17TH ADVANCED BEAM DYNAMICS WORKSHOP ON

FUTURE LIGHT SOURCES

WG3 Summary Viewgraphs

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ARGONNE NATIONAL LABORATORY, ARGONNE, IL U.S.A.

SKETCH OF A FUTURE STORAGE RING BASED SOURCE

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BASED ON 2 × APS/ESRF TYPE MACHINE + DAMPING WIGGLERS

- CIRCUMFERENCE ~ 2 KM
- MORE THAN 30 6M LONG STRAIGHT SECTIONS FOR IDs
- THE REST WILL BE OCCUPIED BY WIGGLERS, RF CAVITIES, ...

E = 4 GeV

$\varepsilon_x \searrow$ 1) DOUBLING THE CIRCUMFERENCE (θ^3 DEPENDENCE)
2) SCALING WITH E^2
3) DAMPING WIGGLERS

$\downarrow$

ε_x = 20 pm

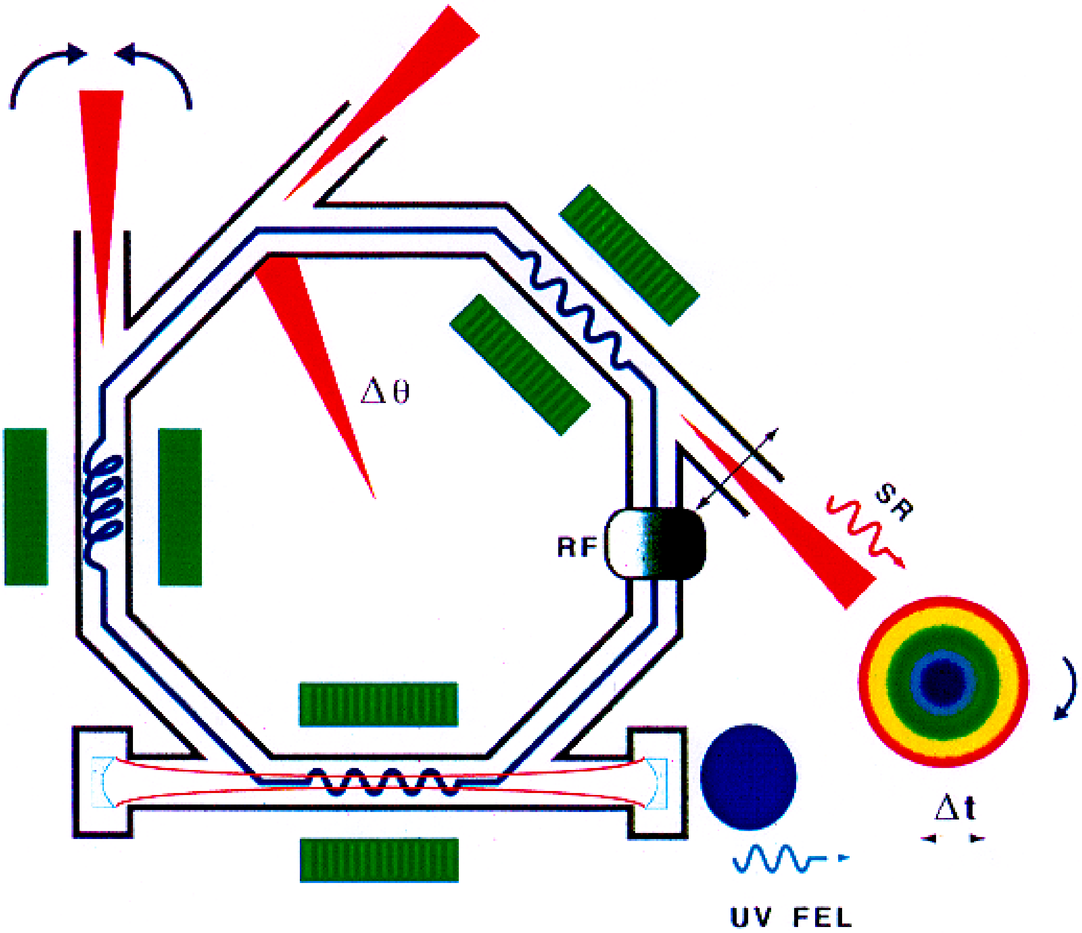
I = 2 A (RF at 350 MHz, 2000 - 2500 bunch $\Rightarrow$ 1 mA/bunch $\Rightarrow$ far from the intensity threshold)

$\Downarrow$

BRILLIANCE $2\ 10^{24}$ at 1 Å

i.e 4 orders of magnitude higher than operating facilities

"RING BASED SOURCES" OBJECTIVES



- Transverse and longitudinal dynamics. Modelization
- Ultimate performances opening new scientific opportunities
- Present situation and prospects concerning SRFELs
- Sources comparison

- Storage Ring Based sources provides 146 100 hours of operation / year (1998)

ref R. Walker EPAC

→ with 117 ID "

→ multi-users

10 000 users in 3 y. in Europe

Variety of ring based sources (E, I, generation, temporal structure)

3 BL in IR asked on Diamond

under construction

CLS, ANKA, INDUS II, New Subaru, SLS

under project

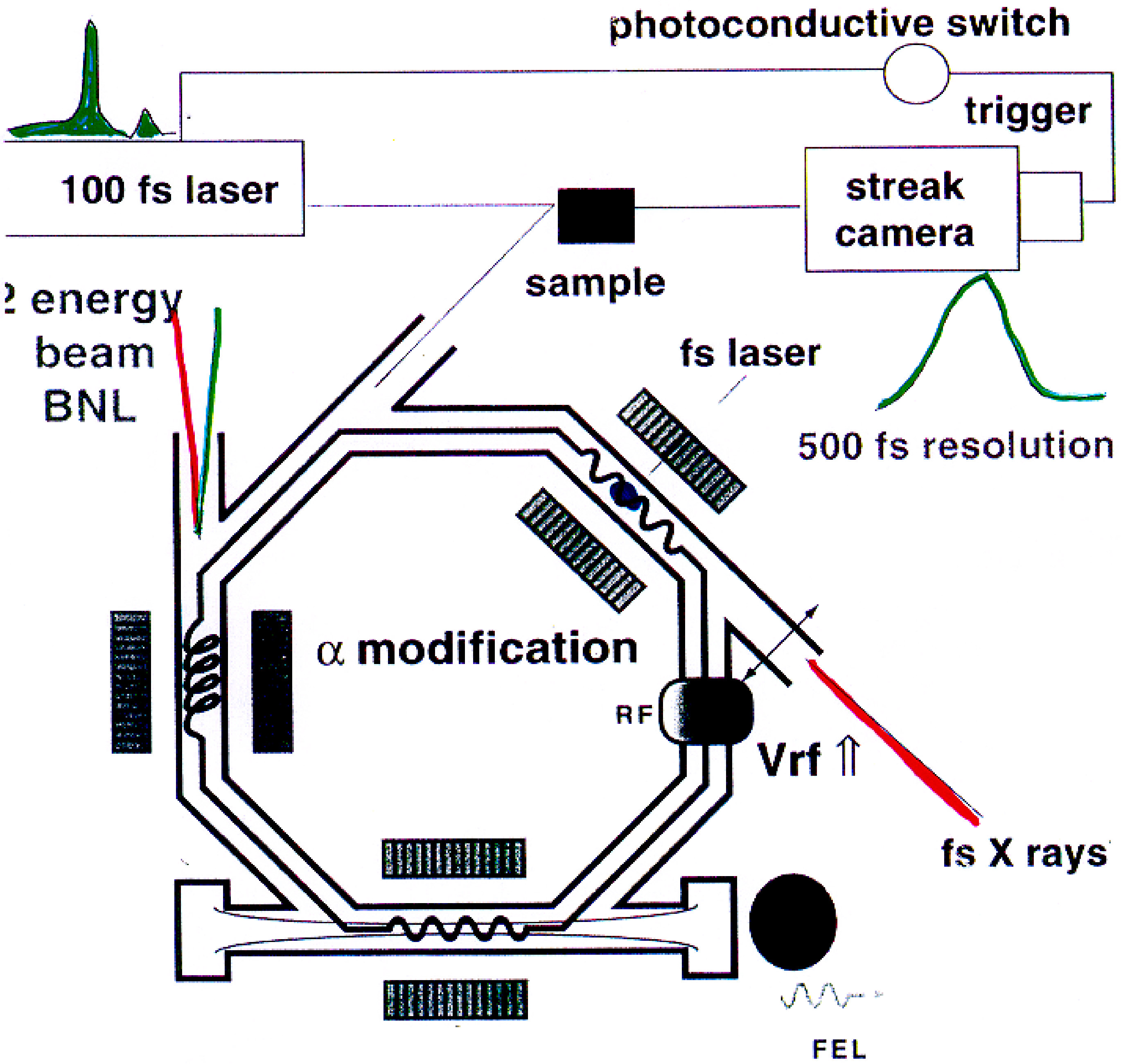
SSRF, ASTRID II, DIAMOND, SOLEIL, PF-AA, Tohoku U, VSX, LSB

- High stability (sub-μm
- High reliability
- Polarization (fast switching)
- Energy scan
- Small gap undulators
- Topping-up

high developments in the future

6th april WGS3-4

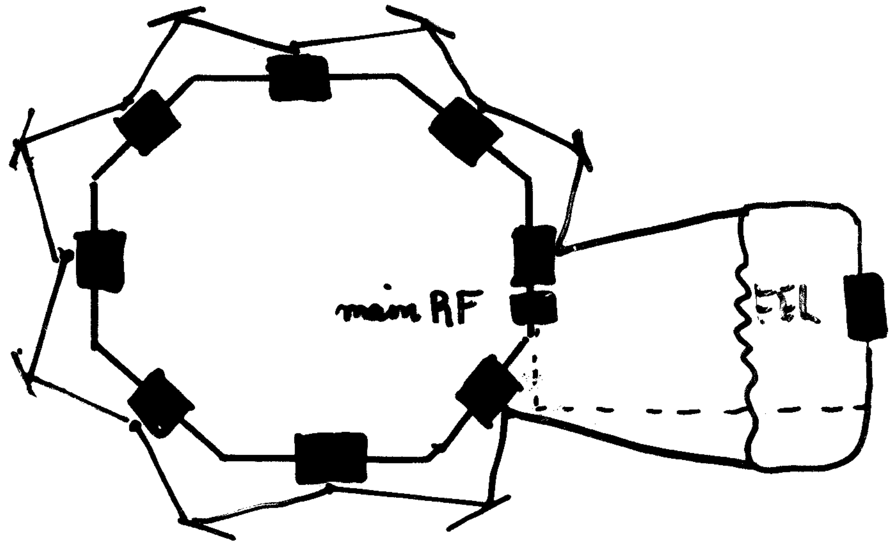
Longitudinal beam dynamics- Short electron bunches



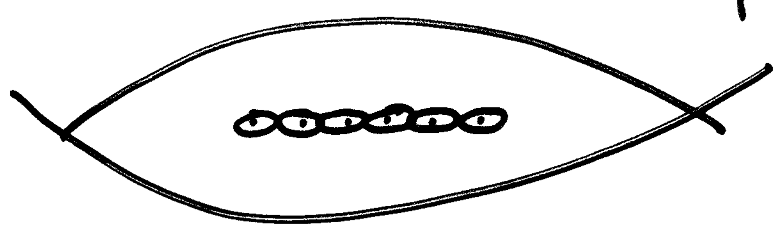
ultimate : strong focusing

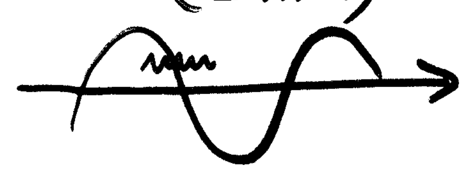
Sub-ps pulses from a storage ring

V = 8 MV
at 1 mm
(300 GHz)



Strong focusing ⇒ microbunches
separated by 3ps
(1 mm)





1 GeV
$\alpha = 10^{-3}$
$\sigma_\gamma/\gamma = 1.3\ 10^{-3}$
$\sigma_\ell = 200$ fs
100 MHz
8 strong focusing
cavities 8 MV
$\nu_s = 1.52$

4 GeV
$\alpha = 5\ 10^{-4}$

$\sigma_\ell = 200$ fs
16 RF cavities
at 8 MV, 1mm

$\sigma_\ell = 1$ ps
16 RF cavities
at 3 MV, 1 m

already includes coherent synchrotron radiation
microwave instability (x3)

"RING BASED SOURCES" REPORT

Brilliance

- o focalization closer to the sample at ESRF
- o operation at 4 GeV at ESRF
- o Spring8, Astrid
- o long insertion devices

Topping-up at APS

(has to be included in the design of new ring)

SRFELs

- o new lasing at DELTA
- o shorter wavelength operation
- o relaible operation of Super-ACO and DUKE
- o users applications combining FEL and synchrotron radiation

- LIFETIME LIMITATIONS 1H OVERCOME BY TOPPING-UP

- INTRA BEAM SCATTERING LIMITATIONS
    - operating at full coupling
    - bunch lengthening with an harmonic cavity (3-5 lengthening)

- THE 10^{24} RANGE IS ACHIEVED WITH WELL PROVEN LATTICES AND STANDARD TECHNIQUES

$$\sigma_z = 20\,mm$$

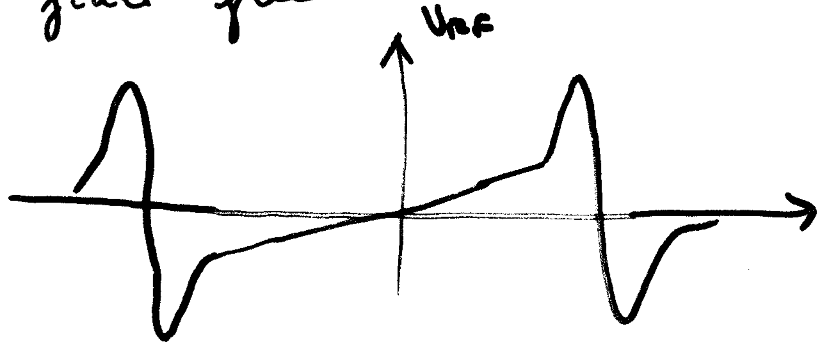
$$\varepsilon\,(0mA) = 20\ pm\text{-}rad$$

$$\varepsilon\,(1mA) = 80\ pm\text{-}rad$$

$$\sigma_\delta = .06\% \rightarrow .08\%$$

$$Q = 7.2\,nC$$

+ sub-ps jitter free streak camera



Storage Ring Free Electron Lasers

So far demonstrated :

- record of the shortest λ in the oscillator mode $\simeq 200$ nm (NIJI 4 - 1998)

- record of the shortest λ in the harmonic generation configuration
  $\lambda = 108$ nm h: 5 (Super-ACO 1990)

- full temporal coherence
  * $\frac{\Delta\lambda}{\lambda} = 10^{-6}$ Fabry-Perot etalon (VEPP 3, 1990)
  * Fourier limit acheived on S. ACO and Duke (1998)

+ • full transverse coherence

- high level of stability
  intensity fluctuations $\sim 1\%$
  jitter of the FEL pulse $\sim 5\%\ \sigma_{FEL}$
  $\Delta\lambda < 10^{-4}\lambda$

Since 1993, user applications in various scientific domains
Natural synchronization between FEL and Synchrotron Radiation $\Rightarrow$ wide variety of 2 color pump - probe experiments

Main Parameters of the ELETTRA FEL Project

FEL beam

Wavelength range	350 nm – < 200 nm
Average power	• 3 W
Peak power	• 90 kW
Pulse energy	• 0.7 µJ
Pulse length (FWHM)	~ 7 ps
Pulse repetition freq.	4.6 MHz
Photon flux (/sec) (in the laser bandwidth)	$2\ 10^{18}$

Electron beam

Energy	1 GeV	
No. bunches	4	
Max. total current	100 mA	
Natural rms emittance	1.7 nm rad	
Natural rms energy spread	0.04 %	
Natural rms bunch length	6.3 ps	
Current/bunch	10 mA	25 mA
Bunch length (measured)	26 ps	35 ps
Peak current	132 A	246 A
Energy spread (calculated)	0.17 %	0.22 %

Optical cavity

Cavity length	32.4 m
Mirrors to undulator centre	17.7 m, 14.7 m
Waist position	Centre of undulator
Rayleigh length	4 m
Mirror radii	18.6 m, 15.8 m
Stability parameter	0.78 m
Waist size (w, 350 nm)	0.67 mm

Undulator

Type	APPLE-2, optical klystron
Period length, No. of periods	100 mm, 2 x 20
Total length	4.76 m
Minimum gap	18 mm
Permanent magnet block sizes	35 mm x 35 mm x 25 mm
Maximum K (circular mode)	5.9-6.1
Nominal K value (350 nm)	5.08

What is the future of SR FELs ?

So far, no storage ring FELs developed on 3rd generation machines for synchrotron radiation

May 1998 : Elettra FEL
(R. Walker, european collaboration)

- 4 bunches 1 – 1.5 GeV
- optical cavity (cooling, several mirrors in vacuum
- Sasaki type helical / planar undulator

- P = 1-10 W 350 – 150 nm
- demonstration of user applications

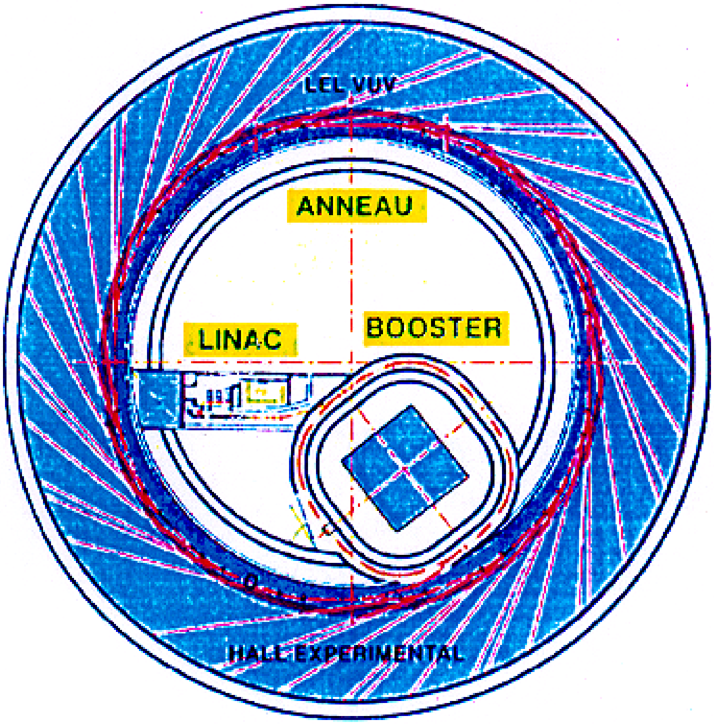
and, with an longer straight section
L = 14 m
ex SOLEIL FEL

and, if the required efforts are gathered:

- λ = 10 nm in oscillator conf. 1-100 W
- λ = 2 nm (h5) coherent harmonic generation at the Fourier limit.
in synchronization with SRad

→ The SRFELs potentialities should be investigated.

Ultimate SRFEL perf. ex of SOLEIL



e. beam

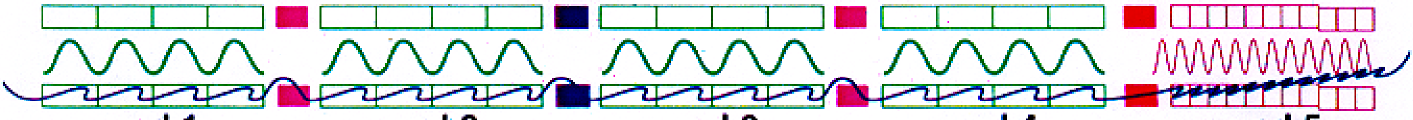
1.5 GeV
4 bunches
σ_x = 160 µm- σ_z = 126 µm
20 mA : $\sigma_\gamma/\gamma = 10^{-3}$, σ_l =30 ps

optical cavity

L=42 m, Rc = 30 m
waist = 380 µm,
DV = 170 µrad

insertion device

L= 14 m
adjustable planar / helical

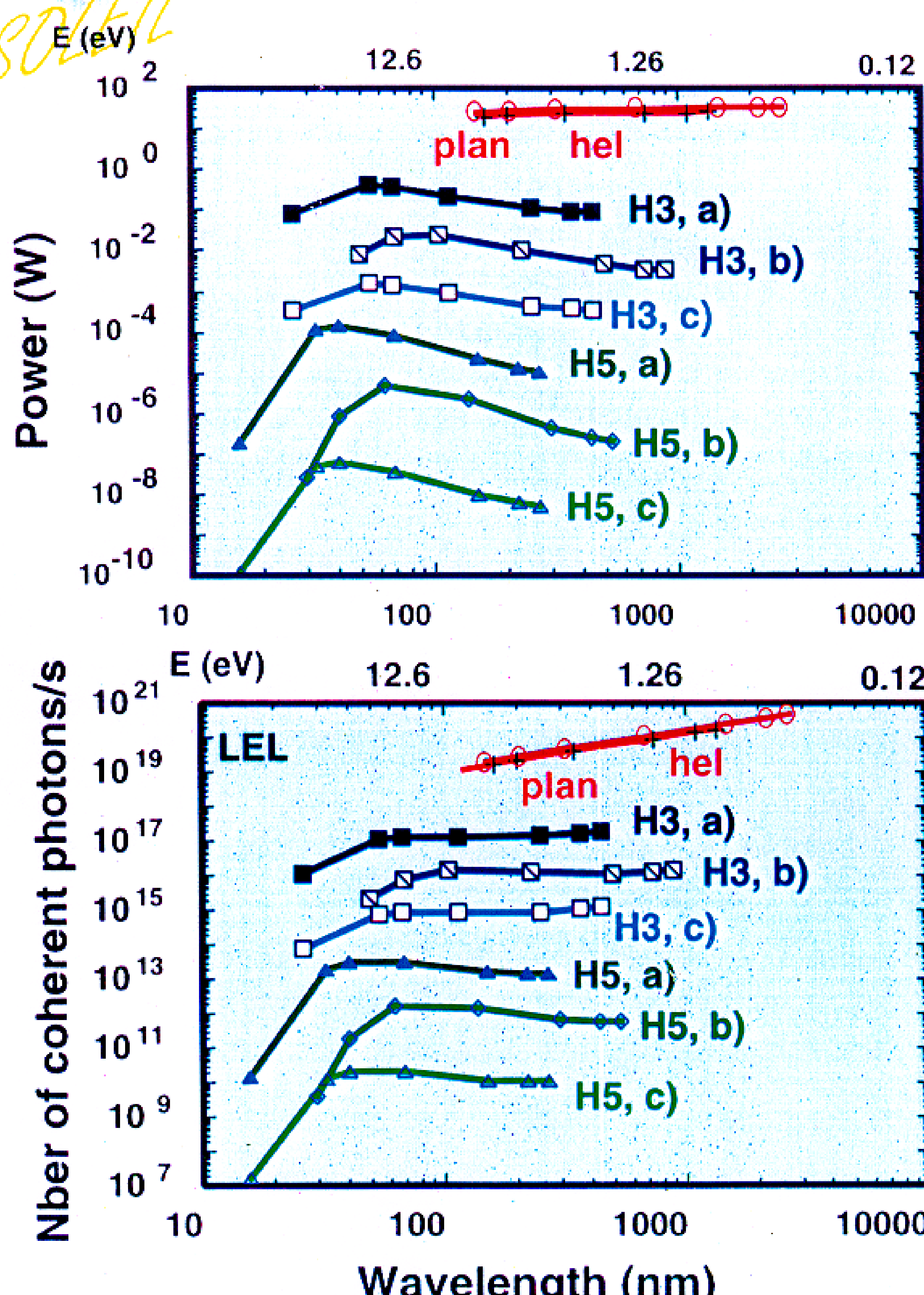


tunability :
oscillator mode : 400-150 (100?) nm
coherent harmonic generation : 150-50 nm
2 color FEL
power = 5-50 W
1-5 ps **pulses** at 280 ns to 1 µs **rep. rate**
relative linewidth : 10^{-4}-10^{-5}

ajustable polarisation

Ultimate SRFEL perf.
ex of SOLEIL

PROSPECTS ON SOLEIL



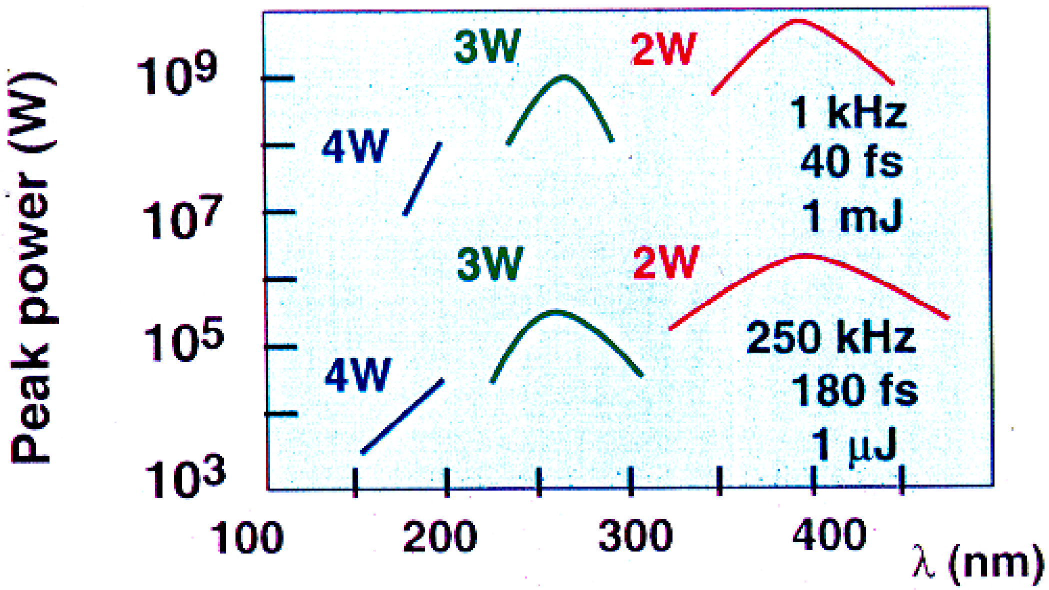
a) KO1 planar + und 5

b) KO1 hel + und 5

c) KO1 planar

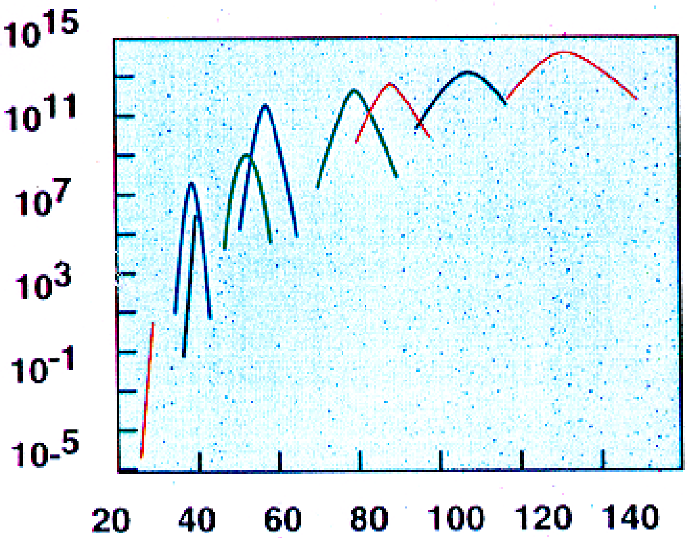
Ultimate SRFEL perf. ex of SOLEIL

COHERENT HARMONIC GENERATION FROM A Ti:Sa LASER

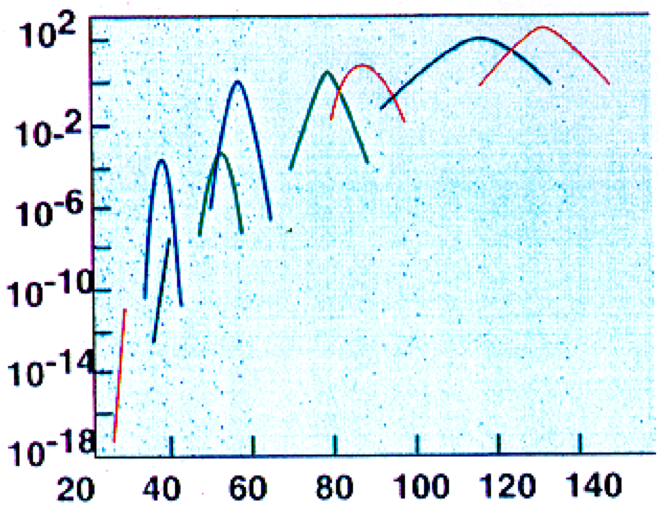


1 kHz system

Nber of coherent photons/s

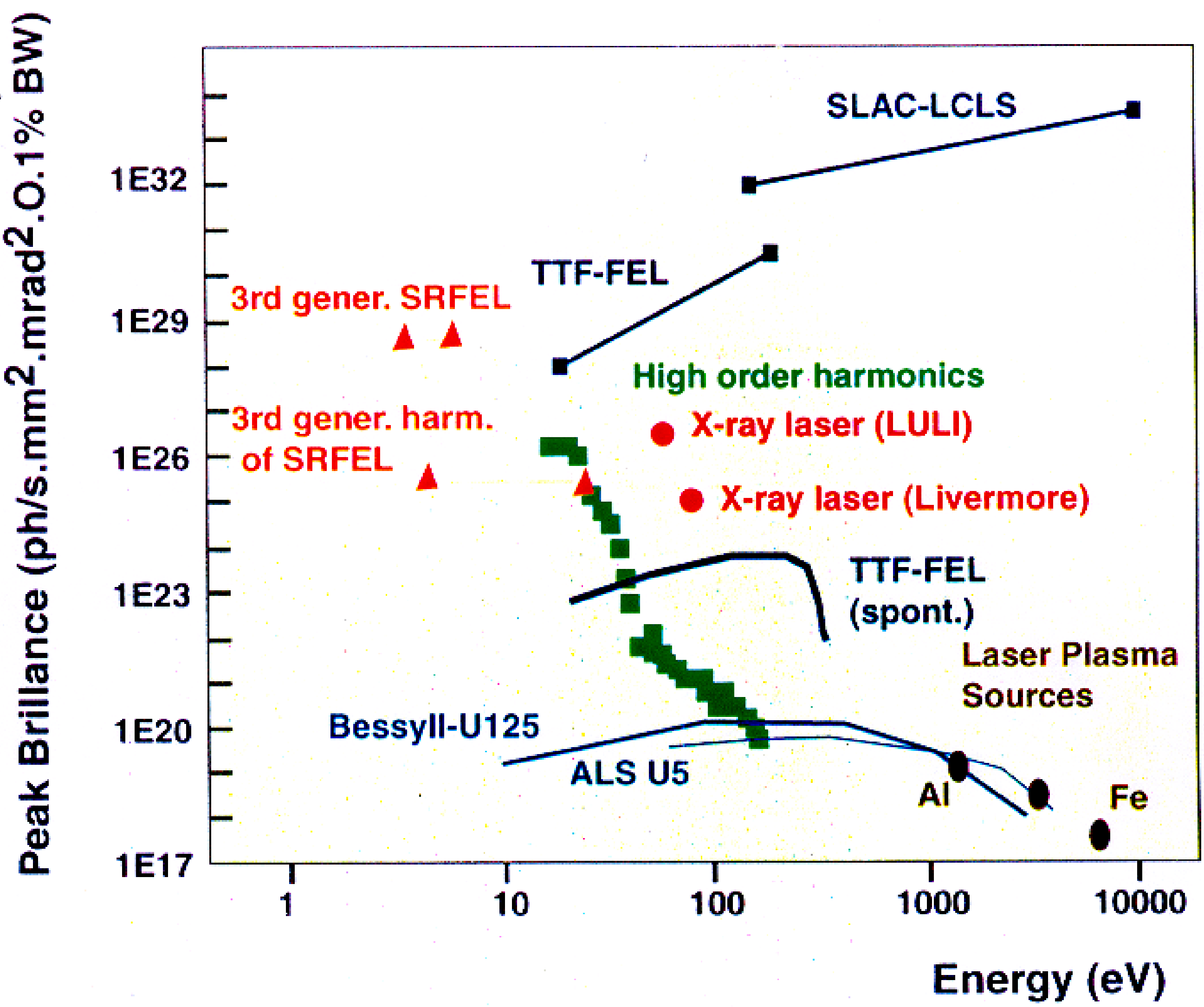


average power (W)



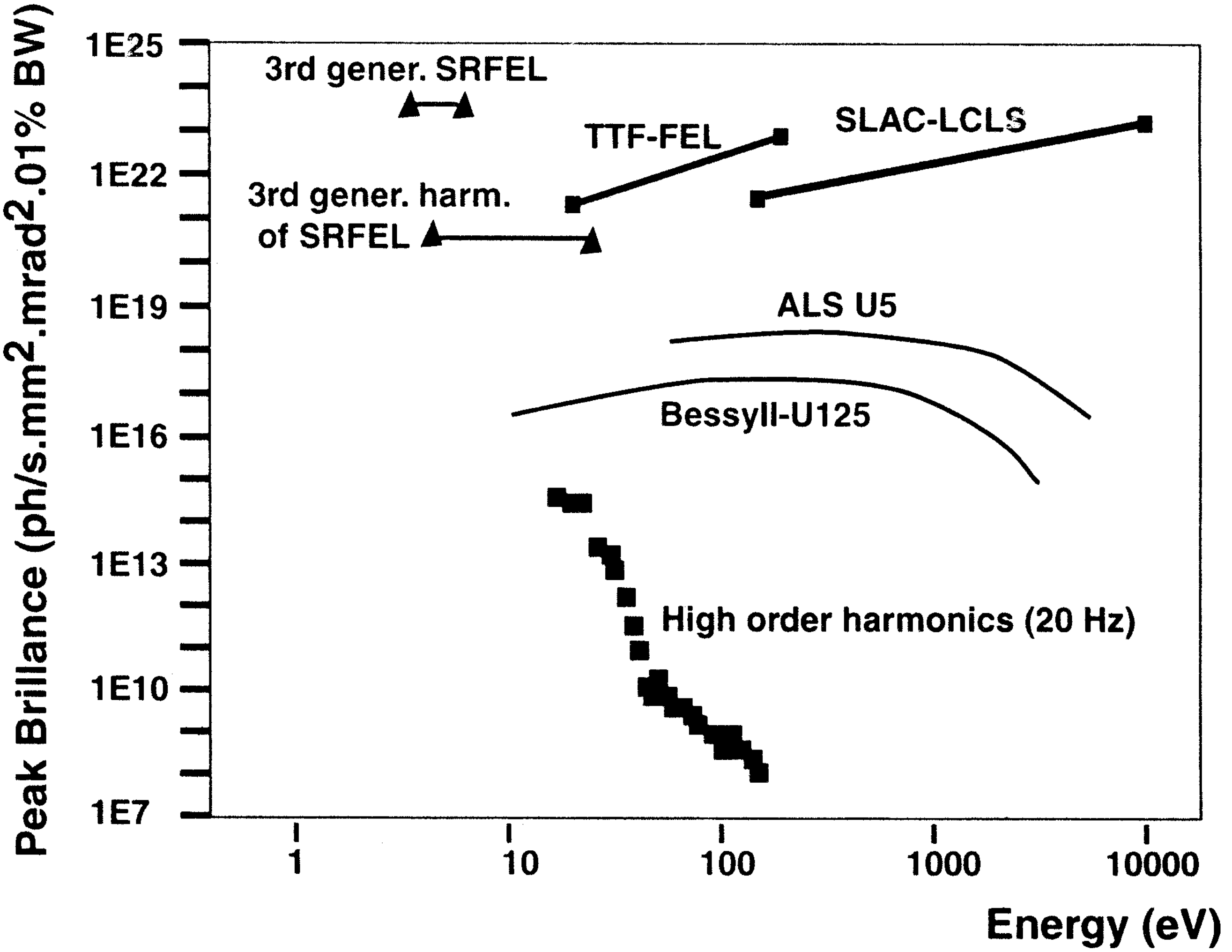
Ultimate SRFEL perf. Sources comparisons

PEAK BRILLANCE

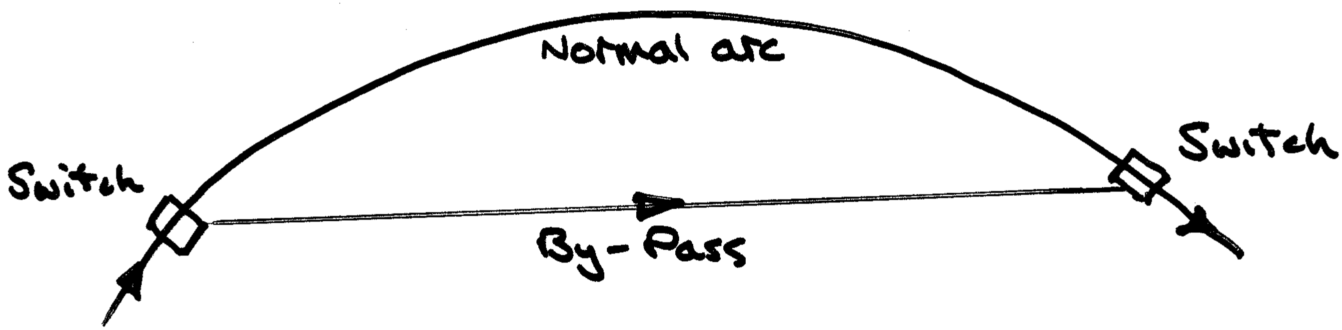


Ultimate SRFEL perf.
Sources comparisons

AVERAGE BRILLANCE



Pulsed By-Pass



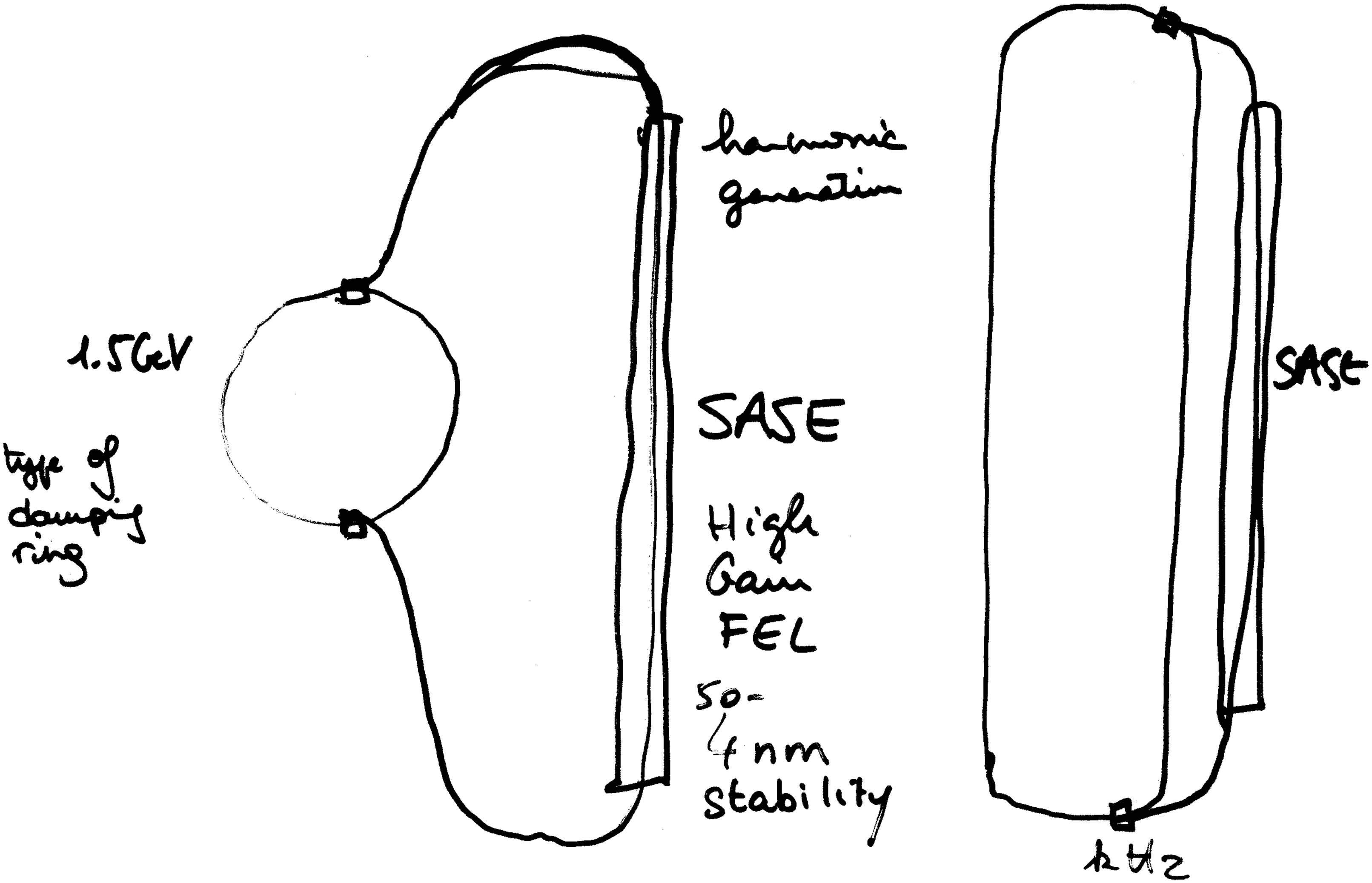
Assume :-

Switch instantly into by-pass for $1 \rightarrow N$ revolutions.

By-Pass can contain:-

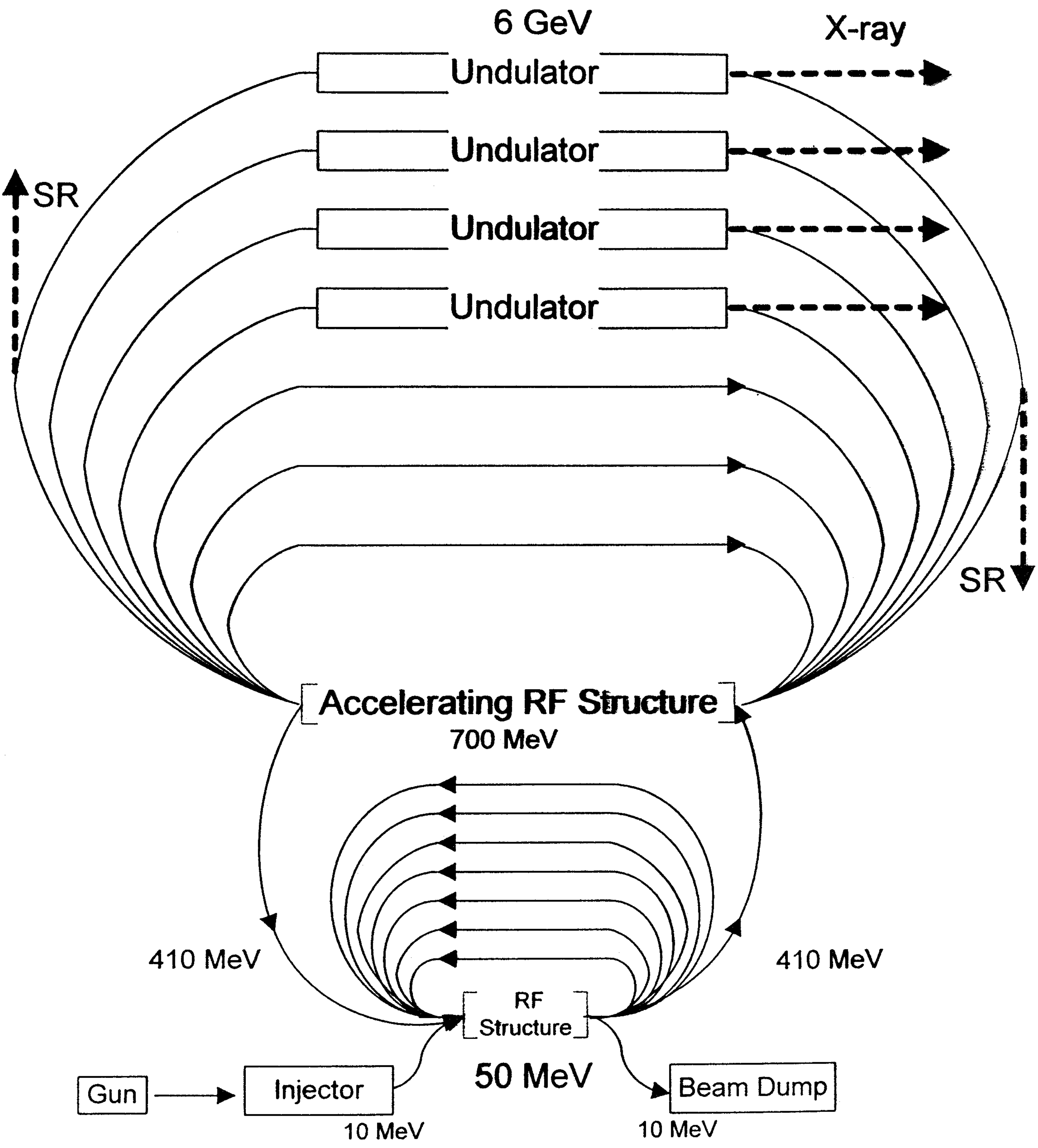
- Mini beta, microgap device
- Special RF devices
- Devices which "heat" the beam
- Extra long straight
- laser for high harmonic generation
- High gain FEL.

cf ALS proposal



optics optionnal

no radiation hazard.


6 GeV
X-ray
Undulator
Undulator
Undulator
Undulator
SR
SR
Accelerating RF Structure
700 MeV
410 MeV
410 MeV
RF Structure
50 MeV
Gun
Injector
Beam Dump
10 MeV
10 MeV

Comparison of various types of the coherent X-ray sources:

	ESRF storage ring	LCLS linac	MARS
Wavelength, nm	.1	.15	.1
Electron energy, GeV	6	14	5.4
Average current, A	.2	3×10^{-8}	10^{-3}
Peak current, A		3.4×10^{3}	1
Relative energy spread		2×10^{-4}	1×10^{-5}
Emittance, nm εx εz	4 2.5×10^{-2}	3×10^{-2}	3×10^{-3}
Undulator period, cm	4.2	3	1.5
Undulator length, m	5	100	150
Coherent flux, photon/s	6×10^{12}	6×10^{14}	7×10^{13}
Bandwidth	10^{-2}	10^{-3}	10^{-4}
Average brightness, ph/s/mm^2/mrad^2/0.1%BW	10^{20}	6×10^{22}	3×10^{23}
Peak brightness, --//--		5×10^{33}	3×10^{26}
Transverse size of source (standard deviation), μm	σ_x 350 σ_y 8	9	10
Radiation transverse divergence (standard deviation), μrad	$\sigma_{x'}$ 13 $\sigma_{y'}$ 3	2	1

Conclusions

- a lot of improvements from the first generation ring to the third generation ...
- and still newsteps overcomed :
  - brilliance enhancement at ESRF
  - long ID at Spring 8
  - topping-up at APS
- more than 50 machines (in operation/project) will serve many users in the future years
- new directions have to be investigated meanwhile in details
  - high circumference topped-up 4 GeV ring
  - sub-ps / ps e. bunches in a strong focusing ring
  - SRFELs
  - MARS

  ...
- and maintain the variety of :

  * energies IR — X ray
  γ-rays (Compton Back Scattering)

  * pulse duration and separation

List of Working Group Participants:

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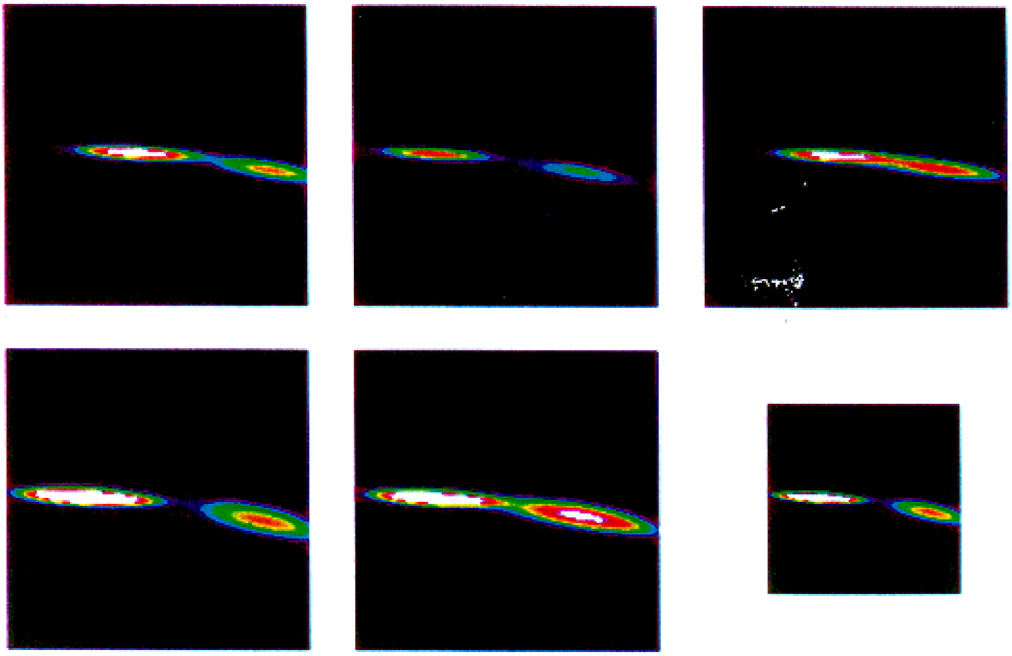
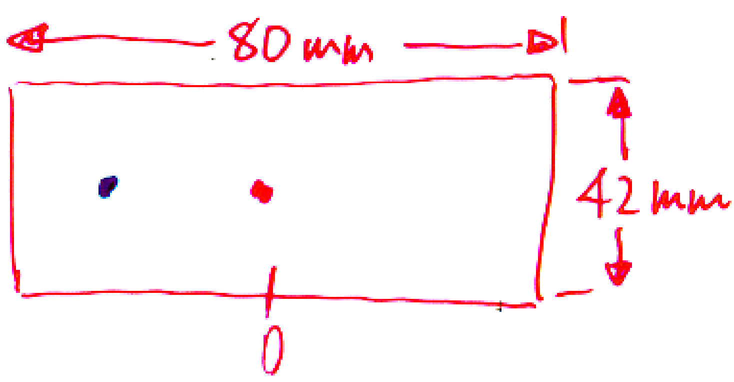
Two Color $\bar{e}$ Beam in α- Buckets
(E)

VUV Electron Beam Stored in α-Buckets
(SLK & JBM, 3/18/99)



1.5 - 2 m

$$\Delta x = \eta_x \cdot \frac{\Delta E}{E} \quad , \quad \Delta y = \eta_y \frac{\Delta E}{E}$$



For $\frac{\Delta E}{E} = 1\%$, $\Delta x \simeq 2$ cm.