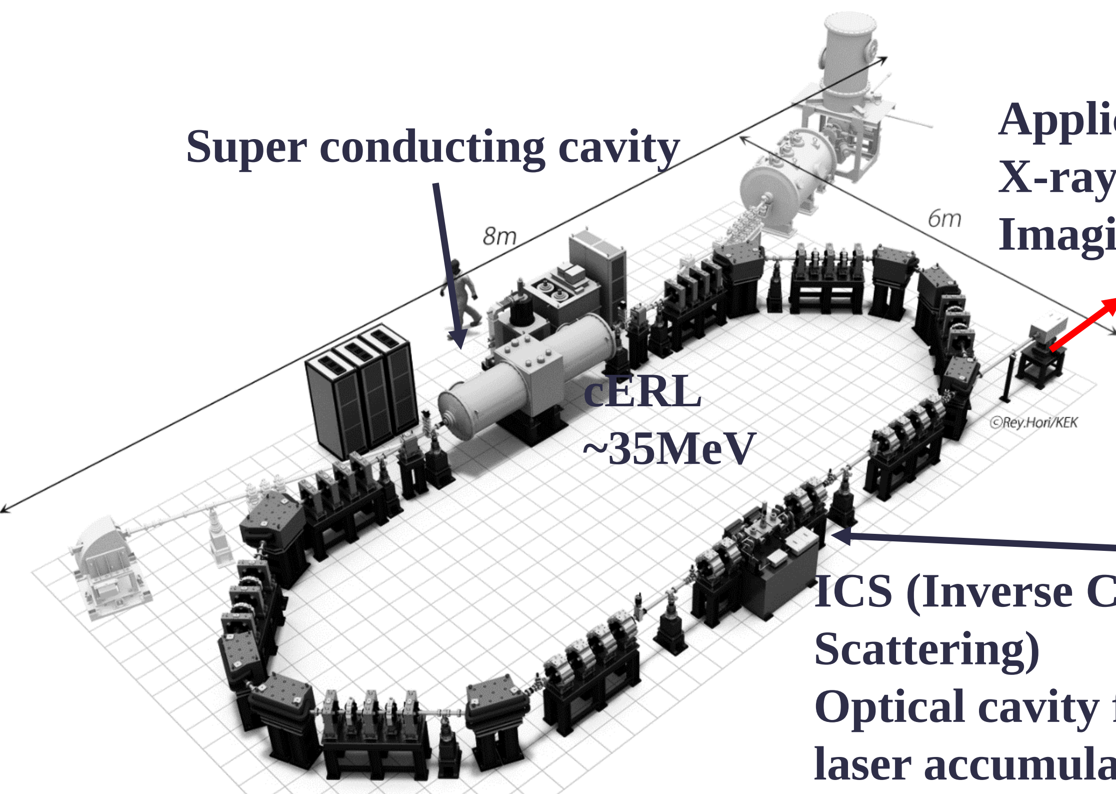
New QB Beam project based on Laser-Compton photon generation

(Fundamental Technology Development for High Brightness X-ray Source and the Imaging by Compact Accelerator under Photon and Quantum Basic Research Coordinated Development Program)

Purpose of our project

LCWS2013 at Tokyo Uni., 11-15 Nov. 2013
KEK Junji Urakawa

Compact X-ray Source (Peak Brightness 10^{19})
~keV-100keV tunable X-ray generation



Super conducting cavity

cERL
~35MeV

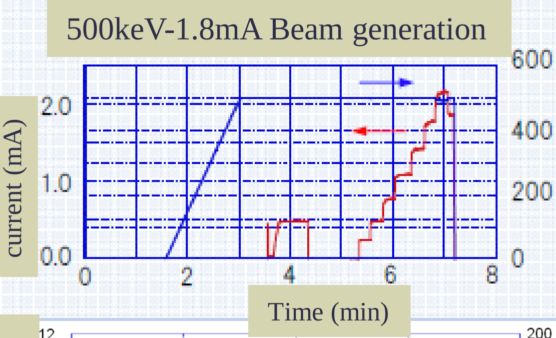
Application of X-ray: Imaging etc.

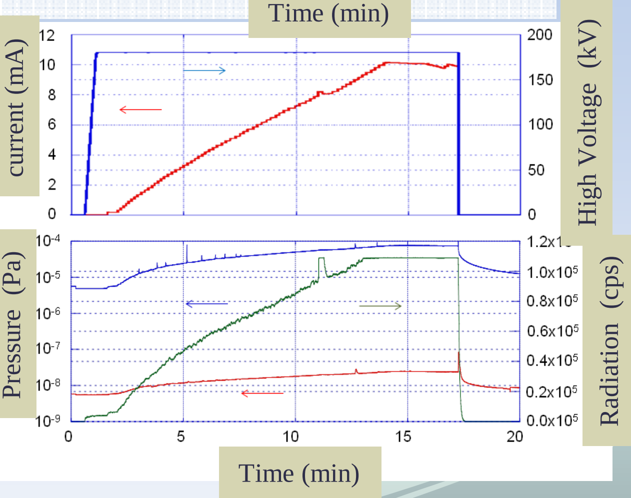
ICS (Inverse Compton Scattering)
Optical cavity for pulse laser accumulation, collision point

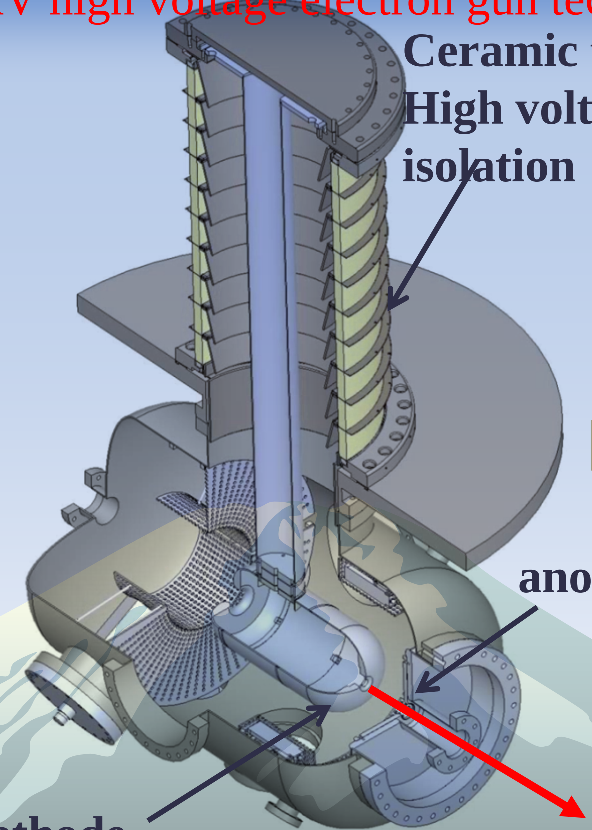
Development of Basic Technologies

1. Multi-alkali photocathode for high average current
2. Cryo-rf-gun
3. ERL
~1MW electron beam
4. ~1MW high-average power laser
5. ~10μm precise collision technique
6. X-ray imaging
7. 4K 325MHz spoke cavity

500kV high voltage electron gun technology



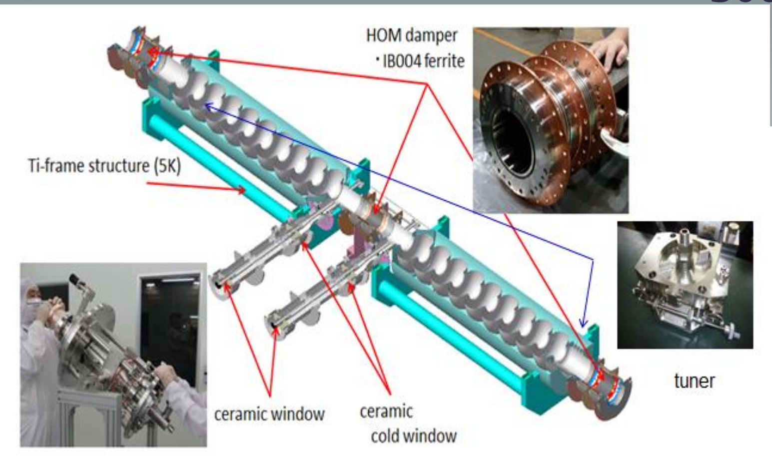


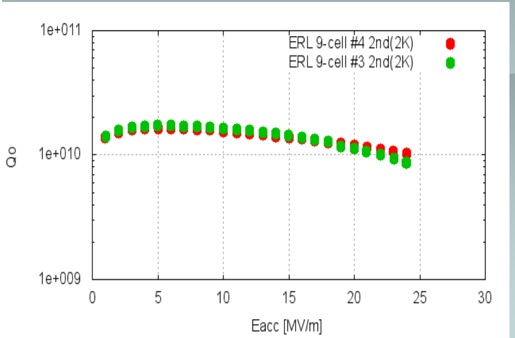


From Negative Electron Affinity (NEA)-GaAs Photocathode to Multi-Alkali photocathode Development
From DC gun to Cryo RF gun Development
Reason: to long lifetime and Compact

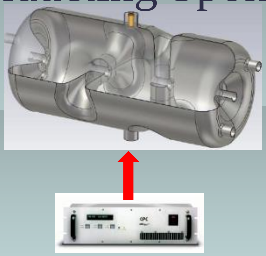
We can proceed our proof-of-principle experiment using DC gun and 2K-Super conducting cavities for high brightness X-ray generation.

500kV-DC Gun



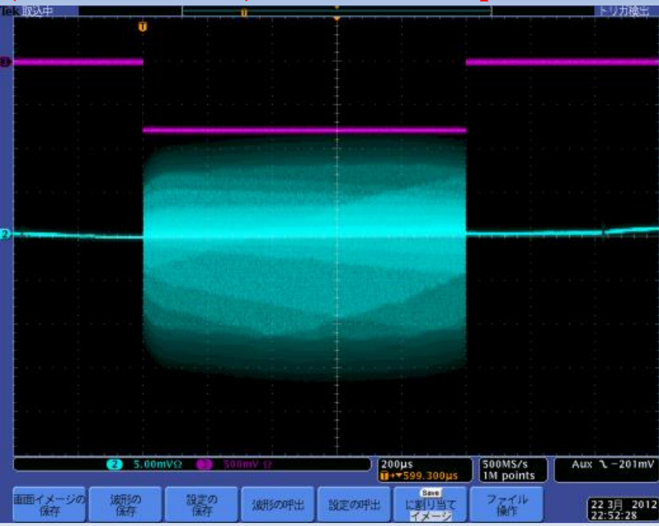


4K 325MHz super Conducting Spoke cavity

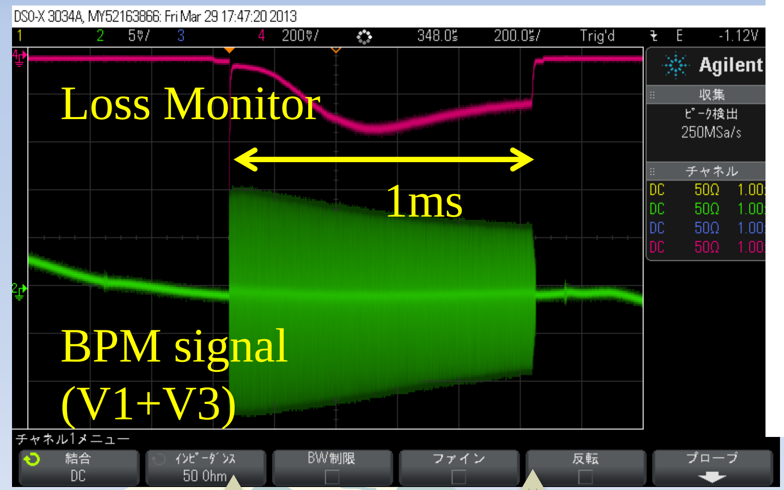


Compact semi-conductor amplifier is commercial available..

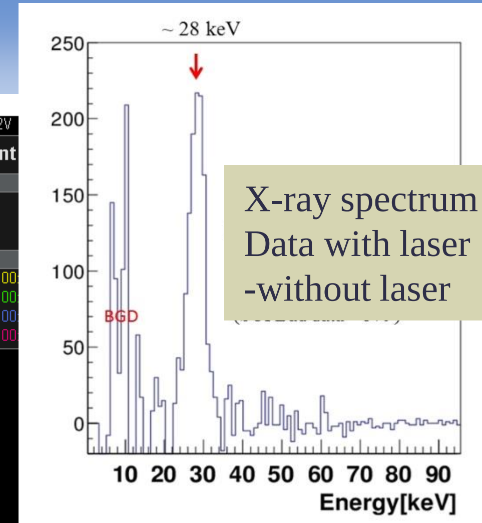
1ms flat beam extraction from RF gun
(RF feedback ON) 03.22.2012 50pC/bunch



1ms beam acceleration in STF accelerator
40MeV, 1ms, 7.5mA Beam Operation

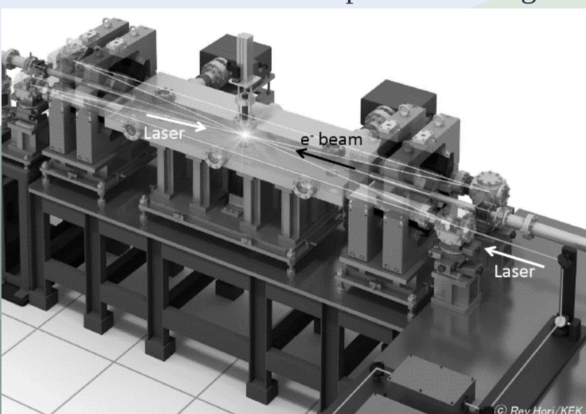


9mA(peak current) **6mA(peak current)**

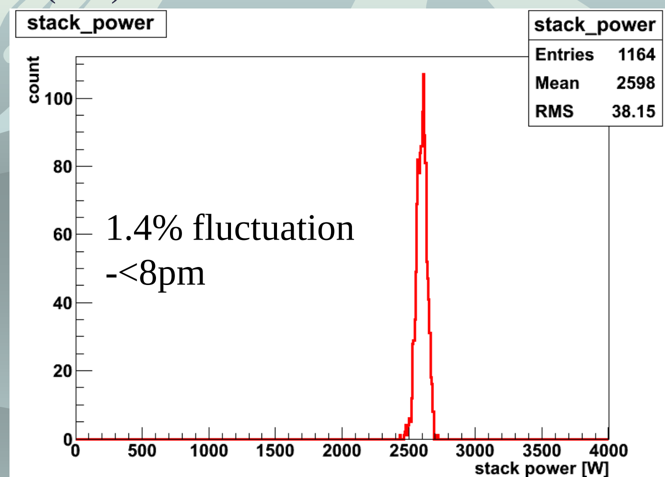


Success of 28keV X-ray detection

Success of 162.5k electron bunches generation and acceleration in 2K super conducting accelerator (STF)!

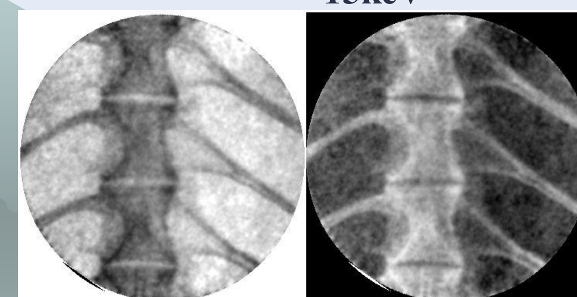


In 2D-4 mirror optical cavity Laser pulse was accumulated by 200kW. By the end of 2014 1MW will be achieved. 375MHz electron bunch and Laser pulse collision is stably realized.



relative mirror position control of 8pm was achieved. Fast polarization control (>10kHz) is possible. Laser IP size 13μm was achieved.

~15keV

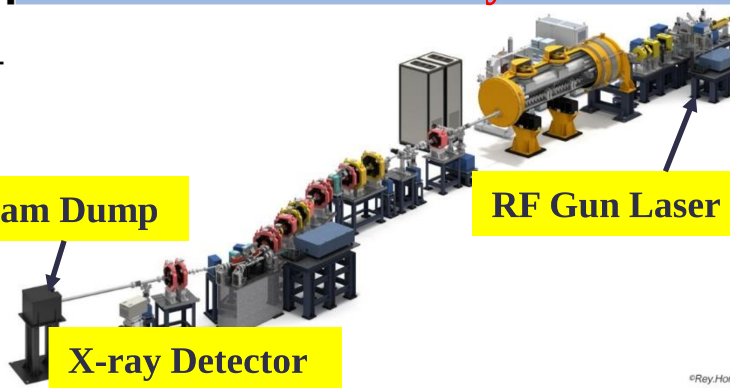


From X-ray absorption imaging To X-ray phase contrast imaging. So, Measurement Using Talbot interferometry The measurement within 1 sec is essential and we should establish above technology within 2~3 years.

６．研究開発推進に必要な施設及び設備備品・機器

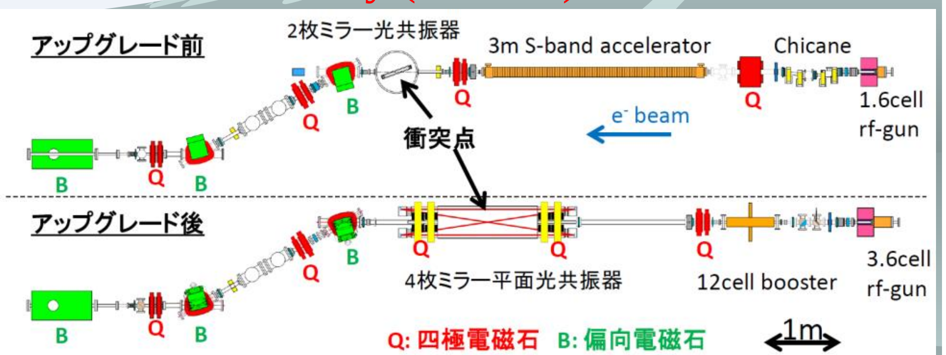
保有・購入・賃貸の区分	品名	仕様	用途	金額（千円）	購入・賃貸の場合の調達時期	賃貸する機関（当事者）
〔小型加速器X線生成実験〕保有（LUCX）・	LUCX	40MeV, 12.5Hz Max. beam power: 320W	X線光源、THz光源開発、利用実験用	800,000	2013-2019	KEK
〔高輝度X線生成実験〕将来保有（cERL、将来計画のR&Dの為建設中）・	cERL	35MeV, 10mA Max. beam power: 350kW	ERL技術開発用、X線およびTHz利用実験	3,800,000	2015-2019	KEK
〔パルス高輝度X線生成実験〕将来保有（STF、将来計画のR&Dの為改造中）	STF	300MeV, 10mA 5Hz-1ms beam Max. beam power: 15kW	ILC技術開発用、X線およびガンマ線利用実験	6,800,000	2016-2019	KEK

STF facility

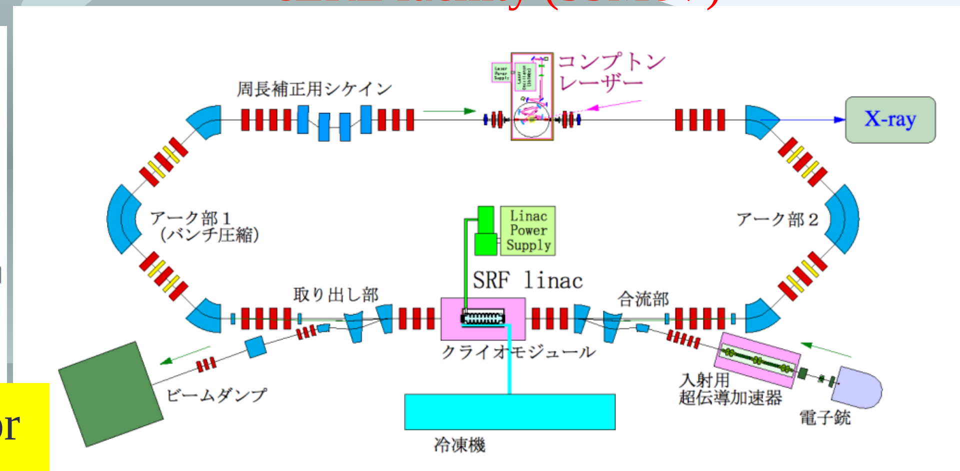


Beam energy upgrade from 60MeV to ~300MeV under going.
Re-operation from 2016 and high energy X-ray generation and the application are expected from 2016.

LUCX facility (40MeV)



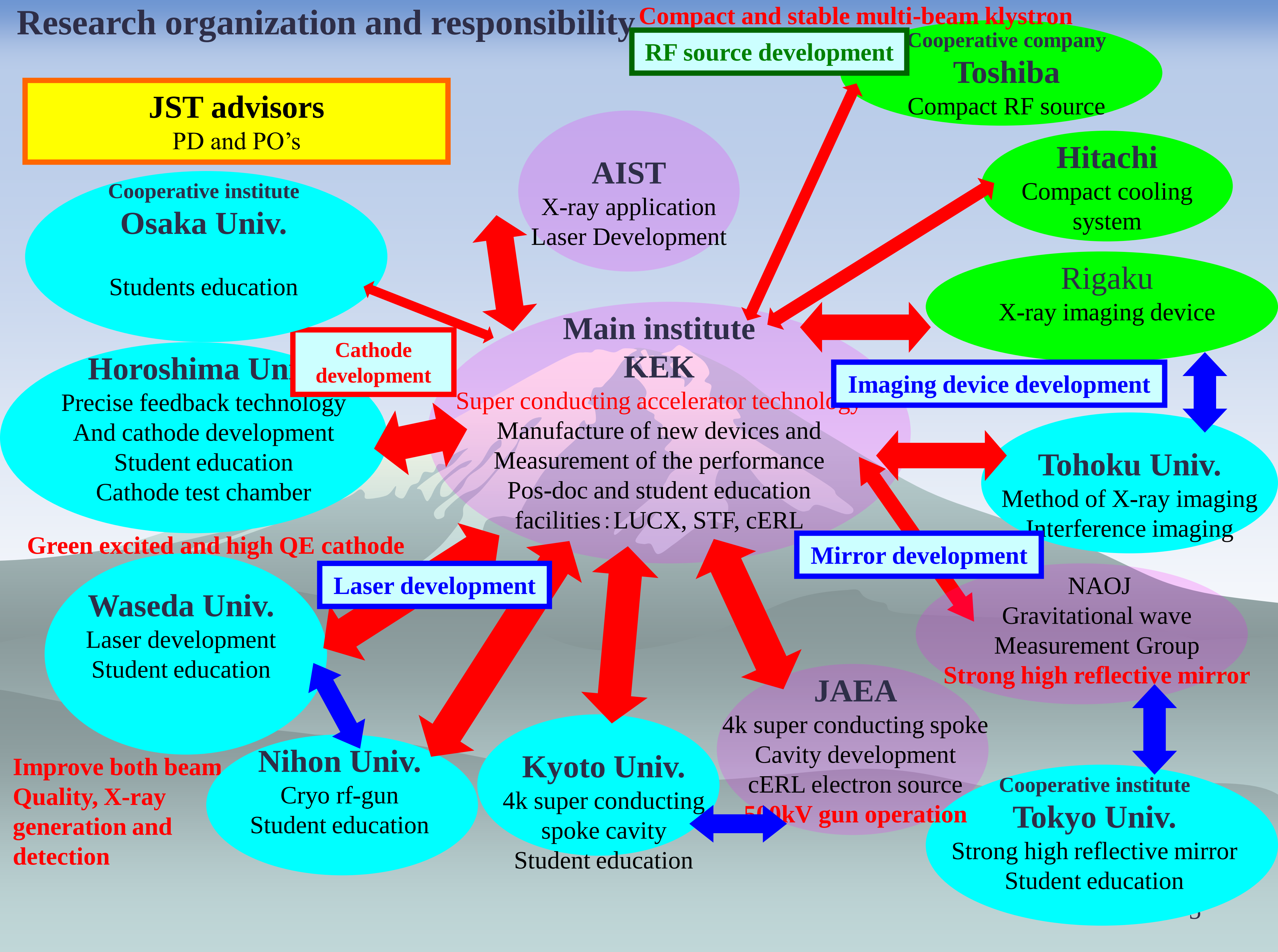
cERL facility (35MeV)



After improvement, technology development for ~1MW laser pulse storage, 357MHz～10μm collision technology and development for imaging technology (2013-2019).

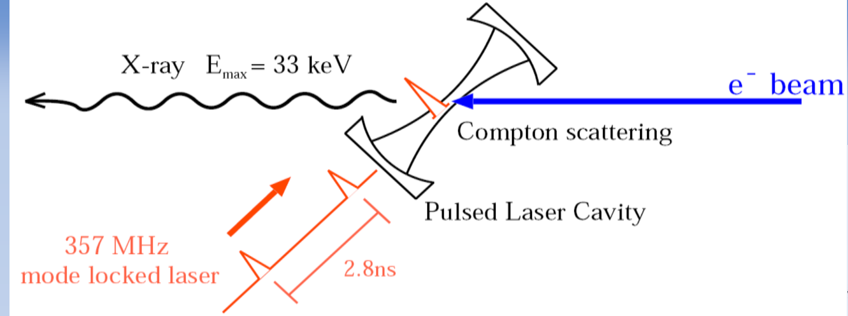
～10mA ERL operation by 2015, ICS X-ray generation and application (2015-2019)

Research organization and responsibility

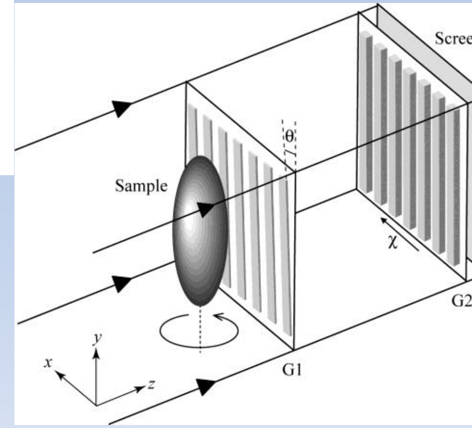


ICS photon beam comparing large photo factory

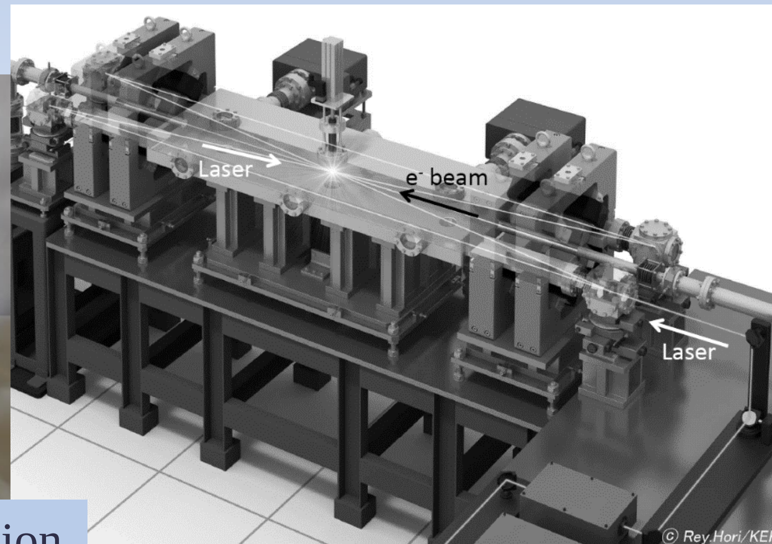
- pulse to make a image in short period.
- large angular divergence to measure large area.
- polarized X-ray generation with fast polarization switching .



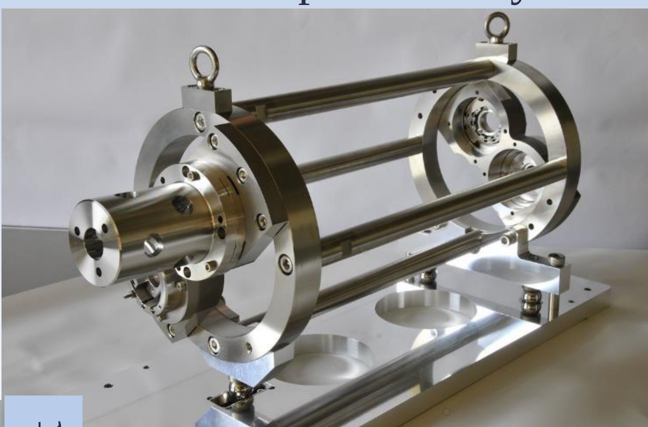
X-ray Talbot interferometry



2D 4-mirror optical cavity

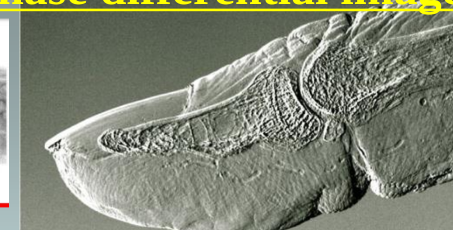


3D 4-mirror optical cavity

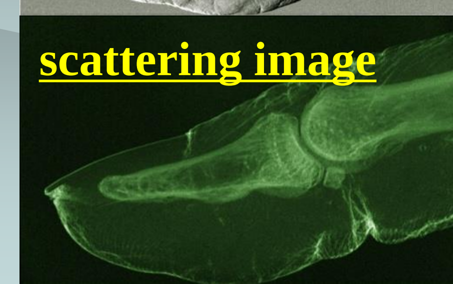


absorption image

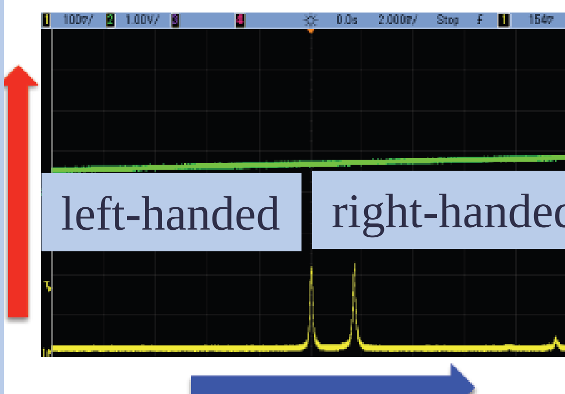
phase differential image



scattering image



Control of circular polarization



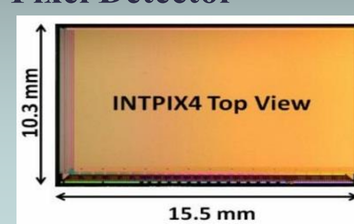
left-handed

right-handed

Intensity of transmitted light

Round cavity length

X-ray Imaging by SOI Pixel Detector



Application of advanced laser and accelerator technology for our life.

http://kocbeam.kek.jp/ from 2008.9 to 2013.3

Photon and Quantum Basic Research Coordinated Development Program Fundamental Technology Development for High Brightness X-ray Source and the Imaging by Compact Accelerator

http://nkocbeam.kek.jp/ from 2013.8

MEXT and JST are administrating and asked me to manage the research program with PD and PO's.
PD: Yasuhiro Ie,
PO's: Makoto Inoue and Sachii Morii

4 mirror cavities are at the ATF

KEK-Hiroshima
installed 2011

relatively simple control system
employs new feed back scheme

LAL-Orsay
installed summer 2010

sophisticated control
digital PDH feedback

2013. November

LAL achieved the Storage of 101kW and continues the optical cavity system tuning more. They found heating problem on mirrors.

2010	2011	2012	2013/07

2010

07/25 : Installation
08/21 : Laser locked to CAV
09/06 : Connected to beam
09/24 : Locked to ATF clock

10/25 : 1st γ generated
12/08 : γ generated

2 papers JINST

2012.01.27 *LAL-LMA-CELIA*

"Non-planar 4-mirror optical cavity for high intensity gamma ray flux production by pulsed laser beam Compton scattering off GeV-electrons"

2012.01.31 *+ KEK*

160W ~3 γ/bunch

"Production of gamma rays by pulsed laser beam Compton scattering off GeV-electrons using a non-planar optical cavity"

T. Akagi,[c] S. Araki,[d] J. Bonis,[a] I. Chaikovska,[a,1] R. Chiche,[a] R. Cizeron,[a] M. Cohen,[a] E. Cormier,[b] P. Cornebise,[a] N. Delerue,[a] R. Flaminio,[c] S. Funahashi,[d] D. Jehanno,[a] Y. Honda,[d] F. Labaye,[a] M. Lacroix,[a] R. Marie,[a] C. Michel,[c] S. Miyoshi,[c] S. Nagata,[c] T. Omori,[d] Y. Peinaud,[a] L. Pinard,[c] H. Shimizu,[d] V. Soskov,[a] T. Takahashi,[c] R. Tanaka,[c] T. Terunuma,[d] J. Urakawa,[d] A. Variola[a] and F. Zomer[a]

2011

03/06 : Fibre Amplifier KO
03/11 : Earthquake
07/20 : Laser KO

LAL recent results 101kW

IMPROVEMENTS

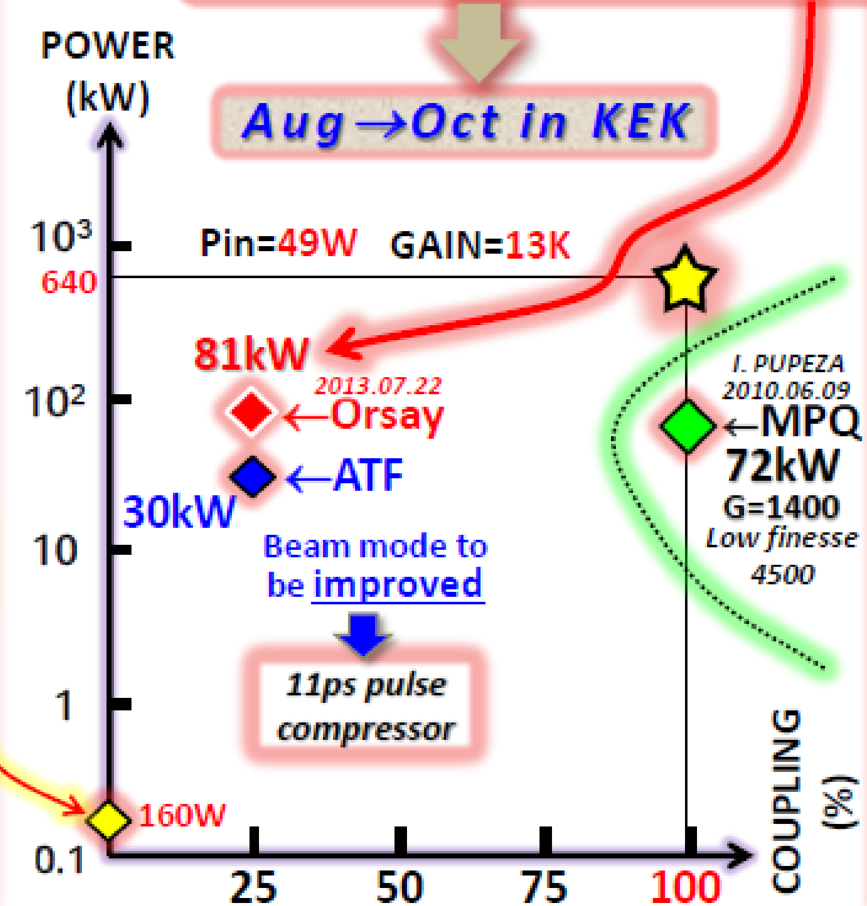
New laser (MENLO)
→ more reliable, robust
→ New actuators for Frep, CEP

New fibre amplifier (CELIA)
→ more reliable, robust
→ 20mW injection, 50W output

New cavity mirrors
→ Finesse 40k, Gain 13K

New power record at Orsay - 07/22 81kW

Aug→Oct in KEK

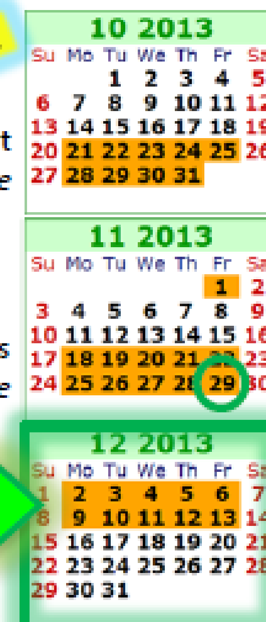


SHIFT REQUEST

not suitable
Beam restart
not suitable

FACET
SLAC
FACET runs
Nicolas Delerue

OK
1 shift / week
+ parasitically



Nicolas + Iryna + 2 PhD

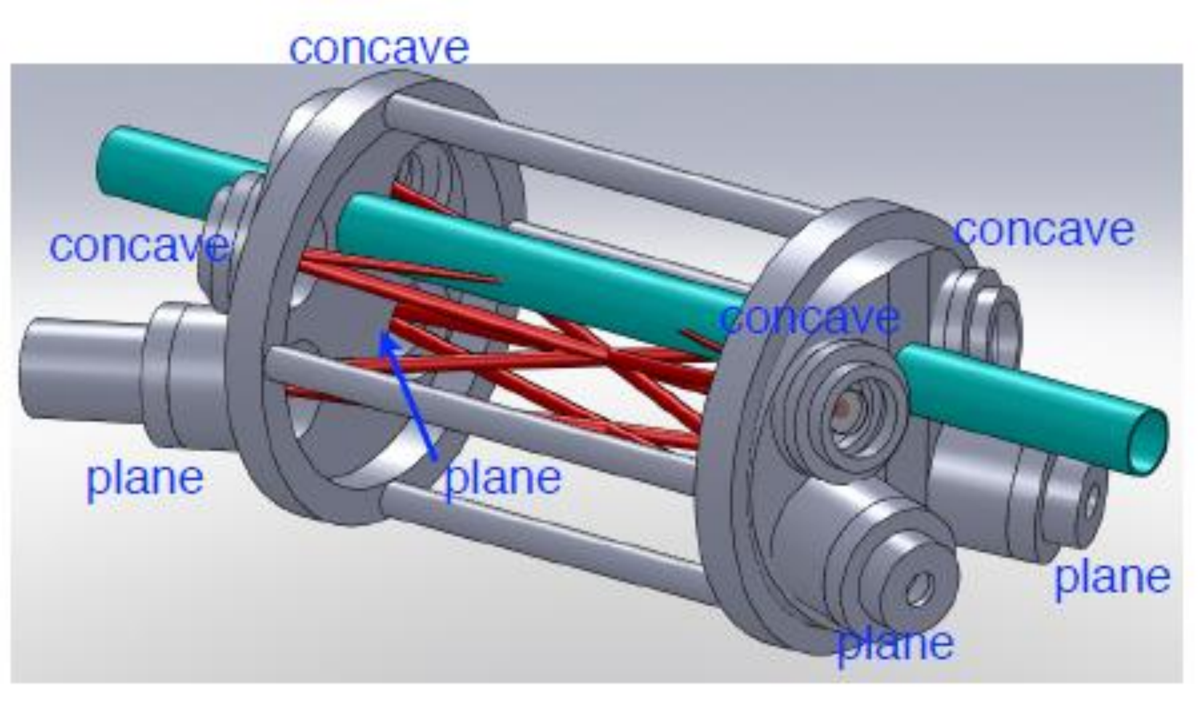
11/15 : calibration with KEK

Highest γ flux + Longest duration

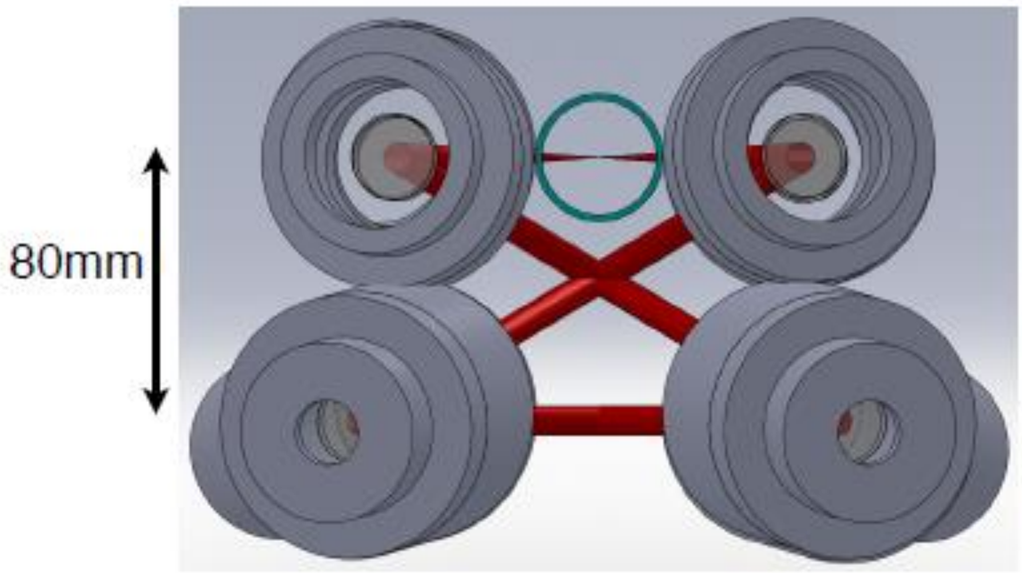
400kWwas stored in single optical cavity by Krausz group of Max Planck Institute of Quantum Optics. They used injection laser power of 450W with 350MHz and 250fs pulse duration. The mirror absorption coefficient is 18ppm. They reported the thermal effect.

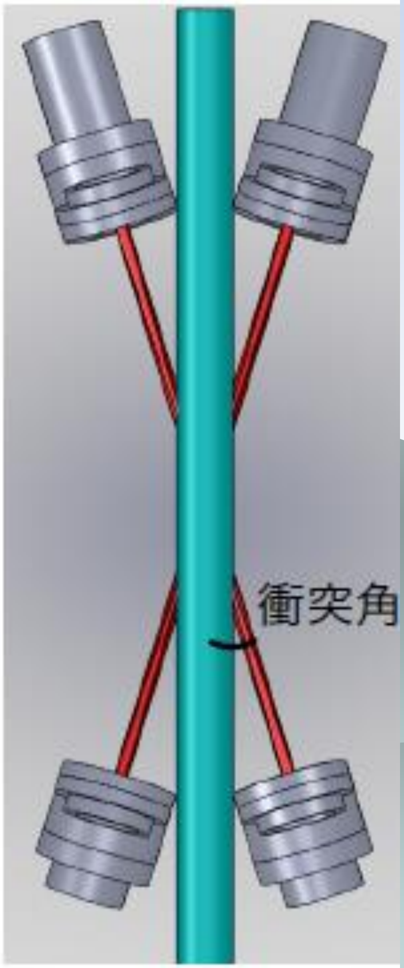
We recently proposed multi ring cavity system in single rigid frame. Following figure show an example which is matched to 325MHz Laser repetition system.

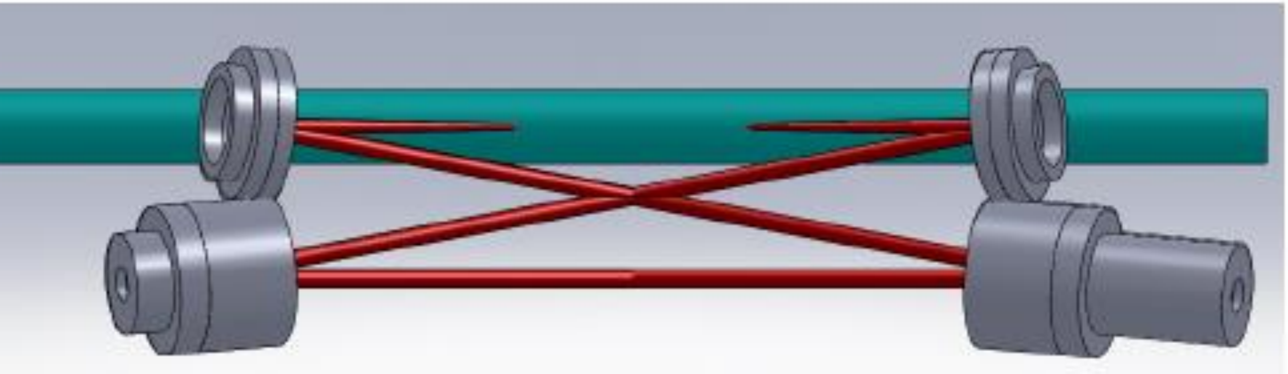
This is not aggressive. I think when we use small electron beam pipe we makes smaller crossing angle, say 10 degrees. Also, we can reduce 80mm to about 60mm with special design.

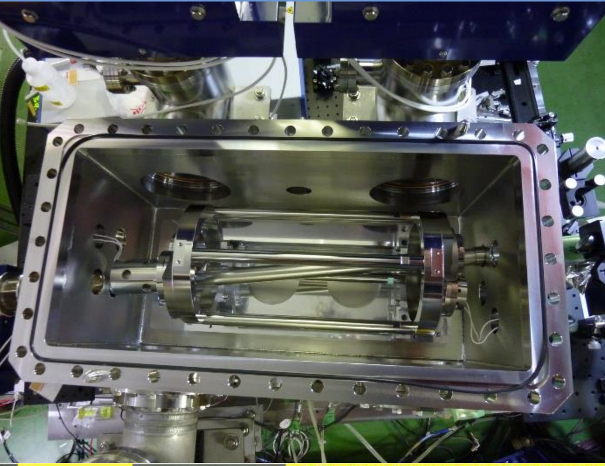


We started the manufacture of this new optical cavity to establish the storage of 1MW average power by end of JFY2014.

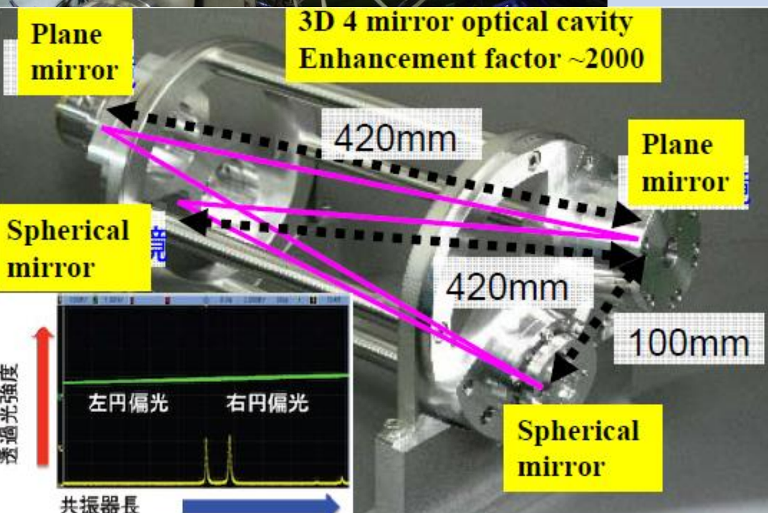


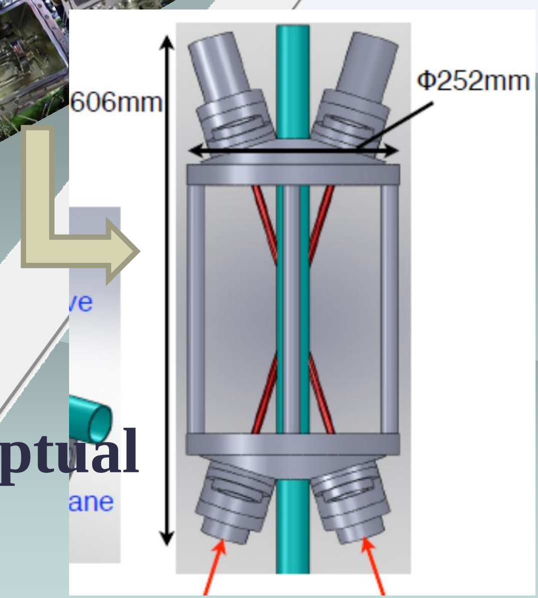






cERL will start the beam commissioning on December and we will install new optical cavity on July 2014. Then, we will start the experiment for X-ray generation from December 2014 to March 2015.



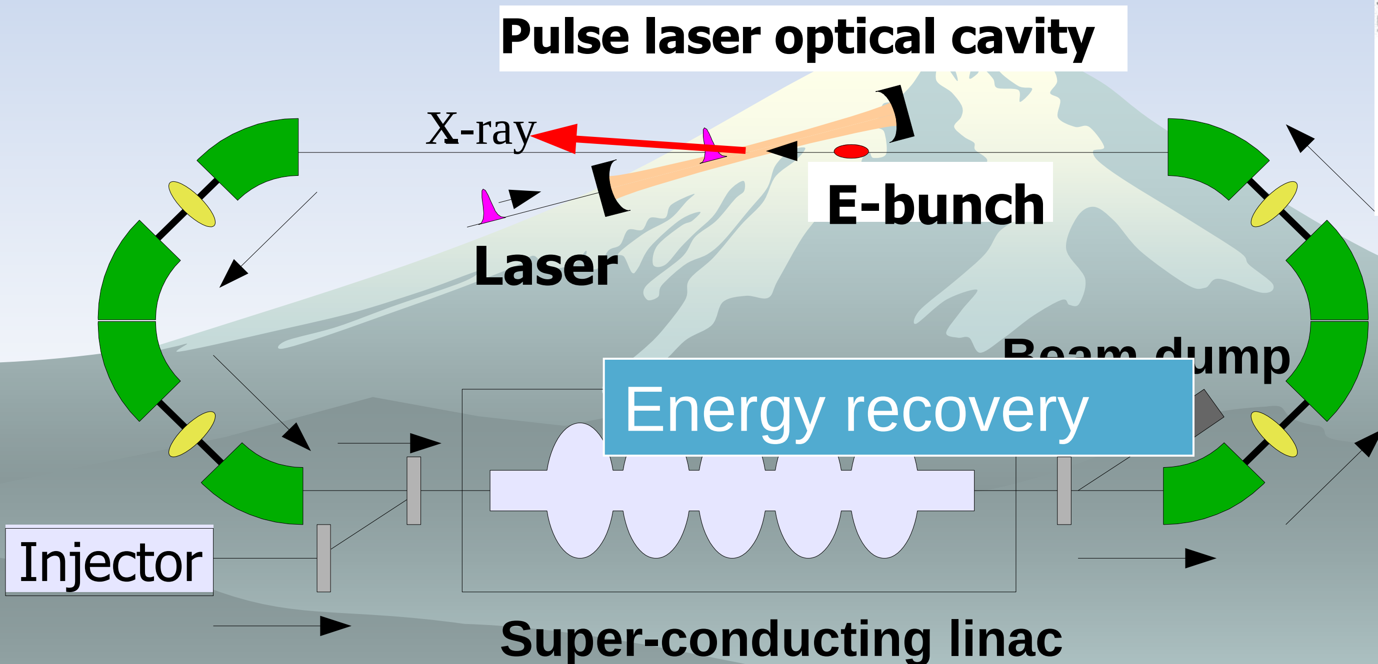


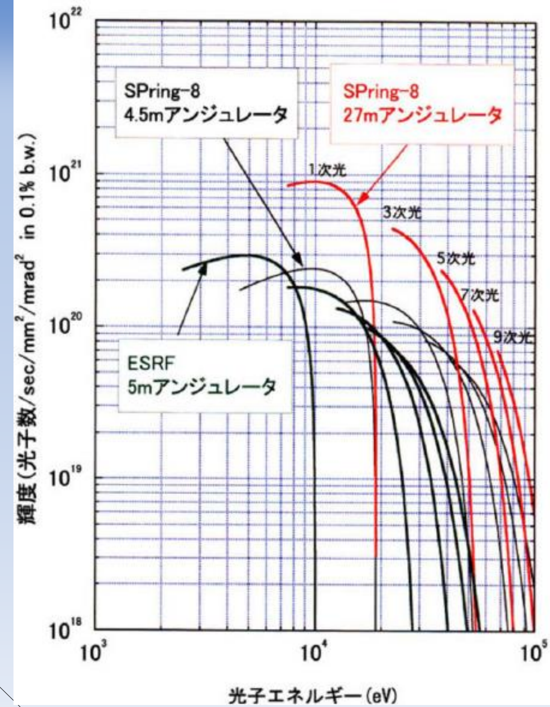
Present conceptual design

Schedule

High brightness X-ray generation at c-ERL
as a demonstration through beam experiment

2015 experiment





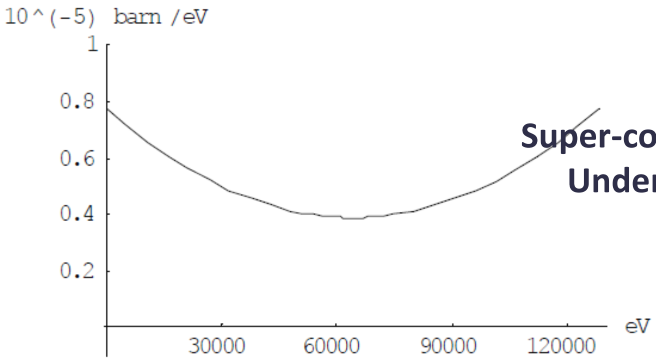
SPring-8
World highest
Av. Brightness 10^{21}
Photons/sec/mm²/mrad² in 0.1%b.w.
from 27m undulator at SPring8

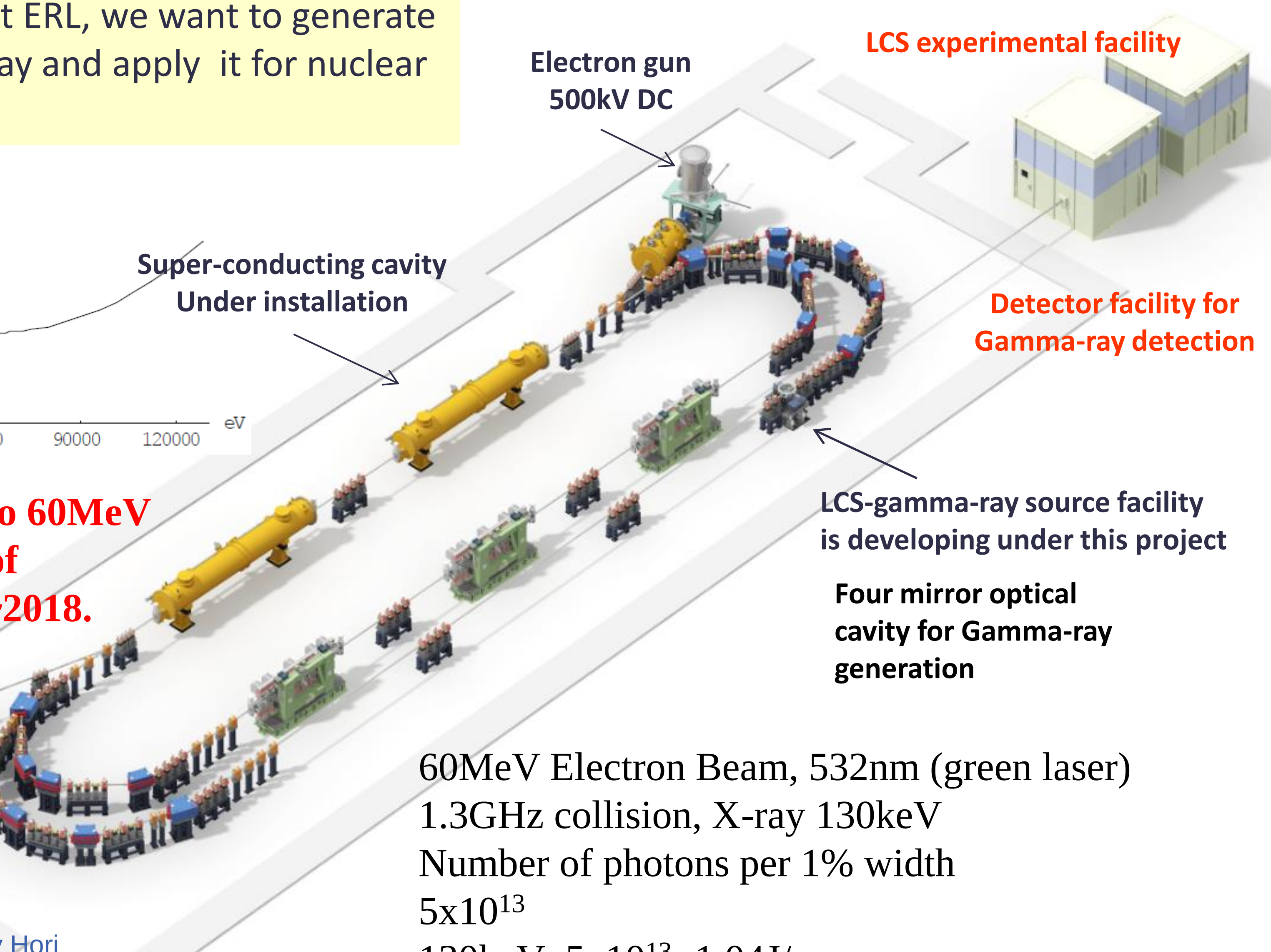
Realize the Brightness 10^{17} Photons/sec/mm²/mrad² in 0.1%b.w. **10^{13} photons/(sec･1%b.w.)**

35MeV electron beam x 1μm laser = 23keV X-ray

Proof-of principle experiment at compact ERL facility

After add super conduction cavities into present compact ERL, we want to generate Several MeV γ-ray and apply it for nuclear physics.





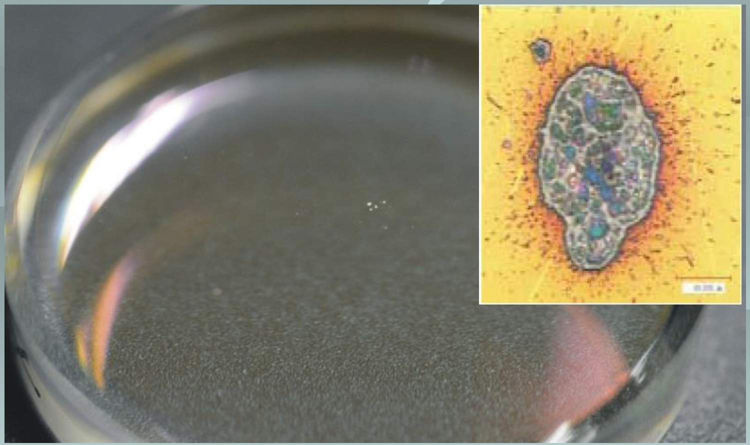
From 35MeV to 60MeV
Second phase of
cERL plan in ~2018.

60MeV Electron Beam, 532nm (green laser)
1.3GHz collision, X-ray 130keV
Number of photons per 1% width
5×10^{13}
$130 keV \times 5 \times 10^{13} = 1.04 J/s$
330 kGy (X-ray size 0.2mm diameter)

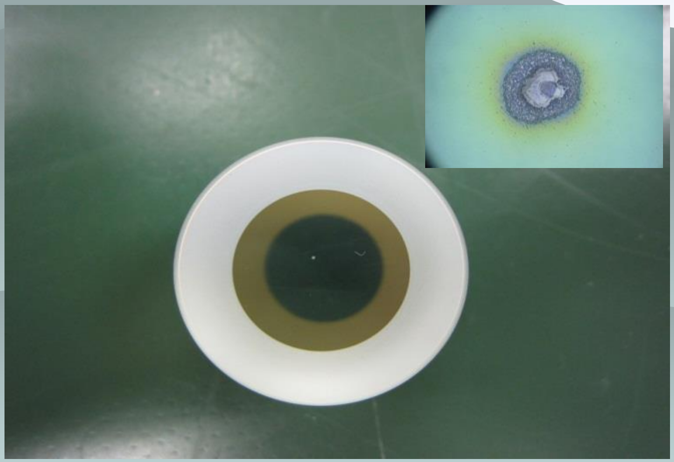
Illustration by Rey Hori

We destroyed the mirror coating many times. First occurred when the waist size was ~100μm with burst amplification and 42cm two mirror cavity. Second occurred when the waist size was 30μm with the burst amplification and the 42cm two mirror cavity. Now we are using 4 mirror cavity with smaller waist size at IP. From our experience, we have to reduce the waist size to increase the laser size on the mirror and need precise power control for the burst amplification. I guess about storage laser pulse energy from 2mJ to 4mJ destroyed the mirror coating with the waist size of 30μm. Also, we found the damaged position was not at the center.

2008



2011



From experimental results at LUCX X-ray generation based on ICS.

Development for stronger mirror : I started the collaboration with NAO (Gravitational Wave Observatory group), Tokyo University (Ohtsu Lab.), Japanese private Co., LMA and LAL.

1. Enlarge mirror size : we started the change from one inch to two inch mirror.

2. LMA prepared mirrors with reflectivity of 99.999% and loss (absorption and scattering) less than 6ppm. Recently, they made mirrors of about 15ppm.

3. We ordered many substrates with micro-roughness less than 1 A to approach low loss mirror.

4. We understood the necessity of good clean room to handle the high reflective mirrors in the case of the mirror which has high reflectivity more than 99.9%.

5. We have to develop how to make the stronger surface which has higher damage threshold.

Measurement of surface roughness for super-polish. Reduce the loss ,which means low absorption and scattering.

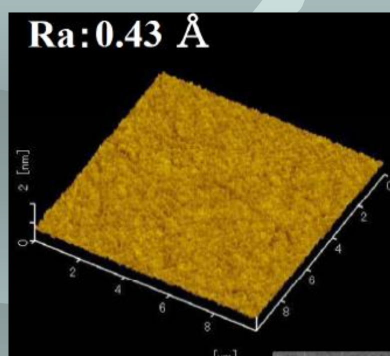
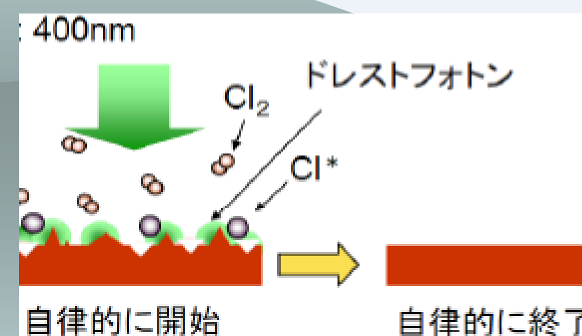


Photo-chemical etching occurred by dressed photon.



We learnt a lot of things which humidity in Japan is high and makes OH contamination to increase the mirror absorption. 50% humidity is suitable to handle the mirrors, especially high quality mirrors. We confirmed this problem. Also, vacuum slow pumping is important.

Mirror treatment:

Clean room,
Air conditioning,
Ion gun,
Slow leak and pumping, etc. are necessary to keep small absorption coefficient.

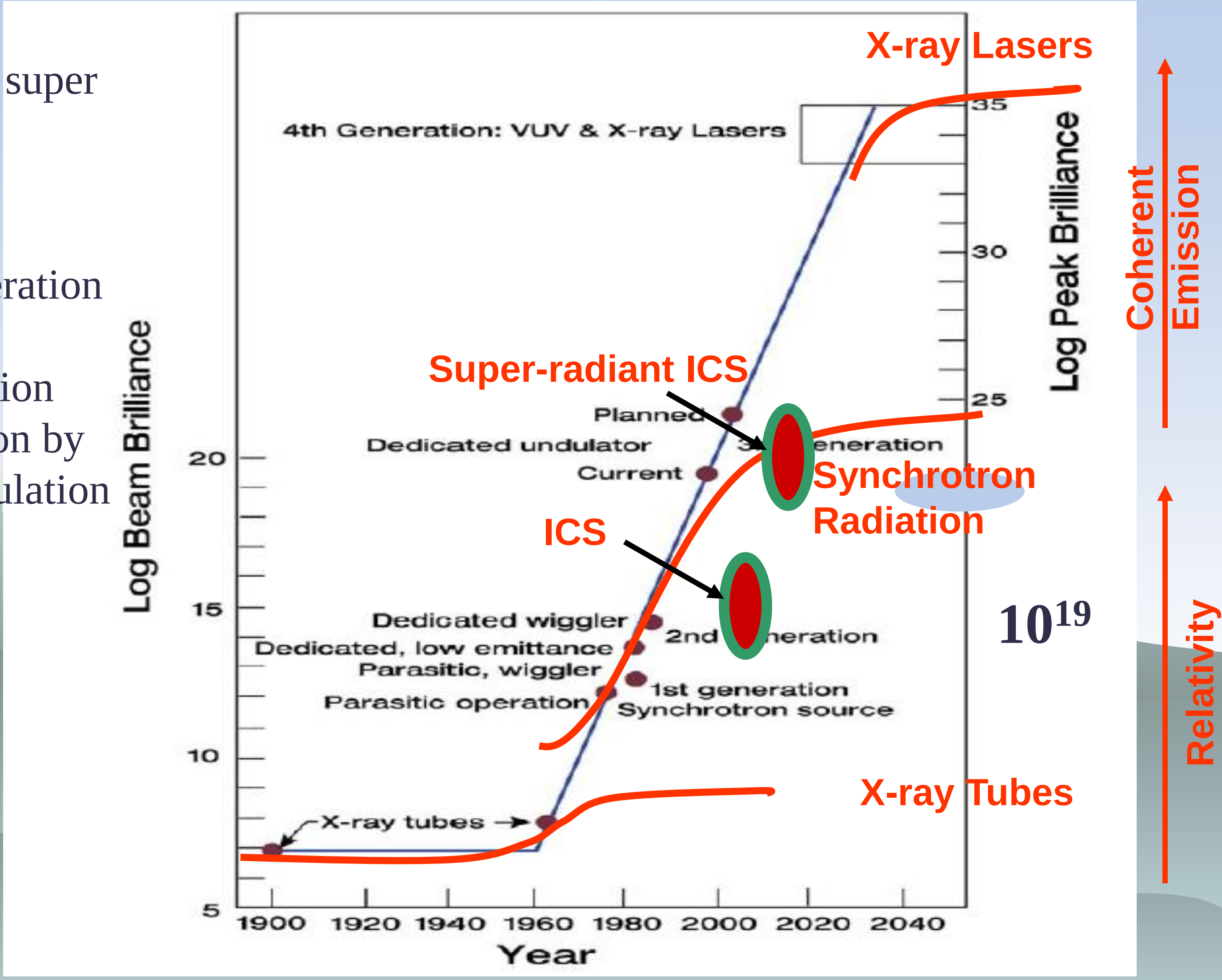
Slides for detail explanation

Key-tech. for stimulated or super radiation

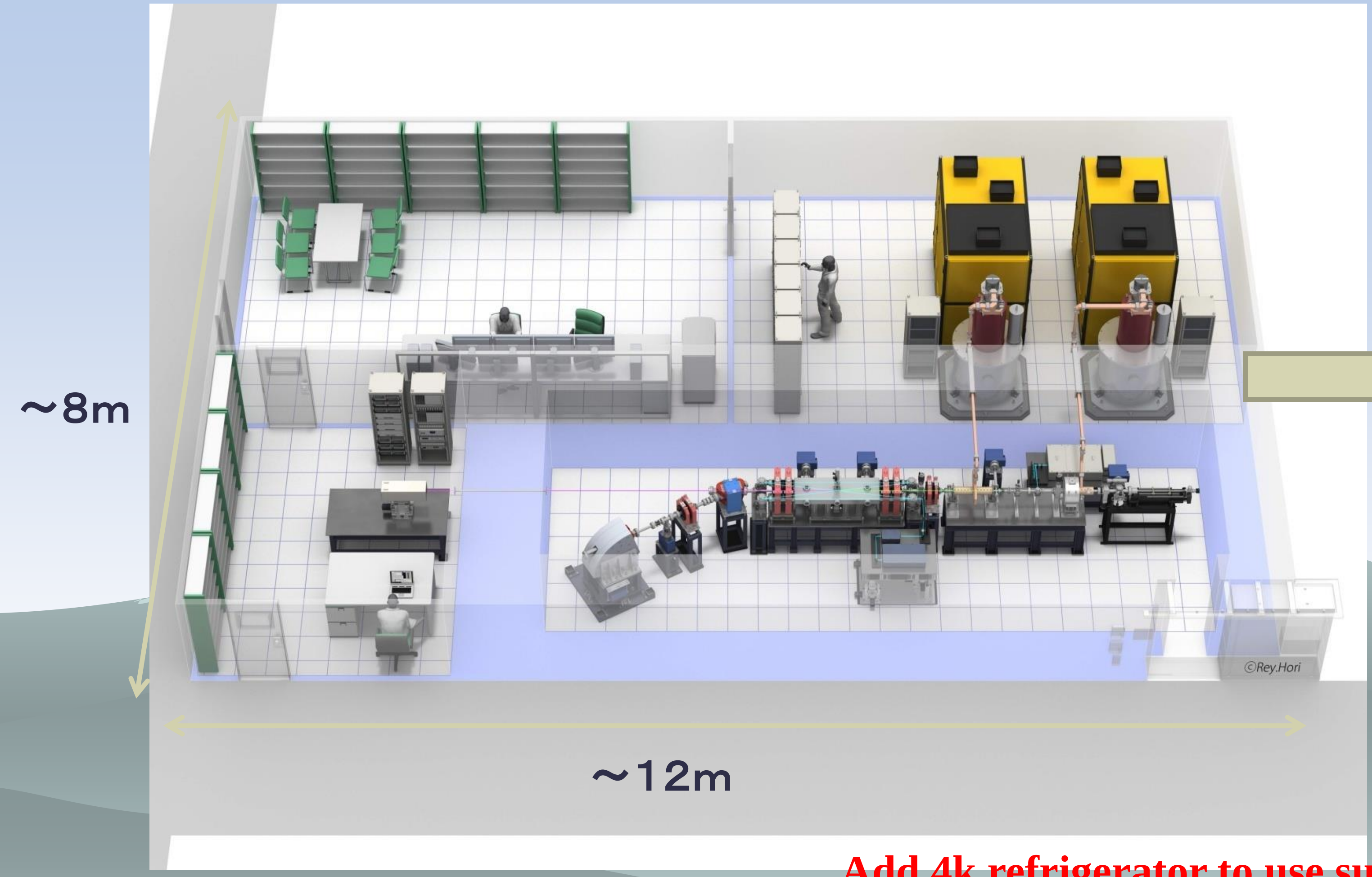
Efficient pre-bunched FEL
and micro-bunch train generation

Energy or velocity modulation
to make intensity modulation by
laser field or intensity modulation
by other tech..

and coherent radiation



High brightness X-ray facility based on ICS



Down size
To 6 x 8m

Add 4k refrigerator to use superconducting cavity keeping compactness in future.

Normal conducting accelerator system for compact high brightness X-ray

Journal of
Synchrotron Radiation

ISSN 0909-0495

Photon Flux :
~10^{10} photons/sec1%bw

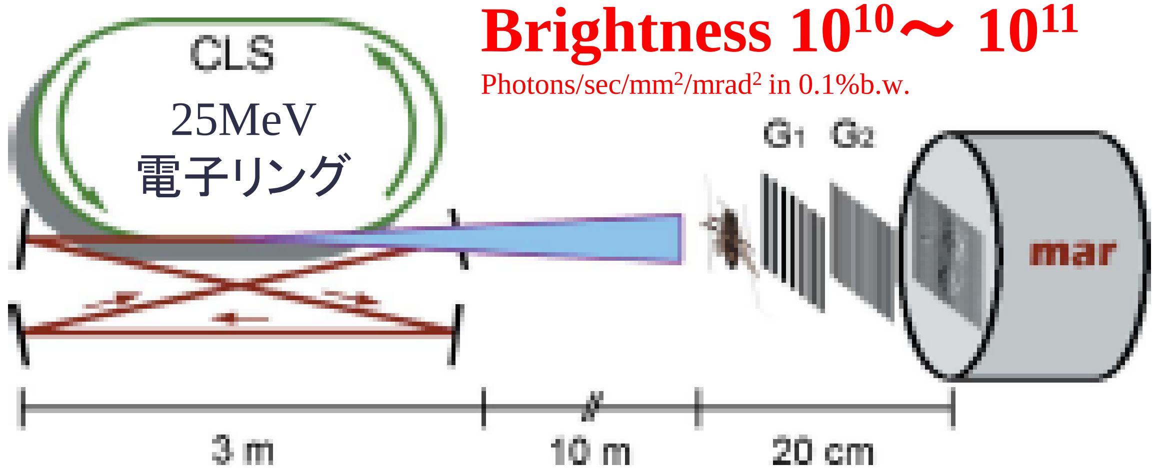


Figure 1
Sketch of the experimental set-up (not to scale). To the left is the [c]Lyncean Technologies Inc. Light Source with an electron storage ring and a laser cavity. A X-ray beam is produced at the electron–laser intersection point, shining onto the sample. The grating interferometer to the right consists of two gratings, G_1 and G_2, and a MAR CCD detector.

Hard X-ray phase-contrast imaging with the Compact Light Source based on inverse Compton X-rays

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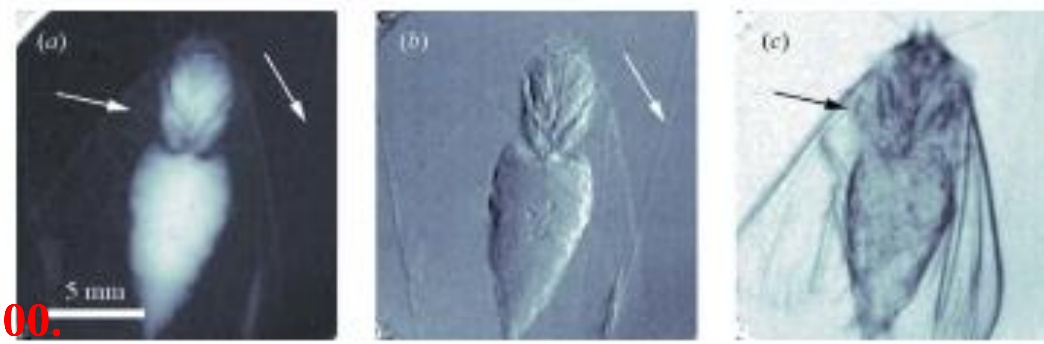

Figure 2
Three types of image contrast of a moth after data processing. (a) Standard absorption-contrast ... All three images are obtained from the same data set. Arrows indicate regions where the phase-contrast and dark-field images ... on the standard X-ray image.

Reduce electron beam emittance by 100.
Reduce the energy spread of electron beam by 10.
Reduce electron bunch length at IP , we select high power electron Linac and optical cavity to generate X-ray based on ICS.
Then, we have a possibility to get $10^{17}$and one shot measurement for X-ray imaging.

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X-ray exposing time more than 100sec