世界の放射光施設とPF
－最新の施設と将来計画動向－

物質構造科学研究所
野村　昌治

PF建設を振り返って
SLSの状況
DIAMOND、Soleil
MAX−4、NSLS−Ⅱ
4GLS、BESSYⅡ、ELETTRA
Cornell

稼働最新SR
建設中のSR
計画中のSR/ERL
計画中のERL/FEL
計画中のX-ERL

PF建設を振り返って

1971　総合研究「超高出力X線発生装置建設計画」

1973　フォトンファクトリー計画研究会

計画から終焉まで30～40年

→現在計画でなく本当の将来計画を作ることが納税者に対する我々研究者の義務

1982　first SR beam

1987　高輝度化(300→130nmrad)

1997　高輝度化(130→36nmrad)

2005　直線部増強

DORIS 1974～、DCI 1976～2003、SPEAR 1974～
SRS 1980～、NSLS 1981/82～、CHESS 1980～

Swiss Light Source

ring

office

from office

booster

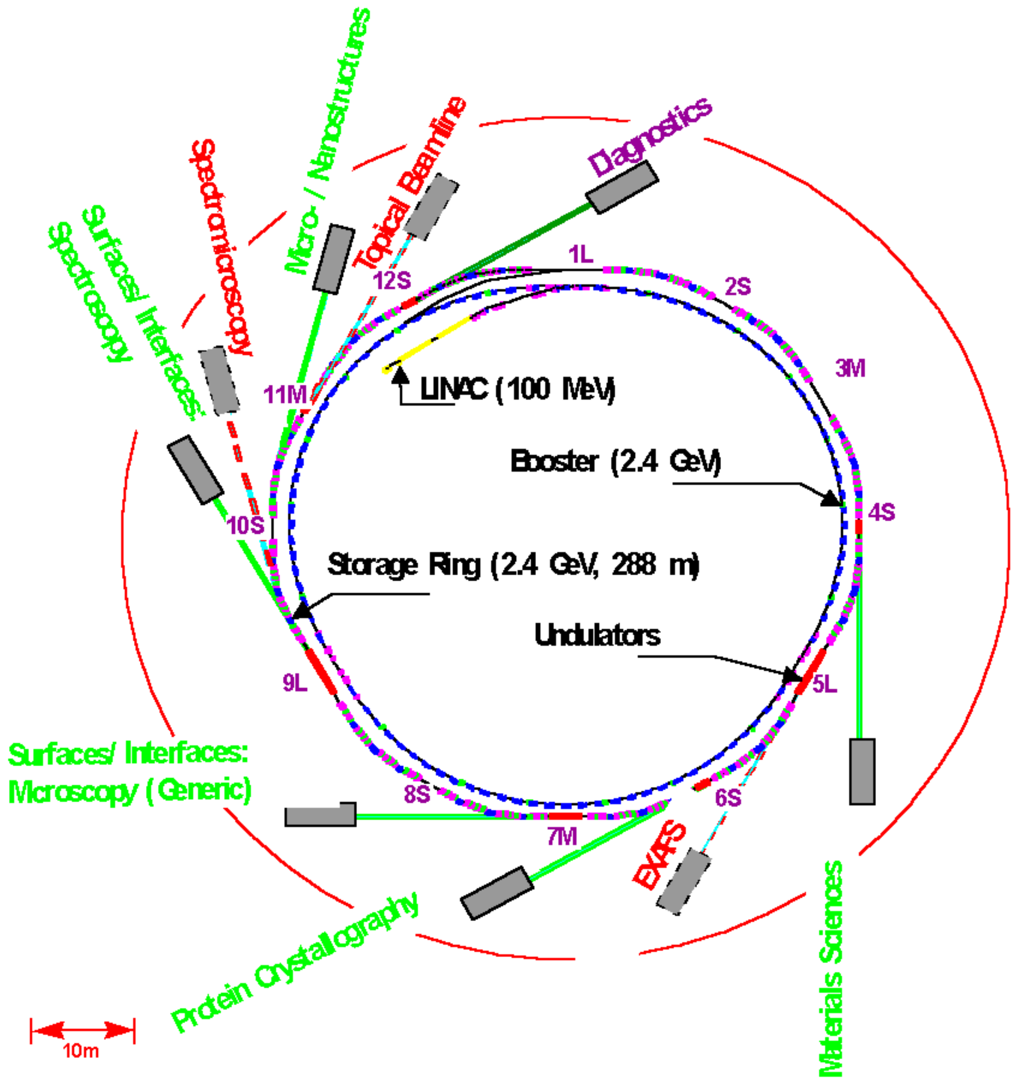
Main ring & ID

最近のSR—SLS

Swiss Light Source

- 2.4 GeV、ε= 4.4nmrad
- 周長　288m　12 TBA
- 直線部　11m×3（内1入射）、7m×3、4m×6（内2RF)
- 174台の四極電磁石、120台の六極電磁石
- Touschek lifetimeは400 mAで3.5 hrs (4 mm gapのundulator使用時）
  → 3rd harmonic cavityの導入(2002.6)で8hrs
- 2000年12月に蓄積成功、2001年8月から試用開始

SLSの加速器



2.4 GeV、ε= 4.5nmrad
周長　288m　12 TBA
直線部　11m×3（内1入射）、
　7m×3、4m×6（内2RF）

蓄積リング架台にFB
振動は0.2μm(V)、2μm(H)

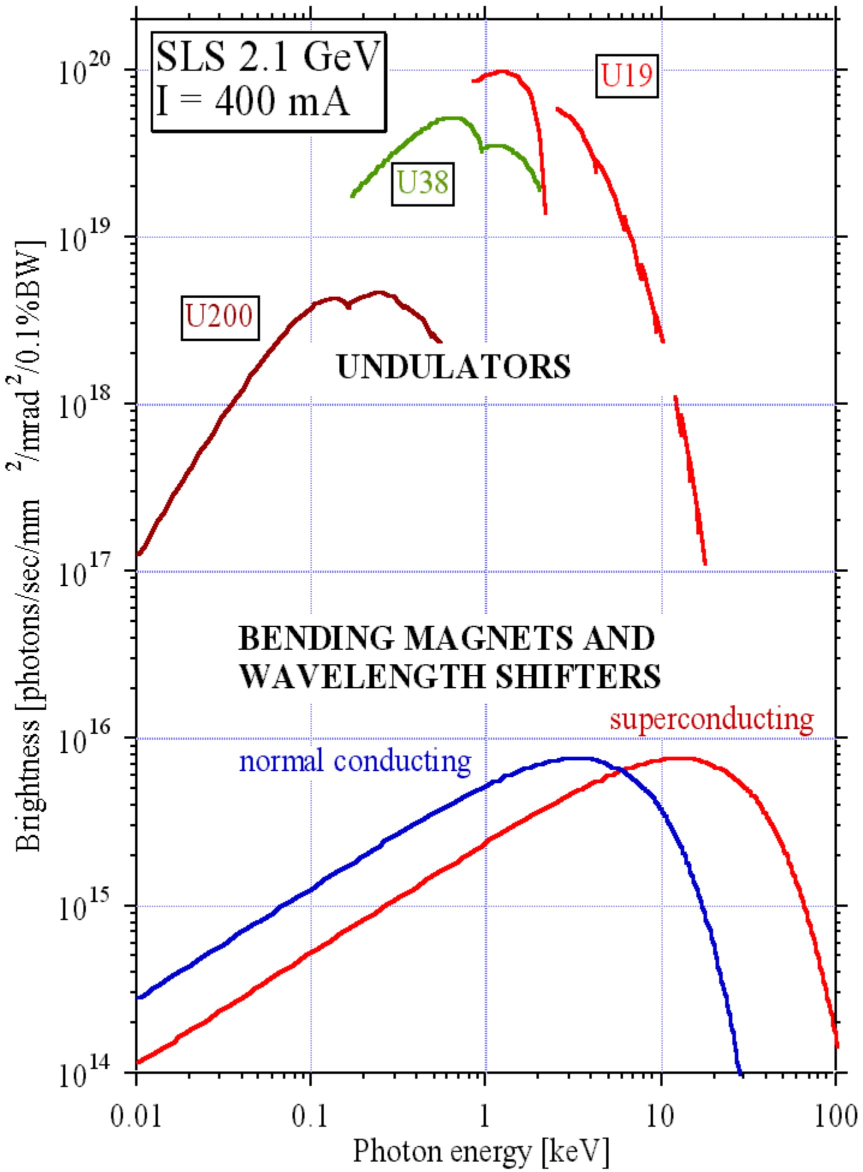
Material Science(4S)
　minigap hybrid undulator

Protein Crystallography
　in vacuum undulator

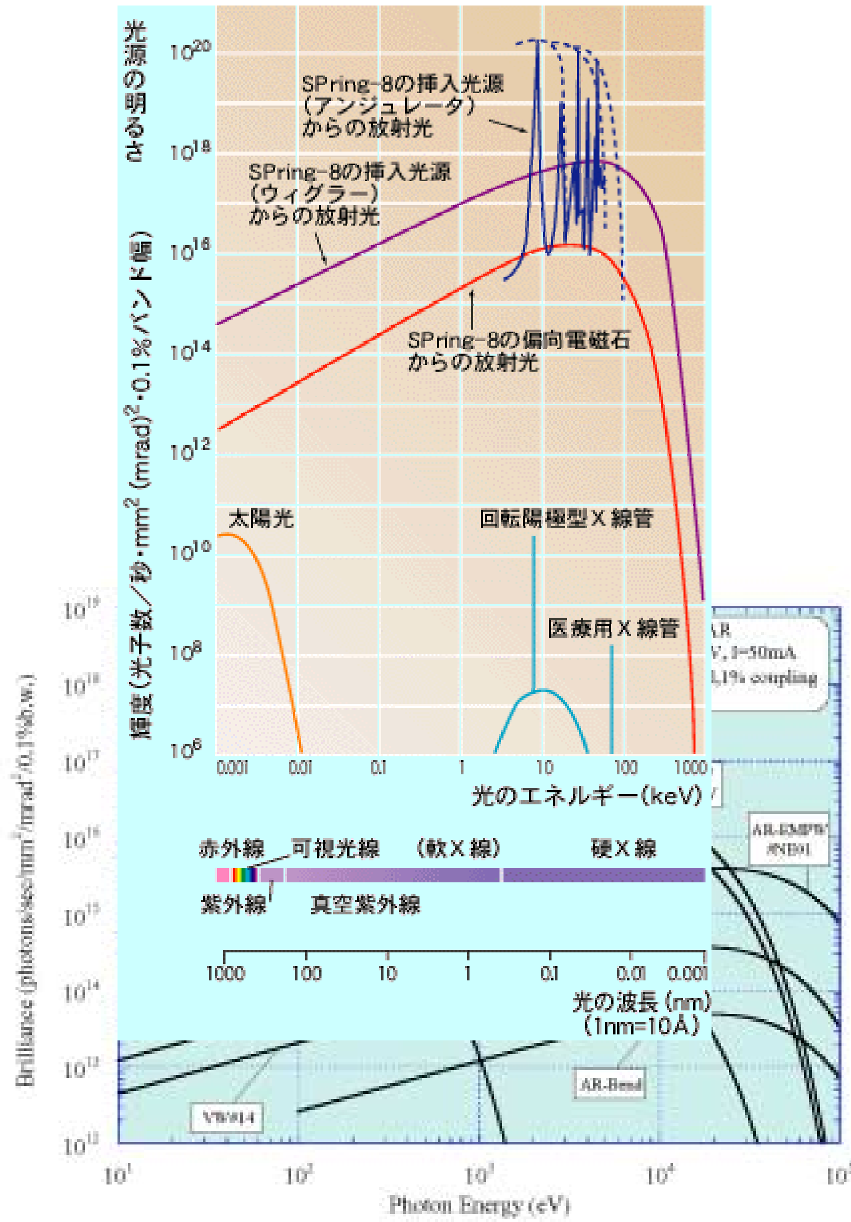
Surface/Interface Spectroscopy
　EM crossed field undulator

Surface/Interface Microscopy
　elliptical twin undulator

SLSのスペクトル



SLS 2.1 GeV
I = 400 mA
U19
U38
U200
UNDULATORS
BENDING MAGNETS AND
WAVELENGTH SHIFTERS
superconducting
normal conducting
Brightness [photons/sec/mm²/mrad²/0.1%BW]
Photon energy [keV]
0.01
0.1
1
10
100



SPring-8の挿入光源
(アンジュレータ)
からの放射光
SPring-8の挿入光源
(ウィグラー)
からの放射光
SPring-8の偏向電磁石
からの放射光
太陽光
回転陽極型X線管
医療用X線管
輝度(光子数／秒・mm²(mrad)²・0.1%バンド幅)光源の明るさ
光のエネルギー(keV)
赤外線
可視光線
(軟X線)
硬X線
紫外線
真空紫外線
光の波長(nm)
(1nm=10Å)
Brilliance (photons/sec/mm²/mrad²/0.1%b.w.)
Photon Energy (eV)
AR-Bend

LIVE from the SLS

This page shows the present status of the SLS machine and beamlines. It is automatically updated every 20 seconds (or whenever you click on reload). The image, (updated every minute), displays the beam current from the last ten hours.

Machine Status

Beamline Development

Tue 09 Mar 2004 14:29

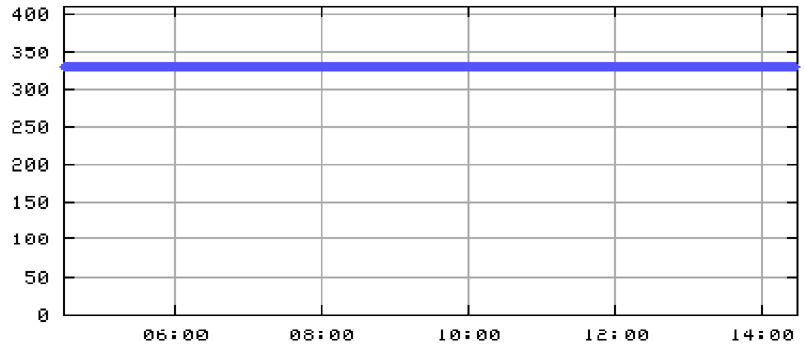
Current	330.8 mA
Lifetime	16 h 26 min
Integrated Dose	3130.4 Ah

Shift Plan Beamline development

Last Shift Summary

Messages from Control Room

08.03.04 15:24 Beamline Development Shift



Beam Current

Beamlines Status

Beamline	ID Status	Shutter Status	Exp. Status
X04SA-MS	8.21 mm	Open	unattended
X05DB-DIAG		Closed	-
X05LA-MicroXAS		Closed	-
X06SA-PX	7.84 mm	Open	attended
X07MA-LUCIA	33.64 mm	Open	attended
X09LA-SIS	39.96 A 39.96 A 0 A 0 A	Open	attended
X10SA-PXII		-	-
X11MA-SIM	98.99 mm 100.09 mm	Closed	offline

建設費

BL, ID	25MSF
加速器	80MSF
建屋	30MSF
インフラ（ハッチ）	25MSF
合計	159MSF 143億円

SLSで進行中の計画

- Energy up 2.4 → 2.7GeV
- Super-bend
- Short bunch
- Current up → 400mA

ビームの安定性

Top-up入射直後6μsは水平に0.8mm動く。鉛直方向は観測されない。

光の安定性　年間<25μm/9m

床振動　20nm

建設中・立上中の施設例

DIAMOND（英）　3GeV 500mA　2.7nmrad
562m　5m×18+8m×4　₤235M(460億円)

Soleil（仏）　2.75GeV 500mA　3.7nmrad
354m　3.5m×8+7m×12+12m×4
278MEu(360億円）

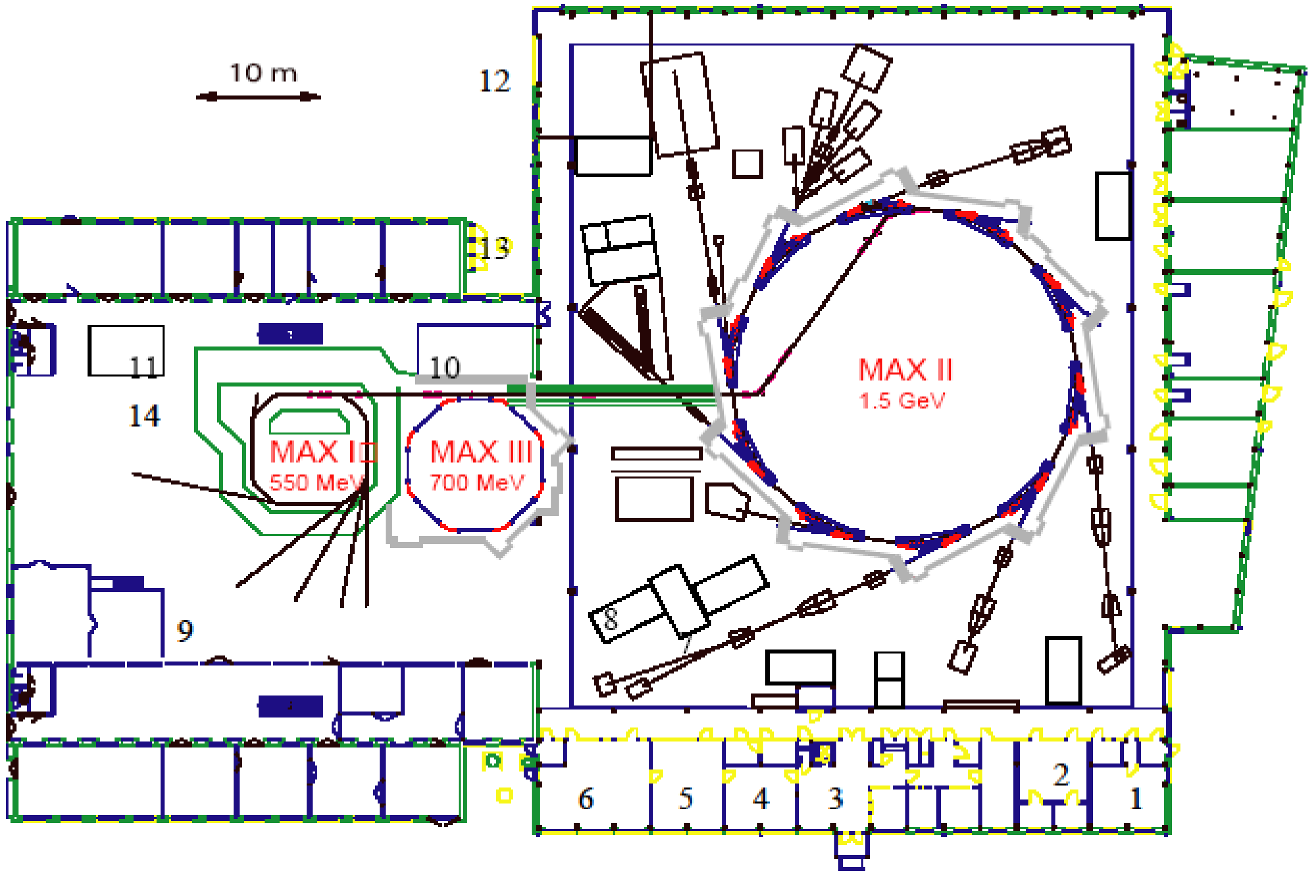
SSRF(中）　3.5GeV 300mA　3nmrad
432m　12m×4+7m×8+5m×8　$150M

CLS（加)　2.9GeV 500mA　27(18)nmrad
171m　5.2m×12　$141M(130～170億円）

Boomerang(豪)　3GeV　7.4nmrad
216m　207MA$(170億円)

Lund univ., Sweden

MAX-lab



500MeV 40nmrad
6本

1.5GeV 8.8nmrad, 90m
8本

ユーザー　600人
報文　　　240報
人口　　　900万

VUV･SX 12本，X 2本稼働、 MPW 2本　立上中

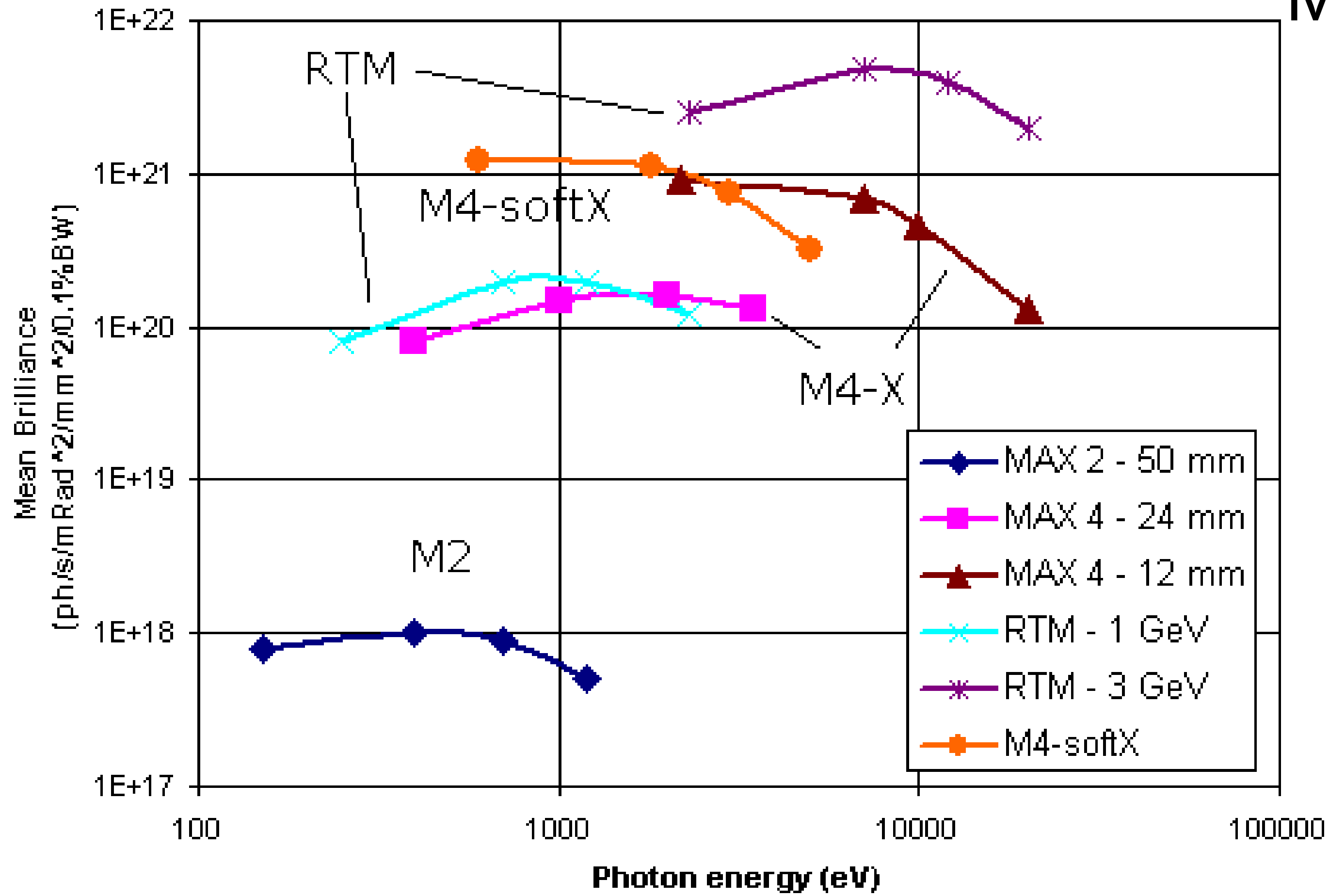
MAX-Ⅳ

MAX-lab

MAX-IV Machine Parameters

	X-ray ring	Soft X-ray ring
Ring circumference (m)	285	285
Operating energy (GeV)	3	1.5
Circulating current (A)	0.5	0.5
Rad. energy loss/turn (keV)	770	50
Hor emittance (nm rad)	1.1	0.29
Qx	26.6	26.6
Qy	9.6	9.6
Nat. Hor. Chromaticity	-33	-33
Nat. Vert. Chromaticity	-29	-29
Hor. Admittance (µm rad)	17	17
Vert . Admittance (µm rad)	1.25	2.8
Energy acceptance (%)	4	4
Nr of straight sections	12	12
Length of straight section (m)	4.6	4.6
Beam 1/e lifetime		
Touschek (h)	18	28.6
El scattering (h)	131	73
Bremsstrahlung (h)	195	195
Total (h)	14.6	18.6
RF (MHz)	100	100
RF Power (kW)	600	200

MAX-Ⅳ



MAX4 - Uses superconducting small gap undulators, see "The machine" to the right. M4-softX is the 1.5 GeV ring while M4-X is the 3 Gev ring.

MAX 2 - (M2) is included for comparison. *1.5GeV 8.8nmrad*

RTM - These are tentative numbers for coherent radiation from the injector. This example uses the Energy Recovery Racetrack Microtron concept.

MAX-Ⅳ

High−brilliance

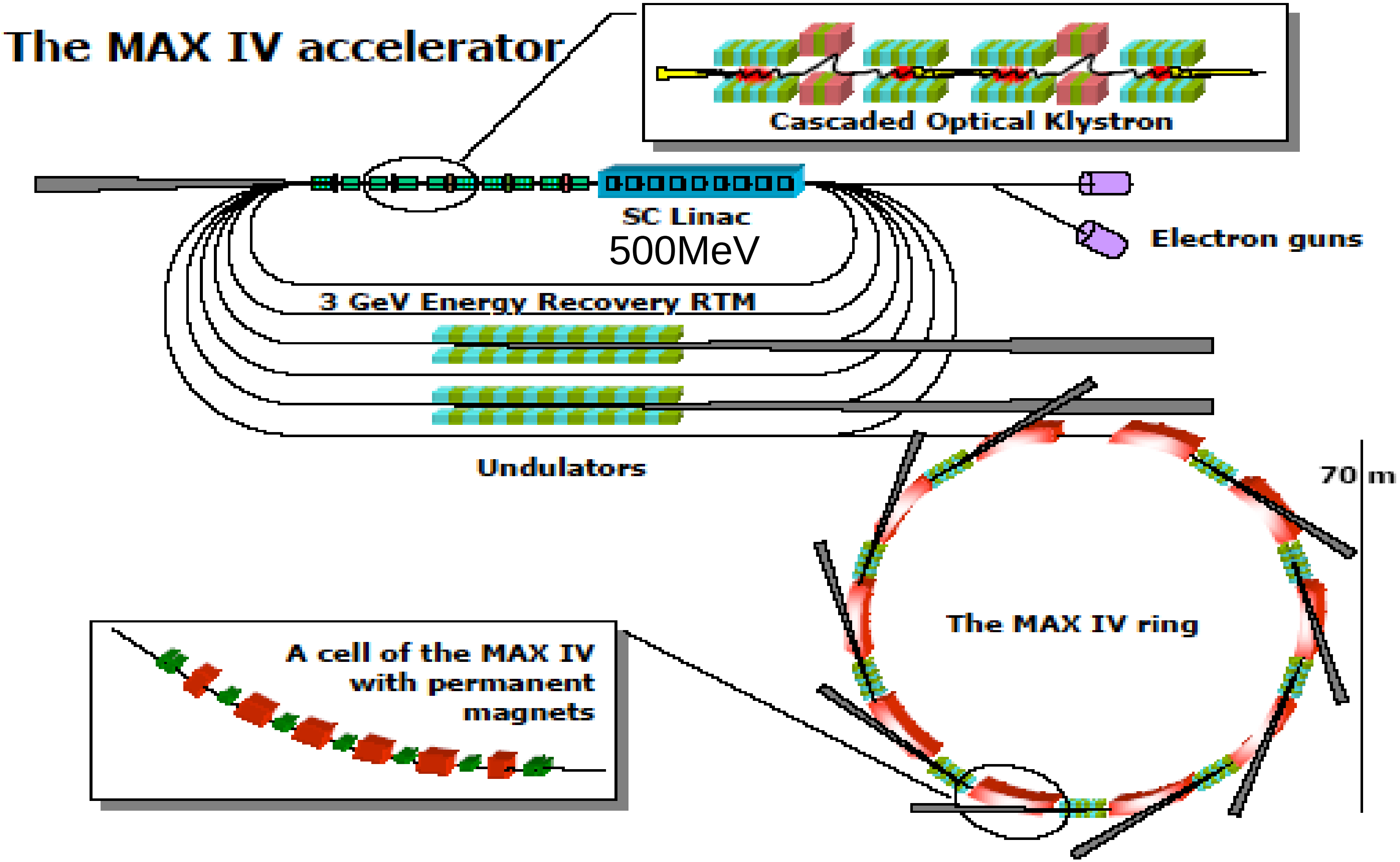
Small gap(3mm), short period superconducting undulator 12mm×200periods、K_{max} 2.3

3GeV energy recovery race-track microtron

Storage ring	high mean brilliance
	multi-bunch filling, top-up
Injector	short pulse(<1ps), coherent light

Web上のデータの間にも異なる数字が出てくる（周長277/285m、直線部 12/14)検討段階。調査費は付いている。

MAX Ⅳ


The MAX IV accelerator
Cascaded Optical Klystron
SC Linac
500MeV
Electron guns
3 GeV Energy Recovery RTM
Undulators
70 m
The MAX IV ring
A cell of the MAX IV
with permanent
magnets

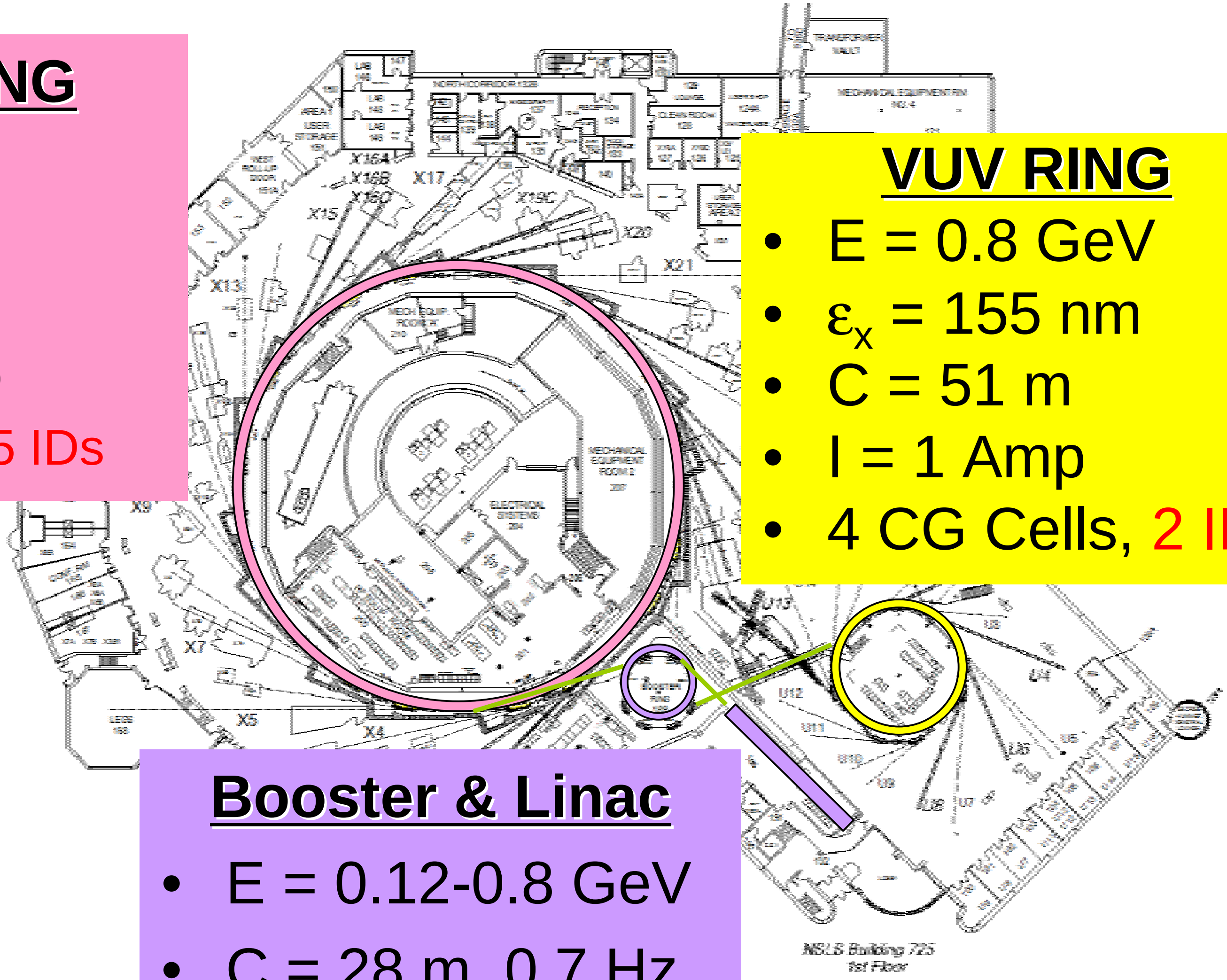
NSLS Accelerators Today

XRAY RING

- E = 2.8 GeV
- ε_x = 60 nm
- C = 170 m
- I = 0.28 Amp
- 8 CG Cells, 5 IDs

VUV RING

- E = 0.8 GeV
- ε_x = 155 nm
- C = 51 m
- I = 1 Amp
- 4 CG Cells, 2 IDs



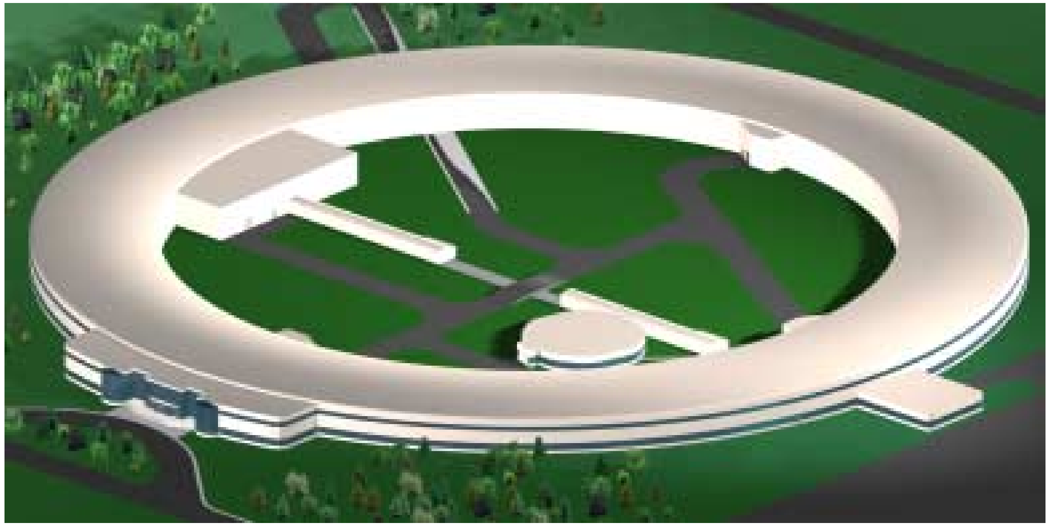
Booster & Linac

- E = 0.12-0.8 GeV
- C = 28 m, 0.7 Hz
- I = 0.01 Amp

NSLS II Design Goals

- Ultra High Brightness ~10^{21} for 1-15 KeV,
- High Photon Flux ~ 10^{16},
- Large Number of Insertion Devices (~20),
- Future Upgrade Potential to an ERL,
- Cost ~ 400M$

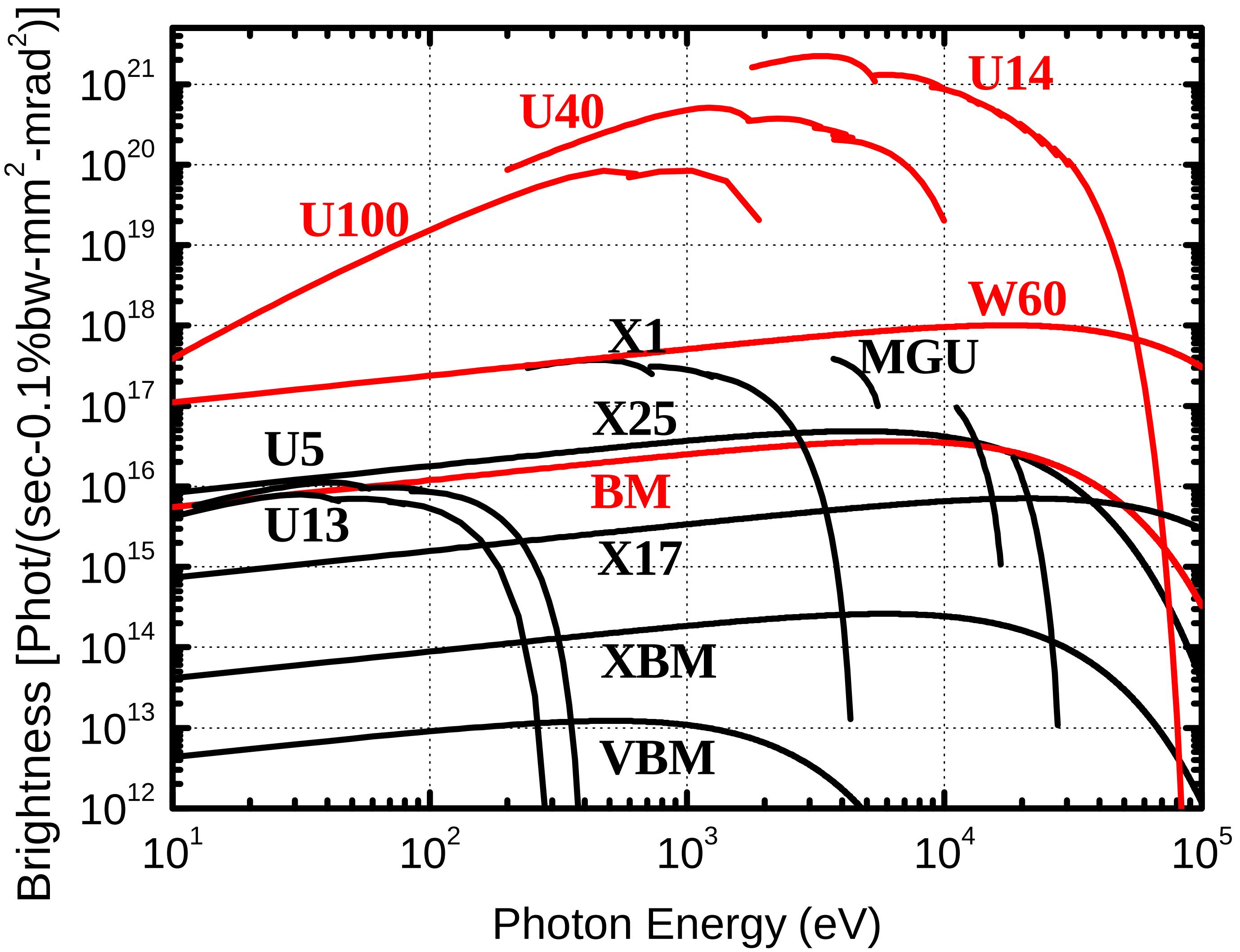
NSLS II Machine Concept



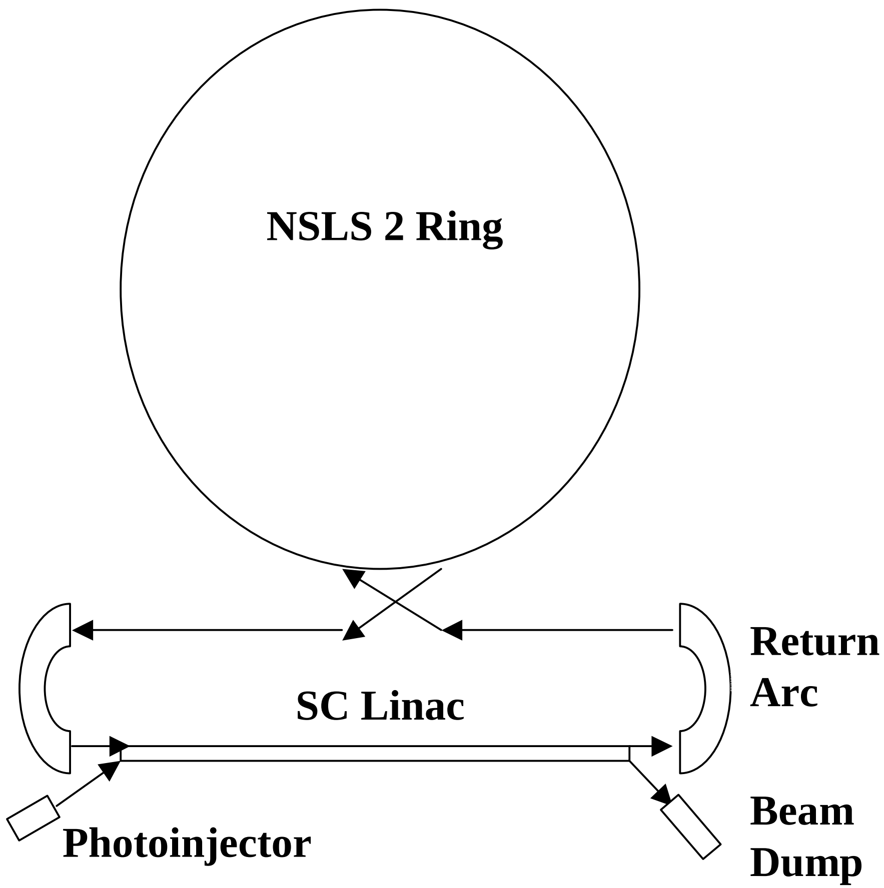
- **New Electron Storage Ring**
- Ultra Low Emittance (1.5 nm)
- Medium Energy (3-4 GeV),
- Large Current (500 mA),
- Top-Off Operation,
- Superconducting Undulators
- Circumference (620 m)
- Provision for IR Source

A machine meeting these design goals exceeds the performance of the existing X-ray ring by many orders of magnitude & would be a “best in class” performer on the world stage as well!

Performance Goals: Average Brightness NSLS-II vs NSLS



Future Upgrade Possibility: ERL



- Add SC linac & return arc to make an ERL

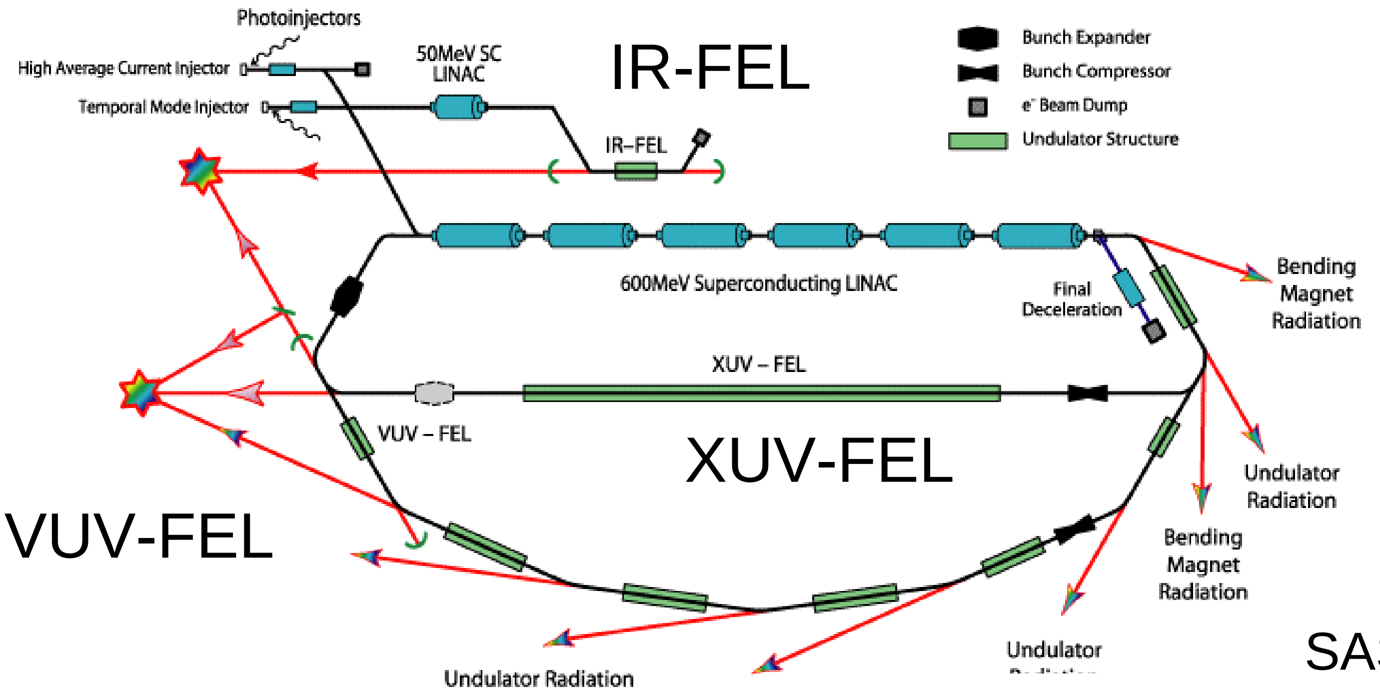
Explore the possibility of staging the upgrade with a “multi-turn ERL” to reduce demand on the photoinjector

4GLS

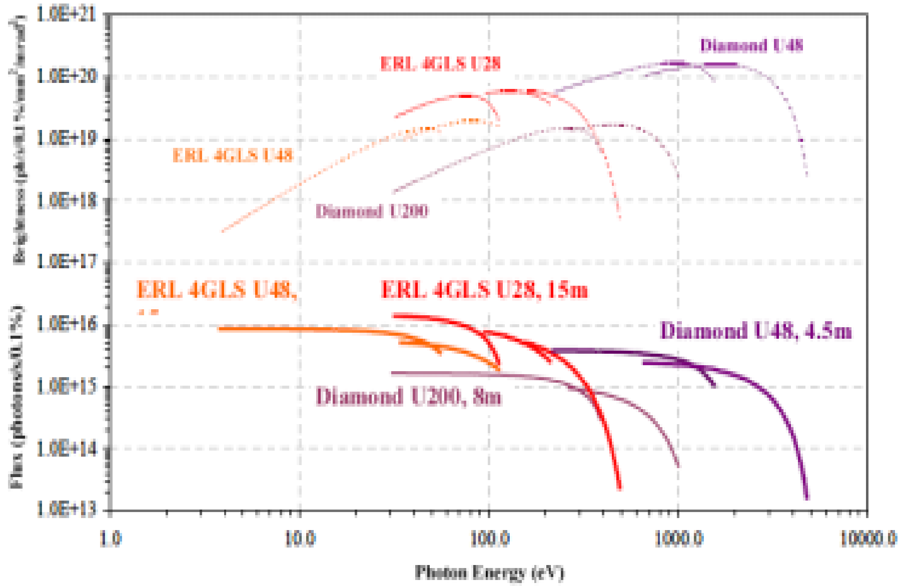
600MeV

? mA

数百fs



SASE-FEL 10^{29}



Our vision for 4GLS is to create the world's leading low energy light source in order to carry out internationally outstanding science that cannot be conducted elsewhere.

The science case for 4GLS

Time-resolved pump probe studies

molecular dynamics, conformational dynamics in biomolecules, electron dynamics, transients, short-lived species and excited states, reaction dynamics at surfaces and interfaces

Nanoscinece

the nanotechnology revolution, free radicals and clusters, clusters as probes of liquid-solid transition properties, electronic structure of single clusters, spin physics of clusters and magnetic materials, ultra-high resolution photoemission, namoimaging, magnetic imaging… functional imaging

Nonlinear processes

Medical

Industrial

BESSY Soft X-ray FEL

Femtochemistry
Magnetization dynamics on the fs time scale
Atoms and molecules
The nature of complex solids
Dynamics in biological systems

FEL will be an extremely powerful "race horse" for its spectral range…complementing the "work horses" of the conventional sources.

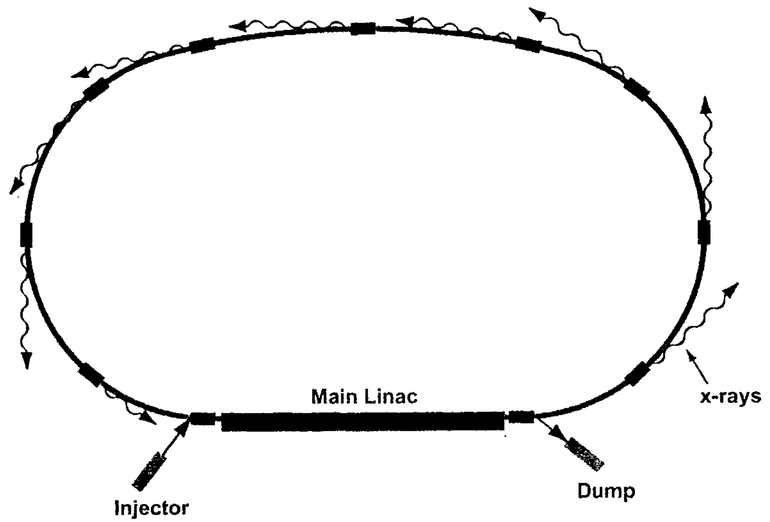
Nanofabrication of materials using soft X-rays
Time resolved spectroscopy
New frontiers in photon-related spectroscopies and coherence

For over 15 years it has been recognised that UK researcher requiring low energy synchrotron radiation are being severely disadvantaged by the lack or access to high brightness VUV photons.

Our vision for 4GLS is to create the world's leading low energy light source in order to carry out internationally outstanding science that cannot be conducted elsewhere.

Energy Recovery Linac (ERL)

- リング型は電子の再利用 ($10^6 s^{-1}$)
- ERLはエネルギーを再利用
  → エネルギー効率
  放射線



- ライナック型とリング型の双方の長所を持つ光源と期待される
  低エミッタンス、極短バンチ
  一定電流、コヒーレンス

- 未だ克服すべき課題がある
  特に大電流化（電子銃、入射部、エミッタンス増大、ビームロス、コスト…)

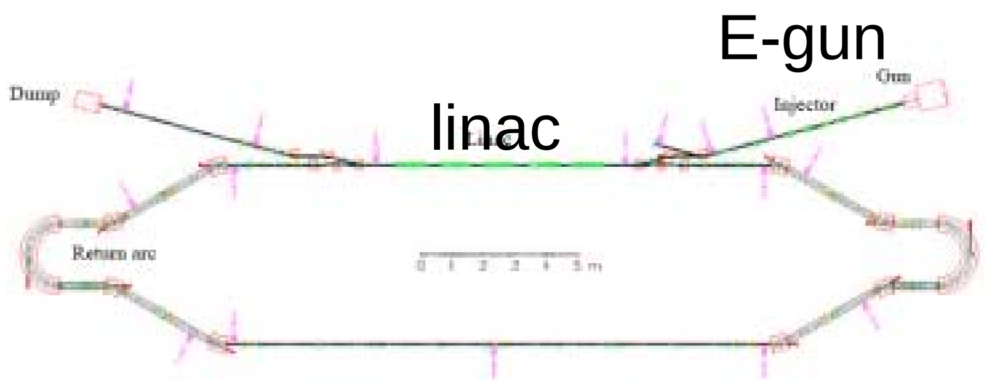
ERL

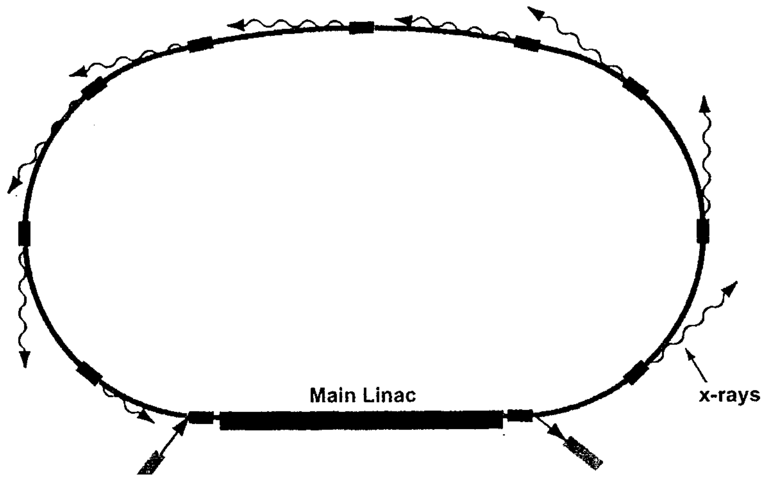
- SRでは到達不可能な低エミッタンス、短パルス
- パルスの構造、タイミング安定、制御可能
- 回折限界光の利用、局所構造解析
- 動的構造解析
- 同時に多数の実験を実施出来る可能性がある

- ピーク輝度ではX-FELに劣る。
- 干渉性も劣る。

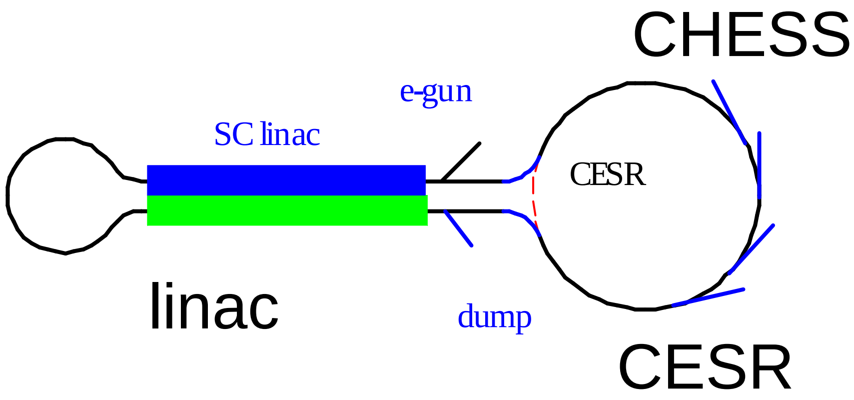
SRのsupersetとなりうる光源

Cornell





Prototype ERL
100MeV 100mA



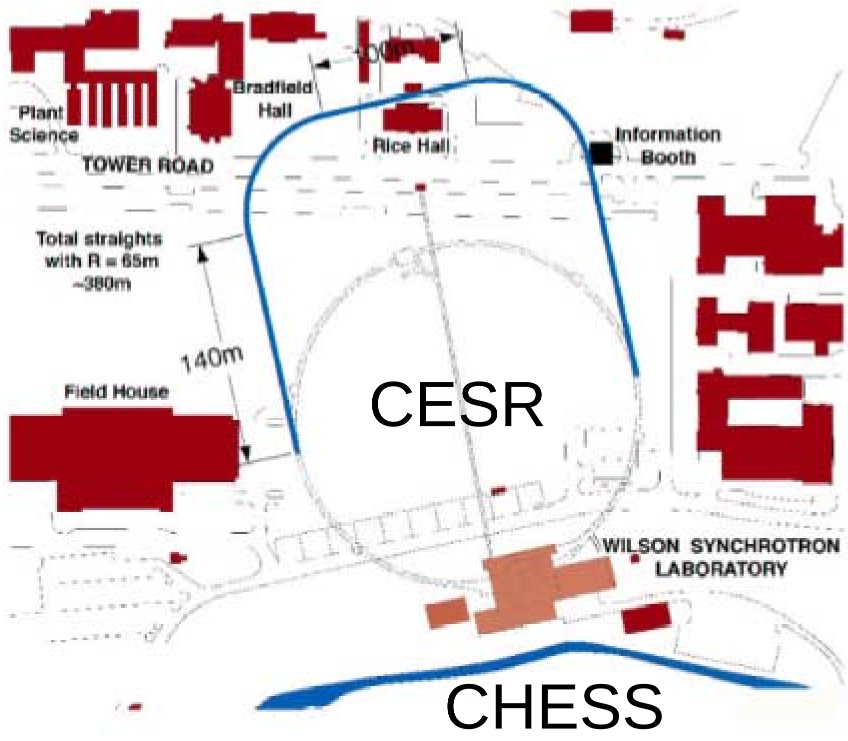
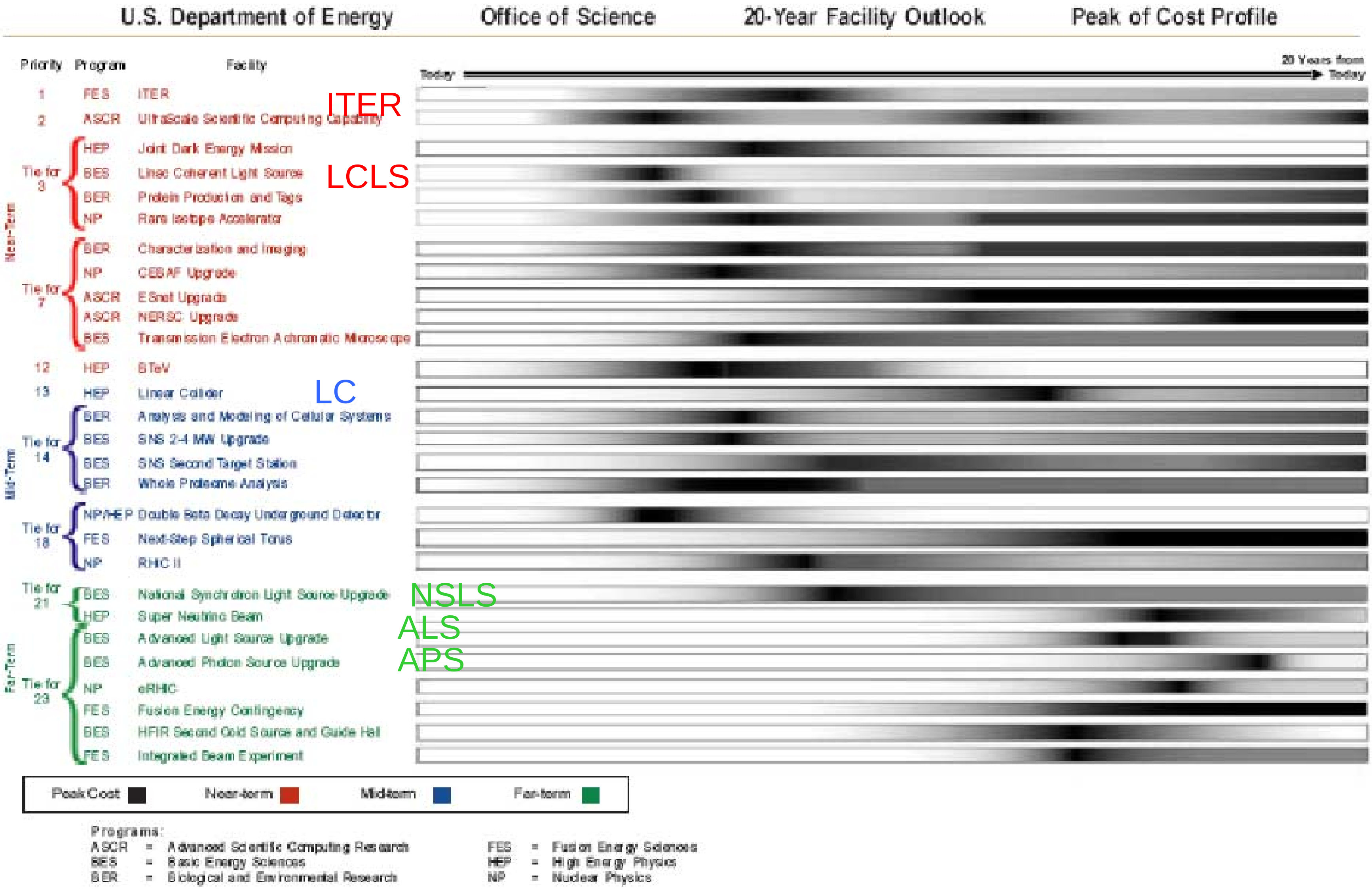


Figure 1: An ERL in an extended CESR tunnel

5GeV 100mA
2m×2、5m×4、25m×1

米国DoEの場合

20年



日本の事情

将来計画は世界が注目するものを

1982.5.8
鈴木総理大臣来所

1982.4.17
ミッテラン仏大統領来所
小川文部大臣来所

将来計画は我々放射光コミュニティが作り、整理する必要がある。

放射光の将来計画は

The realisation time for a new accelerator system is in the order of 8 to 10 years and it is thus of highest importance that the planning for such a project start immediately if we want continue to provide these scientific opportunities for especially **Japanese** researchers.

We envisage a pre-study time of two years to complete a conceptual design report. If, at that time, the decision is taken to construct a new **Japanese** Synchrotron Radiation source there is another 6 to 8 years until new users can start their research.

In parallel with this project PF will elaborate the scientific case for the next Japanese Synchrotron Radiation Source and thus a close interaction about the parameters of the accelerator system will take place.

KEKの中での競争

物構研：　J-PARC第二期計画
　　　　　中性子ビームライン整備

素核研：　Super-B
　　　　　GLC

外の世界：　ITER

競争に勝てるだけの斬新なサイエンスと実現する技術
全日本的視点での計画、コミュニティで一本化

Classification of SLS users

Category A: ビームラインを設計、建設、運転する人、予算を提供。

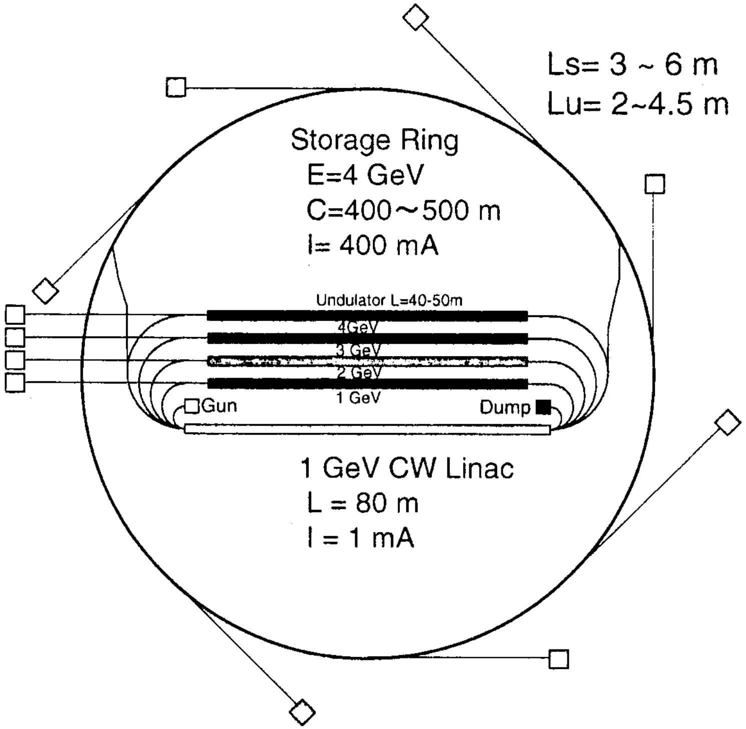
Category B: 学問的、技術的ノウハウを提供し、ビームラインの設計、建設をする技術者を提供し、予算をSLS外から得る。

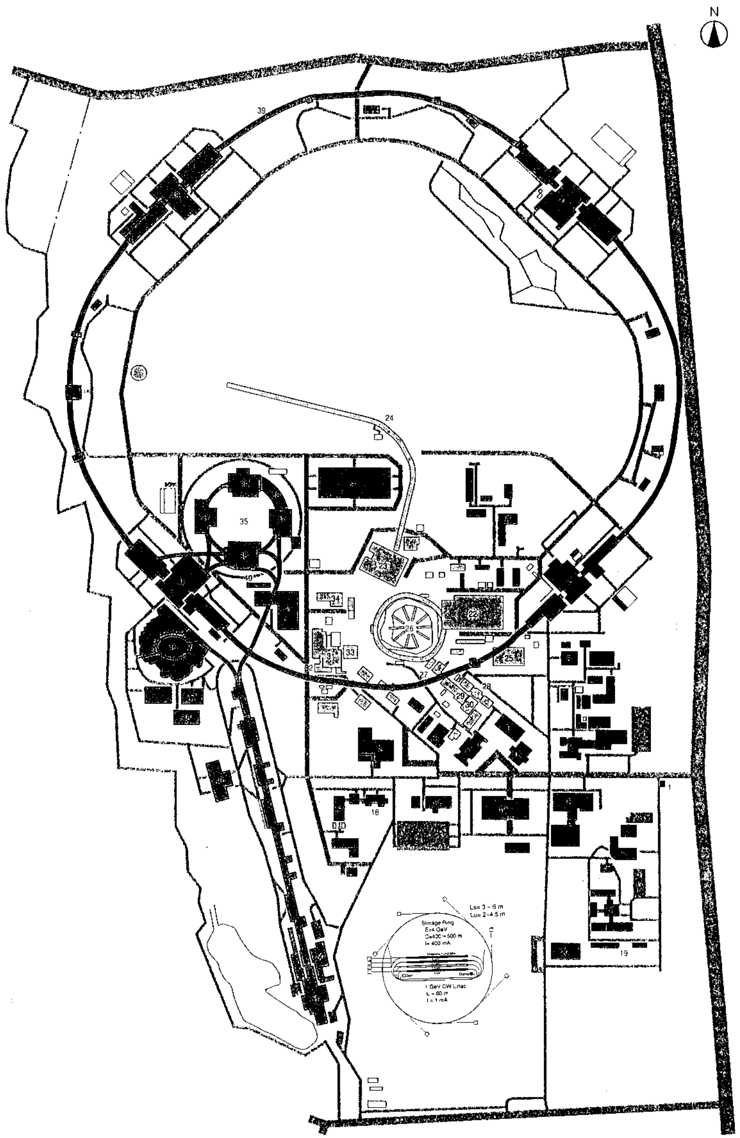
Category C: 訓練された人間と共に来て実験。

Category D: 実験、解析はSLSの支援に負う。

Category E: SLSと共に加速器、X線光学系、検出器、データ解析の開発をする。

放射光次期光源の提案





蓄積リング＋MARS

SLSの歴史

1993.9	ETH boardに詳細提案を提出
1996.3	predecision of the Federal Government of Switzerland
1996.12	スイス政府の建設決定
1997.3	159MCHF（125億円）の予算が認められる
1997.6	最終的な承認
1998.6	建屋建設開始　　1999.7完成

2000.4	リニアック完成
2000.9	ブースター完成
2000.11	真空封止アンジュレーターがSpring-8から到着
2000.12	蓄積に成功
2001.8	Beam on sample

Insertion Devices

- **Superconducting Undulators**
  - Highly desirable for 3 GeV ring
  - K = 2.2, λ_u=14-15 mm & g = 5 mm, L = 2-5 m,
  - Provides coverage to 15 KeV with n = 1, 3, & 5
- **PM Undulators**
  - Longer period, λ_u=19 mm, requires $n \leq 11$
  - High harmonics are effected by σ_E
- **SC Wigglers**
  - Two devices anticipated for $h\nu$ > 20 KeV

Candidate Lattice Parameters

Lattice Type	**DBA**	**TBA**
Circumference, C [m]	630	620.4
Superperiods, N_s	28	24
Straight Section Length, L_{ss} [m]	7	7
Horizontal Emittance, ε [nm]	**2.14**	**1.54**
Momentum Compaction, α	0.000171	0.0000815
Dipole Radius, ρ	8.02	7.64
Dipole Field Index, n	36	21.5
Betatron Tunes ν_x, ν_y	36.37 , 19.27	37.3 , 17.25
Bare Chromaticities, ξ_x, ξ_y	-98, -29	-109 , -32
β_{x0}, β_{y0} [m]	2.53 , 3.99	4.65 , 2.37
Damping Partition Functions, J_x, J_e	1.16 , 1.84	1.04 , 1.96
Energy Loss in Dipoles Uo [MeV/turn]	0.893	0.938
V_{rf} [MV]	2	1.55
ε_{RF} [%]	3	3
Natural Bunch Length, σ_L [mm, ps]	4, 13.3	3.3, 11
Natural Energy Spread, σ_E [%]	0.094	0.094

NSLS-II Machine Advisory Committee Meeting #1

- On November 14, 2003, the first meeting of the NSLS-II Machine Advisory Committee (MAC) was held at the NSLS. The design and parameters of NSLS-II were discussed and presentations were given by several NSLS staff members.
- **MAC Members**
  Dr. Glenn Decker, Advanced Photon Source, Chair
  Dr. Pascal Elleaume, European Synchrotron Radiation Facility
  Dr. David Robin, Advanced Light Source
  Dr. Gennady Stupakov, Stanford Linear Accelerator Center
  Dr. Richard Walker, Diamond Light Source
- **Agenda**
  8:15-9:00Continental Breakfast and Executive Session
  9:00-9:20WelcomeSteve Dierker
  9:20-9:40Science RequirementsChi-Chang Kao
  9:40-10:20Machine OverviewJim Murphy
  10:35-11:10Storage Ring LatticeStephen Kramer
  11:10-11:40Collective Effects and LifetimeBoris Podobedov
  11:40-12:10Linac and BoosterTimur Shaftan
  1:10-1:40InfraredLarry Carr
  1:40-2:10Magnets and Insertion DevicesGeorge Rakowsky
  2:10-2:35RF SystemsJim Rose
  2:35-3:00Shielding and ES&H Bob Casey
  3:15-4:00Facility Layout, Cost, ScheduleErik Johnson
  4:00-4:30Executive Session
  4:30-5:00Closeout