Unexpected resonance line shape broadening of edge-magneto plasmons of 2DES on helium

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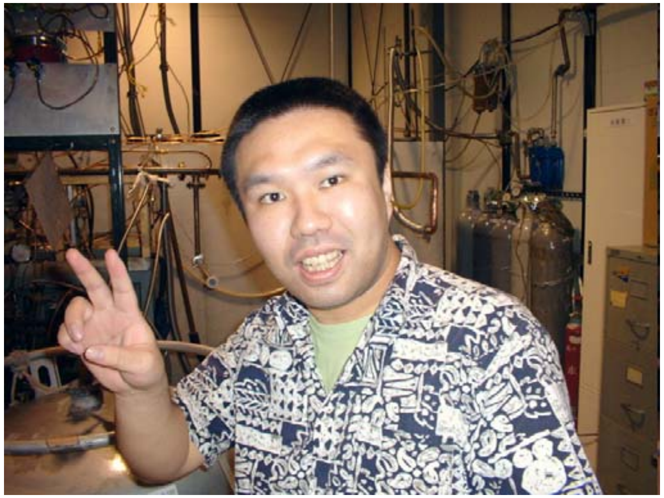
Colleagues



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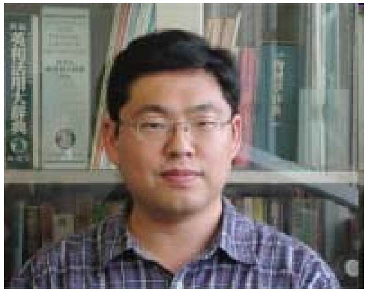
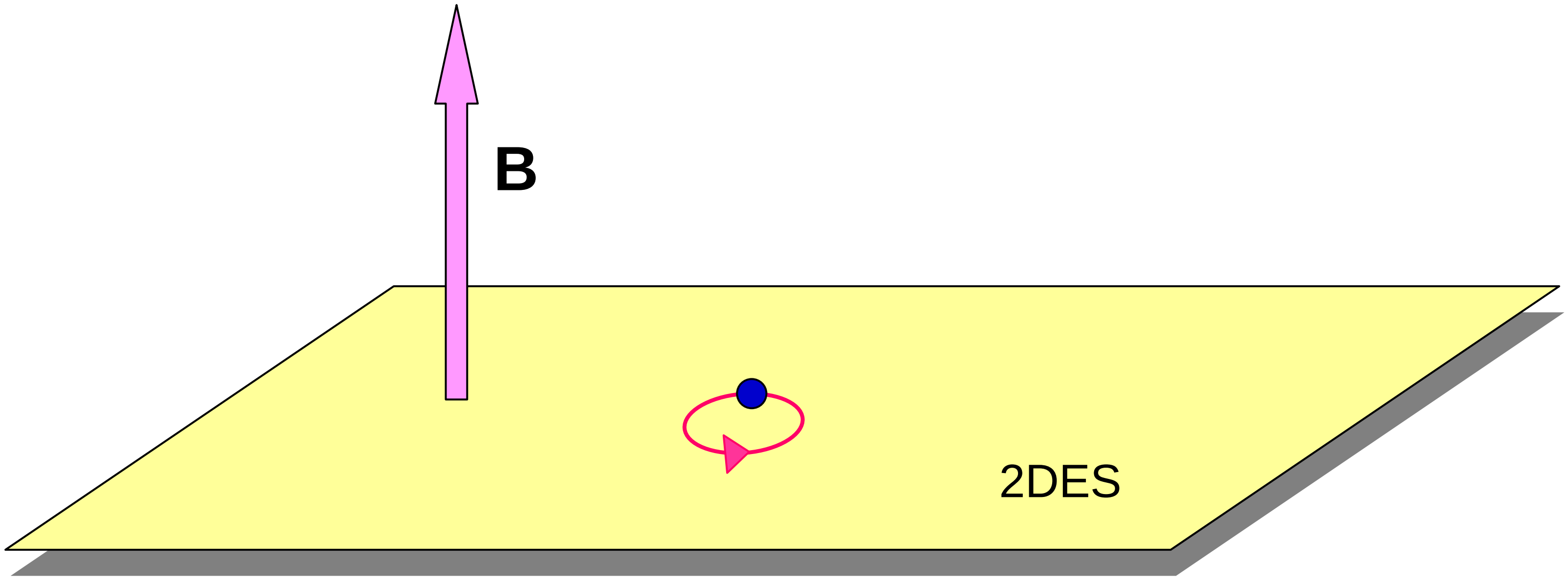


Akira Fukuda

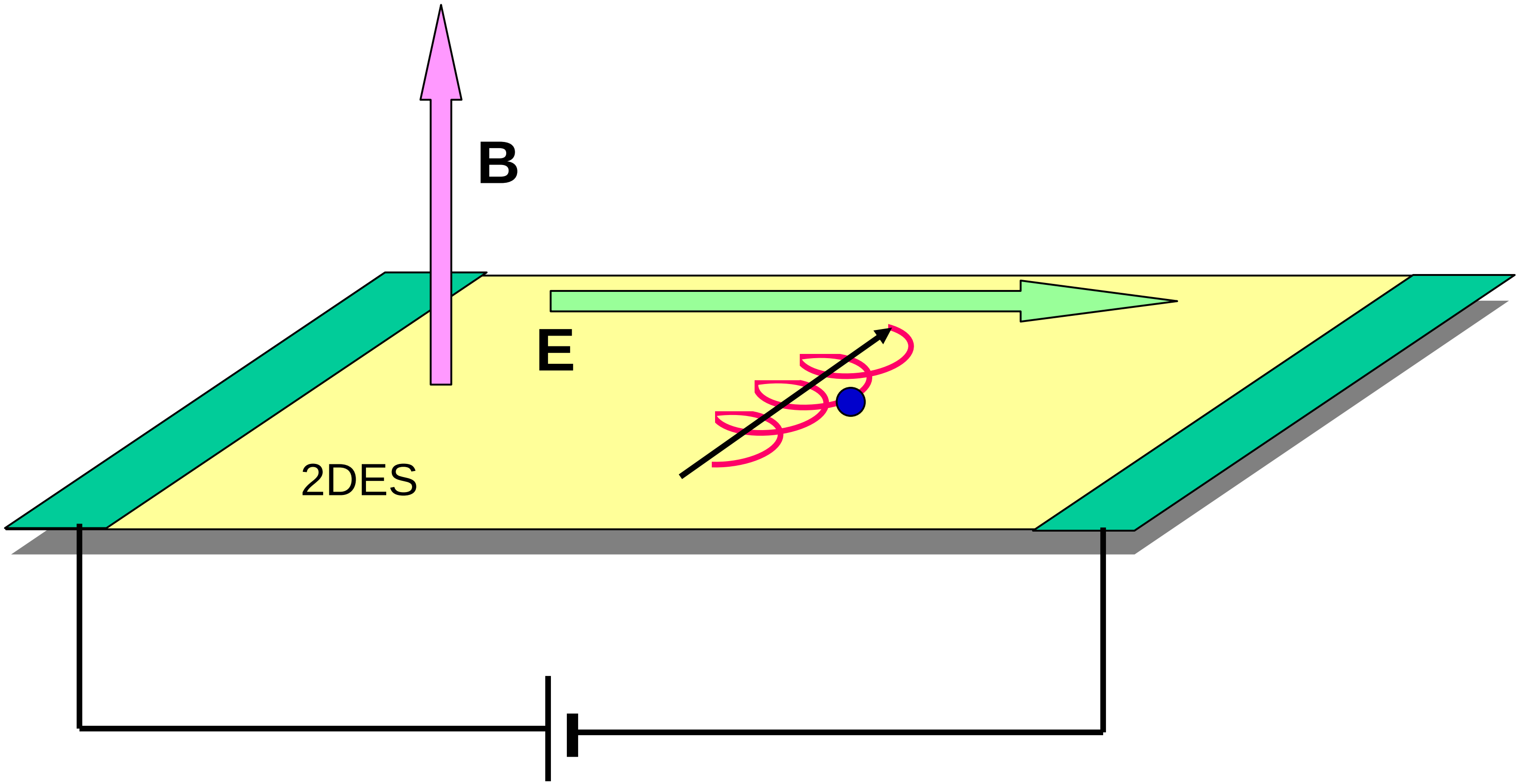
Anju Sawada

Edge of two-dimensional electron systems



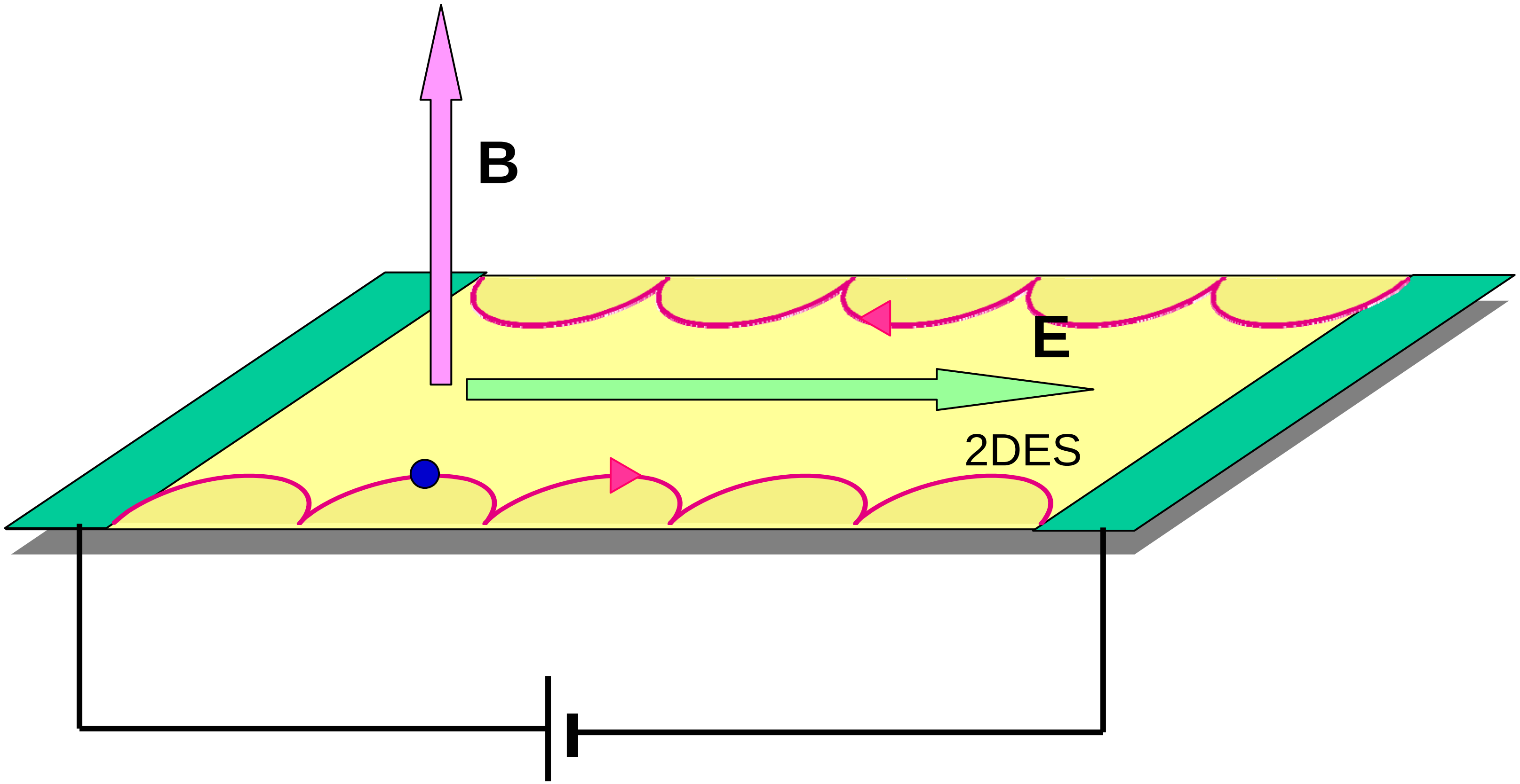
Magnetic field → Cyclotron motion

Edge of two-dimensional electron systems



At large magnetic field, no current flows along electric field. $\sigma_{xx} = 0$

Edge of two-dimensional electron systems

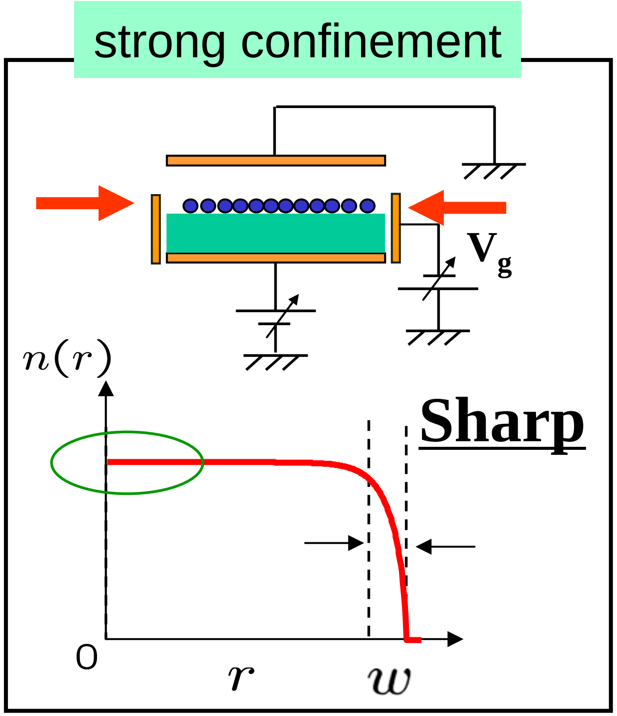


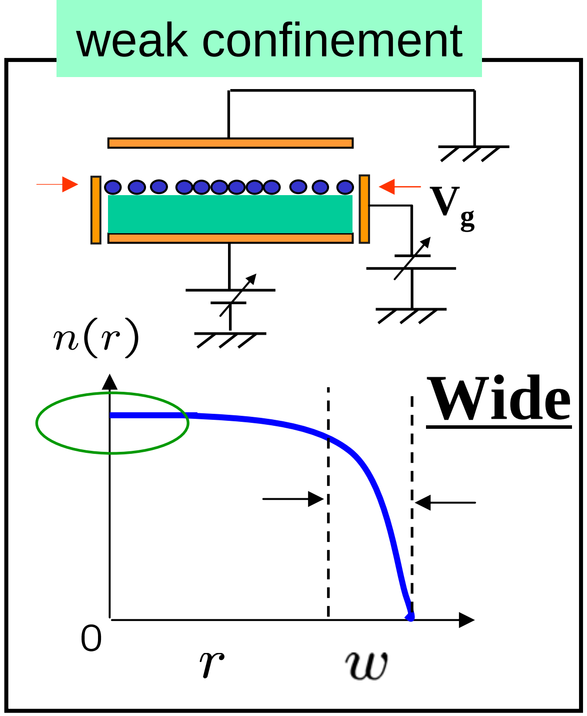
Skipping orbit near the edge supports current along **E**.

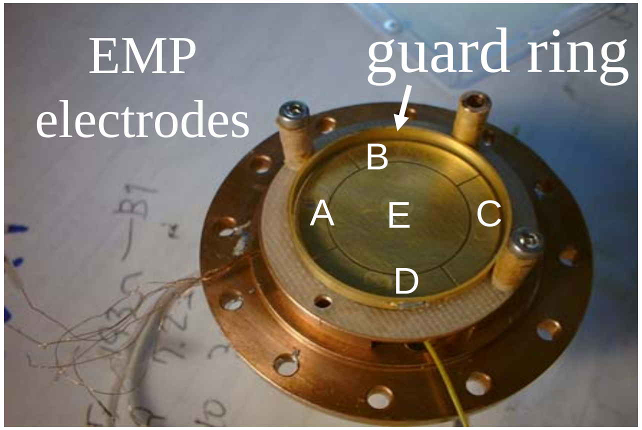
(quantum hall state)

Edge of 2DES over liquid helium

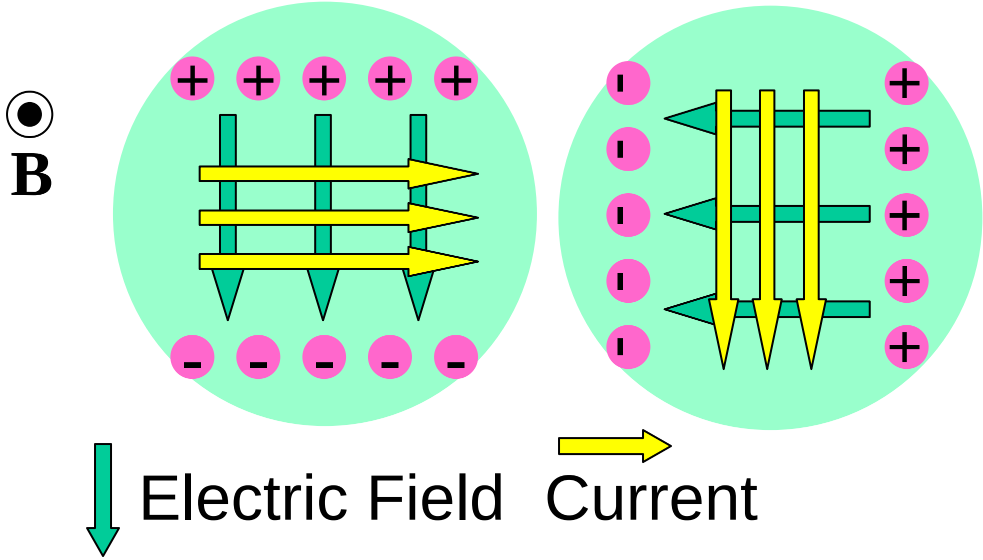
Density profile near the edge can be controlled by electric field.







Edge-magneto plasmons (EMP)



- Collective oscillation mode: propagates along the 2DEG edge.
- Magnetic field B perpendicular to the electron sheet.
- Small damping in strong magnetic field.
- Observed in various 2DEG systems:
  GaAs / AlGaAs heterostructure,
  Metal-Insulator-Semiconductor,
  Helium surface state electrons

Basic Features of EMP

Propagates along 2D electron gas in only one direction.

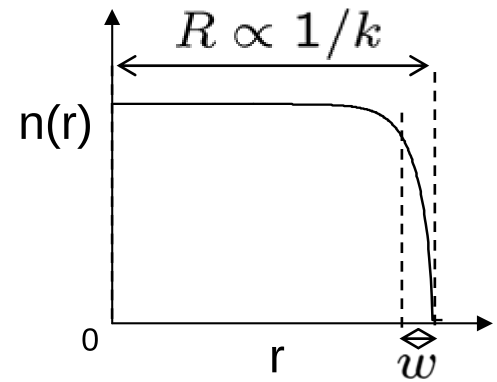
Gapless spectrum $\omega_{\mathrm{emp}} \propto q \ln(1/|q|) << \omega_{\mathrm{c}}$

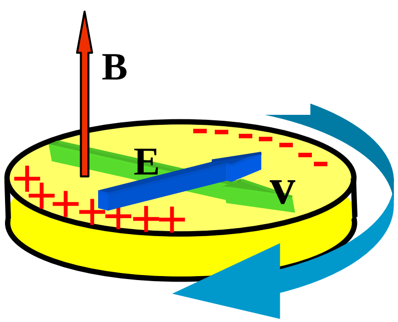
Frequency $\omega_{\mathrm{emp}} \propto n_{\mathrm{e}}$ and B^{-1}

Small damping rate at strong magnetic field ($\omega_{\mathrm{c}}\tau >> 1$).

Frequency: $$\omega_{\mathrm{emp}} = \frac{q\sigma_{xy}}{2\pi\epsilon}\left(\ln\frac{1}{|q|w} + C\right)$$

Damping rate: $$\frac{1}{\tau_{\mathrm{emp}}} \sim -\frac{\sigma_{xx}}{4\pi\epsilon w}\frac{1}{\ln(|q|w)}$$

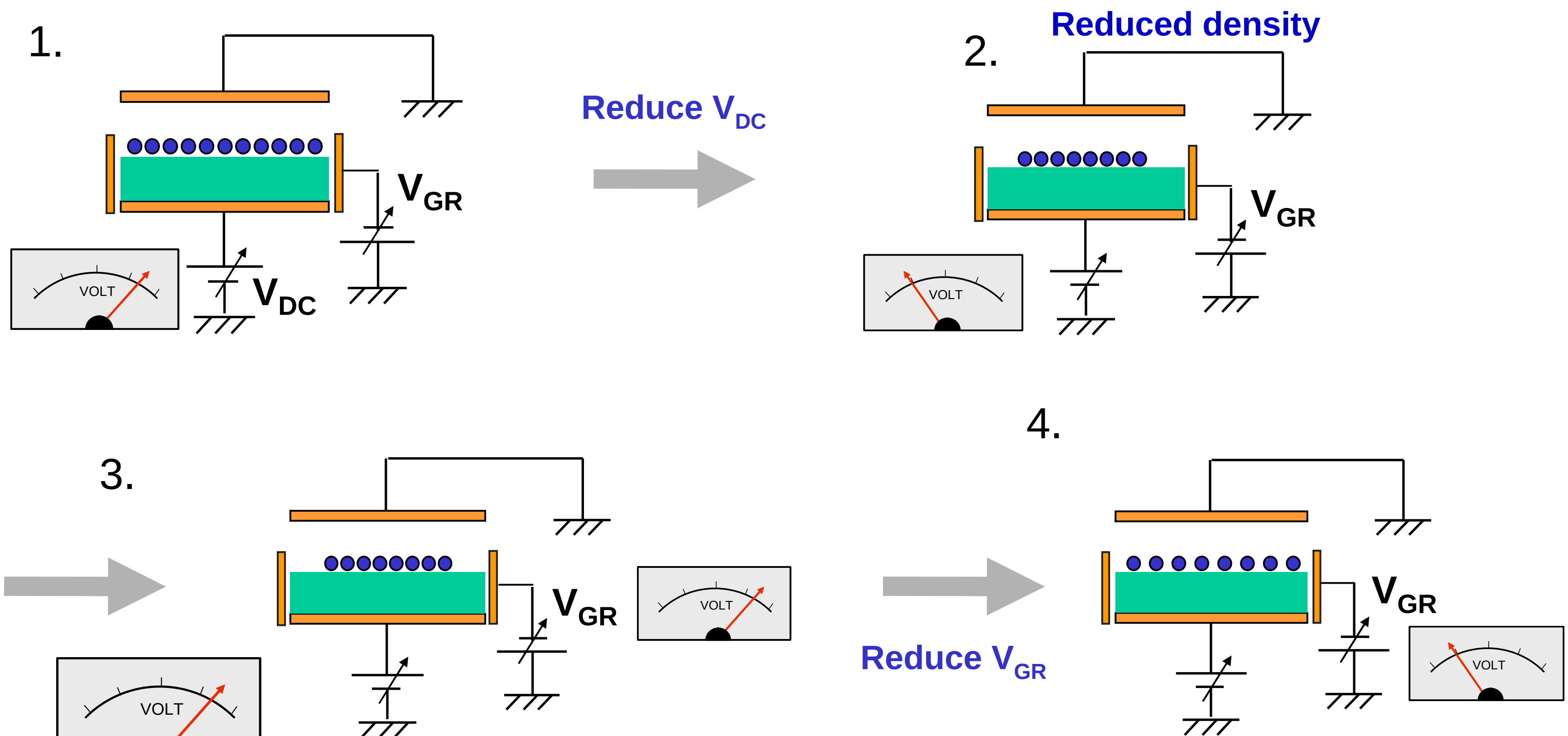




Drude: $$\sigma_{xx} = \frac{ne^2\tau}{m}\frac{1}{1+\omega_c^2\tau^2} \qquad \sigma_{xy} = -\frac{ne^2\tau}{m}\frac{\omega_c\tau}{1+\omega_c^2\tau^2}$$

High magnetic field: $$\frac{\sigma_{xx}}{\sigma_{xy}} = \frac{1}{\omega_{\mathrm{c}}\tau} = \frac{m}{eB\tau}$$

Experiment

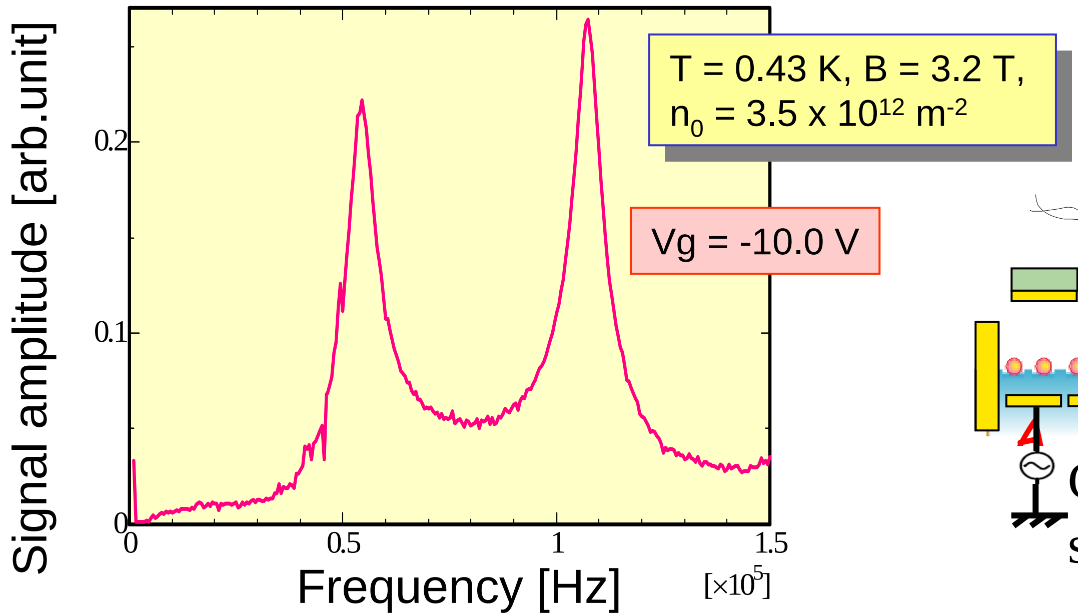


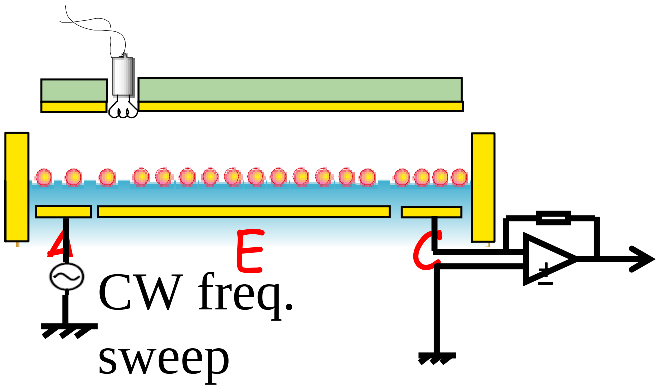
Back to initial V_{DC}

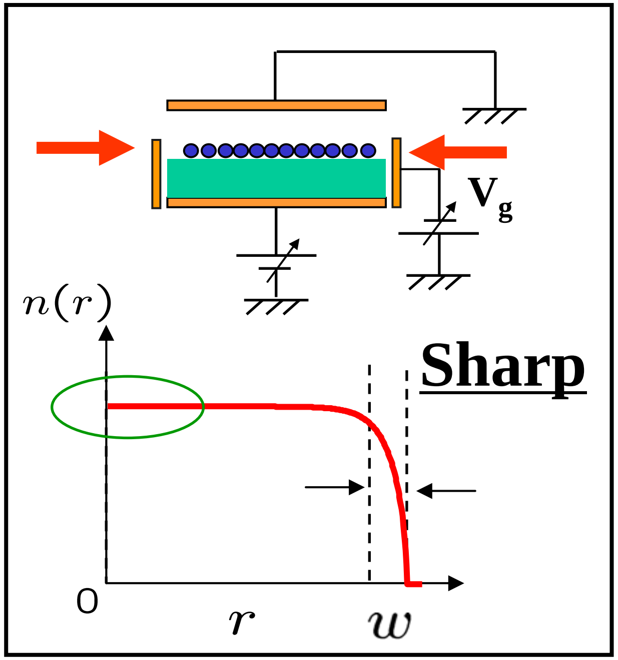
Measure EMP spectrum at each V_{GR}.

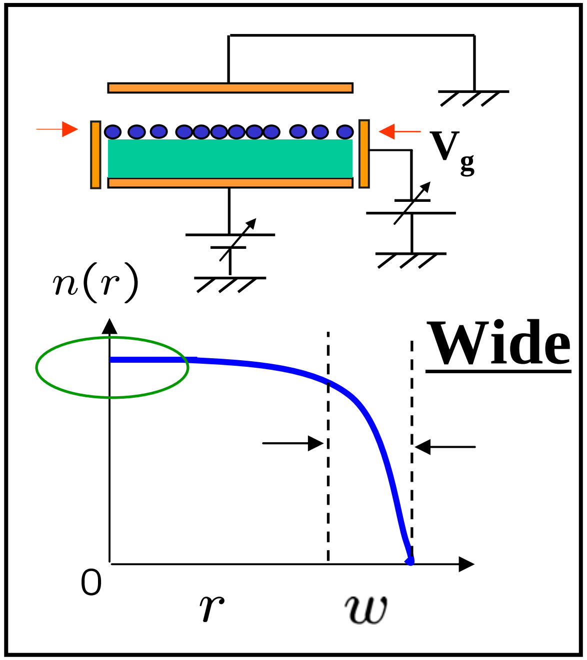
The total number of electrons is conserved through the measurement.

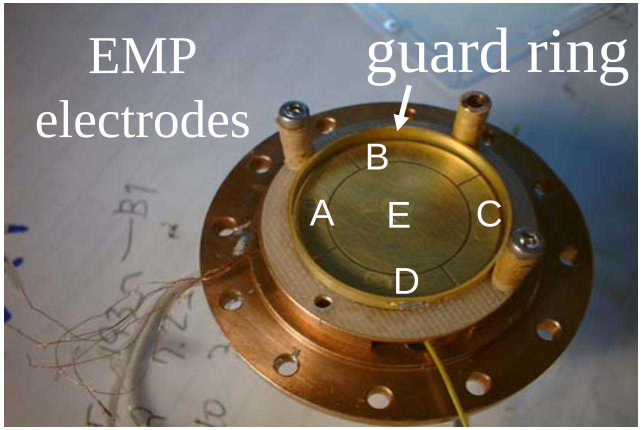
Controlling the density profile near the edge



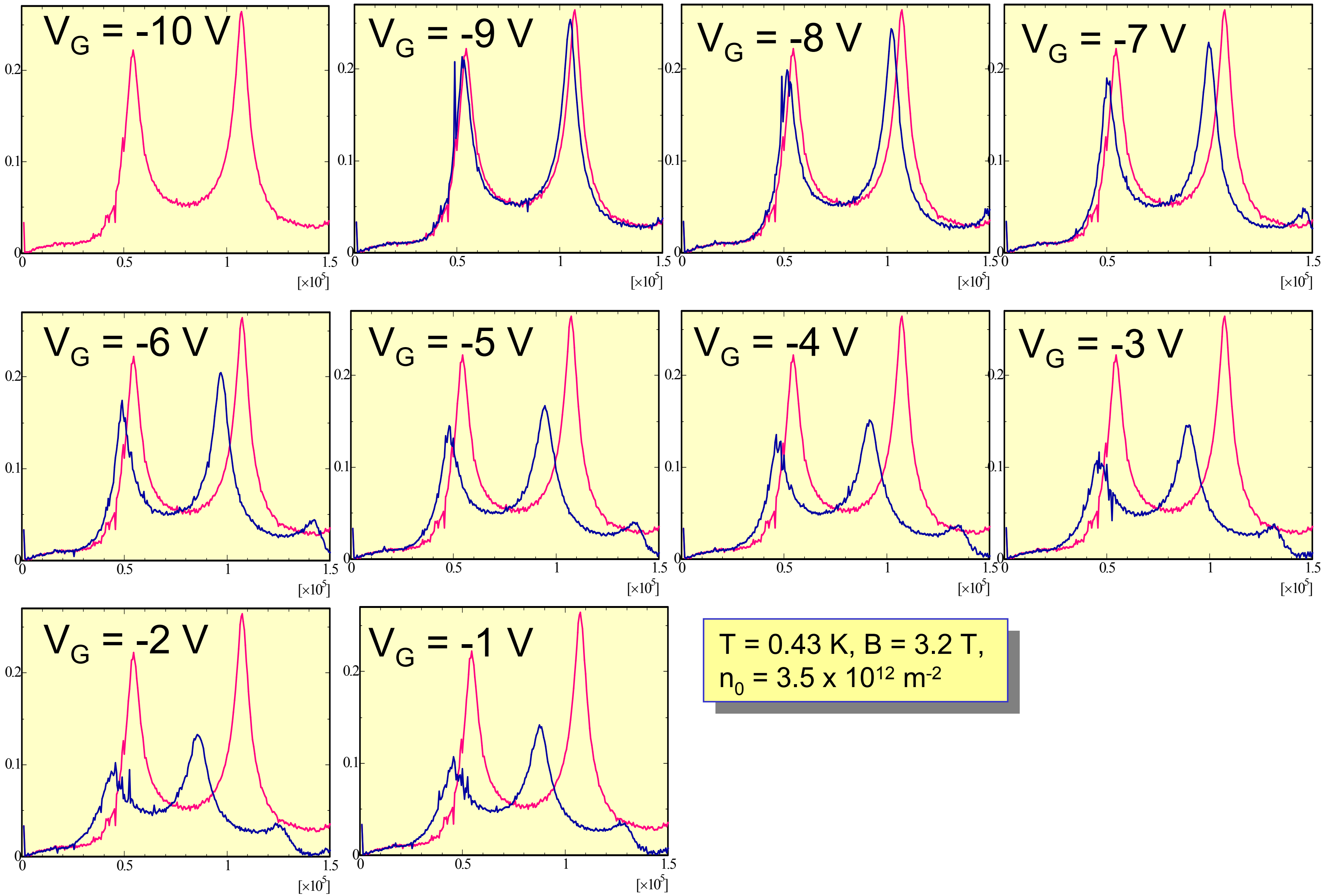








EMP Line Shapes



$T = 0.43$ K, $B = 3.2$ T,
$n_0 = 3.5 \times 10^{12}\ m^{-2}$

Double Lorenzian fitting

Lorenz functions

First resonance

$$L_1(\omega) = \frac{a_1}{\left(\left(\omega_1^2 - \omega^2\right)^2 + \gamma_1^2\omega^2\right)^{1/2}}$$

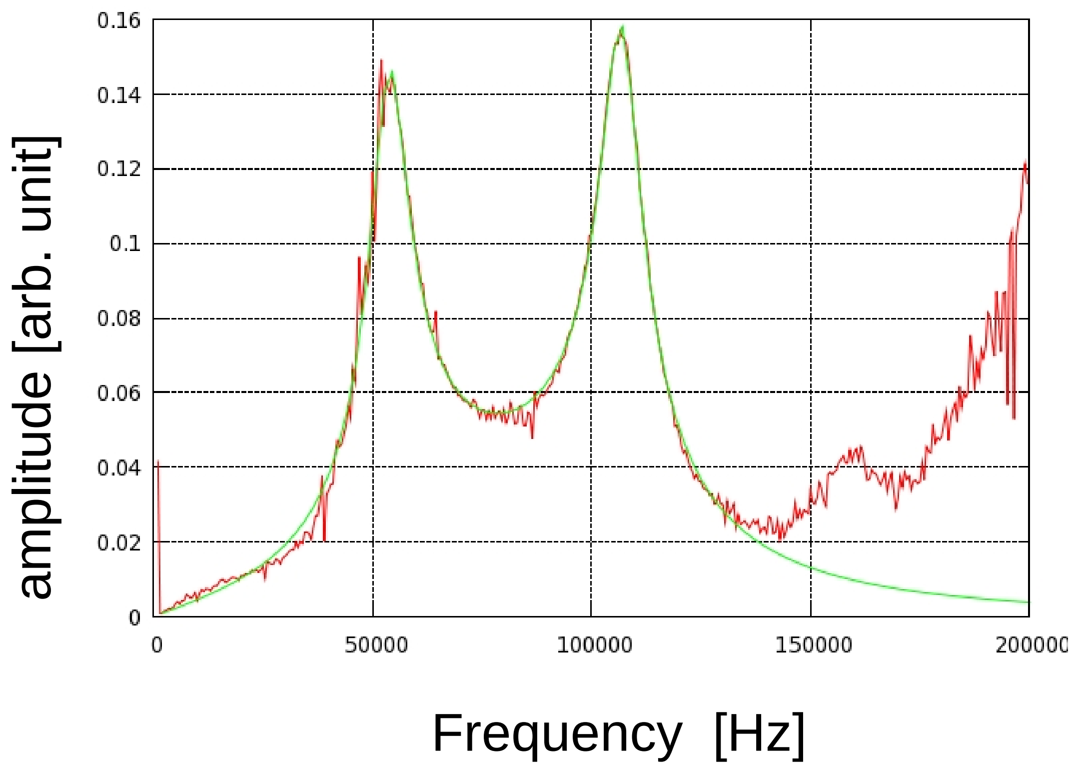
Second resonance

$$L_2(\omega) = \frac{a_2}{\left(\left(\omega_2^2 - \omega^2\right)^2 + \gamma_2^2\omega^2\right)^{1/2}}$$

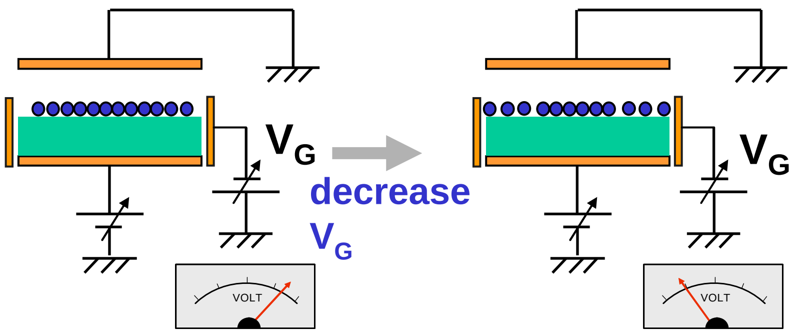
Overall function

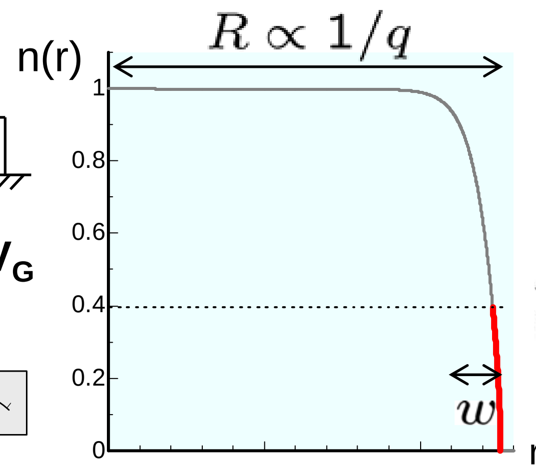
$$F(\omega) = \frac{L_1(\omega) + L_2(\omega)}{\left(R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right)^{1/2}}$$

Required by the electronics.



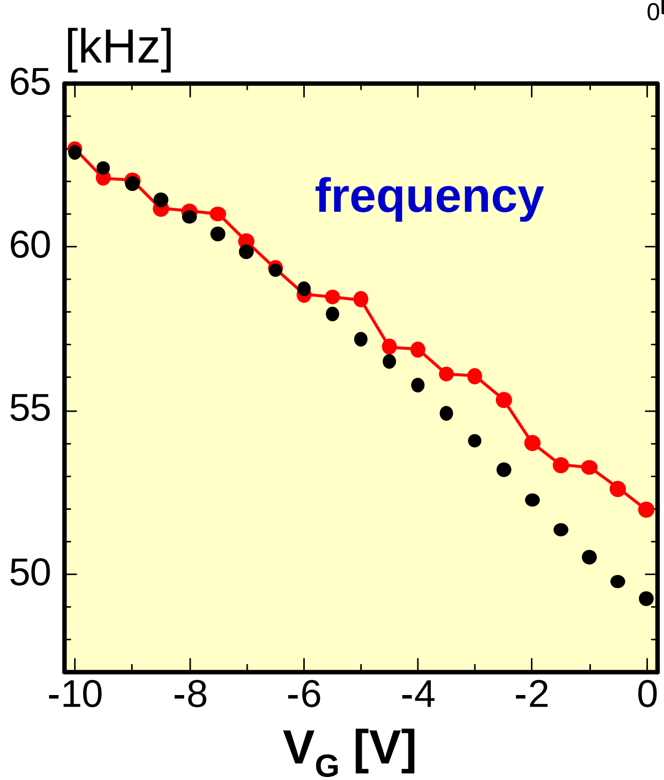
Guard Voltage Dependence

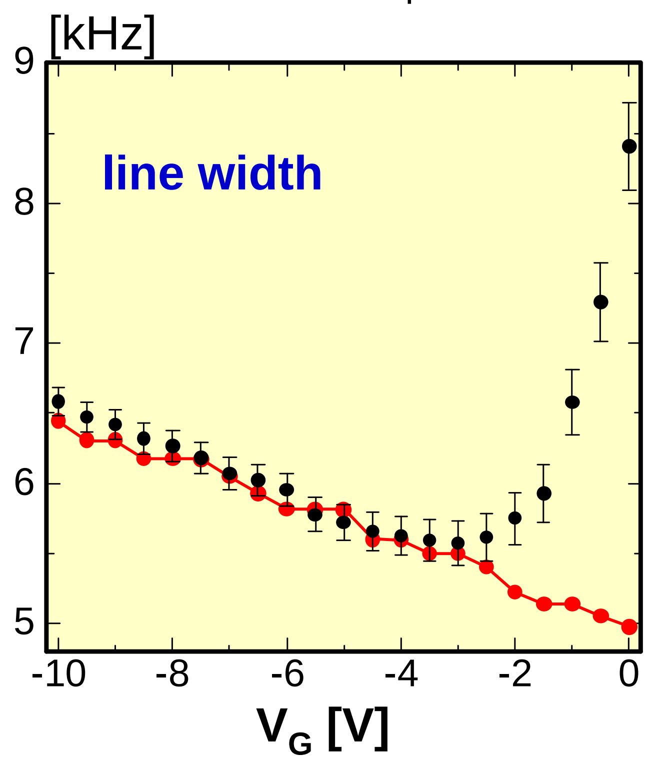




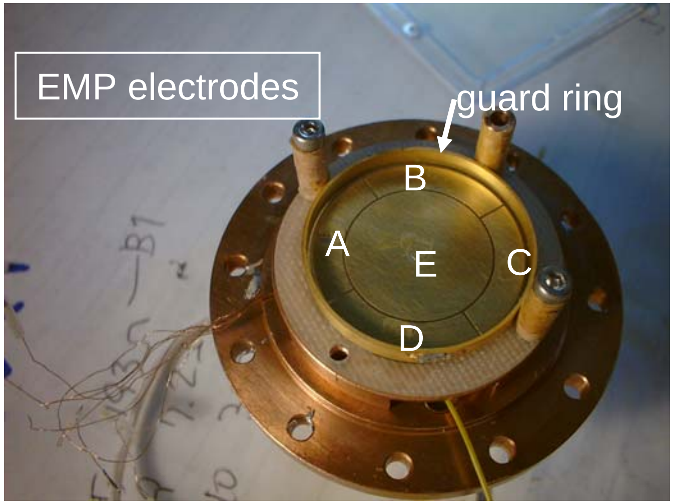
$$\omega_{\rm emp} = \frac{q\sigma_{xy}}{2\pi\epsilon}\left(\ln\frac{1}{|q|w} + C\right)$$

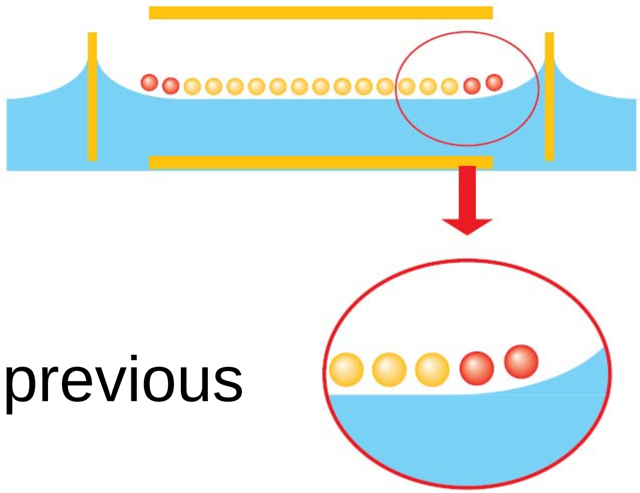
$$\frac{1}{\tau_{\rm emp}} \sim -\frac{\sigma_{xx}}{4\pi\epsilon w}\frac{1}{\ln(|q|w)}$$

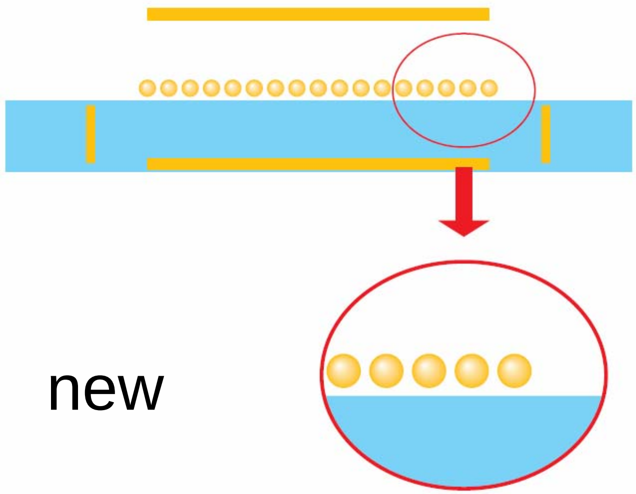




Surface deformation ?



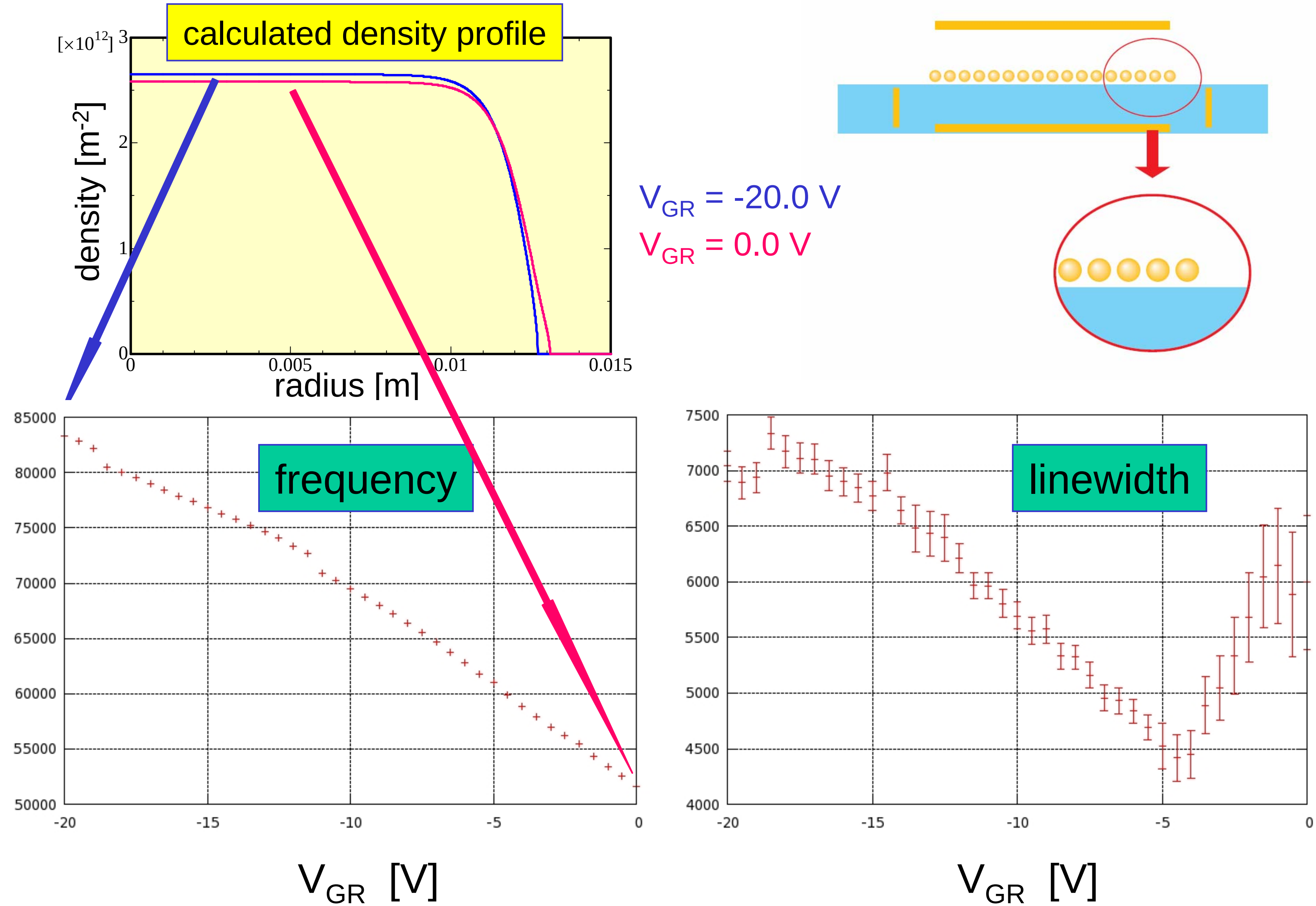




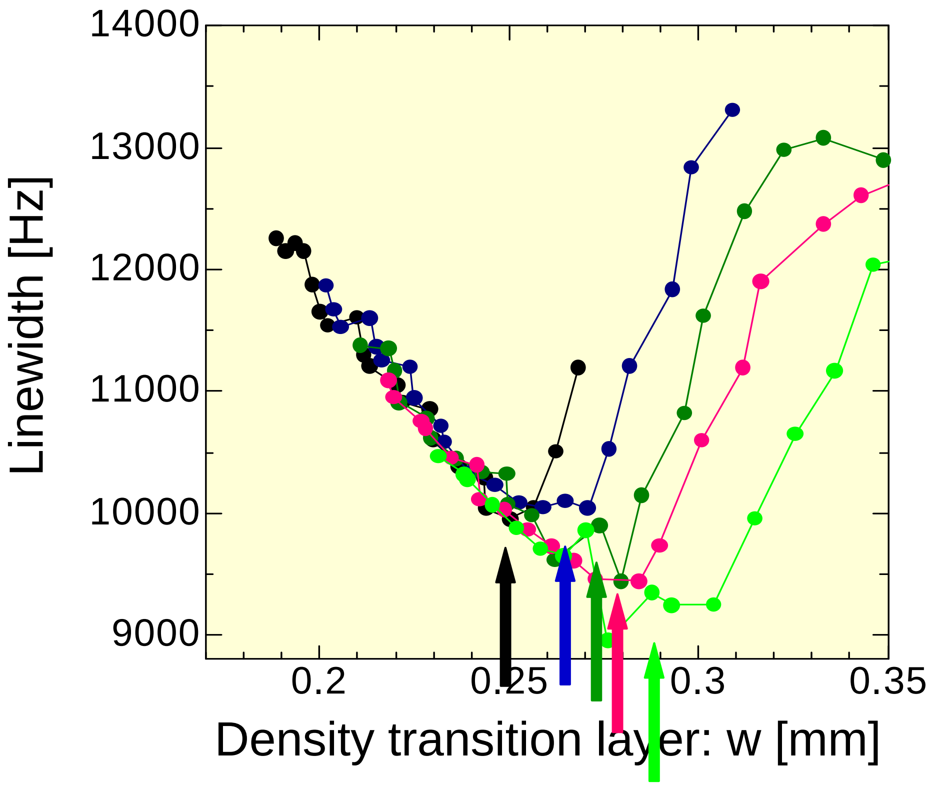
Immersed guard ring

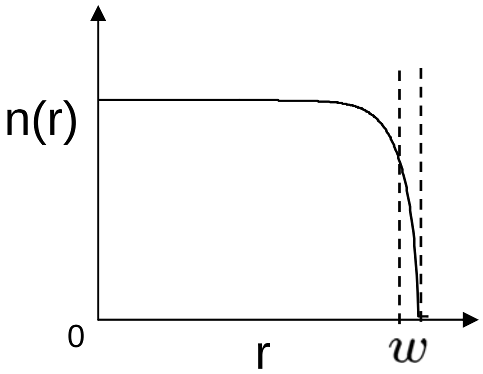
Immersed guard ring result

Line width broadenings are observed even with the immersed guard ring.



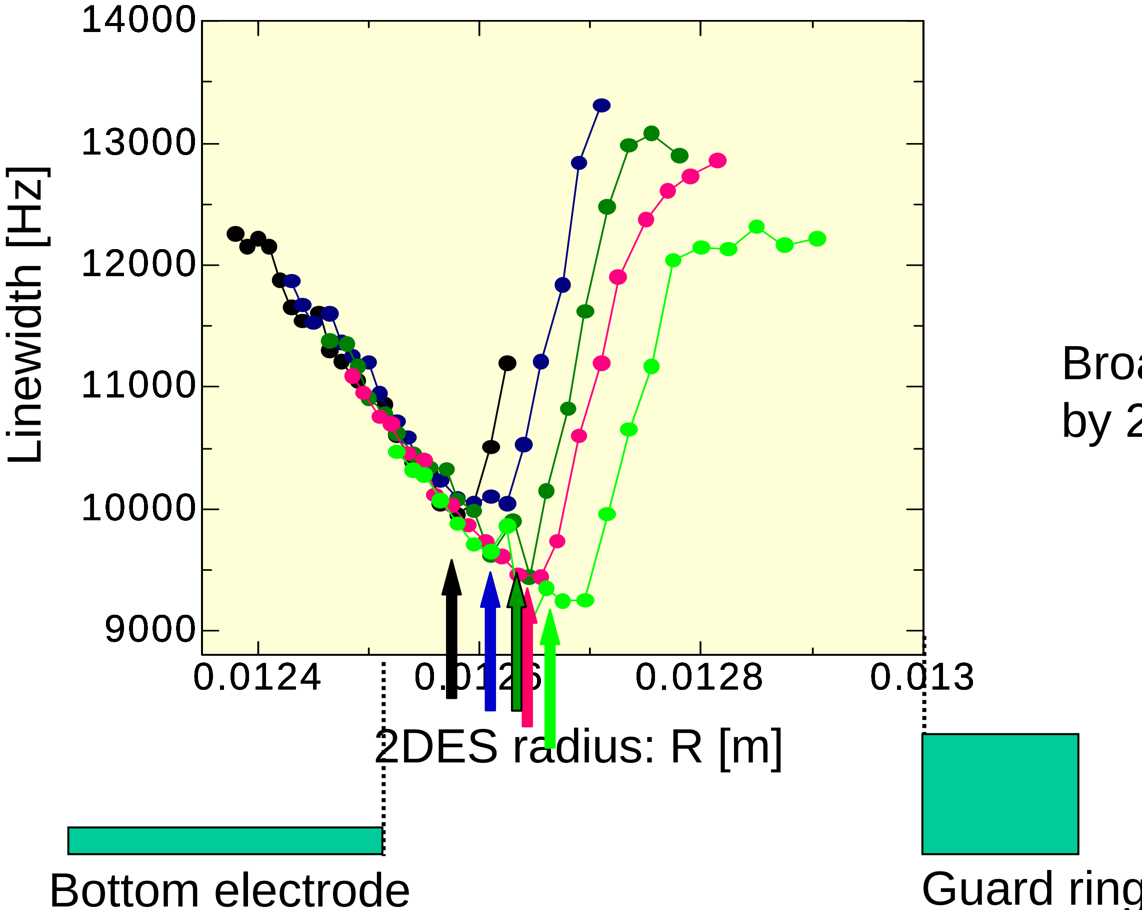
Linewidth – Density transition layer

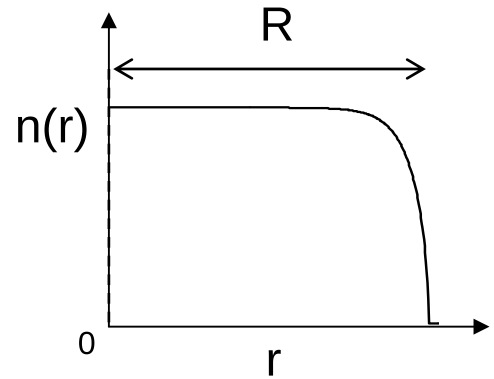




The broadening is NOT governed by density transition layer w.

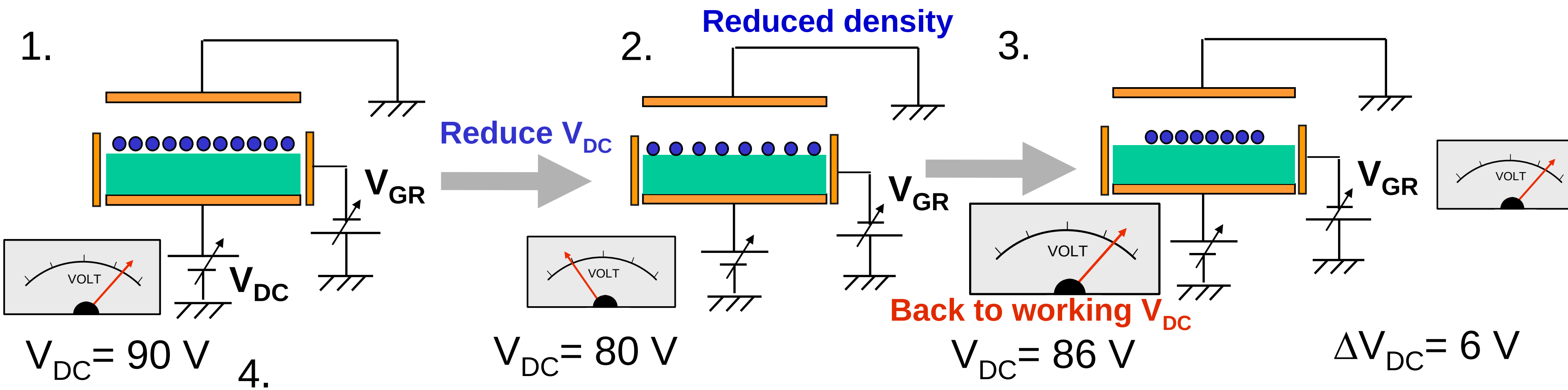
Linewidth – 2DES radius

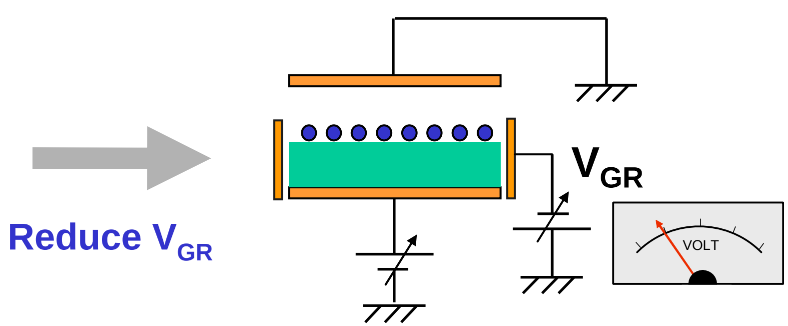




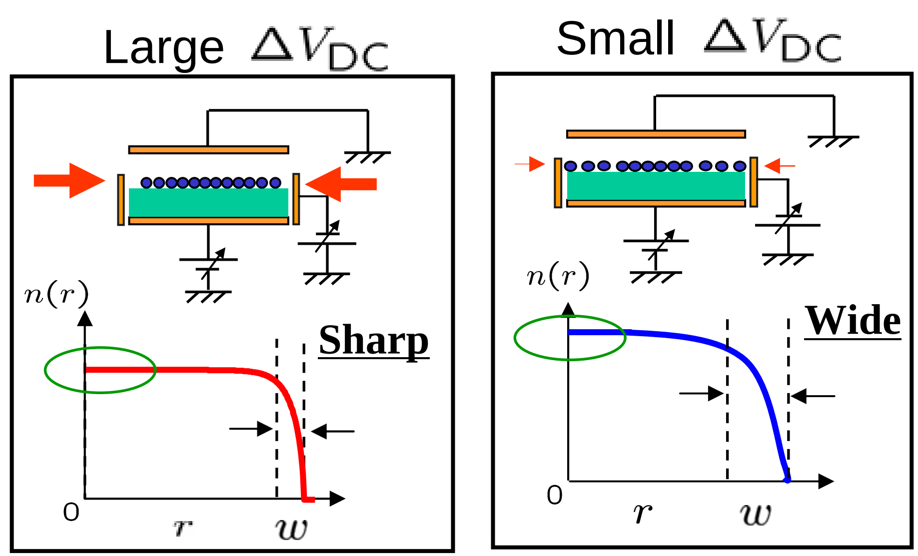
Broadening is NOT governed by 2DES radius.

Controlling lateral confinement pontential





Measure EMP spectrum at each V_{GR}.

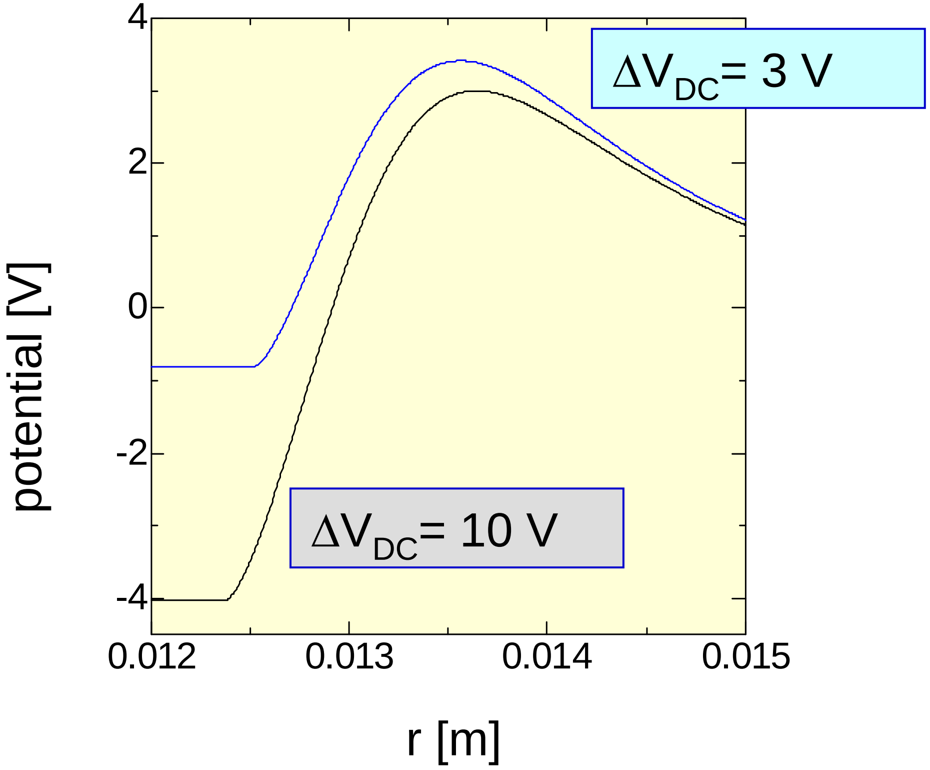


Large ΔV_{DC} corresponds to strong lateral confinement.

The total number of electrons is conserved through the measurement.

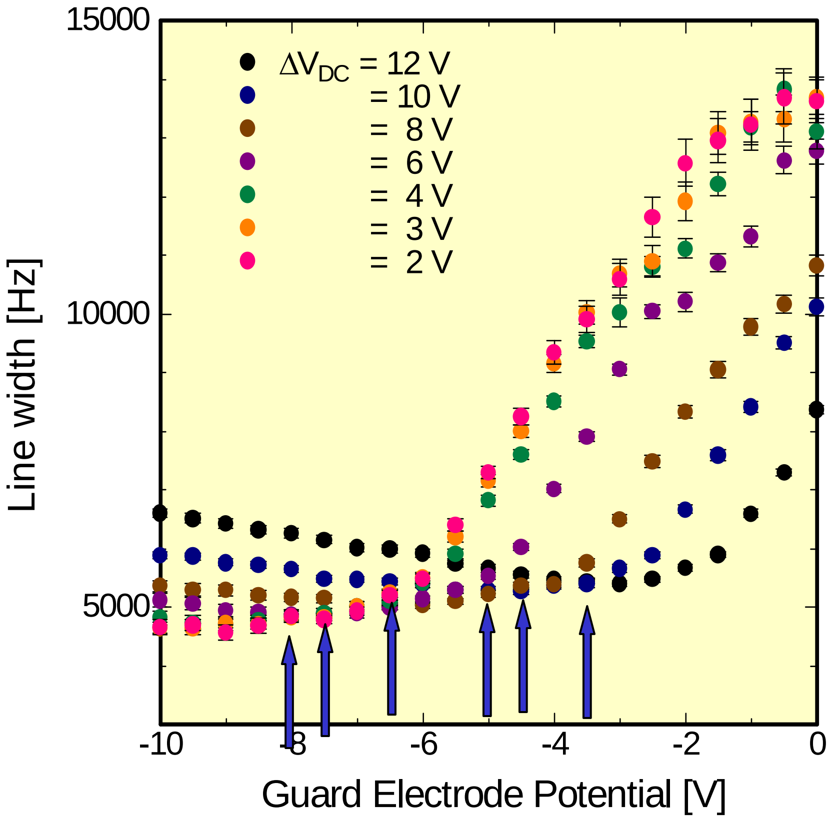
Controlling lateral confinement pontential

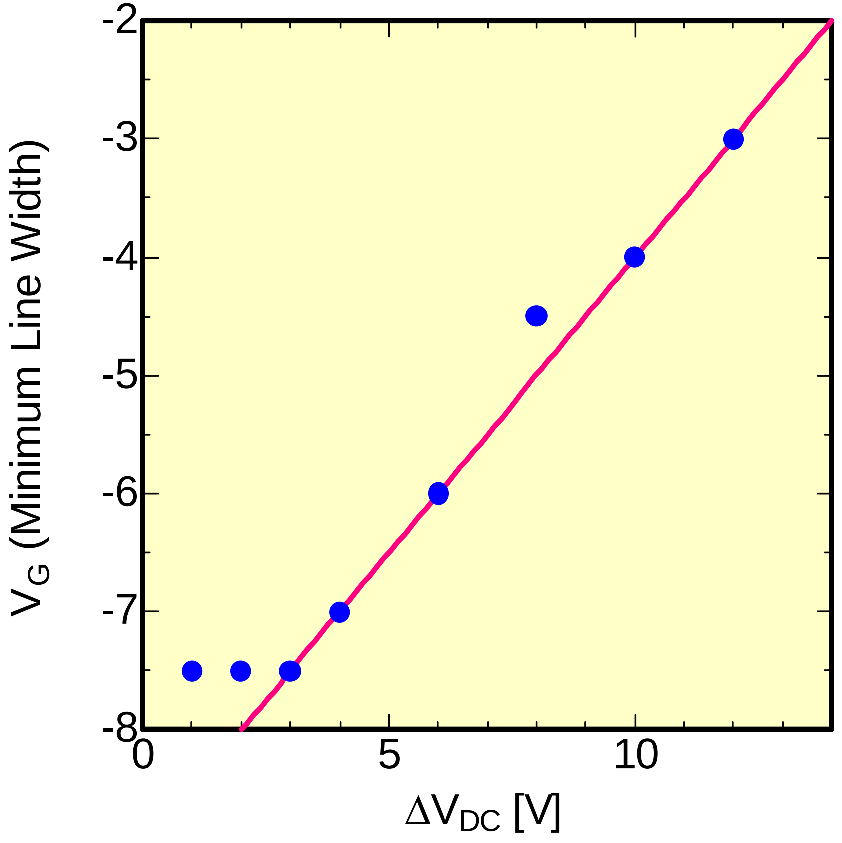
Large ΔV_{DC} corresponds to strong lateral confinement.



Controlling lateral confinement pontential

Weak confinement → Broadening is easier to occur.



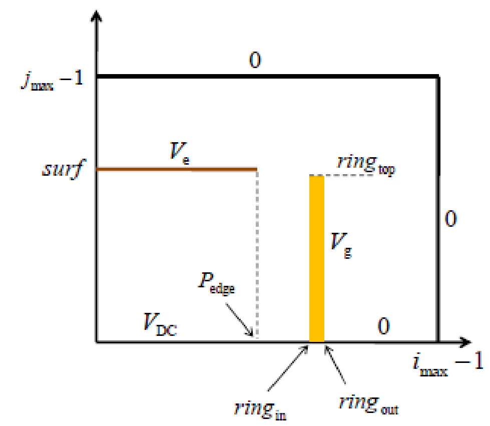


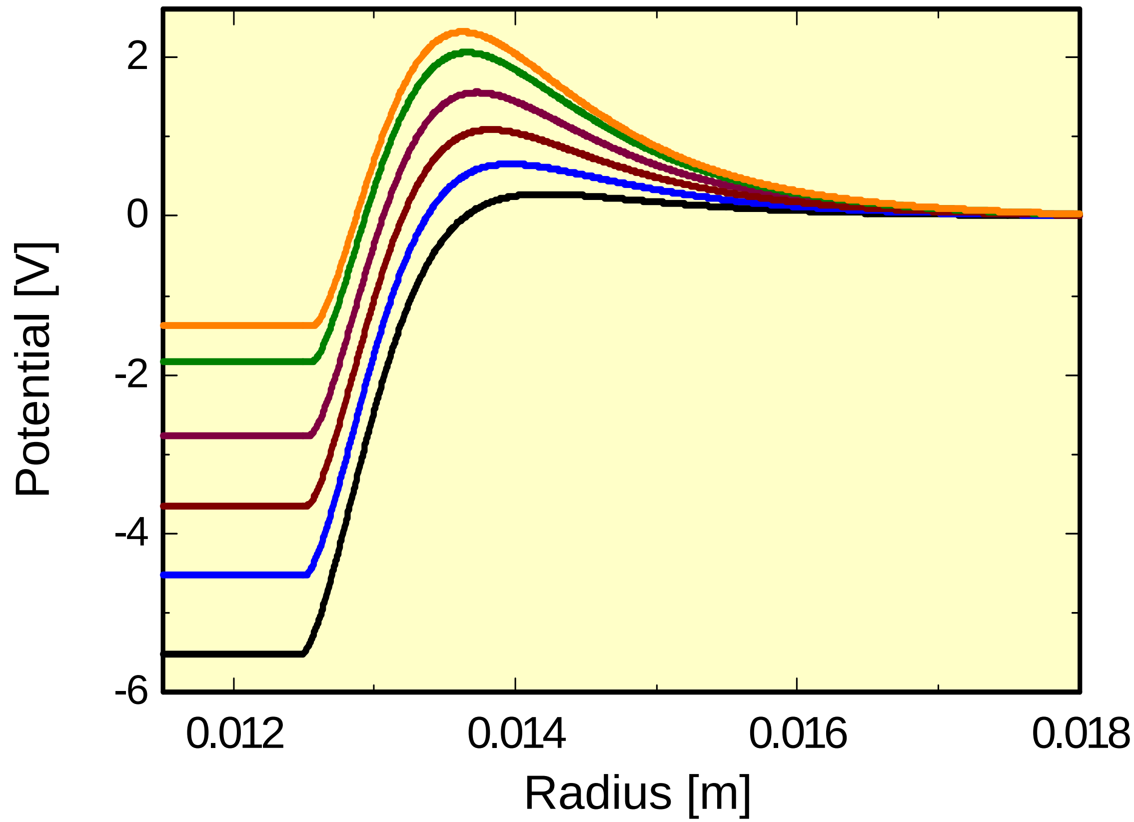
Controlling lateral confinement pontential

Solve $\nabla^2\phi(\mathbf{r}) = 0$

under appropriate boudary conditions.

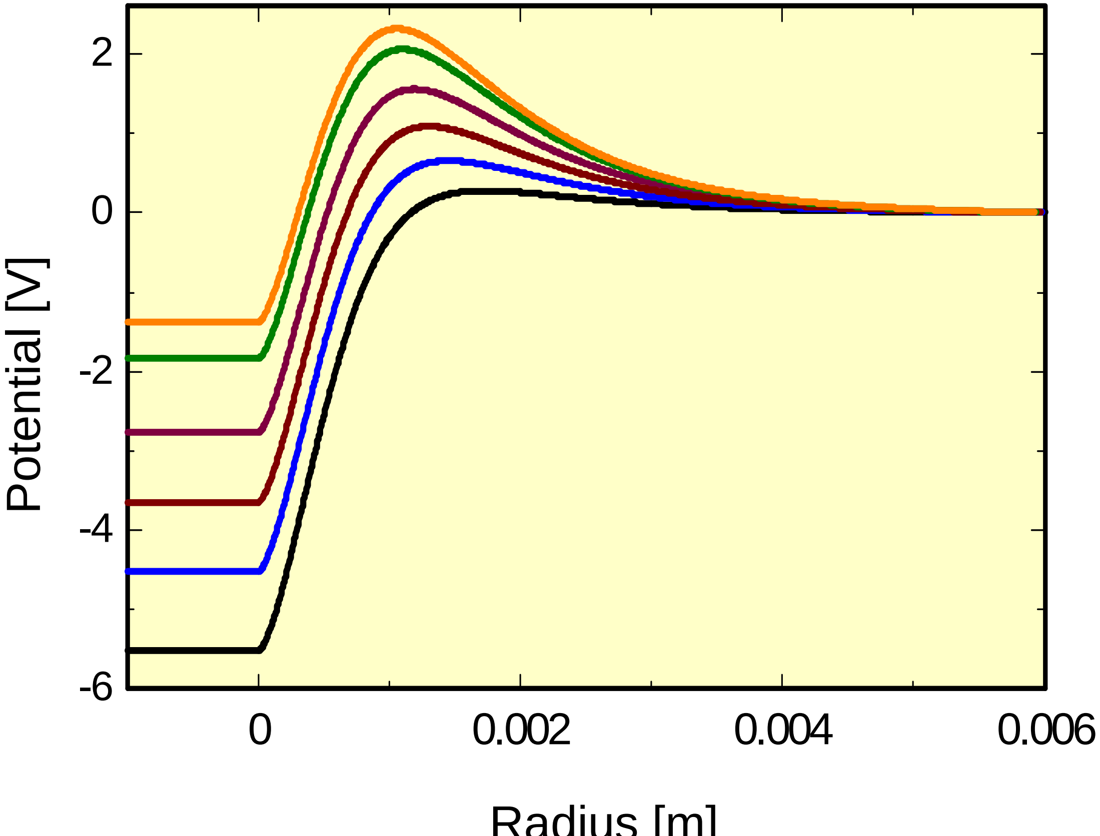
$\phi(\text{surface}) = V_{\text{e}}$, where 2DEG exists.





Controlling lateral confinement pontential

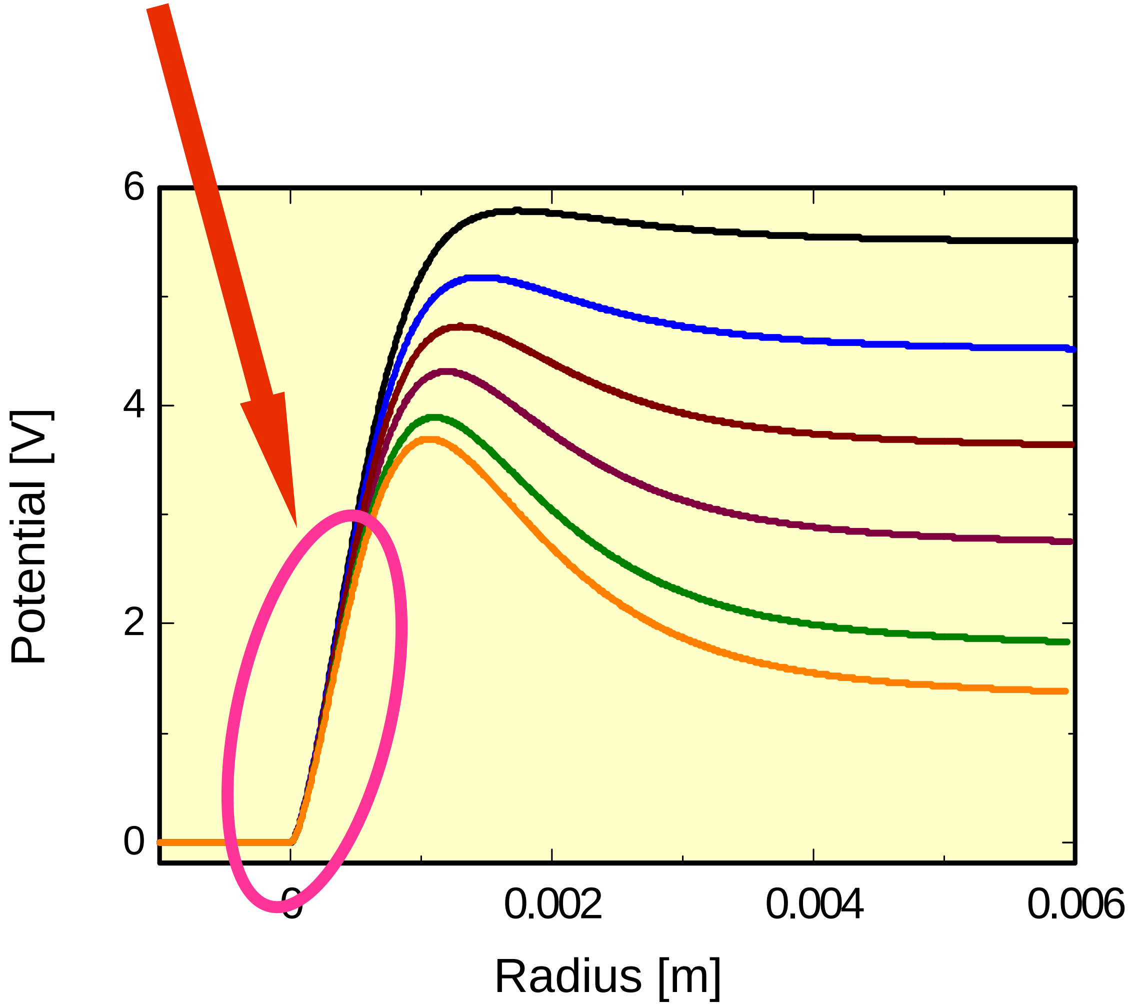
Set the 2DEG edge to r=0.



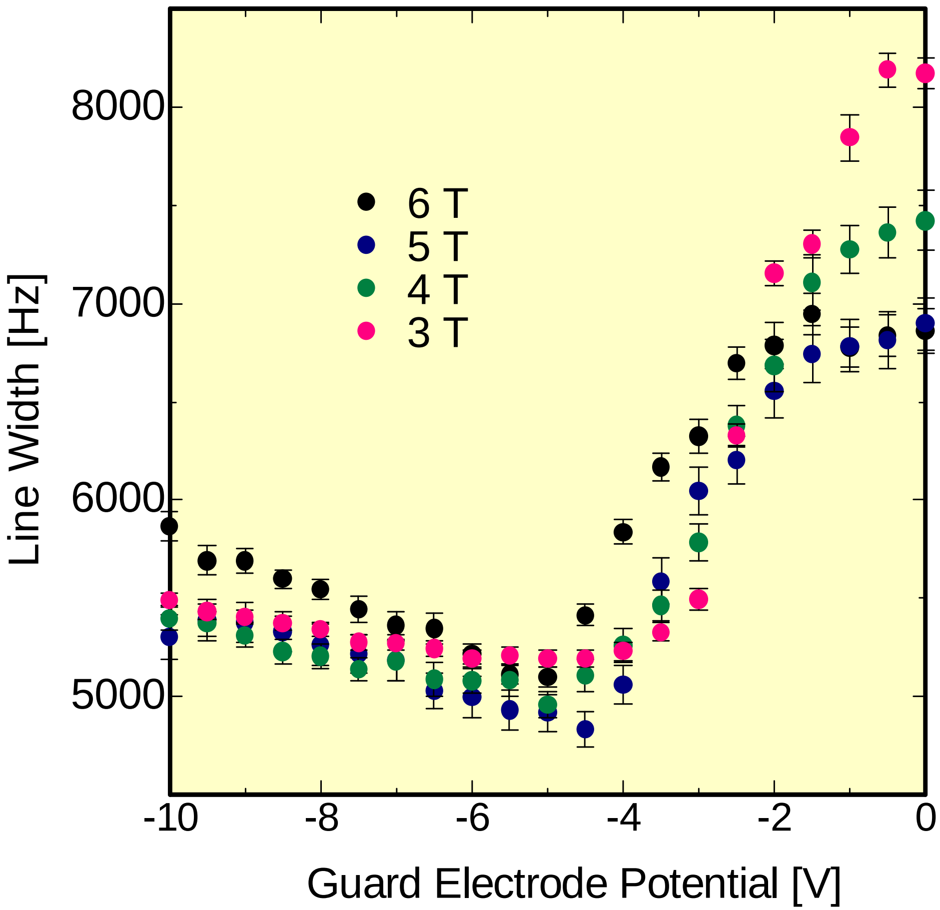
Controlling lateral confinement pontential

Move Ve to zero.

Initial rise of the confinement potentials are the same !!



Magnetic Field Dependence



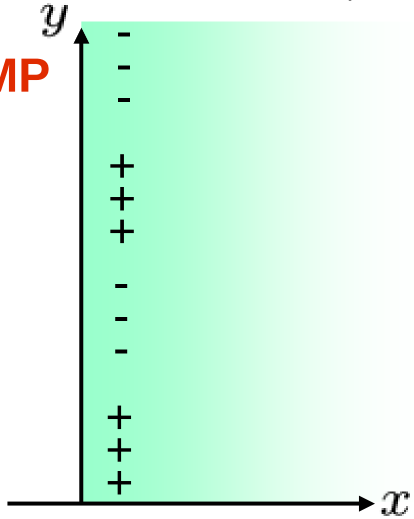
Magnetic field does not affect the turning point.

Sharp switching is observed at strong magnetic field.

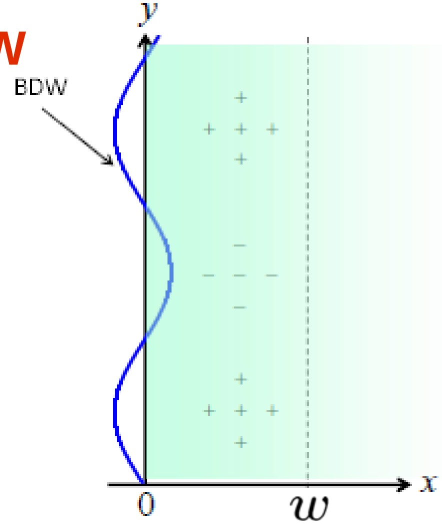
Conventional EMP and Boundary Displacement Wave (BDW)

BDW : Yu. P. Monarkha, Low Temp. Phys. 21, 458 (1995)

Conventional EMP



BDW



Rigid boudary	Movable boundary
Compressible liquid	Incompressible liquid
$\omega_{\mathrm{EMP}} = \frac{\gamma_{\mathrm{EMP}}}{B}$	$\omega_{\mathrm{BDW}} = \frac{\gamma_{\mathrm{BDW}}}{B}$
(Frequency difference is small at large B)	
Small damping	Large damping

Summary

- EMP spectrum was studied with controlling **lateral confinement** potential.
- Unexpected **line broadenings** were observed when the confinement potential is weak.
- The broadening can be qualitatively explained by **boundary displacement wave**.
- The lateral confinement electric field determines EMP or BDW to occur.
- Strong confinement: EMP, Weak confinement: BDW
- Frequencies of EMP and BDW are close at high magnetic field.
- BDW damping is larger than EMP.