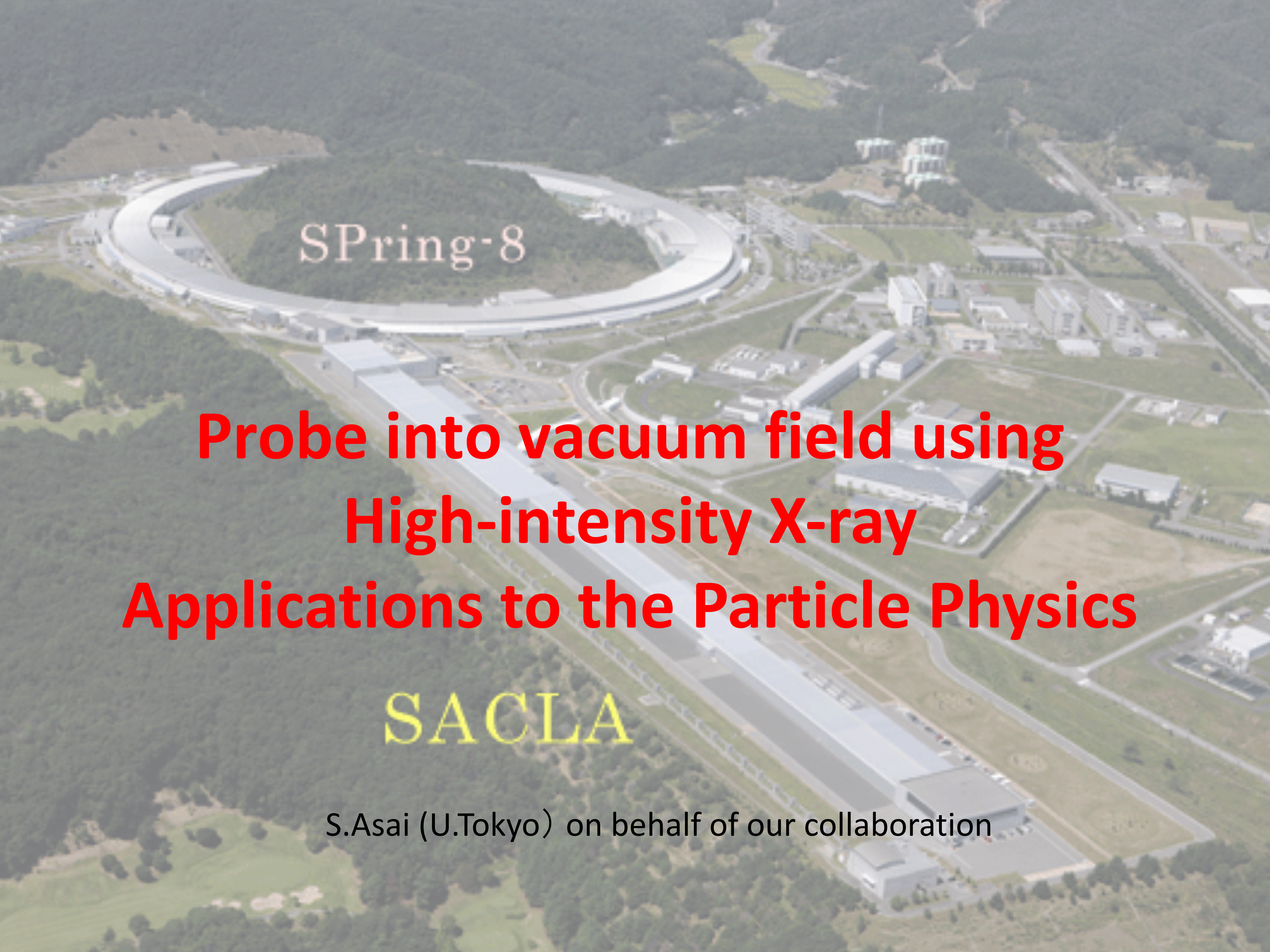


Probe into vacuum field using High-intensity X-ray Applications to the Particle Physics

S.Asai (U.Tokyo） on behalf of our collaboration

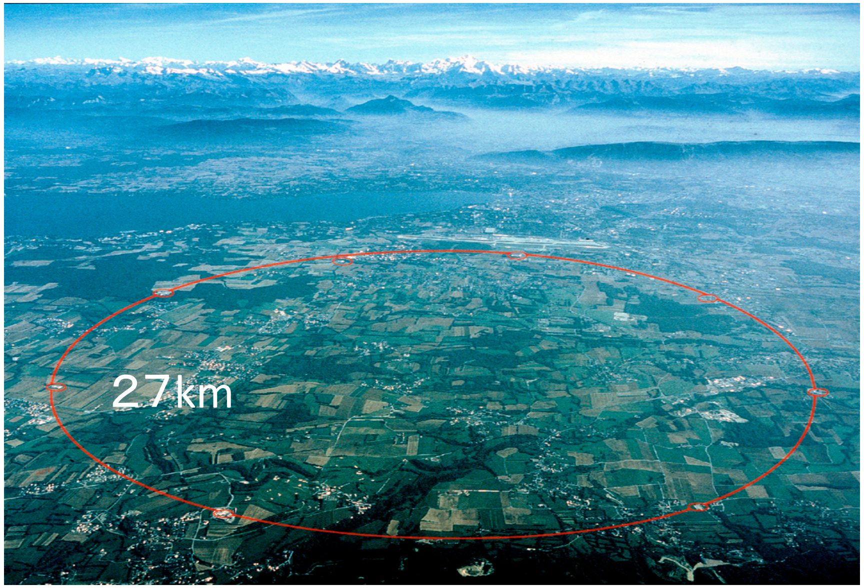
Contents of my talk

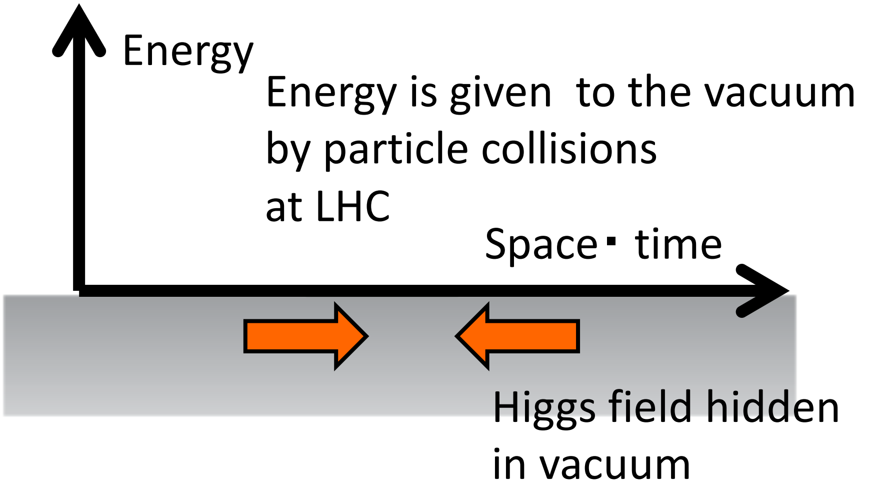
1. What is the Vacuum?
2. Non-linear effect of the Vacuum (QED)
3. [A]Search for the photon-photon scatter at SACLA
4. [B]Using collision of X-ray and Laser at SACLA
5. [C]Using collision of X-ray and strong Magnet at Spring8 (Axion,Dilaton)
6. Summary

Collaboration members are as follows;
Particle Phys, T.Yamaji, Y.Seino, T.Inada, T.Yamazaki, T.Namba, **S.Asai** (U.Tokyo)
SACLA-Spring8 Group: K.Tamasaku, K.Sawada, M.Yabashi, T. Yabuuchi, T. Togashi, Y.Inubushi , **T.Ishikawa** (Riken, JASR), Y.Tanaka(U. Hyogo),

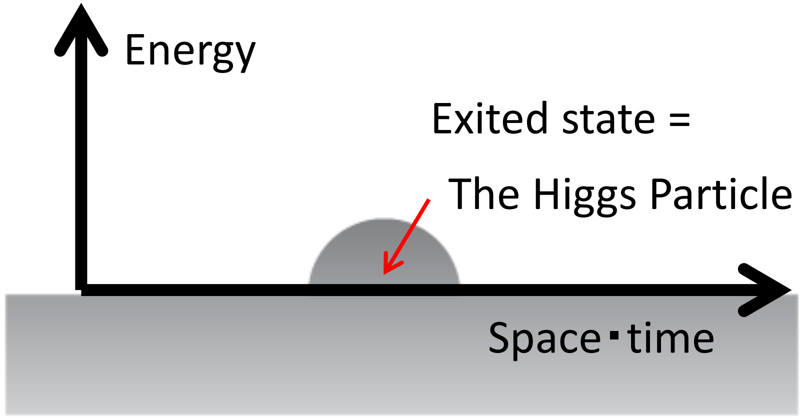
1. What is the vacuum?

The Higgs Boson is discovered in 2012 at LHC





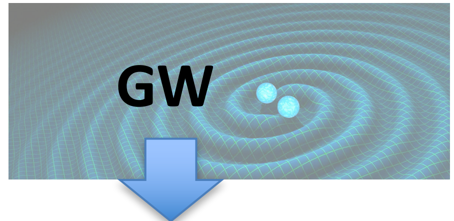
The energy excites the field.



Higgs particle is **NOT important**,
Existence of the Higgs particle shows that **our vacuum is filled with the strange quantum field** (Higgs filed)
Higgs field is hidden in our vacuum.
It is important notice.

Vacuum and Space-time become targets of Particles Physics

Particle is not a target now.



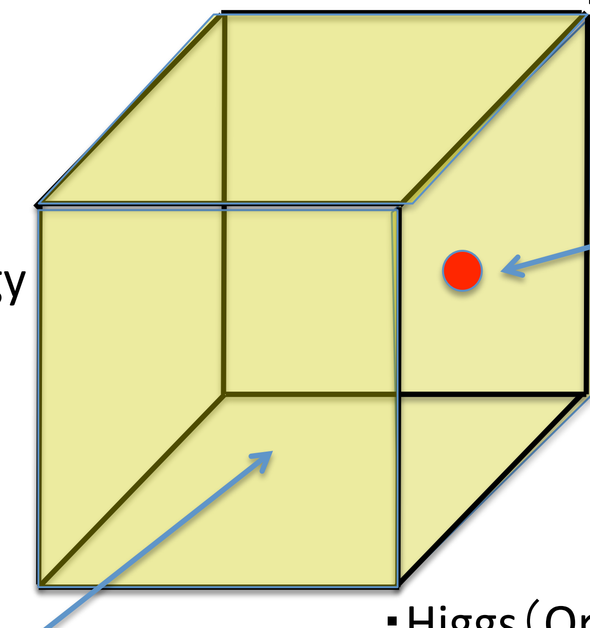
SUSY is the next main target of LHC, since it bridges between

Space-time structure and vacuum structure are studied using particles. Quantum level. First step to unify GR + QM

Space-Time

- Supersymmetry
- Unify the Gravity and Particle physics
- Extra dimension

- Universe (birth and evolution)
- Dark energy



Particle

LHC is Energy frontier
Photon is intensity and Precision Frontier

Vacuum

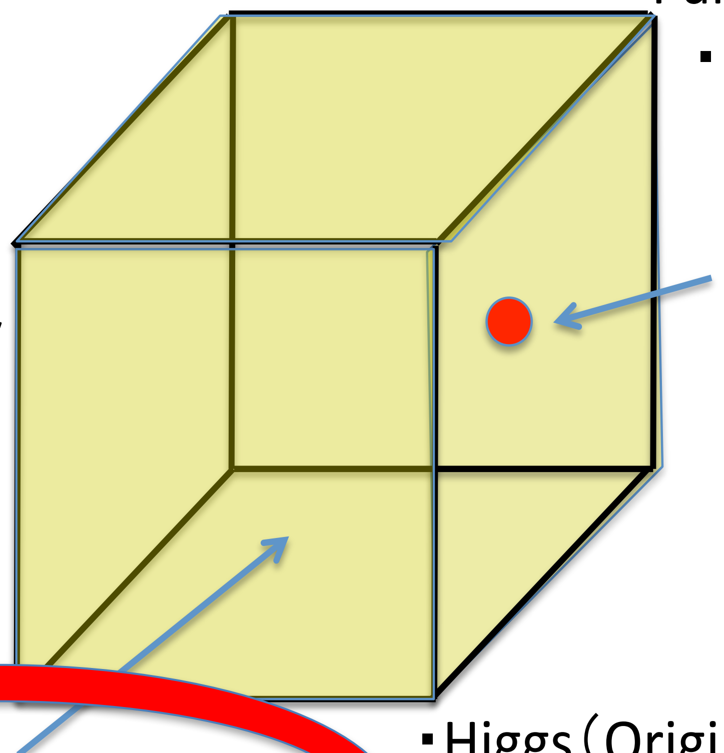
Higgs Boson

- Higgs（Origin of mass）
- Spontaneous symmetry braking →origin of variety

Space-Time

- Supersymmetry
- Unify the Gravity and Particle physics
- Extra dimension

- Universe (birth and evolution)
- Dark energy



Particle

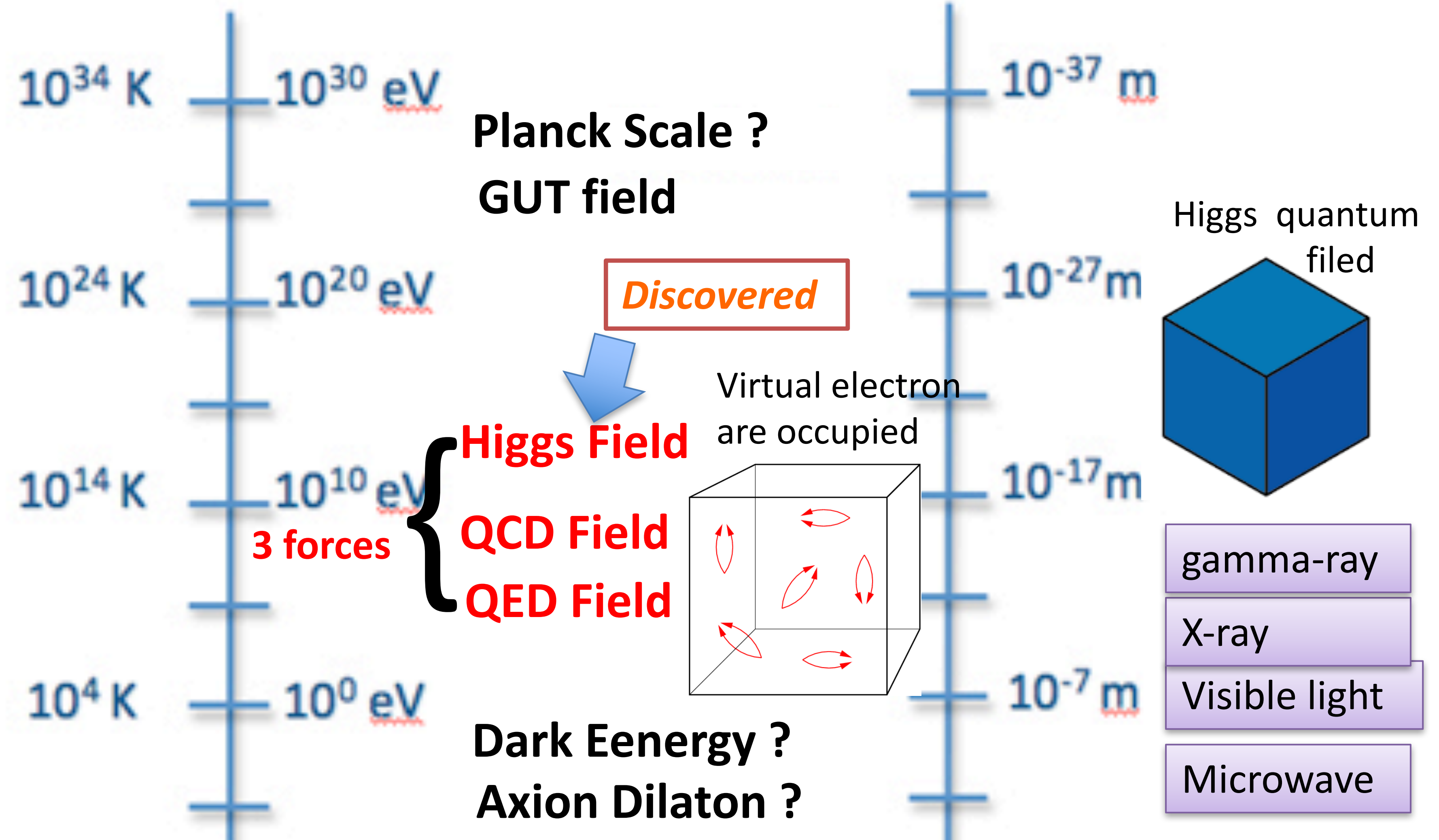
Today I focus on

Vacuum

- Higgs（Origin of mass）
- Spontaneous symmetry braking →origin of variety

Probe the vacuum using Photon, X-ray

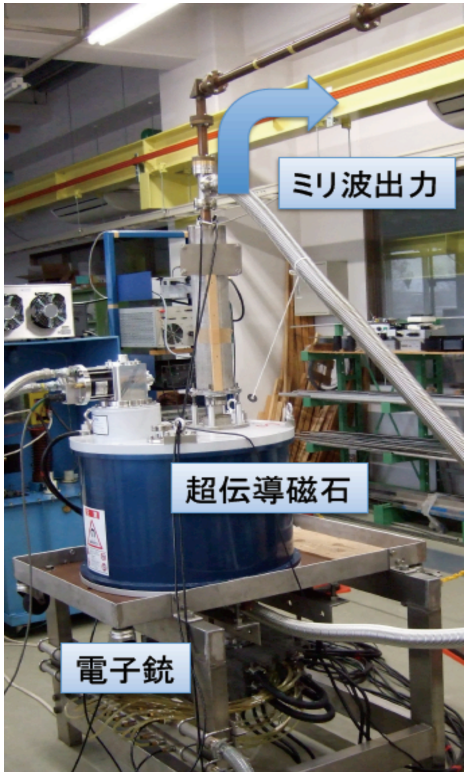
Various fields are hidden in our vacuum



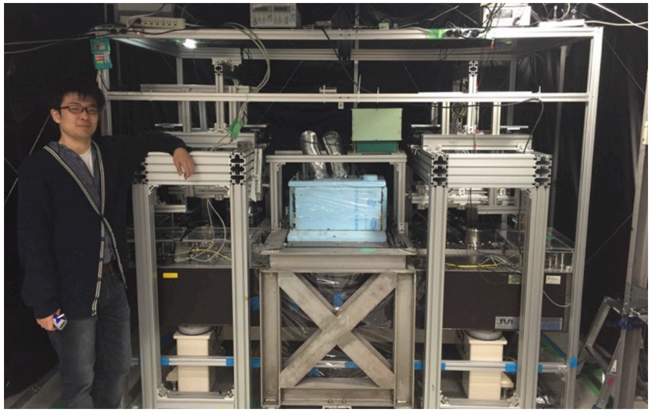
Photon has a good potential to survey these fields, because of spin and property of anti-.

Wide range of Light Sources are developed/used

meV(THz)	eV (Laser)	KeV（X Ray）



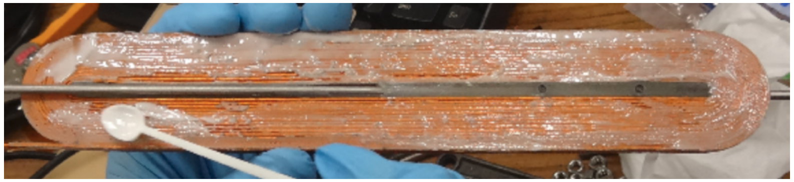
Gyrotron + FP resonator
E>20kW　10^{26} Photon



F=450,000 FP resonator

Hidra-100(2.5TW)

10T strong Magnet

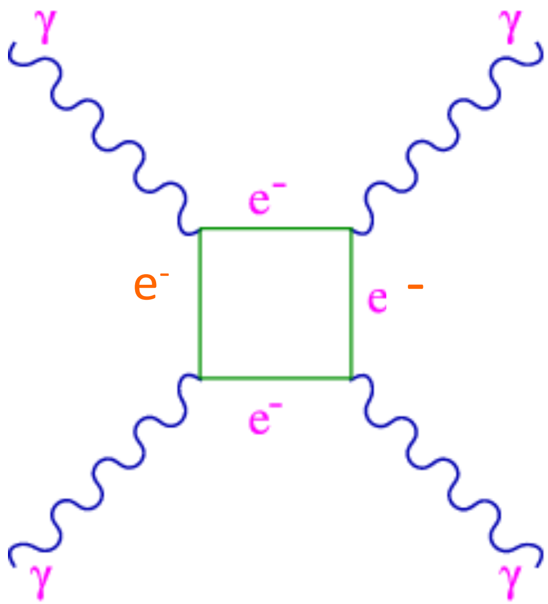


SACLA・Spring8

Various combinations
of these light sources
cover various CME for survey

2 . Non-linear effect of the vacuum

This is BG for hunting of a new field(Axion, DE..) but It is also a very interesting target. Nobody see it



In Maxwell eq, photon does not couple to photon itself.
But virtual electron-positron pair exists in our vacuum. (This is the QED vacuum)
Photon-photon scatter through this loop.

Photon-Photon collision
is the direct evidence of
the QED field hidden in the Vacuum;

QED predicts

$$\frac{d\sigma}{d\Omega} = \frac{139\alpha^4}{(180\pi)^2 m^2} \left(\frac{\omega}{m}\right)^6 (3+\cos^2\theta)^2$$

This process is seriously suppressed by α^4 and highly suppressed by electron mass m.

The expected cross section $\sigma = 1.8 \times 10^{-70}$ [m²] for ω=eV Too small!!

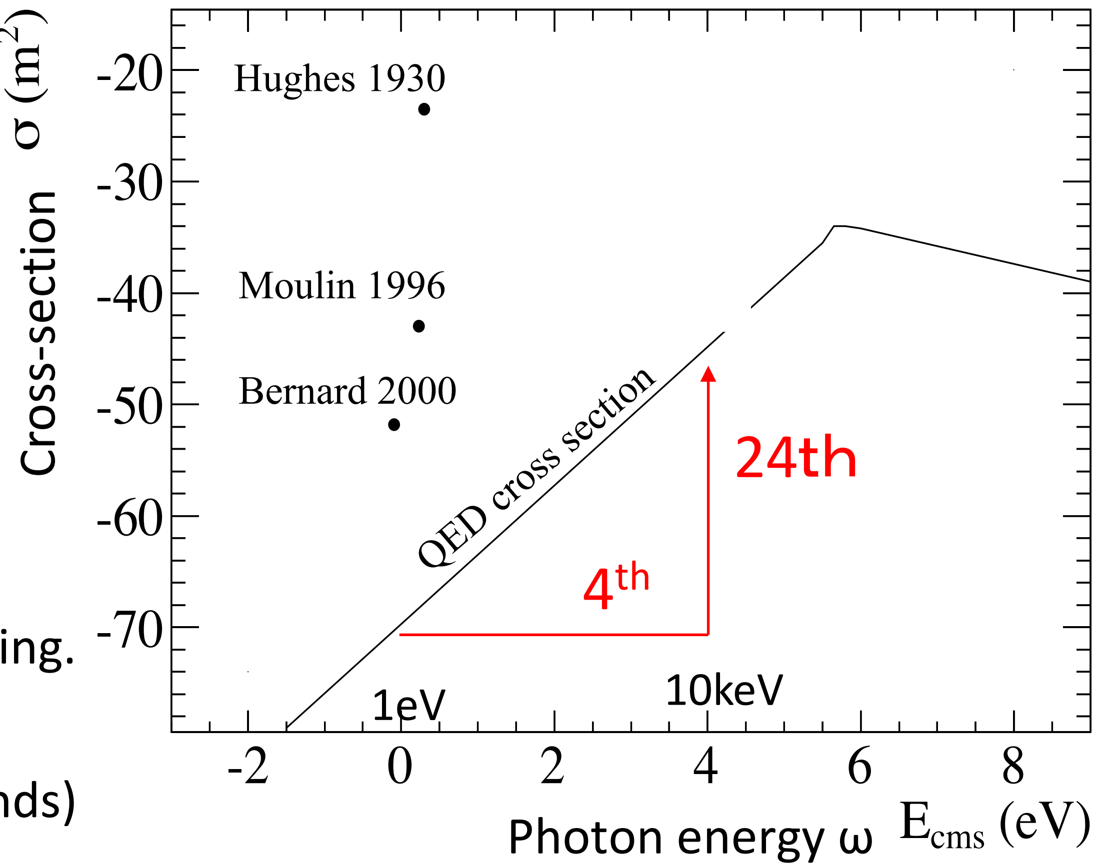
10^{-27}fb

X-ray has advantages to probe the QED vacuum

✧ Cross-section has the strong dependence on ω; $(\omega/m_e)^6$ 6^{th} power!!
Enhanced by 24^{th} order of magnitude for 10KeV X-ray comparing to visible lights.

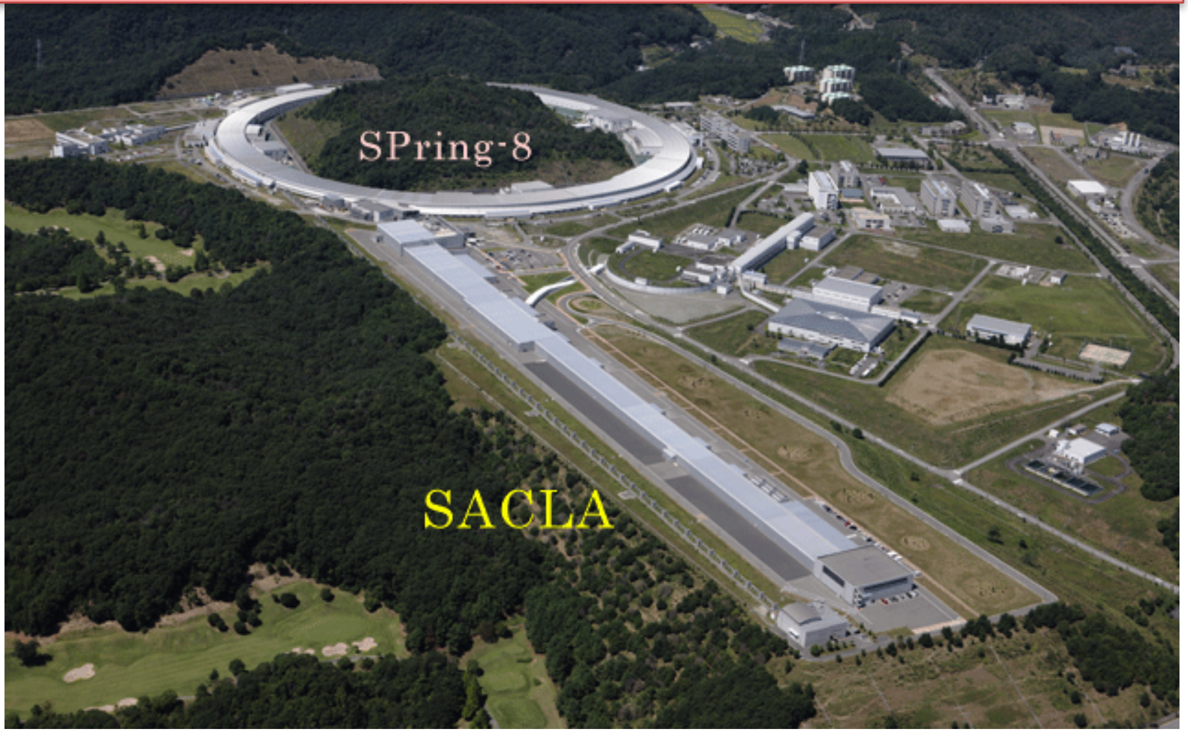
✧ Previous searches have been performed using visible/infrared light.
Many filed may be hidden in the vacuum.
Let's use different ω, and
Explore a new regions.

✧ X-ray is vey interesting
(1) Squeeze upto ~ O(1) nm
(2) Go straight
(3) Easy a single photon counting.
((1)-> intensity
(2)(3) -> to control backgrounds)



3. [A]Search for the photon-photon scatter at SACLA

We performed to search for photon-photon collision at SACLA(XFEL).



Just collide? Not so easy!!

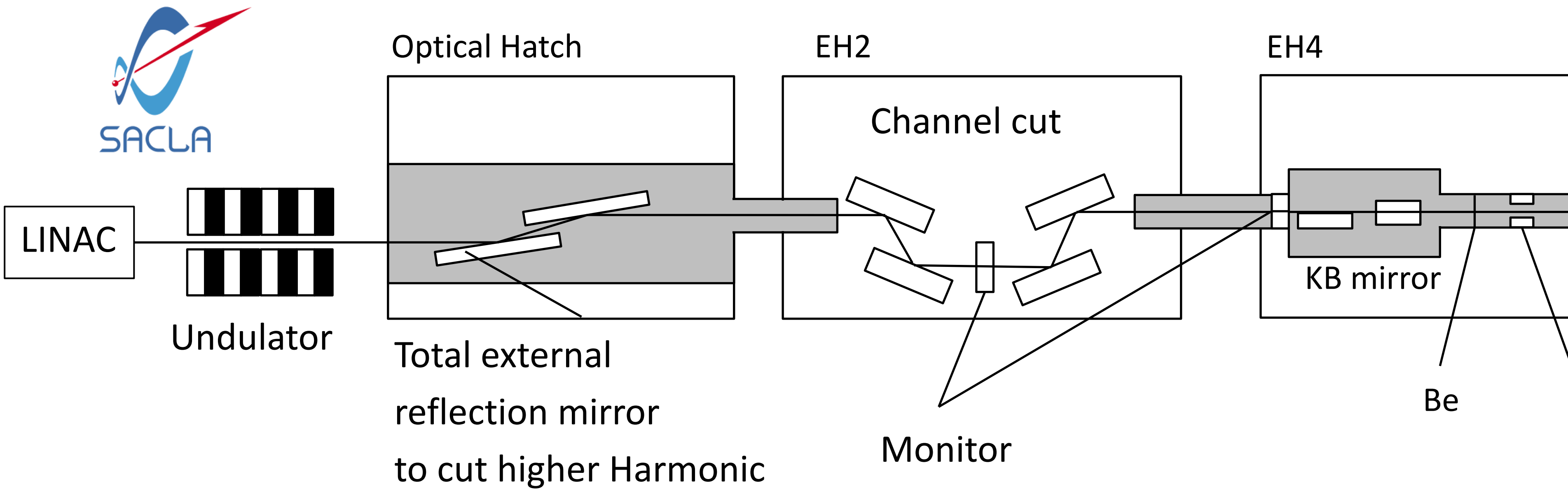
3 challenges

A） Photon Luminosity is crucial.

B） To collide photon to photon, control the optical path accurately in space and in timing.

C） Understand background events and reject them drastically.
Signal is very very small. On the other hand, BG is huge.

A) How to gain Photon Intensity; Upstream



- ✧ **6×10¹¹photons/pulse**@11keV, Pulse frequency is **30-60Hz**.
- ✧ Beam width is **200μm × 200μm** (FWHM), and a pulse length is short as **10fs(=3μm)**
- ✧ Monochromatic spectrum (bandwidth 80eV ->63meV) is obtained using the channel cut in which Si (4,4,0) Lattice is used. E=10.985keV
- ✧ Using the KB mirrors, beam is squeezed into **1 μm** (Horizontal)

→ High Intensity is obtained.

B) How to Split and Collide X-rays

Laue diffraction is used;

Si (4,4,0) Crystal Lattice is used.

$\theta_B = 36^\circ$ for 10.985keV incident X-ray

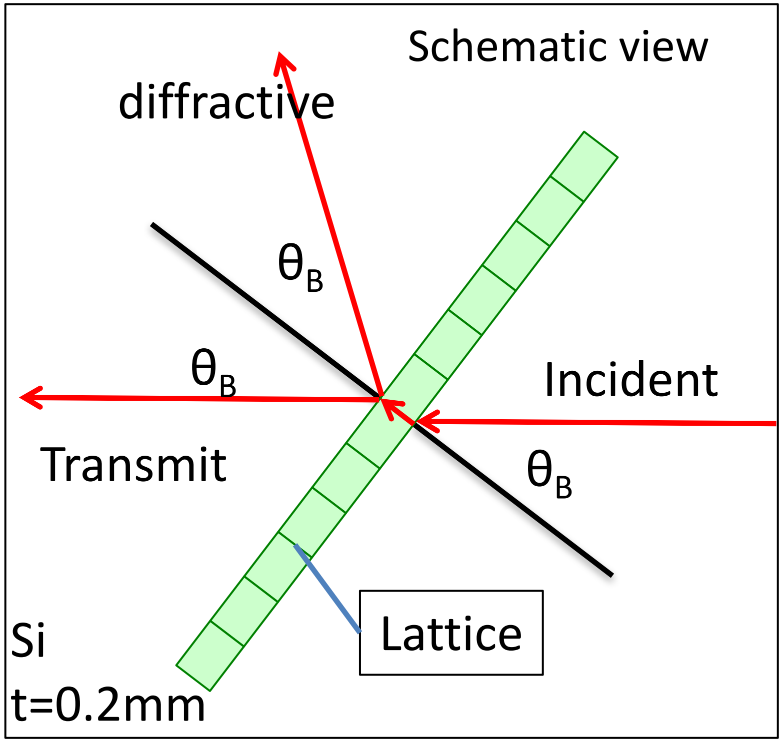
Injected X-ray is split into

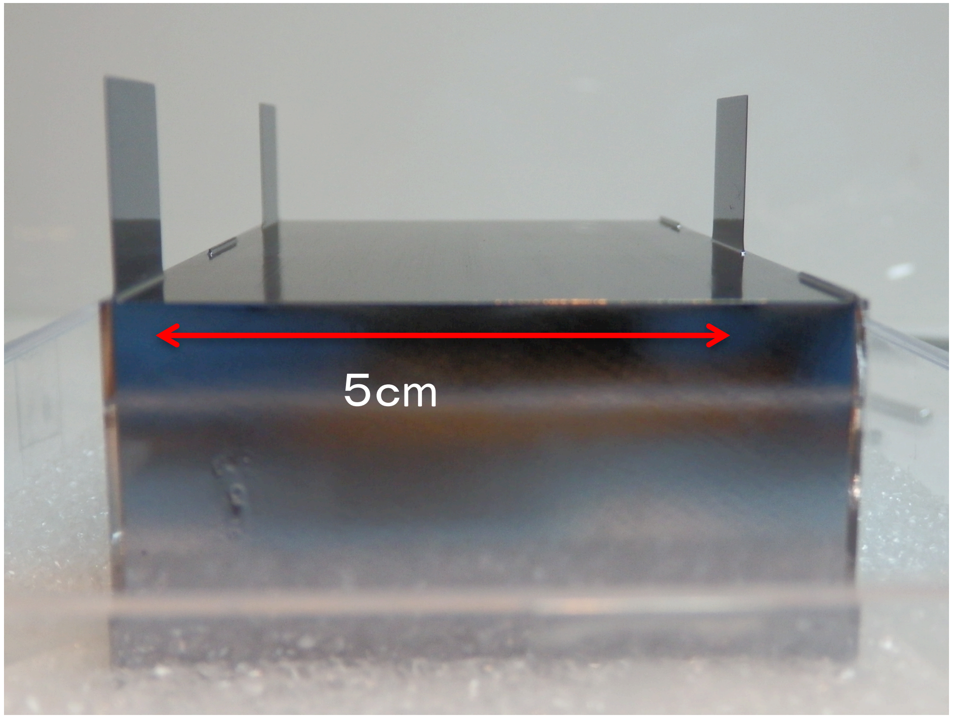
transmit and diffractive. Both efficiencies are about 10%

Laue-Type interferometer is used;

3 blades (t=200μm) are cut

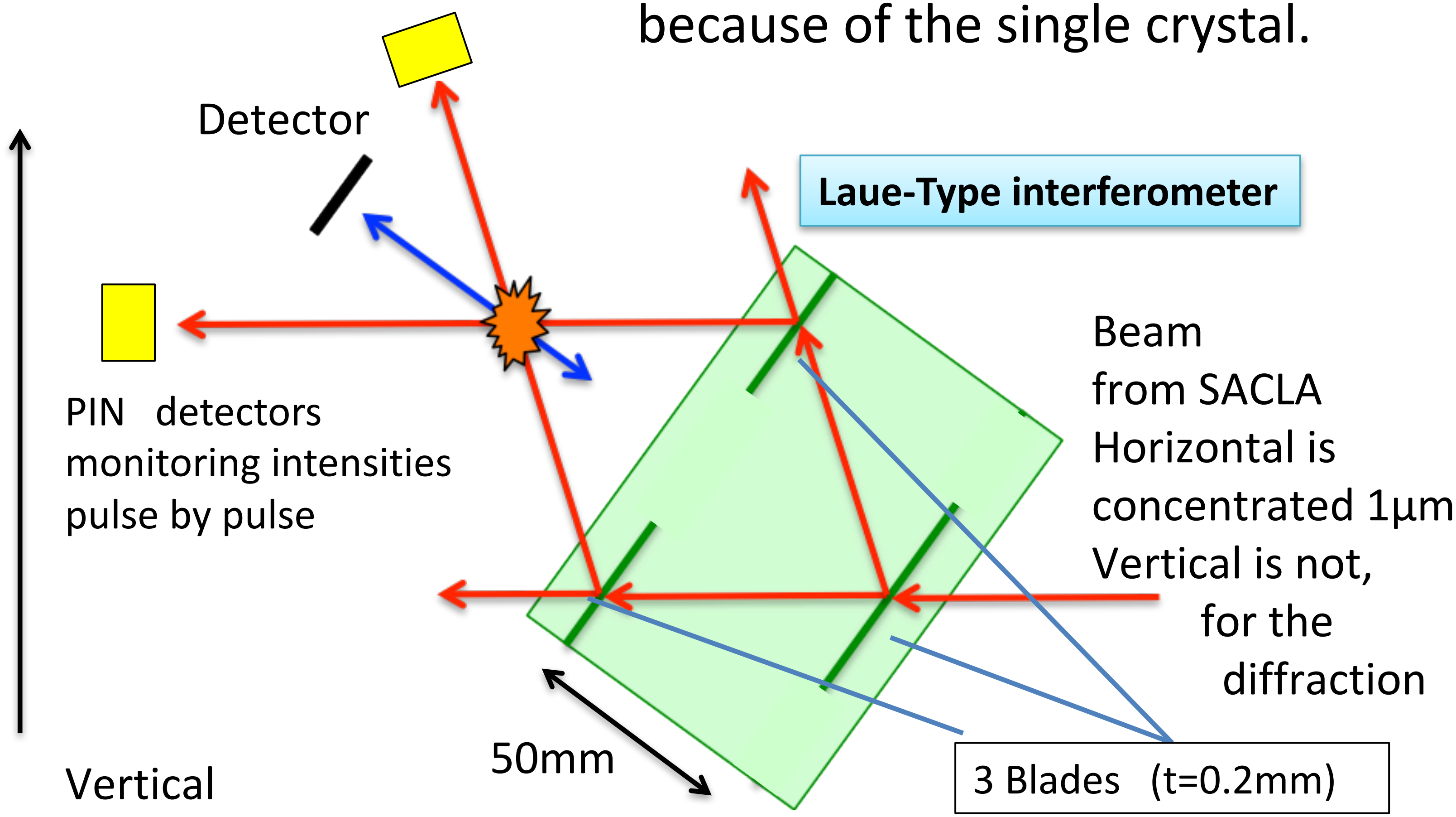
from a single crystal of Silicon.





B’) How to collide X-rays

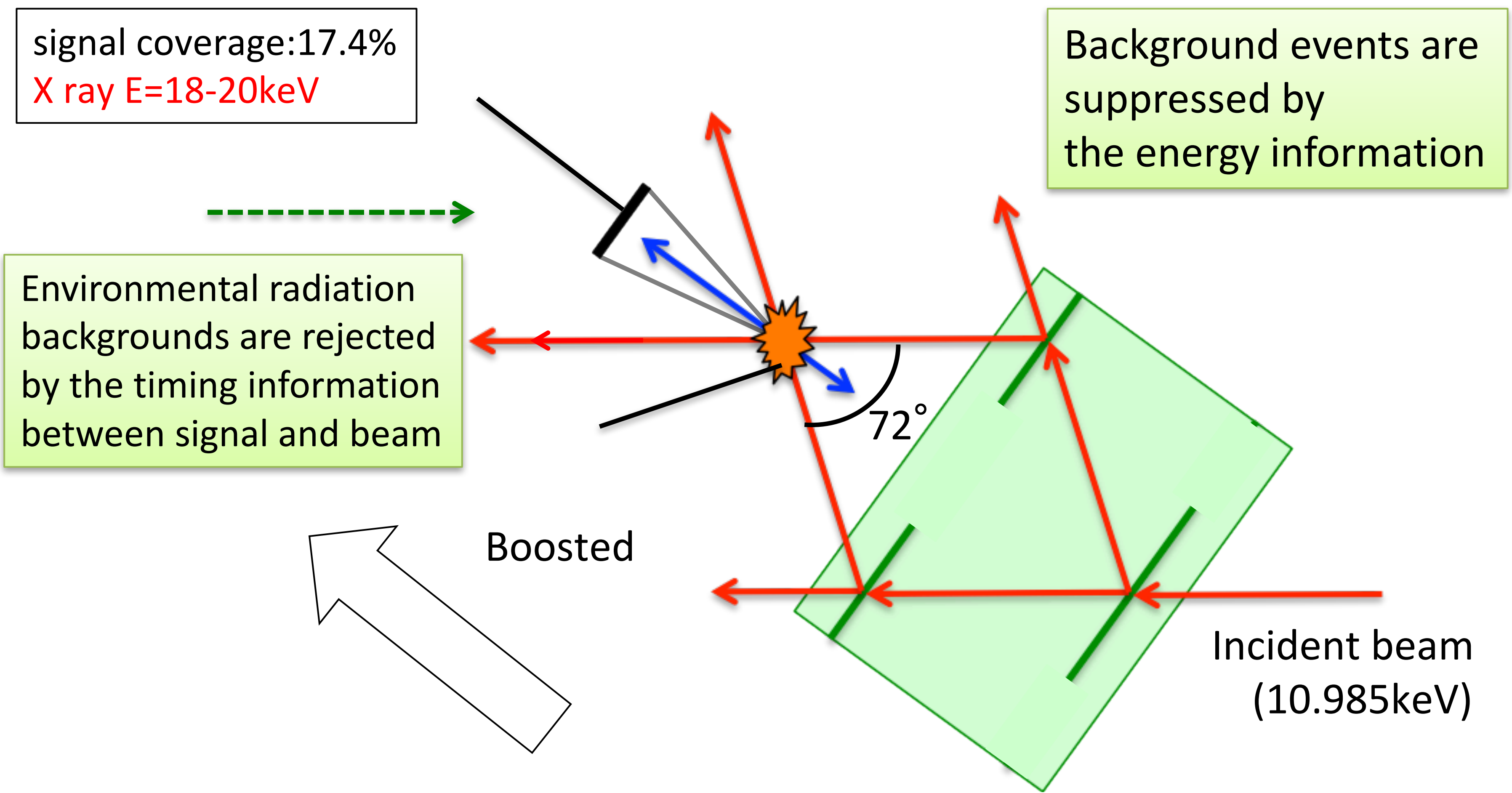
Beam splits into two using the blades, and collide here.
Optical path (both in space and time) is guaranteed,
because of the single crystal.



C) Background suppression (Energy information)

Dominant background is the stray photon of the incident light. (E~11KeV)

Collision is not Head-on (the collision angle is 72 degree), then the CM system is boosted forward. The energy of signal photon becomes 18-20 keV.



Result

◆Potential source of pseudo signals
1)pileups of two stray X rays
: ~0.01 pileups are expected
2)accidental coincident of environmental X rays
:0.43 ± 0.03 BGs are expected

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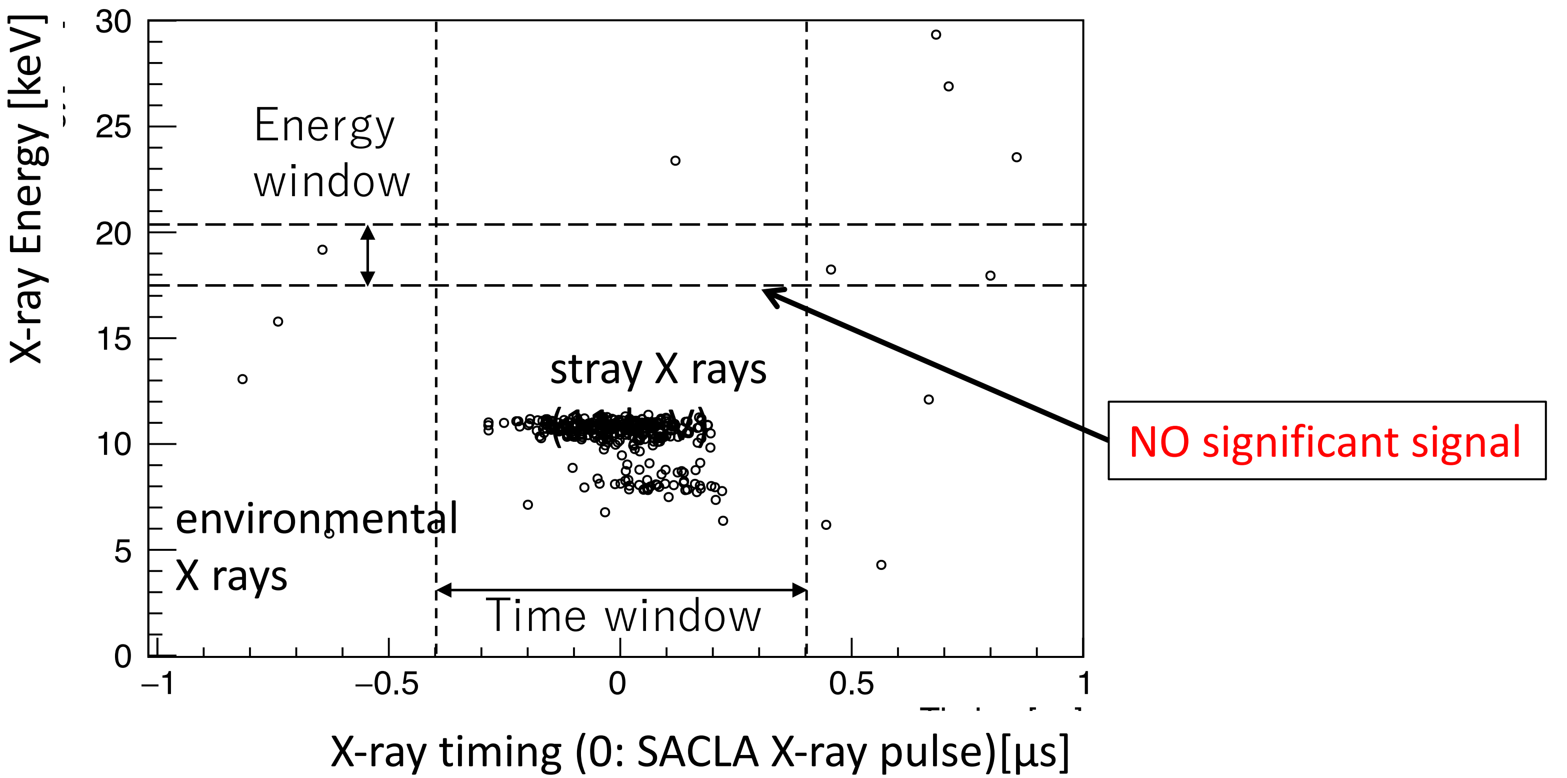
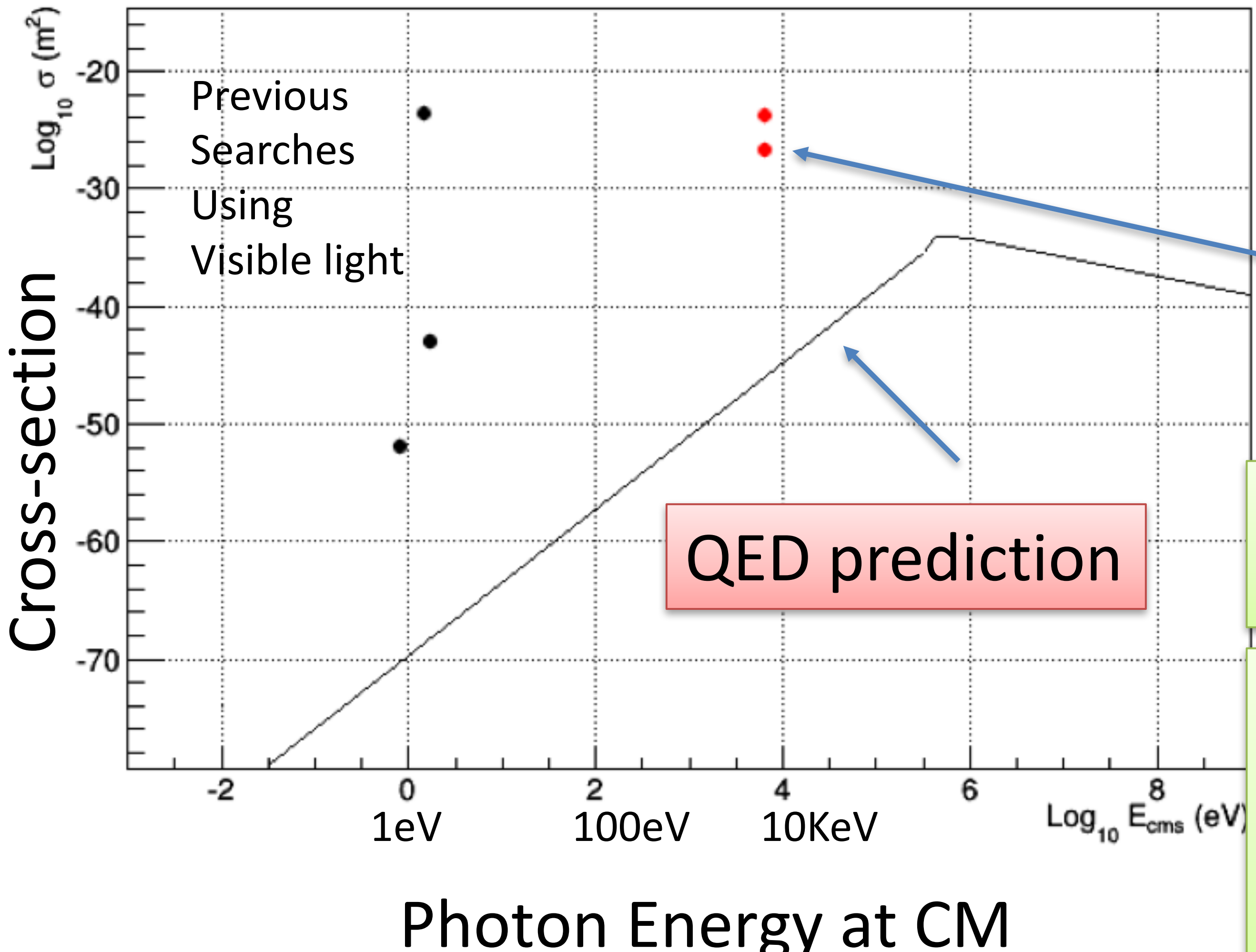


No signal was observed

Upper-limit on the cross-section(95%CL)



1.9×10^{-27} [m^2]
~ 10^{14} fb

We have performed twice in 2014 and 2016

The first results at X ray region.

But still need sensitivity of 10^{20} to observe the QED vacuum

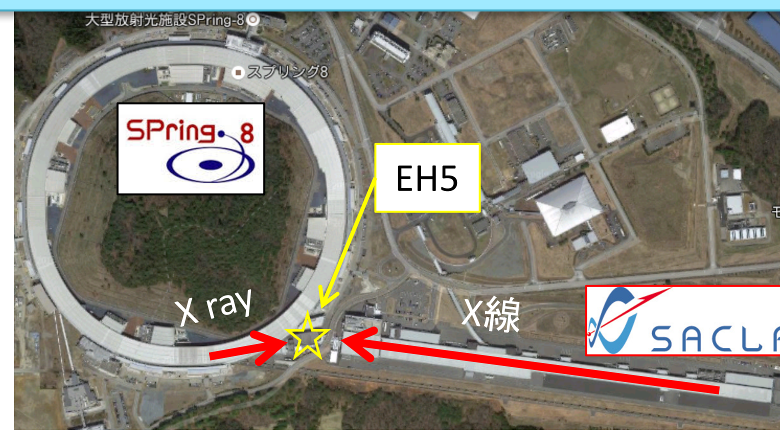
Why so becomes worse? E Width of "Laue scatter" is too narrow
80eV -> 63meV 1/1000 * 2% (2 Laue scatter) -> 10^{-5} photon loss / each

Next Step : Soft mirroring?
SACLA+SPring-8 head-on collision

If Laue/Bragg scatter is used, very narrow Energy width is necessary(63meV). Can we use more loose mirroring valid for the wide width (like mosaic crystal or multi-Layer Bragg)? New idea / New Optics are necessary to use all photons(10^{12}) from the XFEL.

SACLA+SPring-8 co-operation

In EH5: SACLA and SPring-8 will be synchronized in near future.
From Spring8 ~10^3 photon/pulse 40ps (pulse intensity is 10^{-9} weaker than SACLA)
All photons from SACLA/Spring8 can be used.
・50nm focusing can be used in head-on collision
→sensitivity 10^{11} is enhanced.

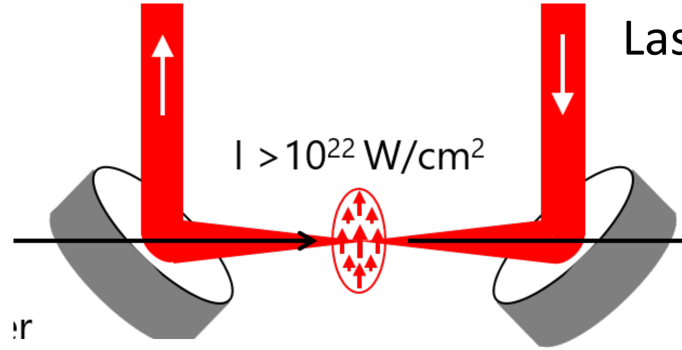


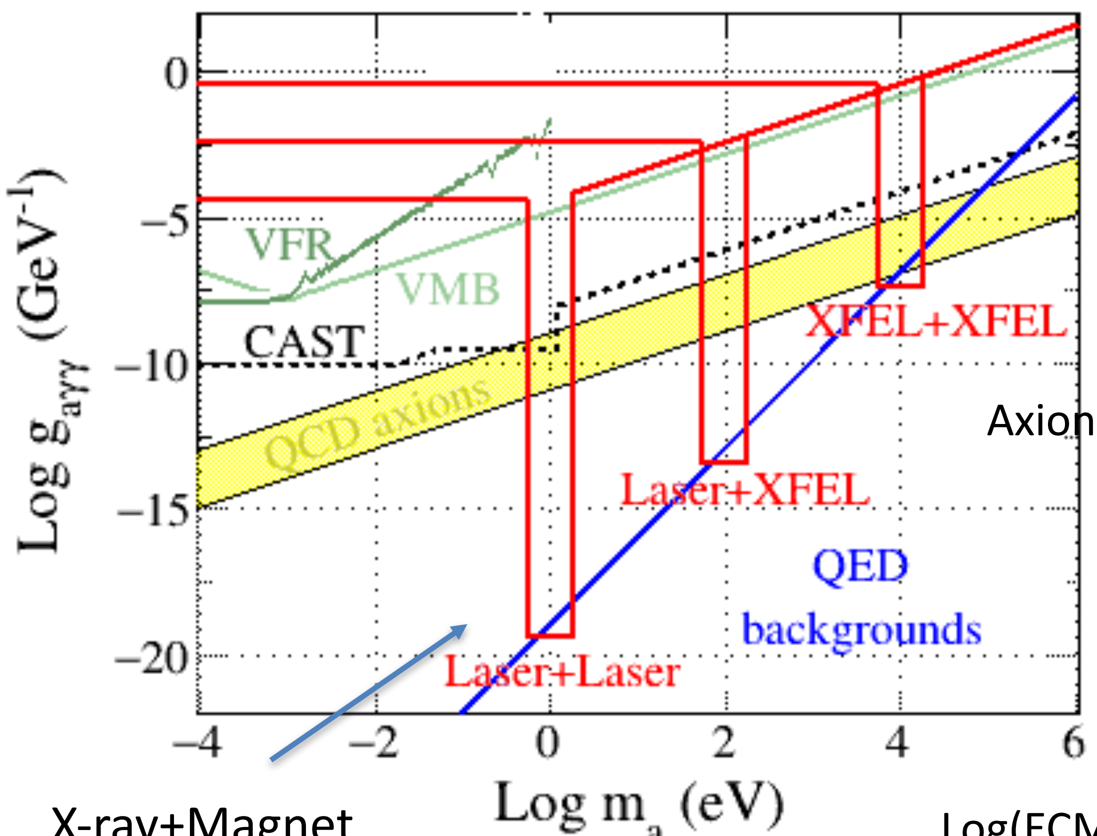
Then we can reach the QED vacuum or discover a new unknown field(Axion, Dilaton).

4. [B] Using collision between X-ray and Laser at SACLA

Particle Physicist View:

Laser(Visible light) + X-ray(E=10keV)
Center-of-Mass energy is
~ 100 eV.





3different ECMs are covered.

Material scientist View: pump-probe spectroscopy, target is “vacuum”

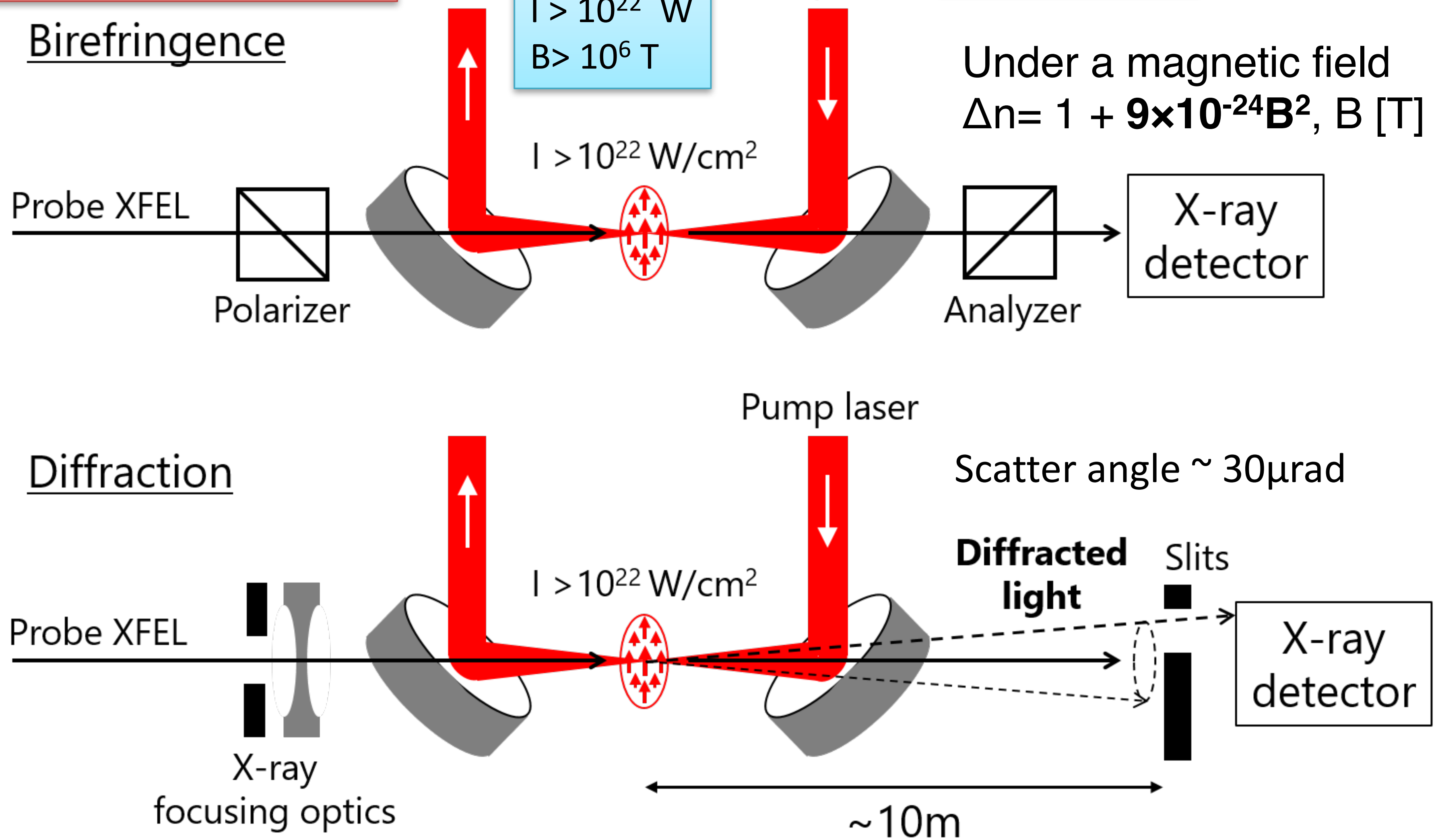
2 methods to probe polarized vacuum / ES

Squeezed into 1 µm, $I > 10^{22}$ W, $B > 10^{6}$ T

500TW 25fs Laser (800nm)

Under a magnetic field
$\Delta n = 1 + \mathbf{9\times10^{-24}B^{2}}$, B [T]

Scatter angle ~ 30µrad

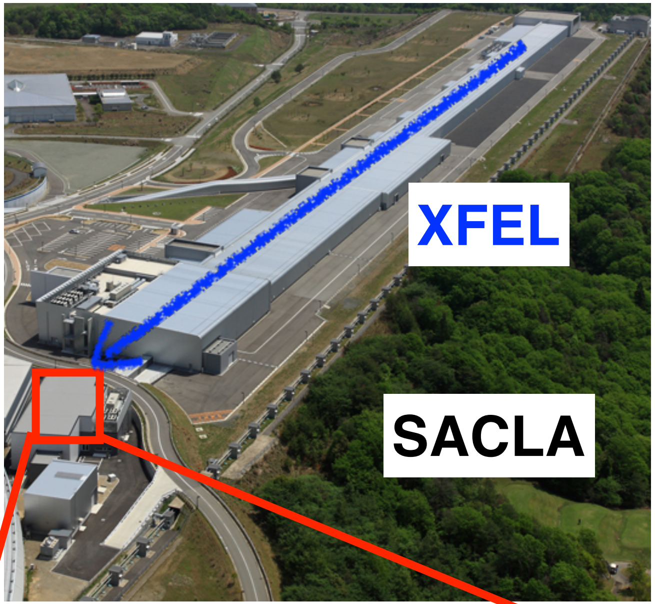


Light Sources to Pump and Probe

Probe

Performance of the SACLA

- Photon number : 6×10^{11} photons/pulse @10 keV
- Pulse width : <10 fs
- Beam size after focusing -> 1 μm



Pump

A high power laser is synchronized with SACLA
a **500 TW laser** is under installation.

Performance of the 500 TW laser

- Wave length : 800 nm
- Pulse energy : 12.5 J
- Pulse width : 25 fs
- Rate : 1 Hz
- beam size can be squeezed upto 1μm

500 TW laser

2.5 TW laser (Hidra-100) is used now for test experiment.

A) Polarizer is key technology for birefringence exp.

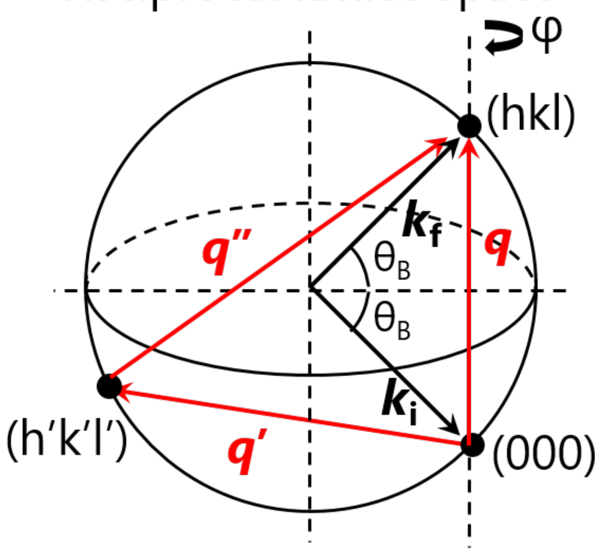
$\Delta n \sim 10^{-11}$ for $I=10^{22}$ W/cm^2

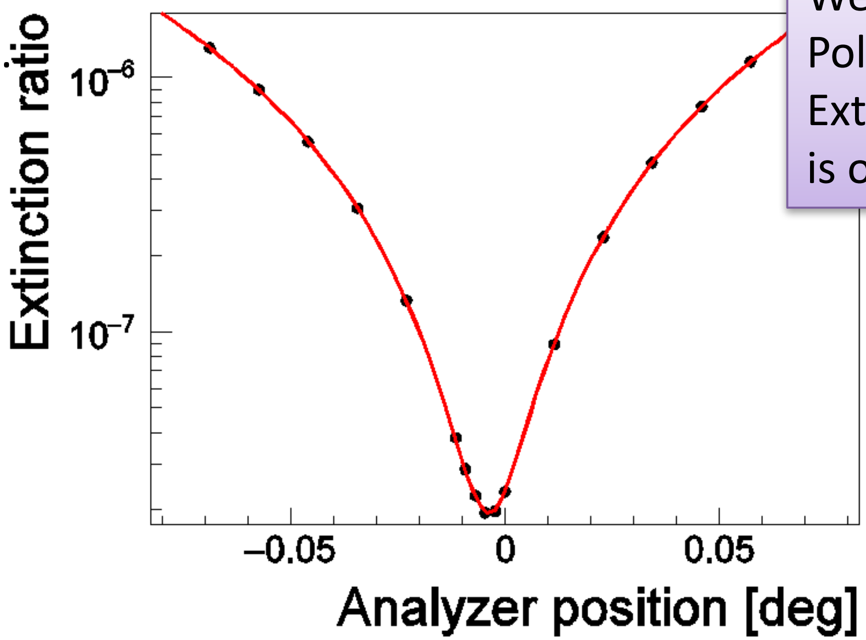
High Extinction ratio $\sim 10^{-11}$ is necessary

Big Trial!!

Multi-Beam Refraction
Is background to make worse.

Reciprocal lattice space





We have tested a new Polarizer at Spring8
Extinction ratio 10^{-8} is obtained.

Distance between polarizer and analyzer Is close at test,
Divergent angle makes ER worse,
we hope 10^{-10}

Ki: input vector , q is transfer by Bragg. Usual path
MBR: at least twice scatter, a lattice structure is examined, -> Choice no q′ lattice

B) Diffraction experiment case

Angle distribution of Diffracted light is given by

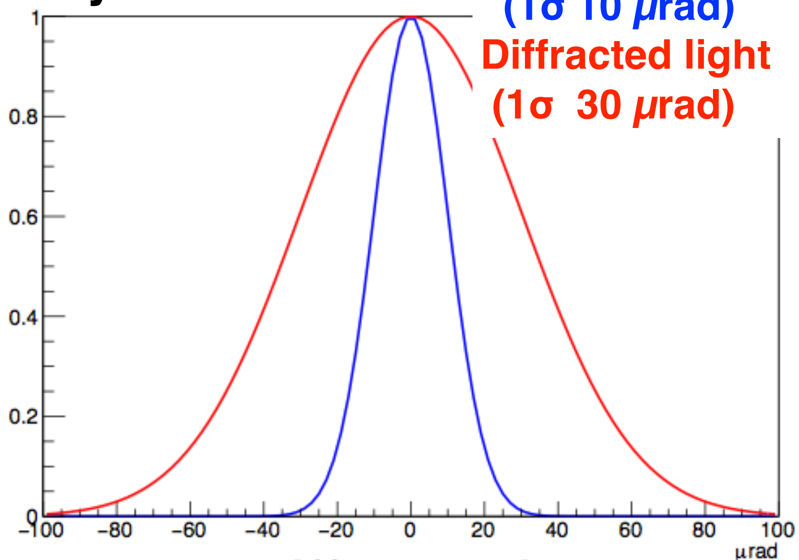
$$\frac{dN_{\rm diffracted}}{d\cos\theta} \sim \frac{JE^2W^2}{w_{\rm L}^2(w_{\rm L}^2+2w_{\rm X}^2)} \times (Ew)^2 e^{-\frac{1}{2}(Ew\theta)^2}$$

$$w^2 = \frac{w_{\rm L}^2 w_{\rm X}^2}{w_{\rm L}^2+2w_{\rm X}^2}$$

PRD 94, 013004 (2016)

High Energy E
Squeezed both
High Flux J
High Power W

Estimated disribution

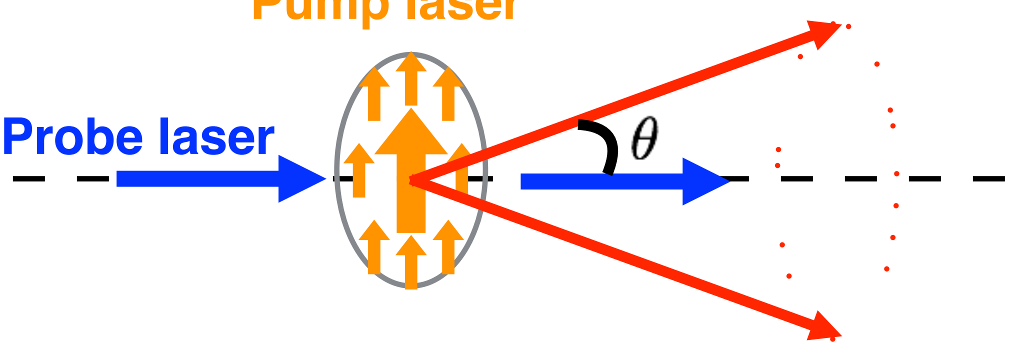


Diffracted light

Probe X-ray laser (Gaussian beam)
Photon flux : J
Photon energy : E
Beam waist : ω_X

Pump laser
Pulse energy : W
Beam waist : ω_L

Probe X-ray is diffracted
~ 30μrad (Very small angle)



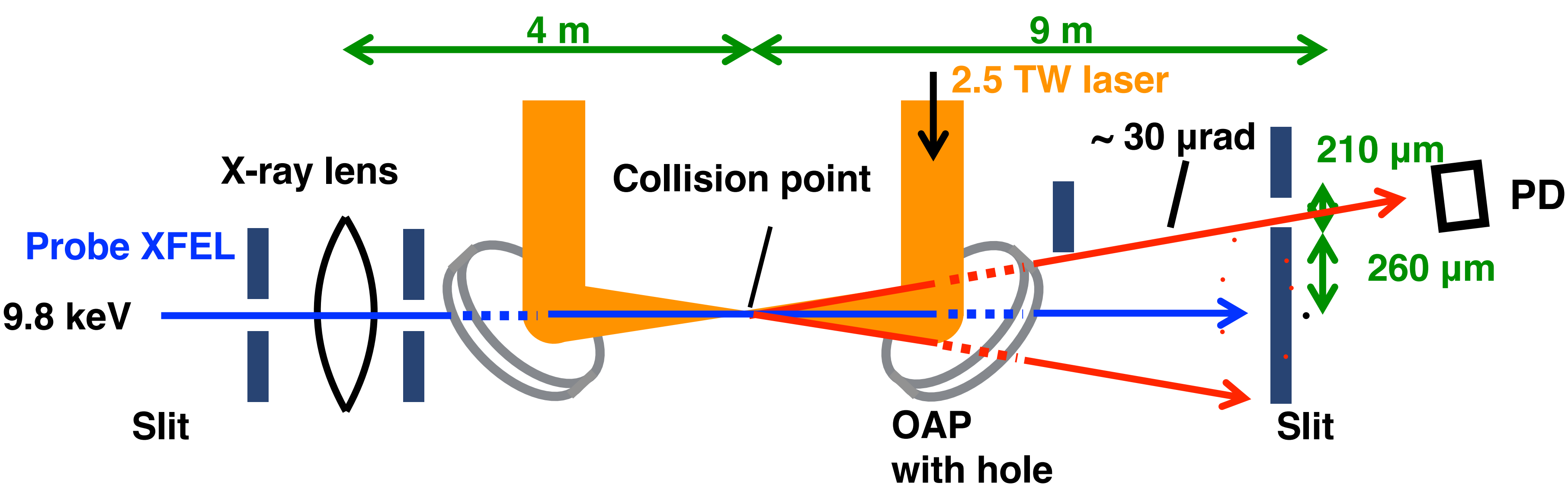
B') The first research has been performed at SACLA (2016)

2.5 TW laser light is sqeezed upto 10 μm with Off-Axis-Parabolic mirror with hole. (beam size of both are estimated with CCD and wire-scan -> 10 μm)

3 big Challenges !!!

1) **Timing:** Laser is synchronized with SACLA (within a few ps)
2) **In Space**: Collision point is exactly controlled (within beam size)
3) **Background suppression (Suppression factor 10^{-16})**

Photon Detector is used.
Scatter is



Photograph in Vacuum chamber

h has been performed at SACLA (2016)

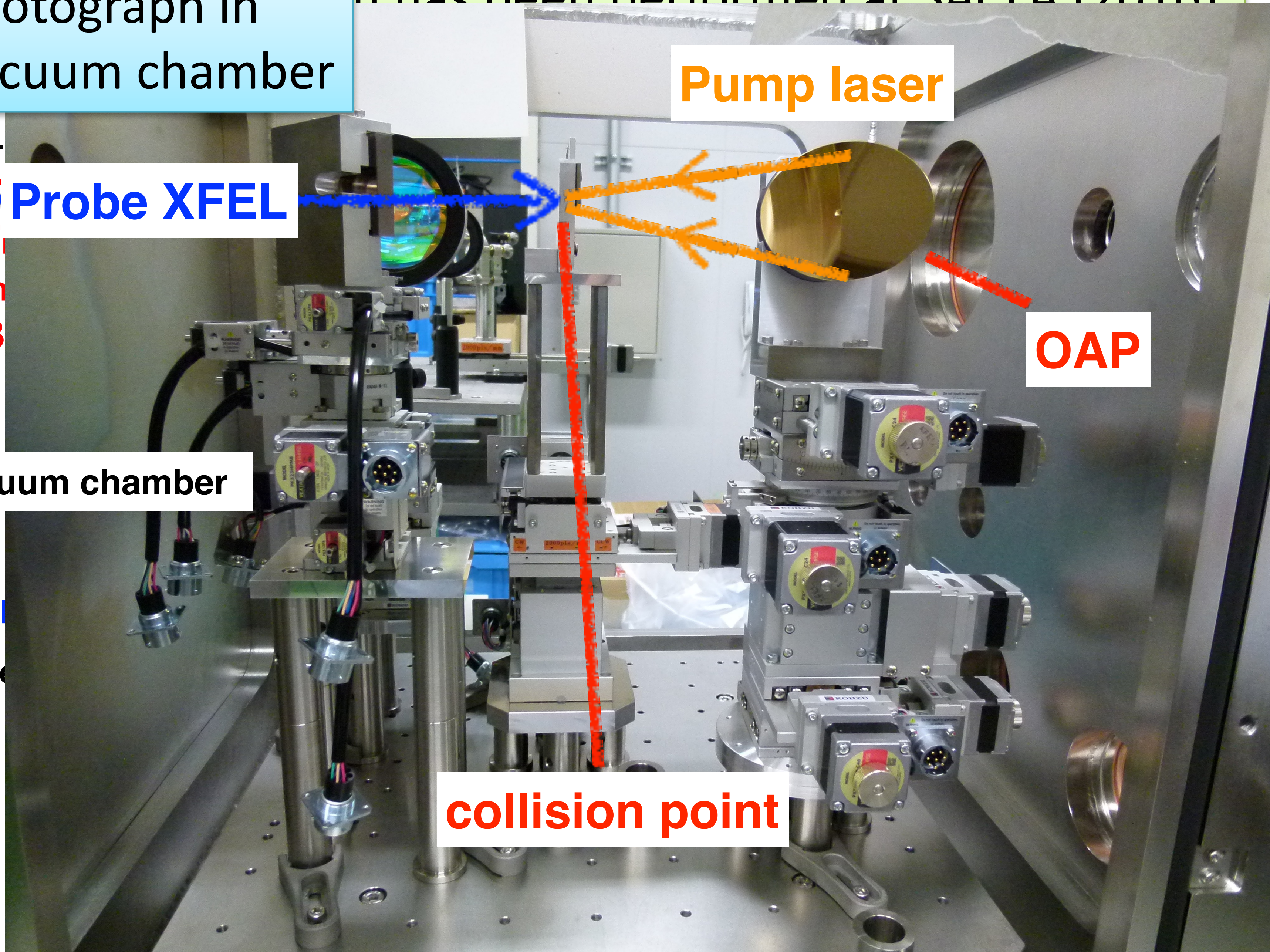
hole.

3 Tr

1) T

2) In

3) B

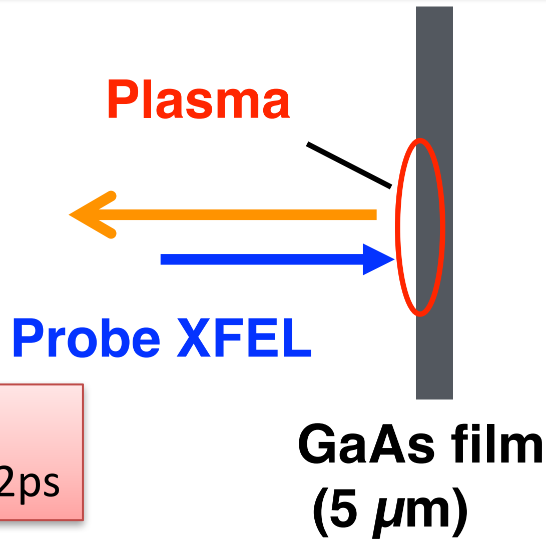


Prol

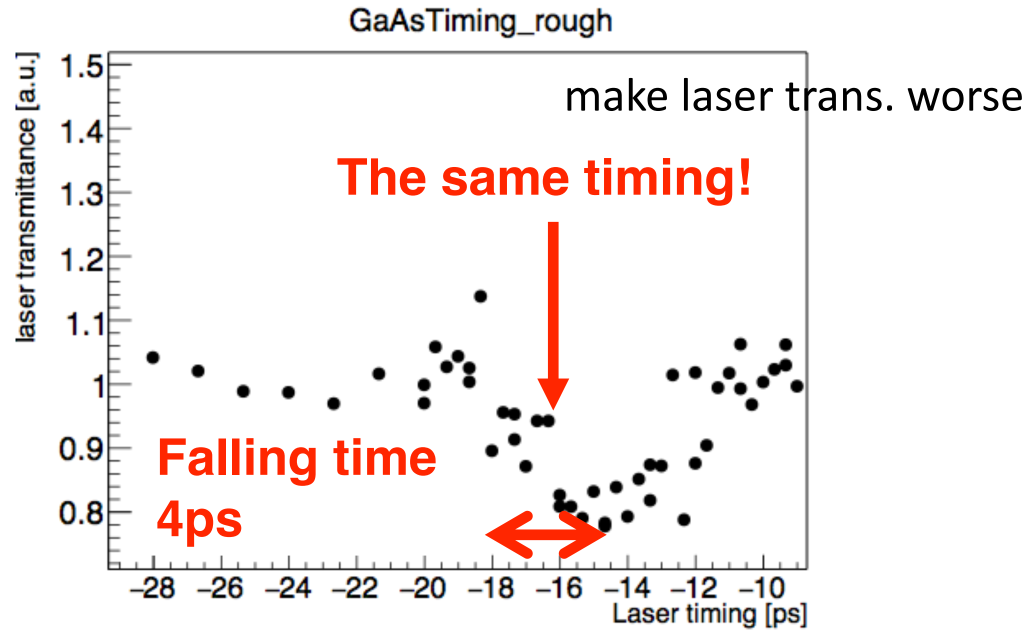
9.8 k

Timing is estimated with GaAs film

X-ray hits GaAs film
Plasma is produced

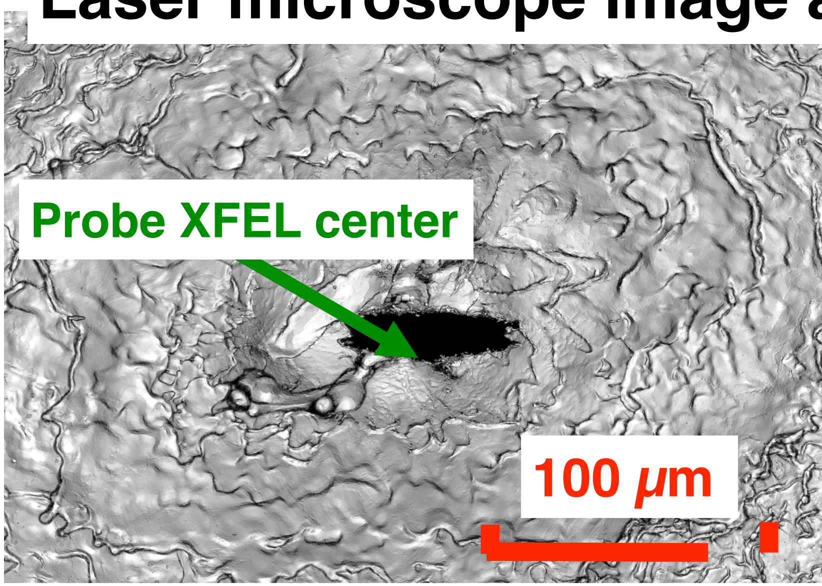


timing is OK within 2ps

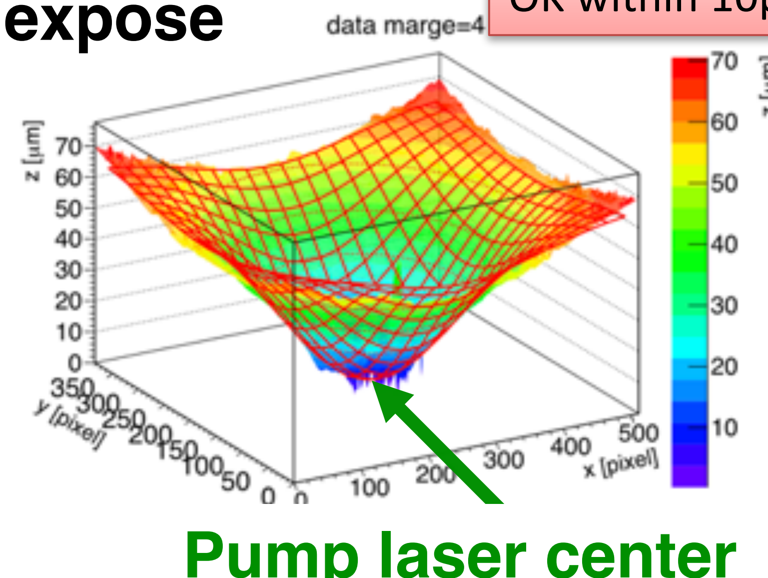


Position is estimated with Zn thin film

Laser microscope image after expose



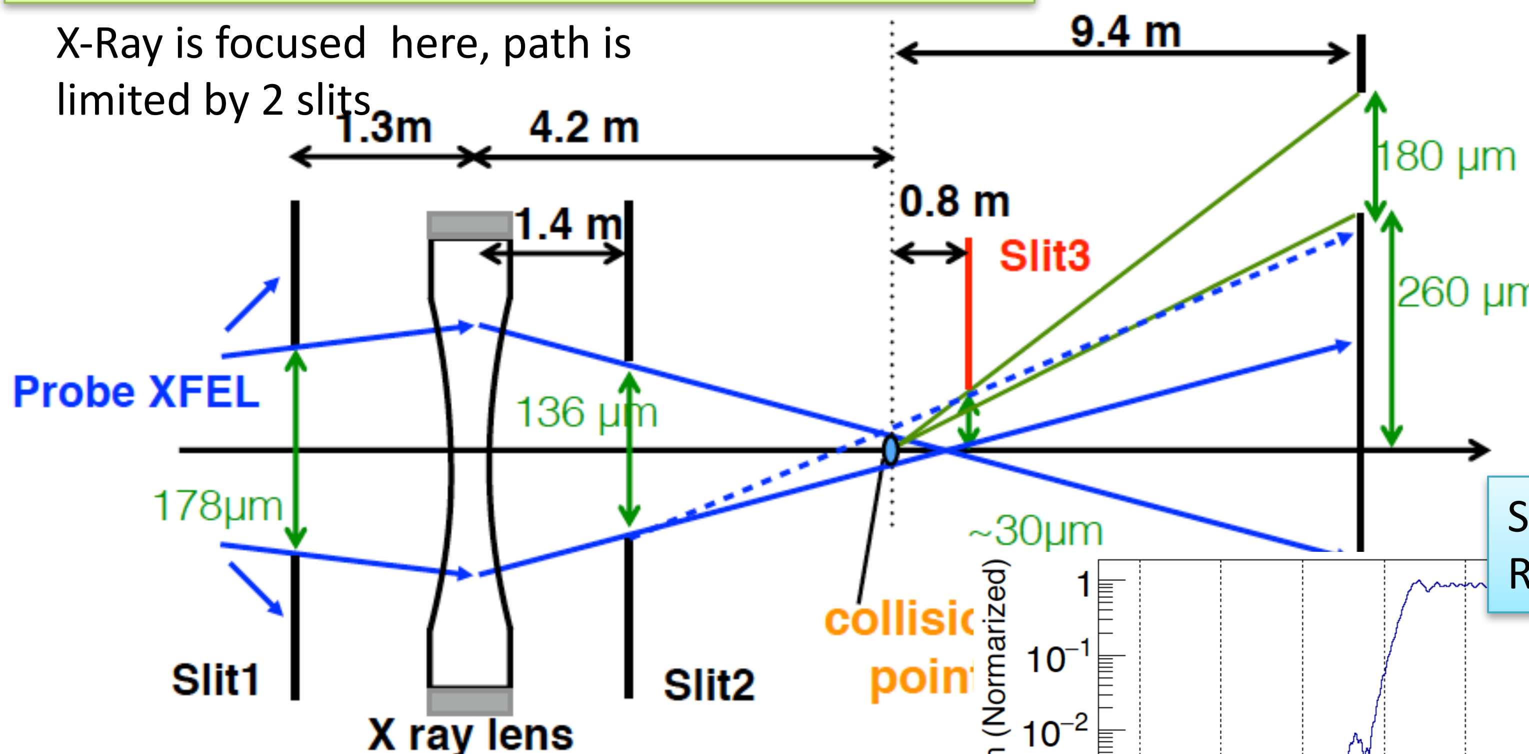
Center is OK within 10μm



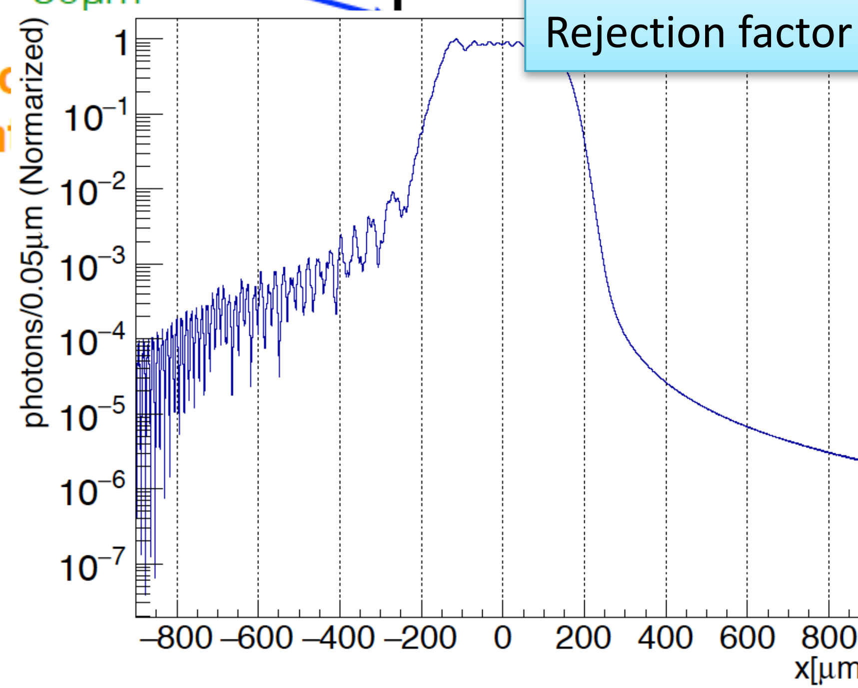
But Background level is still high

Layout of setup

X-Ray is focused here, path is limited by 2 slits

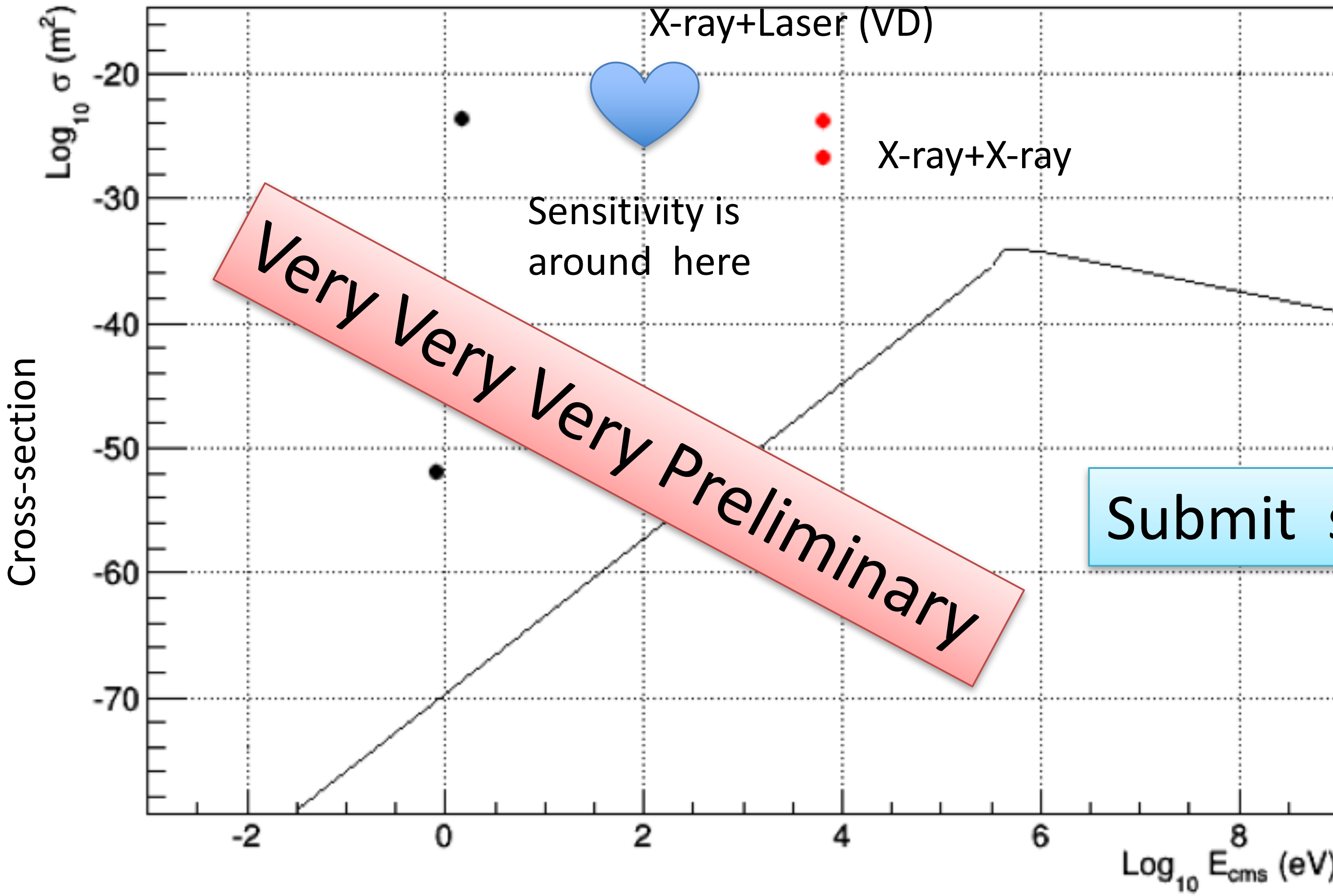


Simulated Rejection factor



Scattered X-ray is suppressed
By the Slits (S3, S4).
10^{-16} suppression is necessary,
But still about 10^{-4},
Maybe, diffraction at the edges
contributes to BG. (New slits are needed)

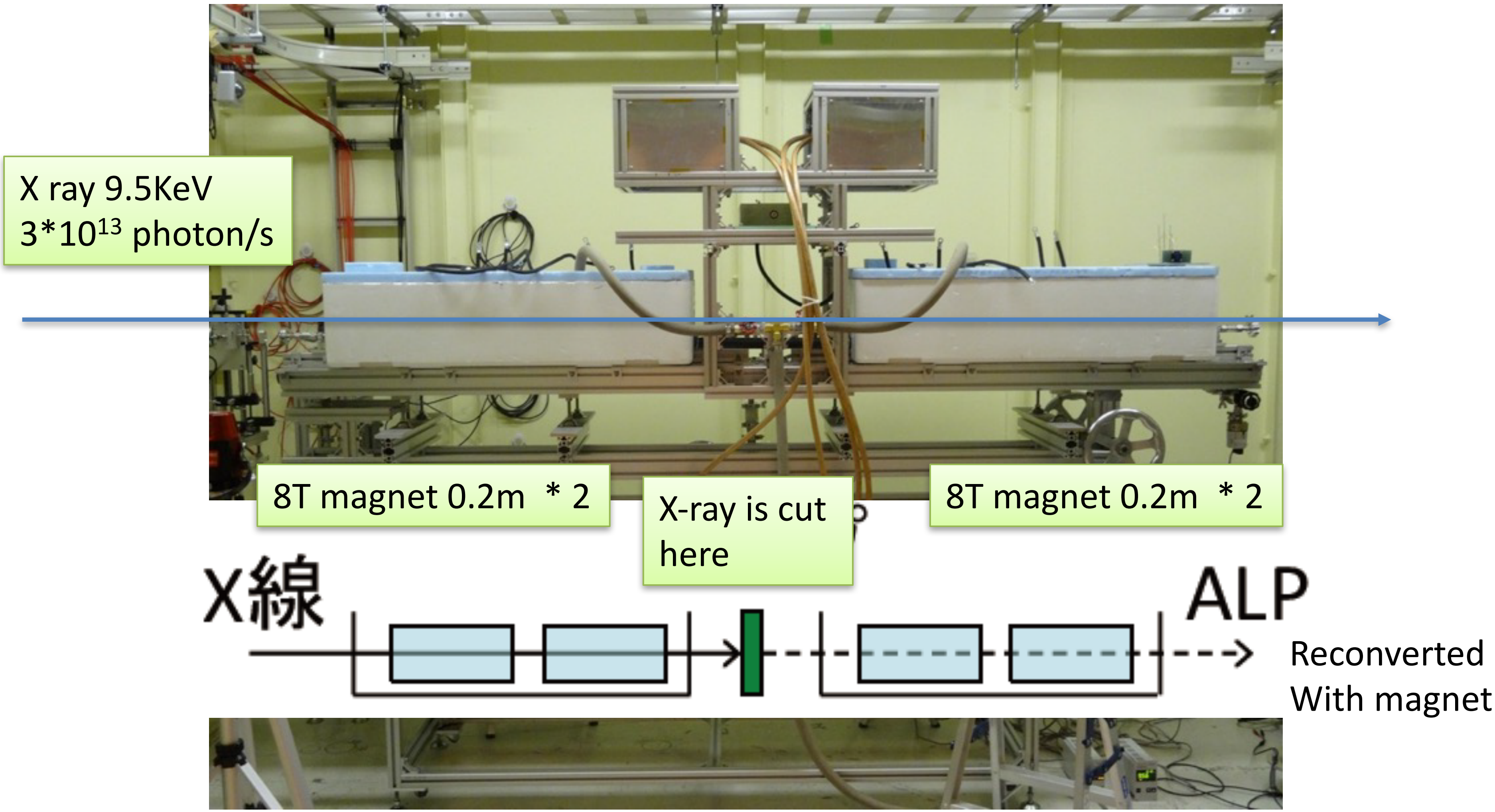
The first research has been performed with 2.5TW laser + SACLA
Focusing size ~ 10μm

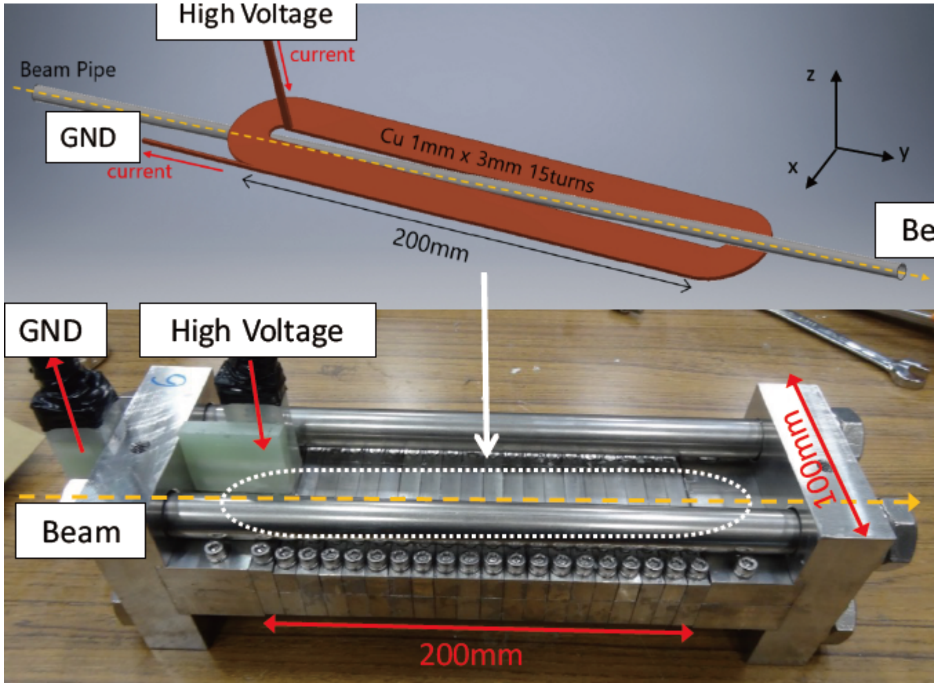


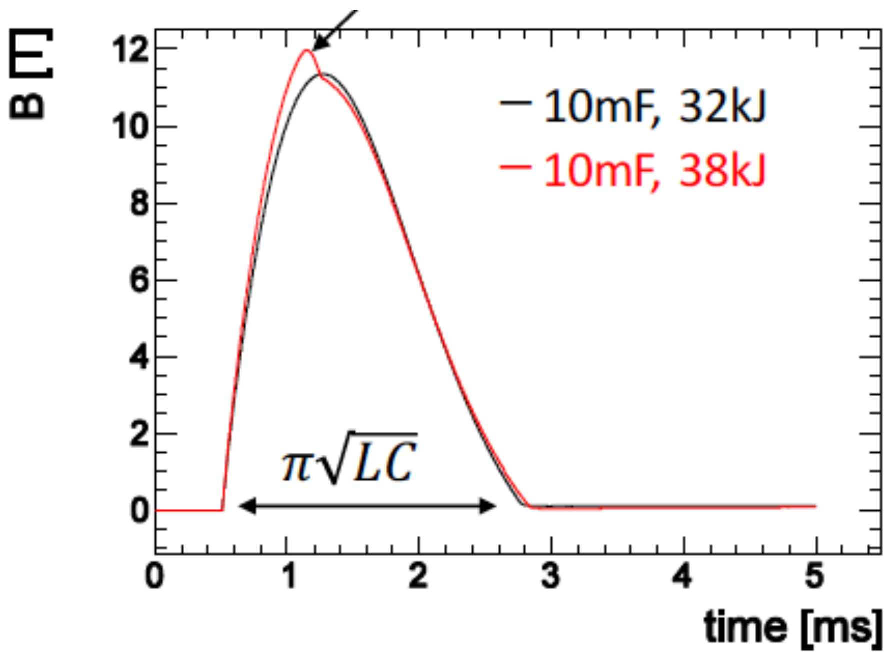
Submit soon

Log (Center of Mass Energy of gamma gamma system)

5. [C] Using collision of X-ray and Strong Magnet at Spring-8 (Axion/Dilaton like particle)





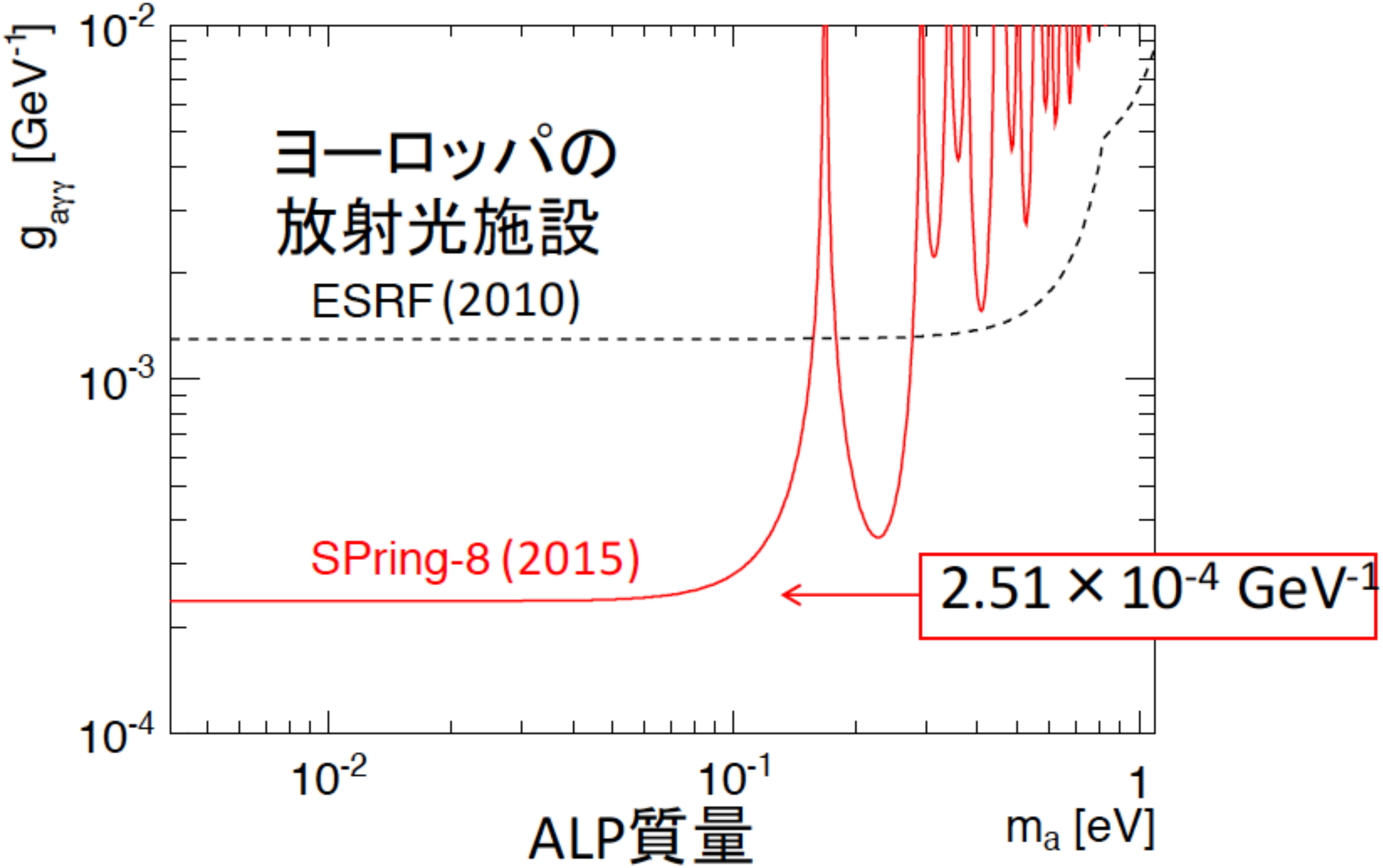


10T Magnets are used (4 units)

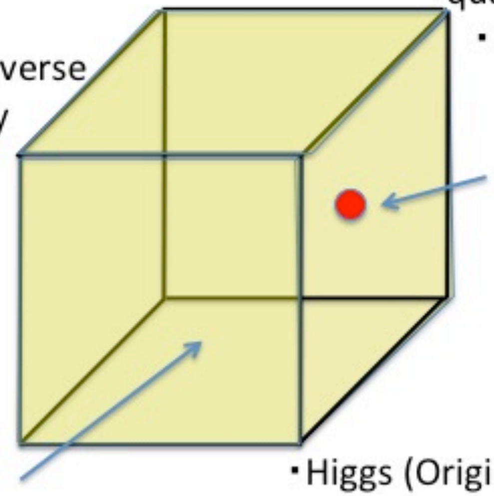
L.Ne is used to cool magnet down
100L/h is exhosted.

3mF Condenser bank
30KJ (1HZ rep.)

Sensitivity is for 0.1 eV



Summary



- After Higgs Boson discovery, "Vacuum" becomes one of the frontier field.
- Many fields are hidden in vacuum. Photon is key technology to probe the vacuum.
- Using XFEL SACLA/Spring-8, three different energy regions (10KeV, 100eV, 0.1eV) are explored with the different technologies.
- **New developments on X-ray optics / XFEL open new possibilities**

- You can find out more details of experiments and the other activities of our group

http://tabletop.icepp.s.u-tokyo.ac.jp/Tabletop_experiments/English_Home.html