TRANSVERSE COUPLED-BUNCH INSTABILITY BY ELECTRON CLOUD IN LER

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In this work,

1) Transverse Coupled-Bunch Instability (TCBI) was studied
   - ❖ experimentally from the positron bunch oscillation data and
   - ❖ by computer simulation presuming electron cloud (EC) instability.
2) The experimental observations were compared with the simulation results in order to understand the mechanism of EC formation and distribution of electrons around the beam.

EXPERIMENTS (1)

- Positron bunch oscillation data were taken by Bunch Oscillation Recorder with and without solenoid field.
- From the experimental data, the TCBI is characterized by the mode spectrum and the growth rate of oscillation amplitudes.

Machine parameters of LER in TCBI experiments

Energy (GeV)	3.5
Circumference (m)	3016.26
Revolution frequency (kHz)	99.39
RF frequency (MHz)	508.887
Harmonic number	5120
Beam current (mA)	300 ~ 900
No. of train/No. of bunches	1/1153
Bunch spacing (ns)	8
Transverse tune, ν_x/ν_y	45.51/43.56
Inner dia. of vacuum chamber (mm)	94 (circular)

EXPERIMENTAL OBSERVATION OF TCBI (2)

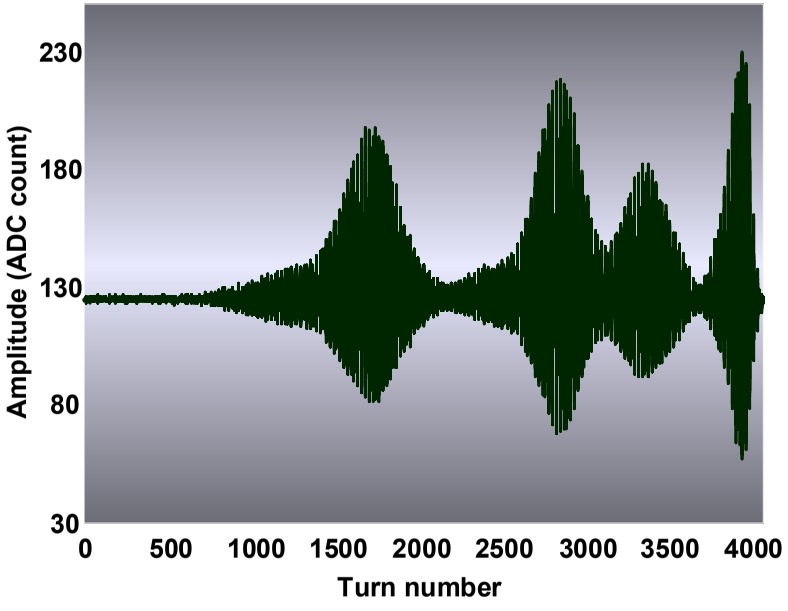


Figure 1: Bunch oscillation recorded by BOR (700 mA, horizontal, Bunch #31)

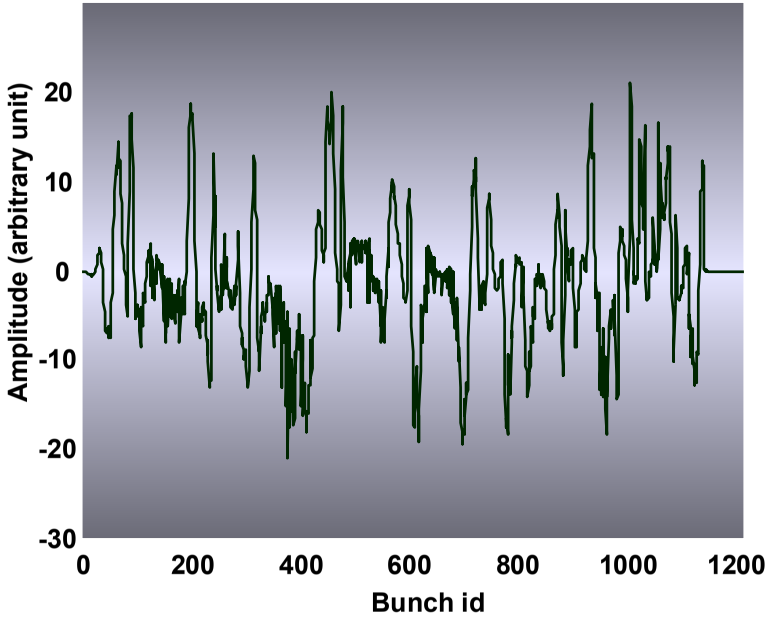


Figure 2: Snapshots at 6 ms (700 mA, horizontal)

EXPERIMENTAL OBSERVATION OF TCBI (3)

Mode Spectra

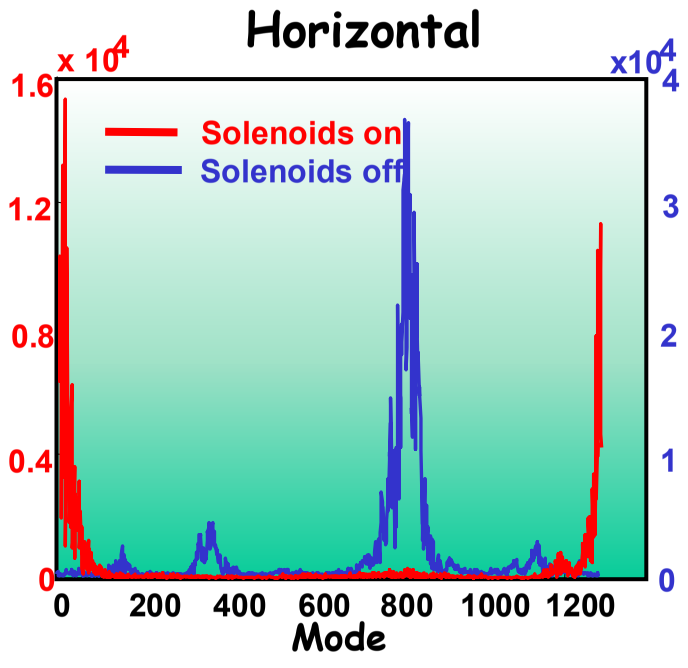


Figure 3: Mode spectra in horizontal plane at 600 mA beam current

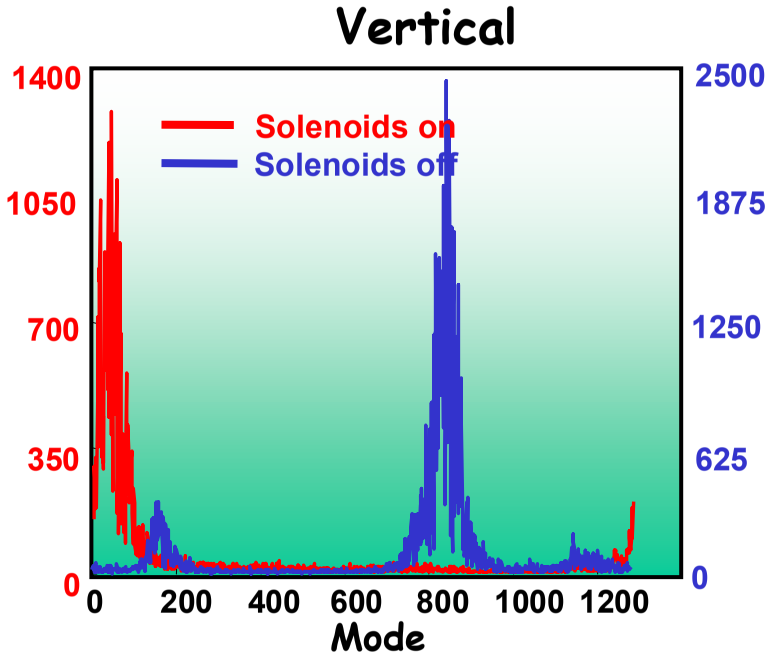


Figure 4: Mode spectra in vertical plane at 600 mA beam current

Fill pattern: 1 train/1153 bunches/8 ns bunch spacing Beam current: 600 mA

EXPERIMENTAL OBSERVATION OF TCBI (4)

Growth rates

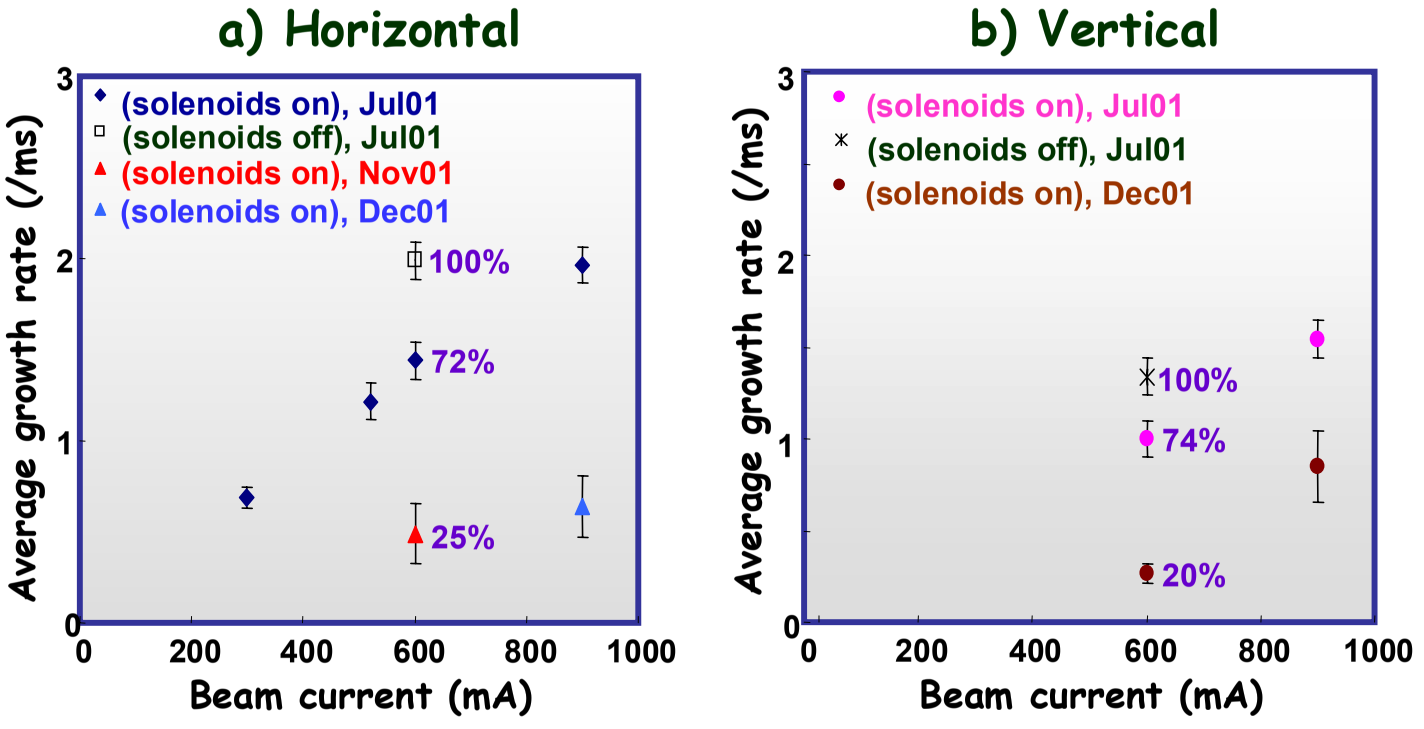


Figure 5: Observed growth rates when solenoid-off and solenoid-on in a) horizontal and b) vertical planes.

Simulation study of TCBI caused by electron cloud (1)

PEI model was used. (PEI was originally developed by K. Ohmi ,KEK).

Simulation parameters:

Beam energy (GeV)	3.5
Circumference (m)	3016
No. of train/No. of bunches	1/1153
Bunch current (mA)	0.52
No. of positrons per bunch	3.3×10^{10}
Average β_x/β_y (m)	10/10
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	18/0.36
Betatron tune ν_x/ν_y	45.52/43.57
Initial energy of photoelectrons(eV)	10 ± 5 (Gaussian)
Photoelectron yield	0.1
Secondary electron yield of copper δ_{max}/E_{max} (eV)	1.5/300

Assuming 2 cases:

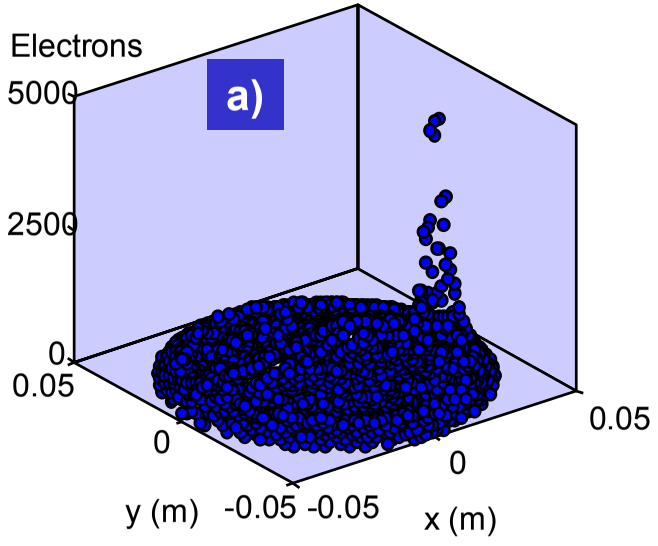
Case I: Electrons are mainly produced at the illumination point with 30% reflection

Case II: Electrons are produced uniformly over the surface

LER SIMULATION STUDY - SOLENOID-OFF (2)

Electron Distribution

Electron distribution 1



Electron distribution 2

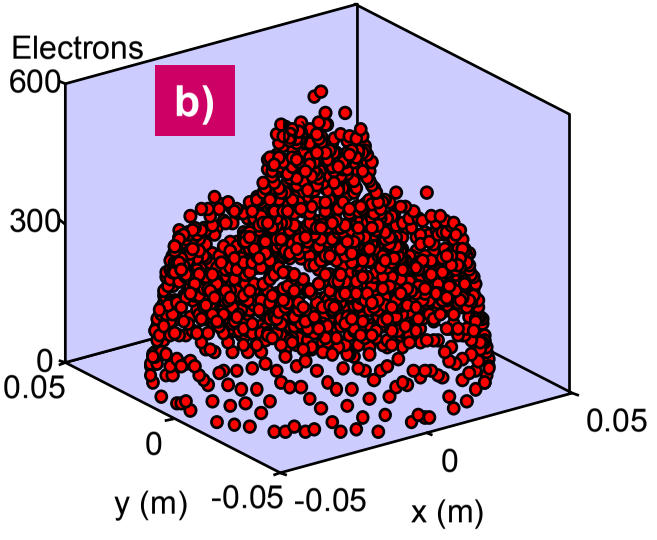
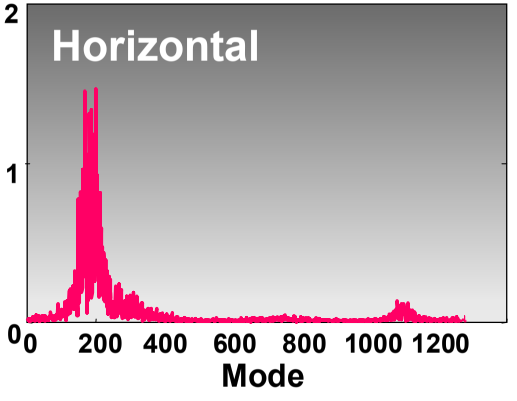
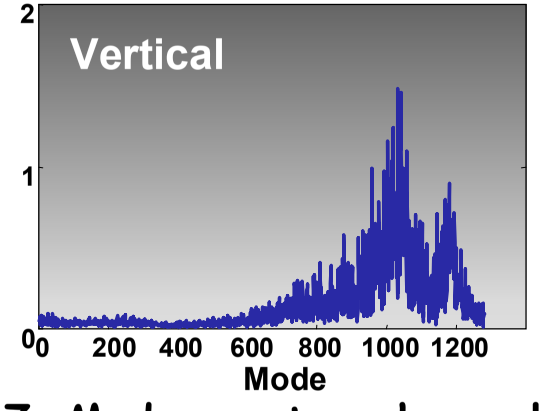


Figure 6: Electron distribution over cross-section of beam chamber assuming that photoelectrons are produced a) at illumination point with 30% reflection and b) uniformly on the surface of beam chamber.

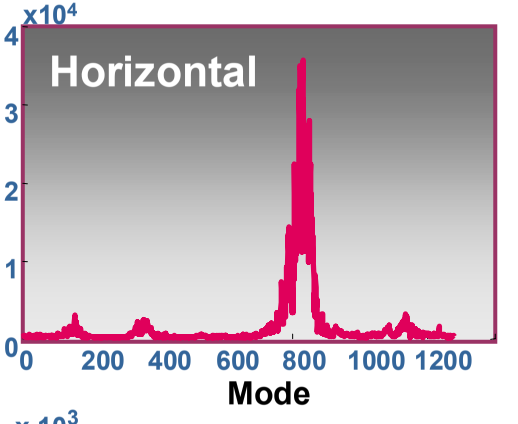
SIMULATION STUDY - SOLENOID-OFF (3)

Production of electrons at illumination point





Experiment



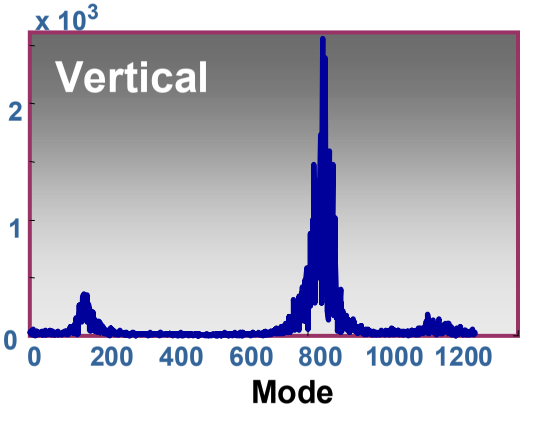
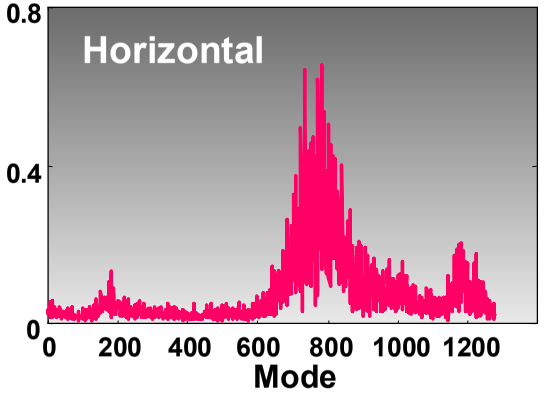
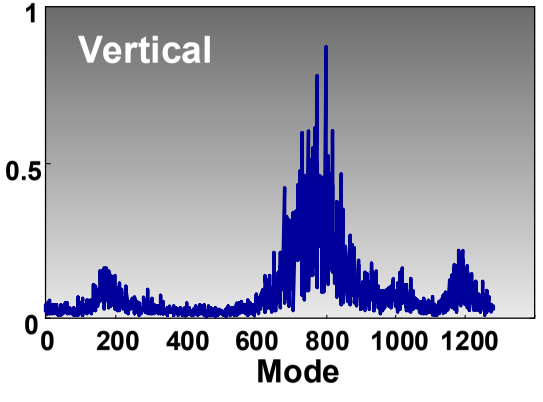


Figure 7: Mode spectra when solenoid-off assuming photo-electrons are produced at the illumination point with 30% reflection

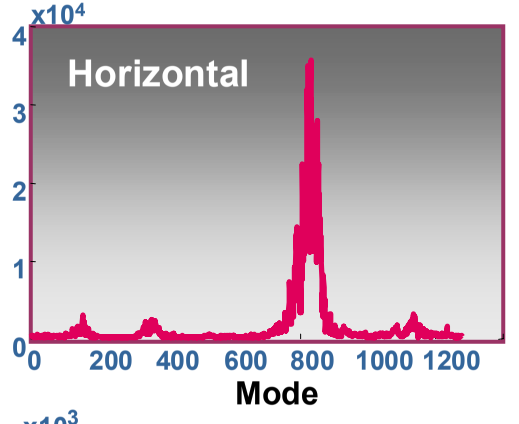
SIMULATION STUDY - SOLENOID-OFF (4)

Uniform production of electrons





Experiment



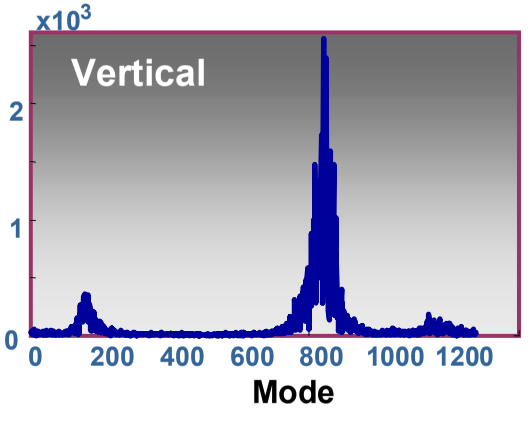


Figure 8: Mode spectra when solenoid-off assuming photo-electrons are produced uniformly on chamber wall

Production of electrons at illumination point [Solenoid-OFF & ON] (5)

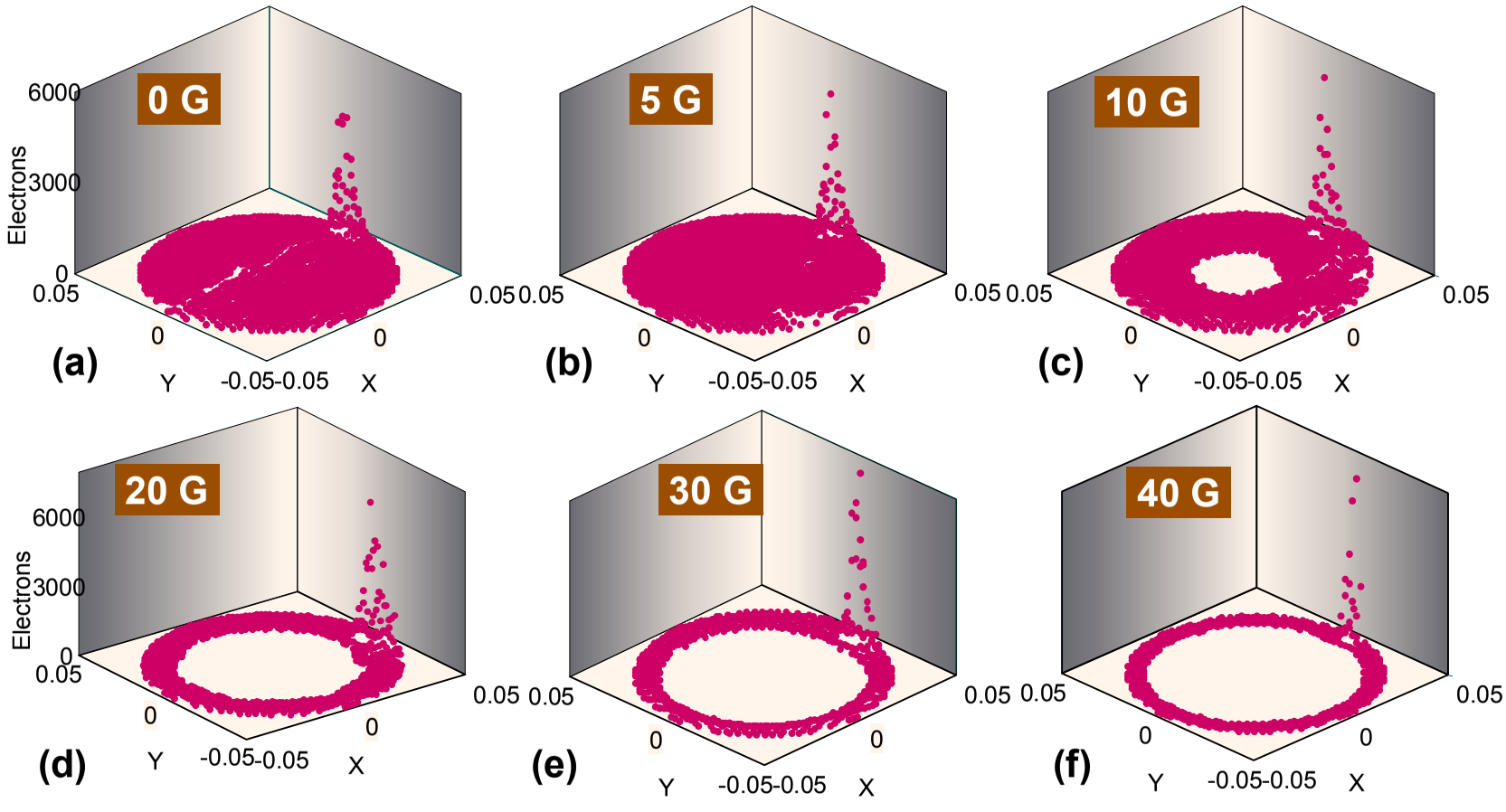


Figure 9: Projection of electrons over the cross-section of the vacuum chamber due to various solenoid fields in Case I. (X and Y in m)

Production of electrons at illumination point [Solenoid-OFF & ON] (6)

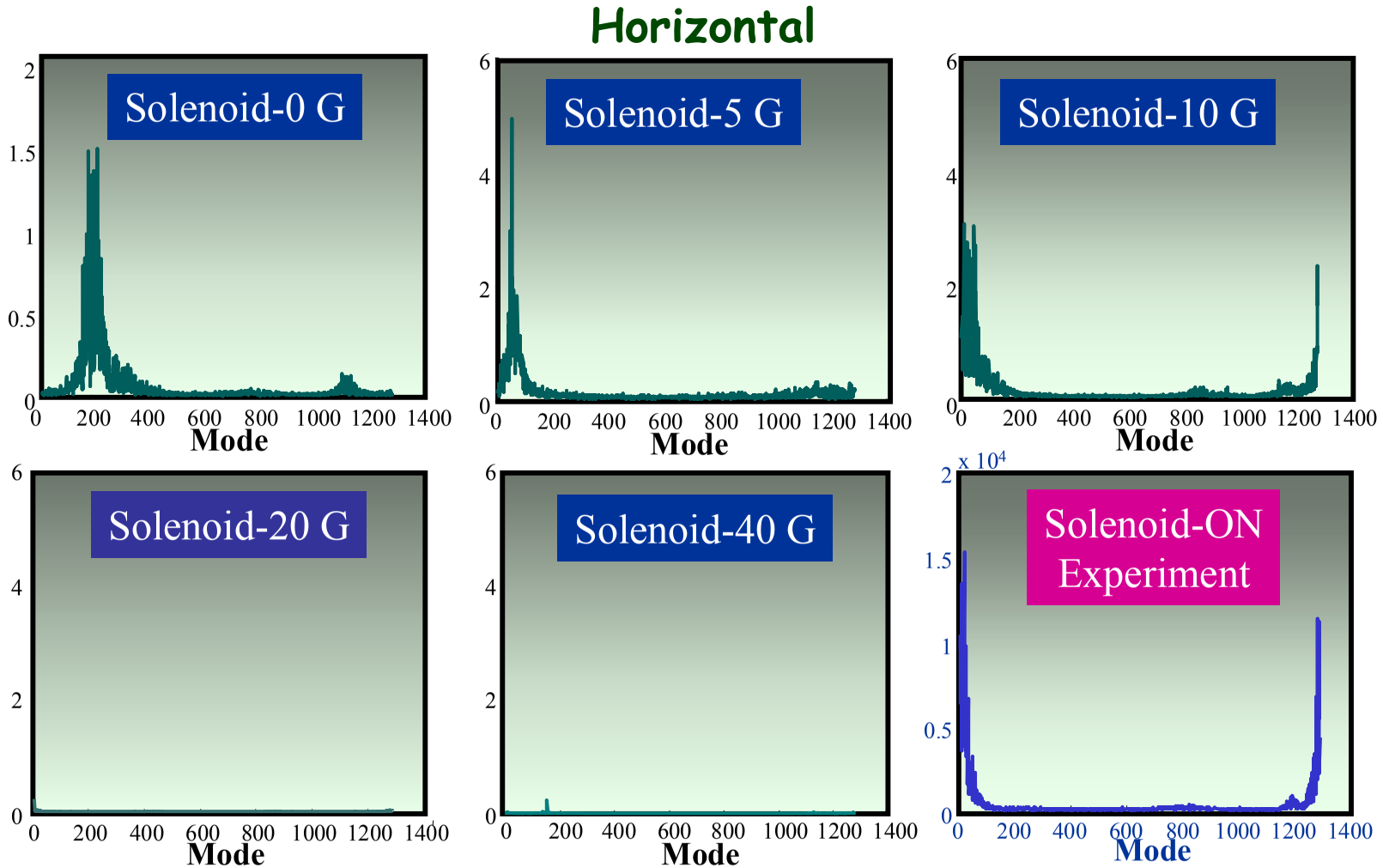


Figure 10: The mode spectra in horizontal plane due to various solenoid fields in Case I.

The mode spectrum due to 10 G solenoid field is consistent with the experimental observation.

Production of electrons at illumination point [Solenoid-OFF & ON] (7)

Vertical

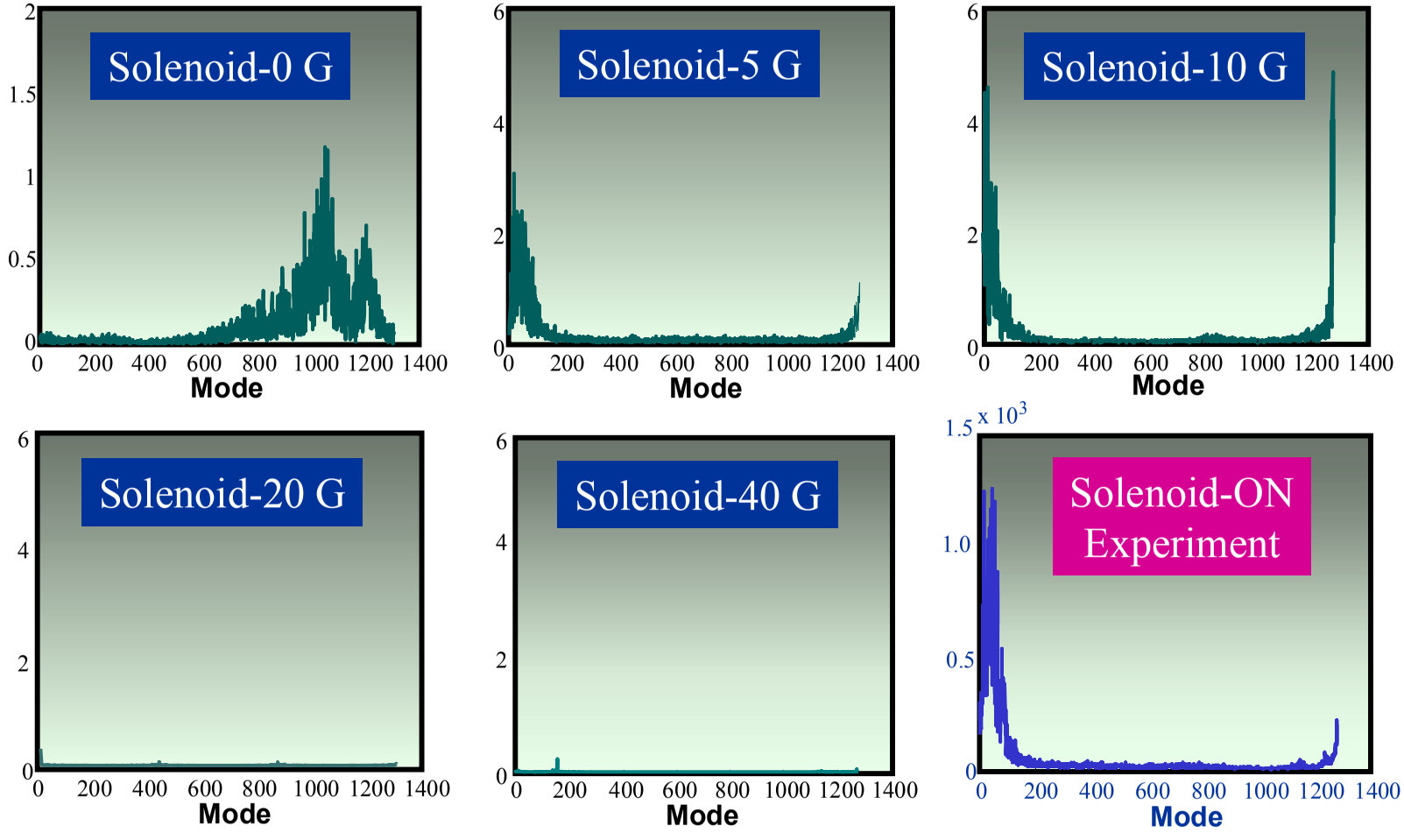


Figure 11: The mode spectra in vertical plane due to various solenoid fields in Case I.

The mode spectrum due to 5 ~10 G solenoid field is consistent with experimental observation.

Uniform production of electrons [Solenoid-OFF and Solenoid-ON] (8)

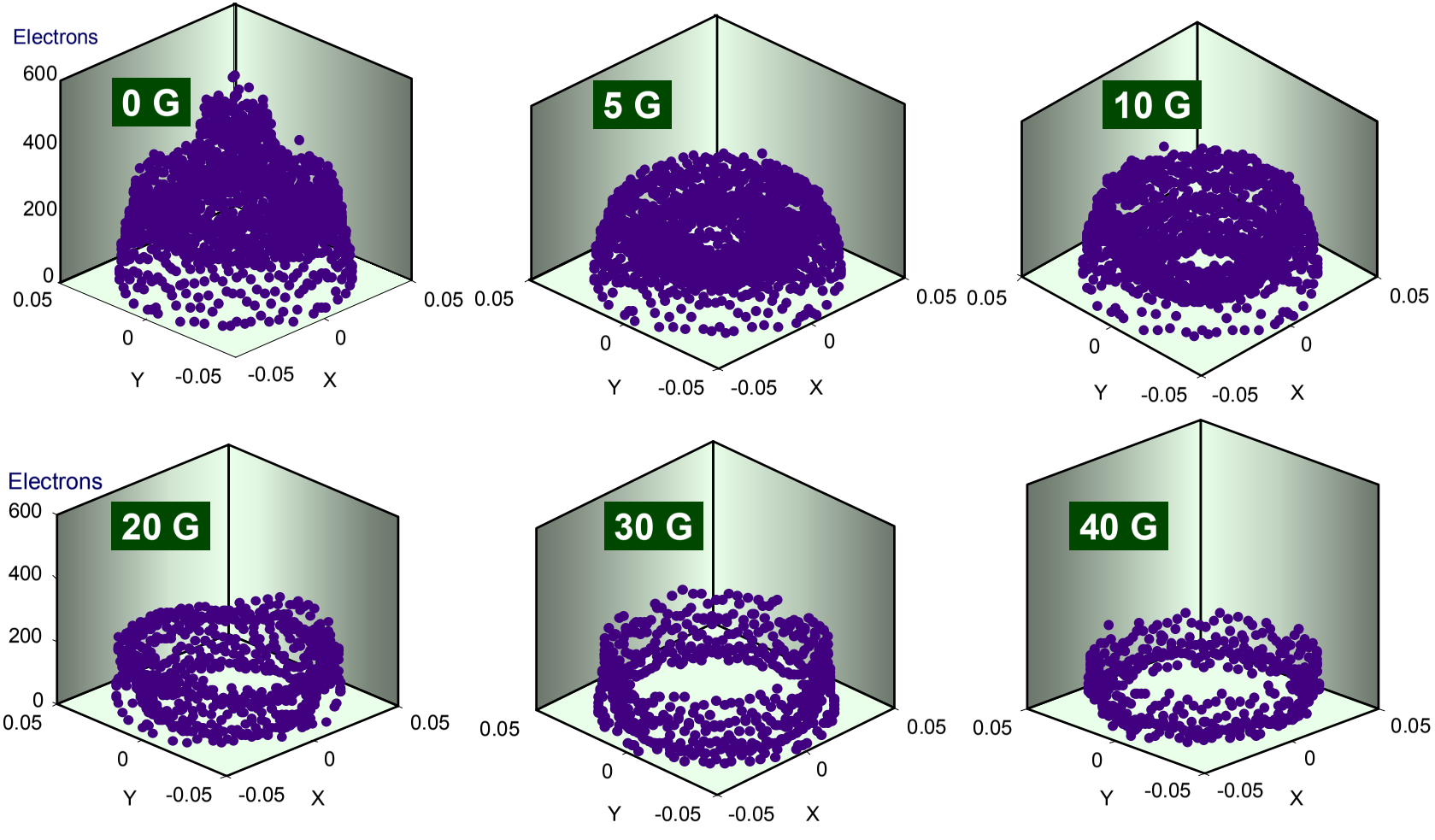


Figure 12: Projection of electrons over the cross-section of the vacuum chamber due to various solenoid fields in Case II. (X and Y in m)

Uniform production of electrons [Solenoid-OFF & ON] (9)

Horizontal

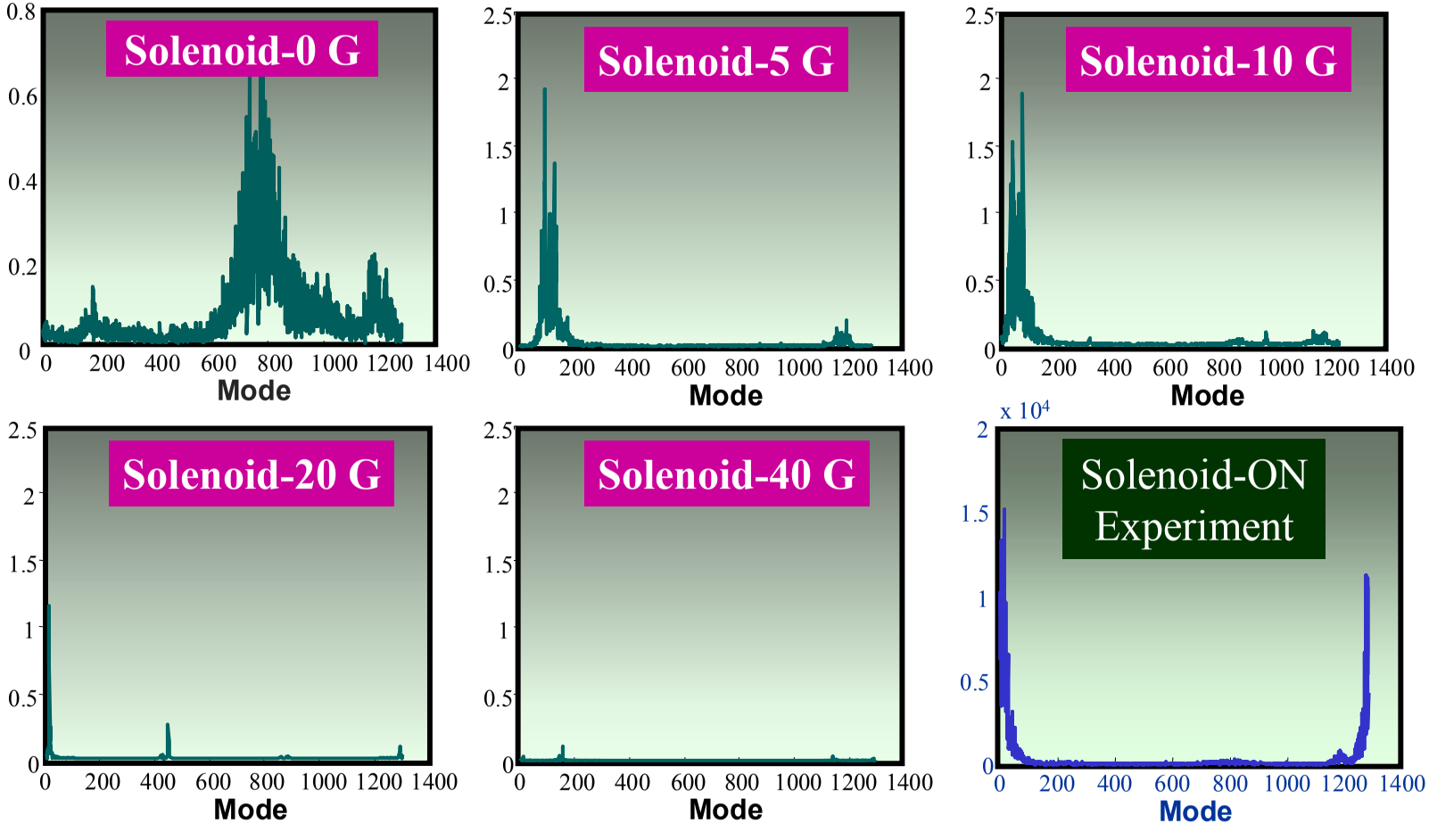


Figure 13: The mode spectra in horizontal plane due to various solenoid fields in Case II.
The mode spectrum due to 10 G solenoid field is consistent with the experimental observation.

Uniform production of electrons [Solenoid-OFF & ON] (10)

Vertical

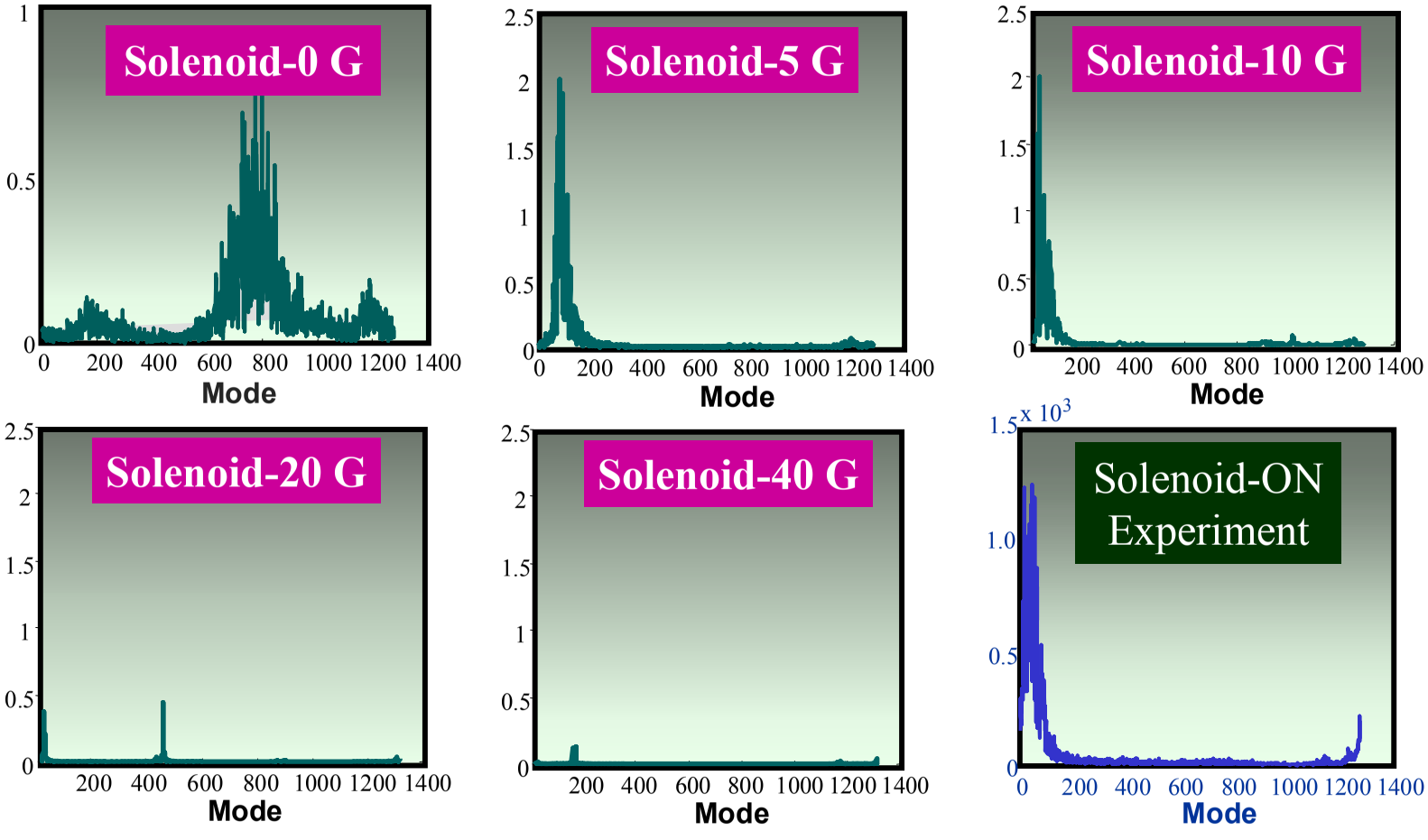


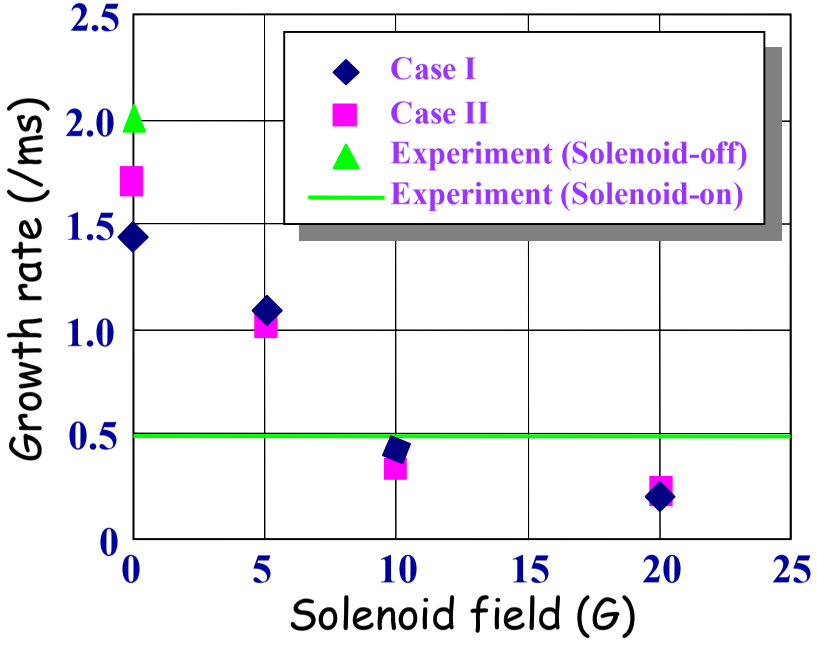
Figure 14: Mode spectra in vertical plane due to various solenoid field in Case II.

The mode spectrum due to 10 G solenoid field is consistent with the experimental observation.

SIMULATION STUDY - SOLENOID-OFF and ON (11)

Growth rates

a) Horizontal



b) Vertical

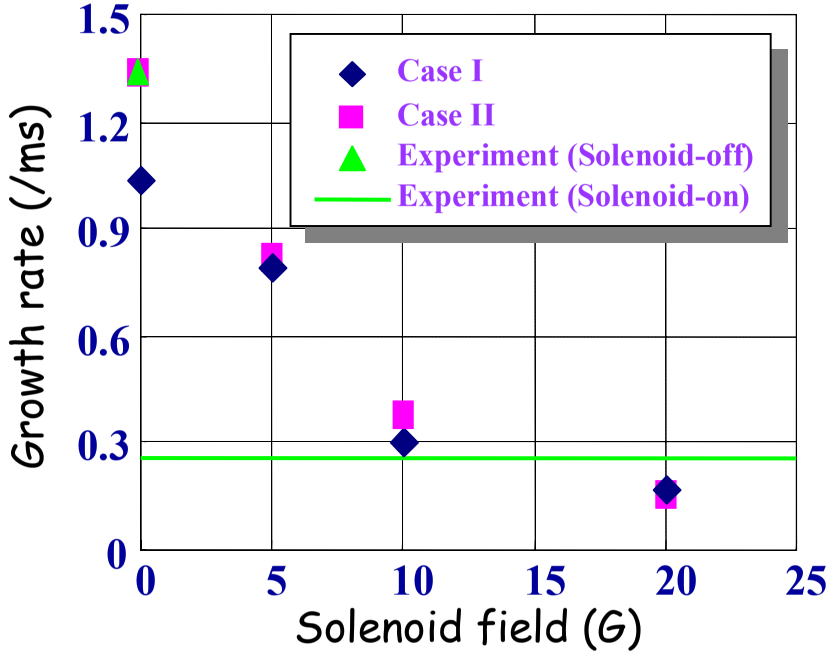


Figure 15: Average growth rate of bunch oscillation with and without solenoid fields assuming Case I and Case II in (a) horizontal and (b) vertical plane.

Case I. Photoelectrons are produced at the illumination point with 30% reflection.
Case II. Photoelectrons are produced uniformly over the surface of vacuum chamber.

Summary

We performed

- experimental study of the TCBI with solenoid off/on and
- simulation study of the coupled bunch instability due to the electron cloud without and with applying various solenoid fields.

The results show that:

- From the experiment, the transverse coupled bunch instability observed in the KEKB-LER is caused by the electron cloud.
- From the comparison between experiment and simulation results, it is suggested that the electrons are produced uniformly over the surface of the vacuum chamber.
- The effective solenoid field is not less than 10 G to explain the observed mode spectra and the growth rates of the coupled bunch instability.