}_{rf}}} \qquad I \propto \alpha$$

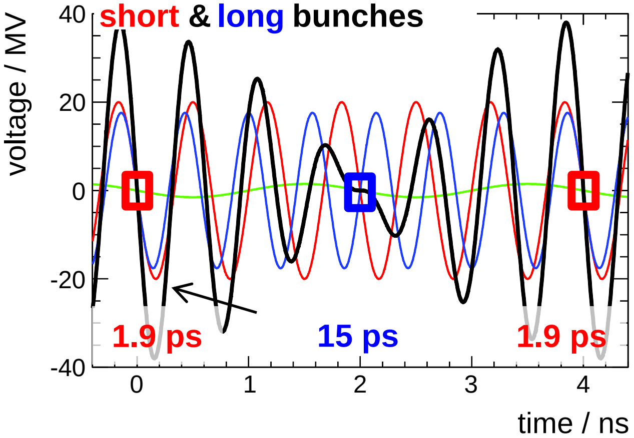


high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by to orders of magnitude
→ ca. 1/10 bunch length @ constant momentum compaction

Combining two RF systems with different frequencies (1.5 GHz & 1.75 GHz) generates long and short buckets, which can be filled individually to generate optimized fill pattern.

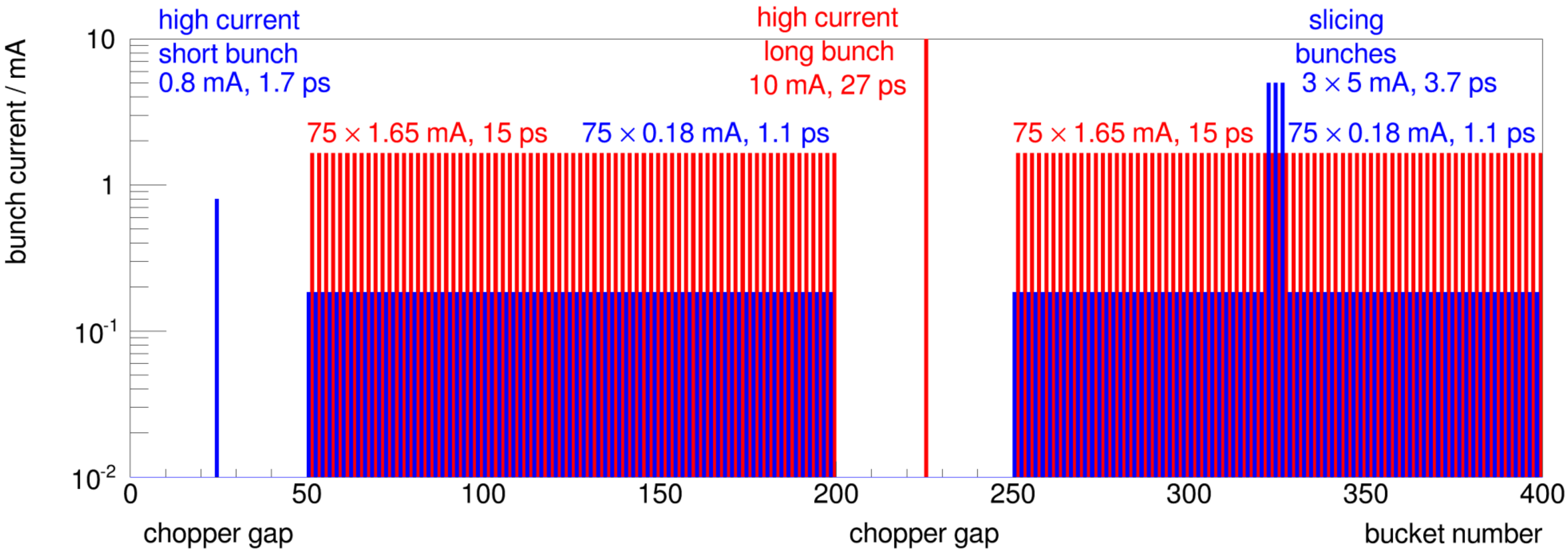


One cryo-module with:
2 x 4 cell @ 1.5 GHz & 2 x 4 cell @ 1.75 GHz
operating at **1.8 K LHe** temperature
active length: **1.50 m** with **20 MV/m**
total gradient: **2π 50 MV×GHz (x 60 increase)**



Installed voltage: 16 MV @ 1.5 GHz
14 MV @ 1.75 GHz

VSR – adding advanced timing capabilities to storage rings



- 300 mA average current
- camshaft single bunches (short and long) in gaps
- ion clearing provided through gaps

in low alpha mode
500 fs @ 0.04 mA / bunch

multi functional hybrid mode

ps short single bunch, high current single bunch, slicing bunches,
high average brilliance, background of intense CSR/THz radiation

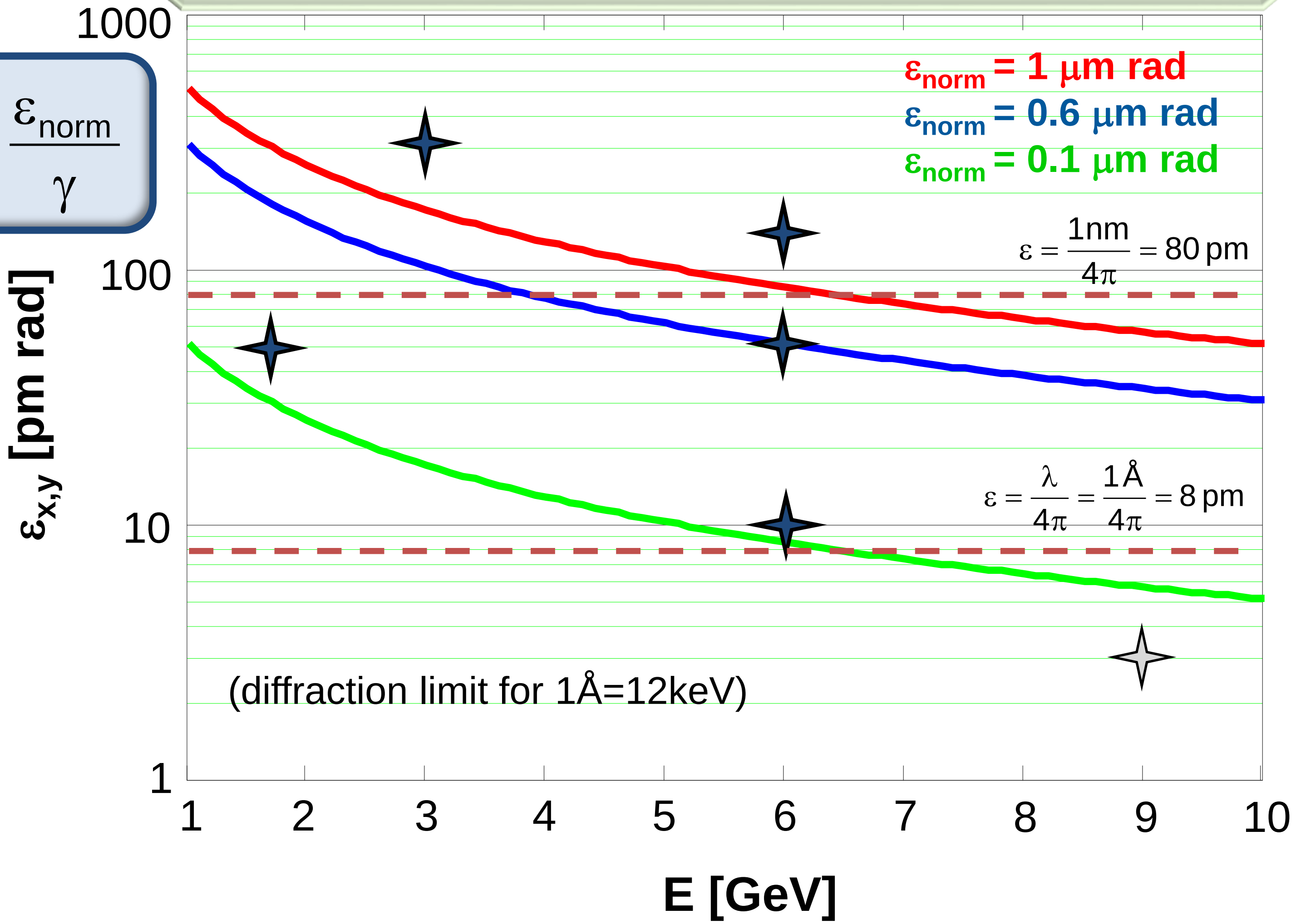
preserving BESSY II emittance and TopUp capabilities

Quo vadis storage rings

3rd generation light sources in operation (selection):

ALBA (5 nm@3 GeV), SOLEIL (4 nm@2.7 GeV), DIAMOND (3 nm@3 GeV),
ESRF (4 nm@6 GeV), APS (3 nm@7 GeV), SPring8 (3nm@8 GeV)
ALS (2.2 nm@1.9 GeV), PETRAIII (1 nm@6 GeV)

$$\varepsilon = \frac{\varepsilon_{\text{norm}}}{\gamma}$$



(H)MBA
ultra low emit.
lattices:

320 pm, MAX IV
(in operation)

147 pm, ESRF II
(2020 back in op.)

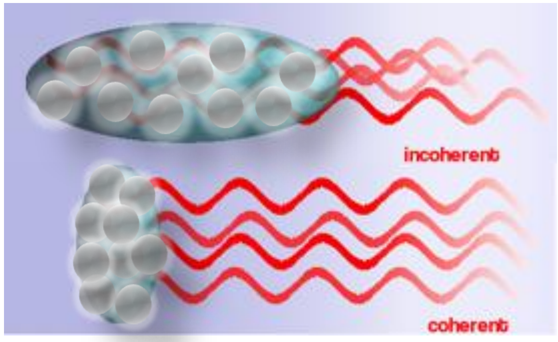
50 pm, APS
(design phase)

50 pm ALS
(design phase)

10 pm, PETRA IV
(design study)

3 pm, tUSR
(design study)

Other line of development – coherence / FELs



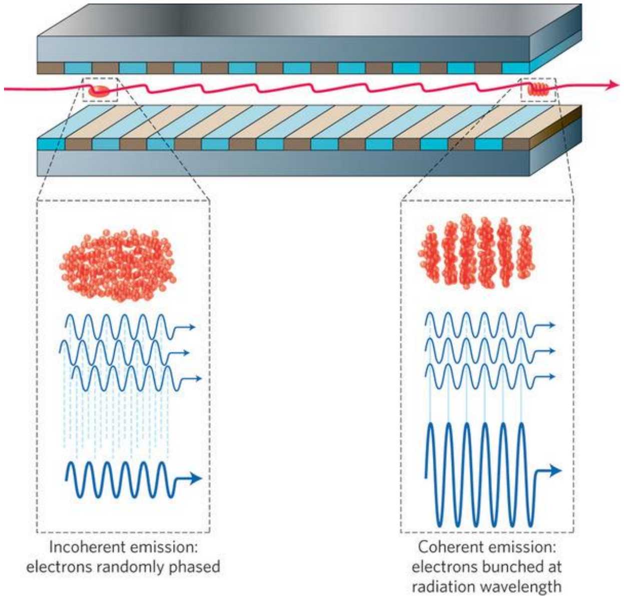
3ps **1mm**

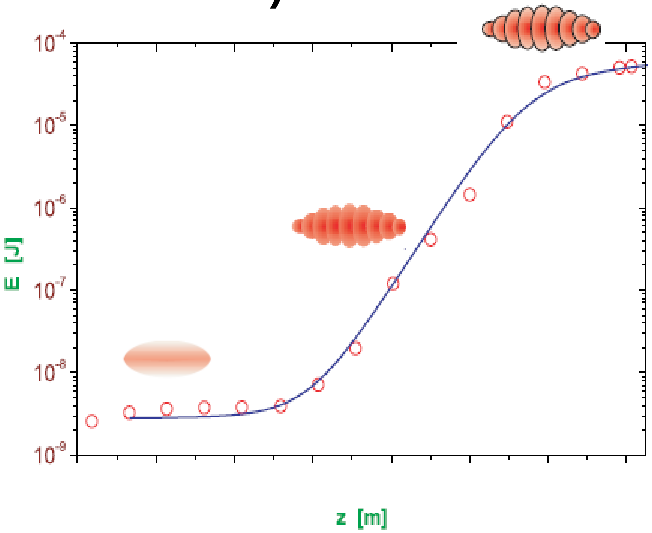
I ~ n_e (bunchlength > wavelength)

I ~ n_e^2 (bunchlength ~ wavelength)

SASE FEL

(self amplified spontaneous emission)



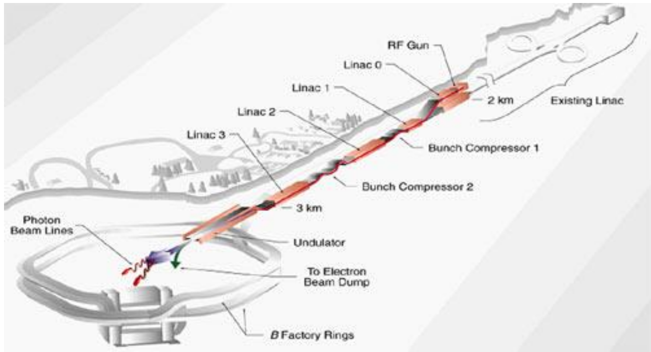


micro-bunching on wavelength scale allows to go for nm and even smaller
(e.g. FLASH 4.12nm@1.25GeV
LCLS 1.3A@15GeV)

SASE FELs

“nc copper machines”
- only 10 to 120 pulse per second

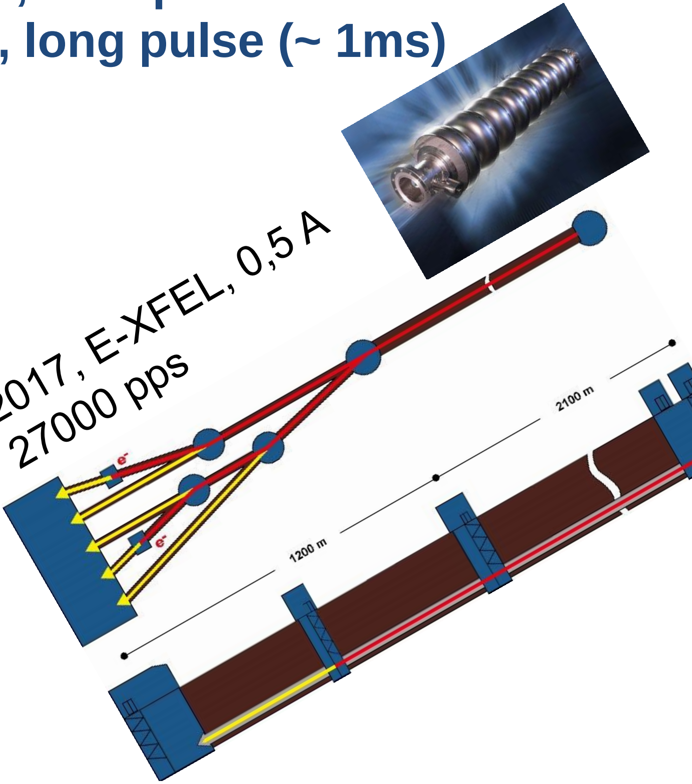
2009, LCLS-SLAC, < 1 A



2011, SACLA-RIKEN, 0.6 A

plus FERMI
SwissFEL, SASE FEL Pohang, …

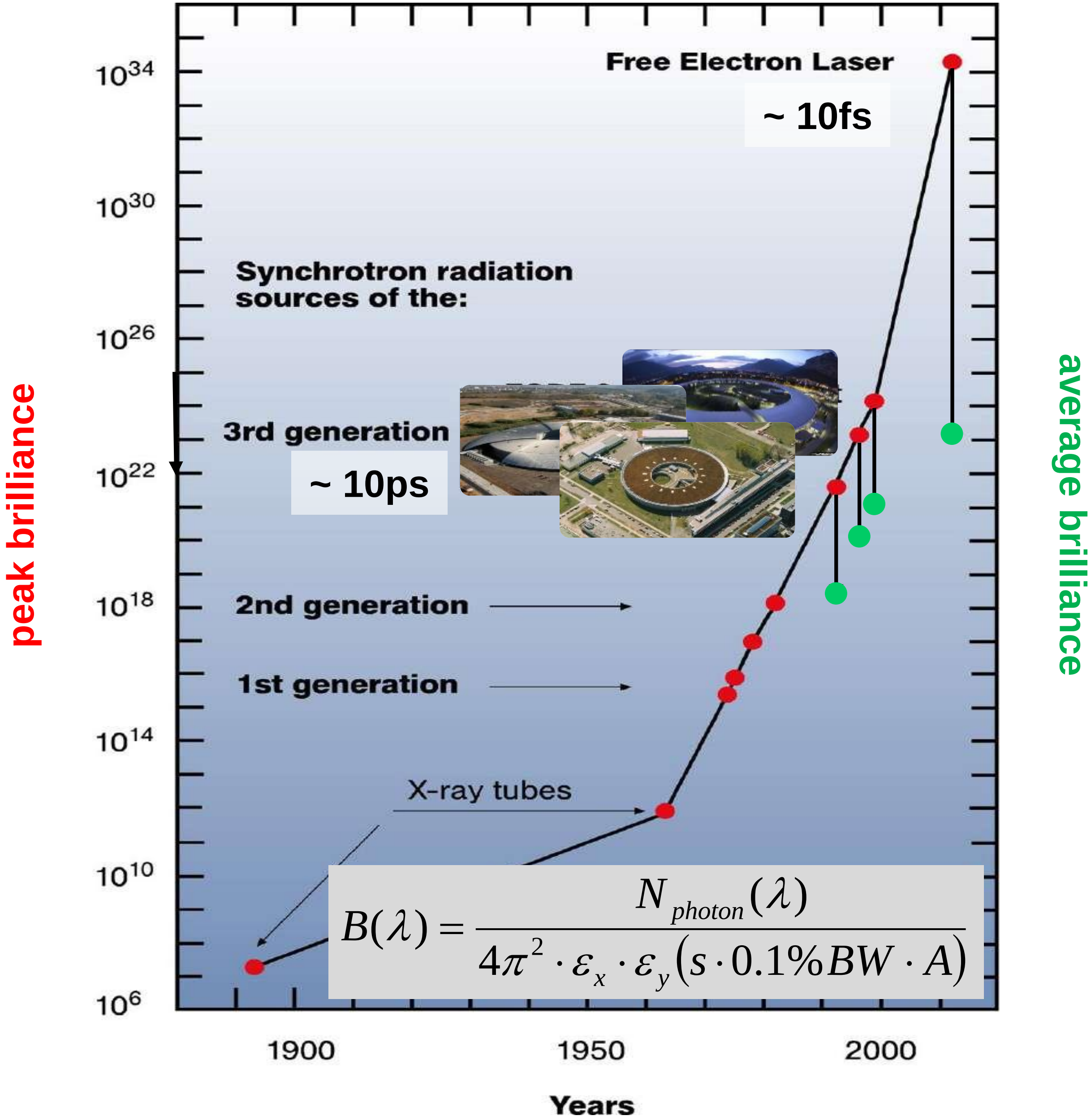
“sc niobium machines”
FLASH, EuropeanXFEL
- 10Hz, long pulse (~ 1ms)



2017 , E-XFEL, 0,5 A
27000 pps

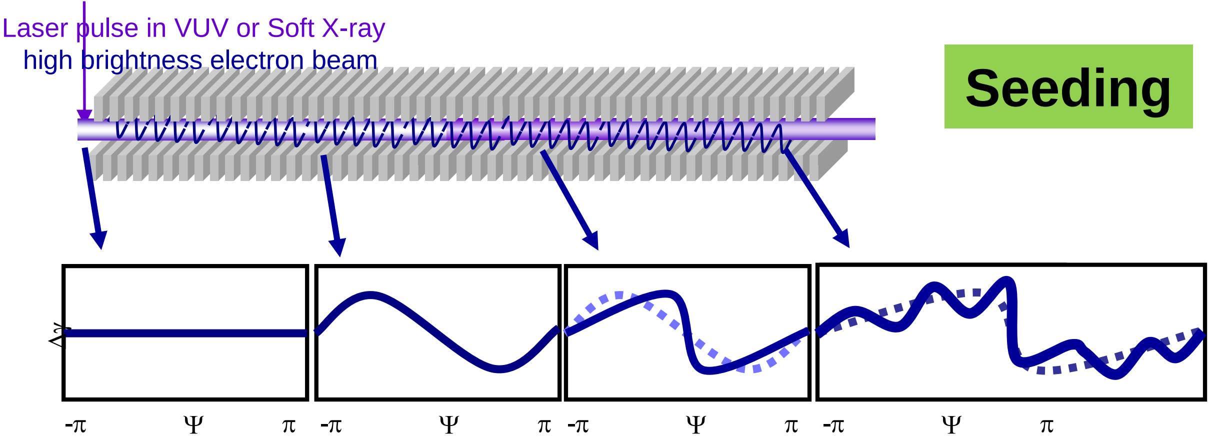
- **full transverse coherence**
- **extreme peak brilliance -> new experimental regime**
- **low number of beamlines**

Quo stas?

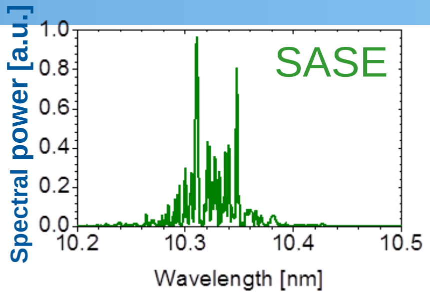


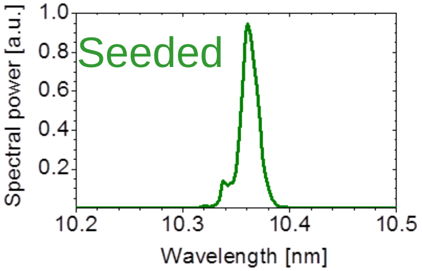
$$B(\lambda) = \frac{N_{photon}(\lambda)}{4\pi^2 \cdot \varepsilon_x \cdot \varepsilon_y \left(s \cdot 0.1\% BW \cdot A\right)}$$

Longitudinal coherence – improving spectral brightness

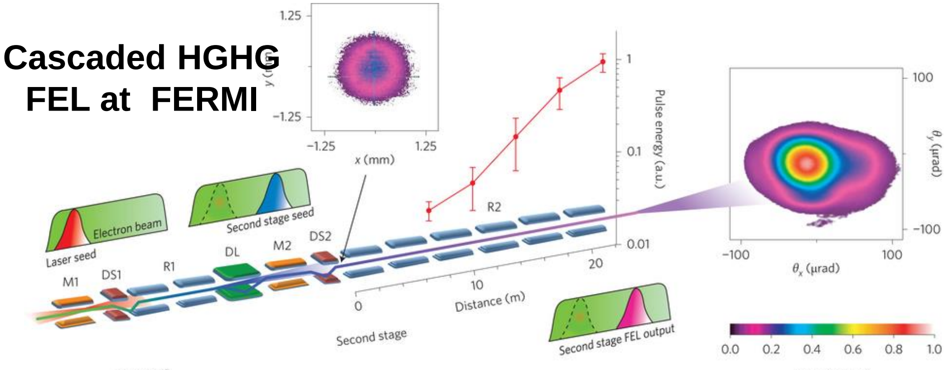


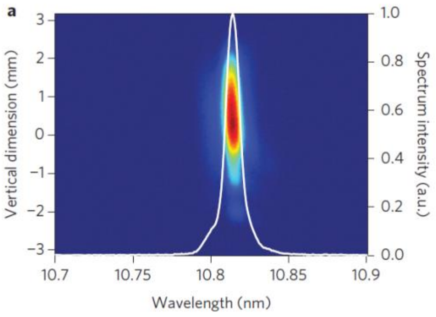
Seeding

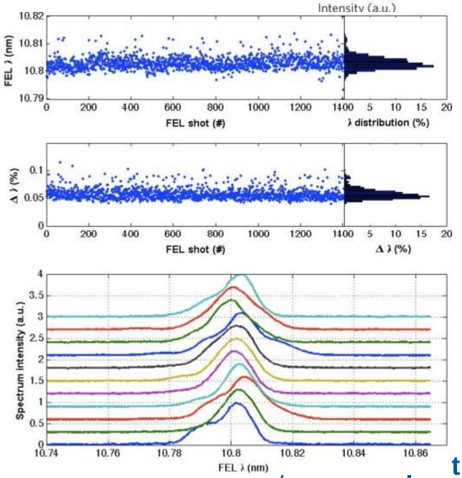




Cascaded HGHG FEL at FERMI

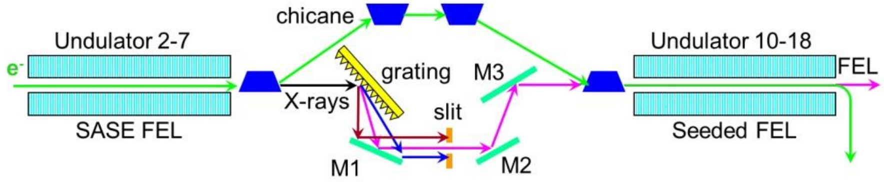




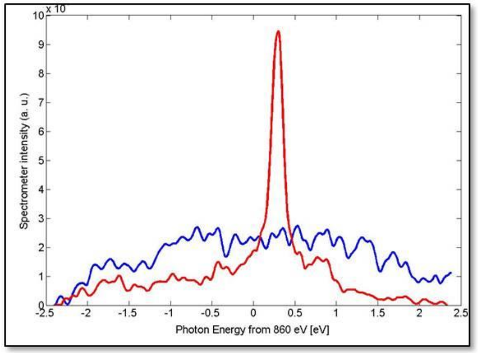


NATURE PHOTONICS | VOL 7 | NOVEMBER 2013 | p913-918

This diagram shows components in the **soft X-ray self-seeding system installed at SLAC's LCLS** X-ray laser.

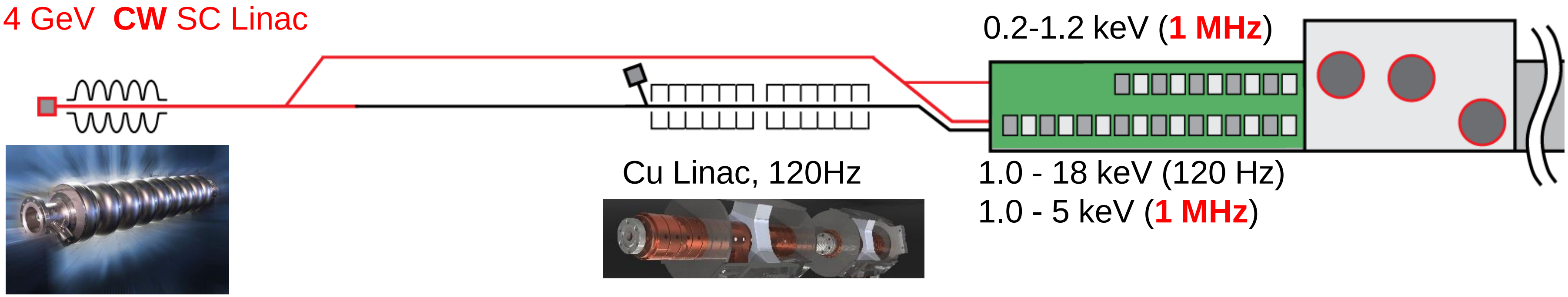


The red line graphed here shows a sharp spike in the intensity of X-ray light produced by a new soft X-ray self-seeding system at SLAC's LCLS X-ray laser. The blue line shows the fluctuations, or "noise," in a typical LCLS X-ray pulse without the use of self-seeding.



Walk on the CW Side !

LCLS II adds CW SRF linac (4 GeV), 10^4 more pulses (30x E-XFEL)



4 GeV **CW** SC Linac

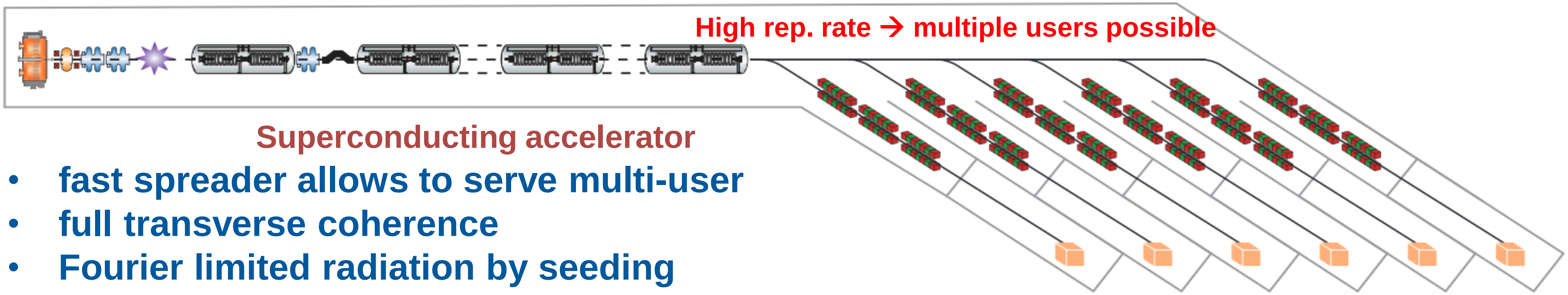
0.2-1.2 keV (**1 MHz**)

Cu Linac, 120Hz

1.0 - 18 keV (120 Hz)
1.0 - 5 keV (**1 MHz**)

CW studies for FLASH and E-XFEL started

And in the future:



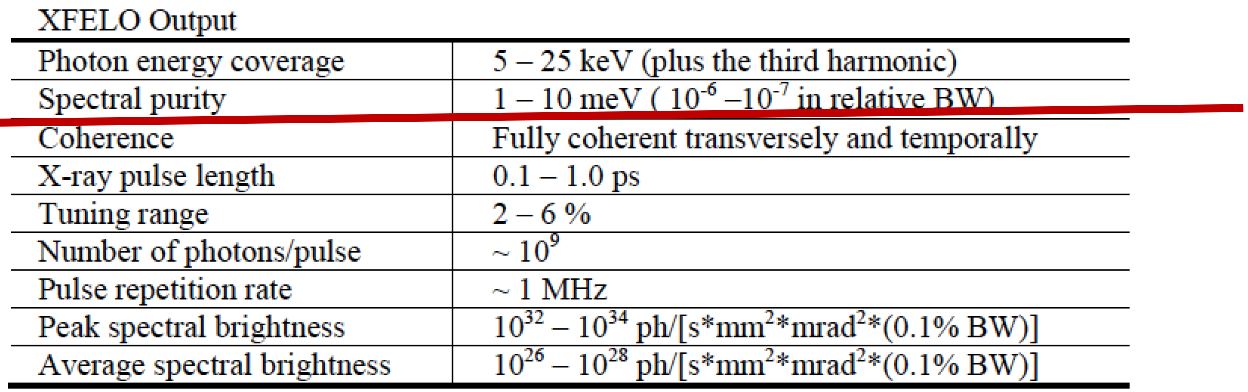
High rep. rate → multiple users possible

Superconducting accelerator

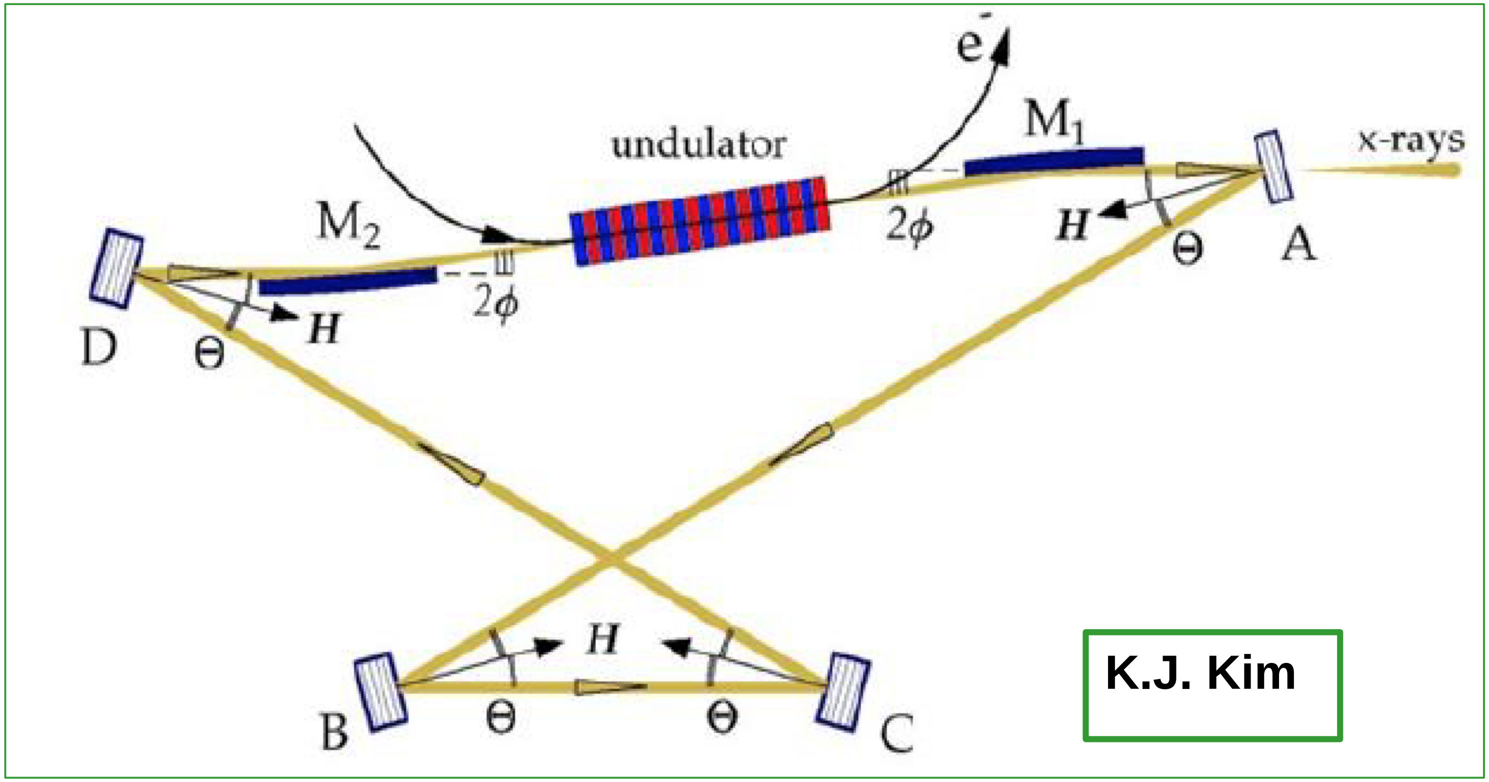
- **fast spreader allows to serve multi-user**
- **full transverse coherence**
- **Fourier limited radiation by seeding**
- **pulse length even down to ~ 100**
- **less peak flux allow to use high average flux**

NGLS like (LBNL, Berkeley)

XFEL – Osciallator (XFELO)



XFELO Output	
Photon energy coverage	5 – 25 keV (plus the third harmonic)
Spectral purity	1 – 10 meV (10^{-6} –10^{-7} in relative BW)
Coherence	Fully coherent transversely and temporally
X-ray pulse length	0.1 – 1.0 ps
Tuning range	2 – 6 %
Number of photons/pulse	~ 10^{9}
Pulse repetition rate	~ 1 MHz
Peak spectral brightness	10^{32} – 10^{34} ph/[s*mm^{2}*mrad^{2}*(0.1% BW)]
Average spectral brightness	10^{26} – 10^{28} ph/[s*mm^{2}*mrad^{2}*(0.1% BW)]



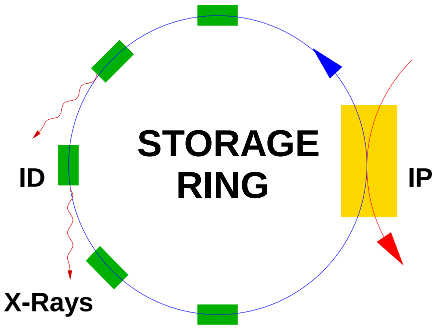
K.J. Kim

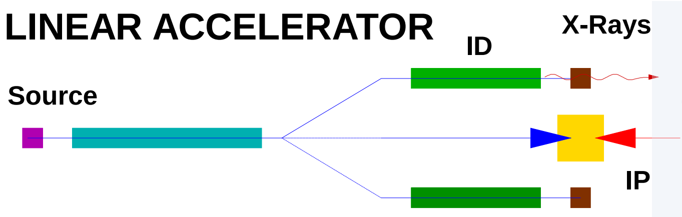
Energy Recovery Linacs – The idea

- high average („virtual“) beam power (up to A, many GeV)
- many user stations
- beam parameter defined by equilibrium
- typical long bunches (20 ps – 200 ps)

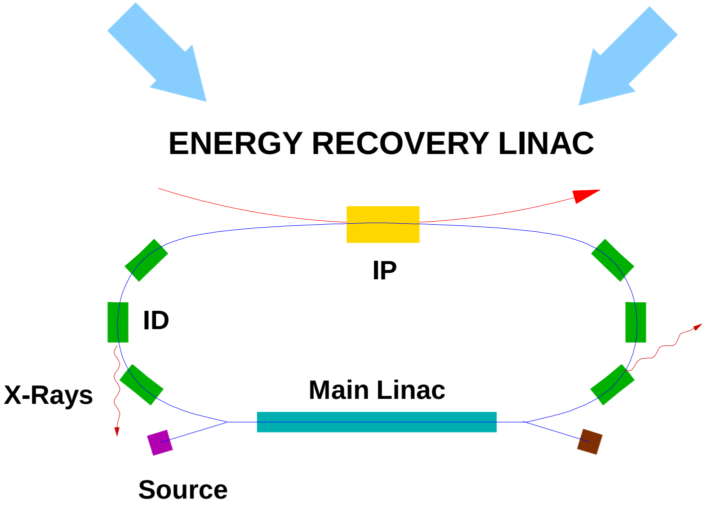
- outstanding beam parameter
- single pass experiments
- high flexibility, short bunches (~ 10 fs)
- low number of user stations
- limited average beam power (<<mA)

e.g. ESRF:
6 GeV, 200 mA
1.2 GW
virtual power,
stored energy
only 3380 J





e.g. XFEL:
17.5GeV, 33 µA
“only” ~ 600kW,
but real power

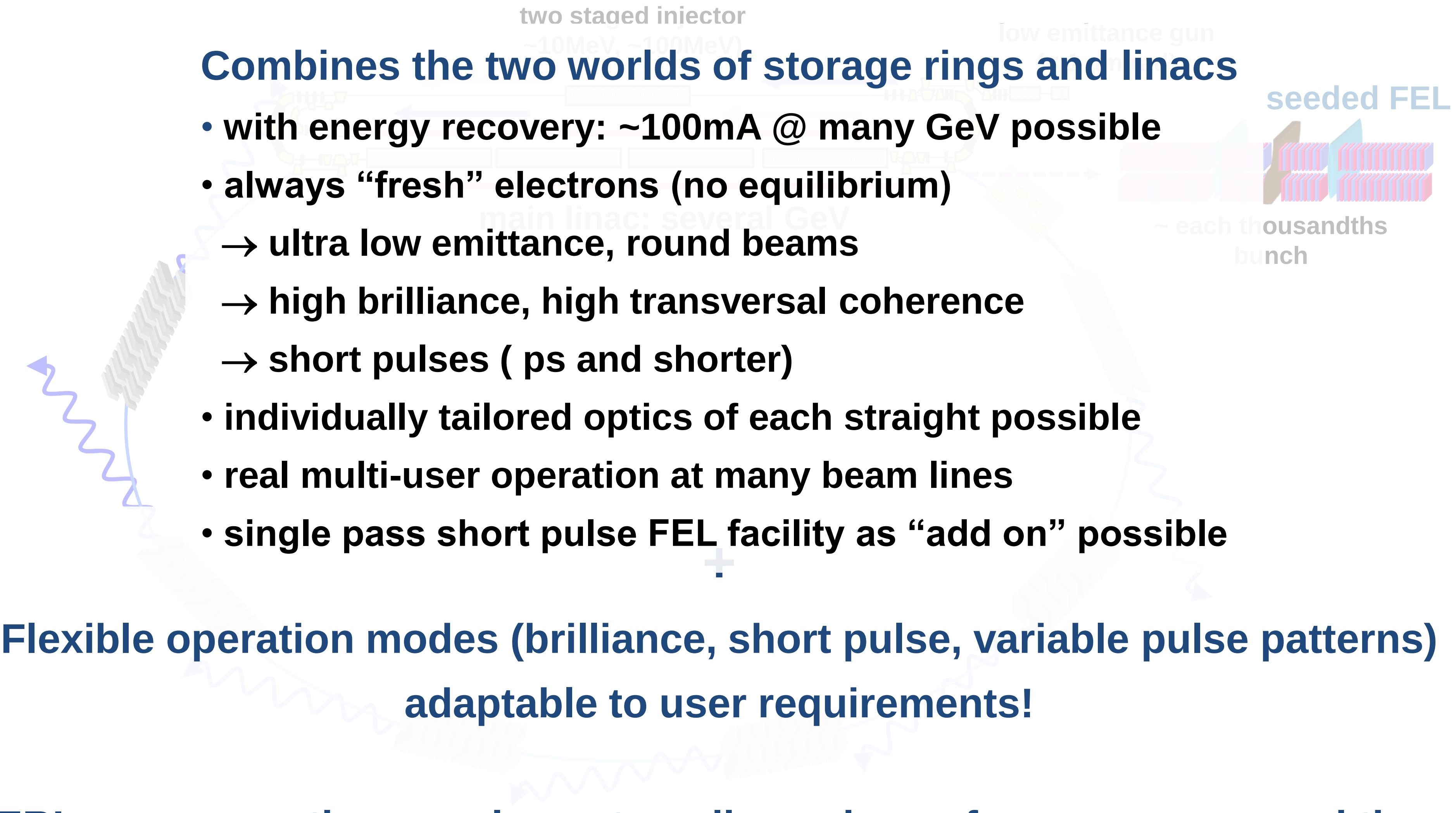


$$\varepsilon \sim \frac{1}{\gamma} \cdot \varepsilon_{\text{source}}$$

intrinsic short bunches,
high current

high average beam power (multi GeV @ some 100 mA) for single pass experiments, excellent beam parameters, high flexibility, multi user facility

ERL as next Generation Multi-GeV, Multi-User SR-Source



Combines the two worlds of storage rings and linacs

- **with energy recovery: ~100mA @ many GeV possible**
- **always “fresh” electrons (no equilibrium)**
  - **→ ultra low emittance, round beams**
  - **→ high brilliance, high transversal coherence**
  - **→ short pulses (ps and shorter)**
- **individually tailored optics of each straight possible**
- **real multi-user operation at many beam lines**
- **single pass short pulse FEL facility as “add on” possible**

Flexible operation modes (brilliance, short pulse, variable pulse patterns)

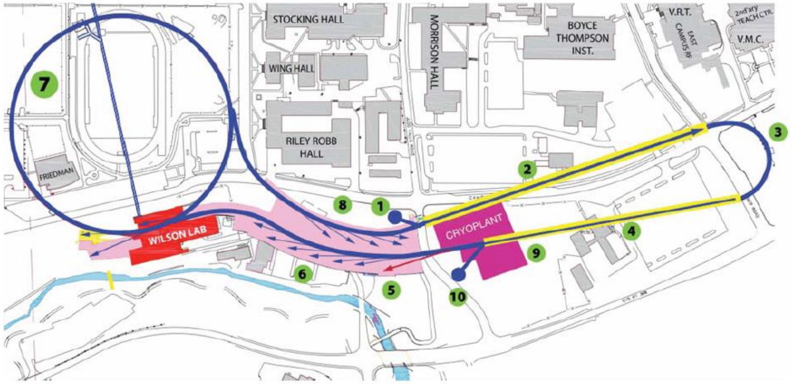
adaptable to user requirements!

ERLs opens up the complementary dimensions of energy, space and time

(spectroscopy, structure und dynamics)

ERL light source design studies

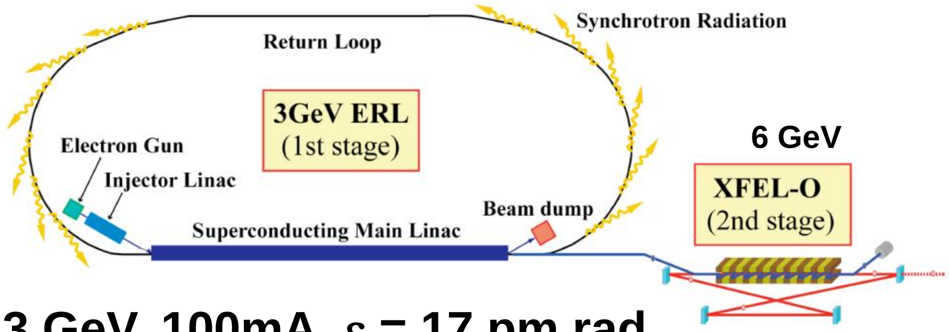
Cornell ERL



5 GeV, 100mA, ε = 8 pm rad

(ε_{norm} = 0.08 μm (@77pC) , 2ps)

KEK ERL

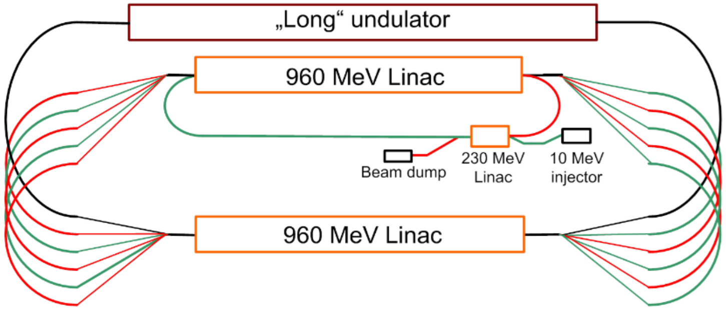


3 GeV, 100mA, ε = 17 pm rad

(ε_{norm} = 0.1 μm (@77pC) , 2ps)

Femto Science Facility (FSF)

(multi turn, split linac), A. Matveenko et al.

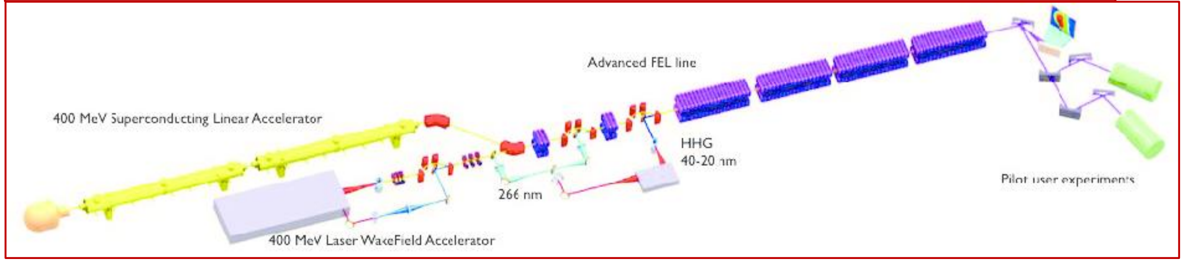


6 GeV, 20/5 mA, ε = 8/40 pm rad

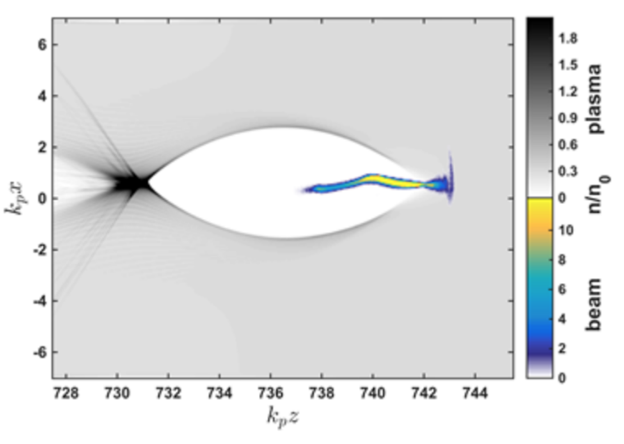
(ε_{norm} = 0.1/0.5 μm (@15/4 pC), < 1 ps / 10 fs)

LWFA / PWFA accelerators

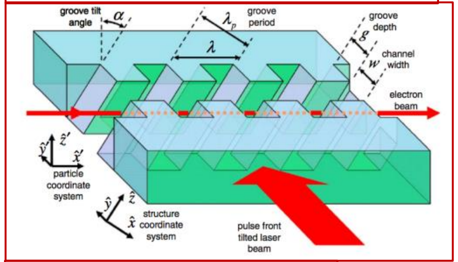
LUNEX 5 (FEL, Using a new accelerator for the Exploitation n of X-ray radiation of 5th generation)



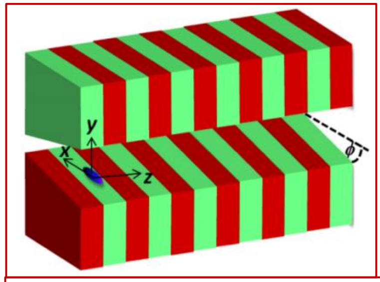
FLASHForward



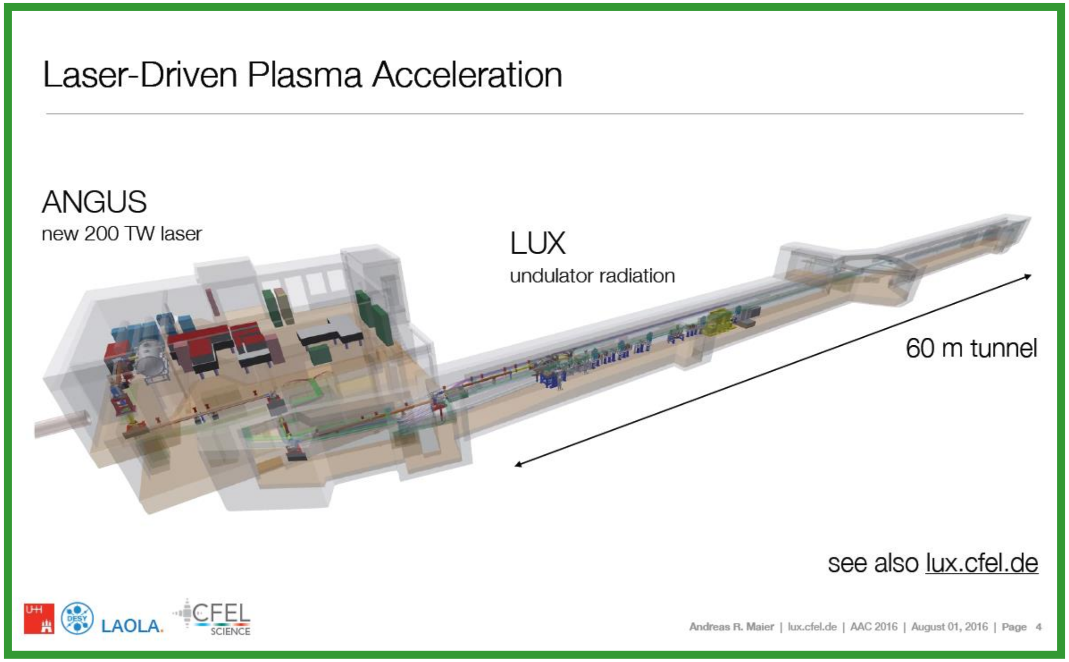
Laser/dielectric



Plettner and Byer



Transverse gradient undulator; Z. Huang



Laser-Driven Plasma Acceleration

ANGUS
new 200 TW laser

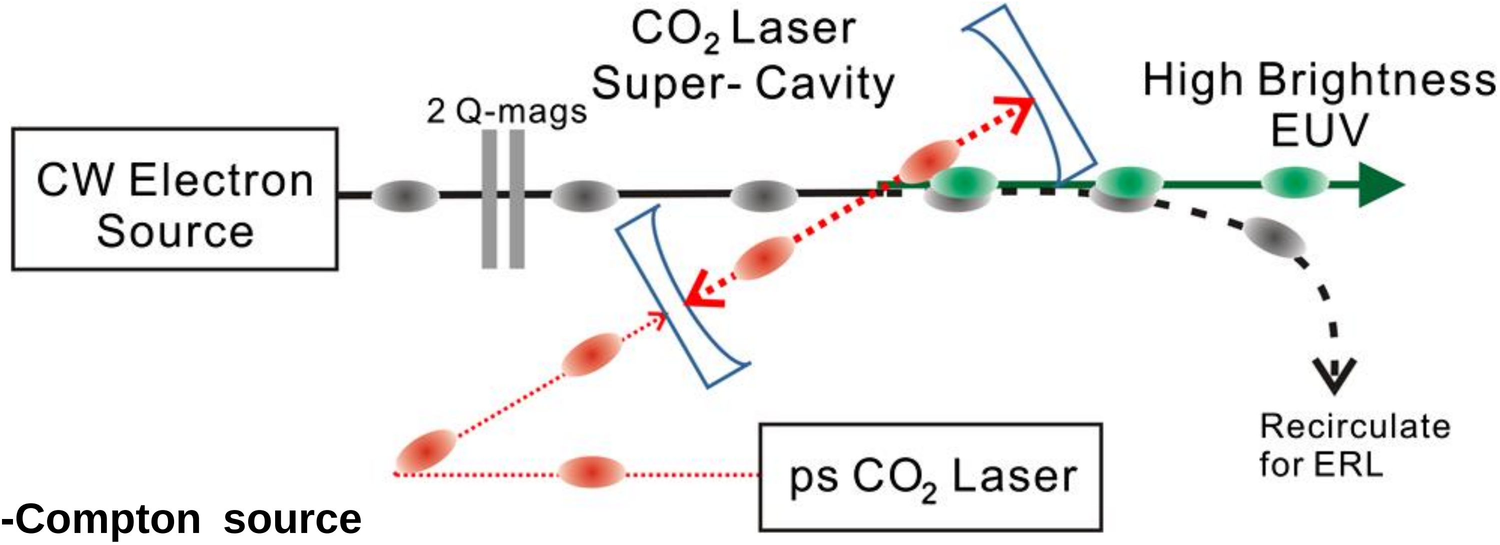
LUX
undulator radiation

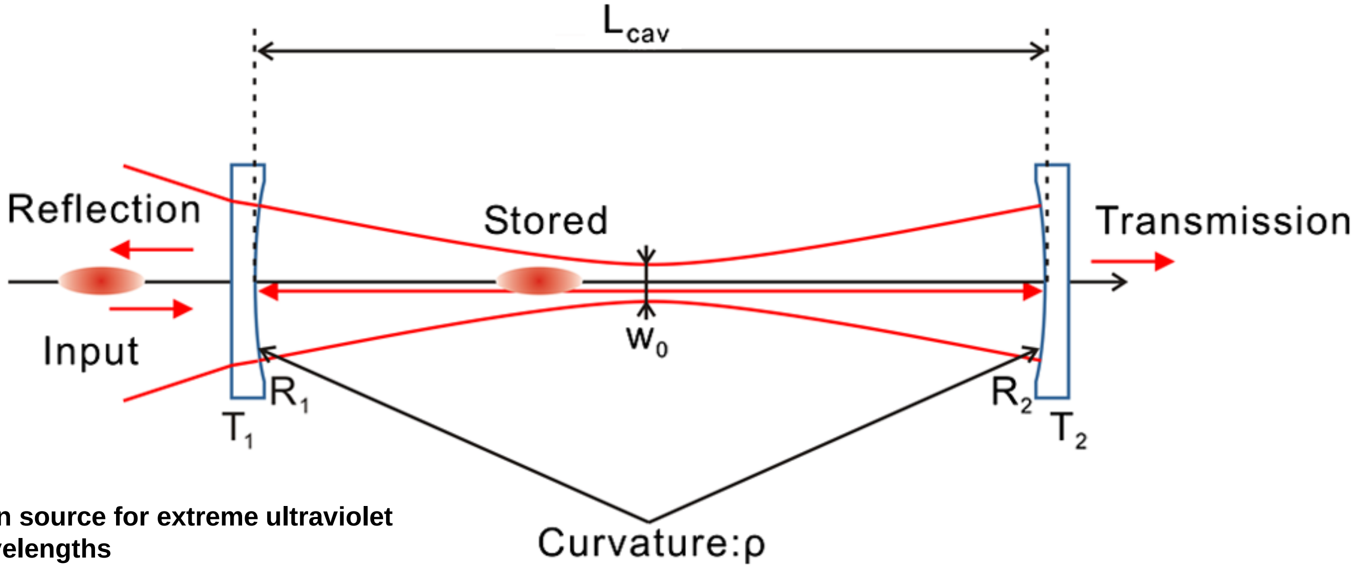
60 m tunnel

see also lux.cfel.de

Andreas R. Maier | lux.cfel.de | AAC 2016 | August 01, 2016 | Page 4

Compton Sources





Laser-Compton source Design of a clean, high-brightness light source is presented for extreme ultraviolet/soft x-ray (EUV/SXR) lithography research and mask inspection.

Design of high brightness laser-Compton source for extreme ultraviolet and soft x-ray wavelengths
Kazuyuki Sakaue ; Akira Endo ; Masakazu Washio
***J. Micro/Nanolith. MEMS MOEMS*. 11(2), 021124 (May 03, 2012).**

Ultra Compact Compton Sources (independent cavity ERL)

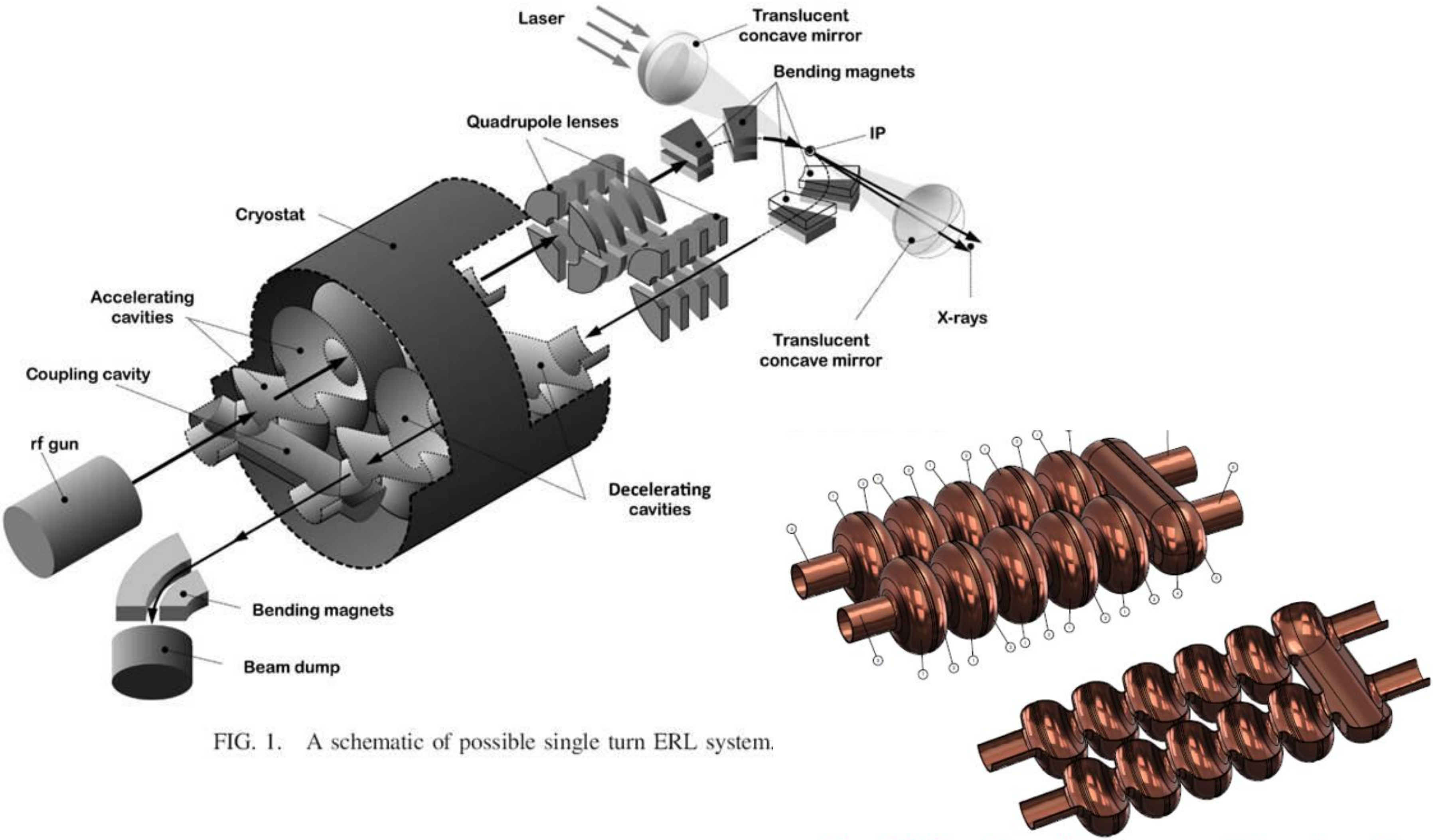


FIG. 1. A schematic of possible single turn ERL system.

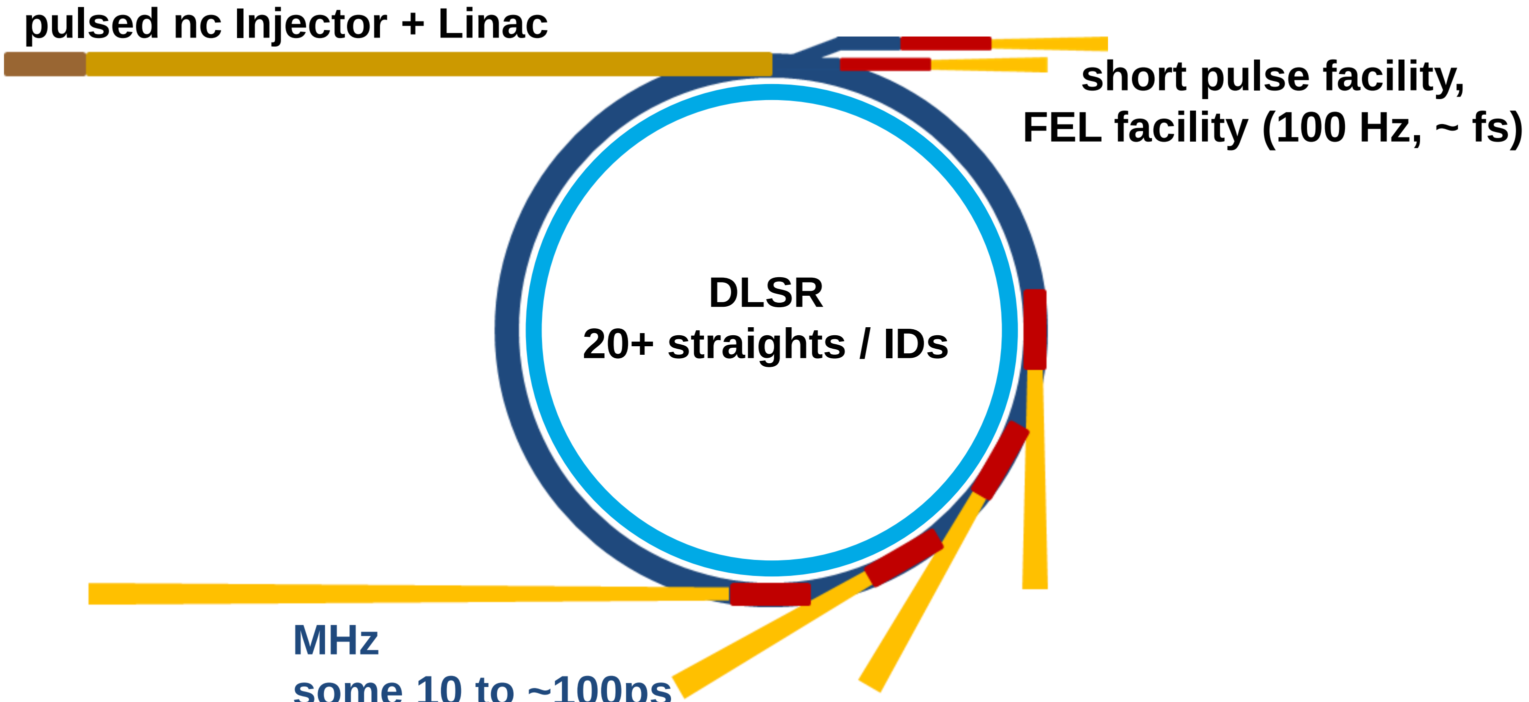
- 11 cell full scale cavity copper prototype is under construction.

PRAB paper:
http://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.19.083502

Conclusion

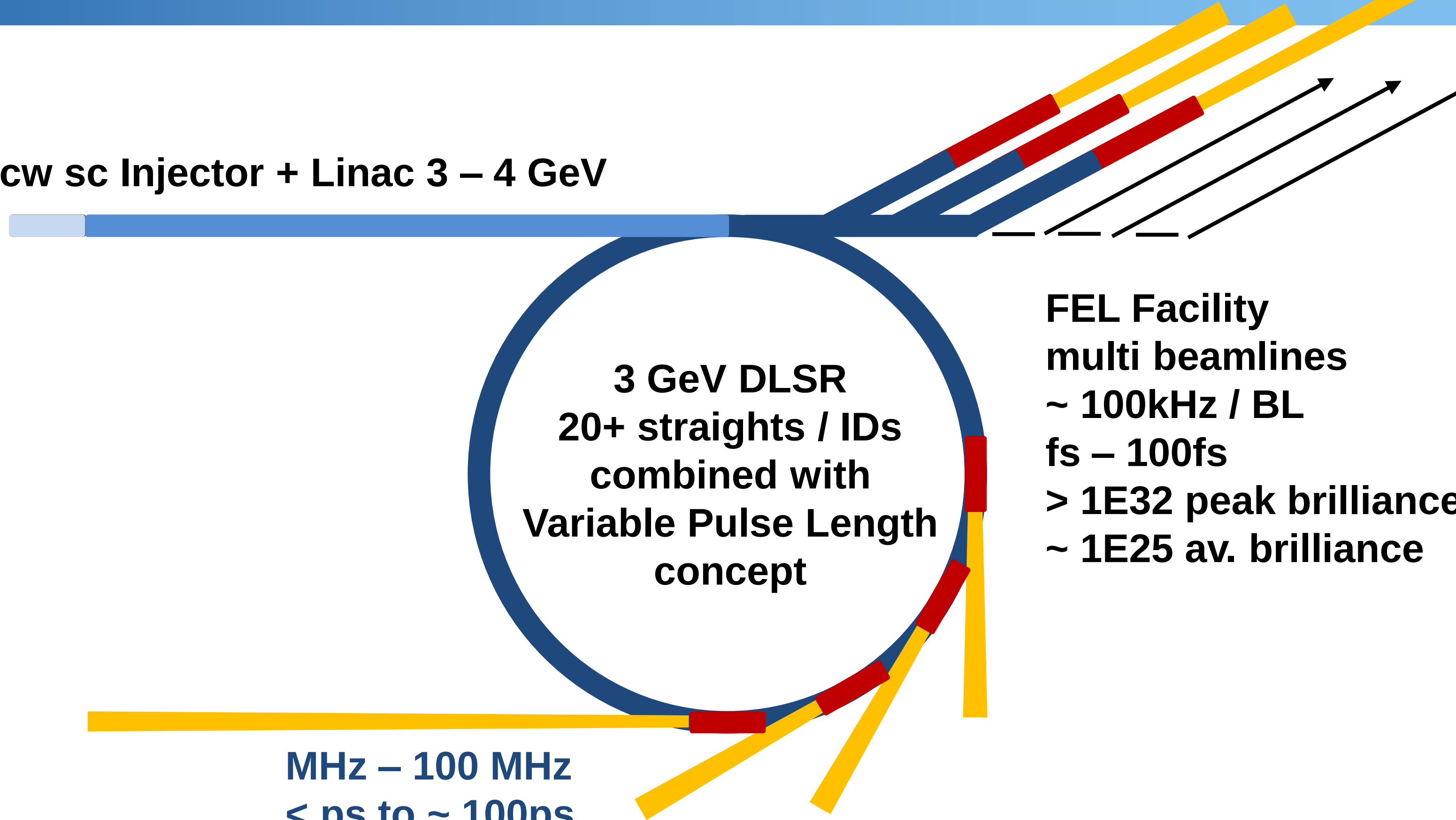
DLSR with NC full energy injector linac

First of its kind:	MAX IV (start 2016)
Many upgrades and new rings:	ESRF, ALS-U, PETRA, APS-U, DIAMOND2, SIRIUS, ..



rep rate:	MHz
pulse length:	some 10 to ~100ps
emittance:	< 10 pm rad – some 100 pm rad
	round beams
average brilliance:	> 1E22 /s/mm²/mrad²/0.1% (“usable” photons)
peak brilliance:	> 1E23 /s/mm²/mrad²/0.1%
energy:	some 10eV – 10keV – …
energy width [%]:	0.1

DLSR / multi-user FEL, based on cw sc full energy injector linac



cw sc Injector + Linac 3 – 4 GeV

3 GeV DLSR
20+ straights / IDs
combined with
Variable Pulse Length
concept

FEL Facility
multi beamlines
~ 100kHz / BL
fs – 100fs
> 1E32 peak brillianc
~ 1E25 av. brilliance

rep rate:	MHz – 100 MHz
pulse length:	< ps to ~ 100ps
emittance:	< 100 pm rad
	round beams
average brilliance:	1E22 /s/mm^2/mrad^2/0.1% (“usable” photons)
peak brilliance:	1E24 /s/mm^2/mrad^2/0.1%
energy:	some 100eV – 10keV
energy width [%]:	0.1

CW SC linac driven multi-user FEL facility

First of its kind:	**LCSL II (start 2019/20)**
Design of “real” multi user facility:	**NGLS like (Berkeley)**

many beamlines in parallel,
longitudinal cascaded operation

sc cw Injector + LINAC

spreader

N = 10 (number of BL), f_{rep} = 100 kHz,
E = 10 GeV, q = 200 pC

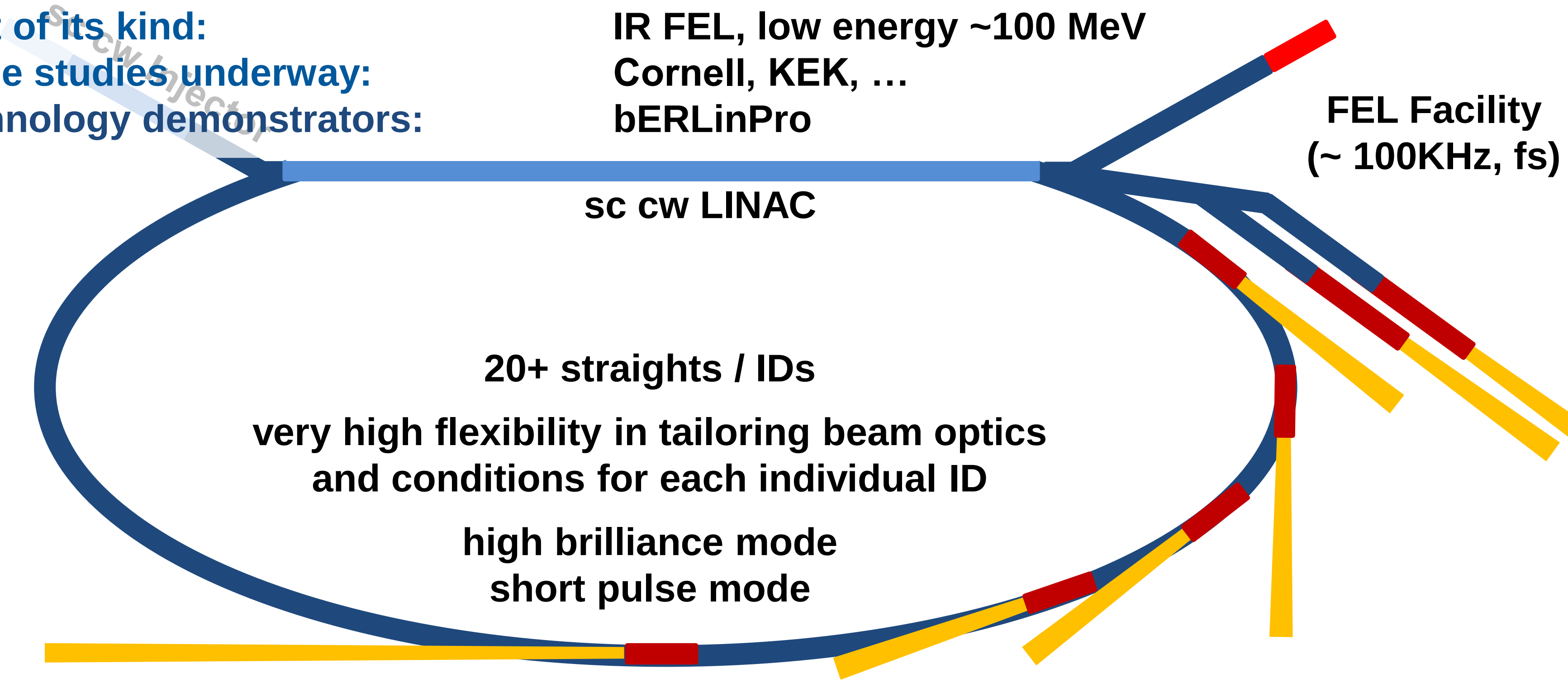
$$P_{beam} = N \cdot f_{rep} \cdot E \cdot q = 2\,\mathrm{MW}$$

rep. rate (per Beamline):	**100 kHz feasible**
pulse length:	**sub fs to 100fs**
normalized emittance/mm^2:	**< 0.6 mm mrad**

average brilliance:	**> 1E25 /s/mm^2/mrad^2/0.1% (“usable” photons)**
peak brilliance:	**> 2E32 /s/mm^2/mrad^2/0.1%**
energy:	**some 100eV – 5keV – 10keV – …**
bandwidth [%] FWHM:	**0.005**

CW SC linac driven ERL

First of its kind:	**IR FEL, low energy ~100 MeV**
Some studies underway:	**Cornell, KEK, …**
Technology demonstrators:	**bERLinPro**



20+ straights / IDs

very high flexibility in tailoring beam optics
and conditions for each individual ID

high brilliance mode
short pulse mode

rep rate:	**MHz to GHz**
pulse length:	**10 fs – 100 fs – 2ps**
emittance:	**20 - 100 pm rad** **round beams**

average brilliance:	**2E22 /s/mm^2/mrad^2/0.1% (“usable” photons)**
peak brilliance:	**1E25 – 1E26 /s/mm^2/mrad^2/0.1%**
energy:	**some 10eV – 10 keV**
energy width [%]:	**0.001 – 0.1**

Somewhat in the future

Conclusion

- **many existing large scale facilities are aiming for upgrades**

  DLSR – ESRF, PETRA, ALS, APS, DIAMOND, SOLEIL, …
  VSR – BESSY
  FEL – cw upgrades FLASH, XFEL, … / more beam lines / higher Energy
  but upgrade = possibilities always somewhat constrained

- **at present no proposal for a “new, greenfield” large scale facility**

  - we have many tools in hand (DLSR, VSR, cwFEL, ERL)
  - science case “for the facility” will decide about technology

- **technology development will be important driver**

  - high gradient (100 T/m and more), multipole and combined function magnets
  - permanent magnets, also for “more efficiency”
  - fast kicker magnets (ns), transparent injection, beam separation in switch yeards
  - new ID concepts, short period, low gap, making use of round beams and small dynamic aperture
  - low aperture vacuum systems (< 5mm)
  - high brightness, high current photon sources (< 0.1 μm rad, mA – 100mA+)
  - high gradient, high Q, high temp. SRF / cwSRF, HOM extraction
  - laser for seeding, pump-probe, synchronisation, seeding technics, ….

- **novel acceleration concepts (PWA, dielectric structure) have great potential**

  - LPWA as “laboratory scale devices”, low rep. rate
  - BD PWA have potential for “compact” multi user facility