Present Status of ERL Project
(Light Source)

Toshio KASUGA

Outline

1. Test Facility
2. Key Components
   - Gun (incl. Laser)
   - Injector
   - Main Linac
3. Issues of Beam Dynamics
4. Site

Test Facility

Test Facility

To realize ERL (5 GeV class)

- **Development of many components**
- **Experimental investigation into beam dynamics**

>>>>

It is important to develope

Test ERL

before construction of 5GeV class ERL

Test ERL (60-200MeV ERL)

With the test ERL

- Development of key components
  - Electron gun
  - Injector linac
  - Merger
  - Main linac
- Demonstration of energy recovery
- Beam dynamics
  - Instabilities, emittance growth, bunch lengthening
  - Effects of CSR etc.

Design of 5GeV ERL!! (through experiences of test ERL)

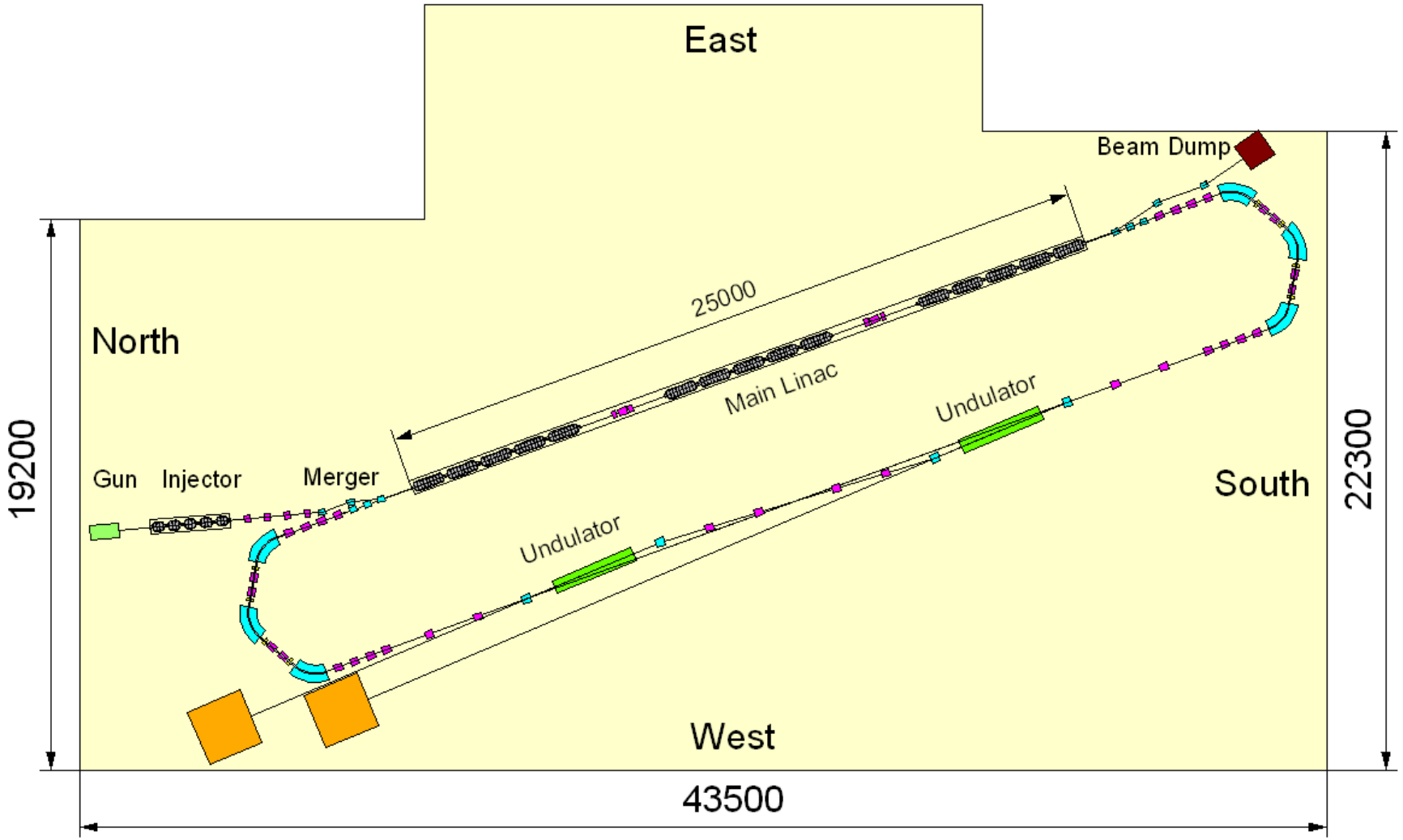
Test ERL >> VUV Light source

Tentative parameters

Injection energy	5 MeV (10-15 MeV)
Injector beam power	500 kW (1 MW)
Beam energy in arcs	~60 MeV (160-200 MeV)
SC cavities for main linac	9cells × 4: single module (two modules)
Normalized emittance	1 mm·mrad (0.1 mm·mrad)
Beam current	10 mA ? (100 mA)
Rms bunch length	Usual mode : σ_τ = 1-2 ps Short bunch mode: σ_τ ~ 100 fs?
Test undulator	No undulators (with an undulator)

Initial goals. Final goals are in ( ).

TEST FACILITY



Total length of 25m for main linac is available.>>150-200MeV class test ERL.

Key Components

1. Gun
2. Injector Linac
3. Main Linac

1.GUN

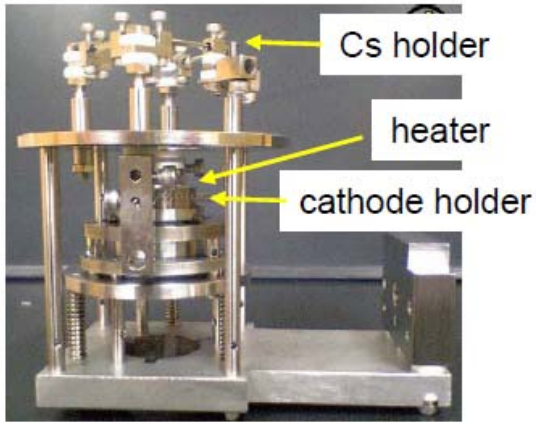
R&D issues for ERL guns

- Performance of ERL-LS relies on its electron gun.
- High-average current (~100mA) and small emittance (~0.1mm-mrad) are essential.
- Further improvement from the existing technologies is required (JLAB-FEL=10mA and XFEL=1mm-mrad).
- “NEA cathode + DC gun” is only the practical solution.
- many R&D issues exist.

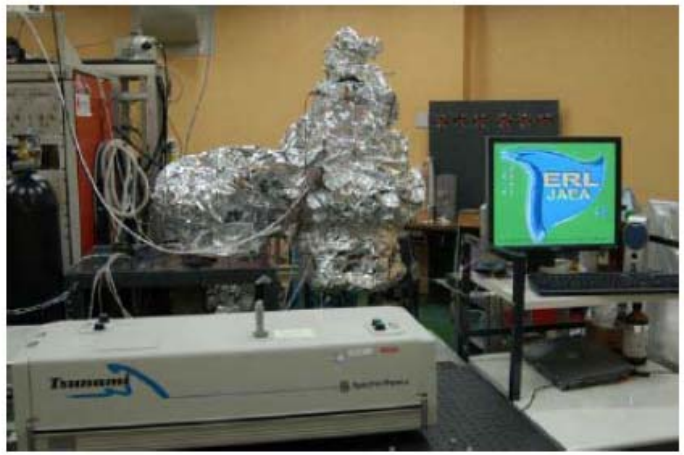
Courtesy of R.Hajima (JAEA)

a photocathode test bench at JAEA

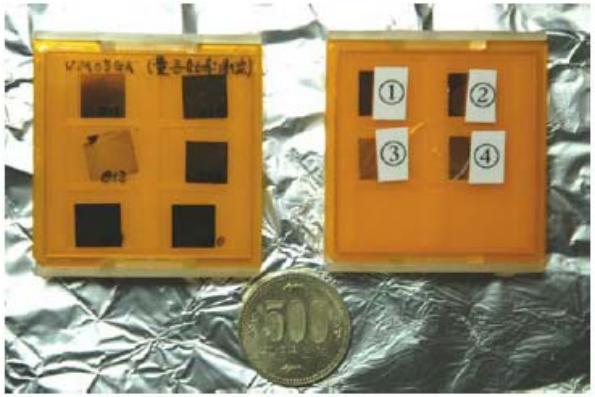
cathode holder



UHV chamber and laser



Optimization of cathode material for the better QE and life.



photocathode prepared at Nagoya Univ(1).

GaAs, $Al_xGa_{1-x}As$

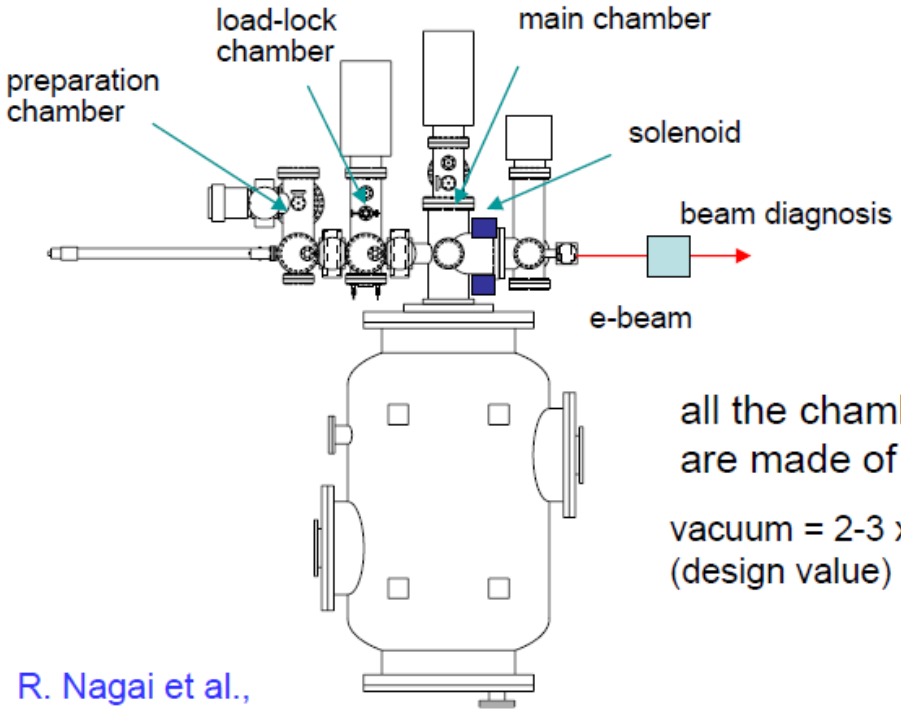
x=0.17, 0.28

(1) Venture Business Laboratory, M. Tabuchi, Y. Takeda et al.

Courtesy of R.Hajima (JAEA)

Development of a 250 kV-50 mA DC gun

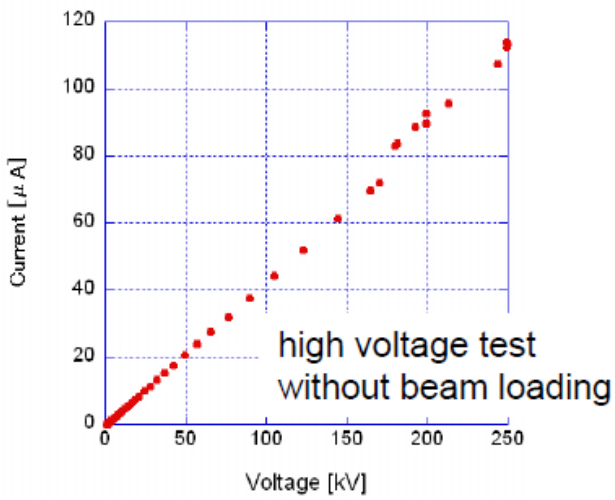
A DC gun is under development.



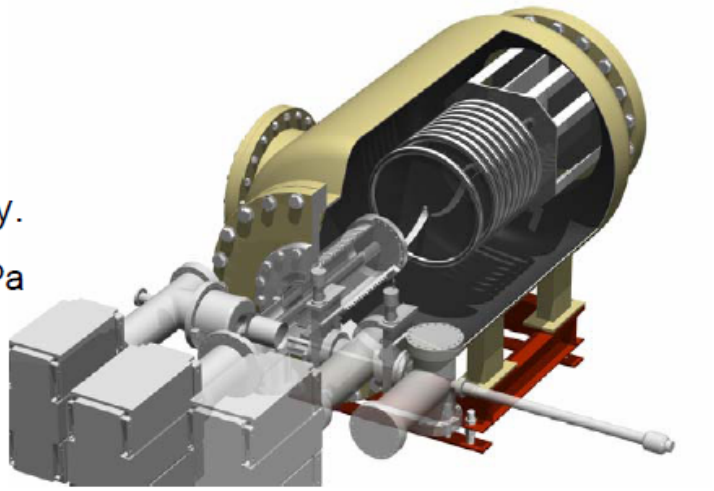
R. Nagai et al.,
Proc. Acc. Meeting in Japan (2006)

all the chambers are made of Ti alloy.

vacuum = 2-3 x 10^{-10} Pa (design value)



H. Iijima et al.,
Proc. Acc. Meeting in Japan (2006)

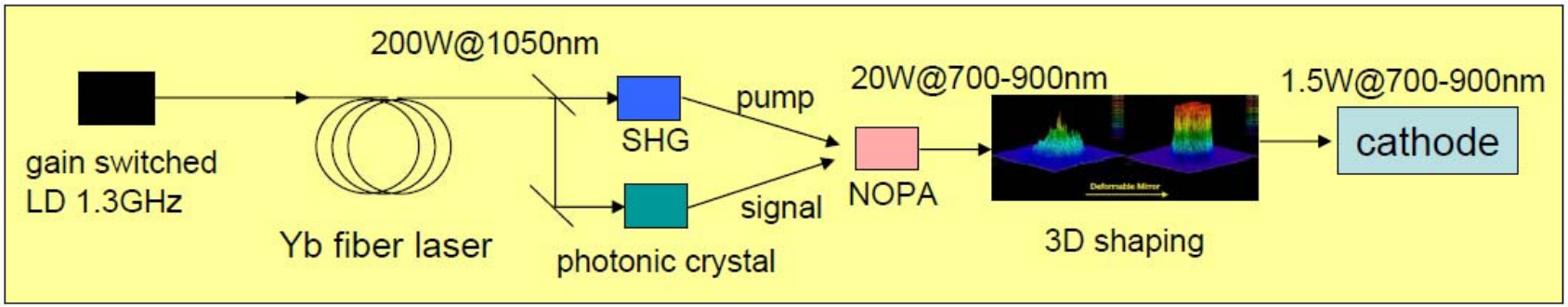


Courtesy of R.Hajima (JAEA)

drive laser

1.5 W, 1.3 GHz, 700-900 nm (tunable)

fund bidding - MEXT-KAKENHI, 2007-2010, ~1M USD for the laser.



NOPA = non-collinear optical parametric amplifier
3D shaping = deformable mirror (transverse) + pulse stacker (longitudinal)

gain-switched LD will be replaced by Yb solid-state oscillator in due time.

related description is found in ERL-REPORT-003 (Aug. 17, 2006)
http://pfwww.kek.jp/ERLoffice/info/index.html

Reinforcements for this field seem to be a matter of great urgency.

Courtesy of R.Hajima (JAEA)

2.INJECTOR

Target parameters and philosophy

- Frequency : 1.3 GHz
- Energy : 10 MeV
- Beam Current : 100 mA cw
- Less Number of Cells

Main components of ERL injector are proceeded and modified by STF baseline cavity for LC project.

Courtesy of H.Sakai (U.Tokyo) and S.Noguchi (KEK)

Cavity for ERL injector

Cavity fabrication and surface treatment were proceeded by STF Baseline(BL) 9cell cavity, which is aimed for 35MV/m high gradient for linear collider.

STF-BL 9cell cavities

Courtesy of H.Sakai (U.Tokyo) and S.Noguchi (KEK)

INJECTOR

Injector Cavity Parameters

Injector Cavity Parameters					
Frequency	1.3 GHz				
Number of cell / cavity (& Cavity)	3 (2)	2 (3)	2 (2)	1 (4)	1 (3)
Effective Length	34.6 cm	23.0 cm	23.0 cm	11.5 cm	11.5 cm
Accelerating Voltage	5 MV	3.4 MV	5 MV	2.5 MV	3.4 MV
Accelerating Gradient	14.5 MV/m	14.7 MV/m	21.7 MV/m	21.7 MV/m	29.5 MV/m
R/Q	300 Ω	200 Ω	200 Ω	100 Ω	100 Ω
Geometrical Factor G	270 Ω	270 Ω	270 Ω	270 Ω	270 Ω
Unloaded Q	$1x10^{10}$	$1x10^{10}$	$1x10^{10}$	$1x10^{10}$	$1x10^{10}$
Cavity Loss (total loss)	8.3 W (16.6W)	5.8 W (17.4W)	12.5 W (25W)	6.3 W (25.2W)	11.5 W (34.5W)
Beam Current	100 mA	100 mA	100 mA	100 mA	100 mA
Beam Power / cavity	500 KW	340 KW	500 KW	250 KW	340 KW
Optimum Coupler Q	$1.7x10^{5}$	$1.7x10^{5}$	$2.5x10^{5}$	$2.5x10^{5}$	$3.4x10^{5}$
Half Band Width	3.8 kHz	3.8 kHz	2.6 kHz	2.6 kHz	1.9 kHz
Number of Input Coupler / cavity	2	2	2	2	2
Number of HOM Coupler / cavity	< 6	< 6	< 6	< 6	< 6
2k Load (static)	10(1.7)W	7.5(1.7)W	14.2(1.7)W	8.0(1.7)W	13.2(1.7)W
5k Load (static)	30(10)W	25(10)W	30(10)W	20(10)W	25(10)W
80k Load (static)	70(20)W	55(20)W	70(20)W	45(20)W	55(20)W
selected					

Courtesy of H.Sakai (U.Tokyo) and S.Noguchi (KEK)

Coupler

- Energy of 10MeV: Final goal
- Injector has to deliver RF power of 1MW to beam of 100mA in CW mode

  >>>
- The most difficult problem of the injector: power coupler
- Cavity power: 340 kW/cavity
- Input coupler (double coupler): 170 kW

KEKB type coupler (500MHz/400kW)

TRISTAN Type ceramic window

Accelerator	Frequency	Size	Operation mode	Operating Power	Maximum Power Tested	Number of Couplers
TRISTAN	0.5GHz	170mm	CW	60kW	0.8MW	36
KEK-B	0.5GHz	170mm	CW	400kW	0.8MW	8
SNS	0.8GHz	108mm	1.3msec. 60Hz	550kW (Peak)	2MW (Peak)	81
JPARC (ADS)	0.97GHz	136mm	0.6msec. 25Hz	500kW (Peak)	2.2MW (Peak)	4
STF-Baseline	1.3GHz	90mm(cold) 112mm(warm)	1.5msec. 5Hz	350kW (Peak)	1.2MW (Peak)	4
This Design	1.3 GHz	120mm	CW	170kW	400kW	6

Courtesy of H.Sakai (U.Tokyo) and S.Noguchi (KEK)

HOM Damping

- Higher-order-mode (HOM) resonances affects beam stability
- Damping of HOMs: important
- Desing study of HOM coupler: underway
- Absorbers

3.MAIN LINAC

Development of superconducting cavity for ERL

- **Required performance for main linac**
  - Eacc=10~20MV/m

  → Heat load 10~40W/m(@2K)
  - 1.3GHz operation
  - Beam current 100mA

  →Need strong HOM (Higher Order Mode) damping to suppress Beam-breakup instabilities and heat load

- **Required performance for injector**
  - 5MV x 100mA = 500kW → Need high power coupler

- **Close collaboration with ILC cavity group to develop several components efficiently.**

Strategy of cavity design for ERL

HOW about the TESLA cavity …

- HOM damping is not enough for ERL operations
- Loop-type HOM coupler has heating problem for the CW operation

TESLA cavity is not adequate for ERL operations

Need L-band superconducting cavity optimized for ERL

Policy of KEK-ERL cavity design

- Suppress dipole modes as strong as possible
- No monopole modes around multiples of 2.6 GHz
- Damp quadrupole modes
- Keep Rsh of accelerating mode as high as possible

Courtesy of M.Sawamura(JAEA) et al.

Nine-cell Cavity

- Nine-cell structure with sufficiently damped HOMs has been optimized to achieve 15-30MV/m @ 100mA
- Large iris diameter, large beam pipes on both ends can propagete out HOMs to absorbers
- Eccentric fluted beam pipe for Q mode damping
- Nb single-cell models are in production

  mid-cell shape &

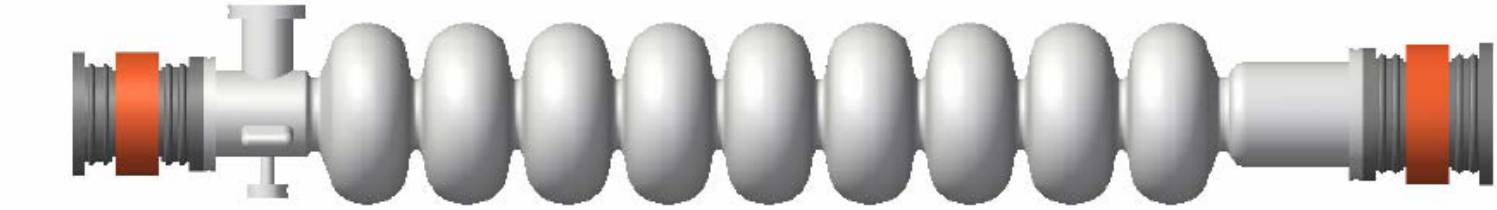
  end-cell shape with coupler ports & flute

KEK-ERL model-2 cavity

1) Cavity cell shape
   - Iris diameter 80mm, elliptical shape at equator
   - Cavity diameter 206.6mm

2) Large beampipe with microwave absorbers
   - Beampipe diameter 120mm & 100mm

3) Eccentric fluted beampipe
   - Damp quadrupole HOMs



Parameters for accelerating mode

Frequency	1300 MHz	Coupling	3.8 %
Rsh/Q	897 Ω	Qo x Rs	289 Ω
Ep/Eacc	3.0	Hp/Eacc	42.5 Oe/(MV/m)

Courtesy of M.Sawamura (JAEA) et al.

Summary (key components)

GUN

- We have initiated R&D for a photocathode DC gun
- QE and life have been measured for GaAs,AlGaAs
- HV test of the 250kV DC gun has been completed
- Design of drive laser is underway

INJECTOR

- ERL injector design started
- 170kW input coupler design is based on KEKB type
- Coaxial HOM coupler can be used

MAIN LINAC

- Model 2 cavity satisfies HOM damping criteria
- Nb single-cell models with coupler are in production

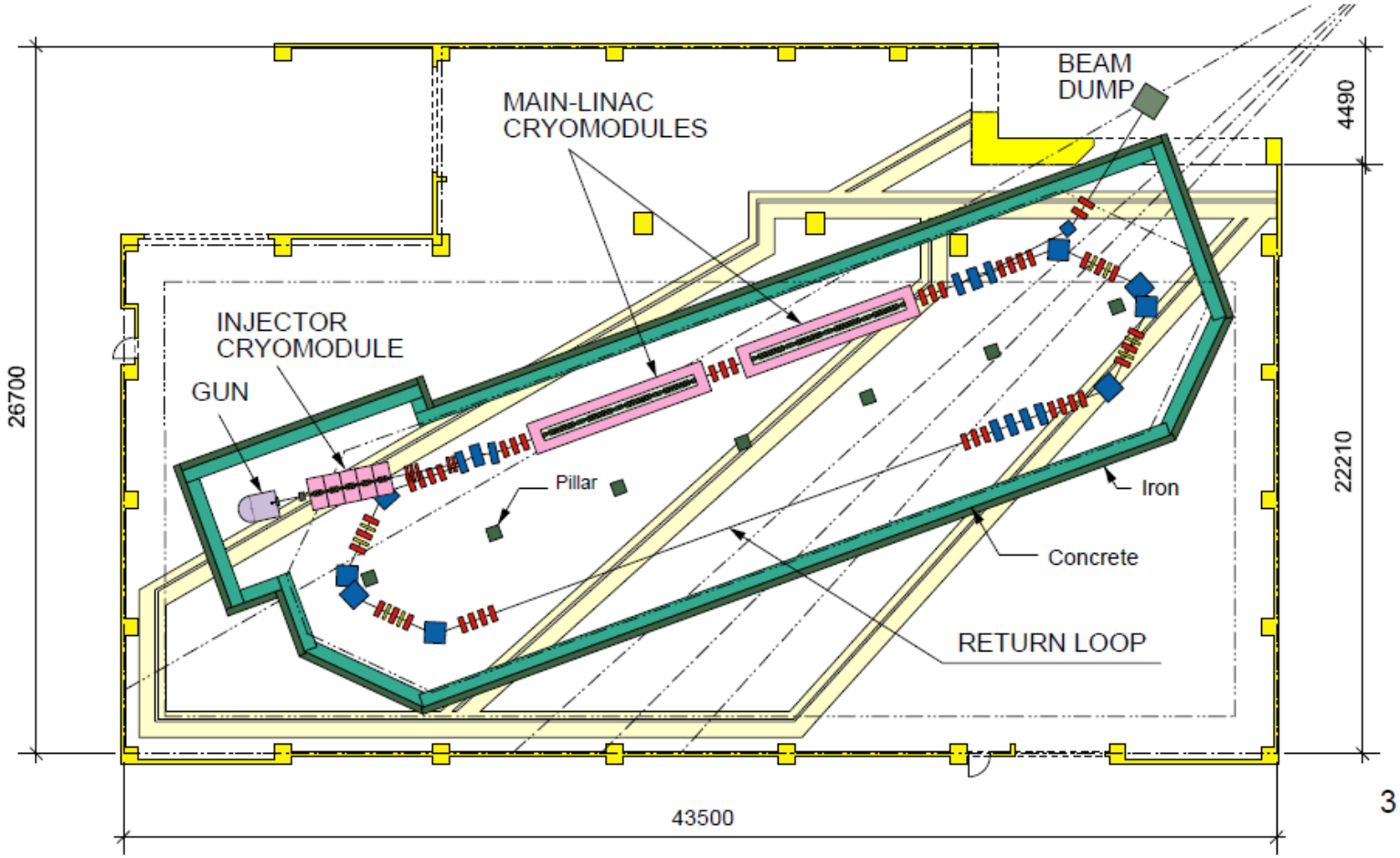
Issues of Beam Dynamics

Planned ERL test facility

Cold neutron building version

Maximum current: 100 mA
Beam energy: 60 – (200) MeV

Normalized emittance: 1 – 0.1 mm·mrad
Injection energy: 5 MeV (10-15 MeV)



Courtesy of S.Sakanaka

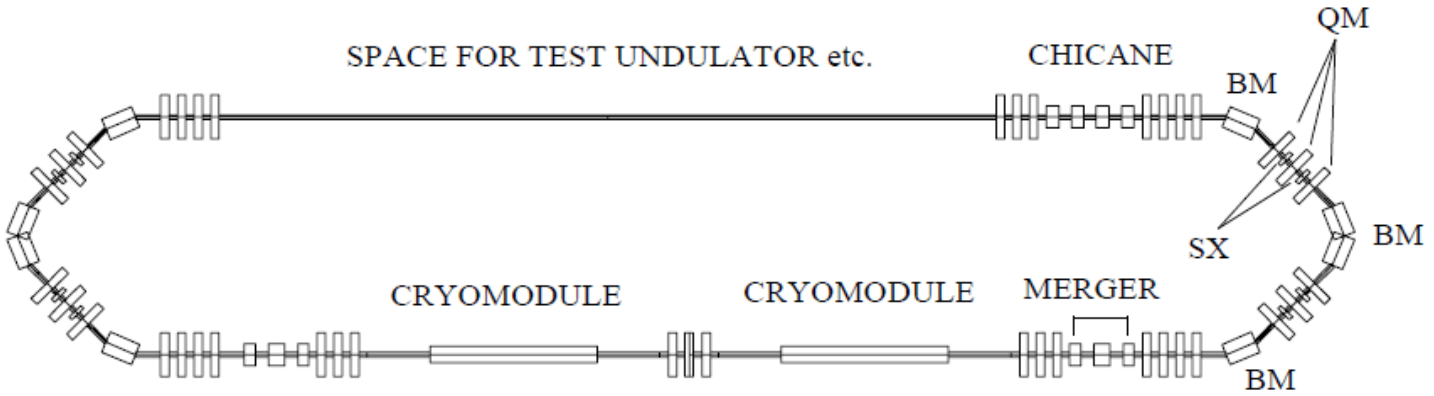
Beam dynamics issues

- Investigation into beam dynamics issues of the test ERL
- Studies optics of recirculation pass incl. bunch compression scheme
- Investing into phenomena that affect beam BBU, Ion trapping etc.
- Optimization of design parameters

Beam optics in return loop

Lattice under consideration (TBA)

K. Harada, Y. Kobayashi (KEK)



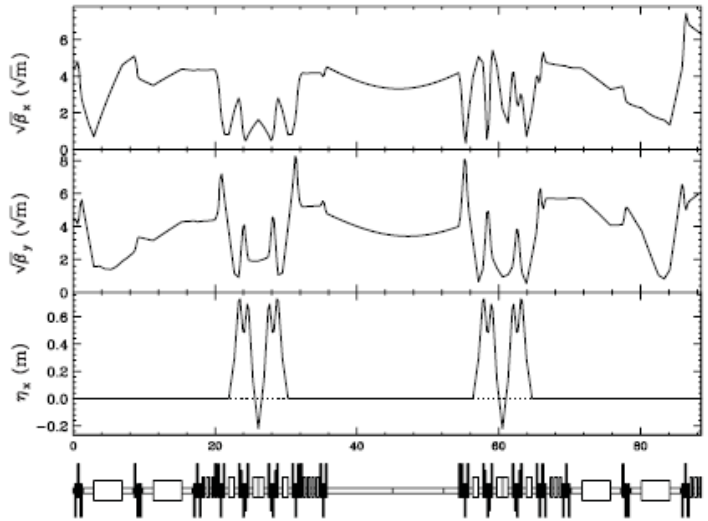
Design issues

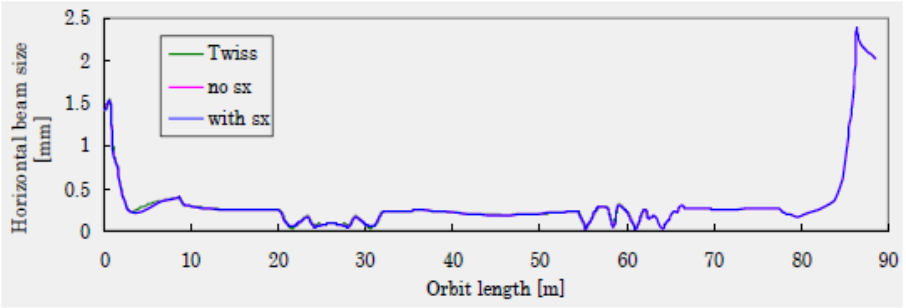
- Similar lattice to that of 5-GeV ERL.
- Minimize emittance growth due to CSR etc.
- Adjustable R_{56} for bunch compression (B.C.)
- Minimizing bunch length under B.C.
- Adjustable circumference for energy recovery
- x-y coupling control for BBU study
- Able to install undulators
- etc.

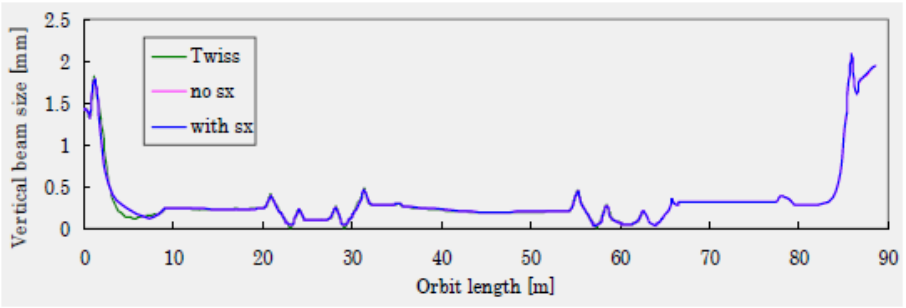
Courtesy of S.Sakanaka

Linear optics and beam sizes (recirculation)

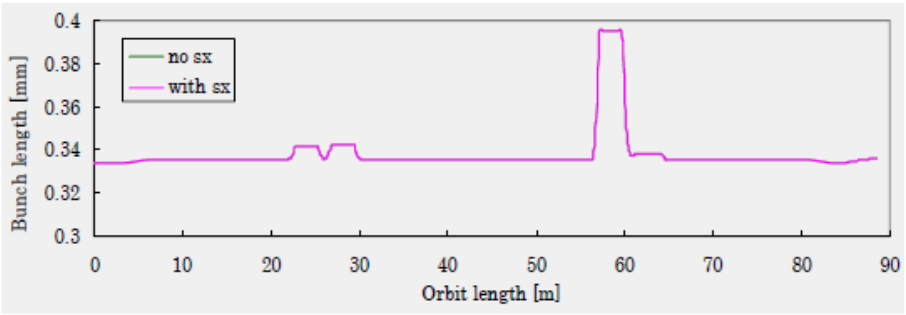
On-crest acceleration (5 → 165 MeV) , σ_τ = 1 ps, $\sigma_E = 1\times10^{-4}$, $\varepsilon_{n(x,y)}$ = 1 mm·mrad, 20 MV/m×(4m)×2 modules.







- Higher order aberrations are not dominant due to small energy spread.
- Negligible emittance growth and bunch lengthening.
- (CSR effects are not included)



Courtesy of S.Sakanaka

Issues of injector

- Requirement for Q-values of HOMs
  (stability of beam)
- Emittance growth in injector/merger
- Distribution of RF power among cavities
  single power source to several cavities?
  or
  separate power source to each cavity?

A young PF staff scientist stays at Cornell
to investigate these issues with the Cornell team.

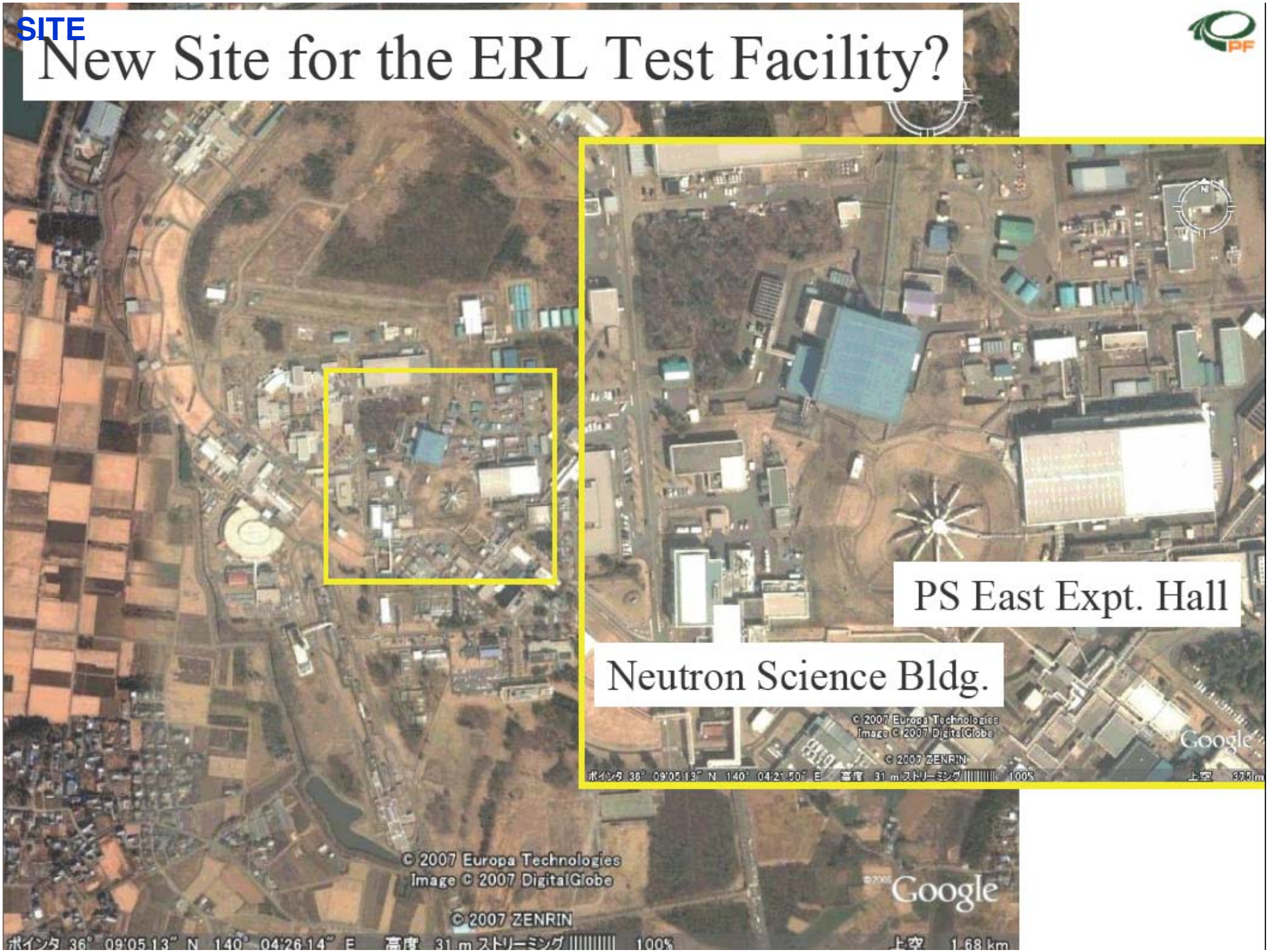
Site

- Exp. hall for cold neutron science:
  one of the candidates for the test ERL
- However
  The hall is not wide enough.
  Problem of radiation shielding.

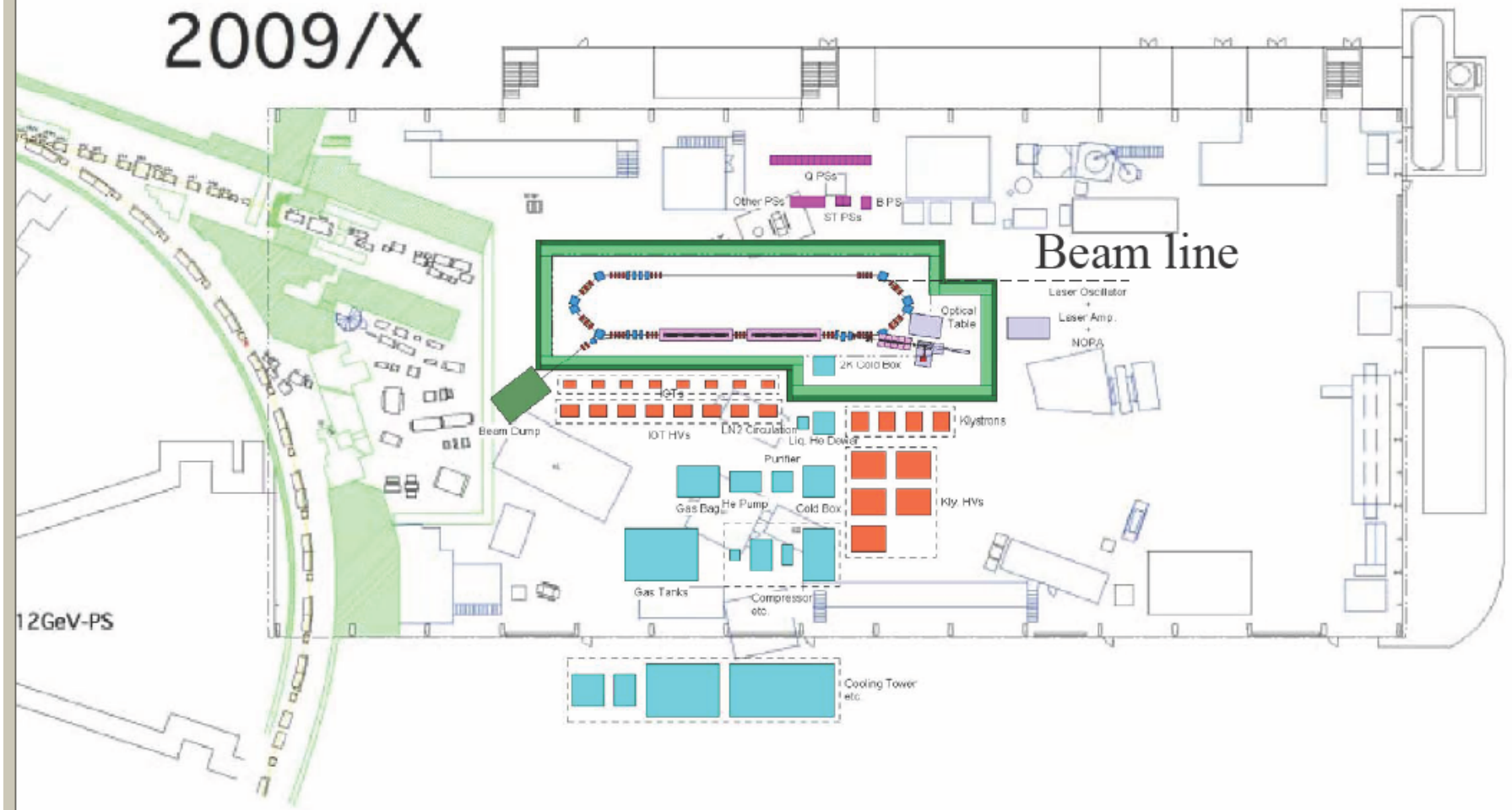
- We are now investigating another possibility.
  East experimental hall of Proton Synchrotron

SITE

New Site for the ERL Test Facility?



Plan for ERL Test Facility in PS East Expt. Hall



Summary

1. A 5 GeV class ERL is the most promising candidate for the future LS.
2. A 100 MeV class test facility is under consideration.
   Key components design has been started.
   - Gun (incl. Laser)
   - Injector
   - Main Linac
3. Investigation on issues of beam d ynamics is in progress.
4. The site will be decided soon.