Experimental Study on Clearing Electrode at KEKB Positron Ring

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Introduction

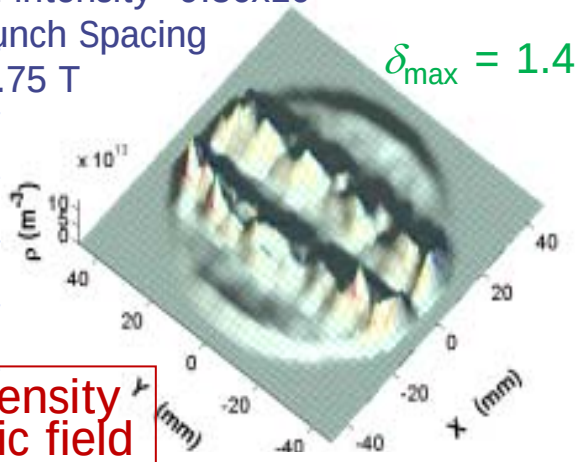
- Clearing Electrode = A possible solution to suppress electron cloud in magnets.
  - Drift space :Solenoid is available.
  - Drastic reduction in EC was indicated by simulations.
- Experimental study on a clearing electrode using KEKB positron ring is planned, as a chain of ILC DR R&D study.
- Goal
  - Developing a clearing electrode with low beam impedance, and available for high current machine.
  - Demonstrate the effect of electrode on electron cloud formation.

Introduction

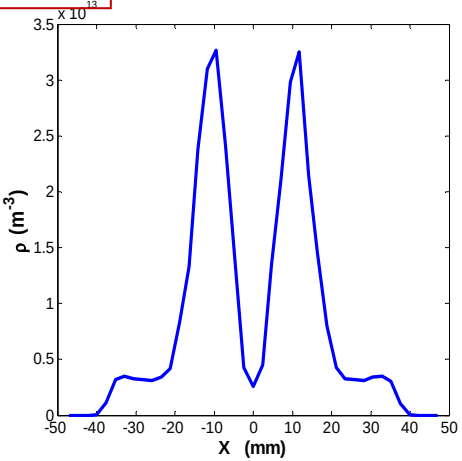
- Simulation

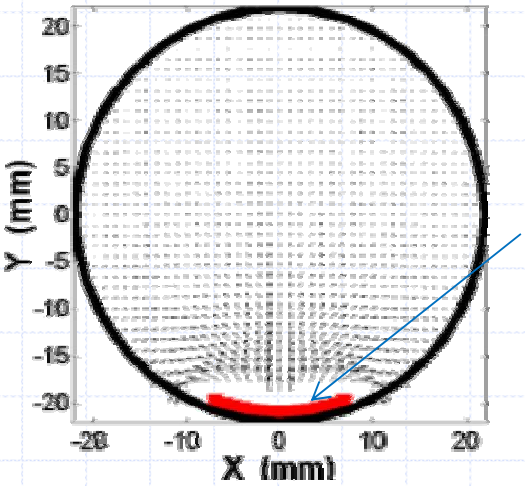
R-pipe=38mm
bunch intensity=9.36×10^{10}
3.5 Bunch Spacing
B = 0.75 T

δ_{max} = 1.4

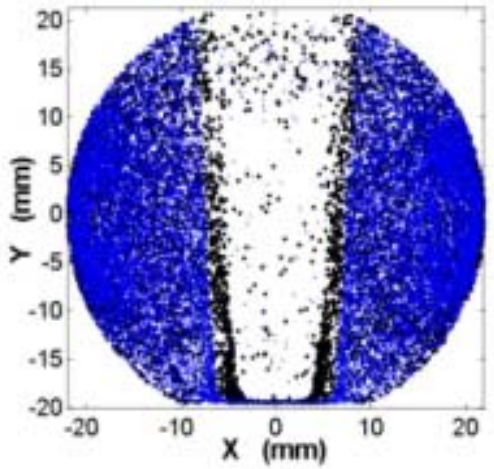


Electron density in magnetic field





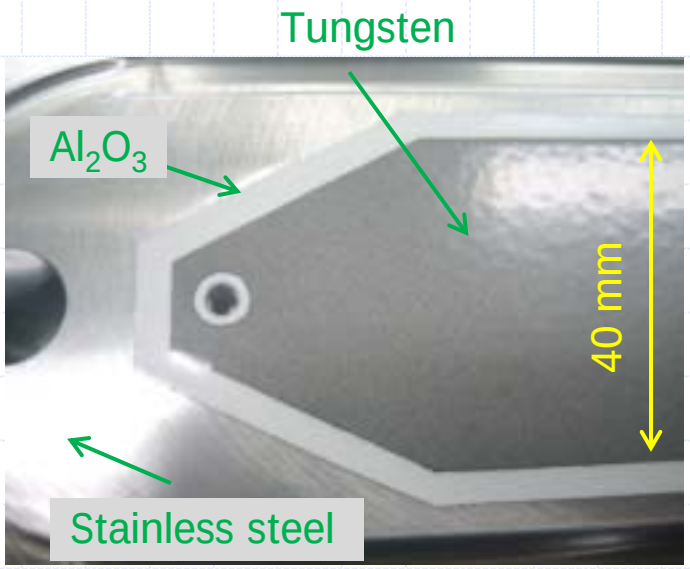
Electrode (+)

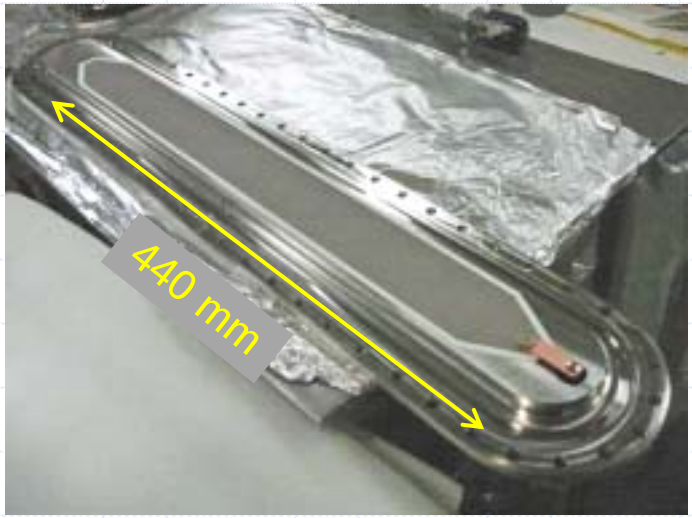


L. Wang et al, EPAC2006, p.1489

Electrode

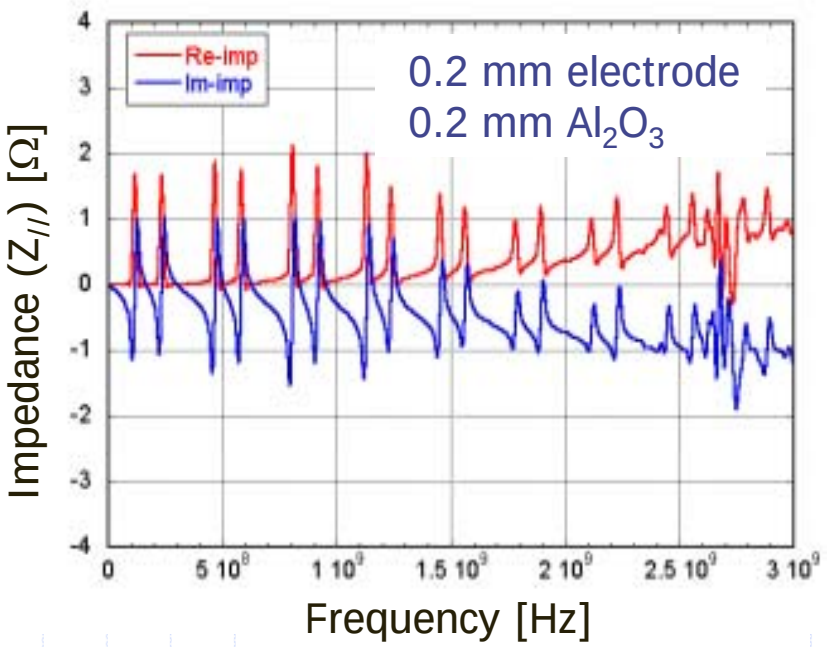
- New strip type electrode was developed.
- Very thin electrode and insulator;
  - Electrode: ~0.1 mm, Tungsten, by thermal spray.
  - Insulator: ~0.2 mm, Al_2O_3, by thermal spray.



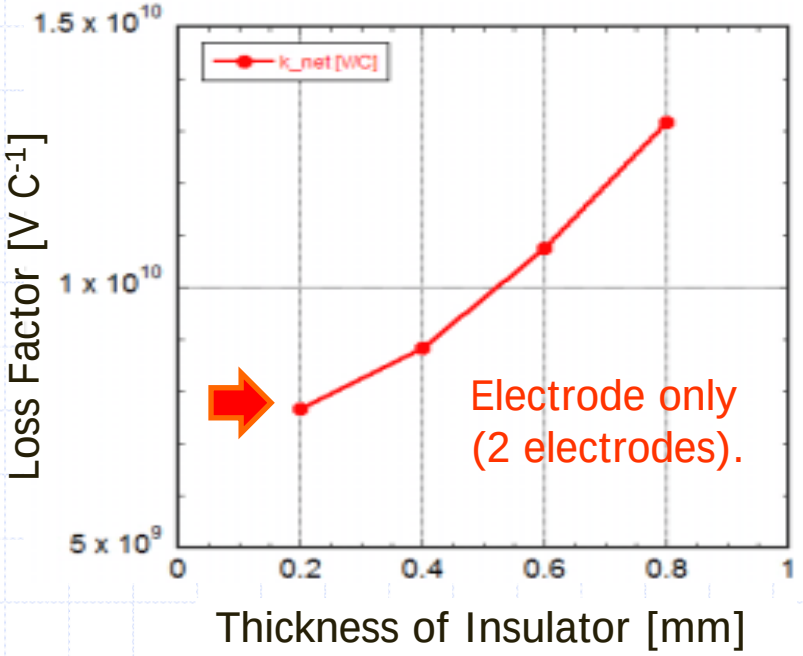


Electrode

- RF properties (calculation by MAFIA)
  - Thin electrode and insulator→ Low beam impedance



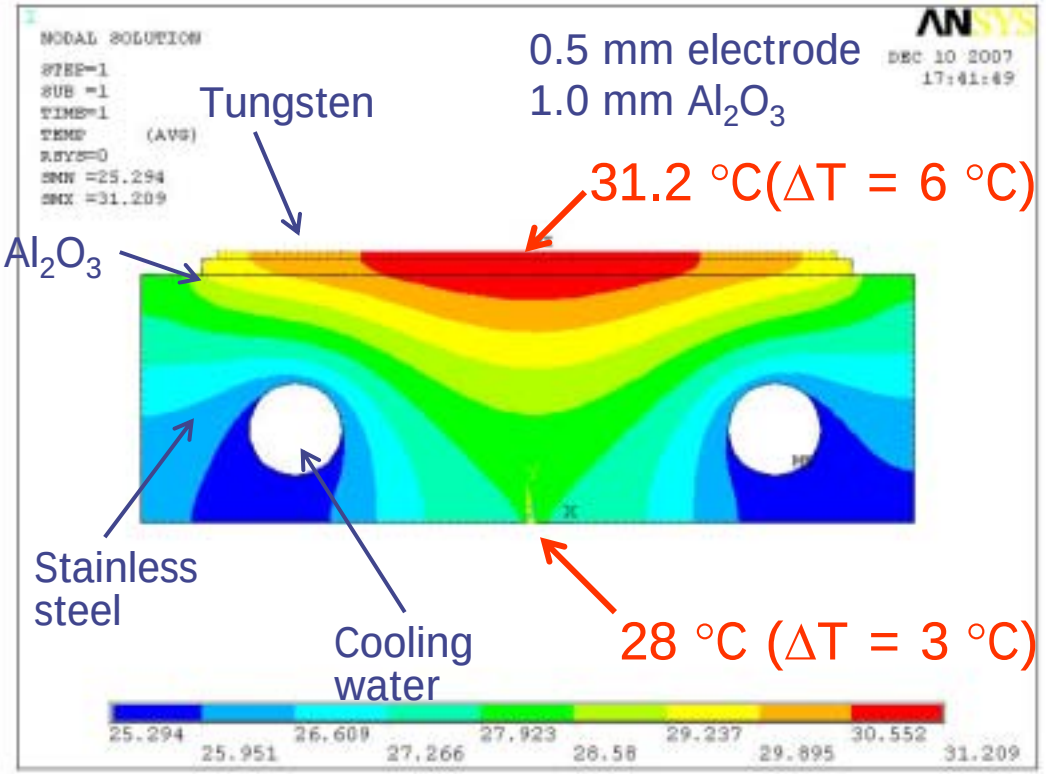
- $Z_{//}$ ~ a few Ohm
- $Z_{//}$ reduced to ~1/5 compared to the case of 1 mm thick.
- R/Q ~ 0.1



- k ~1.5x10^{10} V/C including the connection part (2 electrodes).
- Dissipated power is ~ 120 W for 1 electrode. (@1.6 A,1585 bunches)

Electrode

- Heating (simulation by ANSYS)
  - Expected T for 100 W input

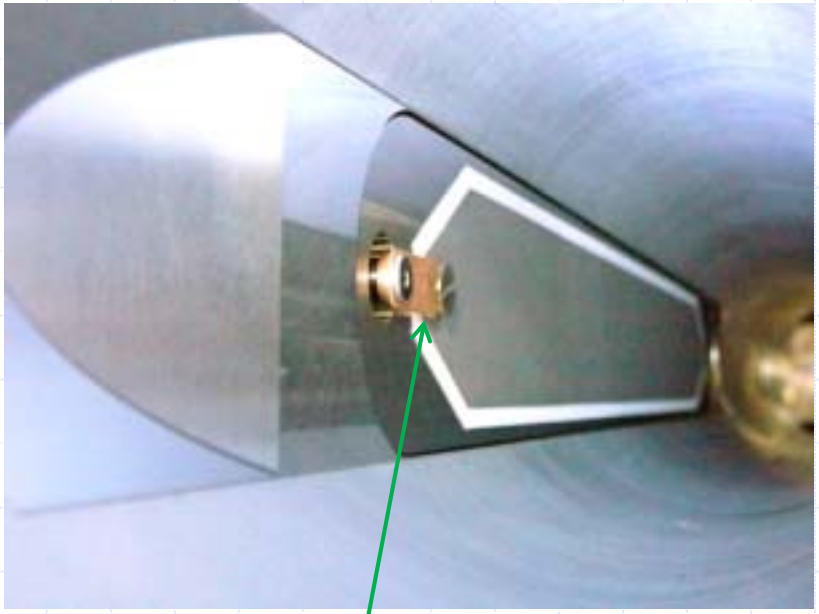


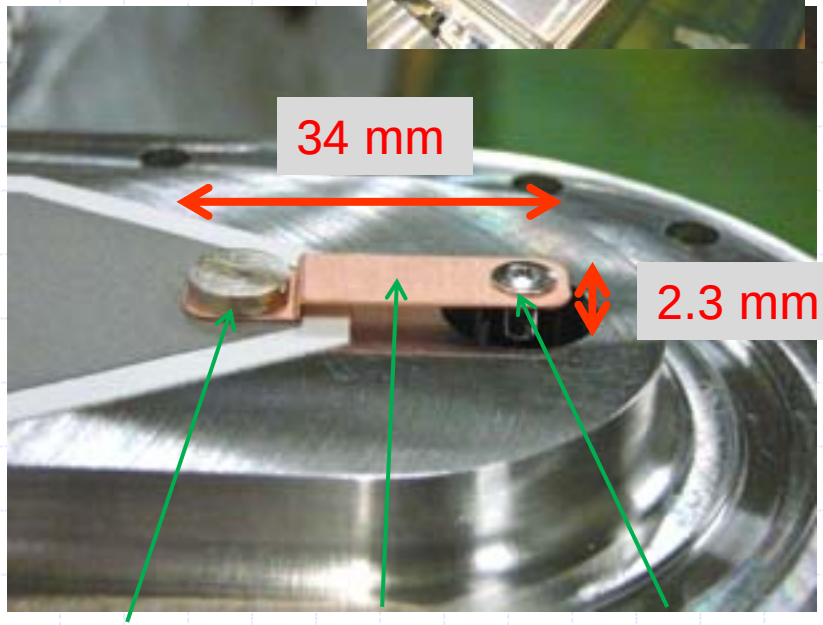
- ΔT ~ 6 °C owing to good thermal conductivity between the electrode and chamber.

Heat transfer coefficient between chamber and water = 0.01 W $mm^{-2}K^{-1}$
Temperature of water = 25 degrees.
λ(SS) =0.017 W $mm^{-1}K^{-1}$
$\lambda(Al_2O_3)$=0.03 W $mm^{-1}K^{-1}$

Electrode

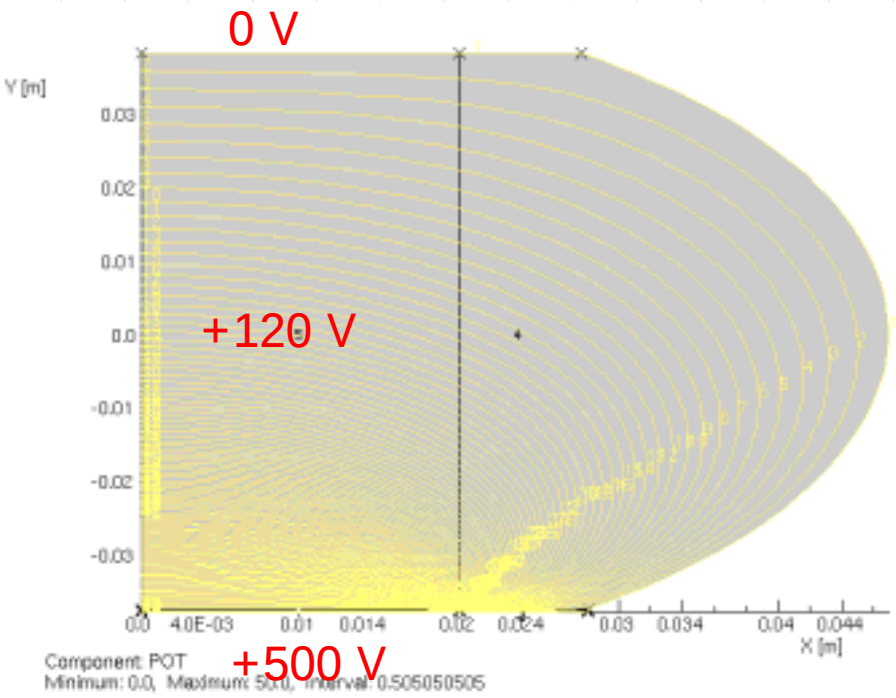
- Assembly to the chamber and connection part
  - The chamber can be baked up to 140 °C.





Electrode

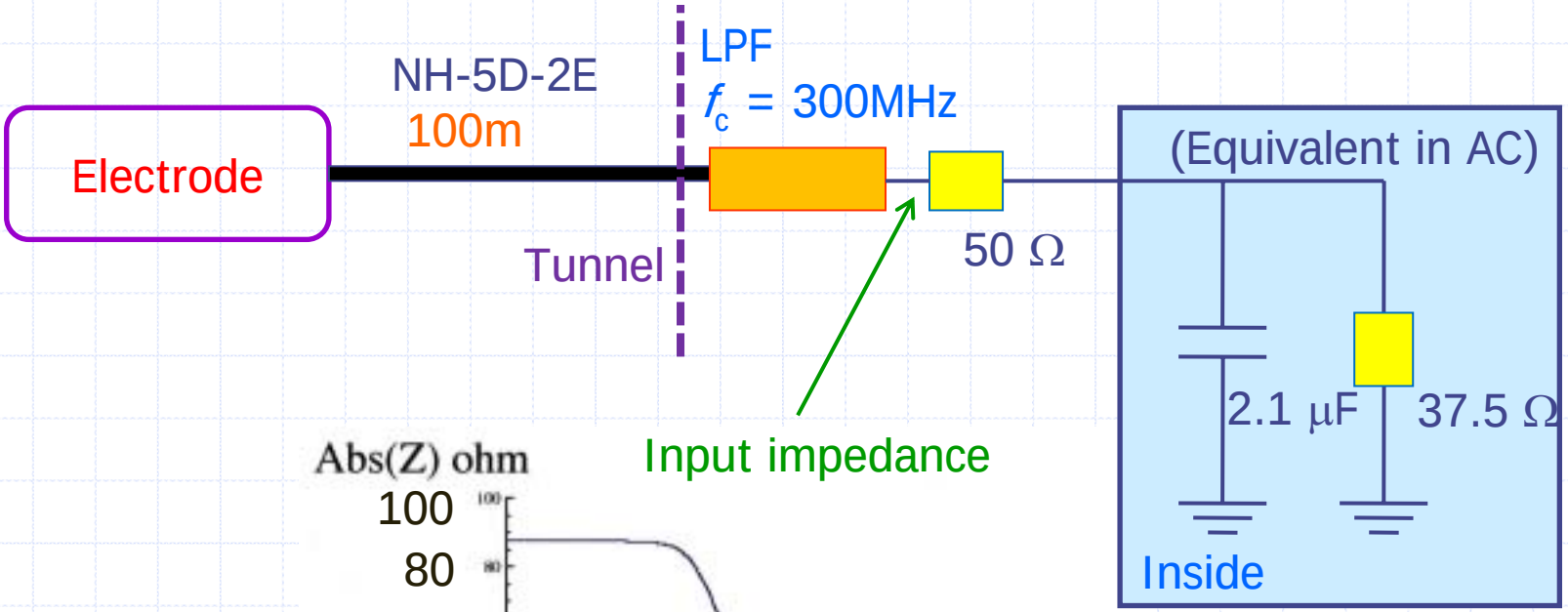
- Notes
  - Potential distribution

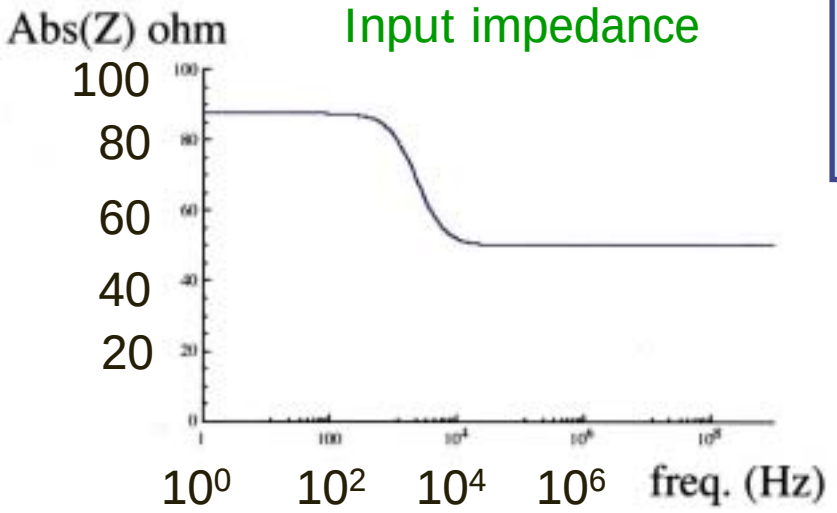


- Similar structure to "Invisible Electrode" by F. Caspers (PAC07).
- Difference: Electrode is made of pure metal (W).
- We used pure metal:
  (1) To avoid Joule loss of the electrode due to high current
  (2) To reduce voltage drop along the long electrode.

Power Supply for Electrode

- Power supply





Input impedance

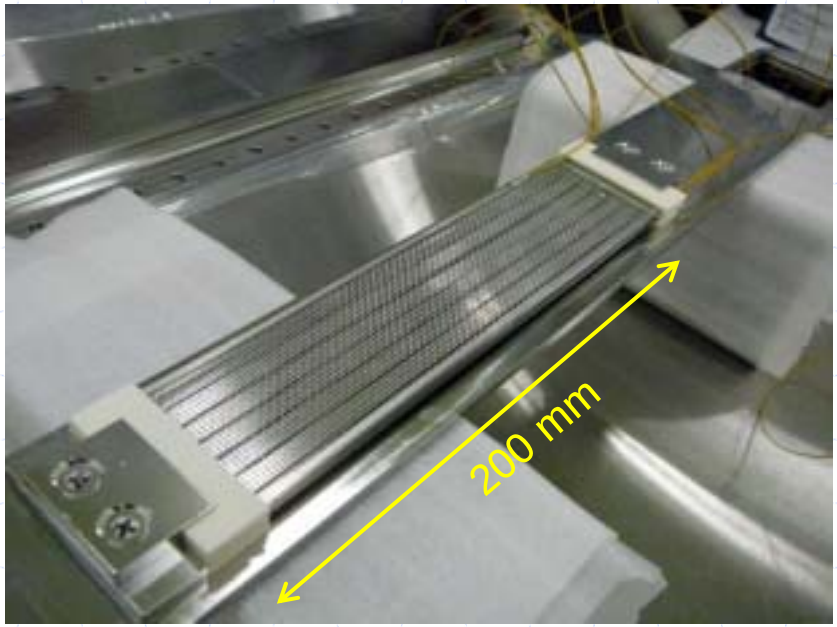
Power supply
HV1.5-0.3, Takasago

V_{max} = 1.5 kV,
I_{max} = 30 mA

Electron Monitor

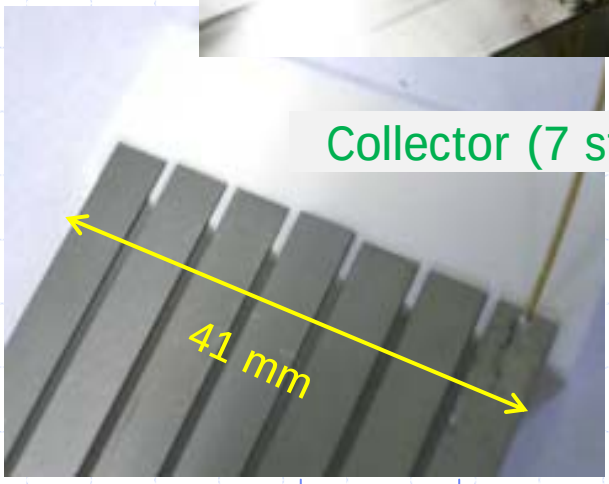
- 7 strip-type collectors measure the horizontal spatial distribution of electrons.

Monitor part



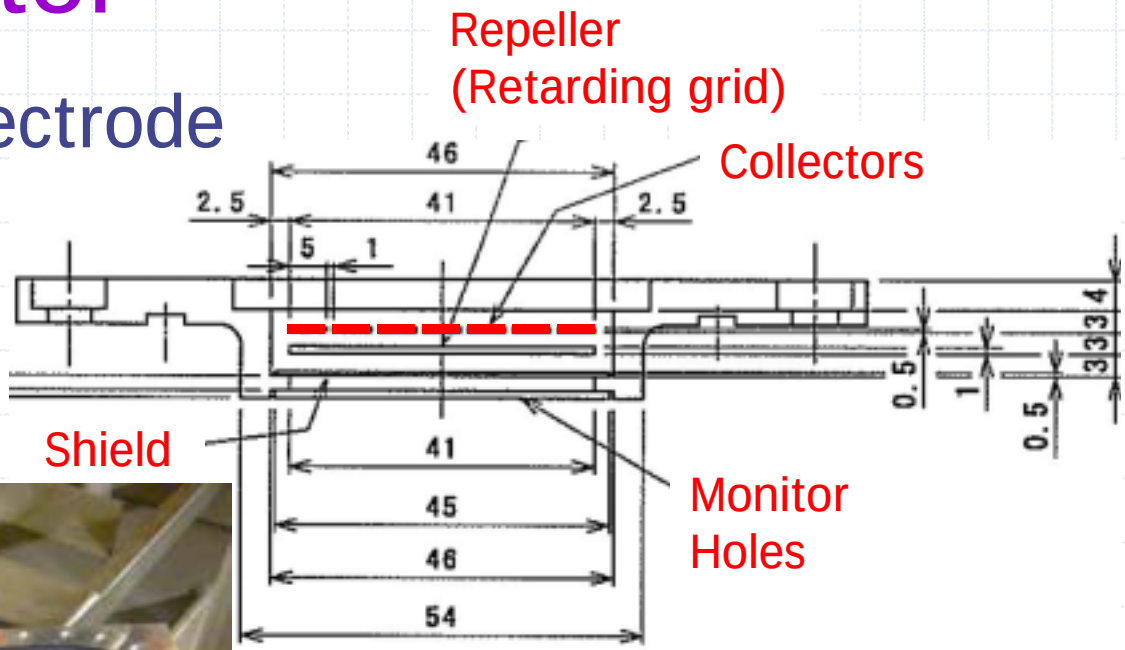
Output feed-through

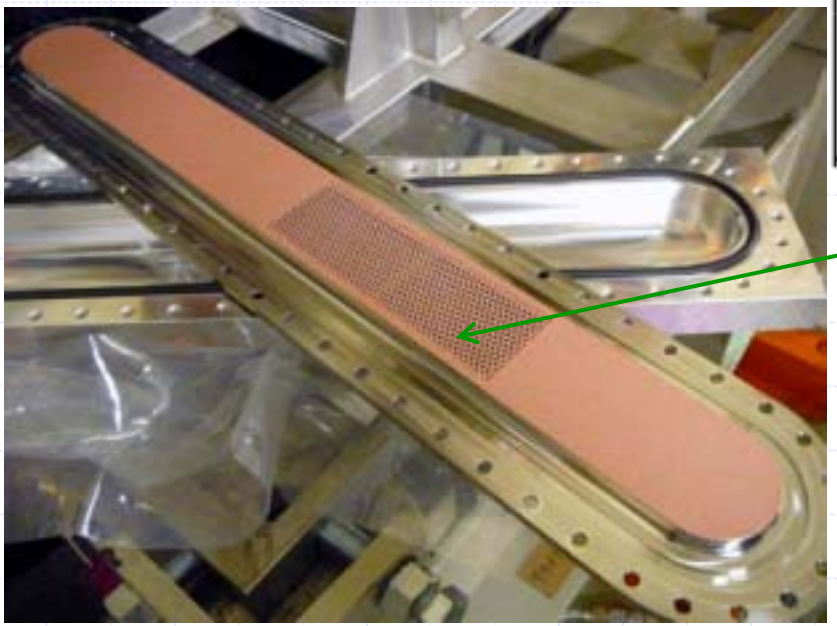
Collector (7 strips)



Electron Monitor

- Assembly of electrode
  - Four layers
  - With RFA



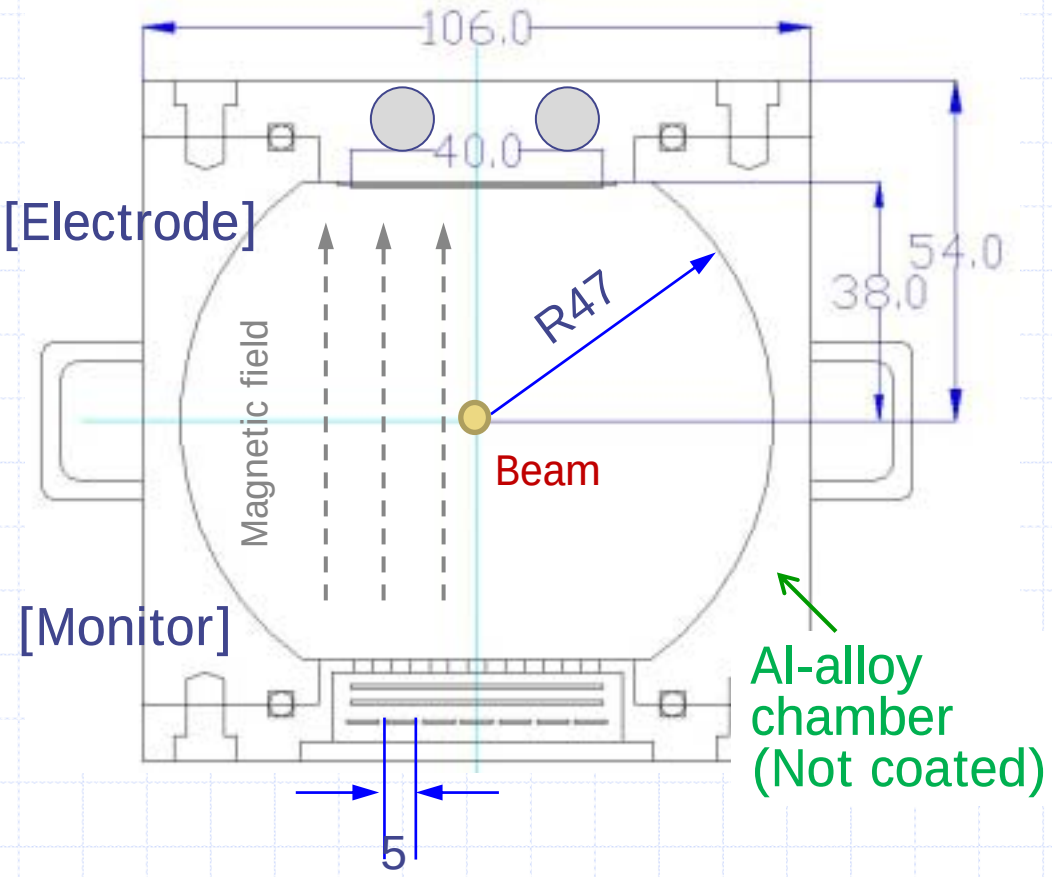


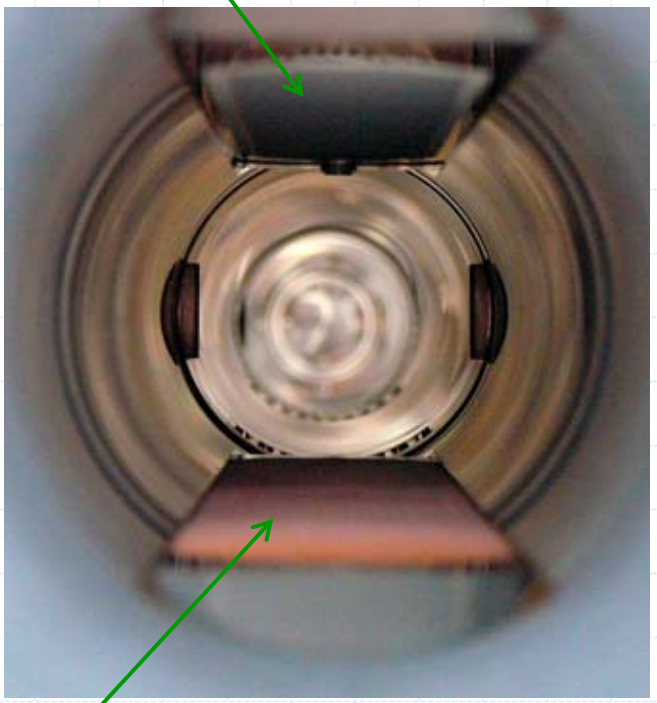
Monitor holes (ϕ2 mm, 3mm pitch)

- Applied voltage
  Collectors: +100V
  Retarding Grid: 0 ~ -1 kV
- Measurement: DC mode

Test chamber

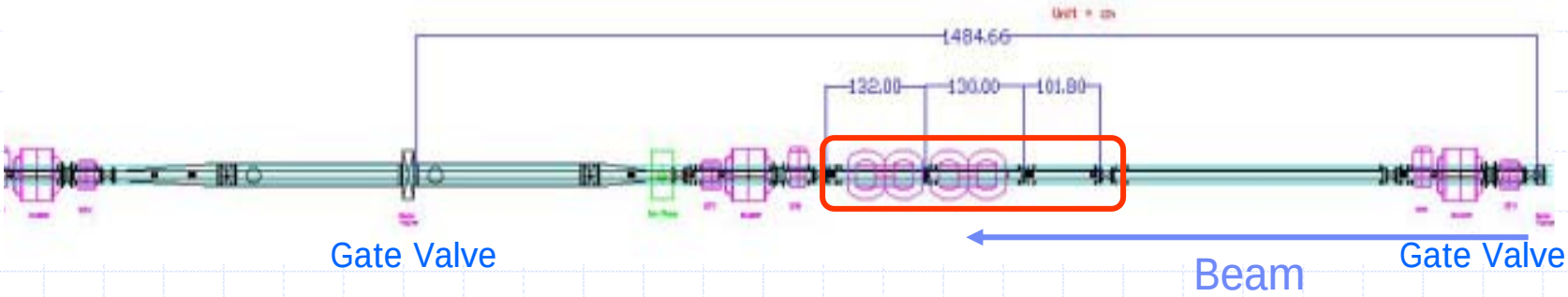
- Electrode and monitor are set face to face
  - Electrode and monitor are detachable.





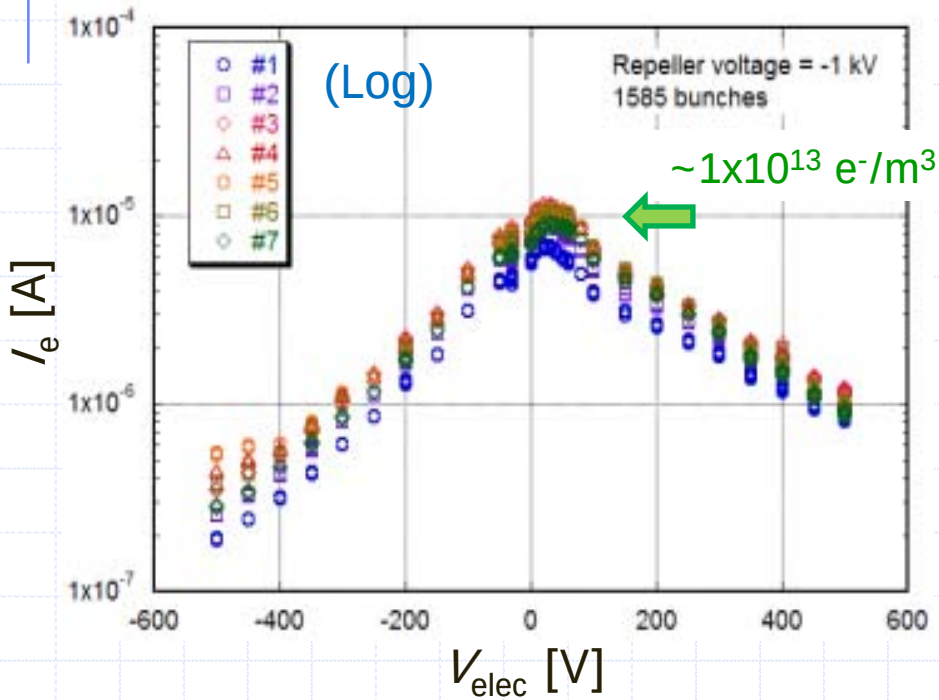
Experimental Setup

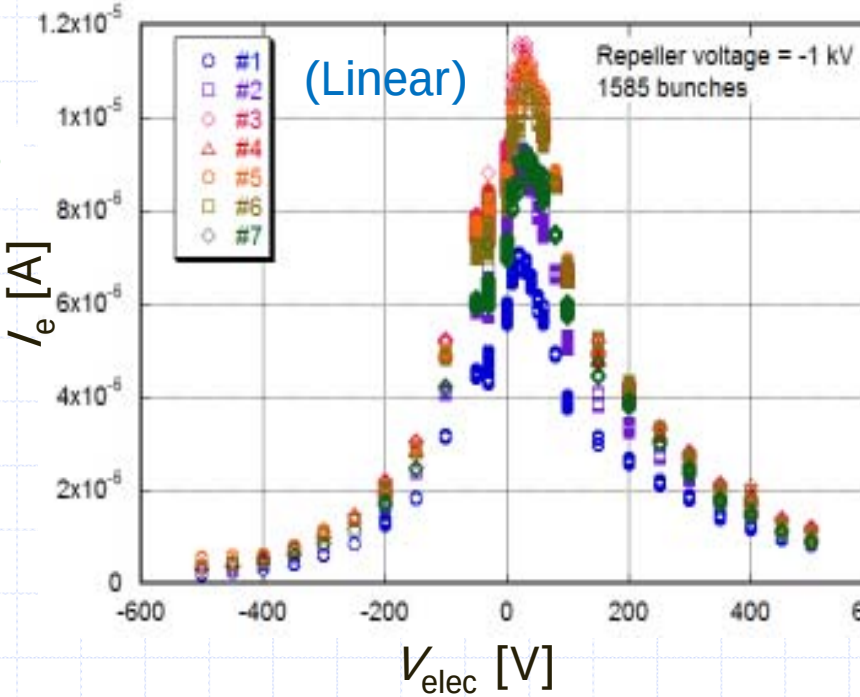
- Test chamber was installed into KEKB Positron ring (Low Energy Ring).
  - 3.5 GeV positron
  - σ_z = 6 ~ 7 mm
  - Beam current (I_b) ~1600 mA
  - Bunch spacing (B_s) 4 ~16 ns
- Wiggler magnet.
  - Magnetic field: 0.75 T
  - Effective length: 346 mm
  - Aperture (height): 110 mm



Results in Field-Free Region

- At first, installed in field-free region
  - 1585 bunches (B_s ~ 6 ns), I_b = 1600-1620 mA
  - V_r (repeller voltage) = -1 kV
  - V_{elec} (electrode voltage) = +500V ~ -500V

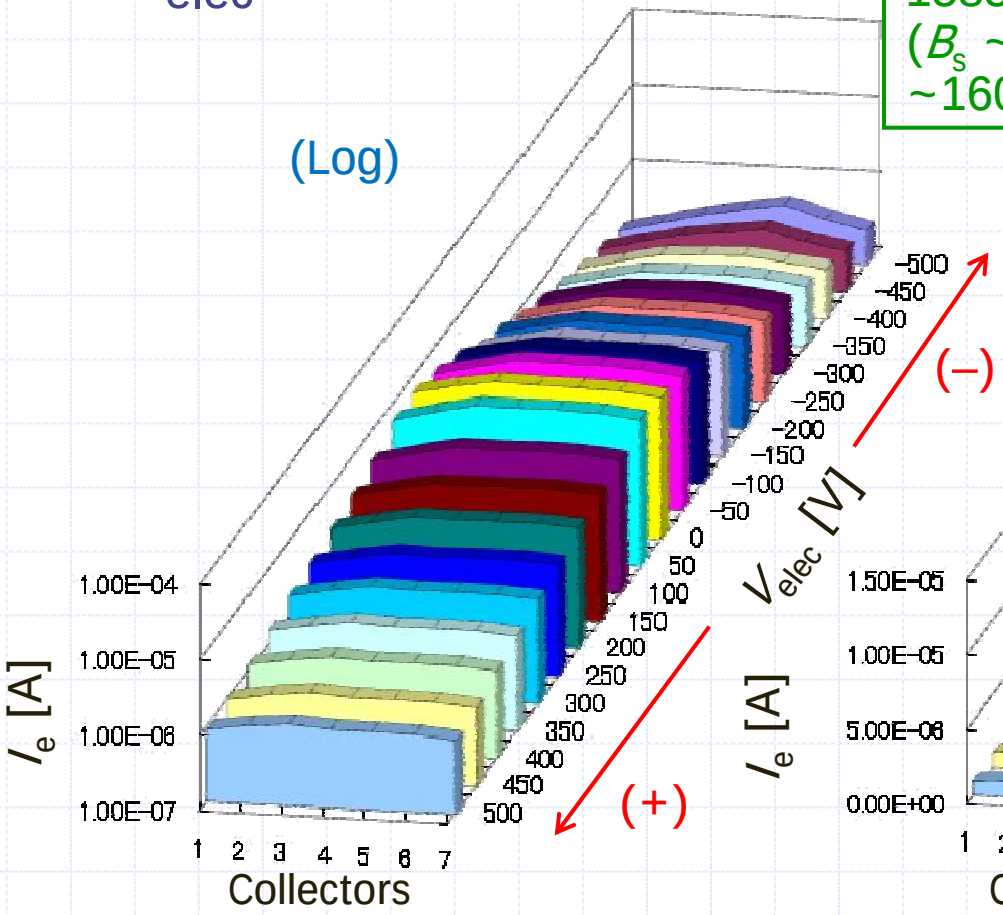


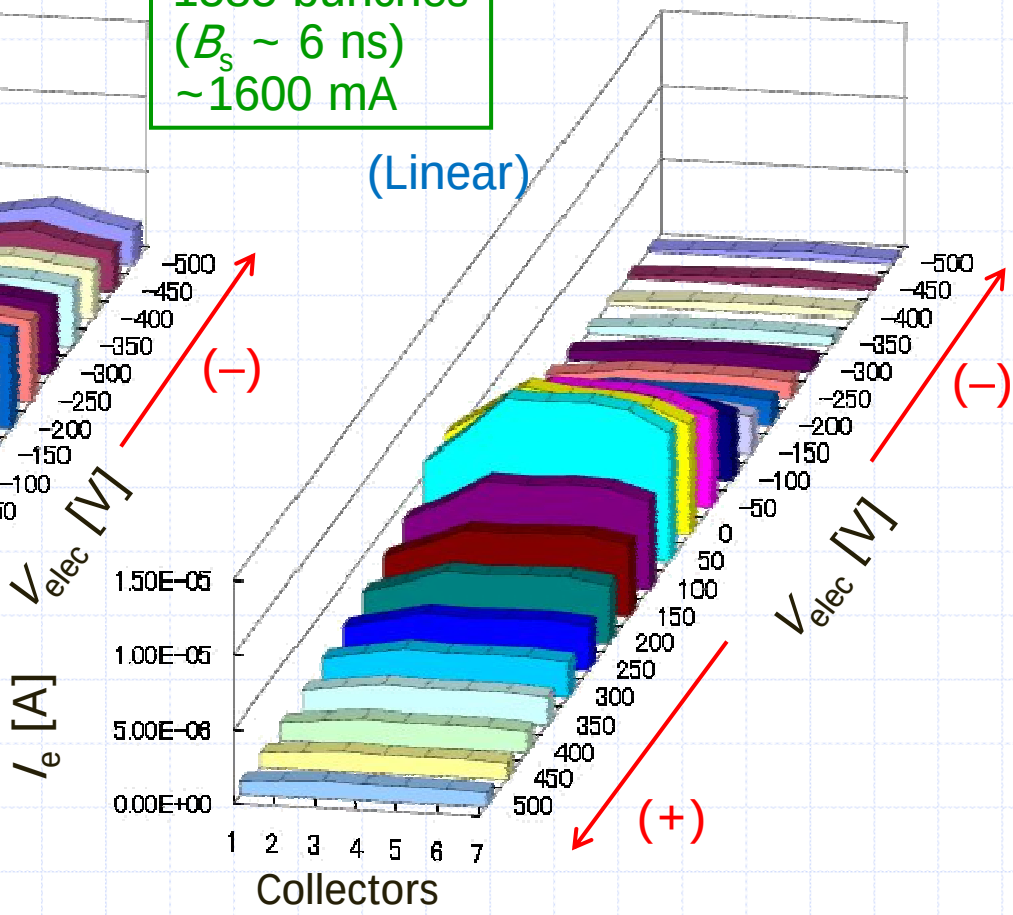


Results in Field-Free Region

- Electron density decreased to < 1/10 at $V_{elec} = \pm 500$ V.

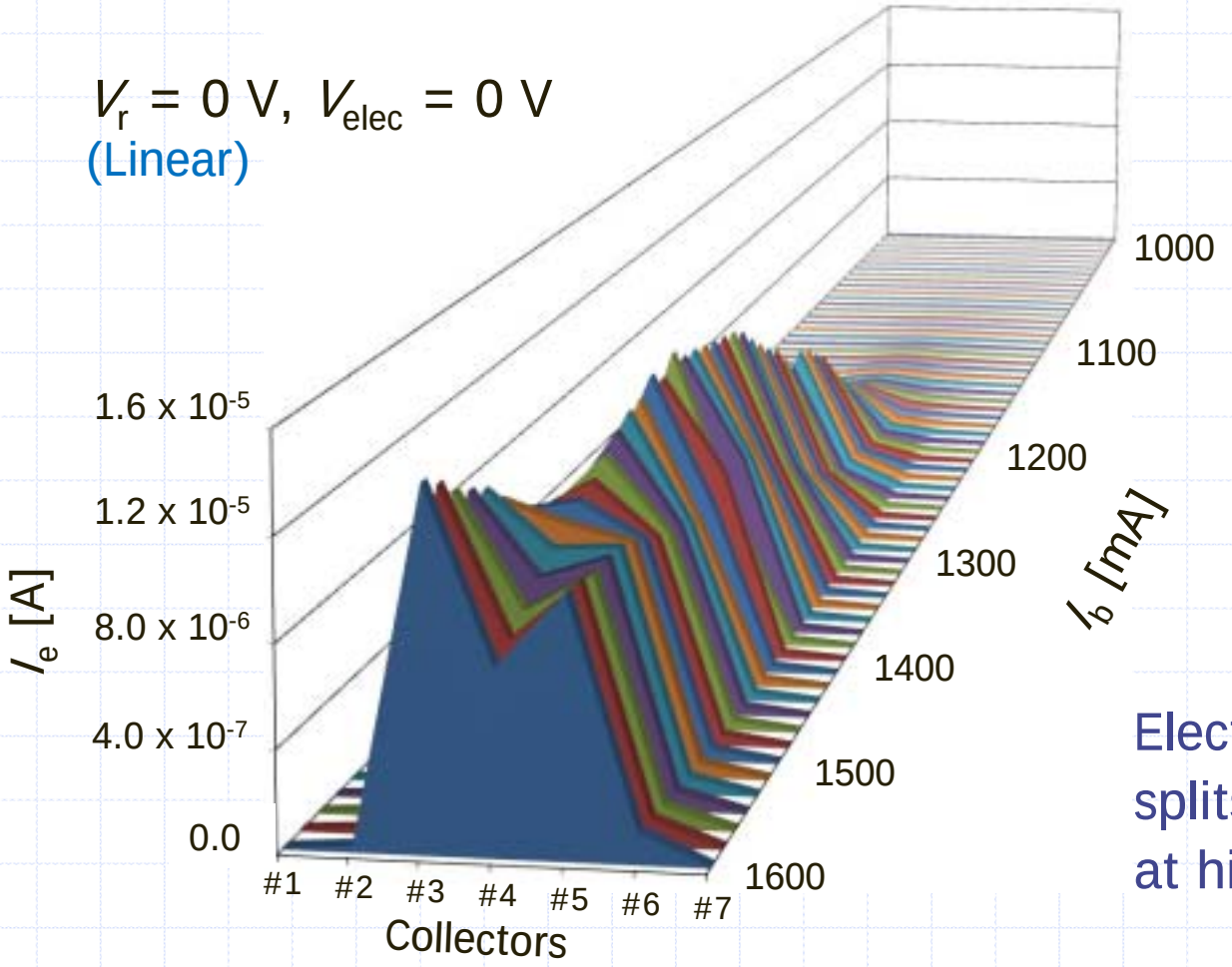
1585 bunches
(B_s ~ 6 ns)
~1600 mA





Results in Magnetic Field

- Spatial distribution during beam injection

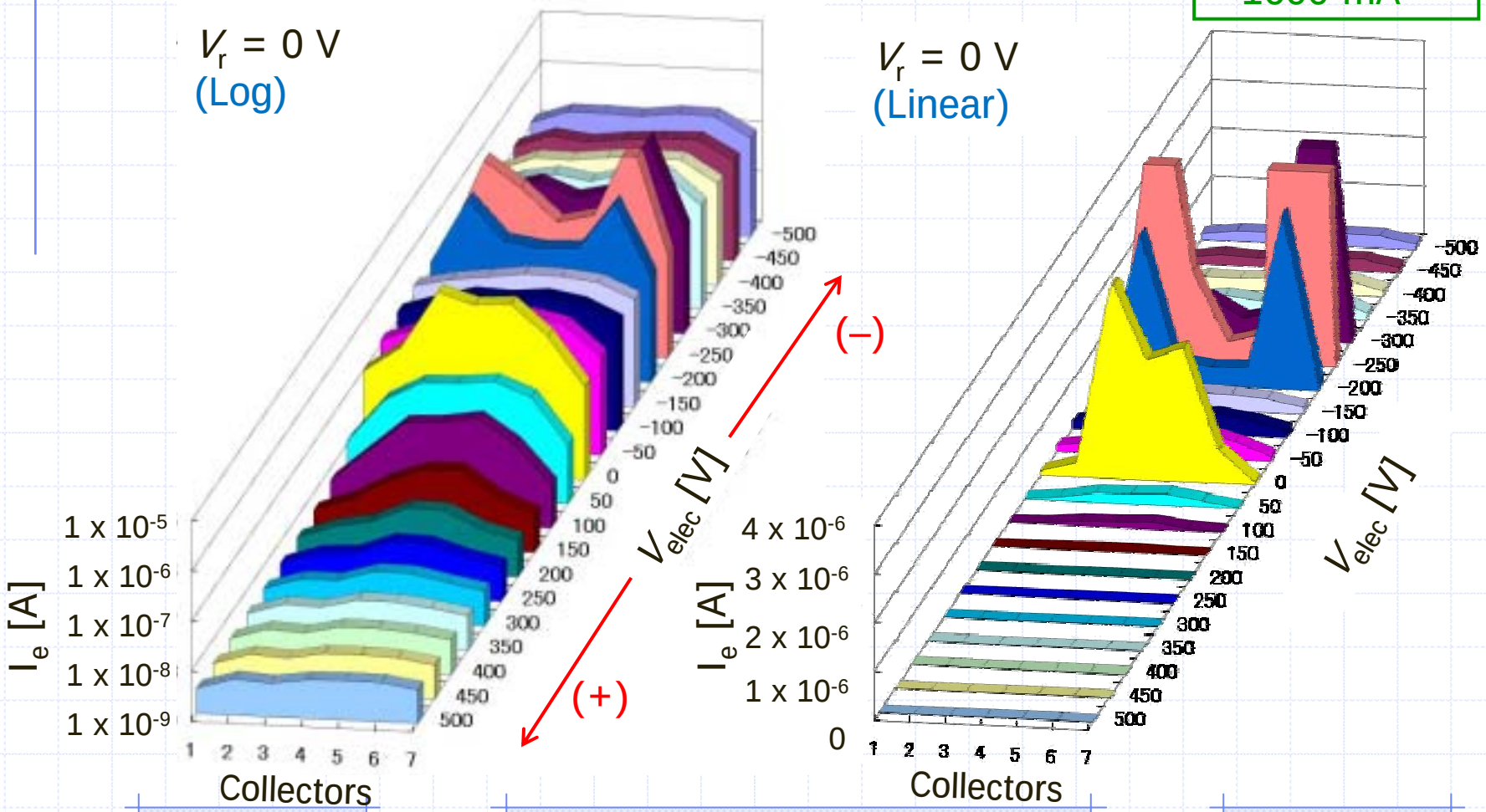


Electron distribution splits to two peaks at high current.

Results in Magnetic Field

- Effect of electrode voltage (V_{elec})

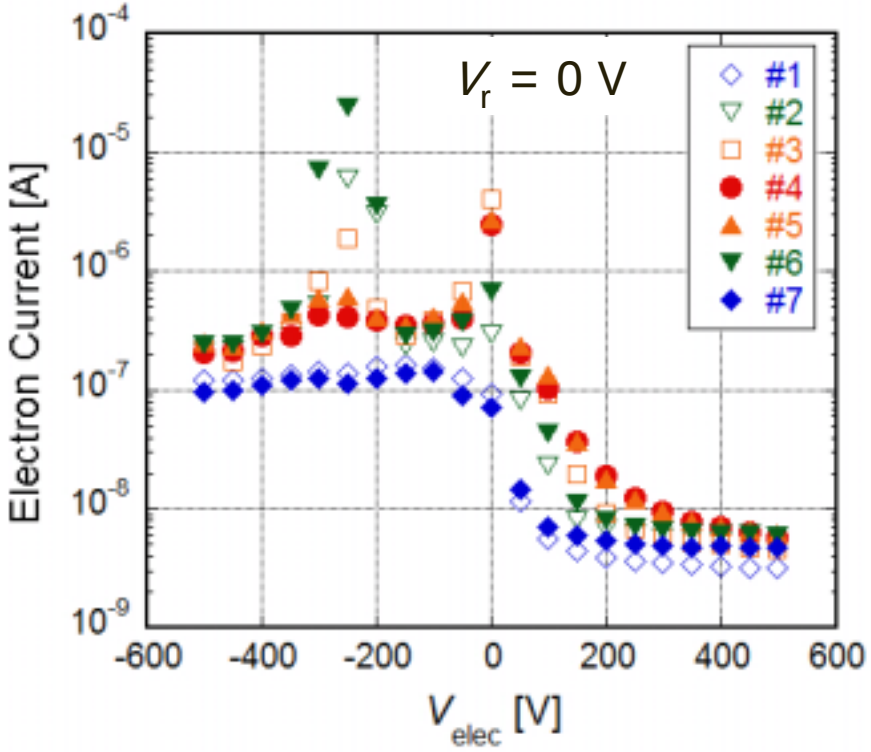
1585 bunches
(B_s ~ 6 ns)
~1600 mA

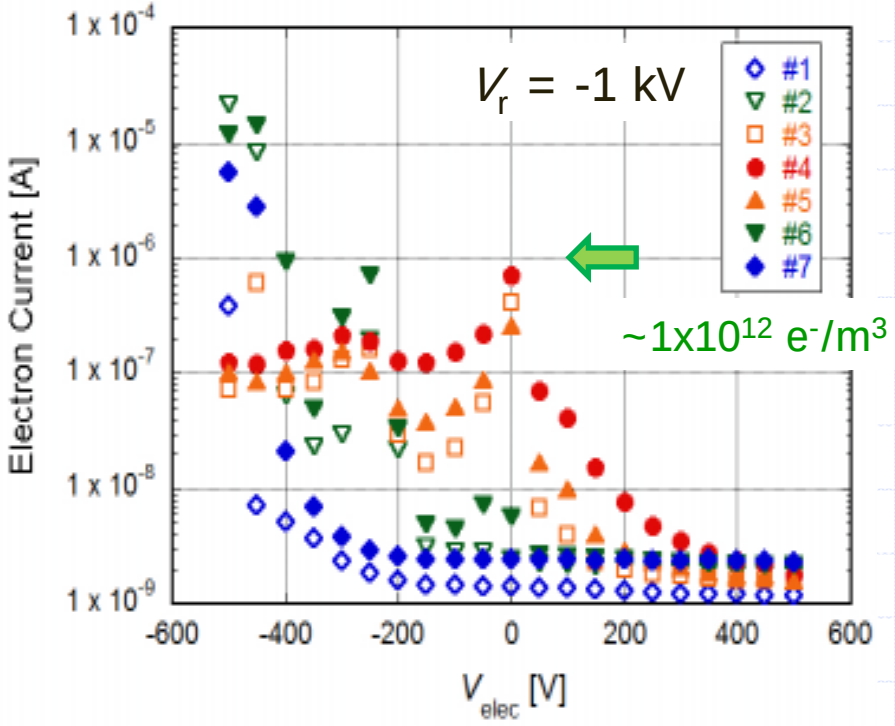


Results in Magnetic Field

- Effect of electrode voltage (V_{elec})

1585 bunches
(B_s ~ 6 ns)
~1600 mA





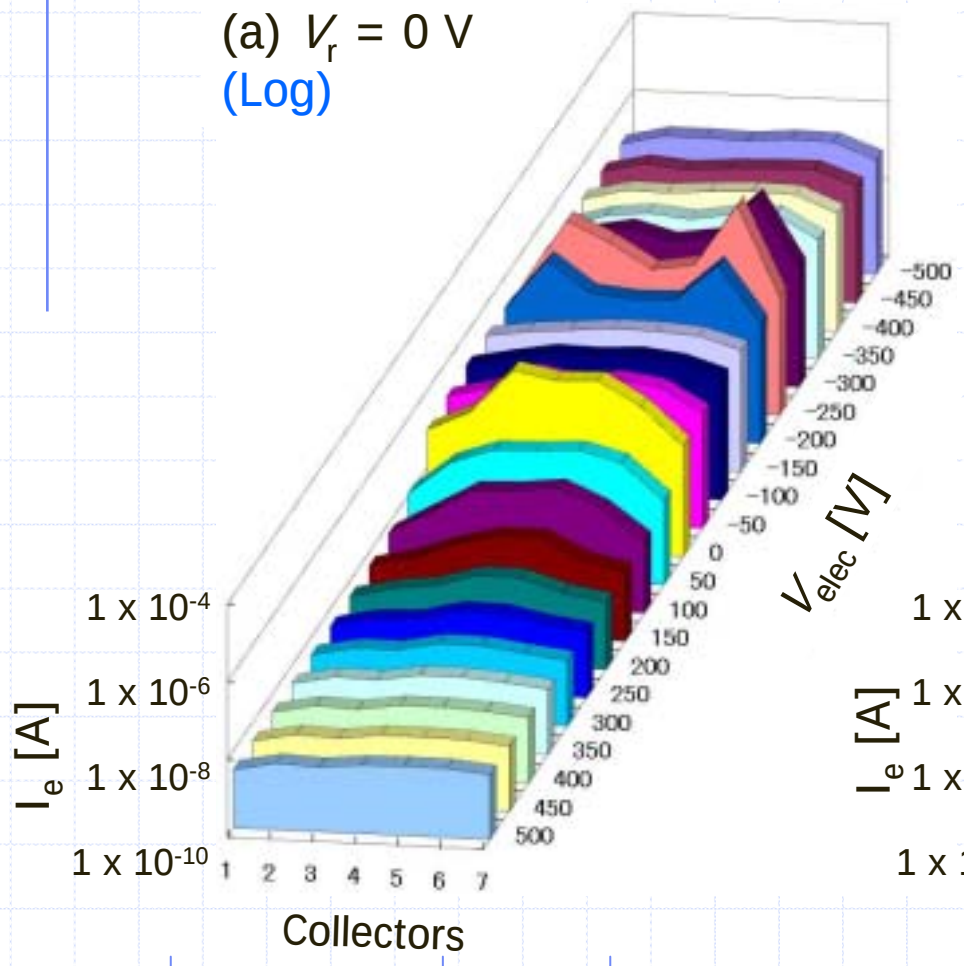
Complicated behavior at negative V_{elec}.

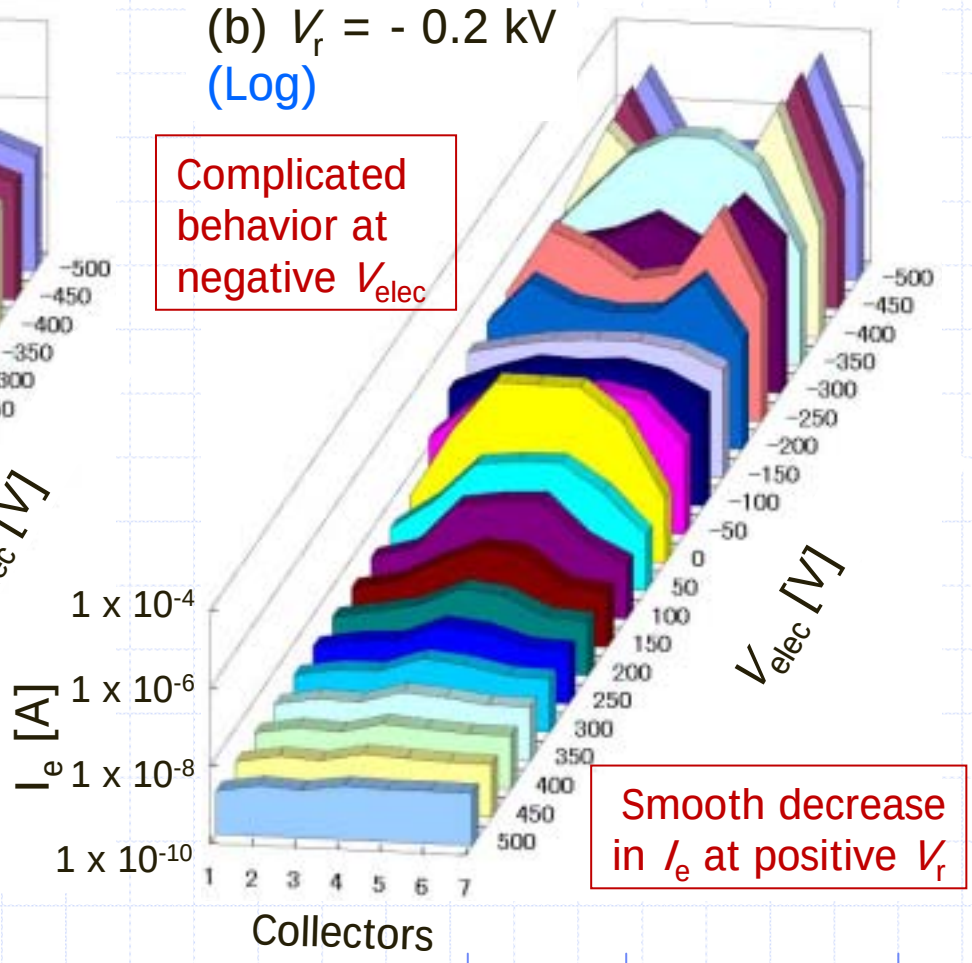
Electron density decreased to
1/10 at V_{elec} = + 100 ~ 200 V
1/100 at V_{elec} = + 300 ~ 400 V

Results in Magnetic Field

- Effect of repeller voltage (V_r)

1585 bunches
(B_s ~ 6 ns)
~1600 mA





Complicated behavior at negative V_{elec}

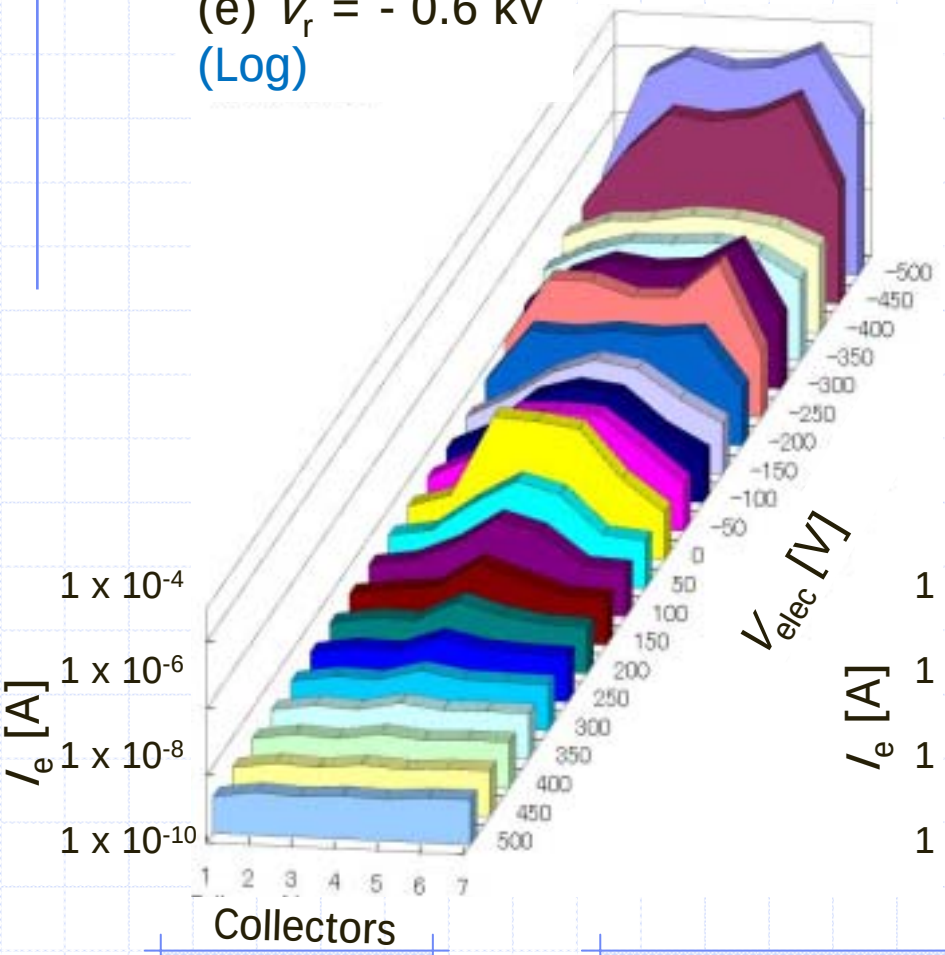
Smooth decrease in I_e at positive V_r

Results in Magnetic Field

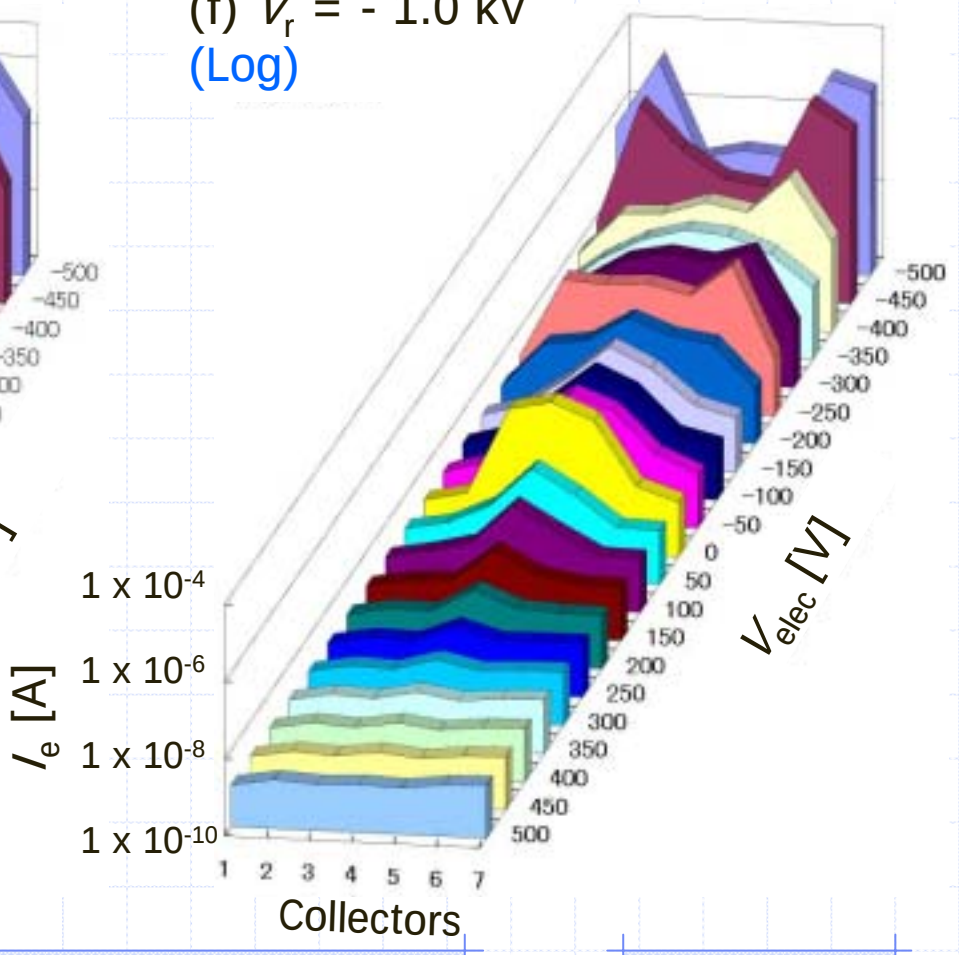
- Effect of repeller voltage (V_r)

1585 bunches
(B_s ~ 6 ns)
~1600 mA

(e) V_r = - 0.6 kV
(Log)



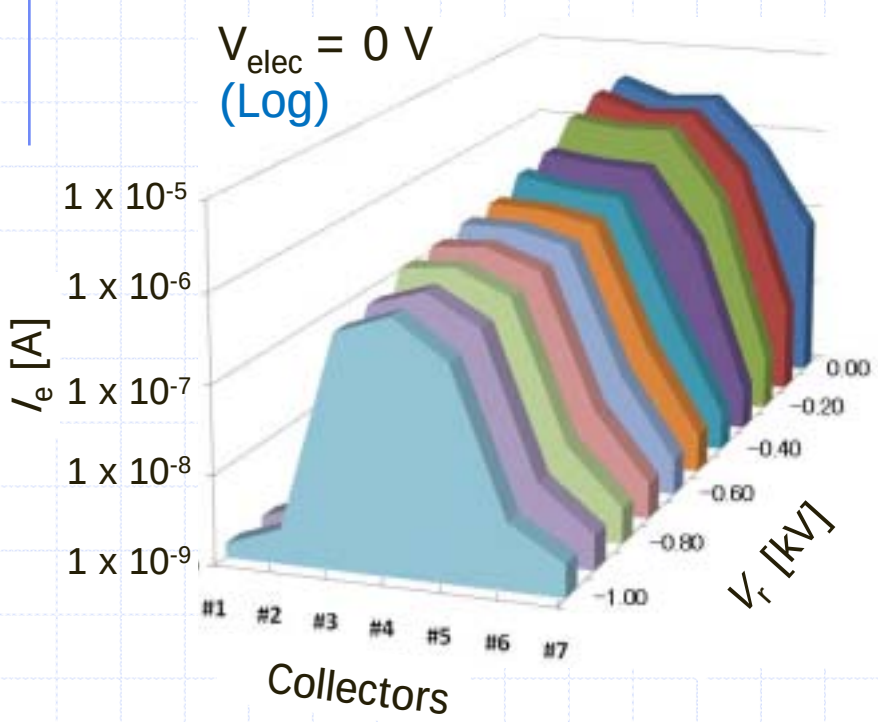
(f) V_r = - 1.0 kV
(Log)

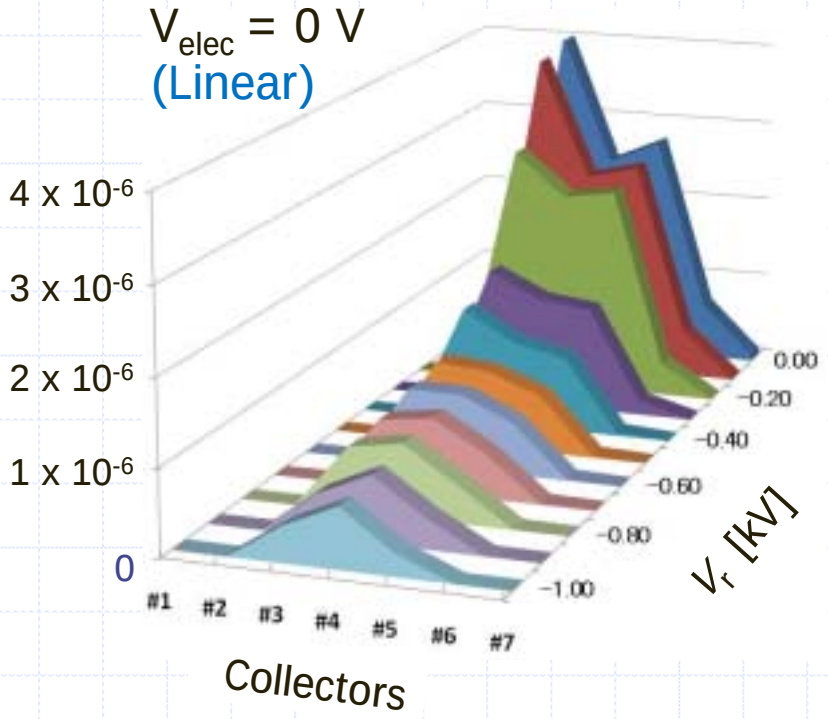


Results in Magnetic Field

- Energy Distribution
  - High energy electrons are around the center (beam orbit)

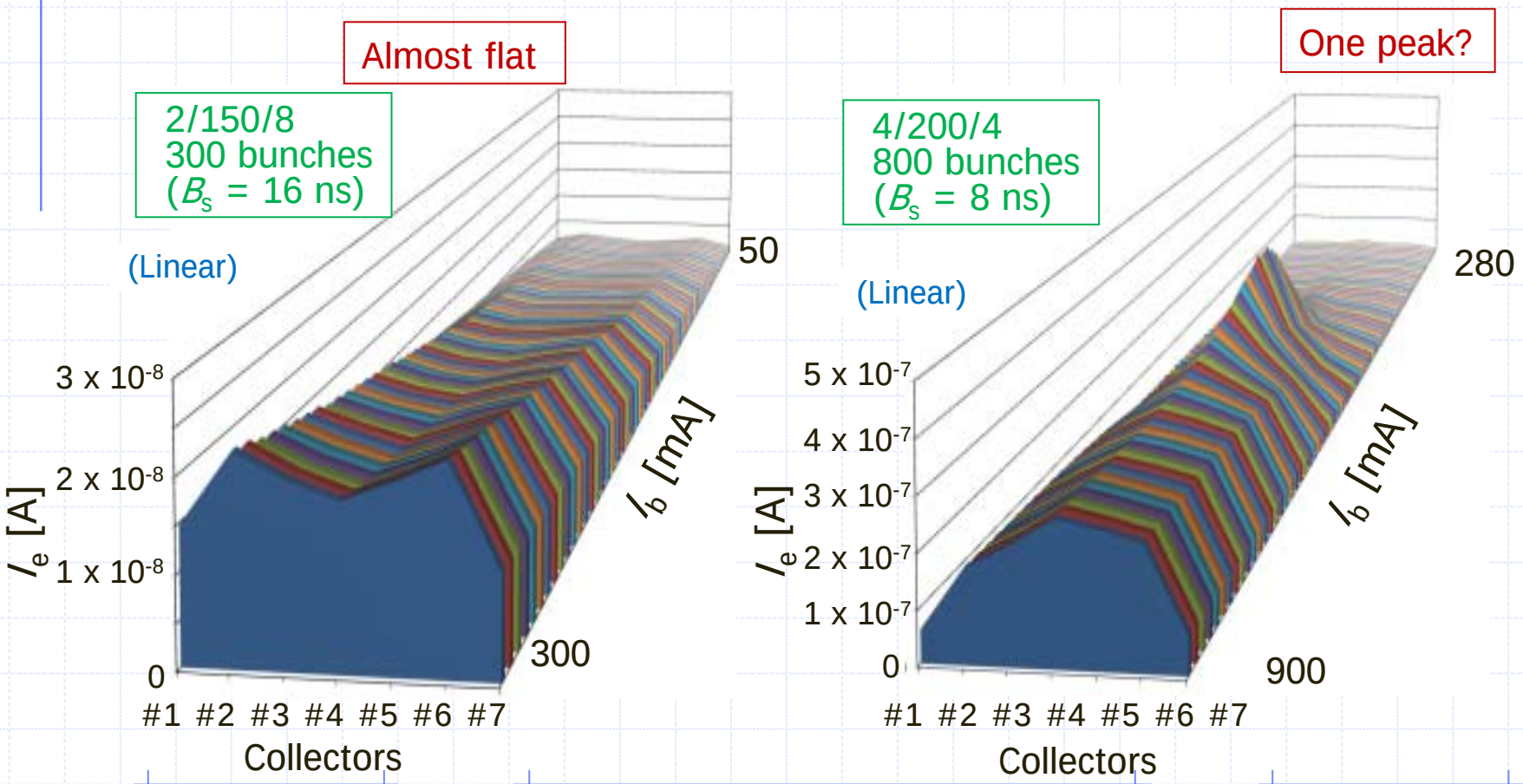
1585 bunches
(B_s ~ 6 ns)
~1600 mA





Results in Magnetic Field

- Fill patterns
  - Spatial distribution changes by bunch filling pattern.



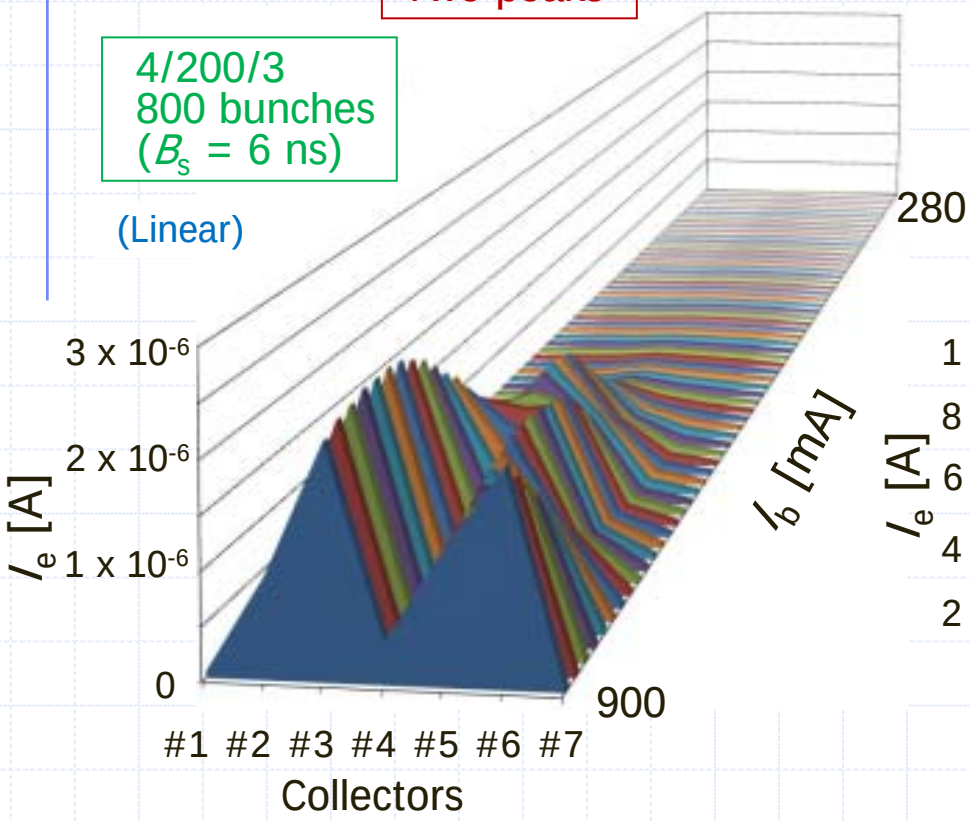
Results in Magnetic Field

- Fill patterns

Two peaks

4/200/3
800 bunches
(B_s = 6 ns)

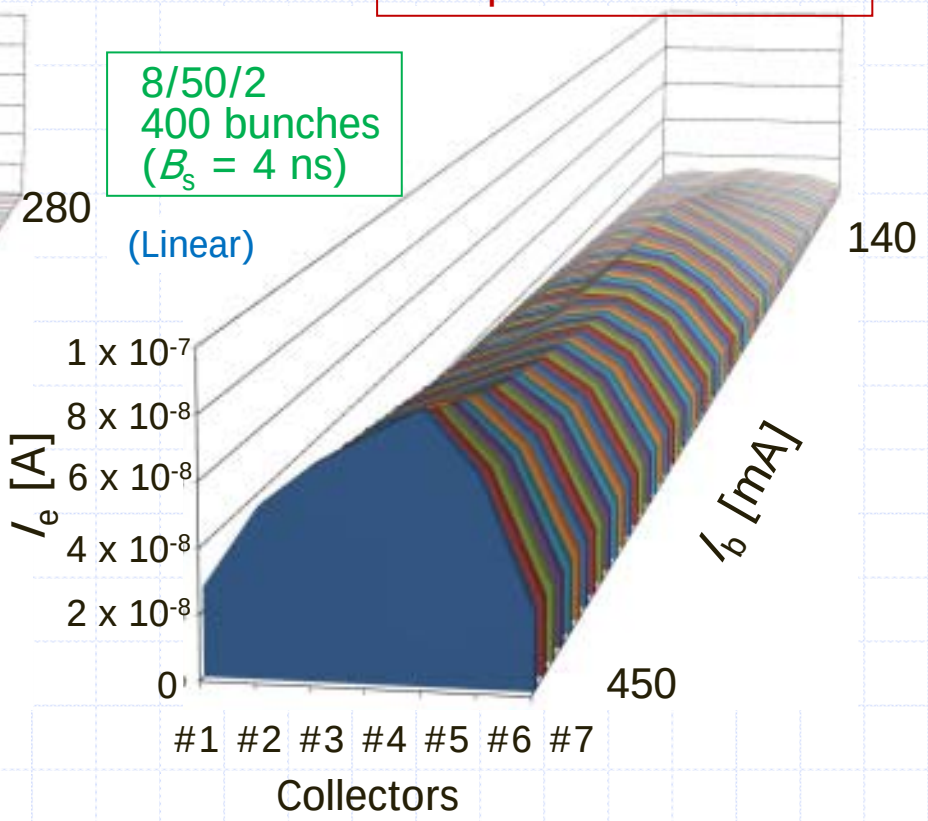
(Linear)



One peak? But shifted?

8/50/2
400 bunches
(B_s = 4 ns)

(Linear)



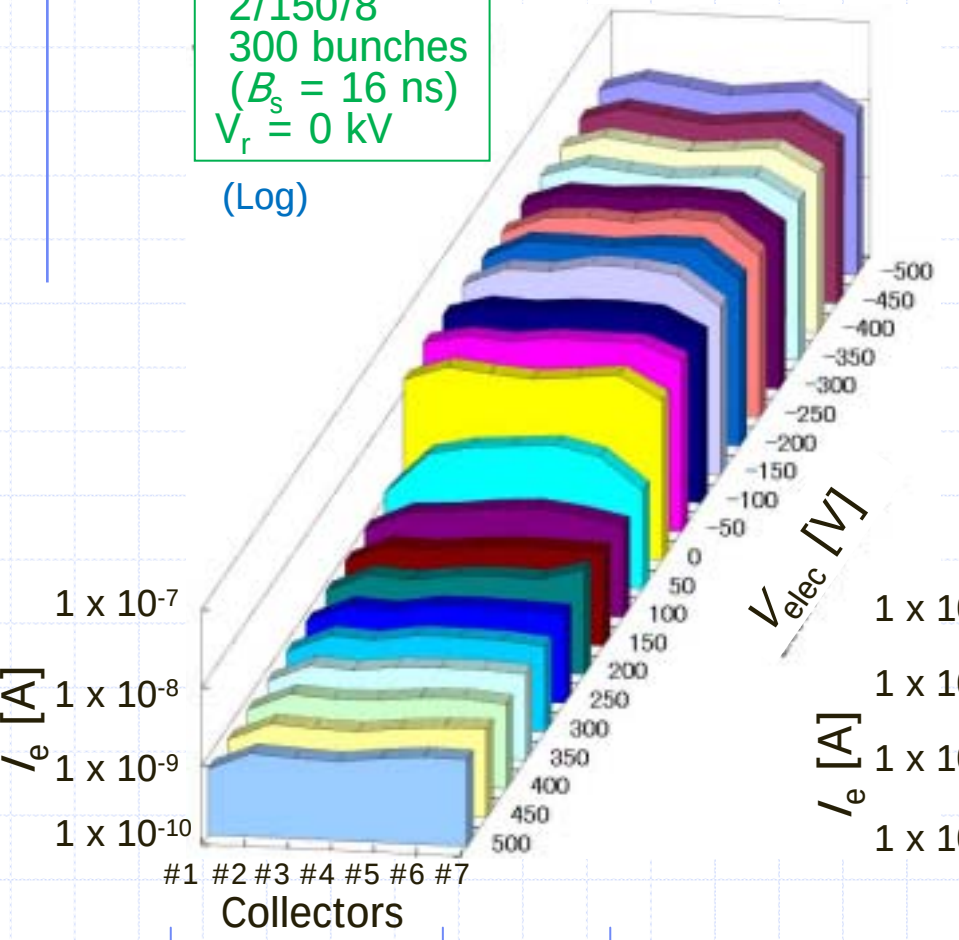
Why? Poor resolution of electron monitor?

Results in Magnetic Field

- Fill patterns

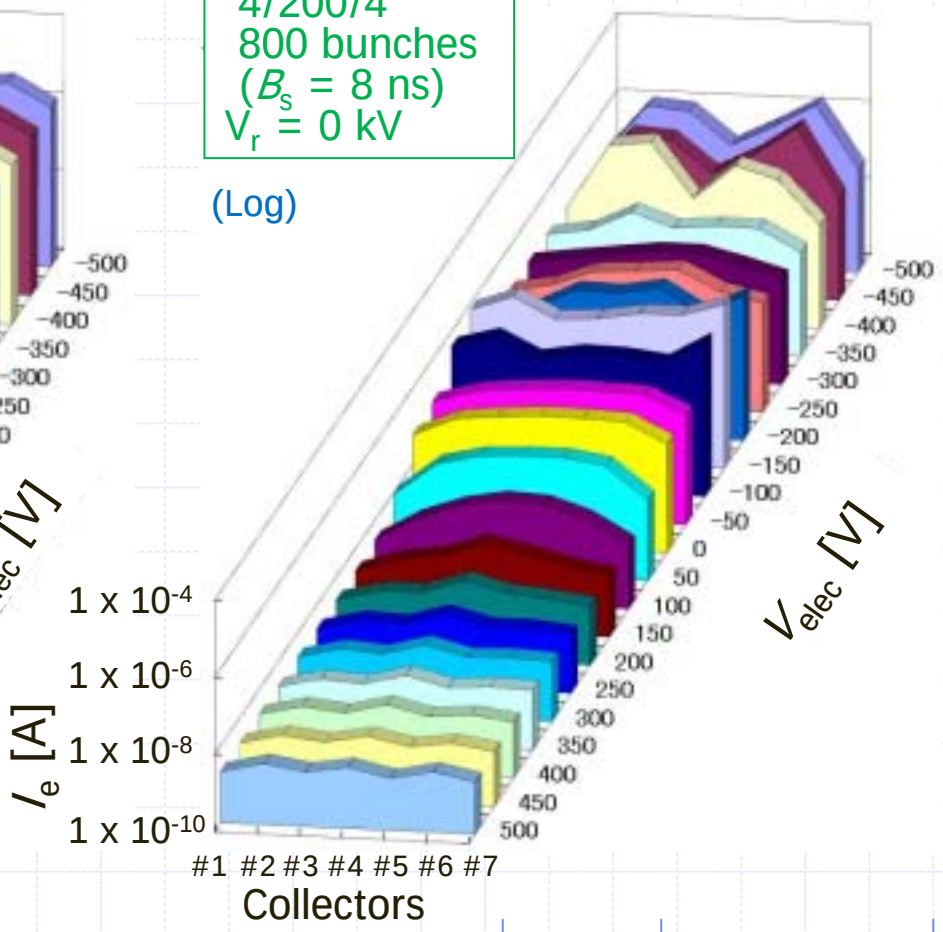
2/150/8
300 bunches
(B_s = 16 ns)
V_r = 0 kV

(Log)



4/200/4
800 bunches
(B_s = 8 ns)
V_r = 0 kV

(Log)

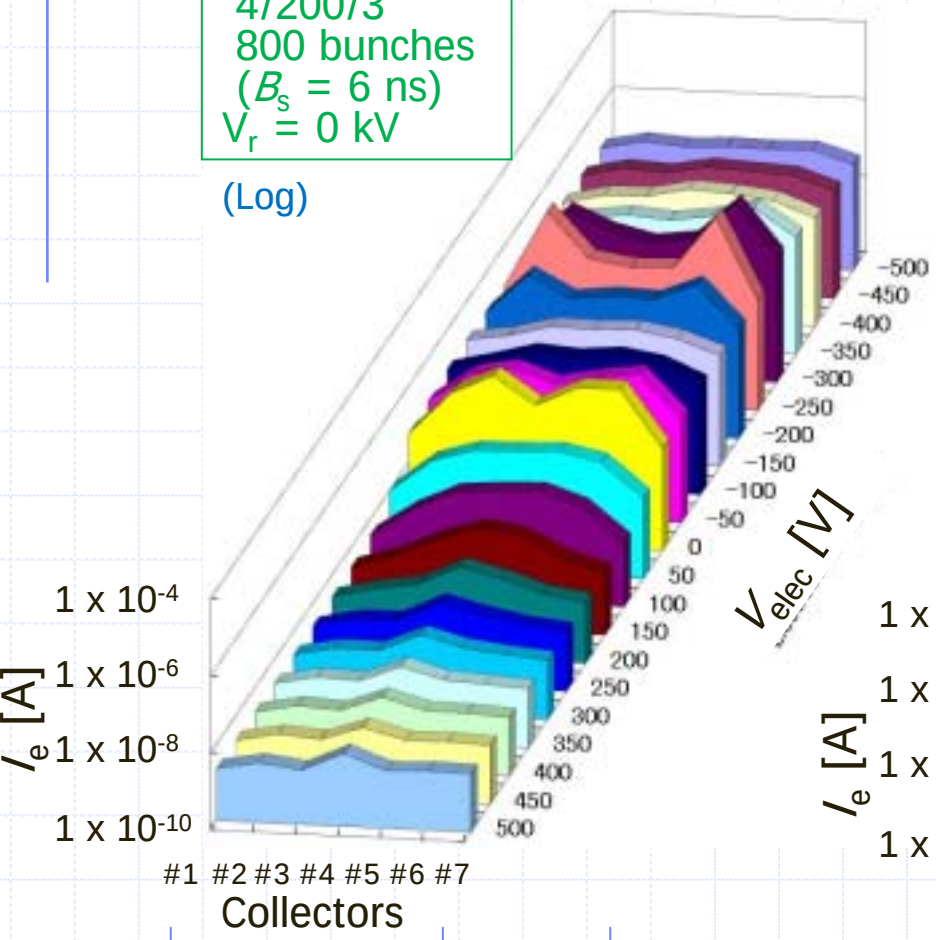


Results in Magnetic Field

- Fill patterns

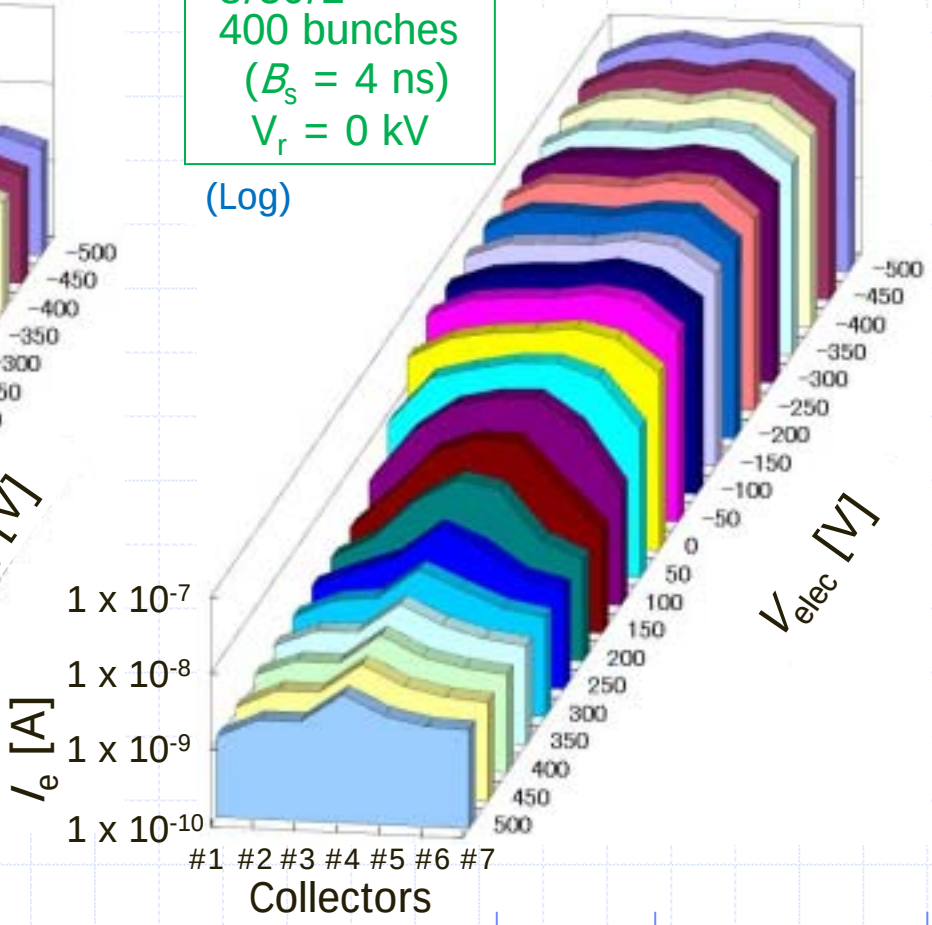
4/200/3
800 bunches
(B_s = 6 ns)
V_r = 0 kV

(Log)



8/50/2
400 bunches
(B_s = 4 ns)
V_r = 0 kV

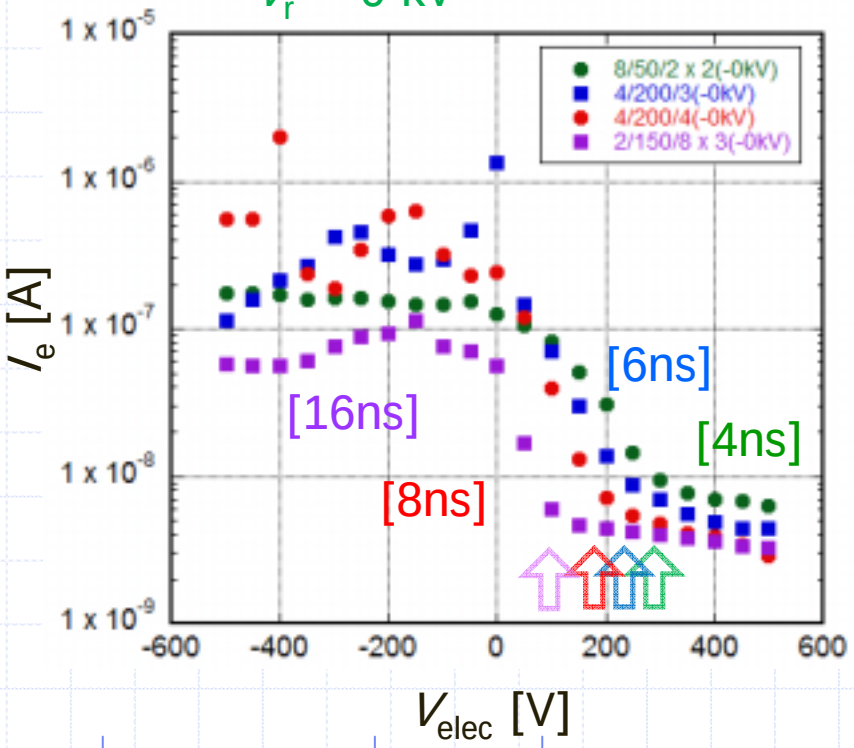
(Log)



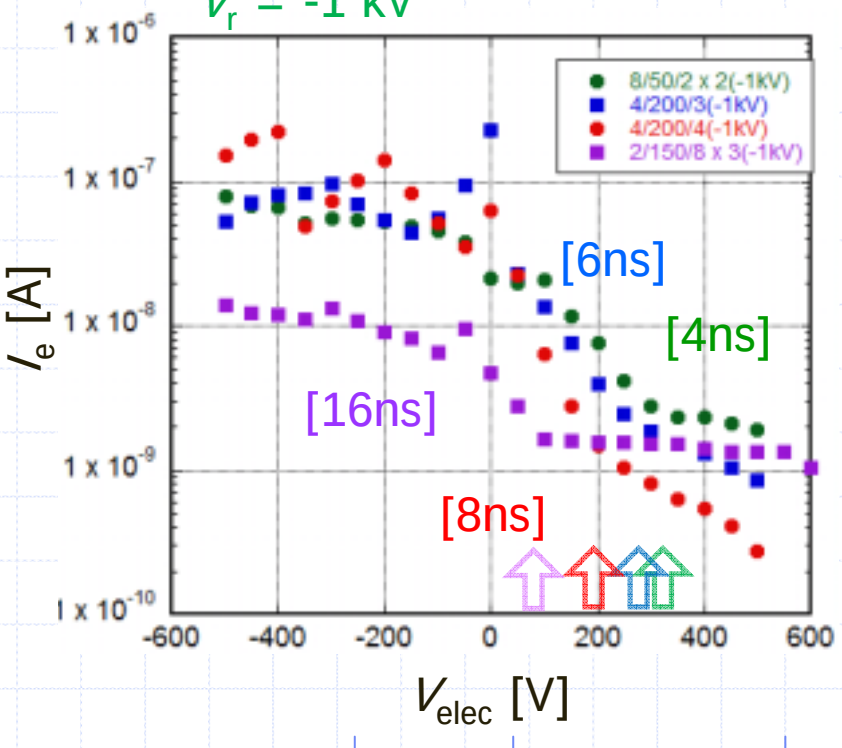
Results in Magnetic Field

- Fill patterns
  - Electrode is effective for any fill patterns.
  - The efficiency seems different by bunch spacings.
    - Less effective for larger Bs?

V_r = 0 kV

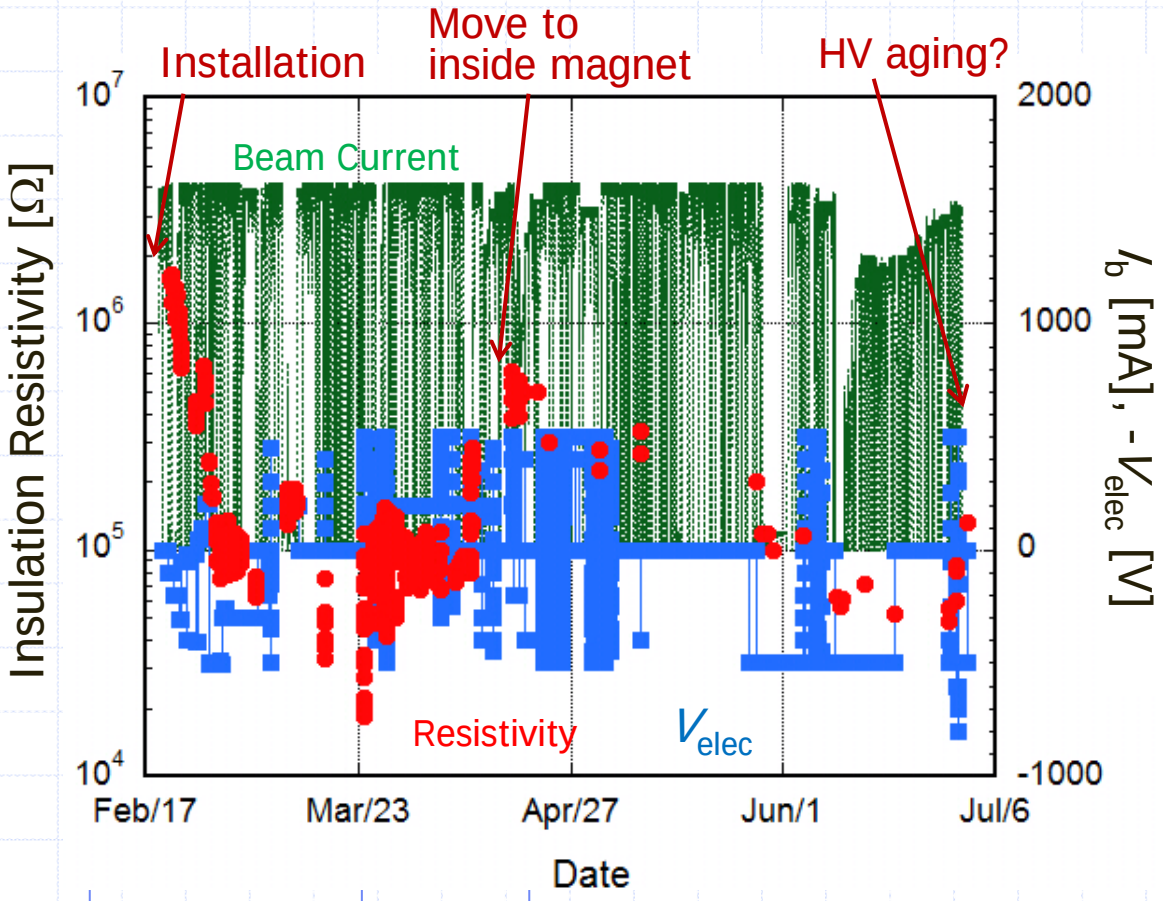


V_r = -1 kV



Problems

- Decrease in insulation resistivity
  - Decreased from 2 MΩ down to several 10 kΩ

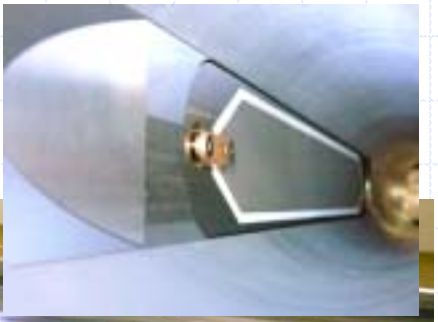


- Not strong dependence on V_{elec}
- HV aging (discharge) seemed to recover the resistivity.

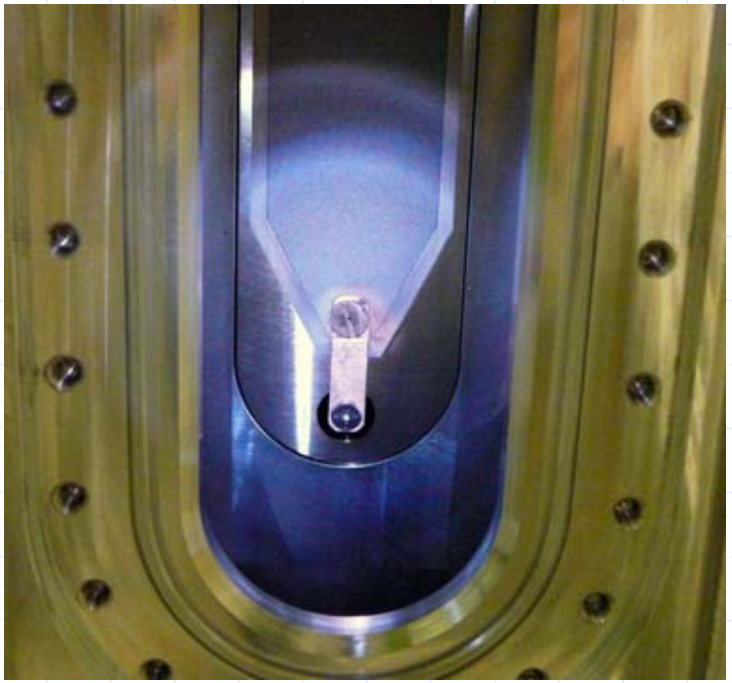
Problems

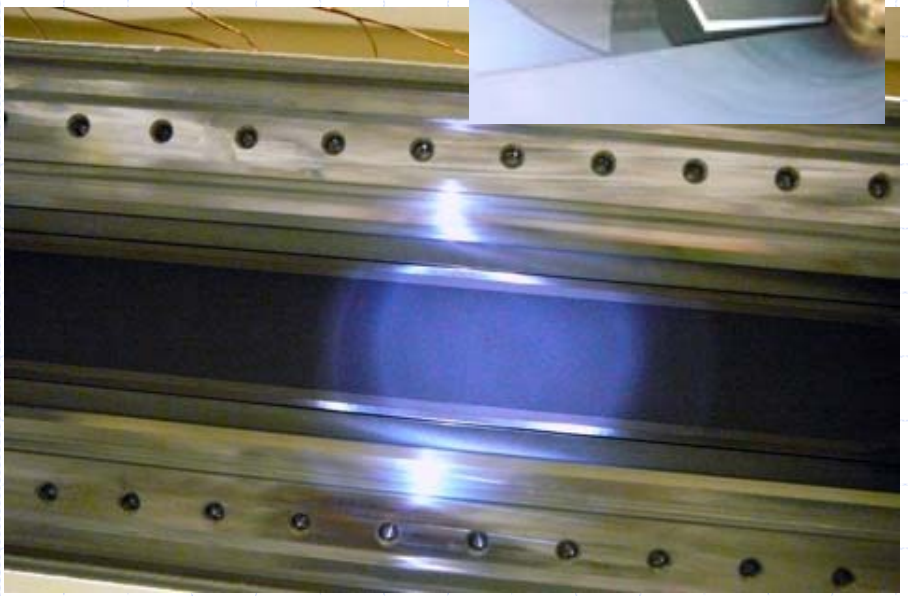
- Possible reasons of the decrease in resistivity
  - Sputtering of aluminum (chamber)?
  - Discharge at connection part?

Original color



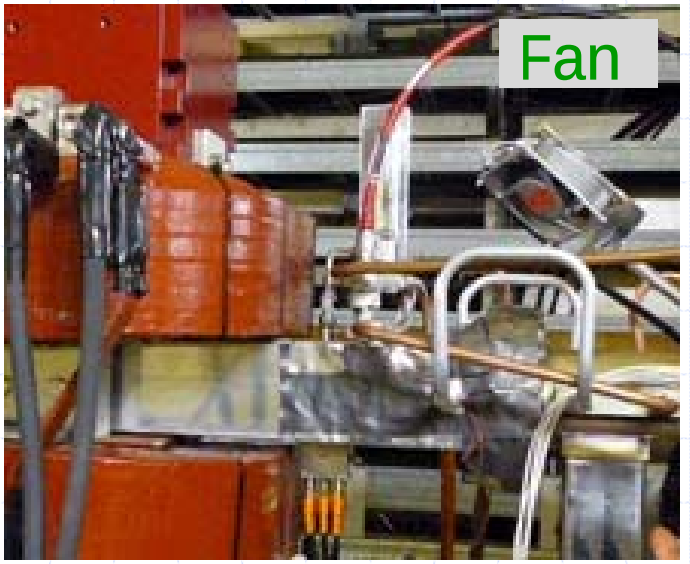
Inside check when moved into inside magnet





Problems

- Heating of feed-through
  - Cooled by air and water
  - Mismatching of impedance?
- Vacuum leak at flange
  - Insufficient fastening?



- No problem for
  - Temperature of electrode (test chamber)
  - Power supply

Mysteries at present

- Complicated behavior of I_e at negative V_{elec}, especially for high $|V_r|$.
  - Not seen in field-free region → effect of magnetic field
  - Electrons can move only along magnetic filed lines.
  - Effect of monitor (holes, repeller grid)?
- Saturation of I_e at high positive V_{elec}.
  - Background of monitor (SR?) ?
  - But sometimes I_e goes down further?
- Spatial distributions for different bunch fill patterns
  - Simulation indicated two peaks for all patterns.
  - Poor resolution of monitor?

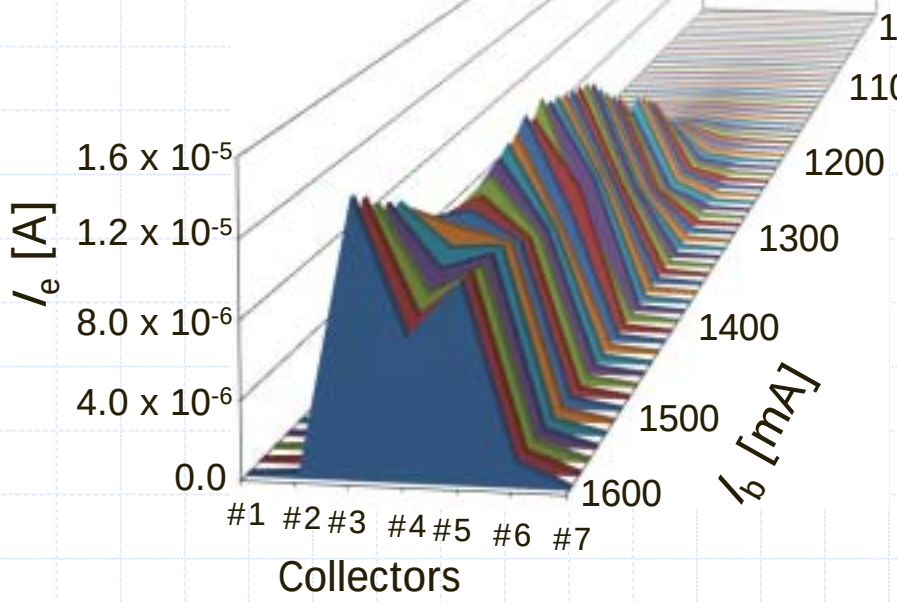
Mysteries at present

- Changes in time
  - Aging of surface?
  - Vacuum pressure (ionization)?

2008/5/2
P =9x10^{-7} Pa

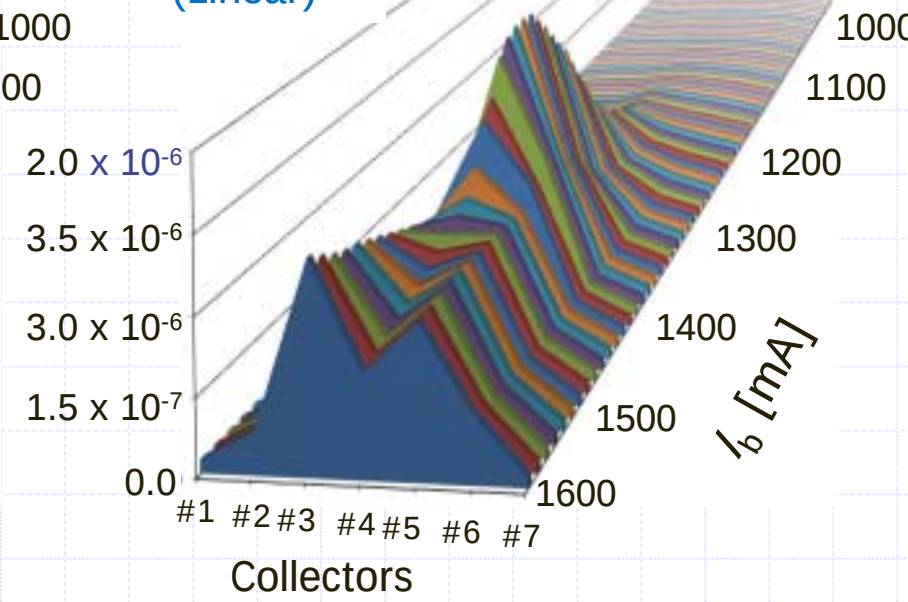
1585 bunches
(B_s ~ 6 ns)

V_r = 0 V,
V_{elec} = 0 V
(Linear)



2008/6/5
P =6x10^{-7} Pa

V_r = 0 V,
V_{elec} = 0 V
(Linear)



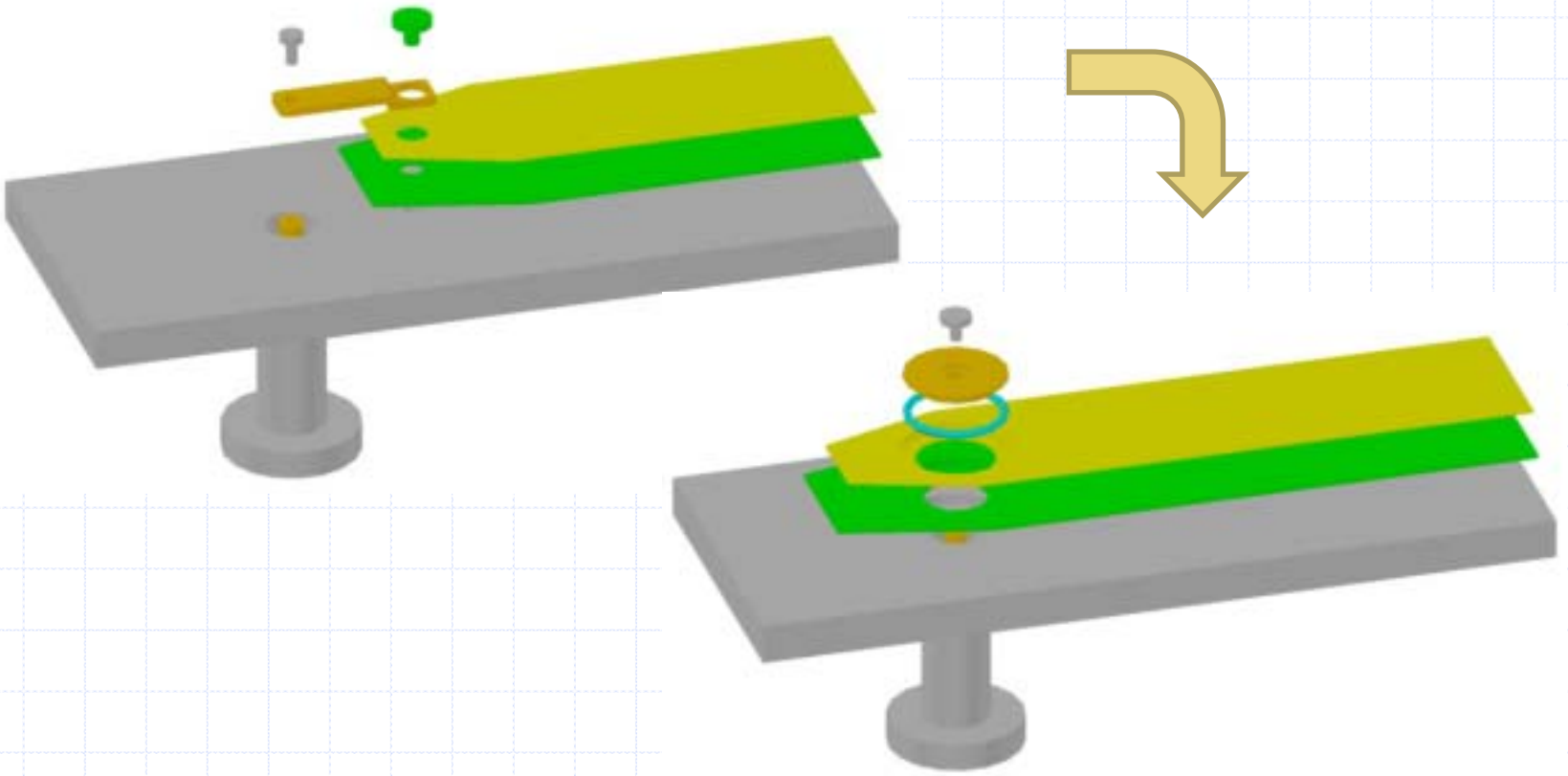
Summary

- A clearing electrode structure with thin electrode and insulator was developed.
  - The thin structure reduced the beam impedance and enhance the thermal conductivity, which make the electrode available in a high-intensity positron machine.
- Clear effect of clearing electrode on the reduction of EC was experimentally demonstrated, both in field-free region and in magnet (0.75 T).
- Some mysteries, such as decrease in resistivity, complicated behavior of measured electron current at negative electrode voltage, remains at present.
  - Further investigation and simulation to understand the mysteries are required.
- Improvement of the electrode structure, to avoid discharges, and the electron monitor is planned.
- How to apply it to real machines ..... to be considered.

Backup

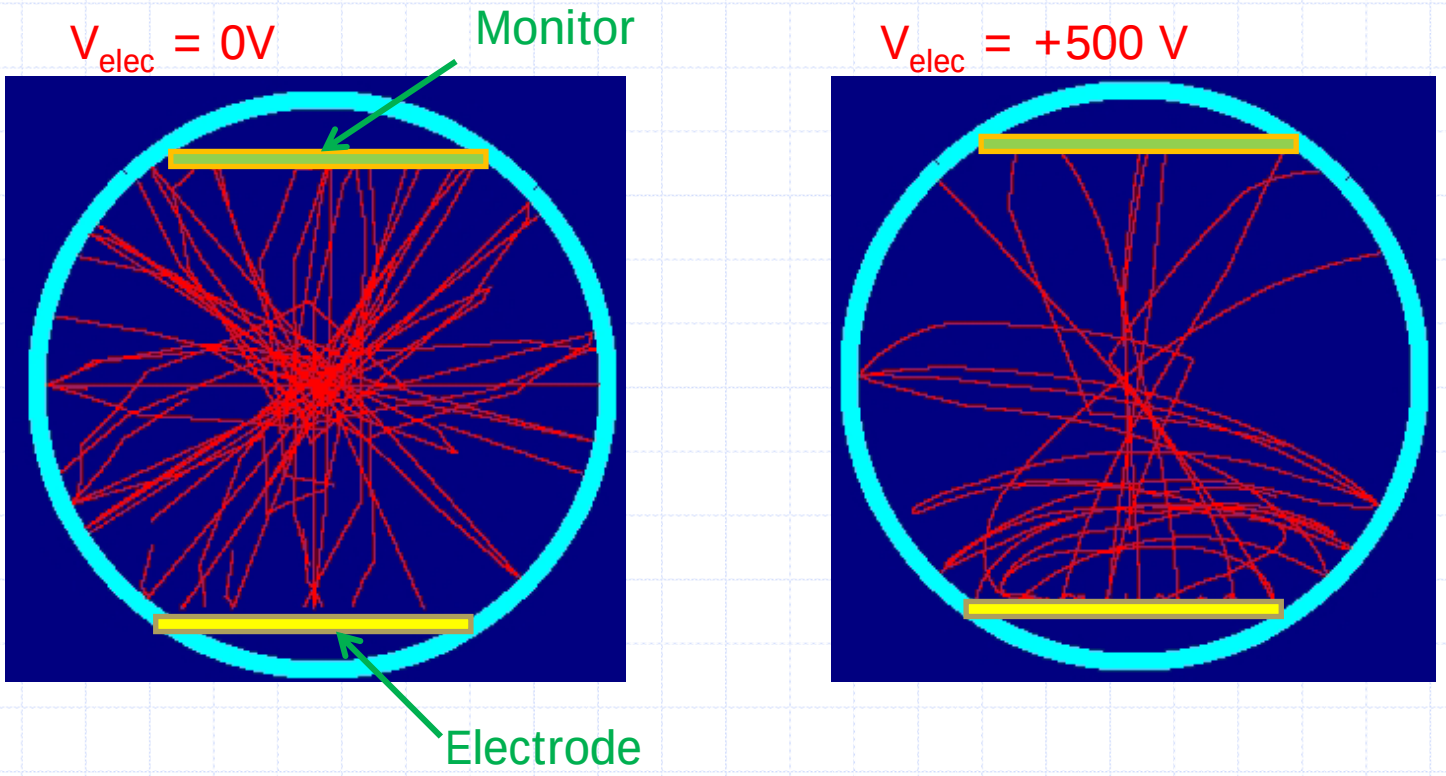
Next version

- Improvement of connector
  - Suggested by Billing-san



Simulation [Preliminary]

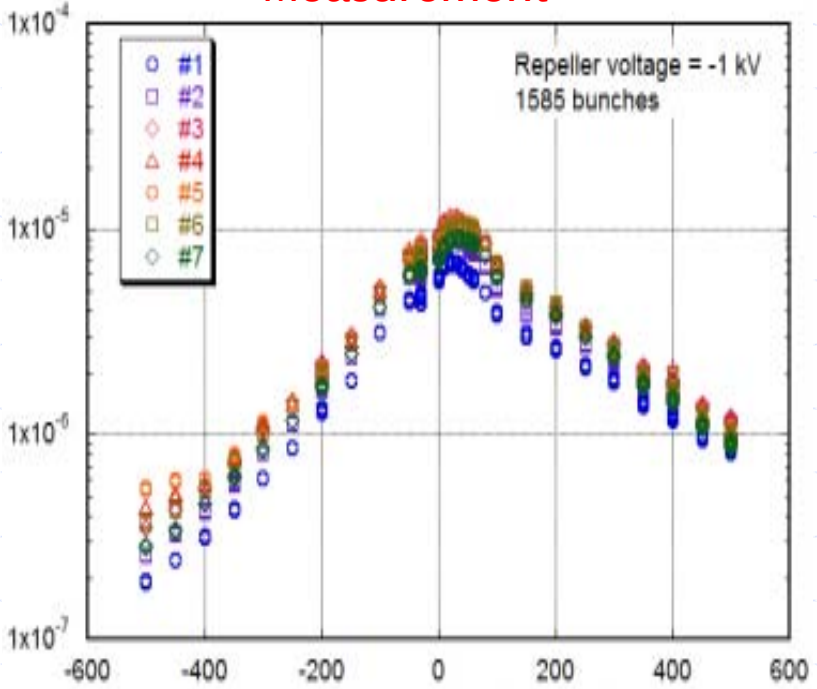
- Trajectories of electrons
  - Field-Free Region
  - 1/1585/3 (Bs ~ 6 ns)



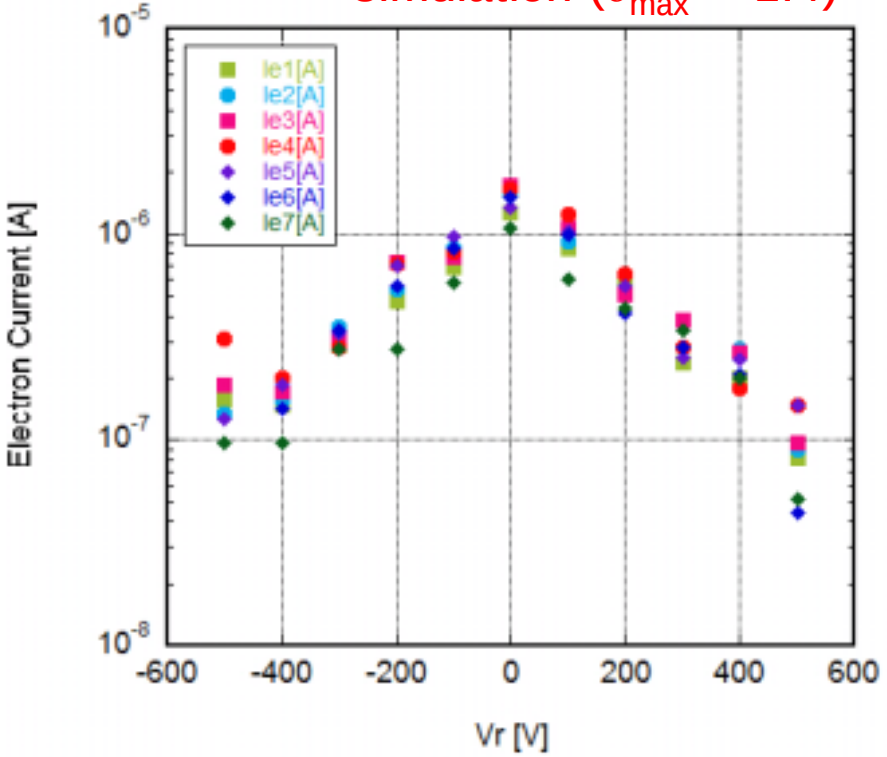
Simulation [Preliminary]

- Measured Electron Current (I_e)
  - Field-Free Region
  - 1/1585/3 (Bs ~ 6 ns), V_r = -1 kV

Measurement



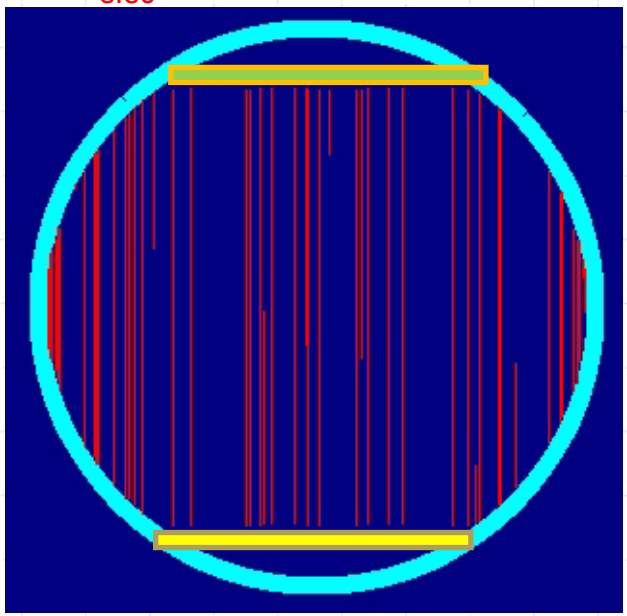
Simulation (δ_{max} = 1.4)



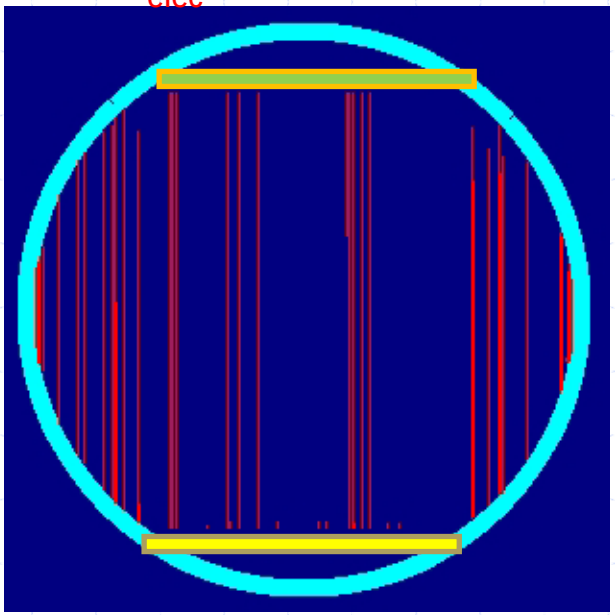
Simulation [Preliminary]

- Trajectory of electrons
  - In magnetic field, but cyclotron motion was neglected for simplicity.
  - 1/1585/3 (B_s ~ 6 ns)

V_{elec} = 0V



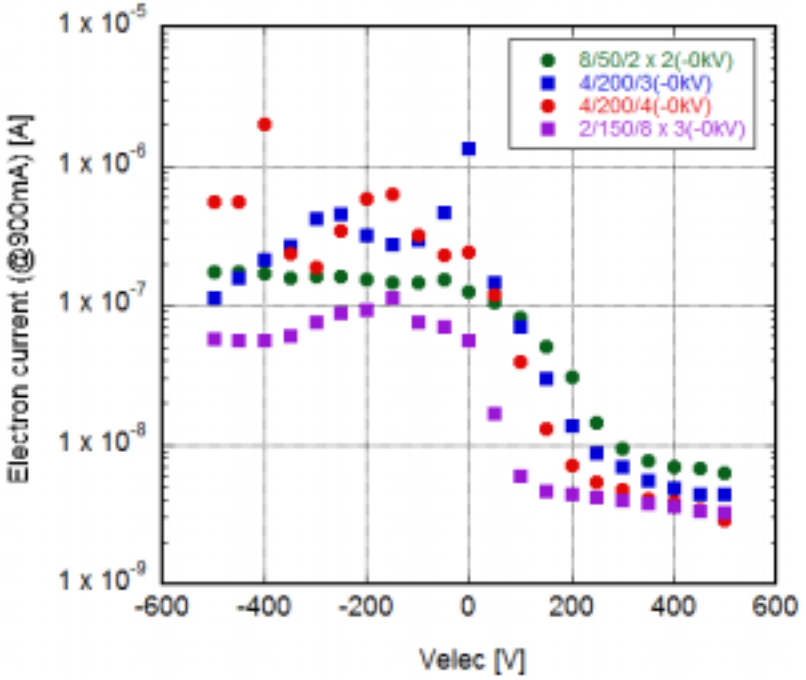
V_{elec} = +500 V



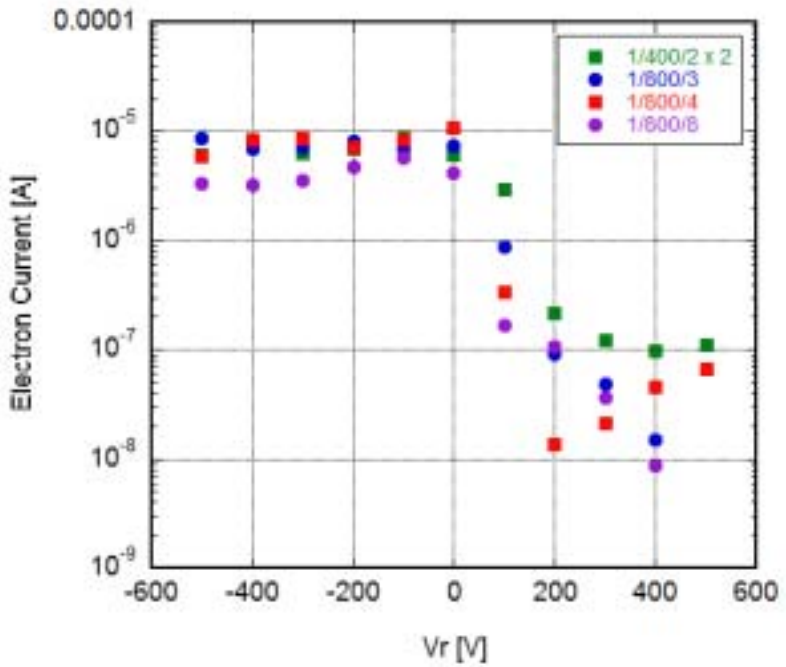
Simulation [Preliminary]

- Measured Electron Current (I_e) for different fill patterns
  - V_r = 0 kV
  - B=0.75 T

Measurement



Simulation (δ_{max} = 1.2)

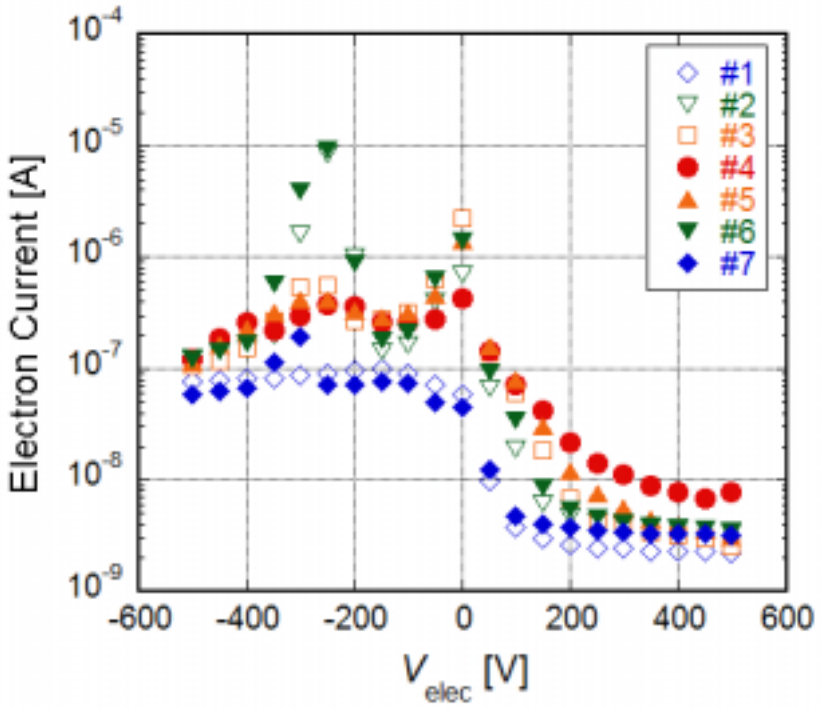


Electrode

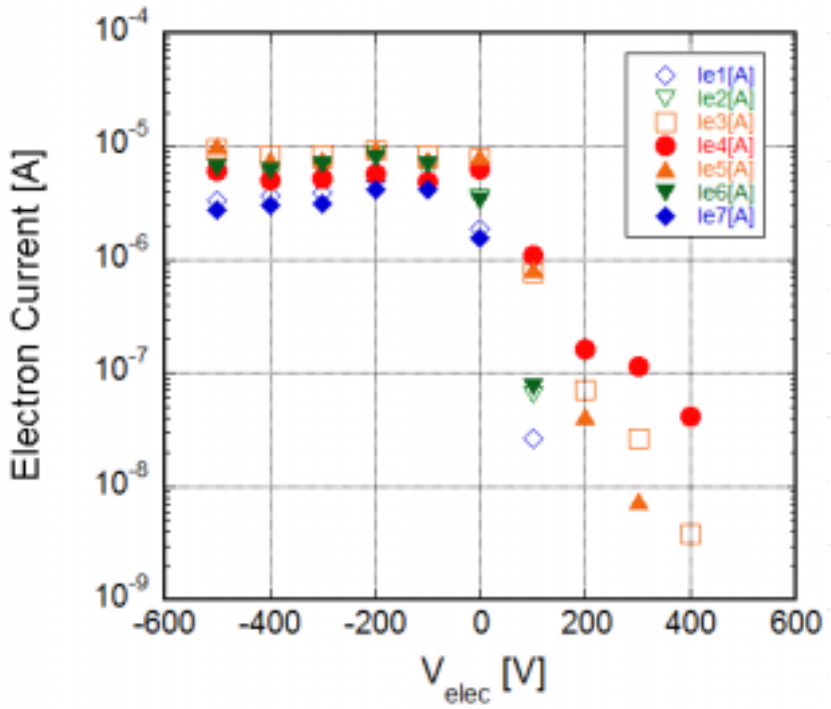
Simulation [Preliminary]

- Spatial distribution of Measured Electron Current (I_e)
  - V_r = 0 kV, 4/200/3 (Bs = 6 ns)
  - B=0.75 T

Measurement

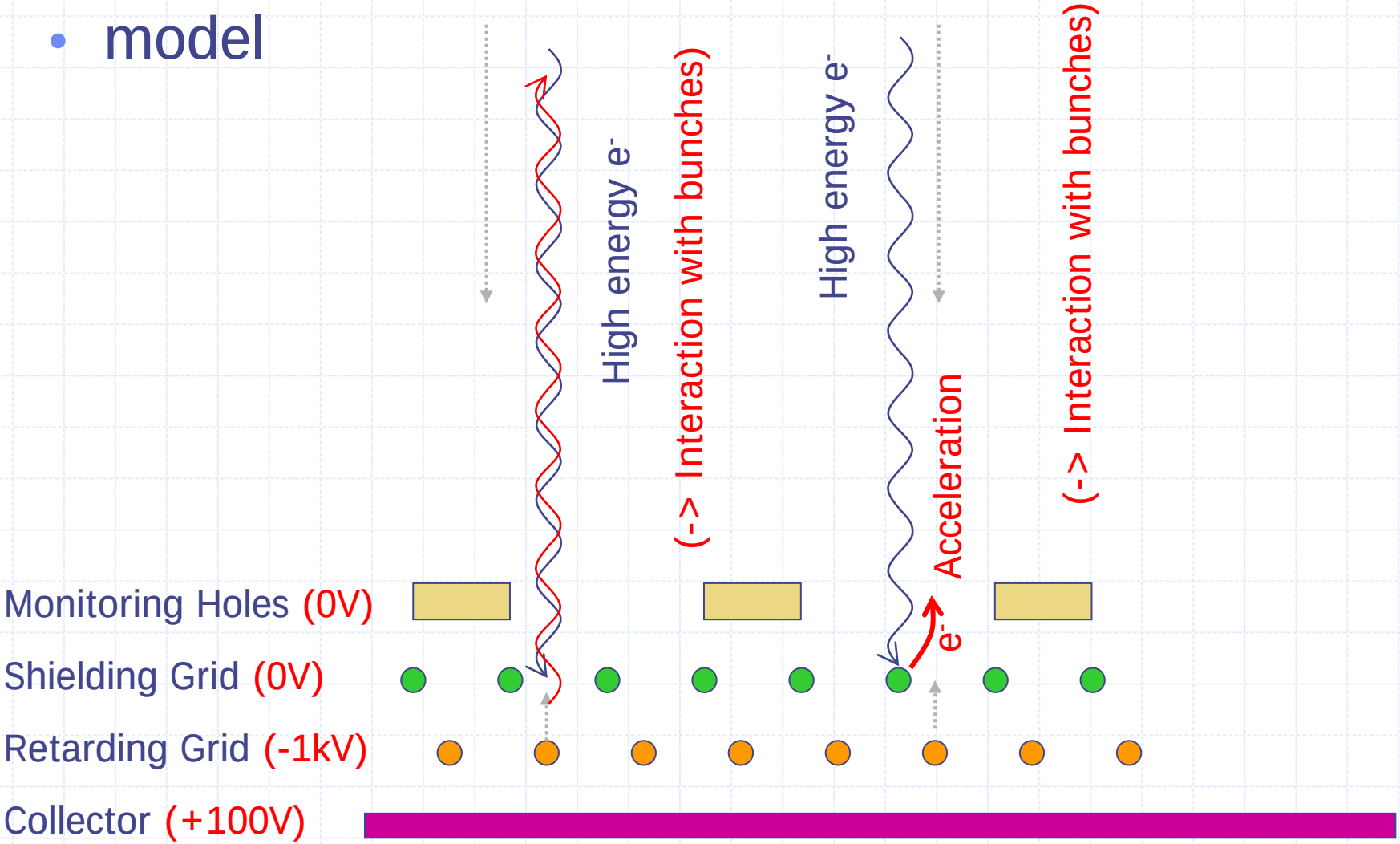


Simulation (δ_{max} = 1.2)



Note

- model


High energy e-
(-> Interaction with bunches)
High energy e-
Acceleration
e-
(-> Interaction with bunches)
Monitoring Holes (0V)
Shielding Grid (0V)
Retarding Grid (-1kV)
Collector (+100V)