Search for X-ray photon-photon elastic scattering with a Laue-case beam collider

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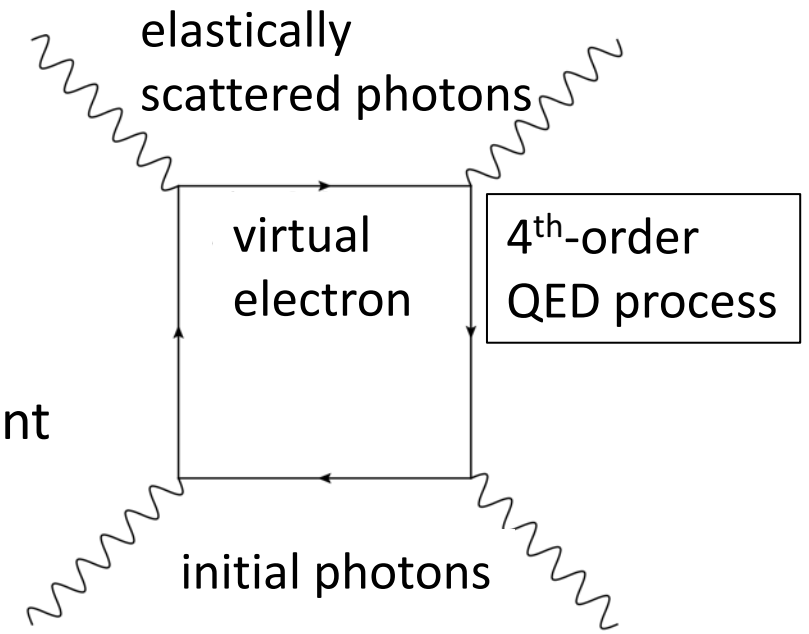
Photon-photon scattering

◆Photon-photon scattering

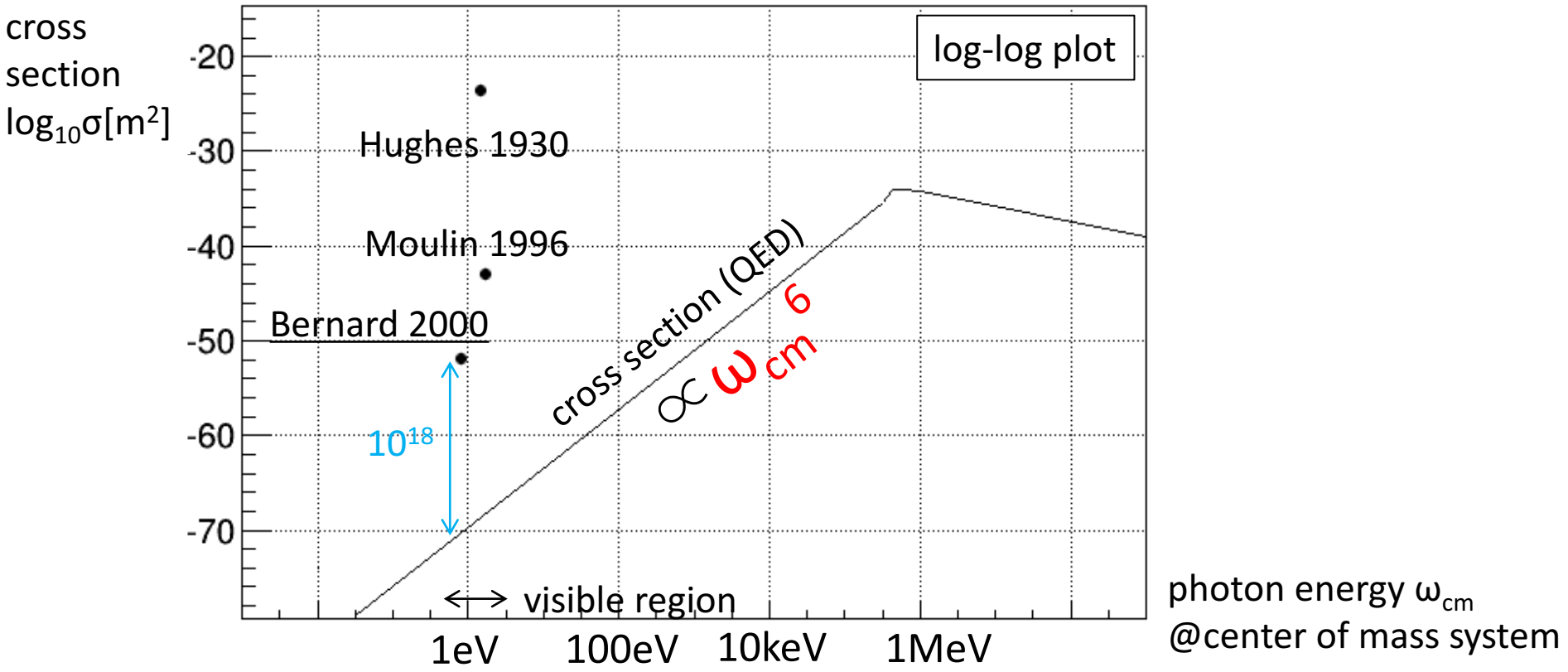
- Quantum ElectroDynamics(QED) predicts
  elastic scattering of photons in vacuum (1936)
  =nonlinear effect of vacuum

- The contribution of virtual photon scattering is inclusively observed: Delbruck scattering, e/μ anomalous magnetic moment
- The scattering of real photons has not ever been observed
  →important verification of QED



- If unknown particles which mediate the scattering exist, scattering cross section can be enhanced by the prediction of QED
  →new physics
  ex)Axion Like Particles(ALP)

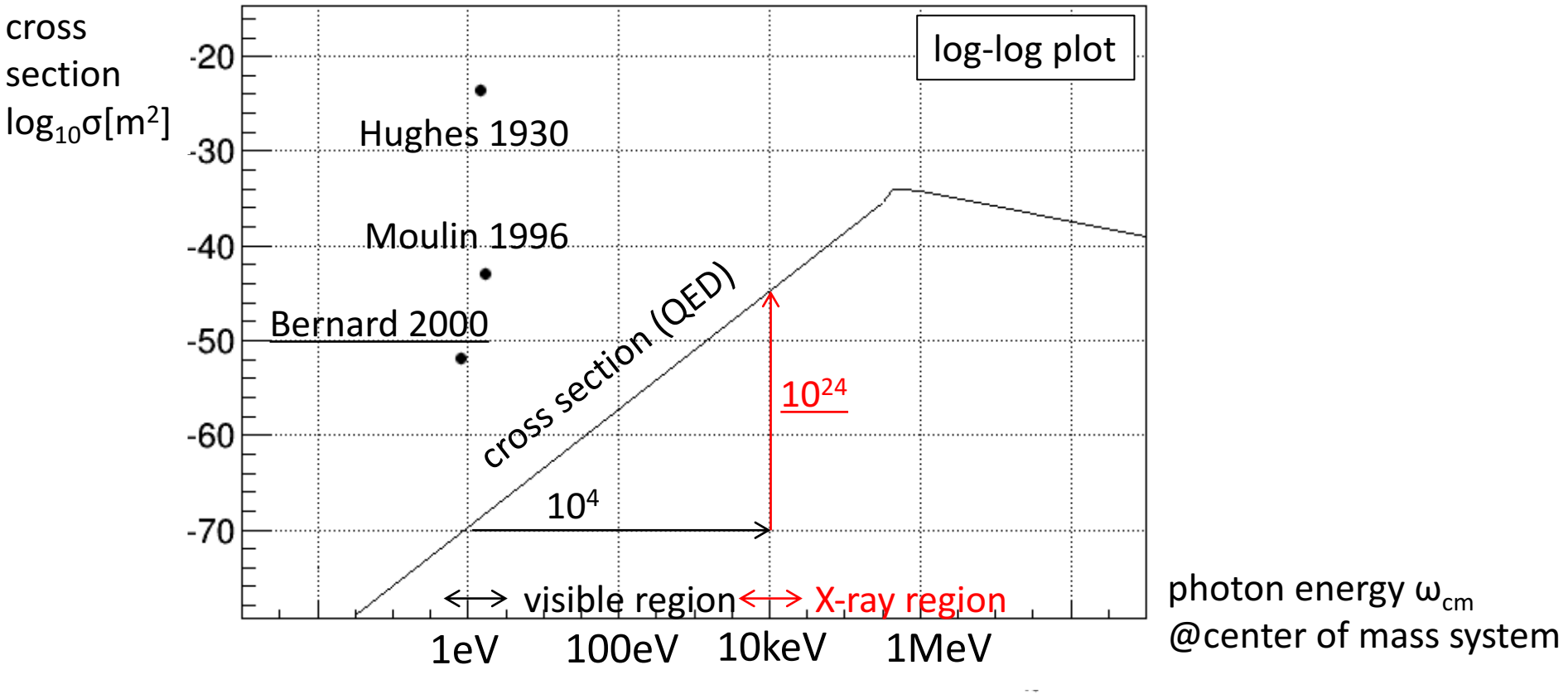
Summary of previous experiments



- cross section (QED) is proportional to 6th power of photon energy

- All previous experiments use visible or infrared sources
- The best upper limit is 18 orders of magnitude worse than the prediction of QED

New experiment using X-ray source



- X rays have 4 orders of magnitude higher energy than visible photons
  →Cross section is enhanced by 24 orders of magnitude
- X-ray detectors with high energy precision improve S/N ratio
- X rays have smaller diffraction limit → beams can be focused more strongly
- X-ray region (~10keV) is new to particle physics experiments→interesting!

X-ray source : SACLA

・the strongest X-ray Free Electron Laser(XFEL) in the world

◆Specs

・pulsed source with the photon flux of ~6×10^{11}photon/pulse and the duration of < 10fs

・beam width: 200μm(FWHM), and 1μm coherent focusing is available
→suitable for scattering experiments with high luminosity

・repetition: 30 Hz @ 2015 November

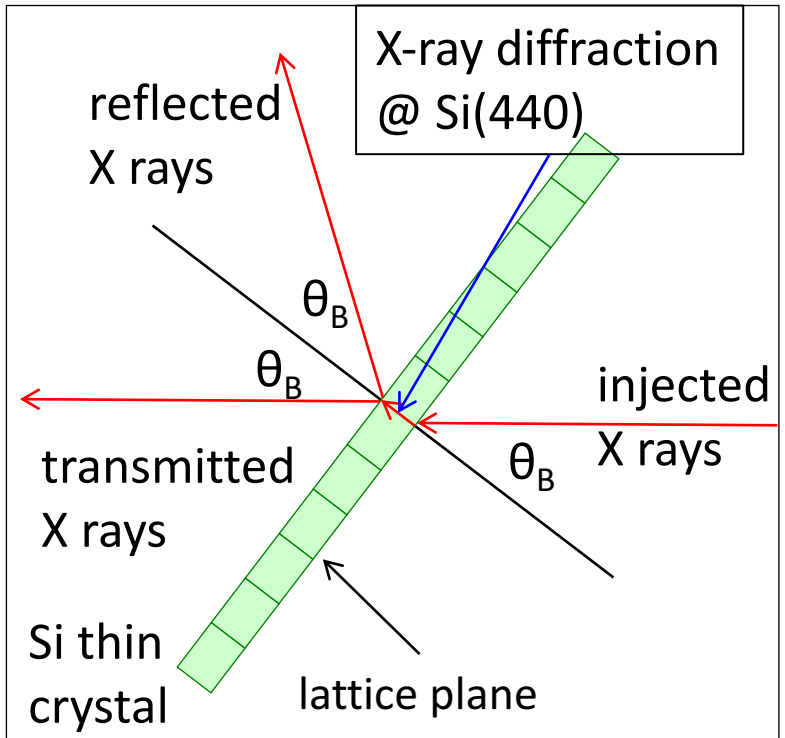
・X-ray energy: 10.985keV with the bandwidth of 80 eV

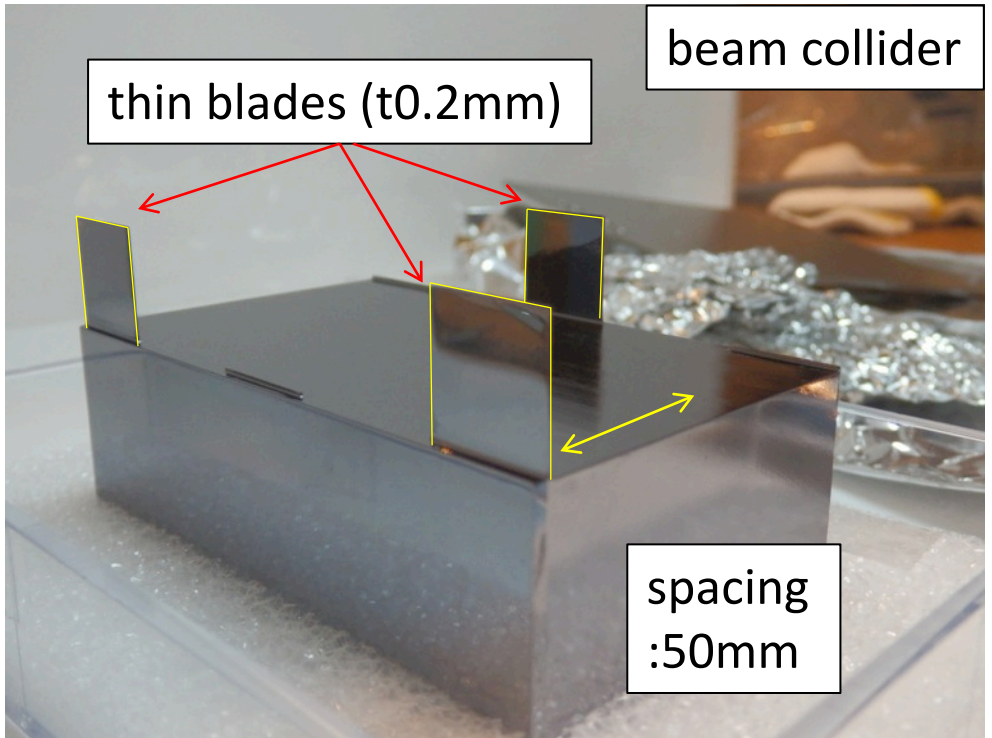
X-ray collision system (1/2)

- X-ray diffraction is used to split X-ray beams and to make them collide
  This technique is developed in X-ray interferometry region

◆X-ray beam collider

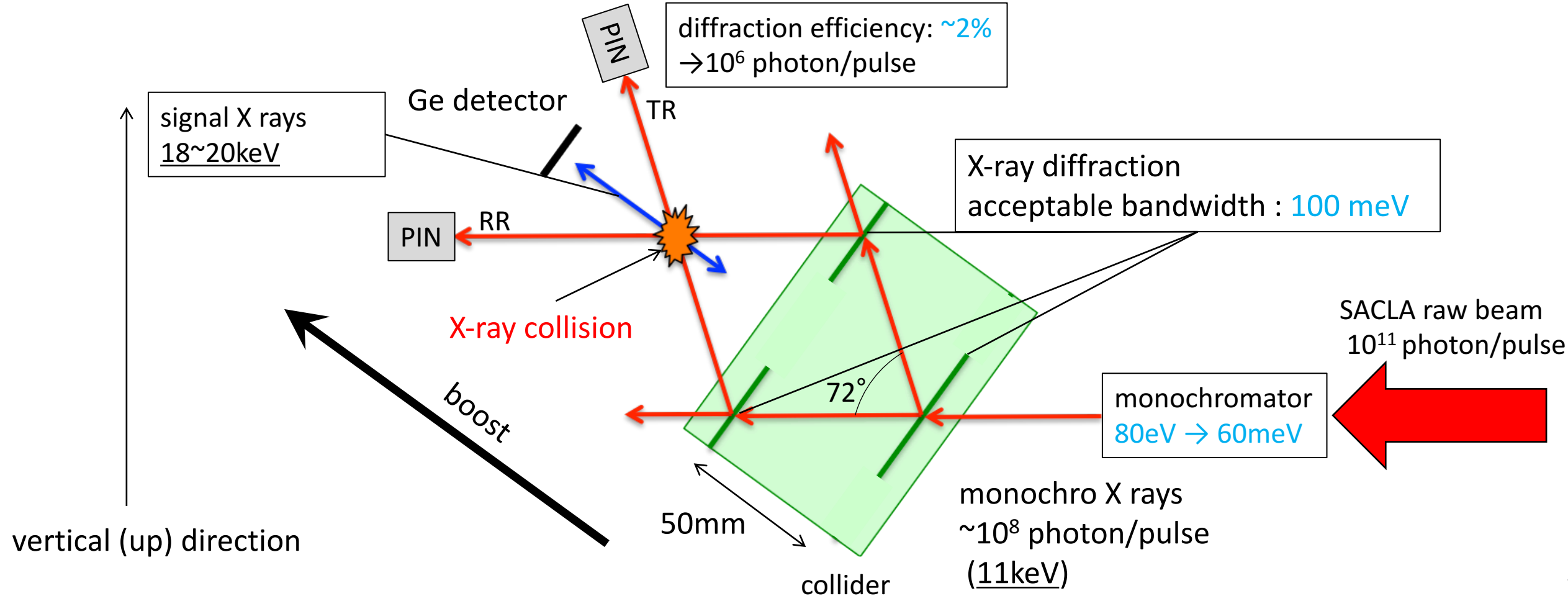
- Laue-case X-ray diffraction at silicon crystal is used
- The collider consists of three blades (t 0.2mm) manufactured on a single mono-crystal





X-ray collision system (2/2)

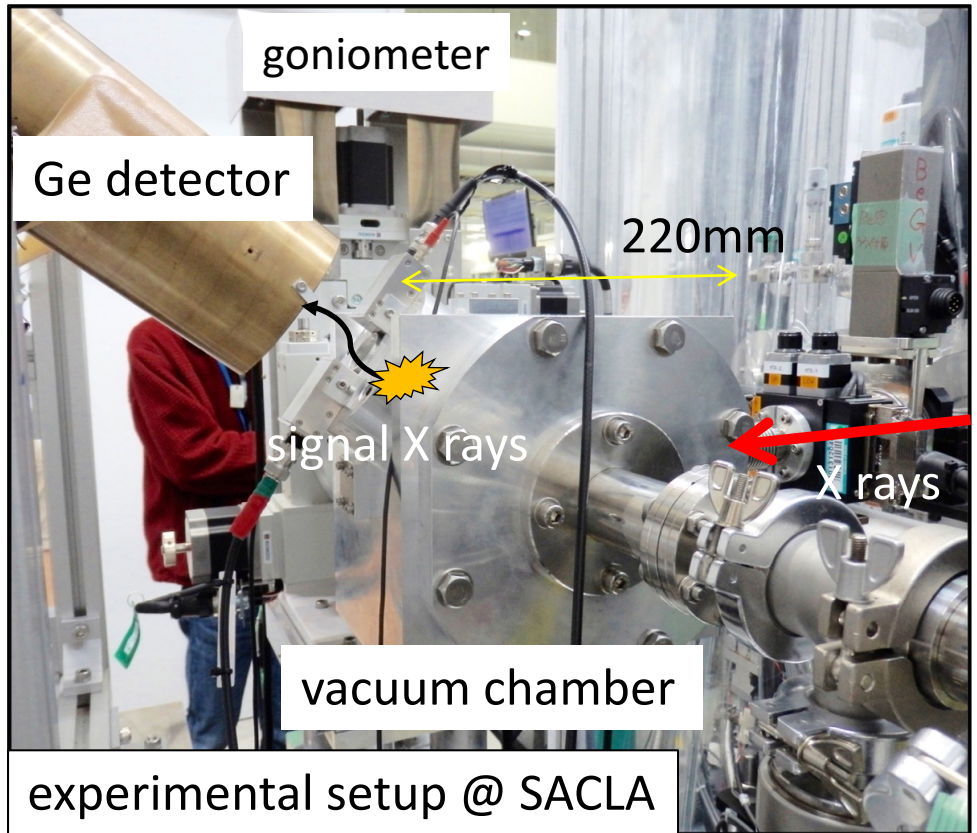
- X-ray collision is spatially and temporally guaranteed by a geometrical symmetry
- The pulse-by-pulse intensity of colliding beams are measured by PIN photodiodes



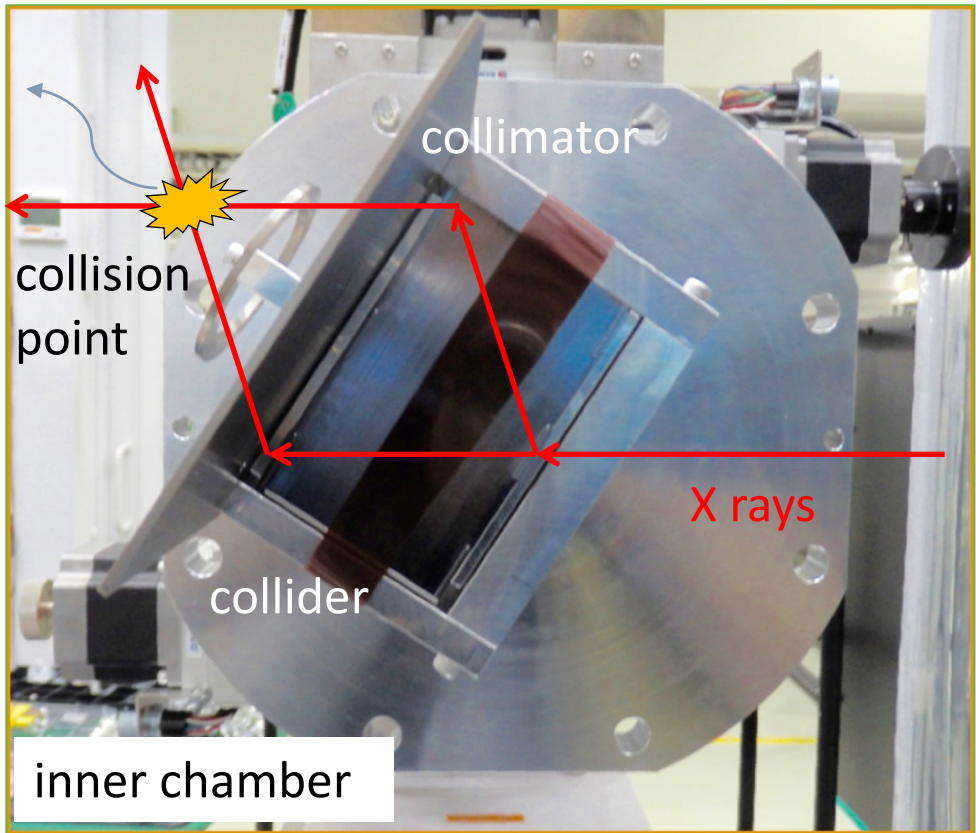
Suppression of stray X rays: vacuum chamber

- Signals are very weak even if they exist → <u>suppression of stray X rays</u> is essential!
- To suppress stray X rays from atmospheric molecules, collider is installed into a vacuum chamber
- Collimators are installed along the X-ray path to cut the path of stray X rays scattered by the collider

→The detection rate of stray X rays is reduced to 10^{-13} of injected X rays, and measurement without pseudo signals is achieved!



experimental setup @ SACLA

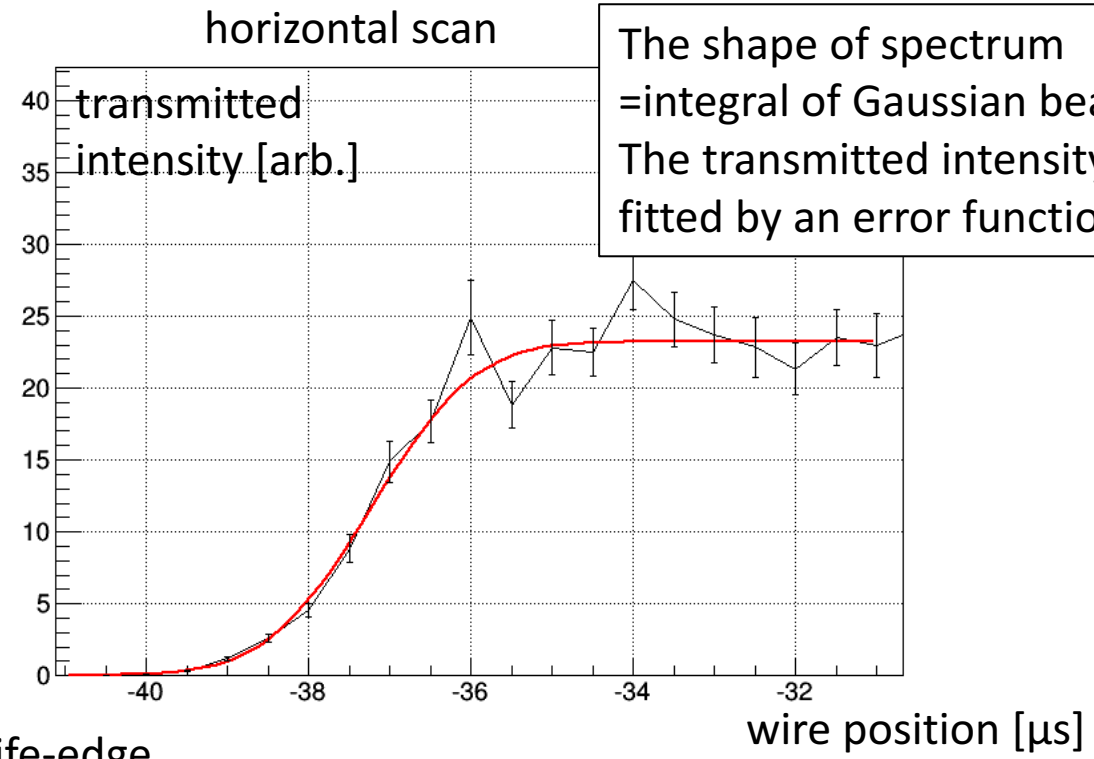


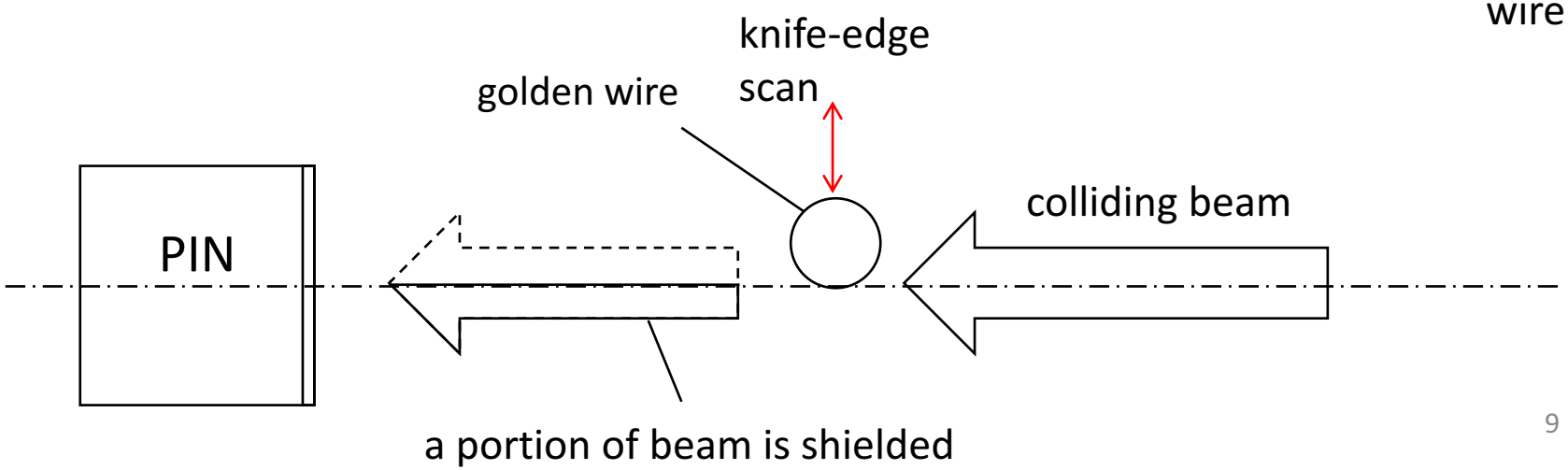
inner chamber

Measurement of beam widths

- Beam widths is measured by edge scan
  1)vertical (not focused) : a stainless rod
  2)horizontal (1μm focused) : ϕ200 μm golden wire

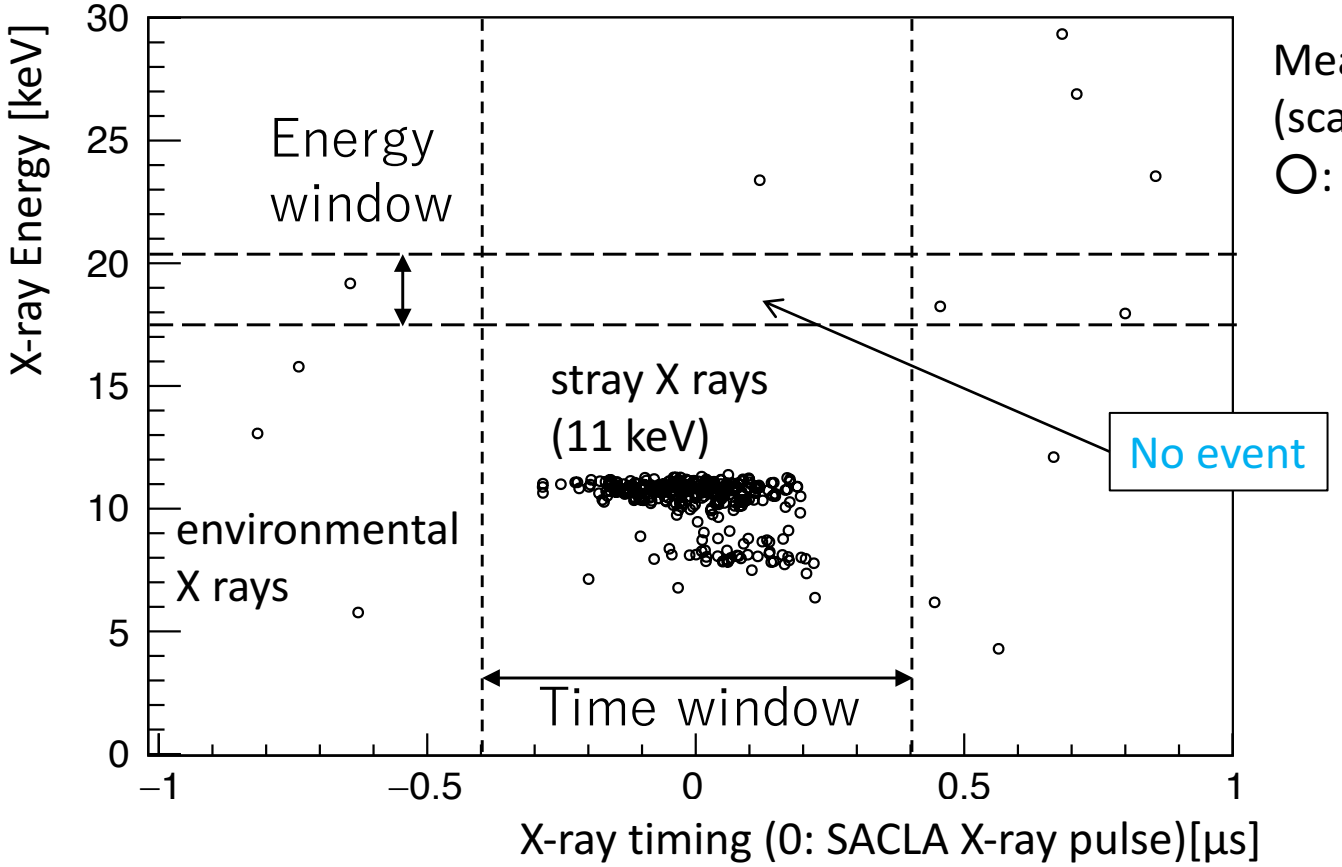
- horizontal width (σ): 0.962±0.037μm (RR)
  0.992±0.044μm (TR)
  vertical widths : 144±12μm (RR)
  124±7μm (TR)





Measured X-ray spectrum

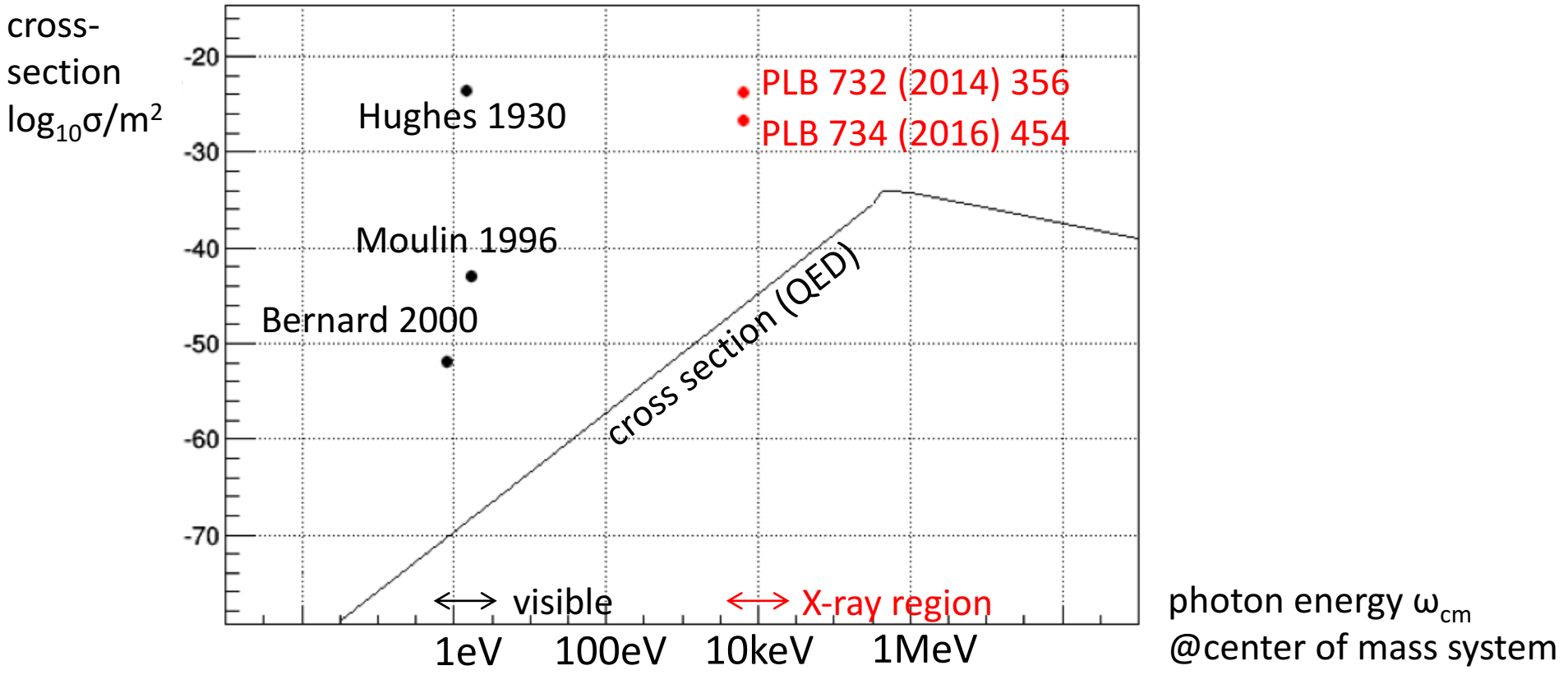
- newest measurement (*Phys. Lett. B 763 (2016) 454*)
- measurement period: 30 Hz × ~38 hour DAQ = 4.1 × 10^6 X-ray pulses
- timing window: detector timing resolution ±5σ=±0.4 μs
- No significant signal is observed



Measured X-ray spectrum
(scatter plot)
○: 1 event

◆Potential source of pseudo signals
1)pileups of two stray X rays (<22keV)
2)accidental coincident of environmental X rays (18~20keV)
- pseudo signals are expected to <u>< 1 event</u>

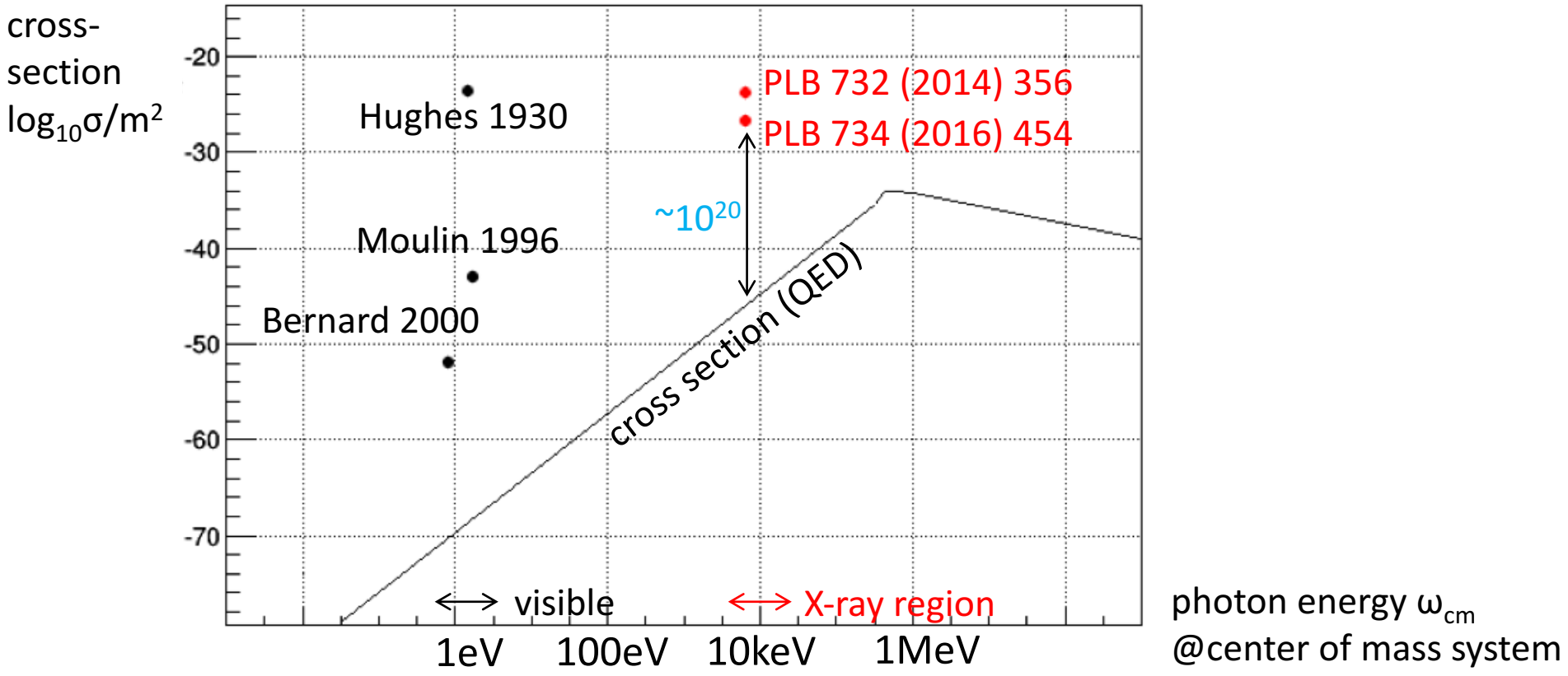
Results



- upper limit (PLB 2016) on the cross section : 1.9×10^{-27} [m^2] @ 6.5keV (95% C.L.)

- This is the unique/most stringent upper limit in X-ray region

Results



- The upper limit is 20 orders of magnitude worse than QED prediction
- In order to enhance the sensitivity and approach to the QED prediction, it is essential to change the experimental setup drastically
- Diffraction efficiency is very small (~10^{-5} of raw beam → 10^{-10} sensitivity reduction)

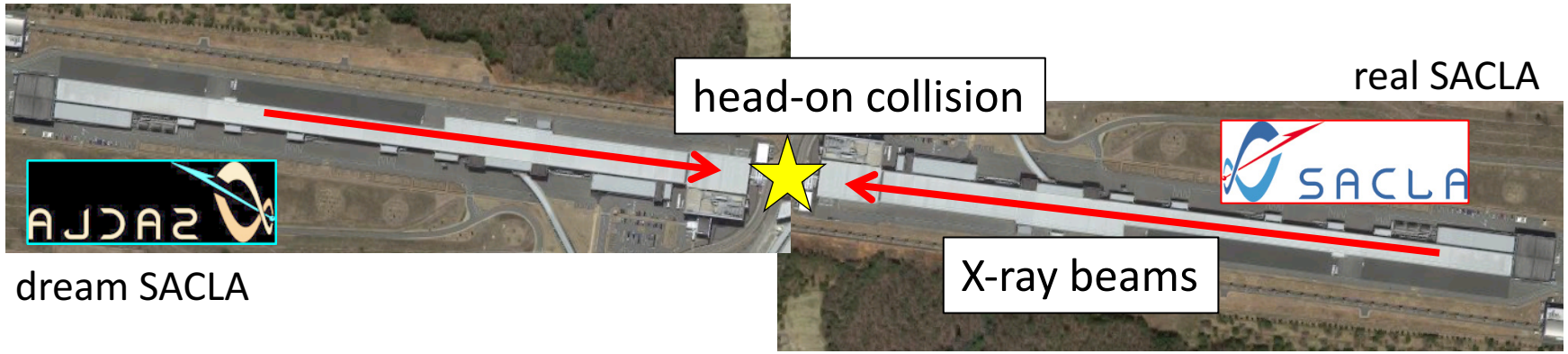
→Experiment without diffraction is needed!

dream plan : SACLA+SACLA head-on collision

- Experiment without diffraction requires an additional X-ray source
- If another SACLA exists in front of SACLA,
  can photon-photon scattering be observed? (thought experiment)

- head-on collision of X-ray pulses with 10^{12} photon/pulse
- 50nm focusing (horizontal/vertical) can be used for head-on collision
  →1 photon-photon scattering per 60Hz 2 day DAQ

- In principle, X-ray collision can be observed by head-on collision of 2 XFELs
  →ultimate goal of scattering experiments in X-ray region

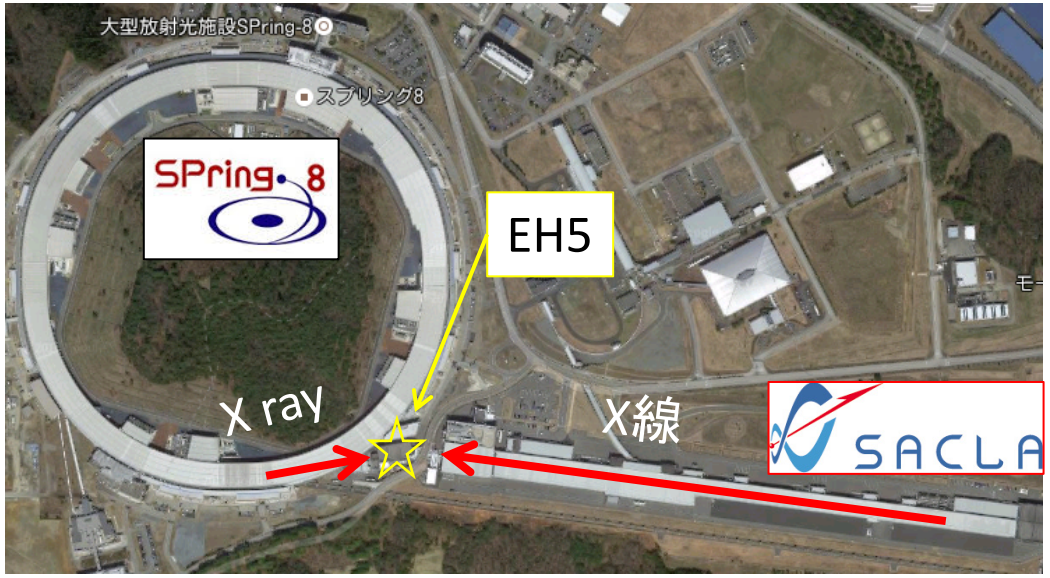


realistic setup : SACLA+SPring-8

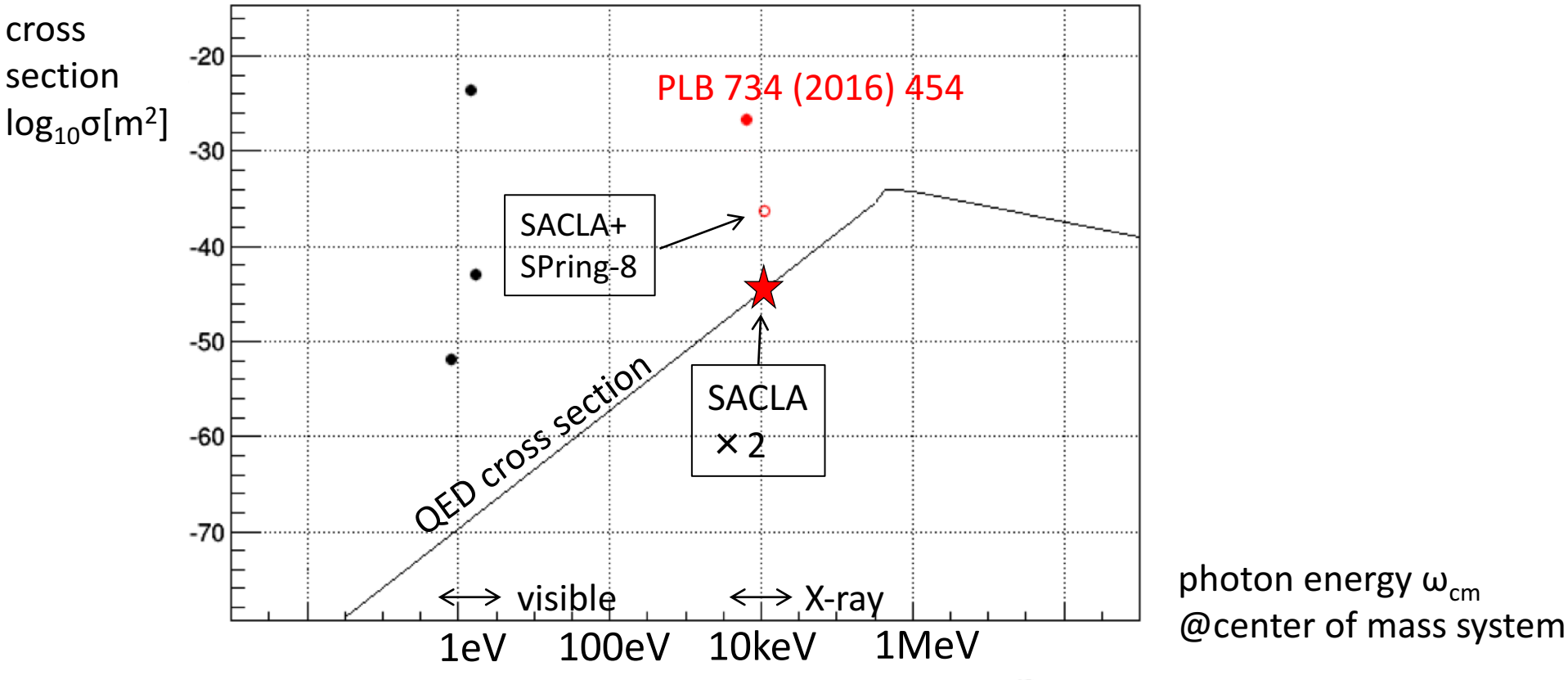
◆SACLA+SPring-8 head-on collision

- SACLA EH5: simultaneous usage of SACLA and SPring-8 BL32
  Synchronized operation will be developed in the near future → realistic setup
- SPring-8 : ~10^3 photon/pulse, 40MHz, 40ps (pulse intensity is 10^{-9} of SACLA)

- The head-on collision experiment with 50nm focusing at EH5
  →sensitivity enhancement of 10^{11} by 60 Hz 2 day DAQ (10^9 worse than QED prediction)
- more realistic than SACLA+SACLA : next step



Summary of prospects



- current upper limit : 20 orders of magnitude worse than QED prediction

- SACLA+SACLA: QED prediction can be verified (in principle)
  : ultimate goal of photon-photon scattering experiment in the X-ray region
- head-on collision of SACLA and SPring-8 : sensitivity can be enhanced by 10^{11}

Summary

- We are performing particle experiments using photons
- Photon-photon scattering of real photons has not ever been observed
  : important verification of QED
- We have performed first scattering experiment in X-ray region
- X-ray diffraction is used to split X rays and make them collide
- Background X rays are suppressed to perform 0-pileup experiment
- The upper limit on cross section is 10^{20} worse than QED prediction
  : drastic change of experimental setup is necessary

- SACLA+SACLA: sensitivity can approach to QED prediction in principle
  : ultimate goal of X-ray photon-photon scattering experiment
- head –on collision of SACLA and SPring-8 : sensitivity is enhanced by 10^{11}
  :next step