LSW experiments with pulsed magnets +Vacuum Magnetic Birefringence (VMB)

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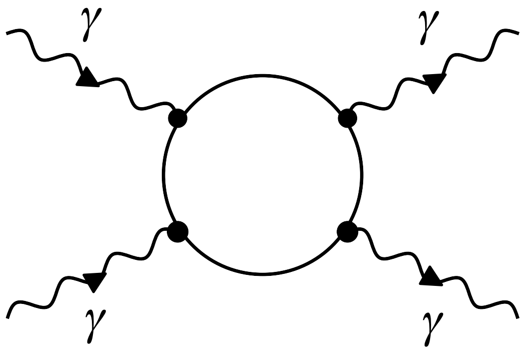
- Magnet/bank: T.Yamazaki et al, NIM A 833, 122 (2016)
- VMB: X.Fan et al, arXiv: 1705.00495
- X-ray LSW: T.I. et al, PRL. 118, 071803 (2017)

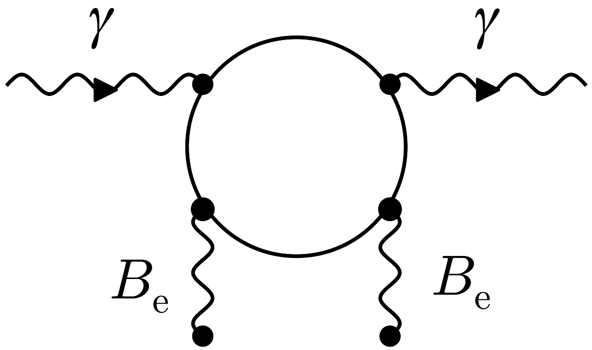
HIMAFUN 30th May 2017

Fundamental physics in vacuum

Nonlinear QED



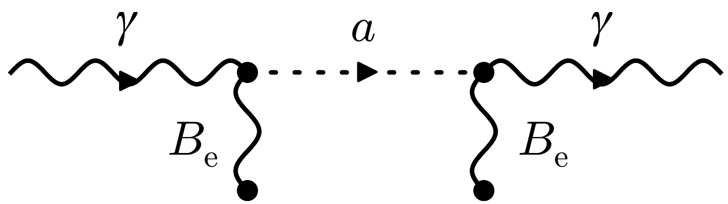
Light-by-light interaction



VMB

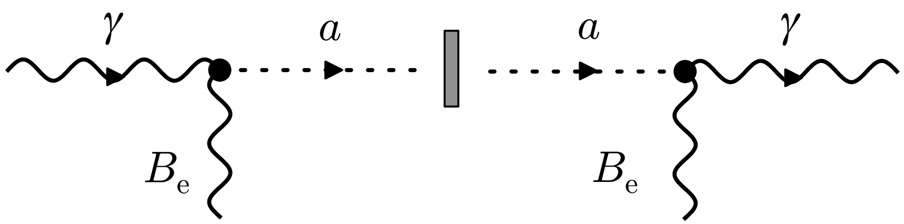
Axions, ALPs

VMB



Haloscope, Helioscope

LSW



We are studying both of these nonlinear QED and axions

Pump-probe scheme for vacuum physics

Probe \ Pump	Laser (～1 PW)	Pulsed magnet
Laser (optics)	Light-by-light scattering Four-wave mixing	Laser LSW VMB
X rays (XFEL)	Laser-induced diffraction/birefringence	X-ray LSW

We use pulsed pump to get a high field

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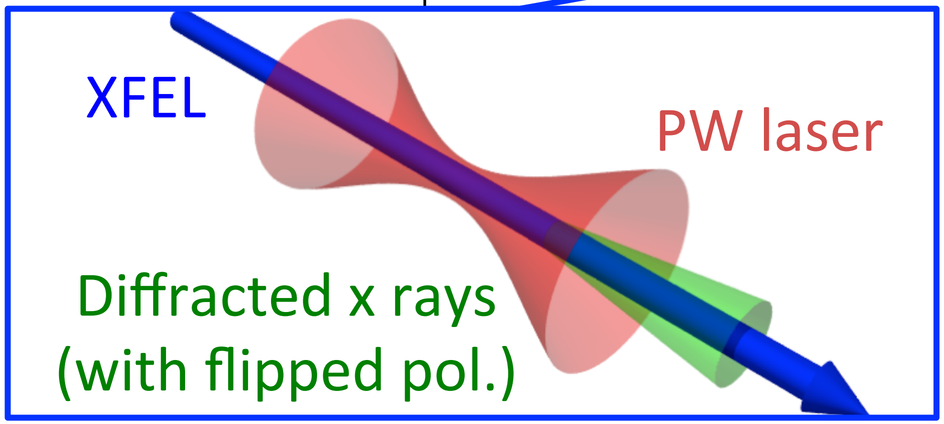


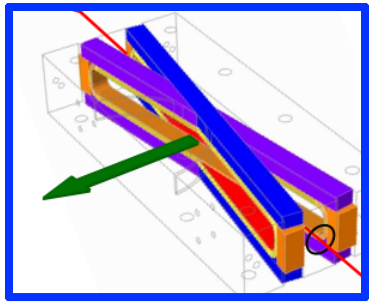
A 0.5-PW laser will be available from 2018

→ Now testing with 2.5 TW

[(link: http://tabletop.icepp.s.u-tokyo.ac.jp/Tabletop_experiments/VB SACLA+laser_files/seino-lnpc17.pdf](http://tabletop.icepp.s.u-tokyo.ac.jp/Tabletop_experiments/VB%20SACLA+laser_files/seino-lnpc17.pdf))

Pulsed magnets

Magnet types
- Solenoid: good symmetry → 80-100 T
- We need a transverse field over large length
- Racetrack: bad symmetry → 31.7 T (XXL-coil)



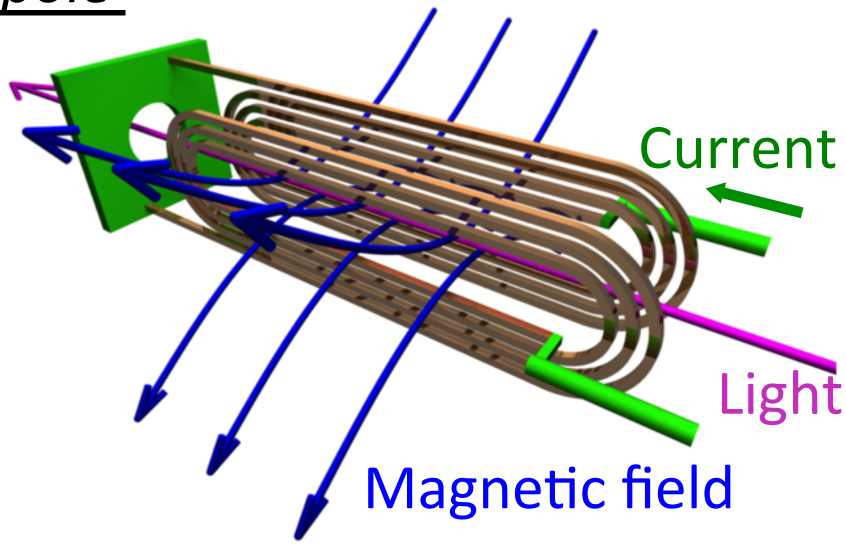
<u>Merits</u>
- Intensity: LSW: B×L, VMB: B^2×L
- VMB with IZ scheme: temporal field modulation

<u>Drawback</u>
Low duty: fast repetition
- Power supply: charging time of capacitors, 0.1 Hz
- Magnet: heating <-> cooling efficiency (LN2)

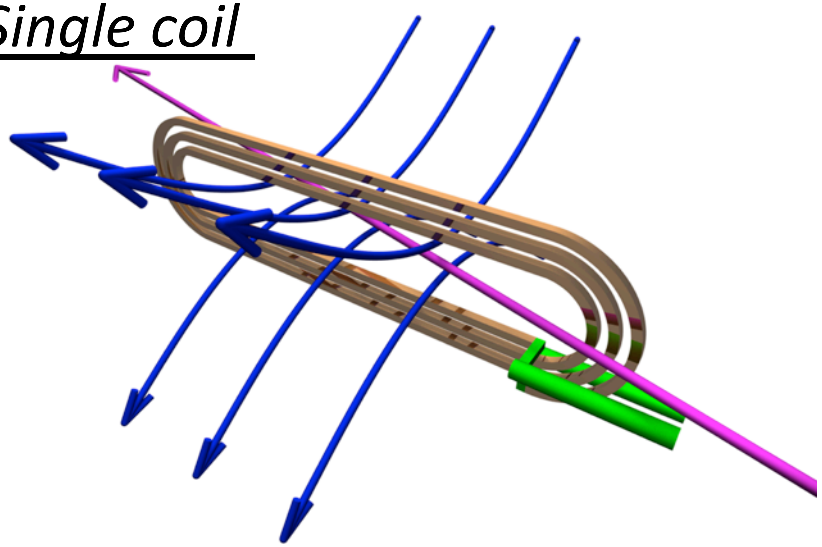
→ as high as possible, hopefully to 0.1 Hz

Coil structures

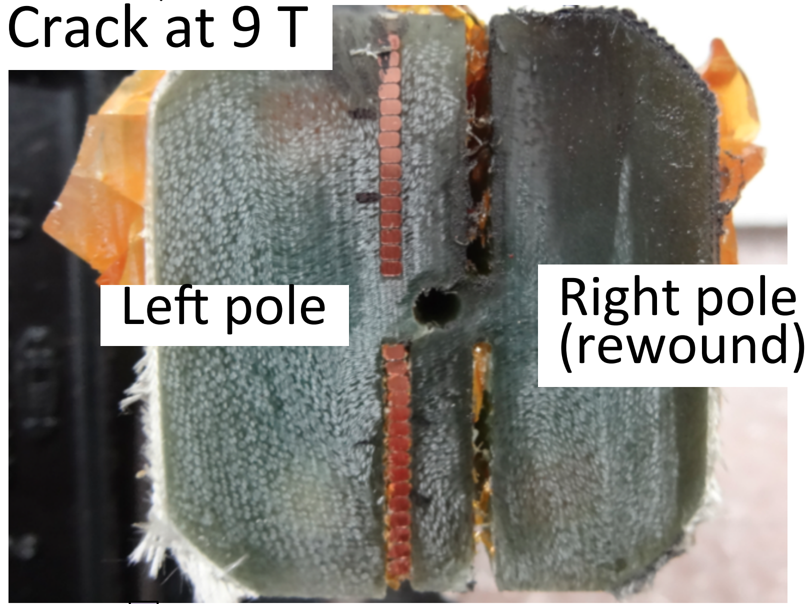
Dipole



Single coil



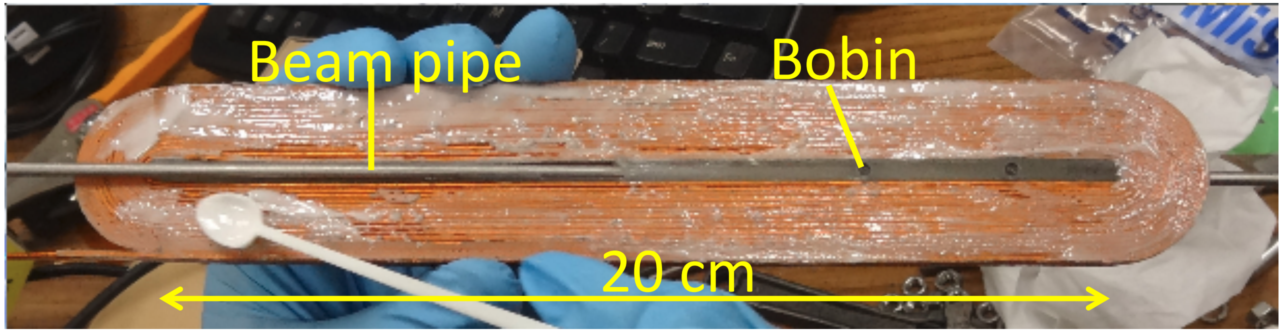
Minimalized field-volume

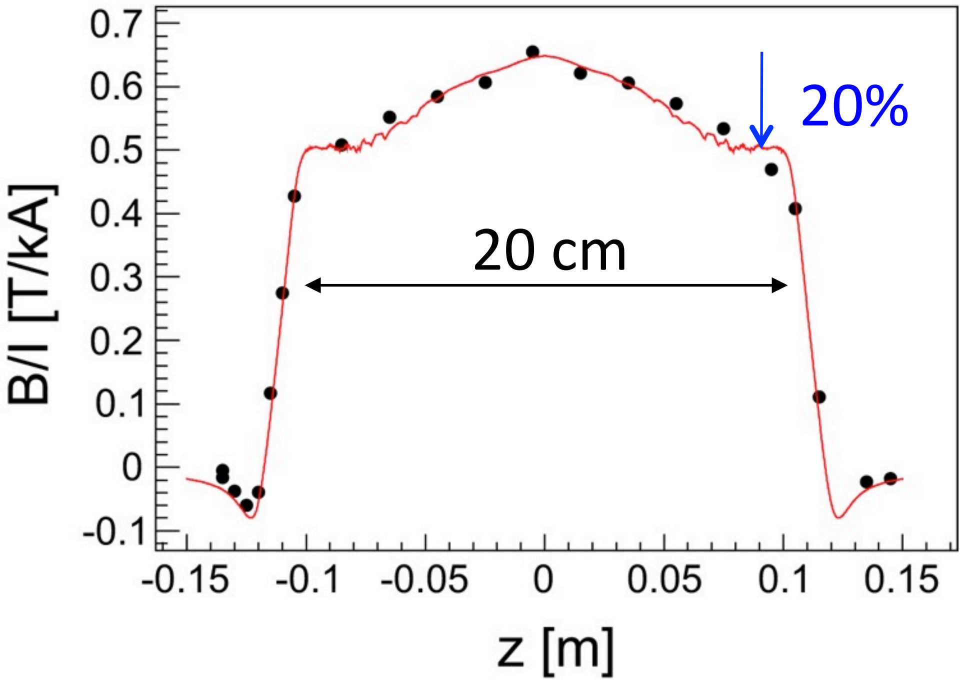


No attractive force with a single coil

Field map along the beam path

- Transverse field along the pipe center (inner diameter 5.3 mm）
- Tilted path (2.75°) → smaller for the edges

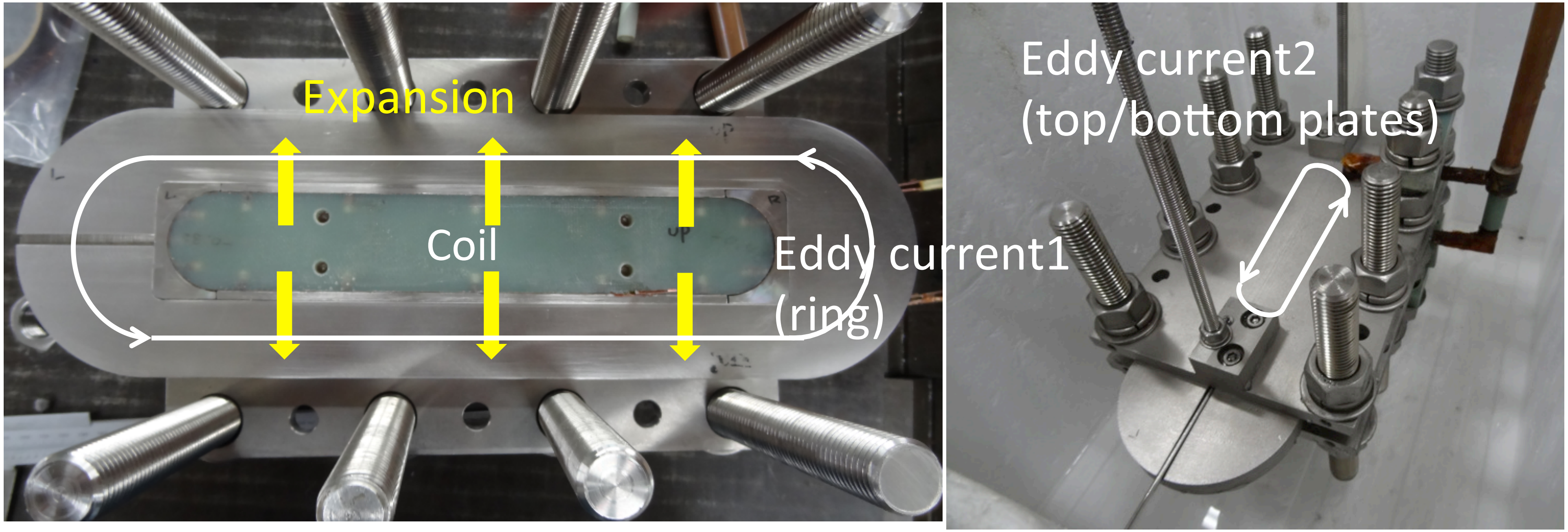




Dot: measurement
Line : finite element simulation in 3D (ANSYS)

Conventional backup metal

(Left) fitting the coil into a backup ring, (right) pressing it with plates

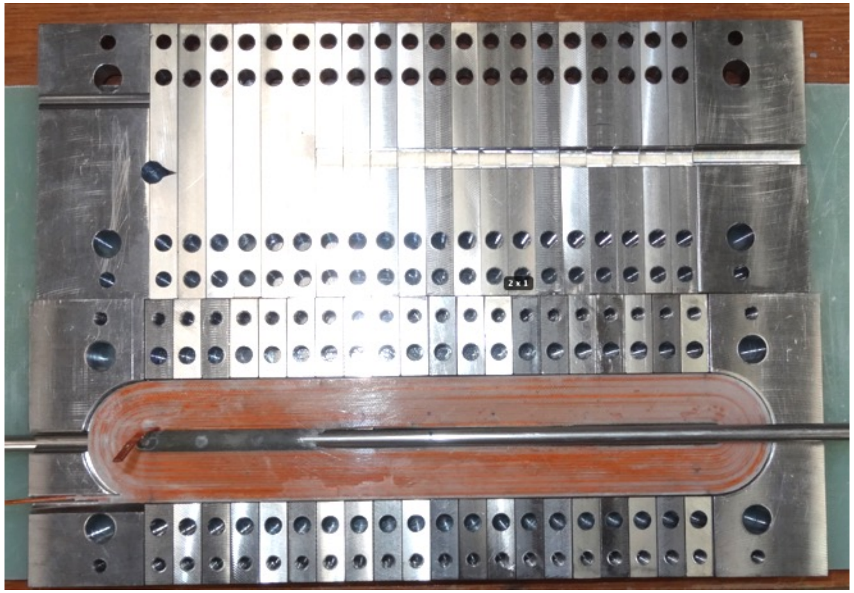


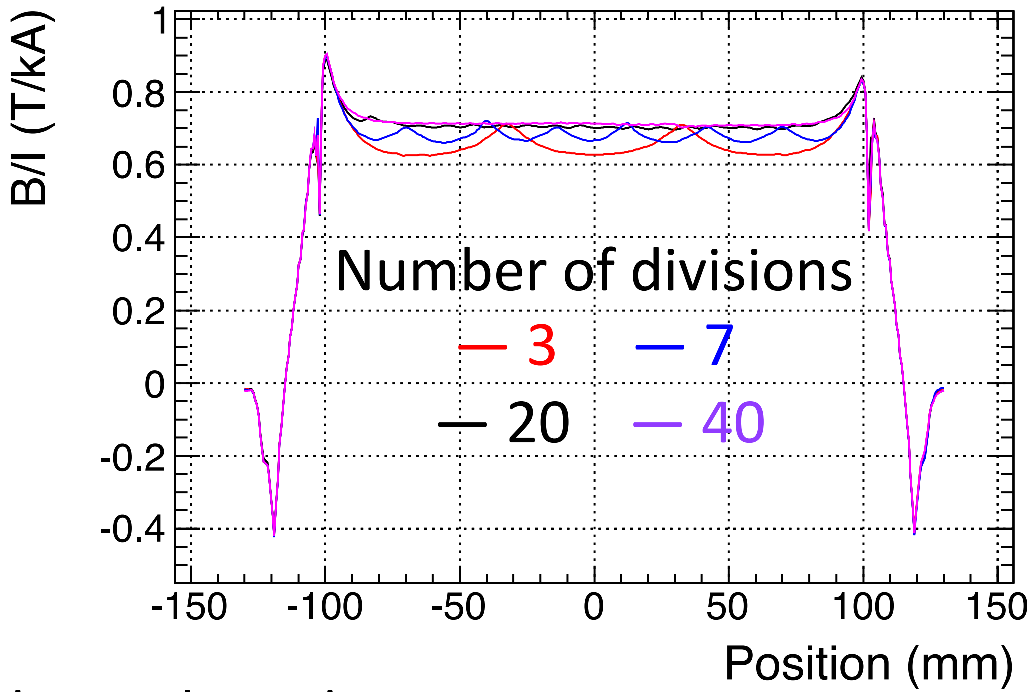
Drawbacks

- Expansion force (Maxwell stress) concentrates on the ring corners
- Large eddy current runs in the ring and plates to cancel the field

Dividing the metal into 20 pieces

- Avoid the concentration of the expansion force
- Divide the backup metal where eddy current runs

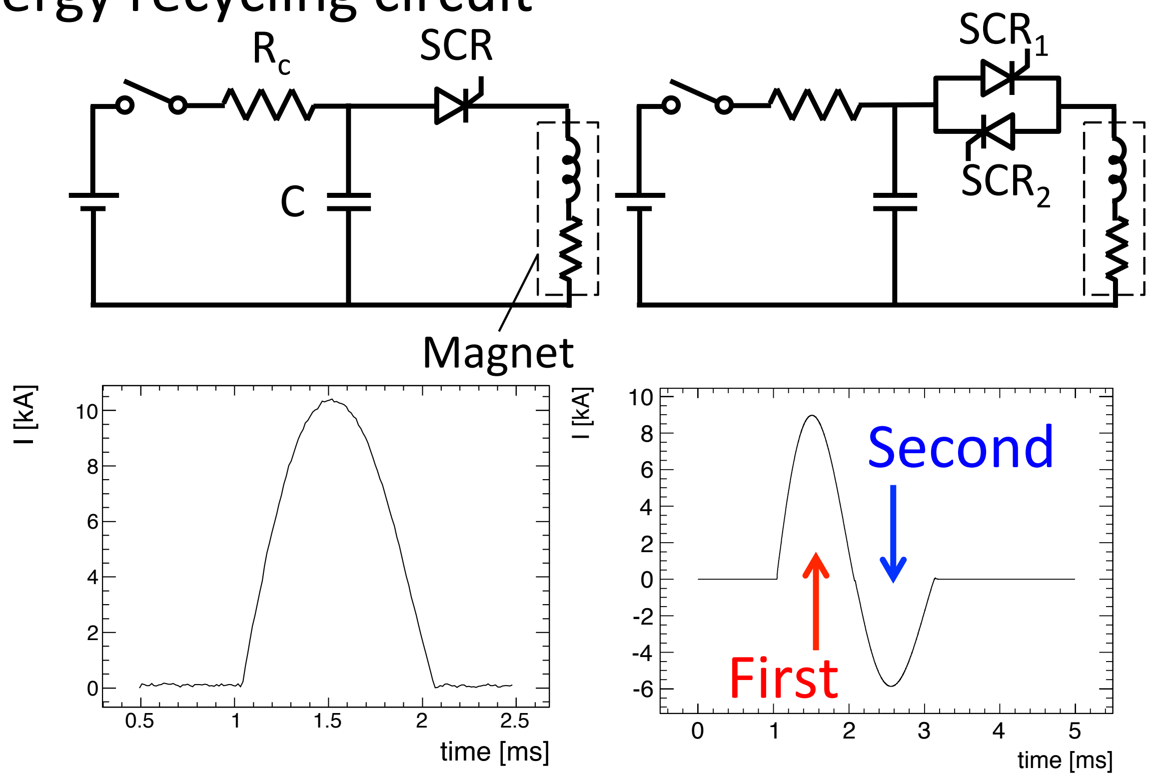




Reducing materials with small thermal conductivity
→ Cooling efficiency

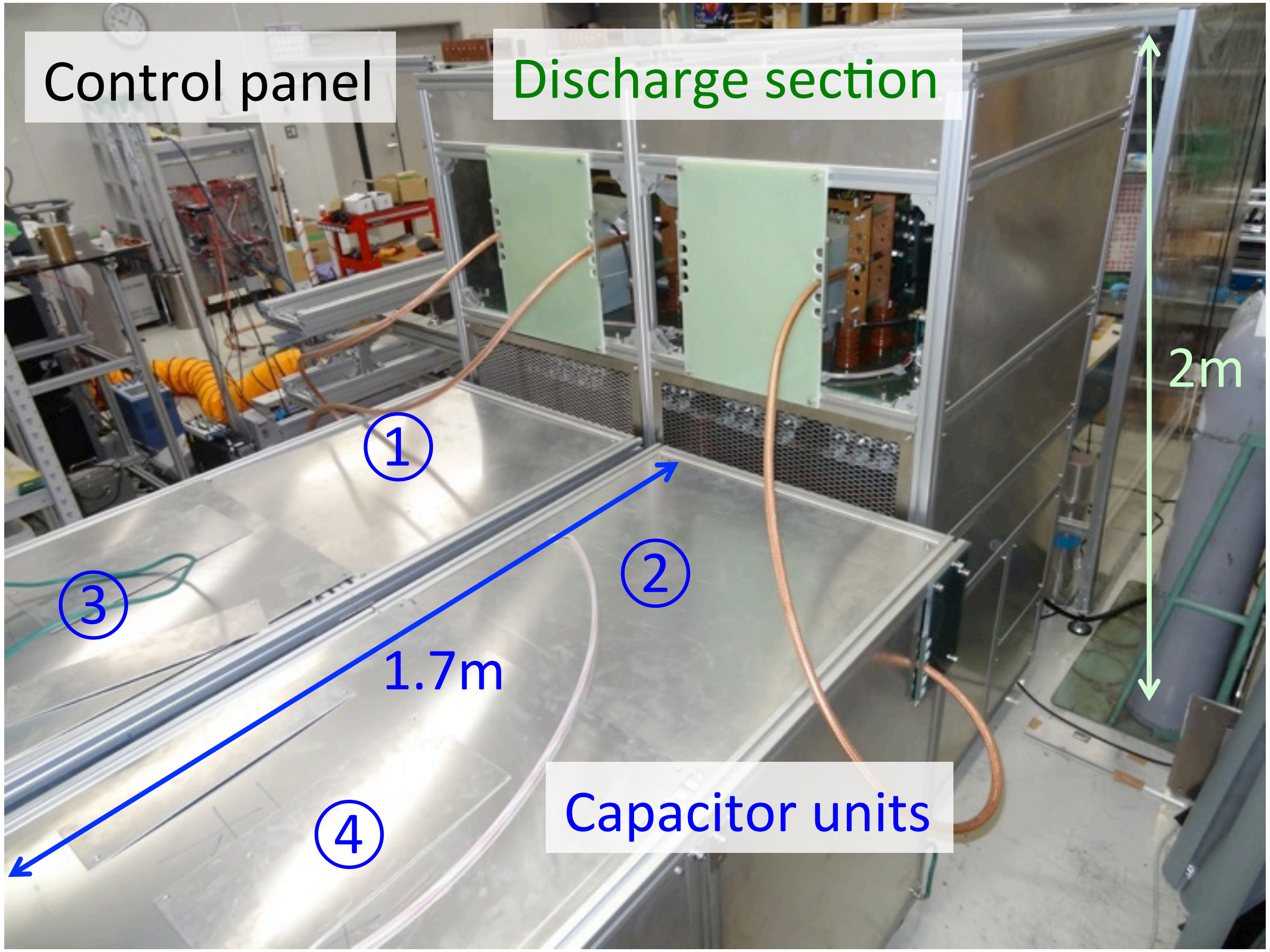
Power supply for high-rep. operation

- Left: conventional single-shot circuit
- Right: energy recycling circuit



One cycle

- Frist pulse (SCR1) → positive field
- Second pulse (SCR2) → negative field
- Re-charge the capacitor by the energy lost by the two pulses

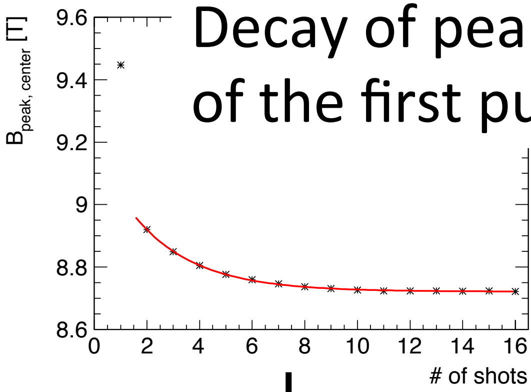


12 capacitors in total: 3mF, 1.9t
→ Dividing them into 4 units for transportability
Max. voltage: 4.5kV (30 kJ)

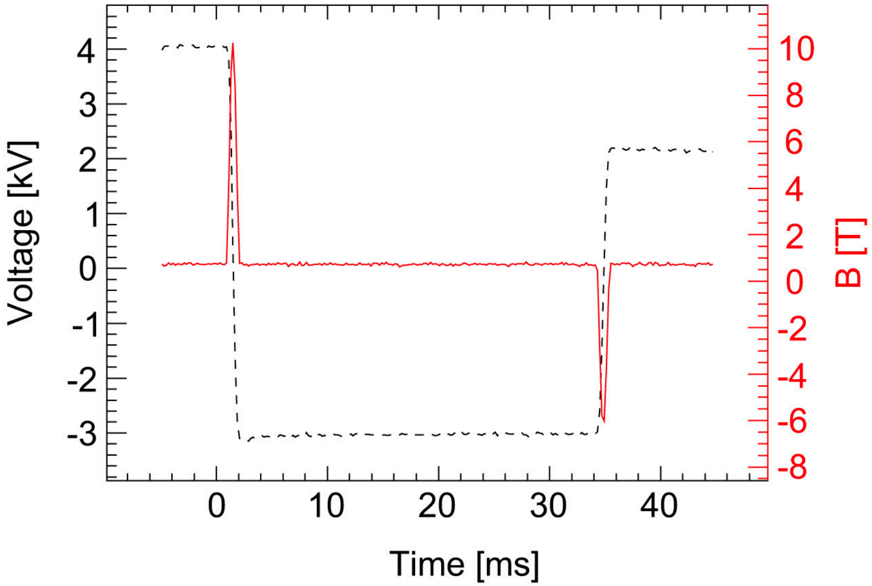
Continuous operation

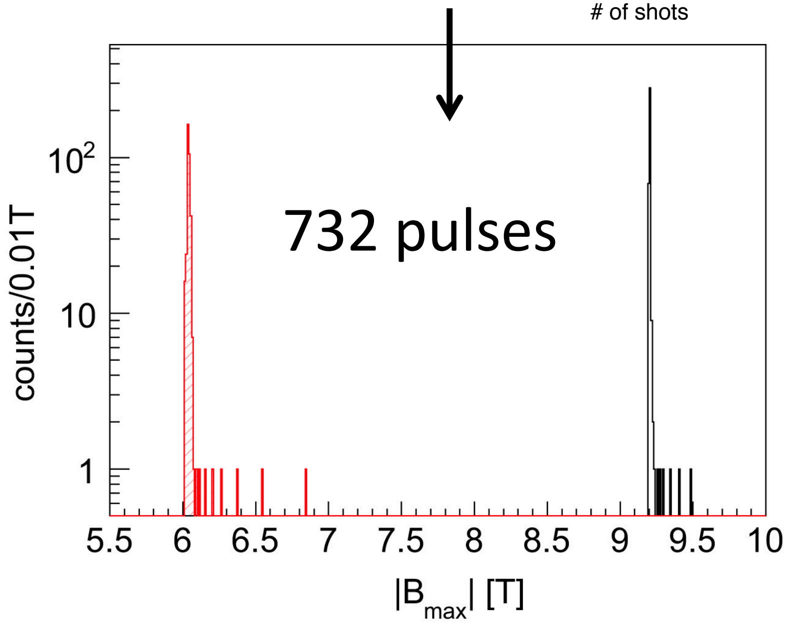
Operational condition

- 4 magnets → 0.8 m
- 4 kV - 3 kV: 9.2 T – 6.0 T cycle
- cycle repetition: 0.1 Hz
- Heat loss: 2.4 kW for 4 magnets



Decay of peak field of the first pulse





Pulse interval is adjustable: 30 Hz in this case

Fields are stable(± 0.5%) after reaching equilibrium

Summary: current status of the field-generation system

Development of a field-generation system suited for repetitive operation

- Multiple racetracks

→ small field-volume, small heating, high cooling efficiency

- Power supply for a high-rep. use

→ energy recycling scheme

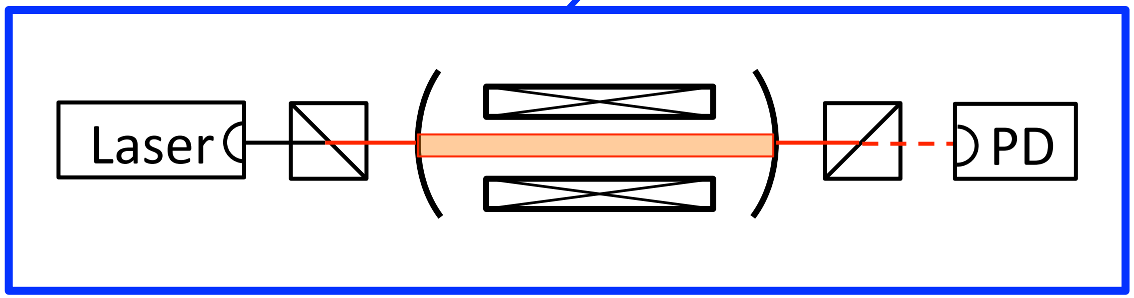
9 T over 0.8 m with 0.1 Hz (cycle) has been achieved

→ $B^2 \times L = 54\ T^2\ m$

- NIM A 833, 122 (2016)

Pump-probe scheme for vacuum physics

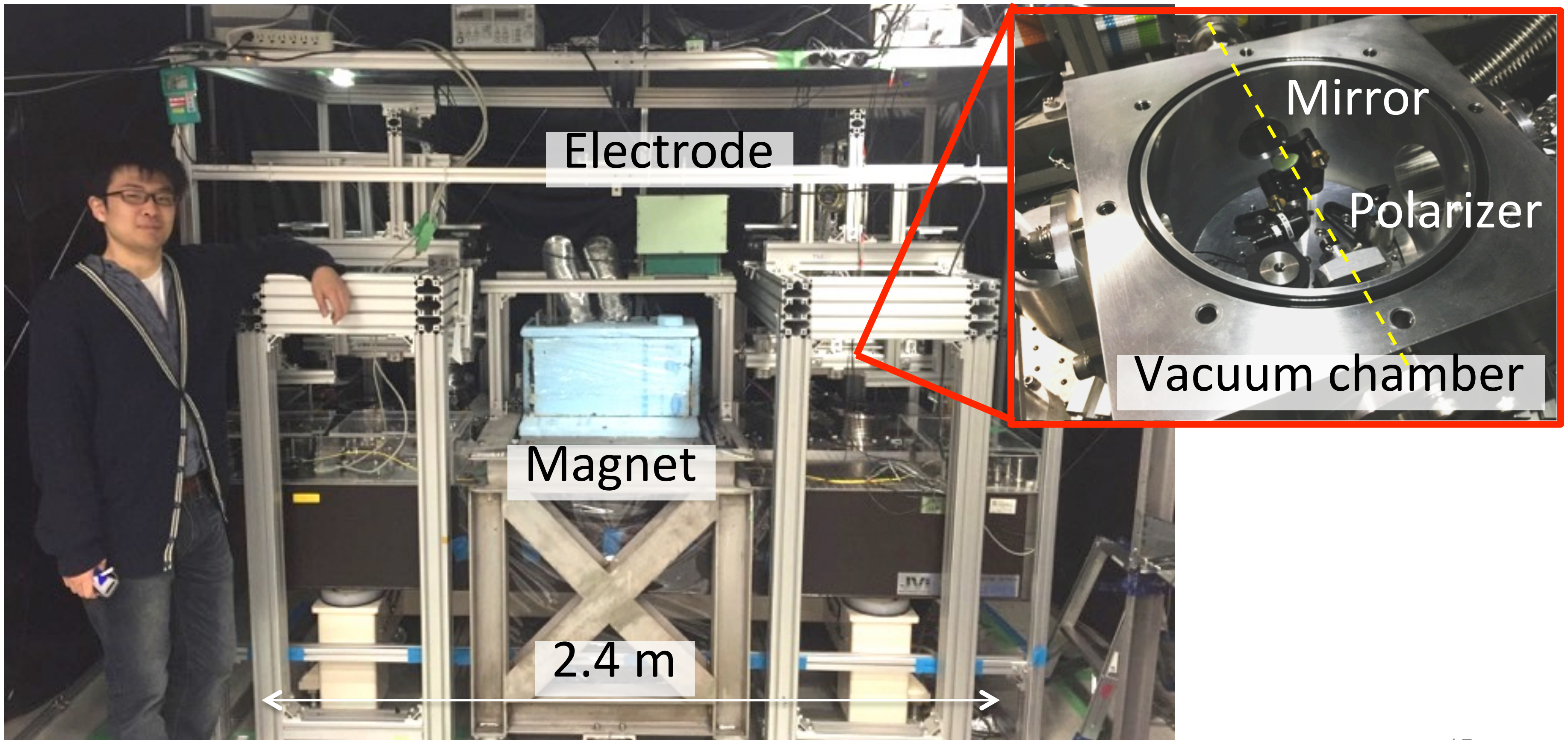
Pump / Probe	Laser (～1 PW)	Pulsed magnet
Laser	Light-by-light scattering Four-wave mixing	Laser LSW VMB
X rays (XFEL)	Laser-induced diffraction/birefringence	X-ray LSW



The OVAL experiment

Observing VAcuum with Laser

- Testing setup with one magnet
- $B^2 \times L = 13.8\ T^2\ m$

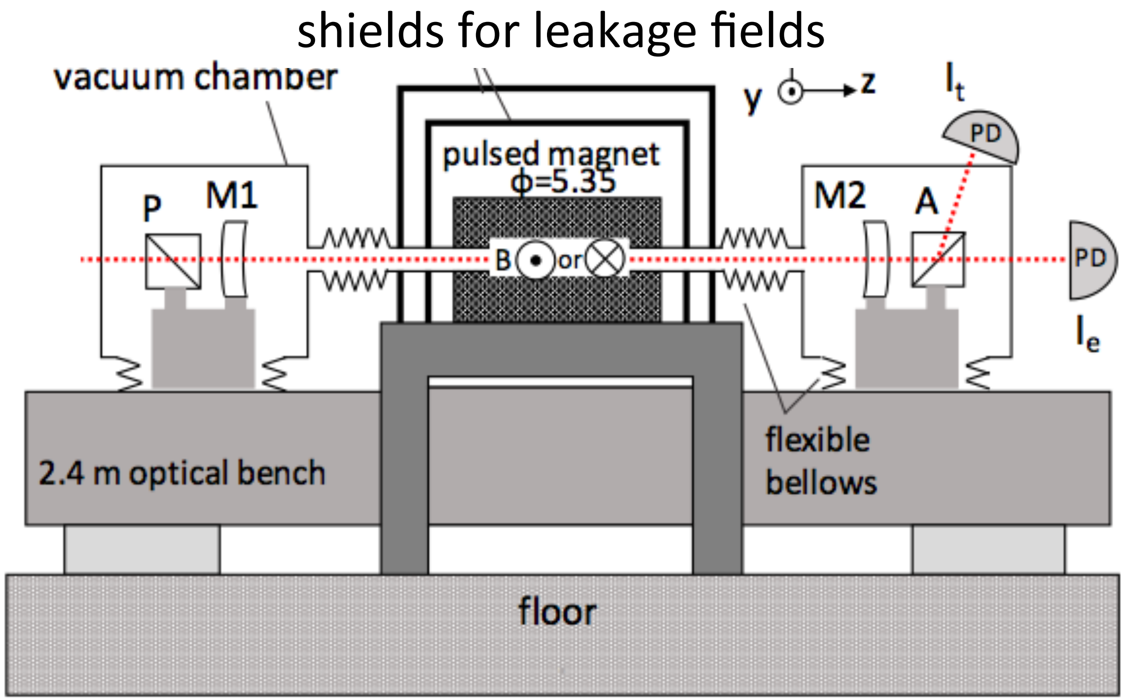


Continuous DAQ

To observe VMB, a long-term run is necessary
- *Cavity resonance has to survive pulsed fields*

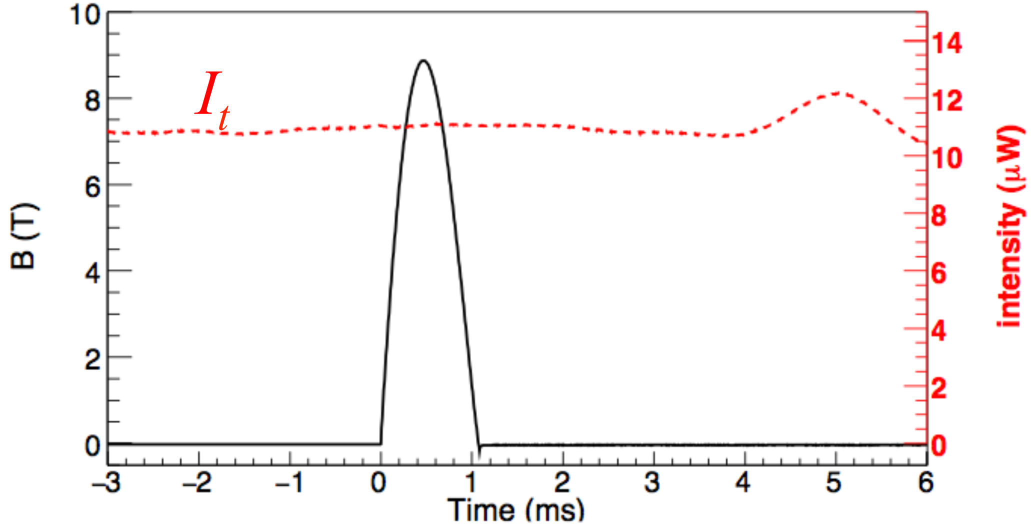
We must remove the disturbance of mechanical shocks
- The disturbance is decoupled by these bellows?

Side view



At present, it works

Typical response of PD_t



<u>During the pulse</u>

- No mechanical shock was observed at 9 T

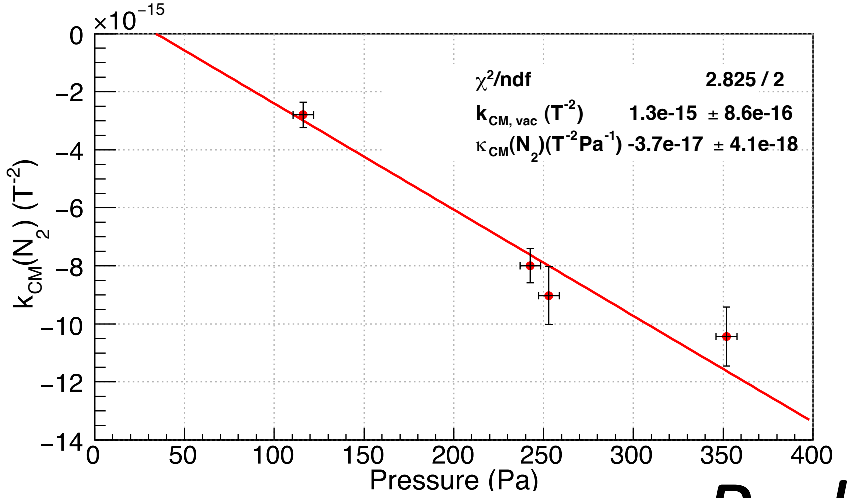
<u>After the pulse</u>

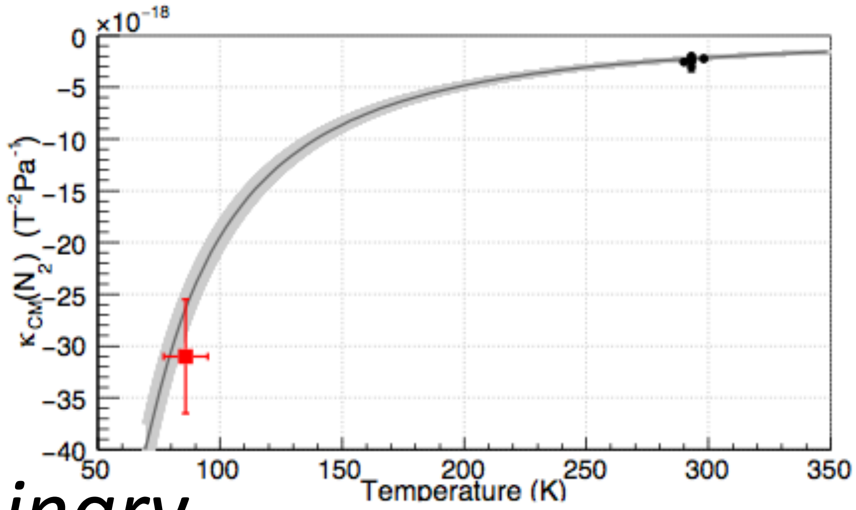
Acoustic shock: arrives at 4 ms

→ Resonance survives

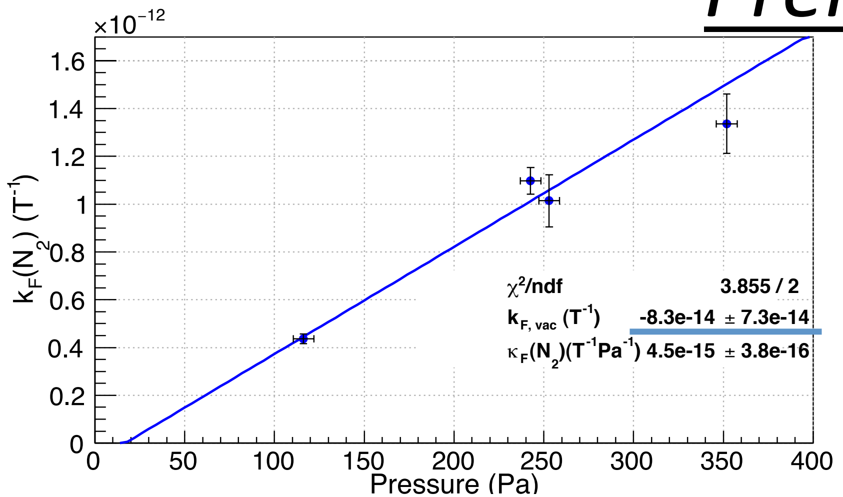
N_2 measurement

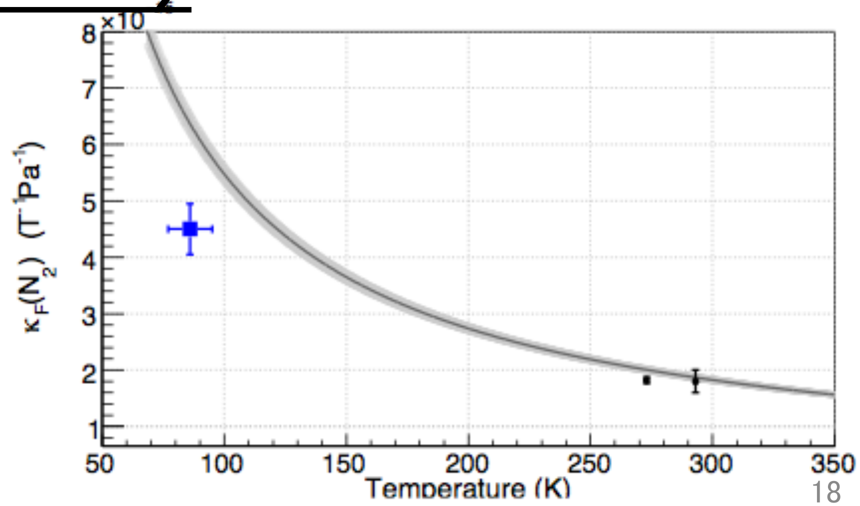
We also measured k_{CM} and k_F of N_2 gas (100-350 Pa)





Preliminary

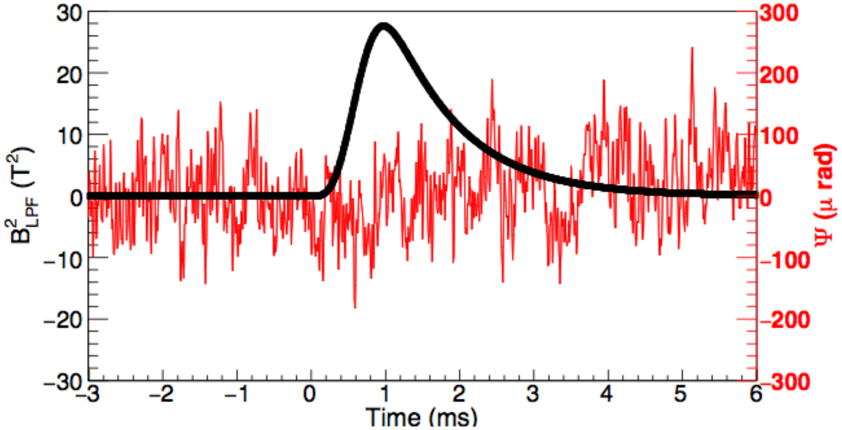




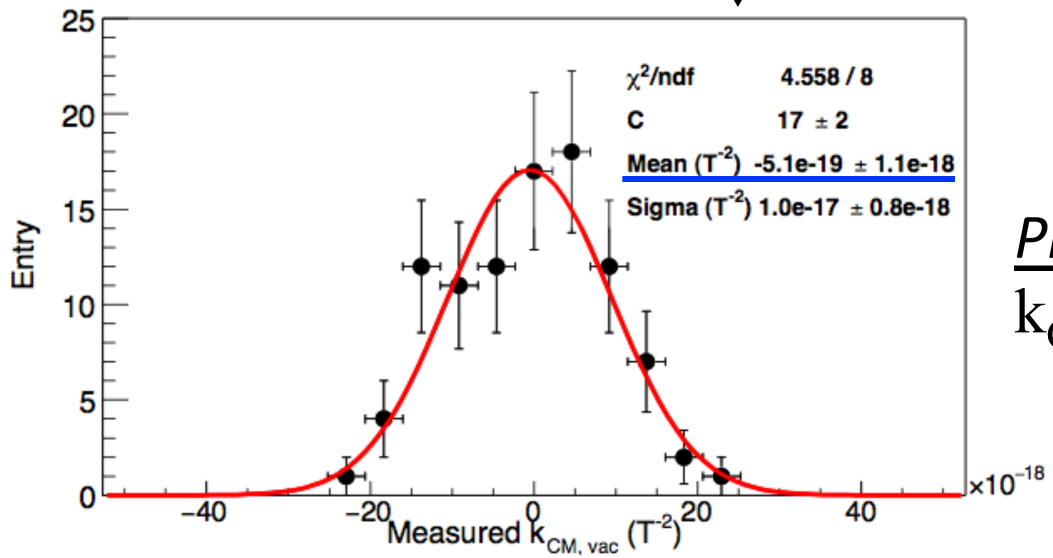
Vacuum measurement

As a test, we applied 100 cycles of 9.0 T and -4.5 T → 15 min

Fitted



for 100 cycles



Preliminary

$k_{CM} = -0.5 \pm 1.1 \times 10^{-18}$ (T^{-2})

Future steps

Table of improvements to observe QED with a 6-month run

	This measurement	Target value	Gain	Upgrade plan/Status
Magnetic filed	9[T]	15[T]	2	Changing wound wire from Cu to Ag-Cu
Field length	0.2[m]	0.8[m]	4	Preparing for loading 4m optical bench now
Pulse width	1.2[ms]	4.8[ms]	2	The Modification of the power supply unit.
DAQ time	15[min]	180[days]	130	Building a stable DAQ system is on going
Finesse	350,000	650,000	2	Upgrade is succeeded
Intensity	0.03[mW]	5[mW]	40	Upgrade is succeeded
Intensity noise	1×10^{-4} [1/√Hz]	1×10^{-5} [1/√Hz]	3	Upgrade is succeeded

Improvements of optics have almost finished
We need to combine it with magnets
- Work in progress!

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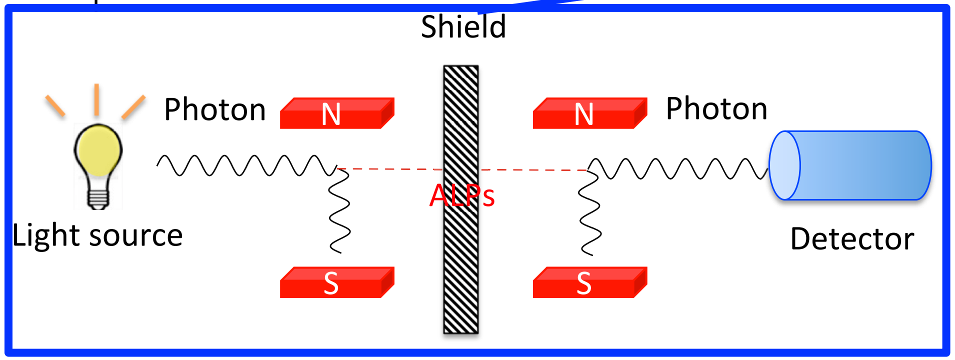
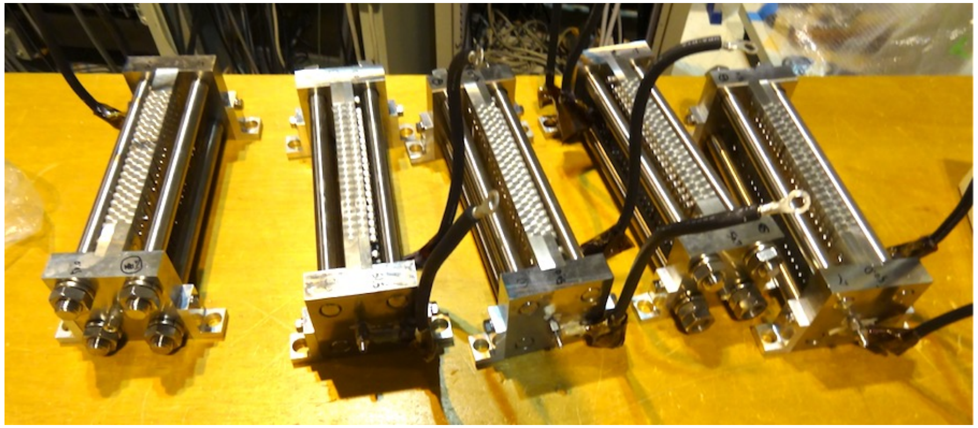


Pioneering work at ESRF: PRL 105:250405 (2010)

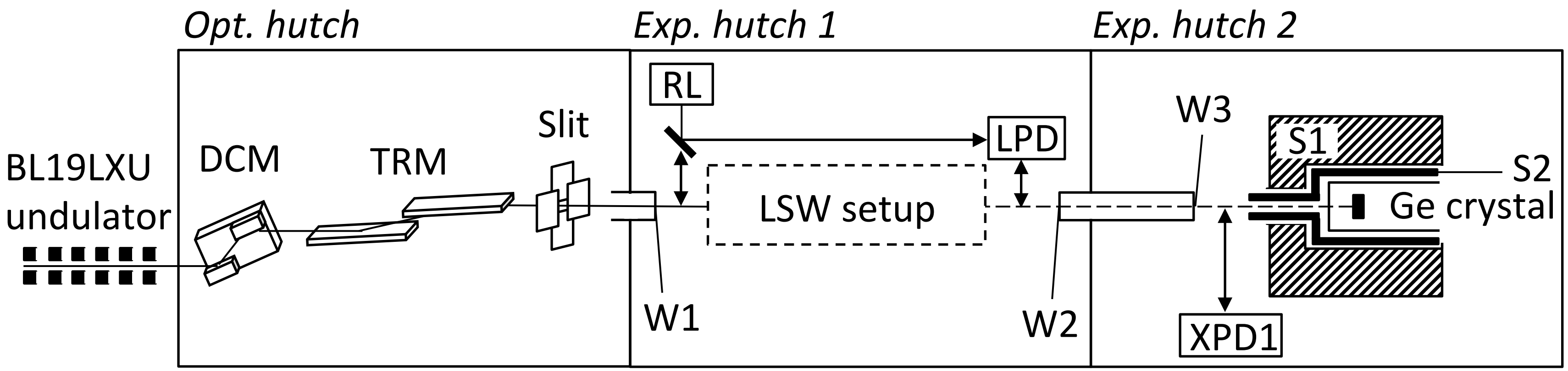
X-ray LSW search for ALPs

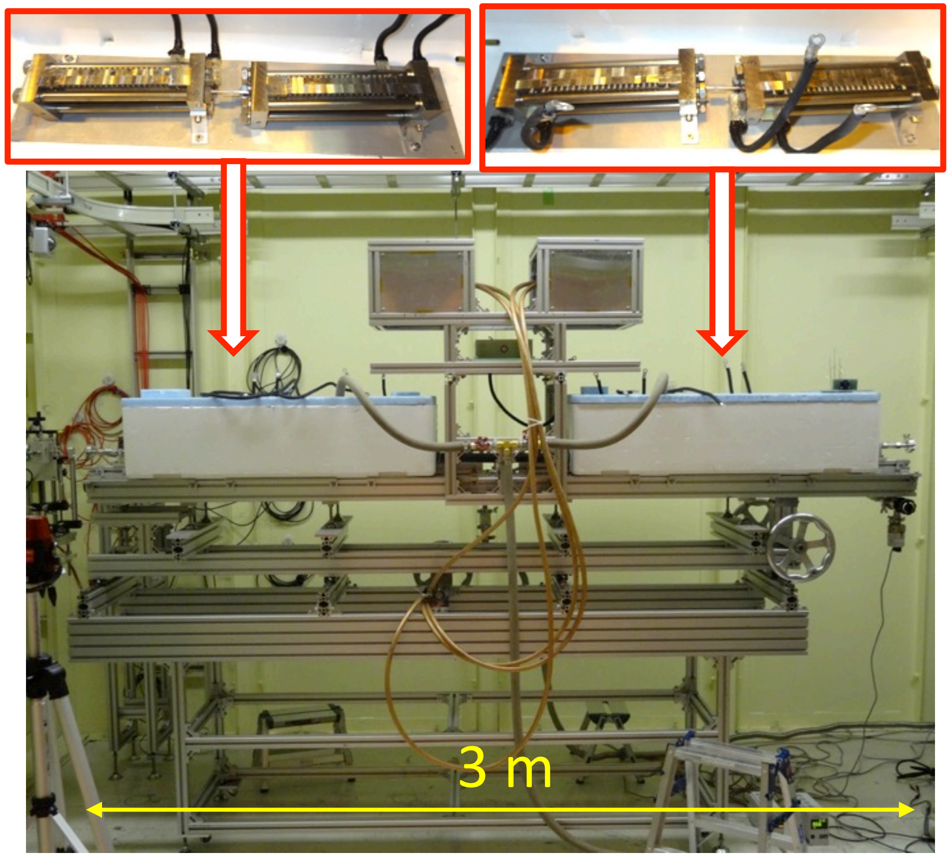
- First-phase experiment:
- DC x rays at SPring-8 BL19LXU: 3×10^{13} photon/s at 9.5 keV
- using 4 magnets
- 2 days for DAQ in Nov. 2015 → 27,676 pulses!

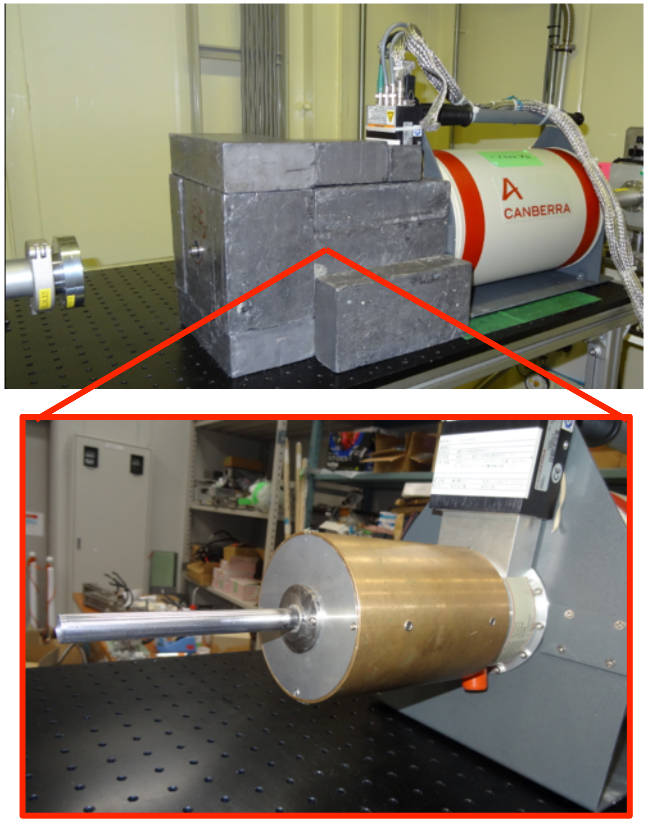


12 vessels (LN2 100 l)

Setup

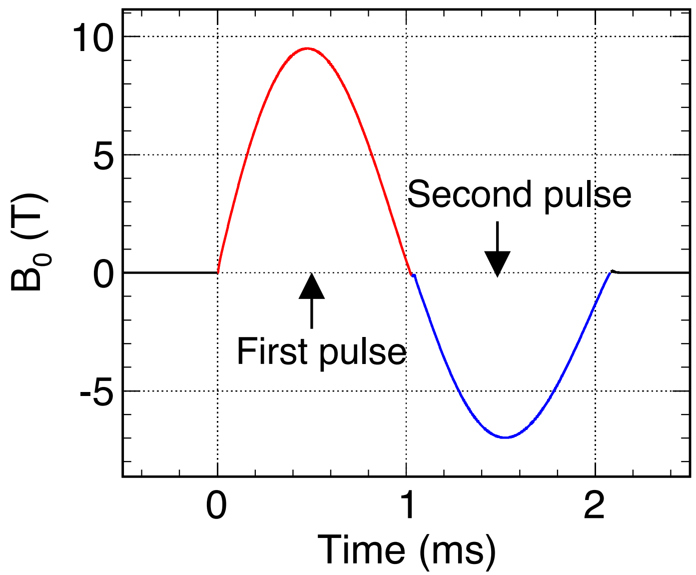

Opt. hutch
Exp. hutch 1
Exp. hutch 2
BL19LXU
undulator
DCM
TRM
Slit
RL
LPD
LSW setup
W1
W2
W3
S1
S2
Ge crystal
XPD1


3 m

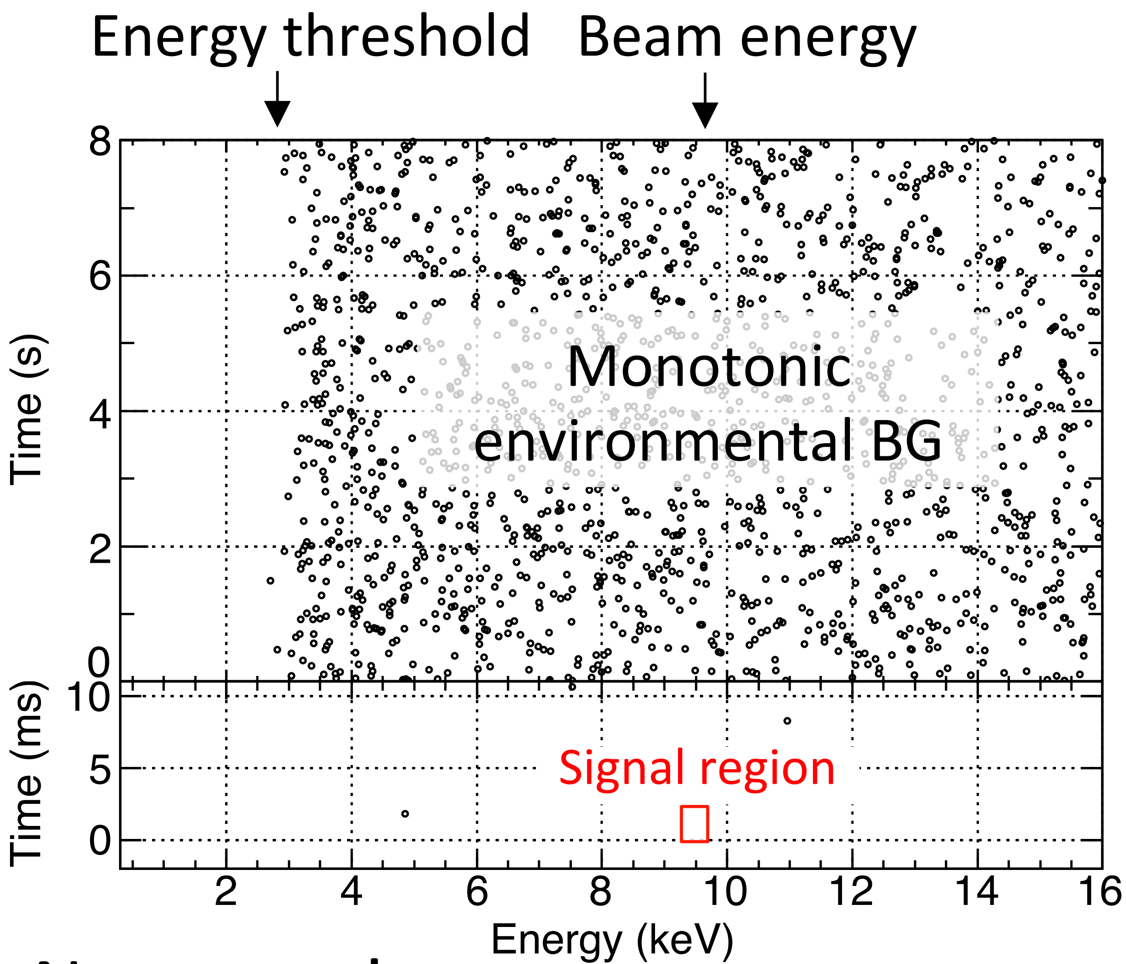

CANBERRA

Time-energy distribution of events

- Time window: 2.1 ms (left)
- Energy window: beam energy (9.5 keV) ±2σ(detector resolution)

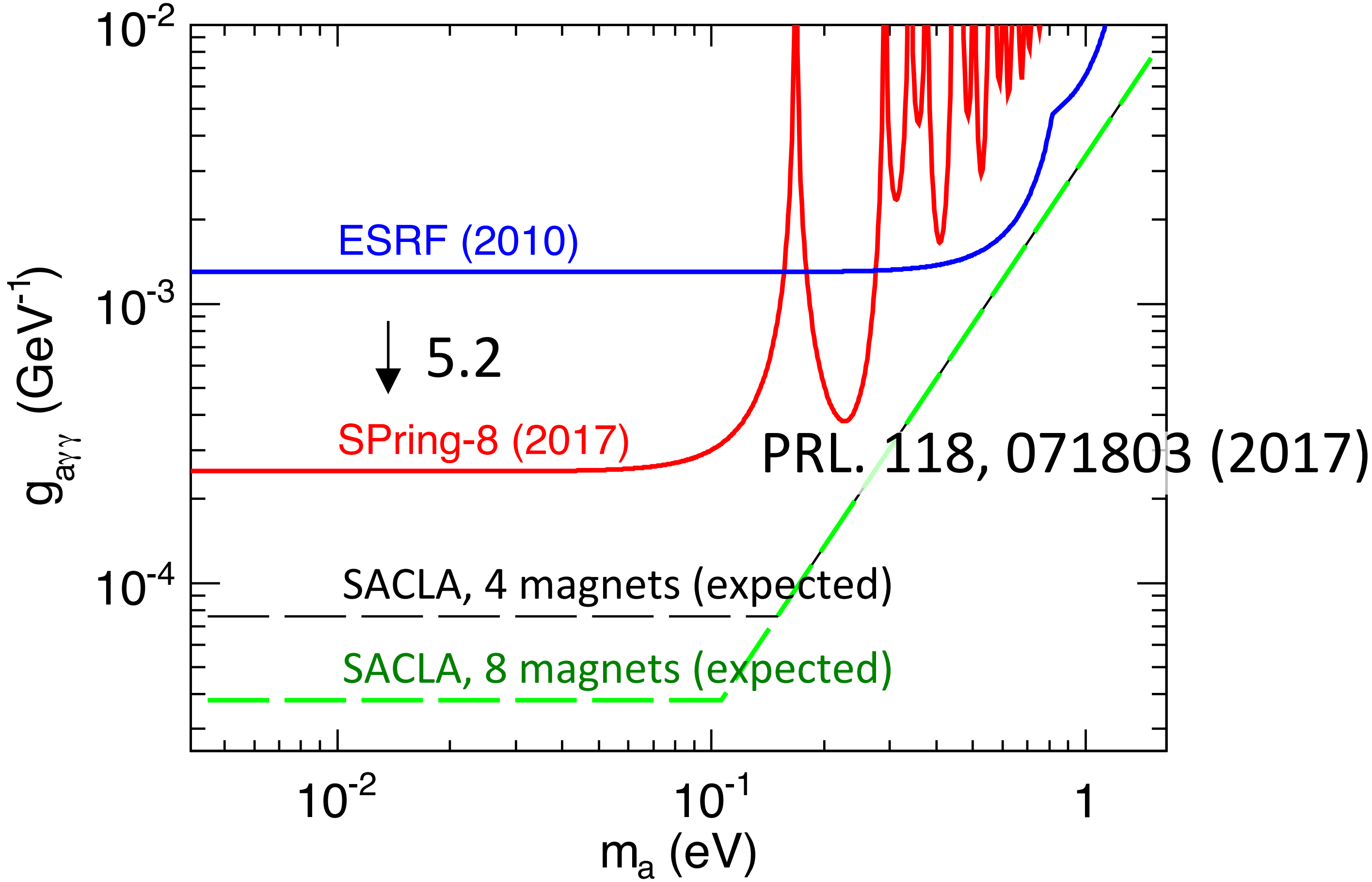


Zoom around the time window



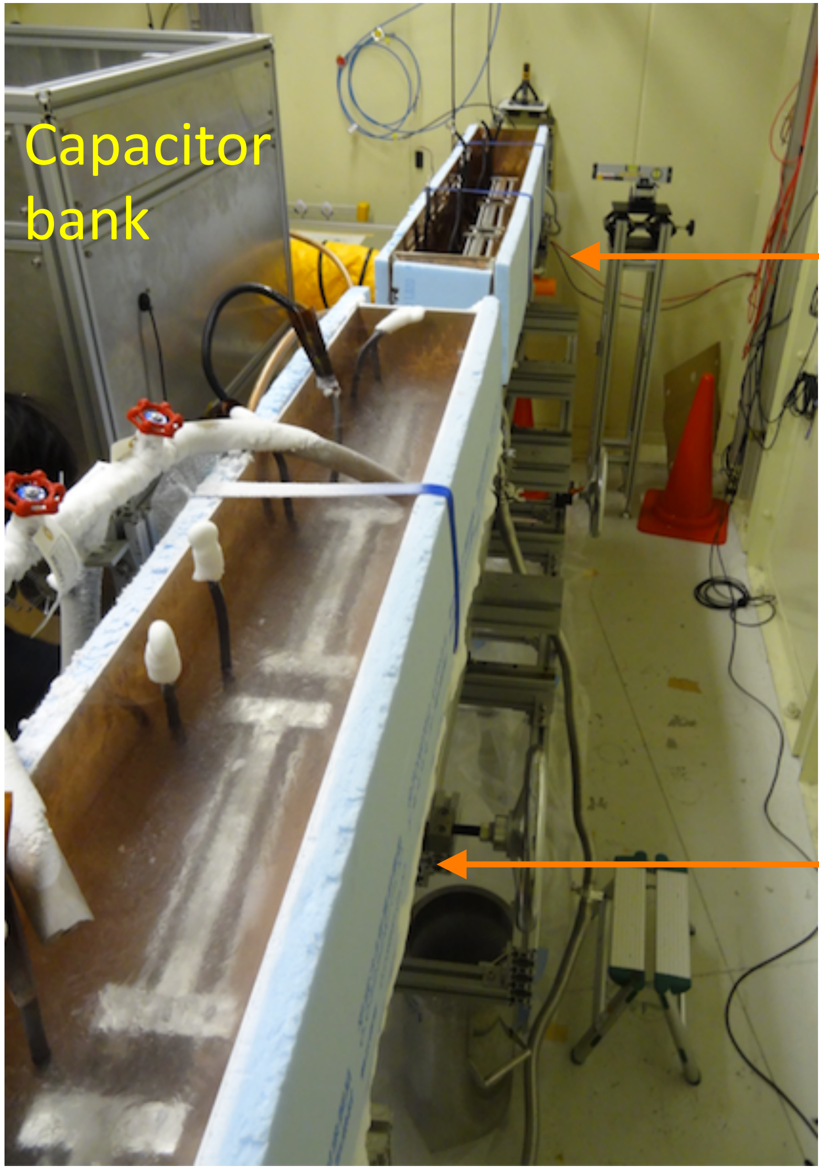
No events!

Limits on the coupling constant



- Next target: XFEL + 8 magnets
- 4×10^{11} photon/pulse, 30 pulse/s, 2-day run
- Also, keep improving the magnet

Test of 8 magnets at SPring-8



Upstream
4 magnets

Downstream
4 magnets in LN2

Summary

We develop racetrack pulsed magnets and study vacuum physics (nonlinear QED, ALPs) with combination of x rays and optical lasers.

We keep improving our magnet toward higher fields.

Using the present version of magnets and XFEL,

- VMB
- x-ray LSW
- vacuum diffraction/birefringence

experiments have started and begun to obtain results in their first phase.