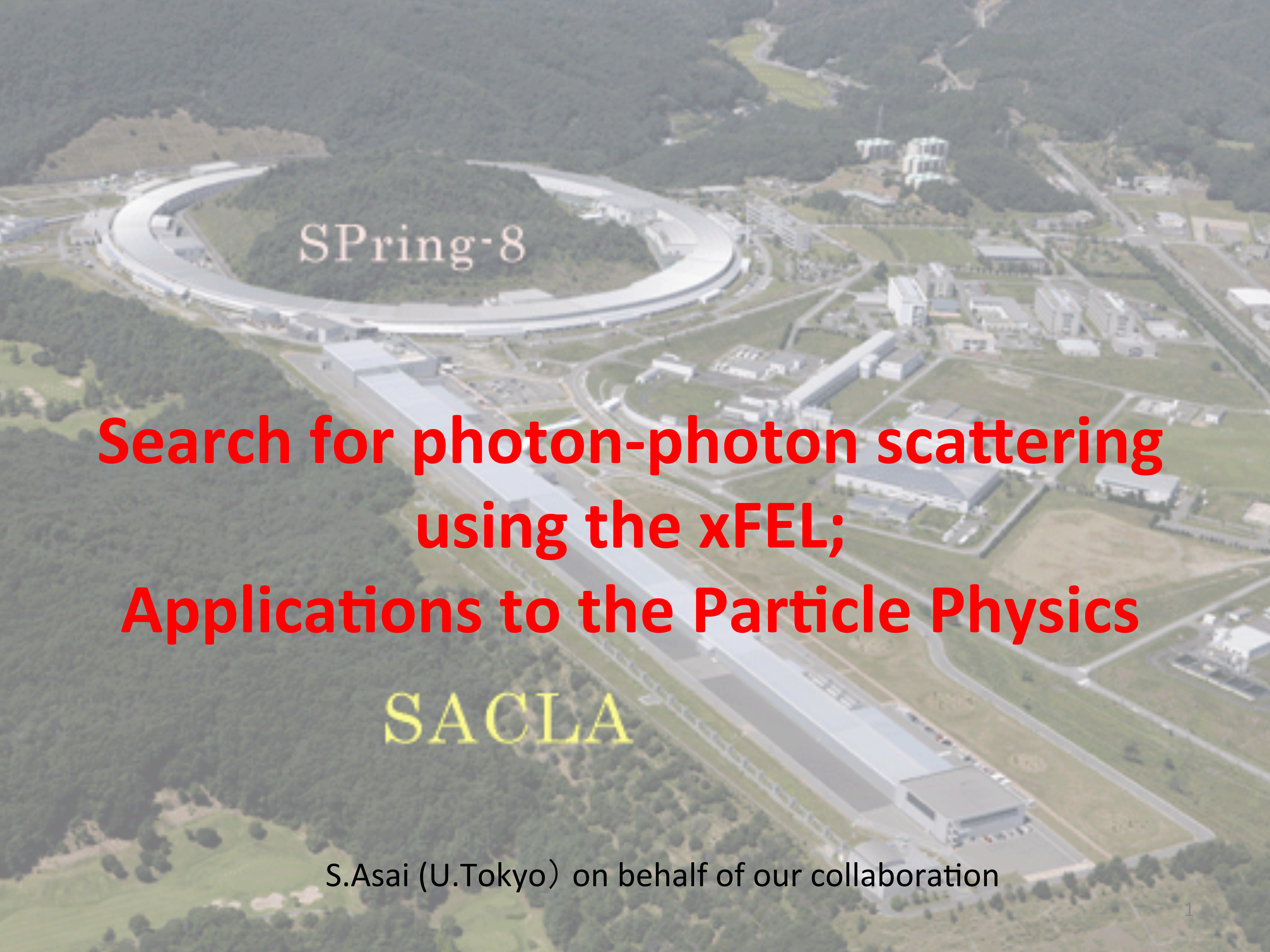


Search for photon-photon scattering using the xFEL; Applications to the Particle Physics

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

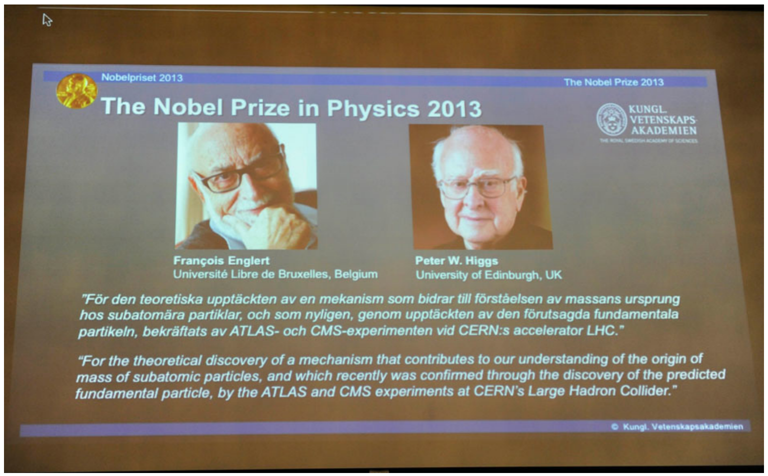
Contents of my talk

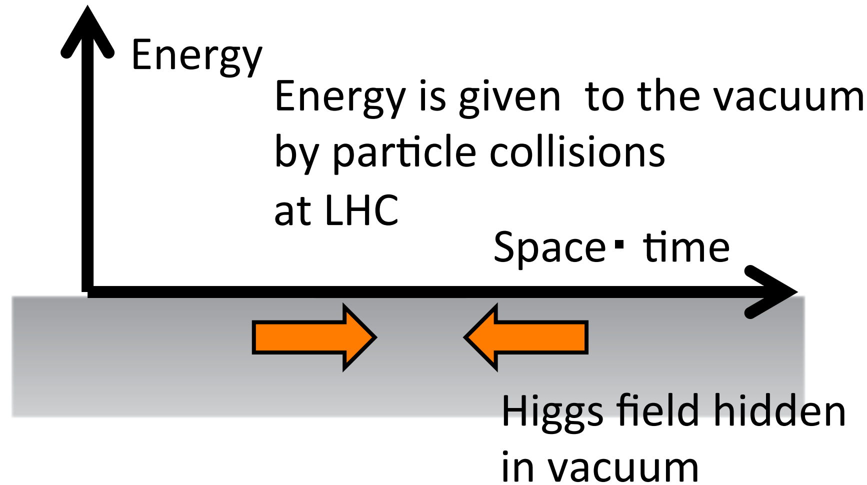
1. What is the Vacuum?
2. Non-linear effect of the Vacuum (QED)
3. Search for the photon-photon scatter at SACLA; Experimental setup &new ideas
4. Results & Prospects
5. Search for the other fields (Axion,Dilaton)
6. Summary

Collaboration members are as follows;
T.Yamaji, T.Inada, T.Yamazaki, T.Namba, S.Asai , T.Tobayashi (U.Tokyo)
K.Tamasaku, K.Sawada, M.Yabashi, T.Ishikawa (Riken)
Y.Inubushi (JASR), Y.Tanaka(U. Hyogo),
T.Takahashi, S.Watanabe (JAXA), G.Sato (U.Waseda)

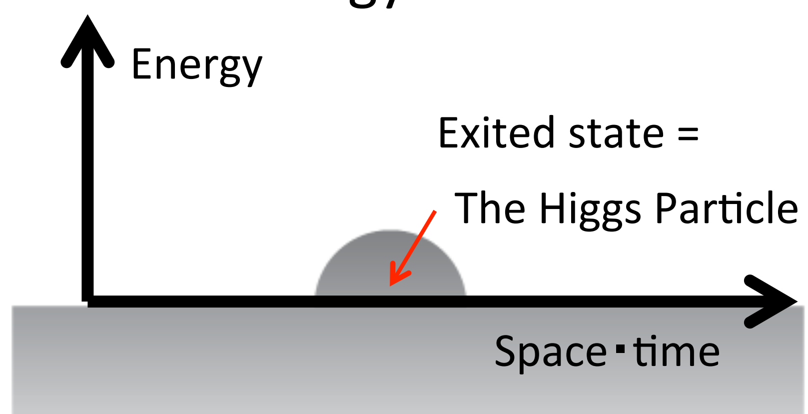
1. What is the vacuum?

The Higgs Boson is discovered in 2012 & wins Nobel Prize in 2013





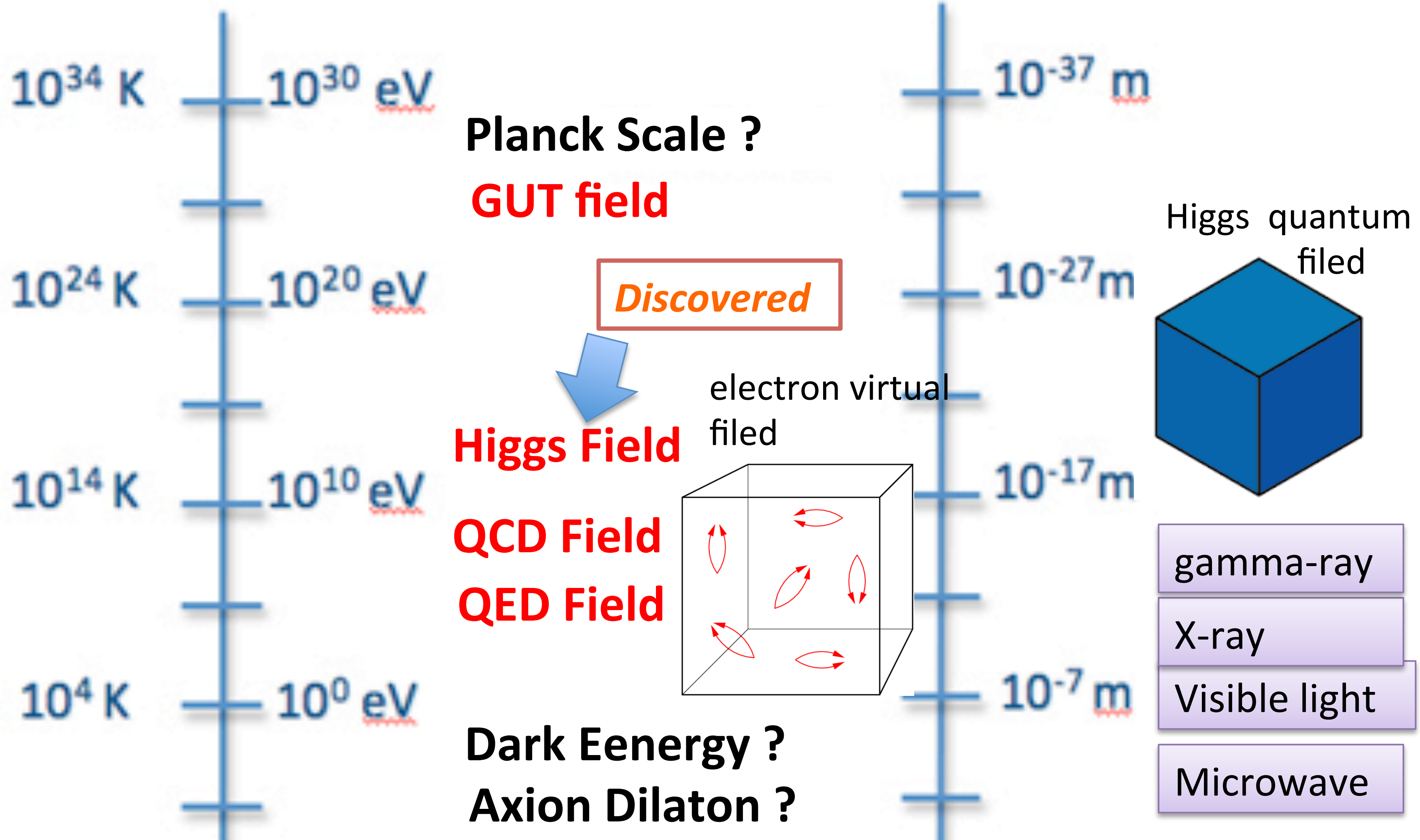
The energy excites the field.



Higgs Particle is **NOT important**, Higgs field hidden in our vacuum is important.

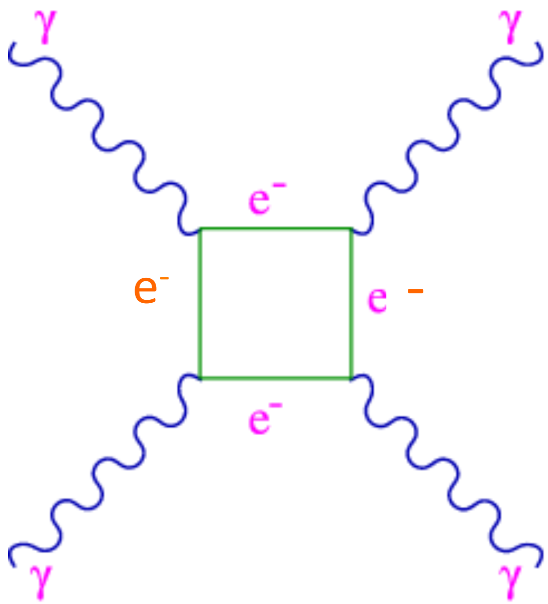
Discovery of the Higgs Boson shows that our vacuum is filled with the strange quantum field (Higgs filed)

Various fields are hidden in the vacuum



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

2 . Non-linear effect; our target is the vacuum



Photon does not couple to Photon itself.
But virtual electron-positron pair exists in the vacuum. (QED vacuum)

Photon-photon scatter through the loop.

This is the direct evidence of Non-linear effect of the Vacuum; Called "Schwinger limit"

QED predicts

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

Suppressed by α^4 and highly suppressed by electron mass m.

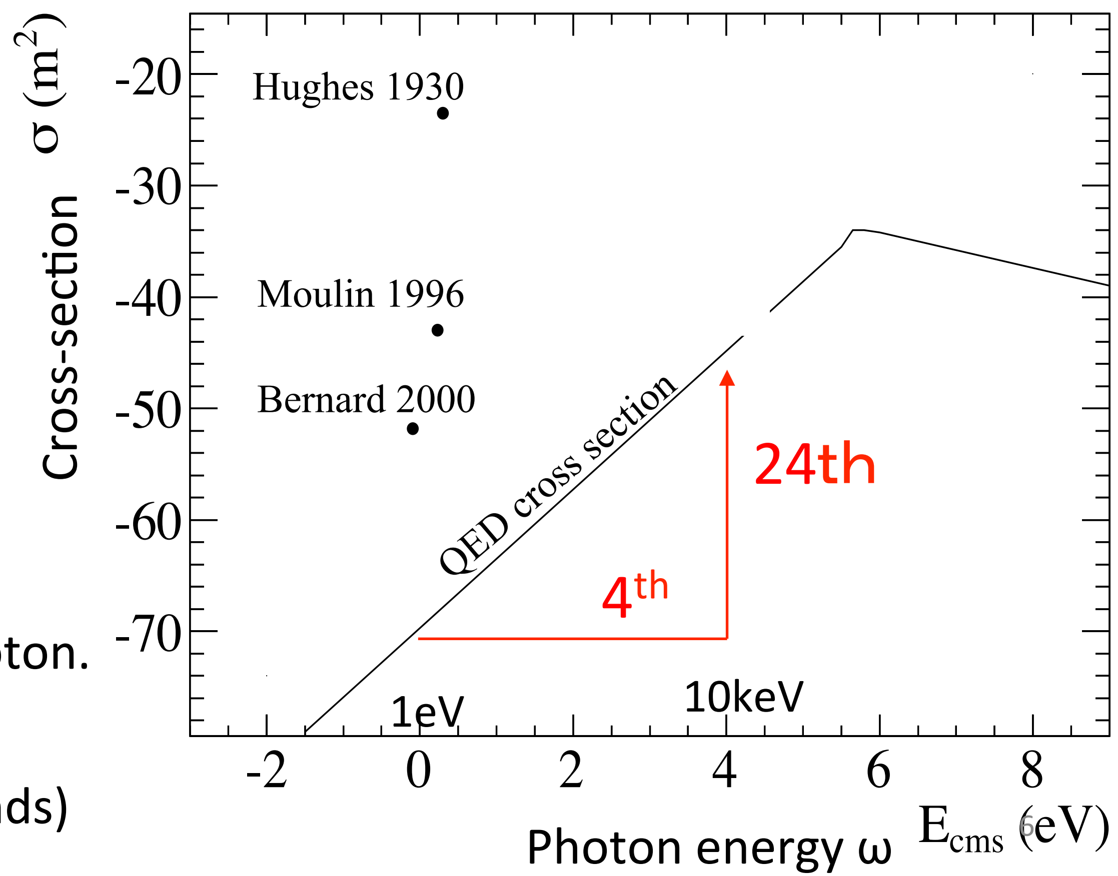
the expected cross section $\sigma=1.8\times10^{-70}$ [m^2] for ω=eV Too small!!

10^{-27}fb

X-ray has advantages

- 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 to visible lights.

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



- X-ray is interesting
  (1) Squeeze upto ~ O(1) nm
  (2) Go straight
  (3) Easy to count a single photon.
  ((2)(3) are important to control backgrounds)

3. Search for the photon-photon scatter at SACLA

Just collide X-rays?
Not so easy than thought.

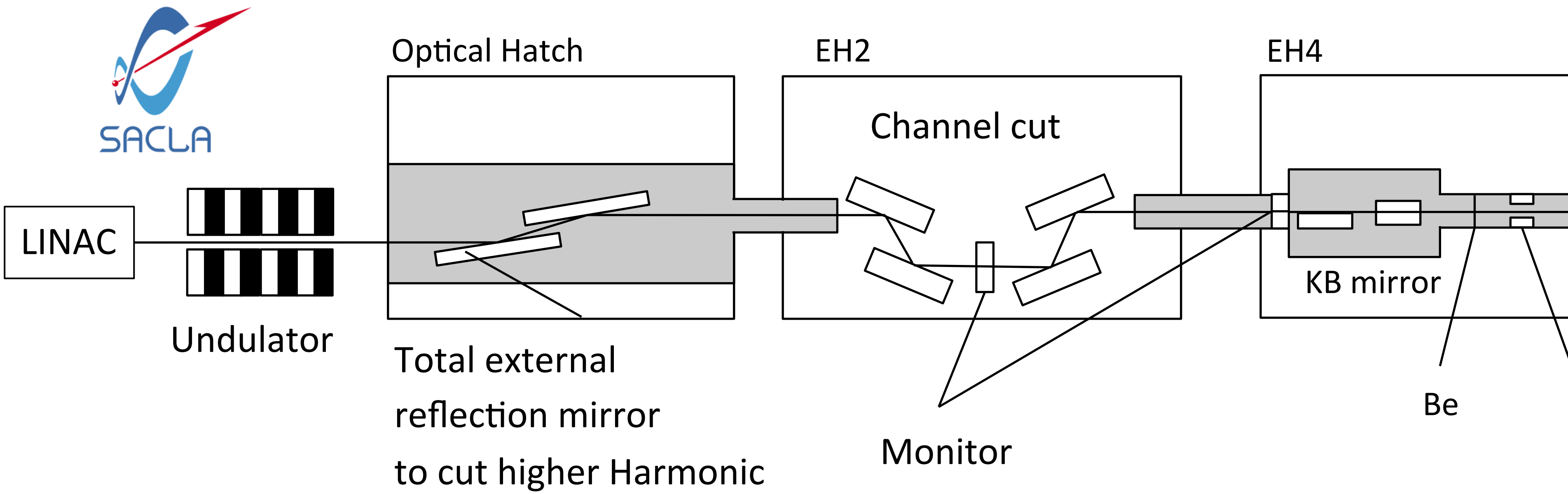
There are
3 challenges

A） Photon Luminosity is crucial. (Ultimate all, number of photon, beam size, and pulse length)

B） Collide photon to photon, control the optical path accurately in space and in time. (Not so easy)

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



- ✧ **1.2×10^{11}photons/pulse**@11keV, Pulse frequency is **30Hz**.
- ✧ 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)

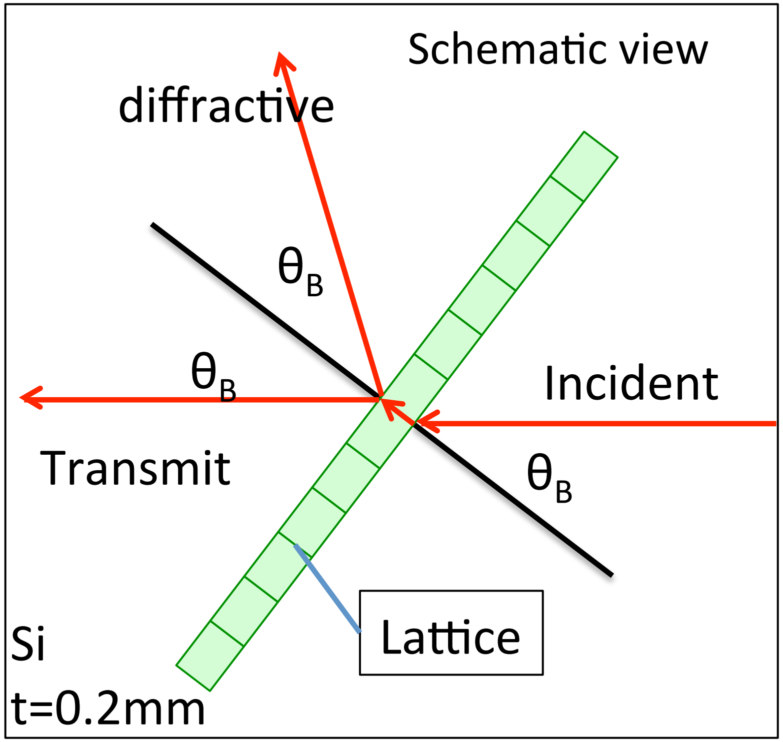
→ High Luminosity

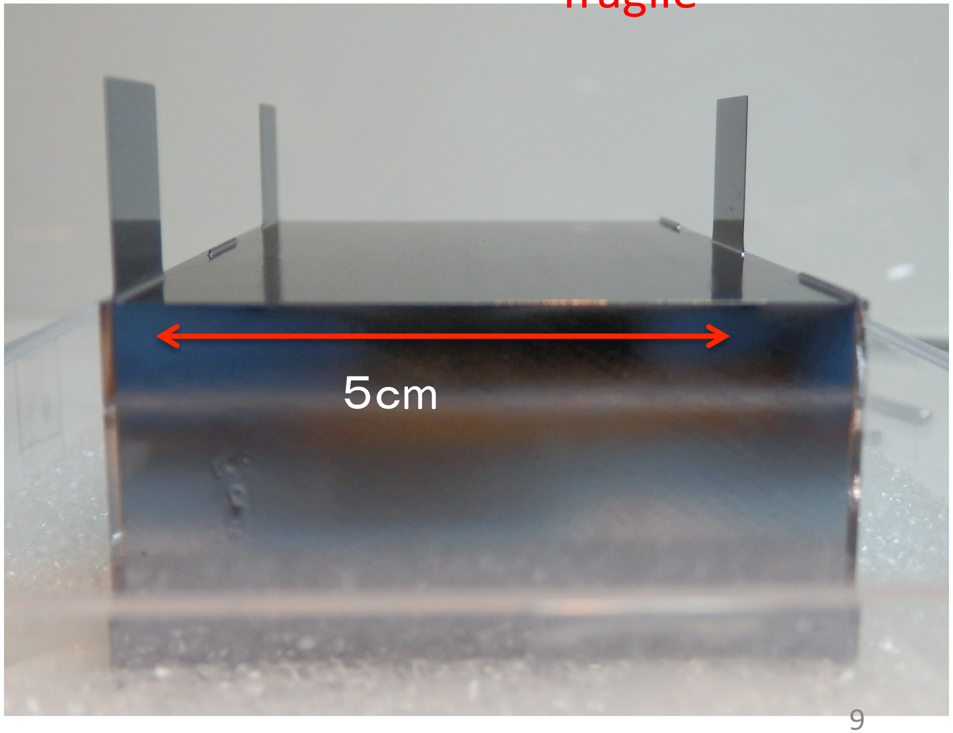
B) How to Split and Collide X-rays

Laue diffraction is used;
Si (4,4,0) Crystal Lattice is used.
θ_B=36° 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.

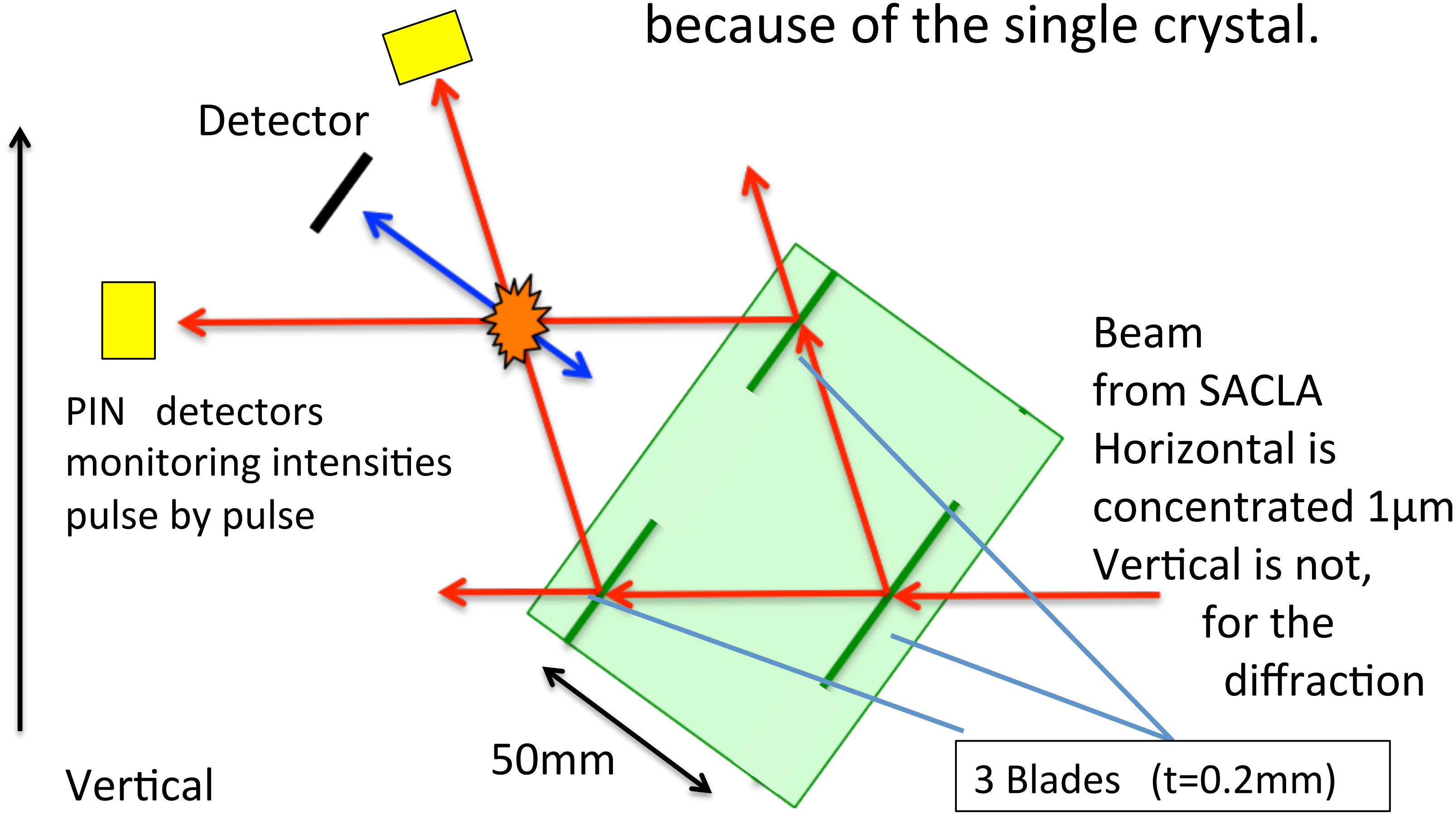
Fantastic but fragile





B’) How to collide X-rays

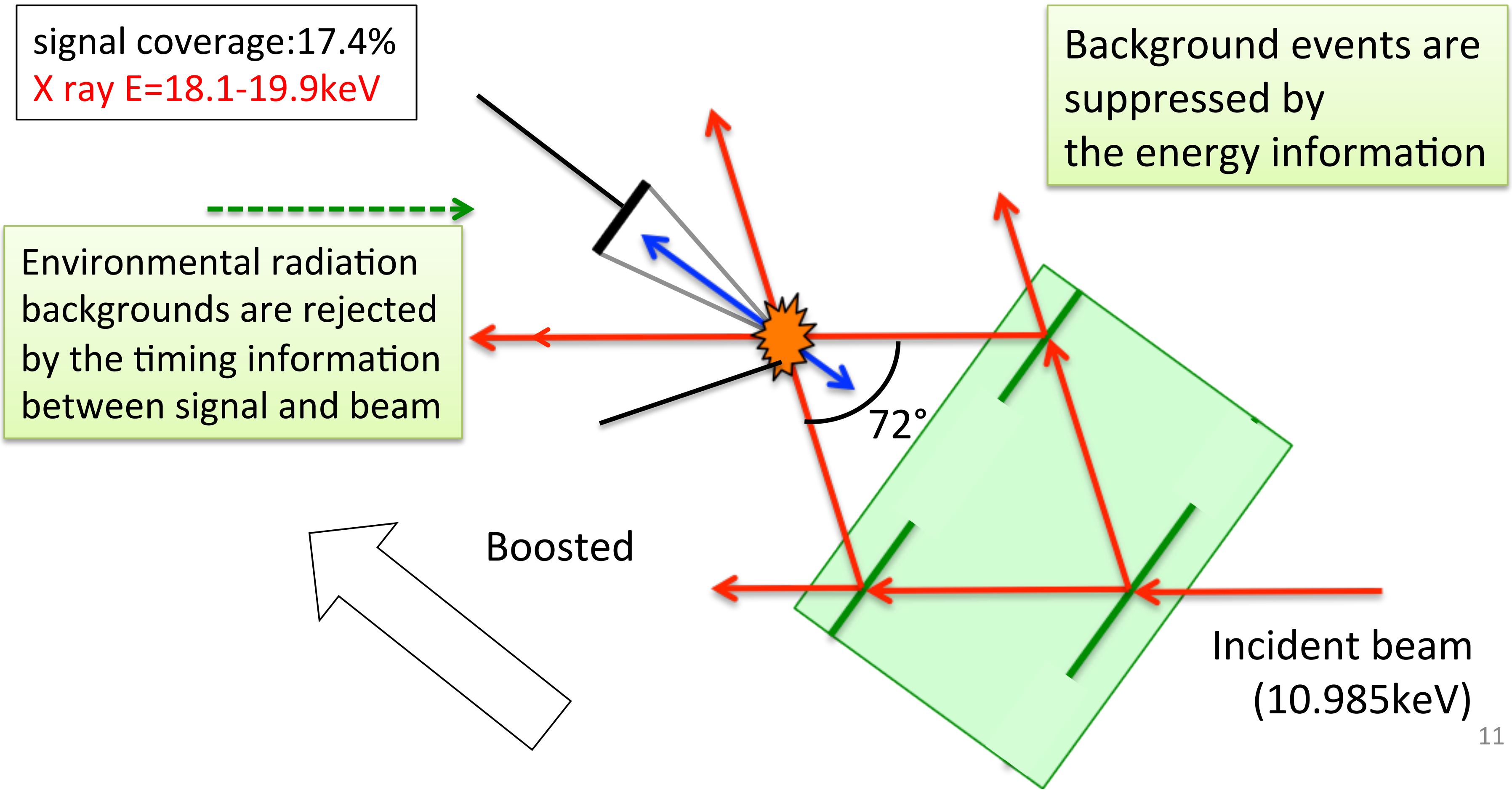
Beam splits into two using the blades, and collide here.
Optical path (both in space and time) is guaranteed,
because of the single crystal.



C) Background suppression (Energy information)

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

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



C') Background suppression (Position information)

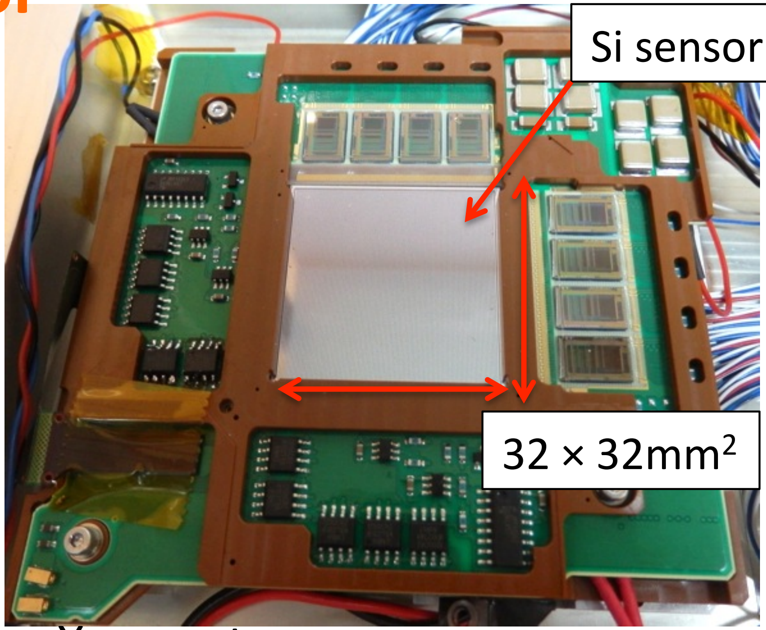
Since all photons are concentrated in a short pulse, 10fsec, Pile-up of two photons becomes the backgrounds, since the sum energy (22keV) of two pile-up photons are close to the signal (18-20KeV).

Position information is also used. To separate pile-up event

Double-Sided Silicon Strip Detector (DSSD) is used.

- sensor 32mm×32mm×t0.5mm
- 128 Strip * double sided (250μm Pitch)
- Very Low Noise for a single counting
- Good energy resolution (FWHM) :
  1.1keV@22keV
- Detection efficiency is 40% @ 20keV
- This is developed for the ASTRO-H satellite. X-ray astronomy.

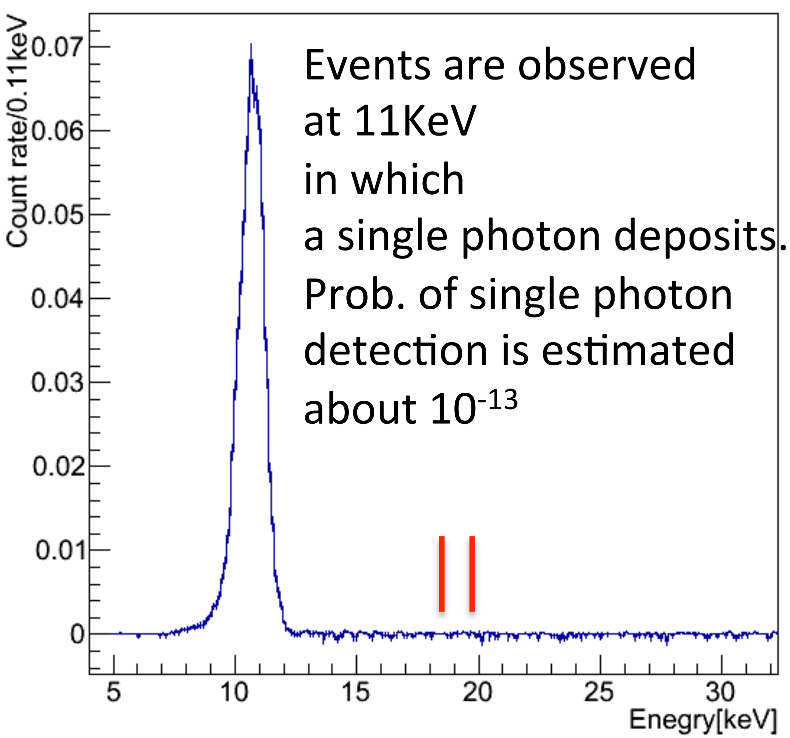
Photograph of DSSD

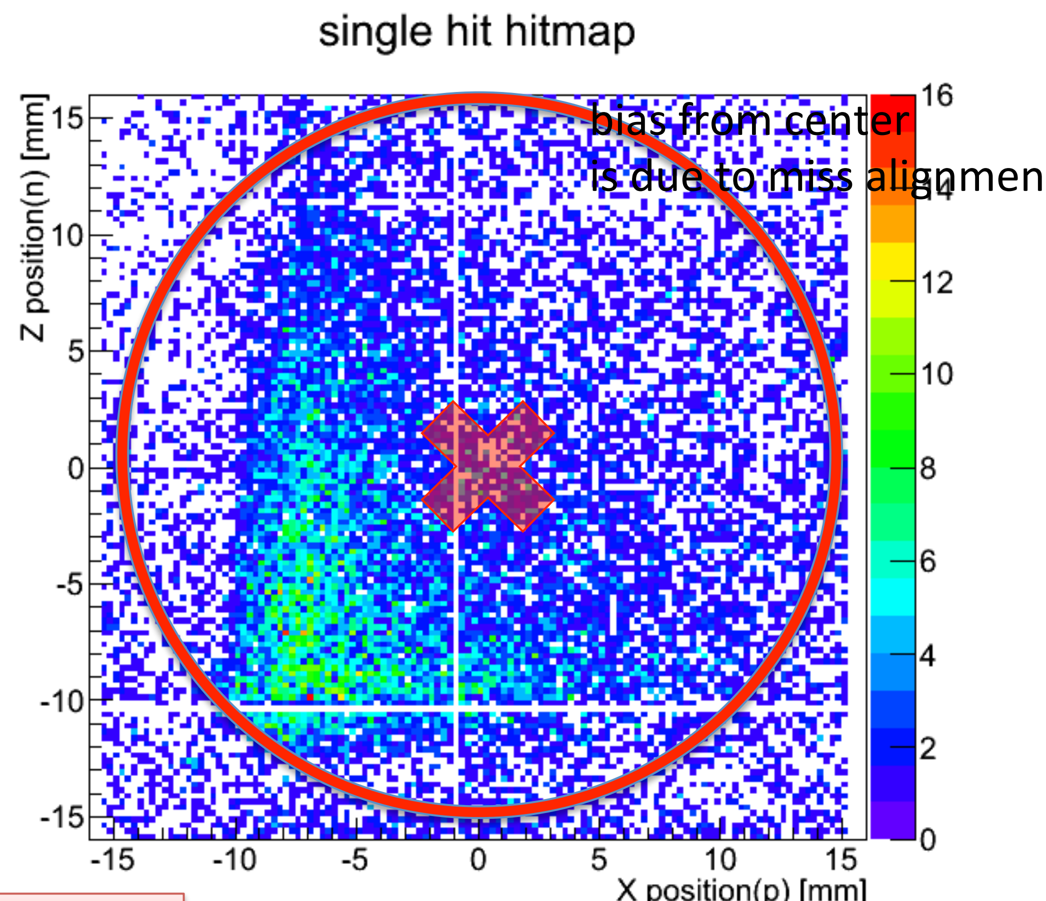


C’’) Estimation of Background rejection Power

SPring8 is the strong X-ray source ($3*10^{13}$ photons/sec, 10times higher but almost DC beam) .
This show the deposited positions measured at SPring8 with the same detector configuration.
Background single photon deposits widely and almost flat.

Obtained BG spectrum at SPring8



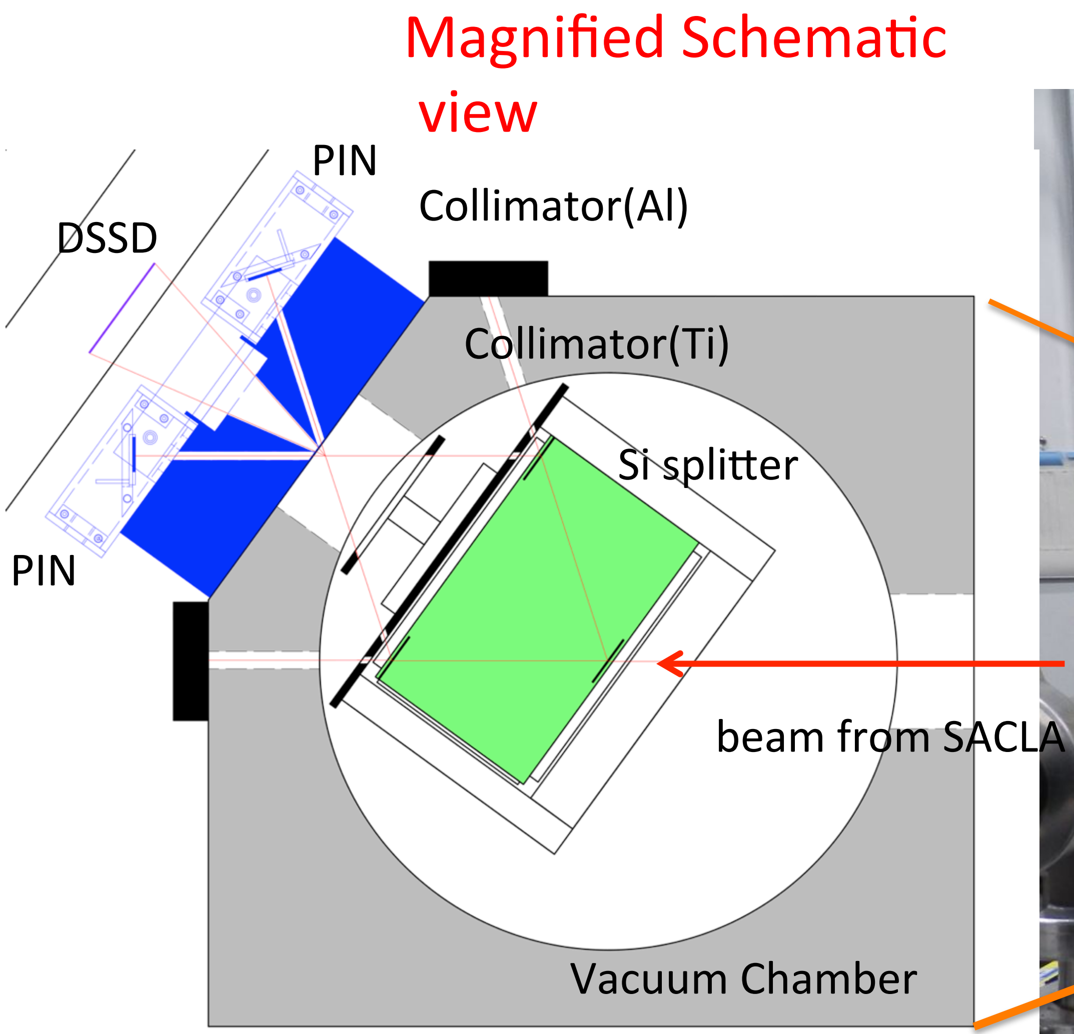


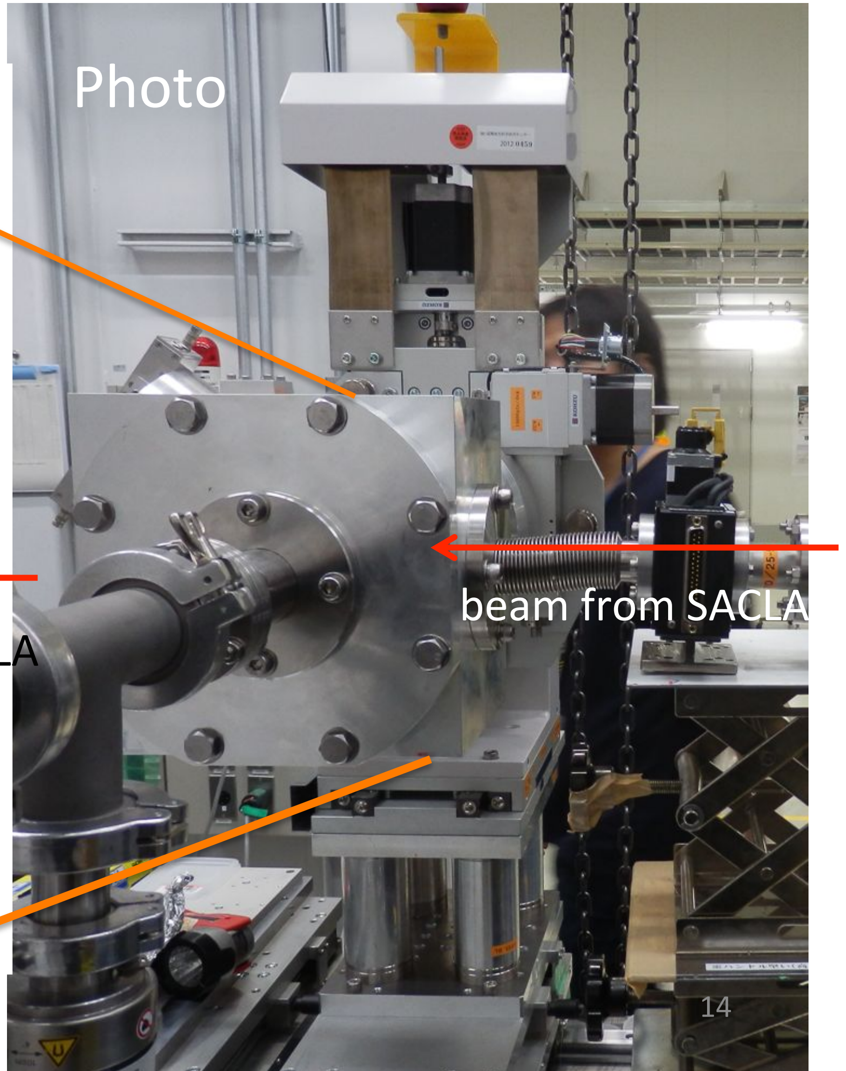
Pileup prob. 10^-26 * 10^-5 * 0.1 ~ 10^-32

Red circle shows expected signal region

Experimental Setup

Setup in SACLA EH4



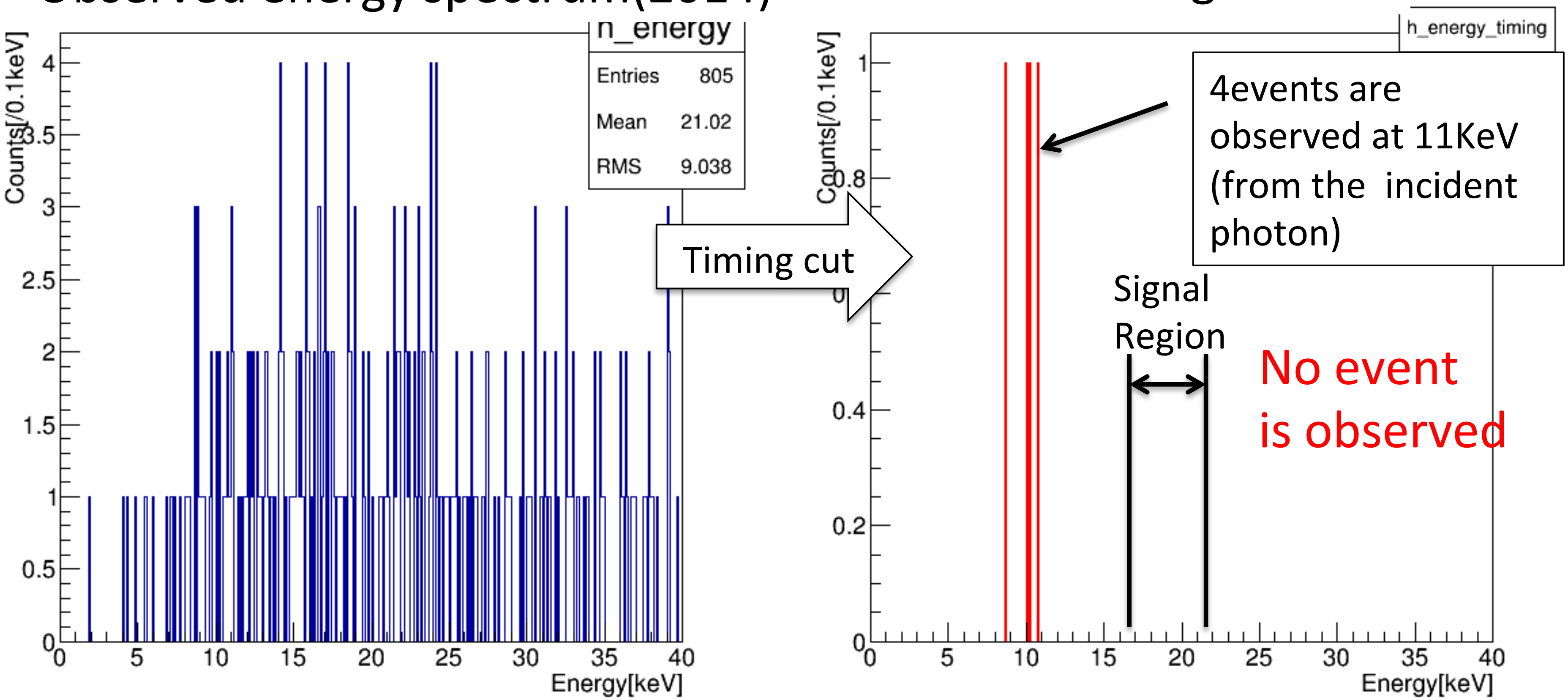


4. Results

July in 2013 (Run time 9 hours)+November in 2014 (29hours)

Observed energy spectrum(2014)

with timing cut



4 events are consistent
with the expectation estimated at SPring8

Luminosity

There are 3 parts in Luminosity

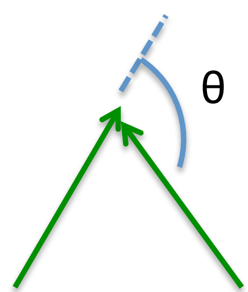
$$L = \frac{I_1 I_2}{4\pi \ell_v \ell_h \sqrt{(1+(\ell_t/\ell_v)^2 \tan^2 \frac{\vartheta}{2})}}$$

Photon intensities in each beam are monitored by PIN
I ~2.8×10^5 γ/pulse

Initial intensity
10^{11} γ / pulse
Why???

Beam size is measured by wire-scan
lv=195μm、lh=0.8μm
Flat shape!
horizontal is squeezed by the KB mirror.
Vertical can not be squeezed since we use the interferometer.

Beam length 10fs=3μm
θ=108 deg.
(Not head on collision)



We can ignore since lt is small

Beam is made monochromatic
(80eV->63meV)
~ 10^{-4}

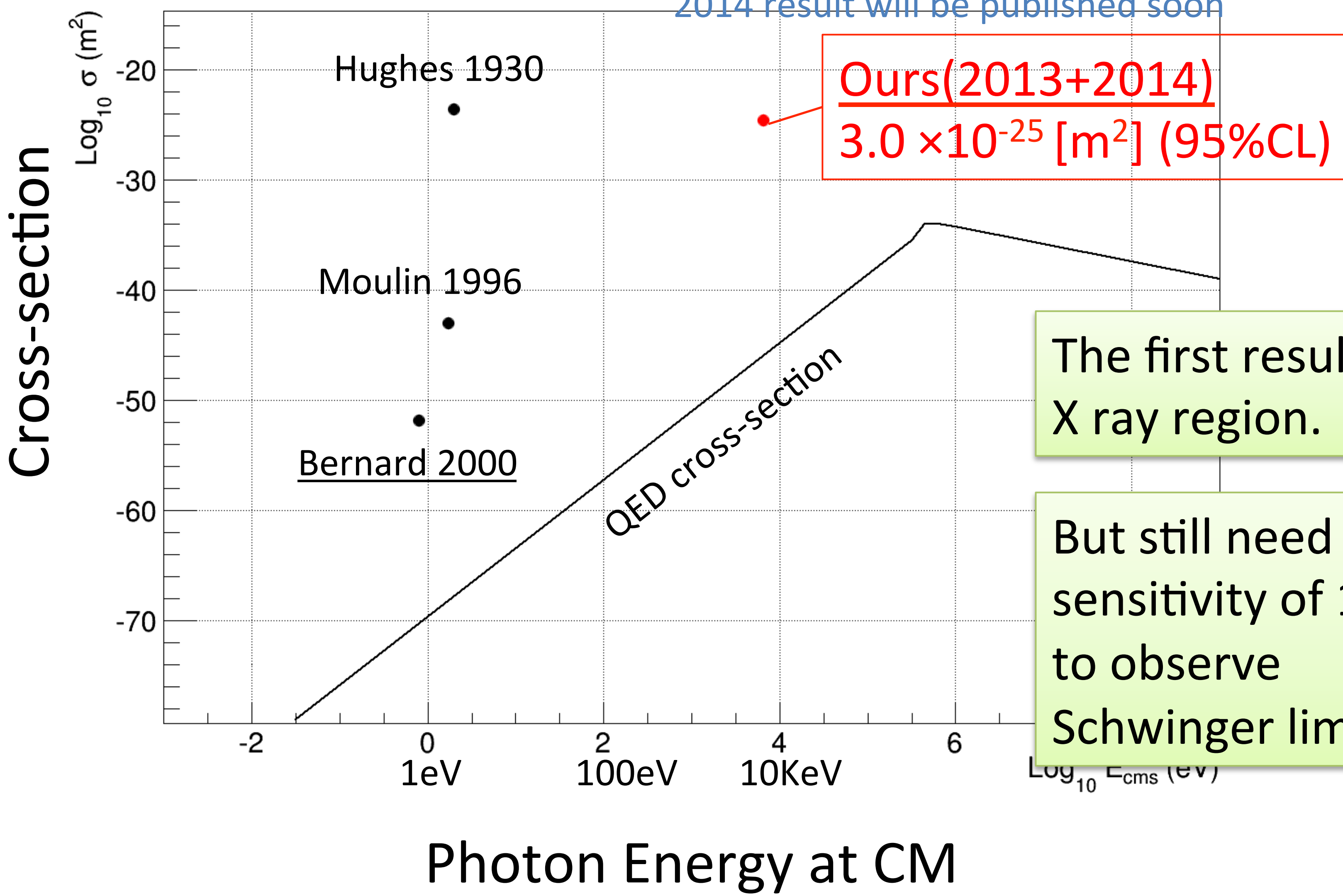
through
two Laue diffraction
0.1*0.1~ 0.02

Int. Luminosity $L=2.25^{+0.23}_{-0.24}\times10^{26}\ \mathrm{m}^{-2}$

No signal was observed

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

(2013 result is published in PLB732(2014)356)
2014 result will be published soon



The first result at X ray region.

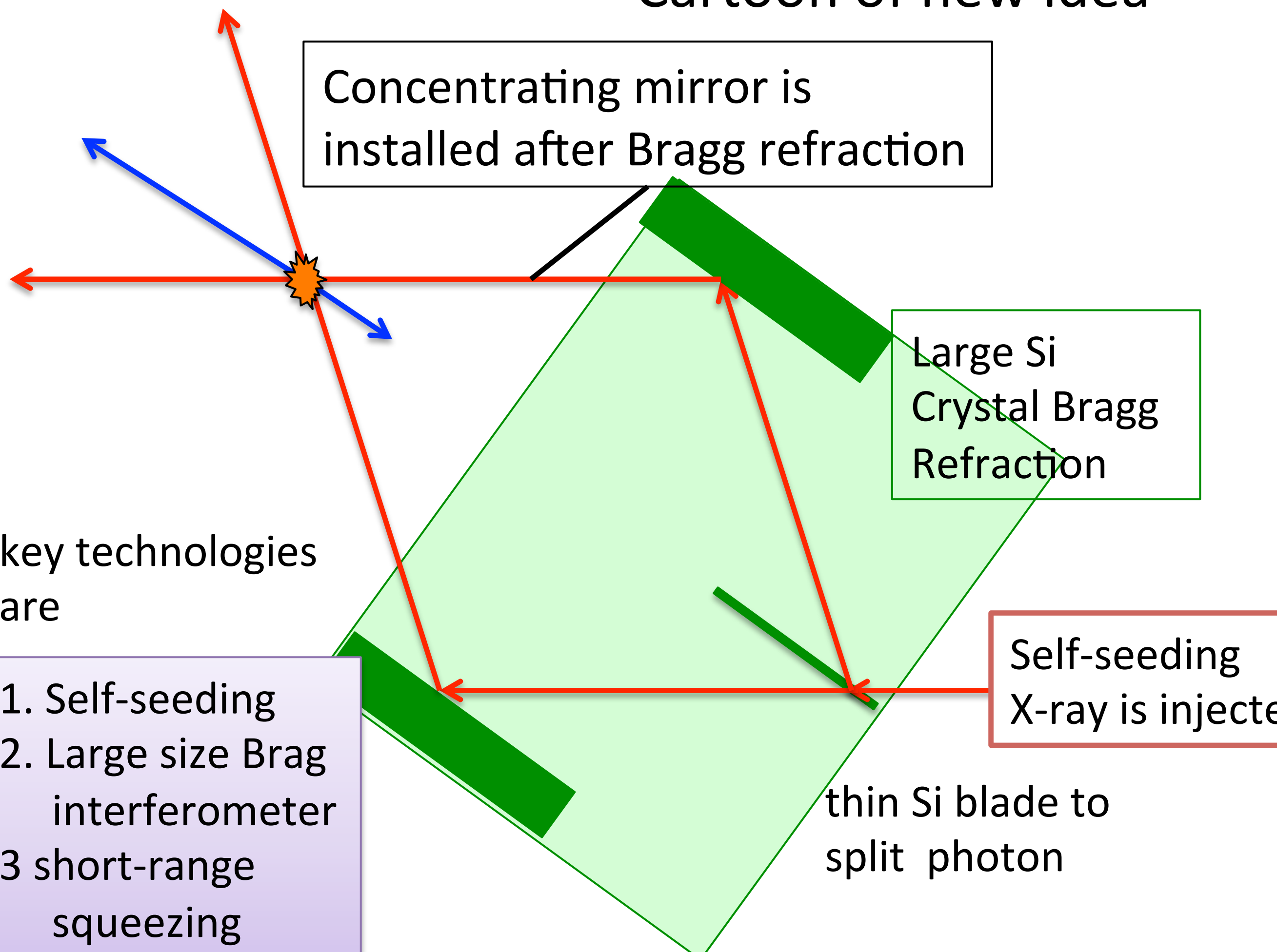
But still need sensitivity of 10^{20} to observe Schwinger limit

How to beat 10^{20}

4B. Prospect (Near Future)

Self-Seeding xFEL +Bragg Ref. + Squeezing

Cartoon of new idea



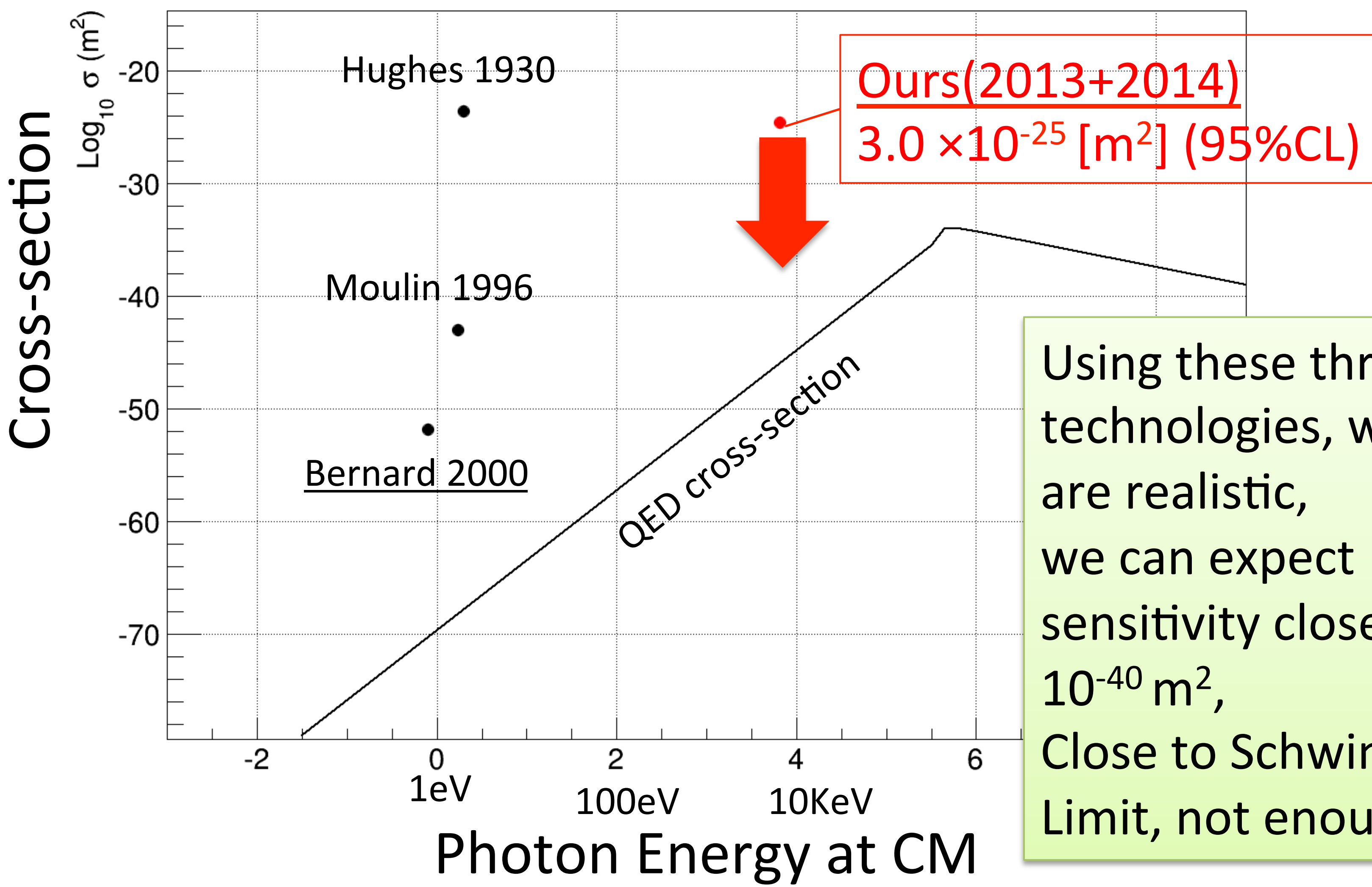
key technologies are

1. Self-seeding
2. Large size Brag interferometer
3 short-range squeezing

- ✧ Self-Seeding of xFEL will gains 10^4 on L
- ✧ Bragg Type interferometer instead of Laue gains 10^4
- ✧ Squeezing into 50-100nm gains 10^4

TOTAL ~10^{12}

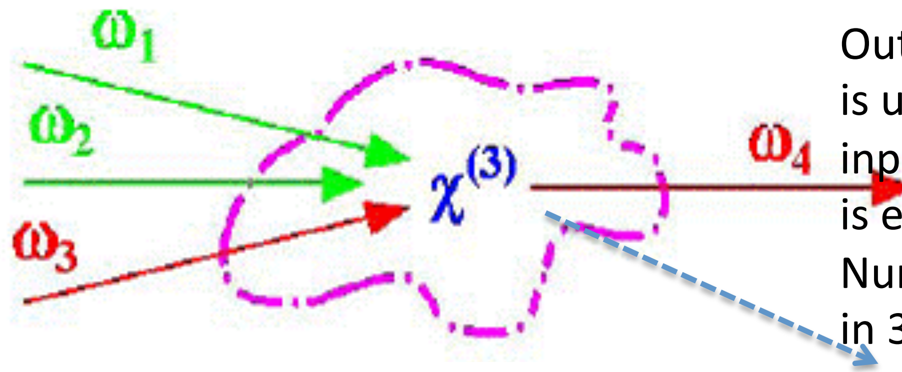
Self Seeding xFEL +Bragg Ref. + Squeezing



Using these three technologies, which are realistic,
we can expect sensitivity close to $10^{-40}\ m^2$,
Close to Schwinger Limit, not enough

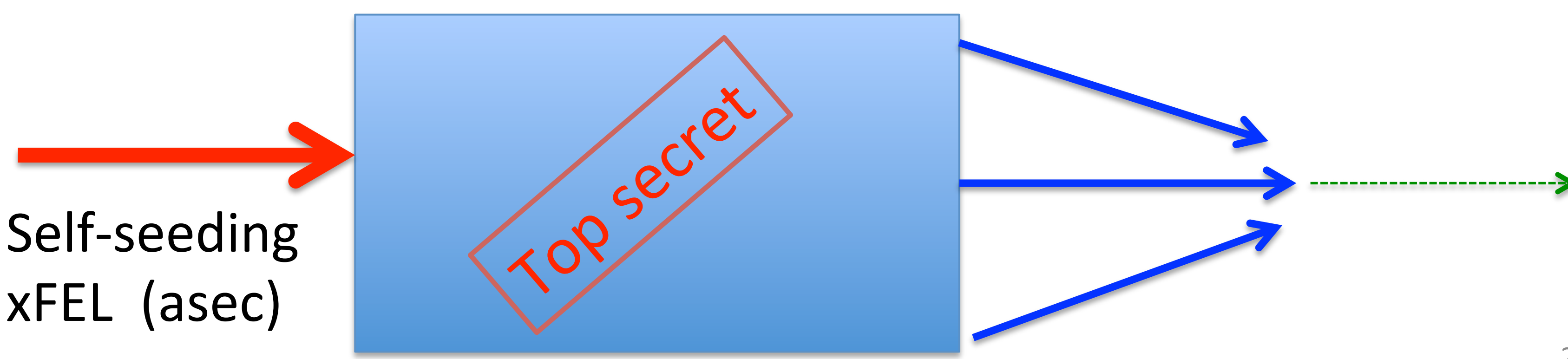
4C. Prospect (Long scale)

Four-wave mixing has already been observed in materials and laser. In Bernard 2000, Four-wave mixing was used to enhance sensitivity, but using infrared lights.



Out-going Photon is used as input, the process is enhanced by Number of photon in 3rd injection.

Using the splitters and super-mirrors, X-ray splits into 3 and change their path.



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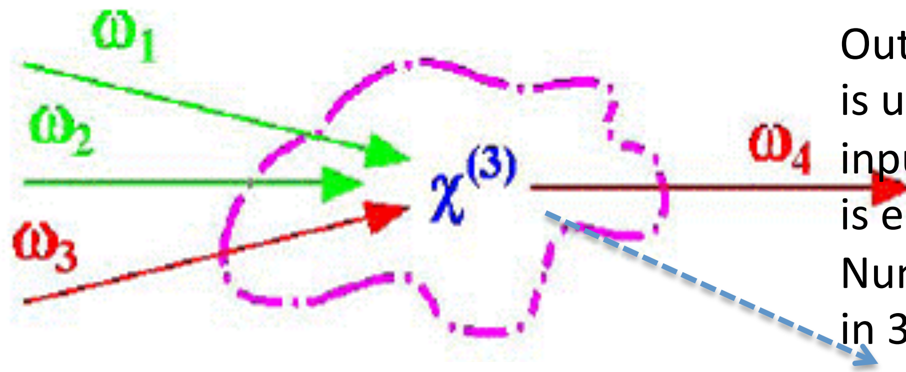


Out-going Photon is used as input, the process is enhanced by Number of photon in 3rd injection.

Using the splitters and super-mirrors, X-ray splits into 3 and change their path

Self seeding xFEL (asec)

?

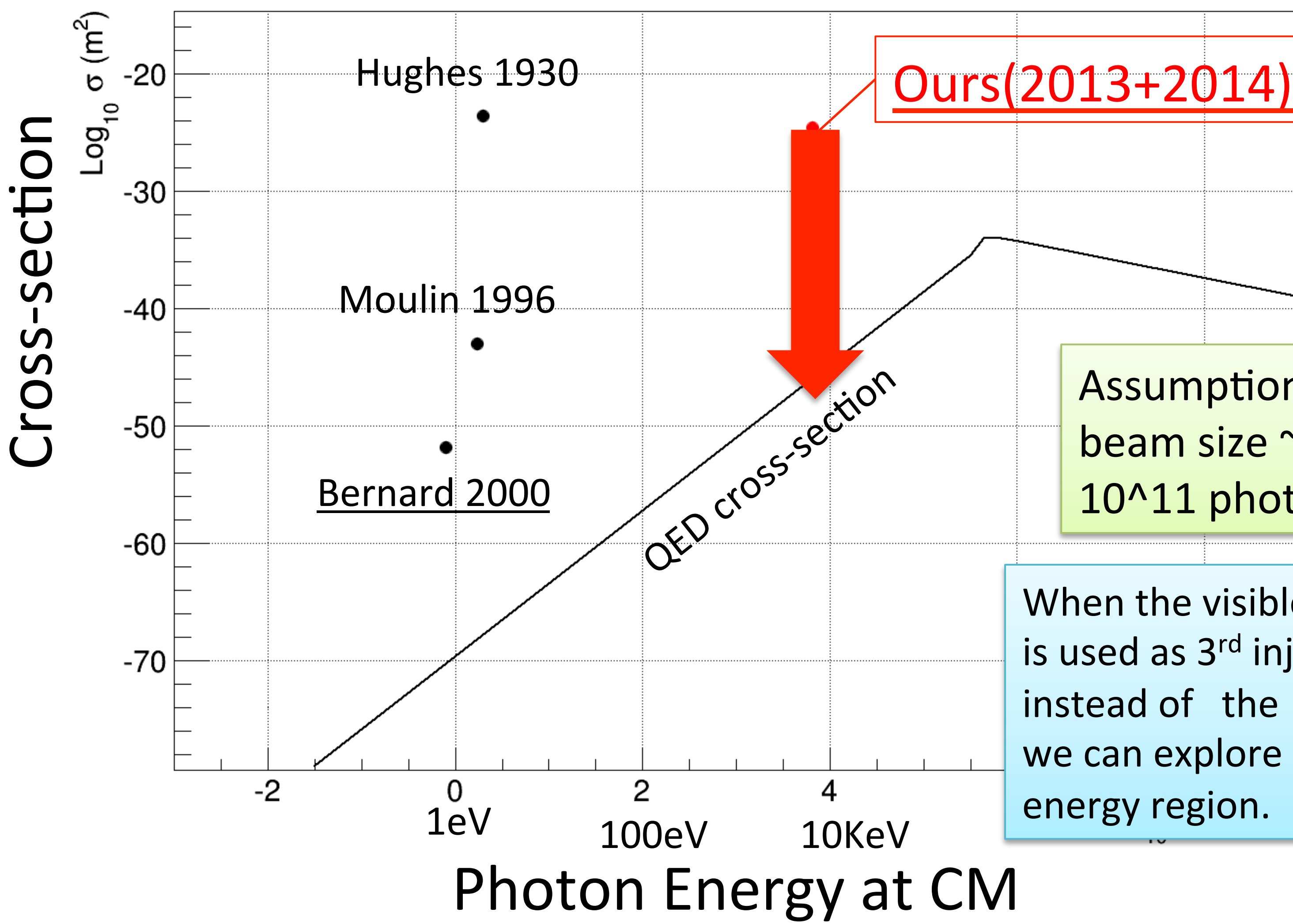
Design is still investigating Still No good idea

1. Splitter for broad spectrum
2. Super-mirror with large refraction angle
3. How to examine path with an accuracy of < 50nm

key technologies for the next generation.

Four-wave mixing

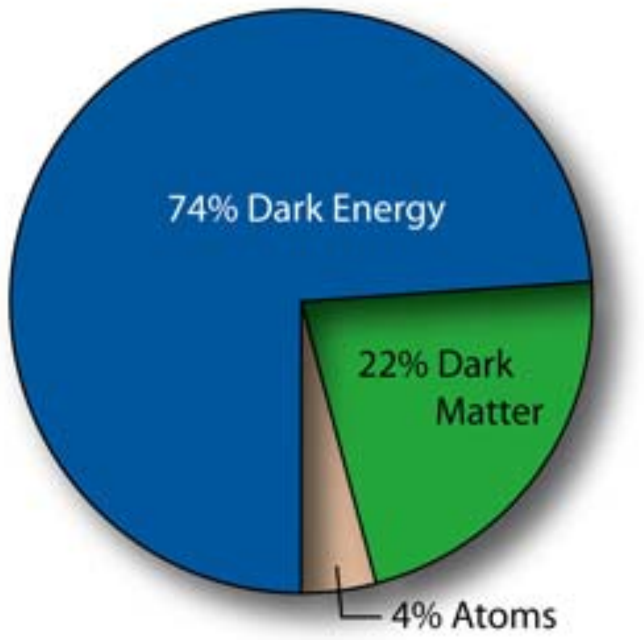
We can discover “Schwinger limit”: if these technologies are ready



Assumptions
beam size ~ 50nm
10^11 photon in each

When the visible laser (200TW) is used as 3rd injection instead of the X-ray, we can explore the different energy region.

5. Searches for the other fields



Budget of the Universe

74% Vacuum energy
22% Dark Matter

electron virtual filed

ield

eld

There are many possibilities

X-ray

How to survey these files?
1） vacuum Birefringence
2） Particle is excited directly

10^4 K 10^0 eV

10^{-6} K 10^{-10} eV

10^3 m

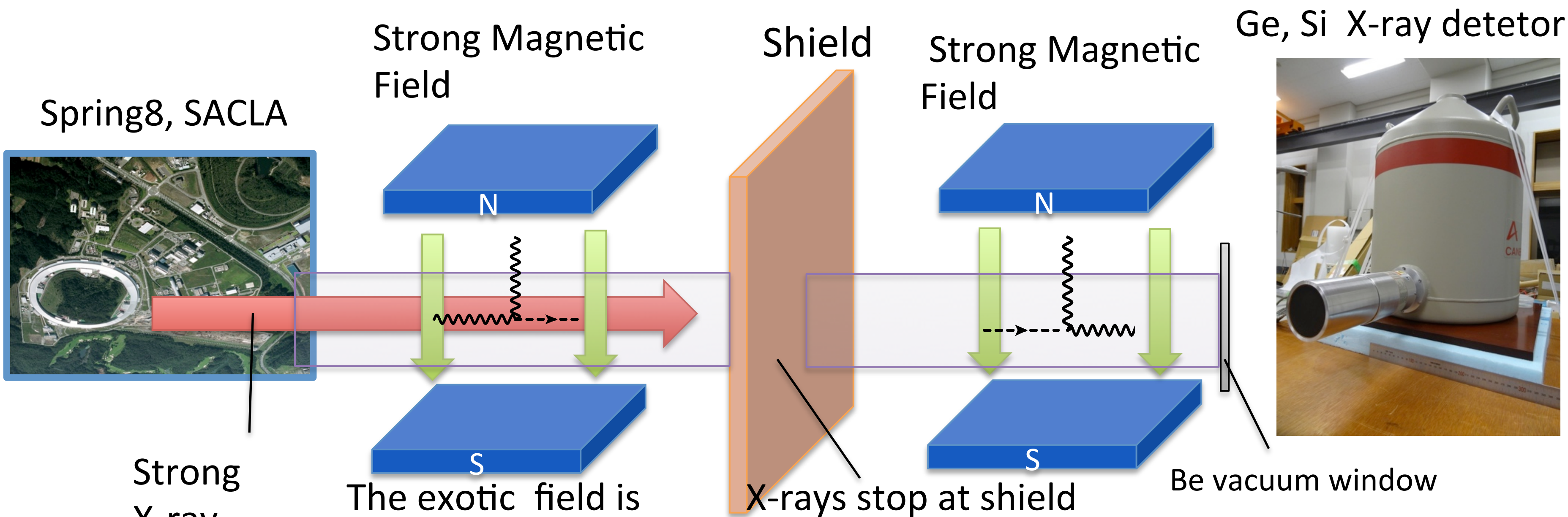
New Gauge Boson (ParaPhoton) ?

Dark Eenergy ?

Axion, Dilaton ?

Exotic filed???
inspired by the String-thory

These new particles are detected as follows



The exotic field is excited, new particle is produced

X-rays stop at shield but exotic particle pass through, since it is dark.

Since it is dark, we have to reconvert into photon

Para-photon mix with X ray

$$P_{\gamma\to\gamma'} = 4\chi^2 \sin^2\left(\frac{m_{\gamma'}^2}{4E_\gamma} L\right)$$

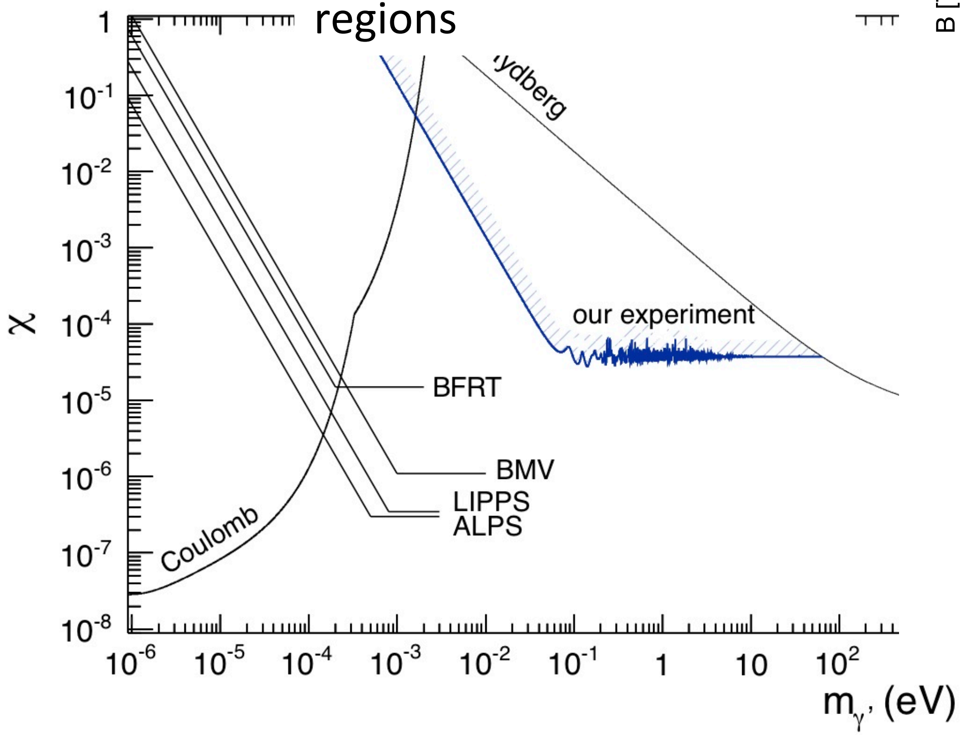
$\boxed{\chi\text{: mixing parameter}}$

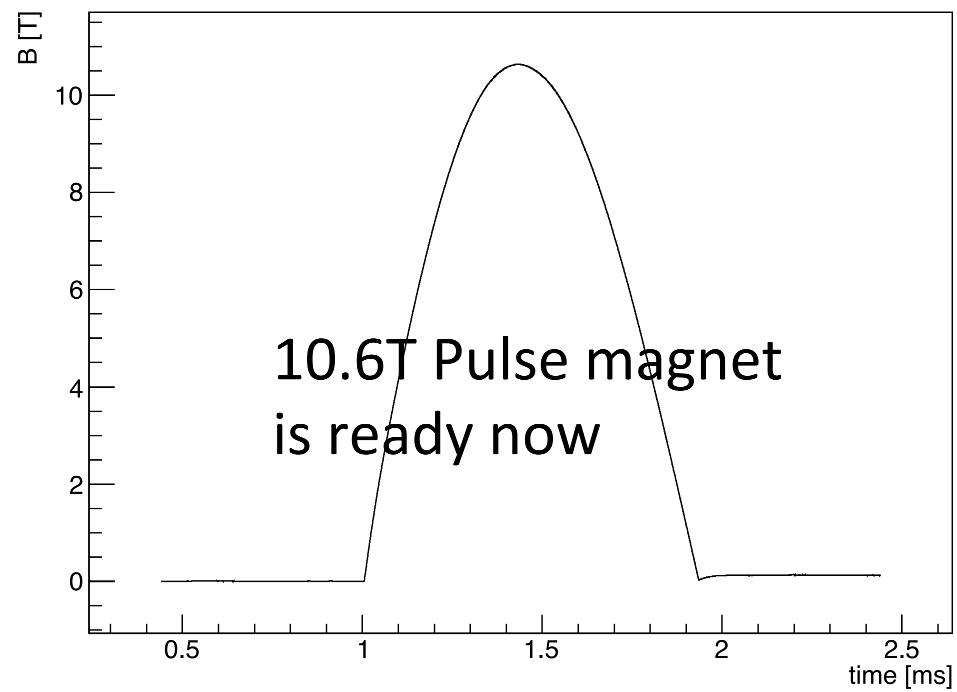
Axion/Dilaton conversion

$$P_{\gamma\to a} = \left(\frac{g_{a\gamma\gamma} B\cdot L}{2}\right)^2 \cong \frac{1}{4}\left(\frac{g_{a\gamma\gamma}}{1\mathrm{GeV}^{-1}}\right)^2 \cdot \left(\frac{B}{1\,[\mathrm{T}]}\right)^2 \cdot \left(\frac{L}{1[\mathrm{m}]}\right)^2$$

These new particles are detected as follows

X-ray covers the different regions





10.6T Pulse magnet is ready now

into photon

Para-photon mix with X ray

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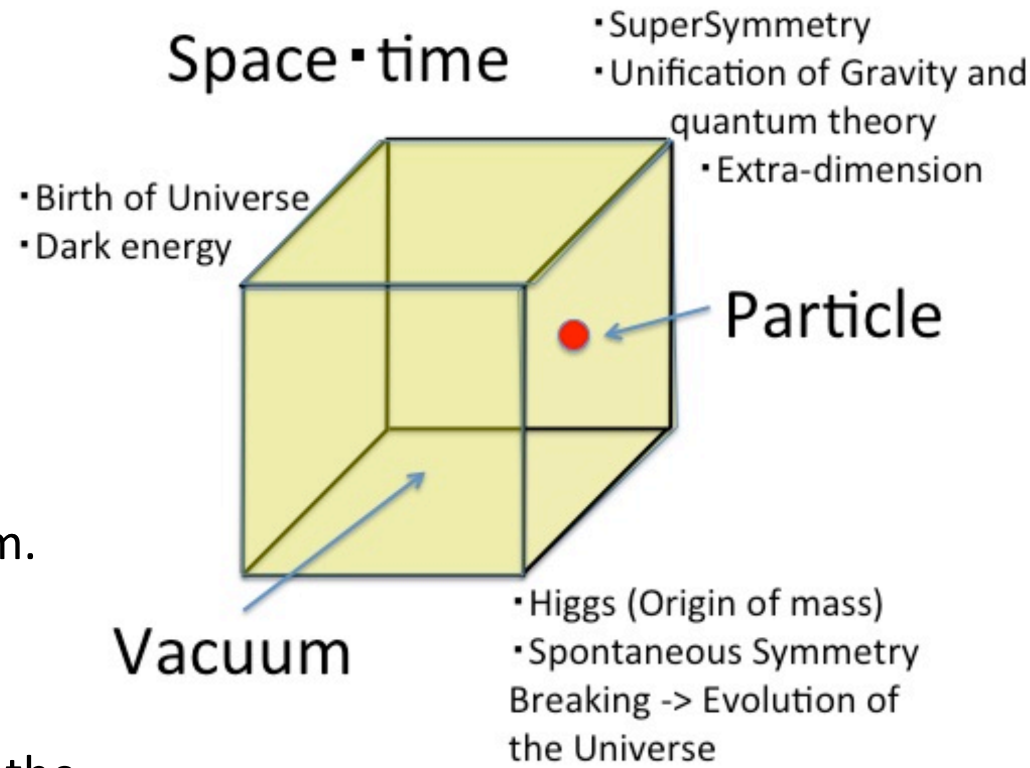
Summary

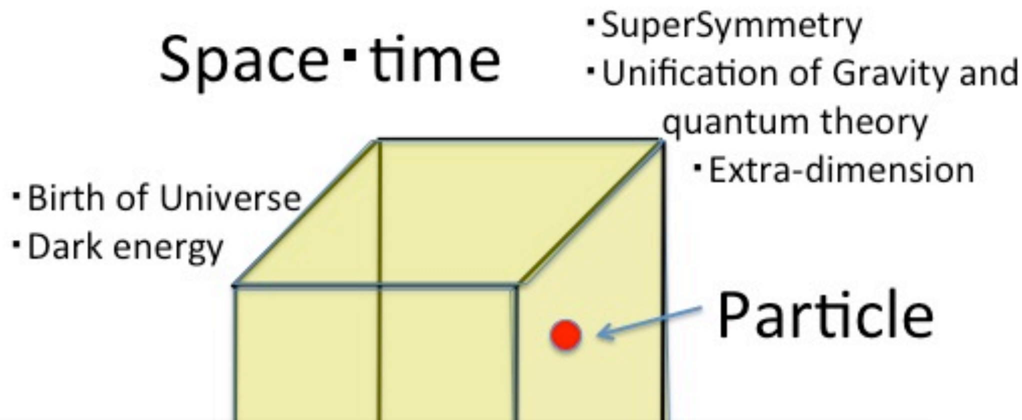


- After Higgs Boson discovery, "Vacuum" becomes one of the frontier field.
- Many fields are hidden in vacuum. Photon is key technology to probe the vacuum.
- Using XFEL SACLA, we search for the non linear effect of the vacuum (Schwinger Limit) Sensitivity still not enough, Set upper-limit on $\sigma(\gamma\gamma) < 3 * 10^{-25}\ m^2$

- Near futures, sensitivity will be improved by 10^{10}-10^{12}, Searches for the other unknown fields (inspired by Dark matter, dark energy) are also in progress. 4WM gains, and we can reach Schwinger limit.

Summary

- After Higgs Boson discovery, "Vacuum" becomes one



xFEL is useful , not only for applied science but also for the fundamental Physics.

The other programs become possible after
* 10 asec, 1nm pulse ready.
* Self-seeding is also important.
* Optical equipment (Fabry Perot resonator, mirror,,)

energy) are also in progress.   4WM gains, and we can reach Schwinger limit.