Accelerators-recuperators as 4^{th} generation X-ray light sources

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Lecture 4

Comparison of the one pass (ERL) and multi-pass (MARS) accelerators-recuperators

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Introduction

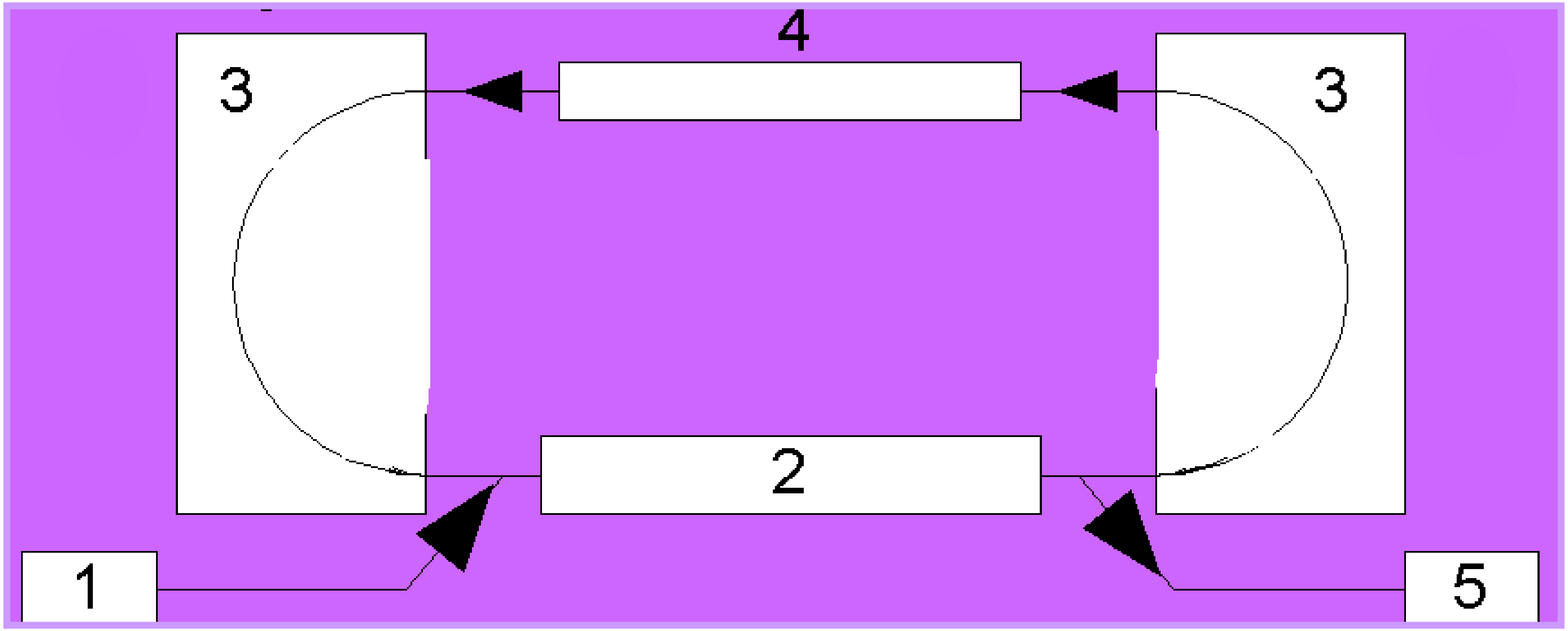
At present, the projects of the 4th generation SR sources on the basis of accelerators-recuperators are considered at Budker INP, Daresbury Laboratory, Jefferson Laboratory, Cornell University, KEK, APS.

As practice many projects assume the use of a single-turn version (ERL) compared to our first proposal of 1997 to use a multi-turn accelerator-recuperator (MARS).

Therefore comparison of the ERL and MARS based radiation sources from the viewpoint of their realization seems to be important.

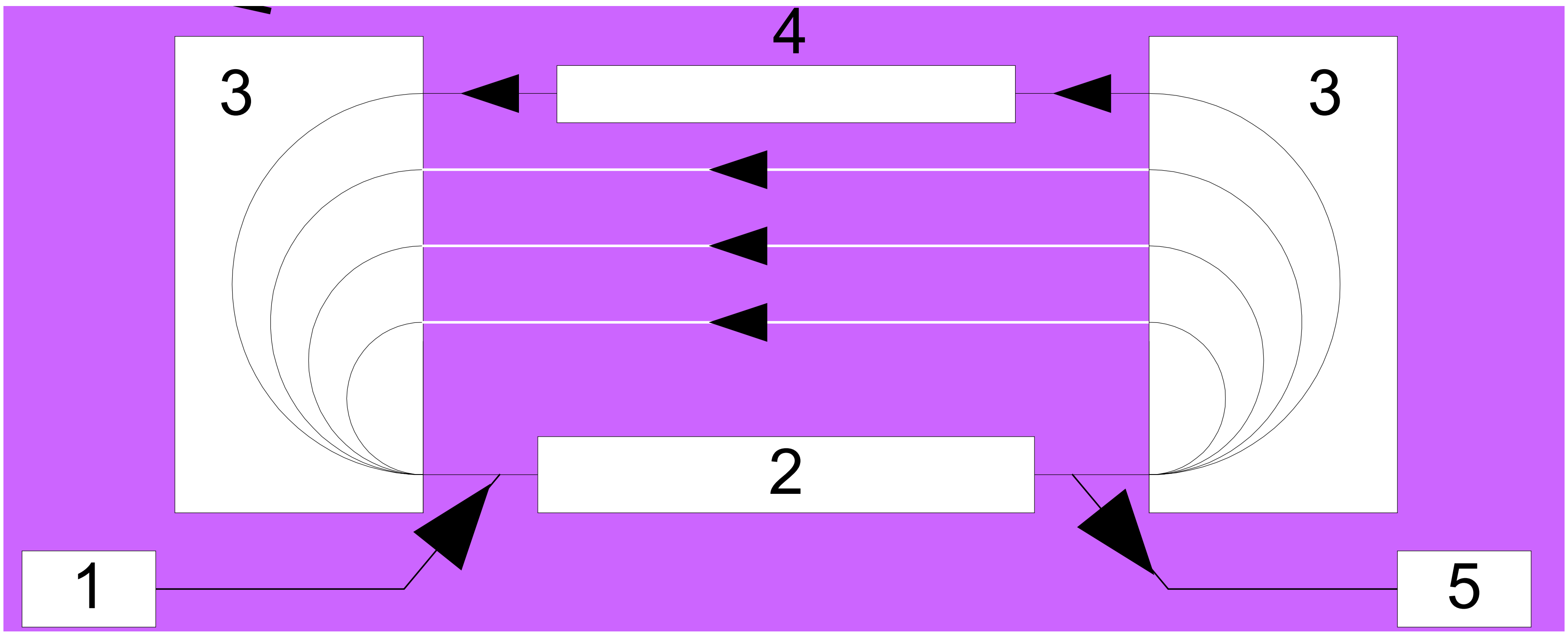
Development of accelerators-recuperators for various purposes (FEL, SR source, electron cooling) have been discussed in detail at the Conference ERL-2005, ERL-2007. Independently of the posed tasks, many accelerator-recuperator systems can technically be realized. Therefore, at present, it is more reasonable to compare parameters, realizeability and costs of the 4^{th} generation SR sources either on the base of single pass (ERL) or multi pass (MARS) accelerators-recuperators,

Layout of the SR source based on one-pass accelerator-recuperator



1 - injector, 2 - RF accelerating structure, 3- 180-degree bends, 4 – undulator, 5- beam dump

Layout of the SR source based on four-passes accelerator-recuperator



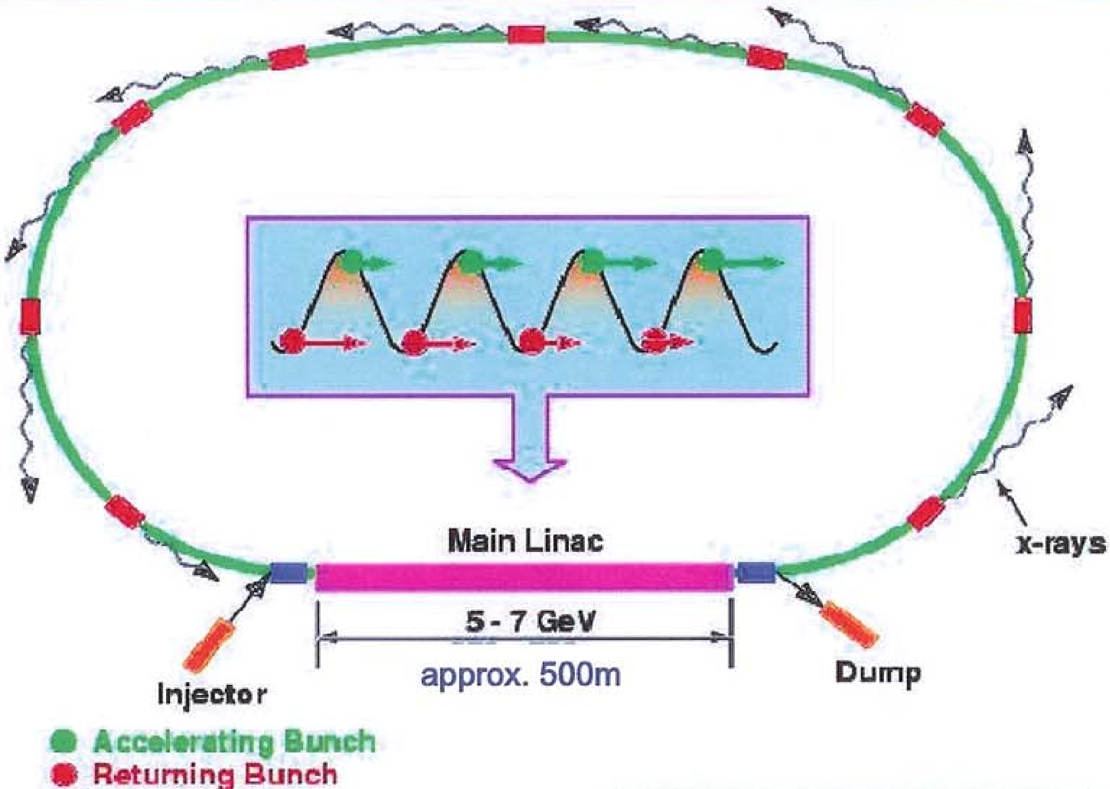
1 - injector, 2 - RF accelerating structure, 3- 180-degree bends, 4 – undulator, 5- beam dump.

Main motivation for accelerator-recuperator:

- to combine the advantages of storage ring (high reactive power in beam, low radiation hazard) and linac (normalized emittance and energy spread can be conserved during the acceleration process);
- due to energy recovery radiation hazard can be eliminated and the cost of the building will be reduced;
- due to multipass acceleration the cost of the accelerating RF system can be reduced.

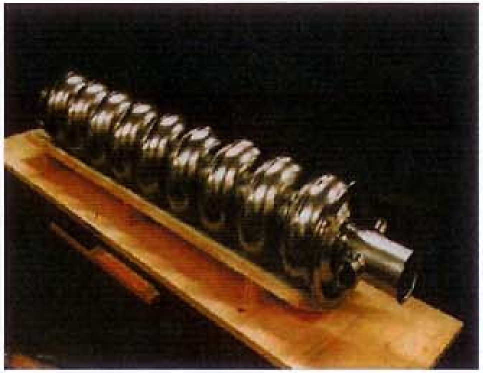
Principle of an X-ray ERL

X-ray analysis with highest resolution in space and time:



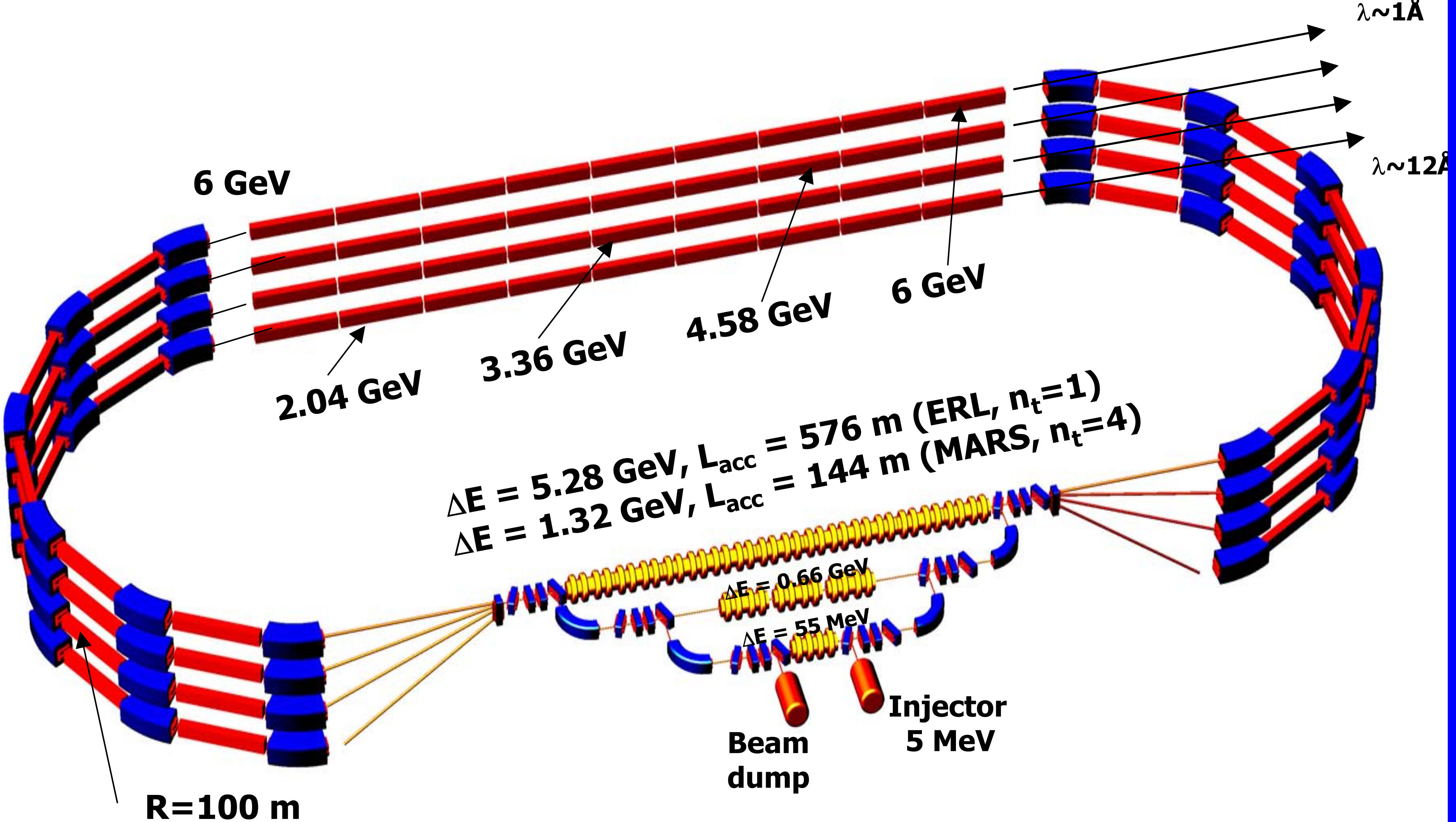
Challenges:

- Low emittance, high current creation
- Emittance preservation
- Beam stability at insertion devices
- Accelerator design
- Component properties, e.g. SRF



Basic overall dimensions of ERL and MARS (E_{max} = 6 GeV)

MARS: 3D view



Both for the single pass and multi-pass accelerators-recuperators it is reasonable to use our proposal ICFA Meeting 1999 of the cascade injection, which enables injection of electrons into all the accelerating structures with the energies of no more than $E_{max}/10$ (E_{max} is the maximum energy of electrons traveling in the accelerating structure), thereby simplifying the problem of focusing particles of different energies, which are traveling simultaneously in the accelerating structure.

On the other hand, it allows the use of injector with $E < 10$MeV thus decreasing the radiation background during the beam drop in the dump and eliminate practically the problem of the induced radiation. In addition, the cost of injector and its RF generator is substuntially reduced.

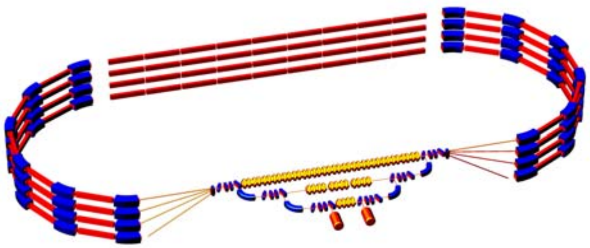
Our proposal is MARS project, that is accelerator for 6 GeV energy, 4-turn recuperator with cascade injection structure and small current (2.5 mA for semiarcs, 10 mA for accelerating structure).

In order to achieve the full spatial coherence of the source and keep at the same time the photon flux on the level of the 3rd generation sources, we suggest to use the current value of 10 mA for a single-turn accelerator and 2.5 mA for the four-turn accelerator.

In this case, we solve the problem of a full spatial coherence for the sources and the 10-100 times decreasing in the current value compared to that of the 3rd generation SR sources is compensated by the use of radiation only from three types of undulators (but not from bending magnets) (N_{u1}=100, N_{u2}=1000, N_{u3}=10 000).

Comparision of parameters of SR sources

MARS (I_e=2.5 mA) and Spring-8 (I_e=100mA)



		Number of beamlines	**B**, ph•sec^{-1}•mm^{-2}•mrad^{-2} ($\delta\lambda/\lambda=10^{-3}$)	**F**, ph/sec ($\delta\lambda/\lambda=10^{-3}$)
MARS	Undulator $N_u \sim 10^2$	32	10^{22}	$4.6 \cdot 10^{13}$
	Undulator $N_u \sim 10^3$	12	10^{23}	$4.6 \cdot 10^{14}$
	Undulator $N_u \sim 10^4$	4	10^{24}	$4.6 \cdot 10^{15}$
SPring-8	Bending magnet	23	10^{16}	10^{13}
	Undulator N_u=130	34	$3 \cdot 10^{20}$	$2 \cdot 10^{15}$
	Undulator N_u=780	4	10^{21}	$1.2 \cdot 10^{16}$

Due to using small current and bunch charge (Q=8 pC) and relatively long bunch length (2 ps) we hope do not observe effects of growth of transverse and longitudinal emittance and beam loss in MARS due to:

- coherent synchrotron radiation.
- intrabeam scattering (Touschek)
- disturbance from ions.

Superconducting RF ("ERL 2005" Conference)

Superconducting RF technology was developed by Cornell University, KEK, CERN, Jefferson Lab, DESY.

Parameters of TESLA cryomodule:

Length of cryostat	L= 12 m
Gradient	15 MV/m
Energy gain	ΔE = 110 MeV

Cost of cryomodule:

- Accelerator structure, Cryostat, RF generator, Cryogenic equipment 5-9 M$
- AC power 0.6-0.9 MW per cryomodule

ERL cavity performance

Operation spec: 16 MV/m

But to have sufficient safety margin we design the Cryomodule for:

- max. supported gradient by cryo module: 20 MV/m at $Q = 1 \cdot 10^{10}$
- RF power installed for 20 MV/m, 20 Hz peak detuning = 5kW / cavity
- Min. (guaranteed) cavity performance in linac: 16 MV/m at $Q = 2 \cdot 10^{10}$
- Average cavity performance in linac: 18 MV/m at $Q = 2 \cdot 10^{10}$ with $\pm$2 MV/m spread to allow loosing 4 cryomodules.
- 5GeV requires 390 seven-cell cavities !
- $\Rightarrow$ Can use BCP cavities (Q-lope starts at $\approx$ 20 MV/m)

- This provides more than 10% safety margin

For a single-turn accelerator-recuperator a number of accelerating modules is n_{mod}=48. The cost of accelerating structure is 336 M$ and power consumption is 36 MW.

For the four-turn accelerator-recuperator a number of accelerating modules is 12, the cost of accelerating structure is 84 M$ and power consumption is 9 MW.

Magnetovacuum system

Taking into account that the accelerators-recuperators are single-flight system, the gap for bending magnets can be taken to be g=1cm; the incicle diameter in quadrupoles is Φ_q=1.5 cm, in sextupoles - Φ_s=2 cm thereby reducing substantially the overall dimensions, weight, power supply and the cost of the magnetic system.

With an account for the fact that in the single-flight system it is enough to have a vacuum of P ~ $10^{-7} \div 10^{-8}$ tor, the vacuum system seems to be rather simple.

Magnetovacuum system

Rough estimations have shown that the cost of the ring (magnetic structure components with power supply system, vacuum system and diagnostics) could be of 30 M$ and power consumption ~2.5 MW.

For four rings, the cost is 120 M$ and power consumption ~5 MW.

Comparison of ERL and MARS

- in both versions one can have the same parameters of the sources satisfying the main requirements to the 4th generation SR sources.

- the cost of many systems (building, photoinjector,cascade injector) are the same both for ERL and MARS;

- the difference in the power consumption and cost is substantial for the magnetovacuum and RF accelerating systems of ERL and MARS.

	RF system		Magnetovacuum system		Σ	
	Power MW	**Cost M$**	**Power MW**	**Cost M$**	**Power MW**	**Cost M$**
n_t = 1	**36**	**336**	**2.5**	**30**	**38.5**	**366**
n_t = 4	**9**	**84**	**5**	**120**	**14**	**204**

Conclusion

Comparing the SR source based on the single pass (ERL) and four-turns (MARS) accelerators-recuperators it is worth mentioning that:

- the version suggested for the one pass projects of using current values of up to 100 mA for keeping the photon flux seems to be far from optimum since with such an increase in the current, the brightness is not increasing and sometimes even decrease.
- in both versions one can have the same parameters of the sources satisfying the main requirements of the 4th generation SR sources.
- the cost of many systems (building, photoinjector, beamlines) are the same both for one pass and multi pass accelerators.
- the difference in the power consumption and cost is substantial for the magnetovacuum system and RF accelerating systems of one pass and multi pass accelerators.

Our analysis shows that practically impossible to create the same type of X-ray source of 4^{th} generation, simultaneously matched to all requirements of user community (see the Table of requirements for 4^{th} generation light sources).

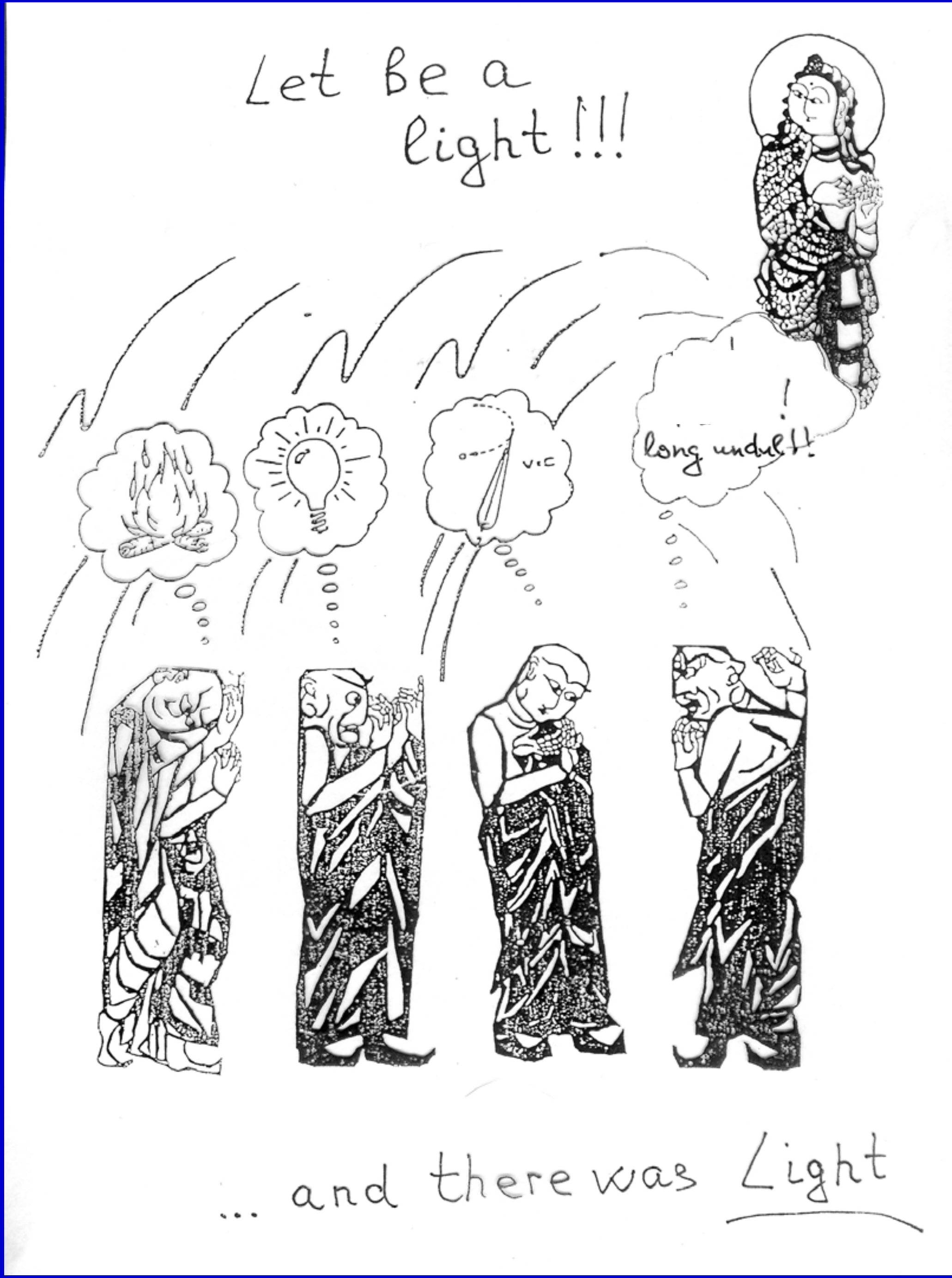
It seems to be acceptable to consider two types of X-ray source of 4^{th} generation:

1. fully space coherent X-ray source with average brilliance for 3-4 orders higher than X-ray source of 3^{rd} generation and having high spectral photon flux compared with light source of 3^{rd} generation; this type of light source can be realized at the base of accelerator-recuperator with energy recovering.
2. X-ray source with ultra-short bunch (~10 fs) and ultra high peak brilliance, that is for 4-5 orders higher than for X-ray source of 3^{rd} generation; this type of light source can be realized at the base of SASE type X-ray FEL (perhaps with energy recovering).

Attempts to design the accelerator for realization of different regimes (full transverse coherence, high average flux, high peak brightness, ultra-short pulses) do show their incompatibility, that requires a number of additional researches related with the problem of obtaining and saving the small emittance or high current (I~100 mA) of electron beam, or very short bunches at moderate current. In case of funding solution for solving all problems there appear another problem such as high costing of accelerator.

- There is no any essential physical problems in the development of the 4^{th} generation SR sources on the base of accelerators-recuperators. The main problem is the cost of the project and its maintenance.

- Therefore, orientation toward the multi-turn accelerators-recuperators (MARS), which enable a substantial reduction in the power consumption and the cost of accelerating systems compared to those of single-turn ERL (for our example, 14 MW instead of 38.5 MW and 204 M$ instead of 366 M$) seems to be rather pragmatic.



Let be a light !!!
v.c
long undul.!!
... and there was Light

Thank you for your attention