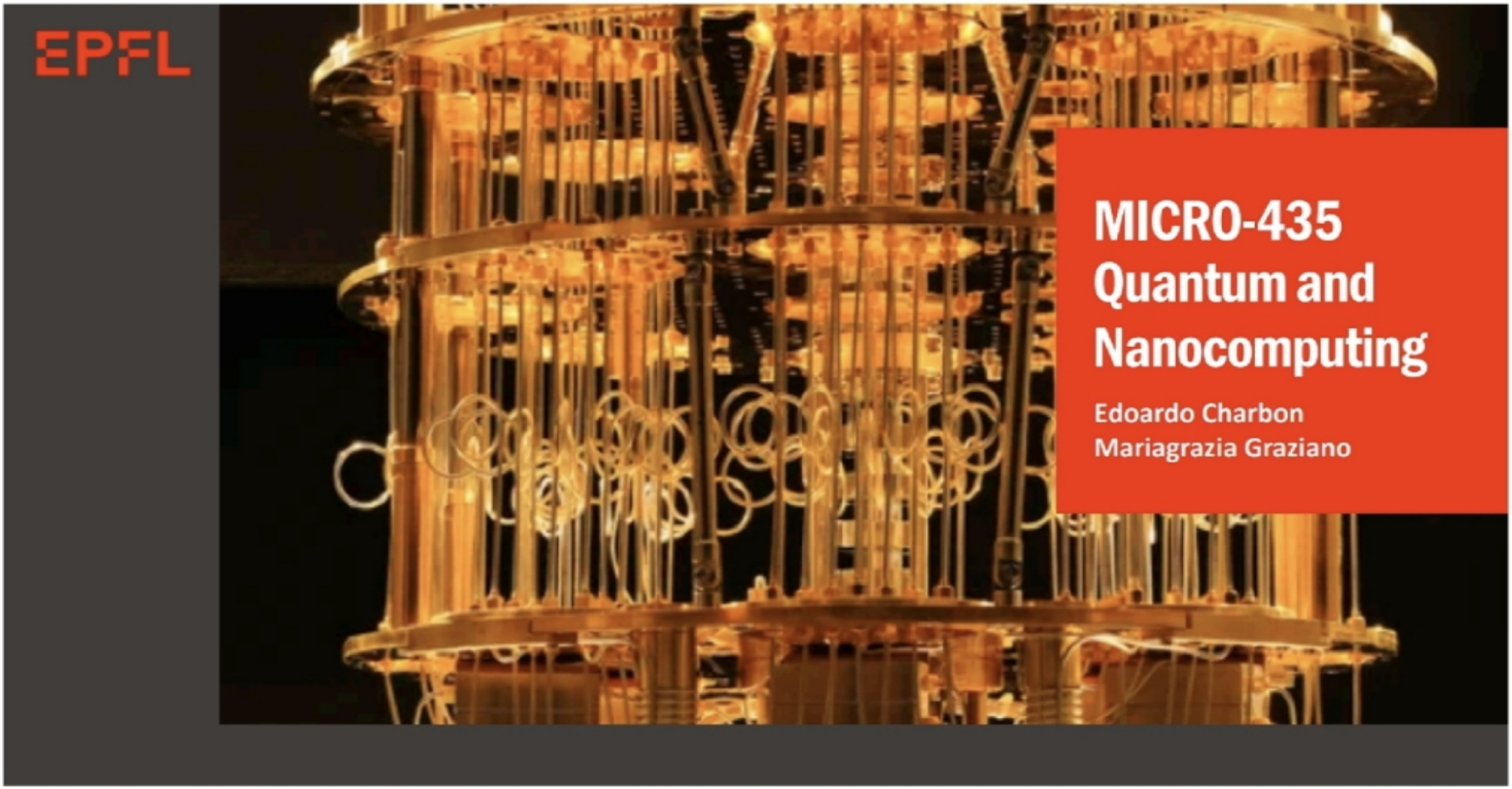


HT BEHAVIOR & CHARACTERISTICS PART 3

OBJECTIVE

a) CHARGING EFFECT & RESONANCE

b) EFFECT OF GATE

b) CHARGING EFFECT & RESONANCE

ELECTROSTATIC EFFECT

APPLY V_{DS} → CREATE DR

→ VARIATION CHANNEL CHARGE

↳ E_L / H_L

⇓

I_{DS}

CHARGING EFFECT

WHEN A CHARGE ENTERS IN THE CHANNEL THE ENERGY LEVELS IN THE CHANNEL ARE ALTERED

CHARGING EFFECT

WHEN A CHARGE ENTERS IN THE CHANNEL THE ENERGY LEVELS IN THE CHANNEL ARE ALTERED

$V_{DS}=0 \longrightarrow T(E)$ @ EQUILIBRIUM

DUE TO N_0 — N° of el. IN CHANNEL @ EQUILIBRIUM

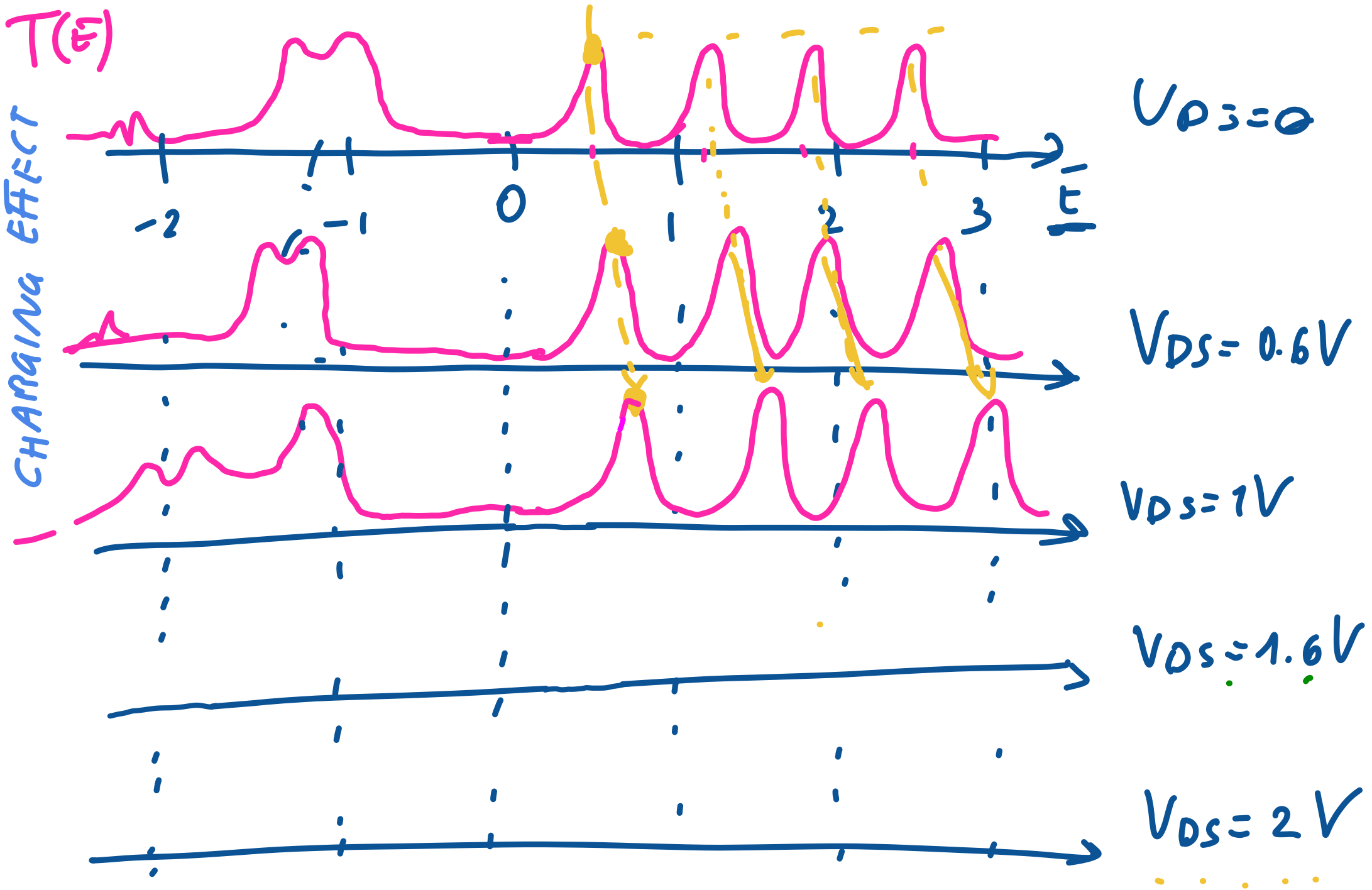
if V_{DS} ↑ or ↓

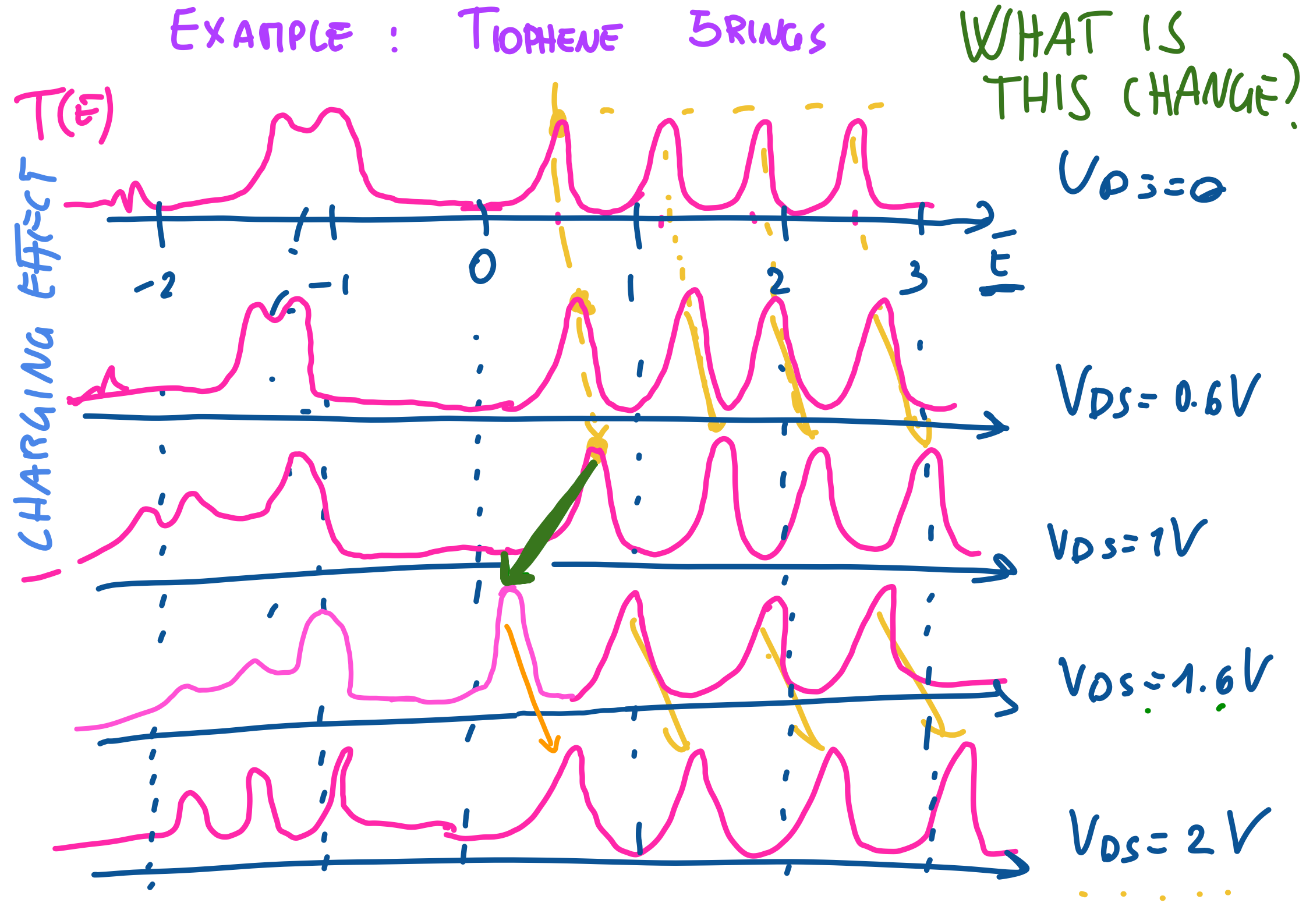
$N_0 \longrightarrow N \neq N_0$ — N° of el. CHANGES

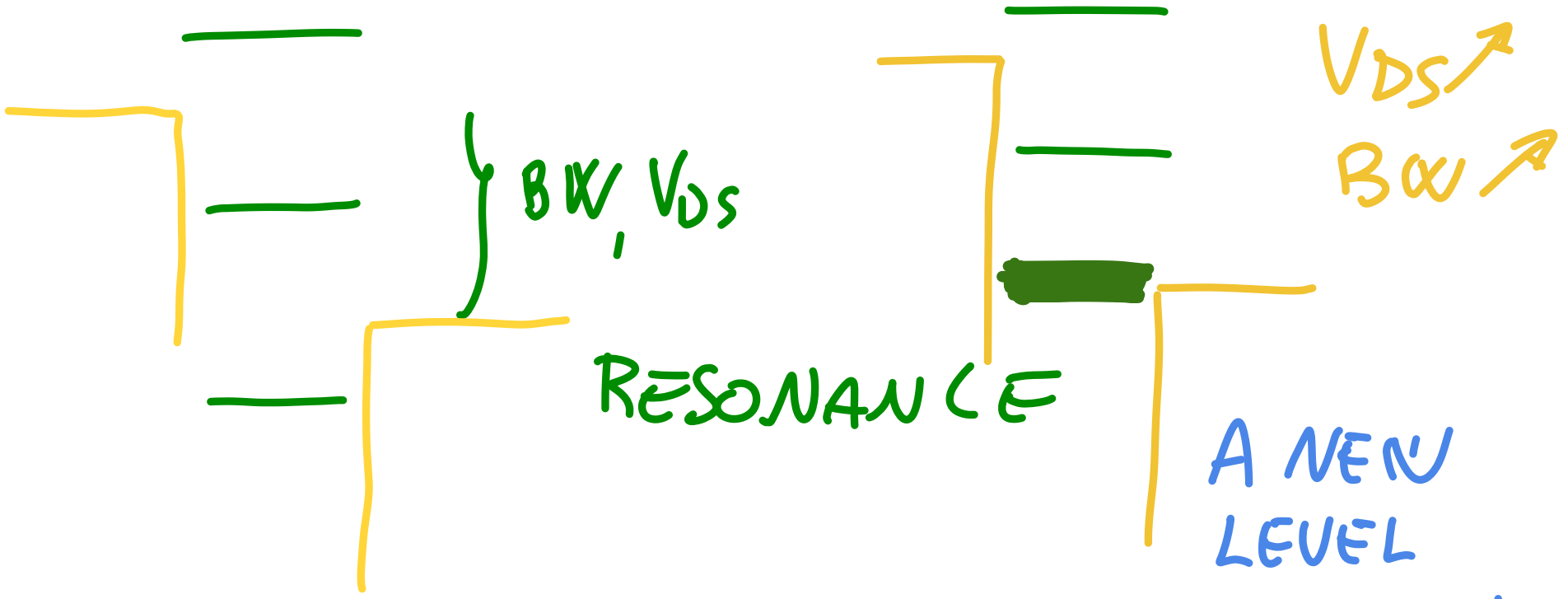
$T(E) \longrightarrow T(E,N)$ T. S. CHANGES

$I_{DS} \longrightarrow I_{DS}(T(E,N))$ CURRENT CHANGES

EXAMPLE : THIOPHENE 5RINGS




EXAMPLE : THIOPHENE RINGS
WHAT IS THIS CHANGE?
T(E)
CHARGING EFFECT
-2
-1
0
1
2
3
E
VDS=0
VDS=0.6V
VDS=1V
VDS=1.6V
VDS=2V



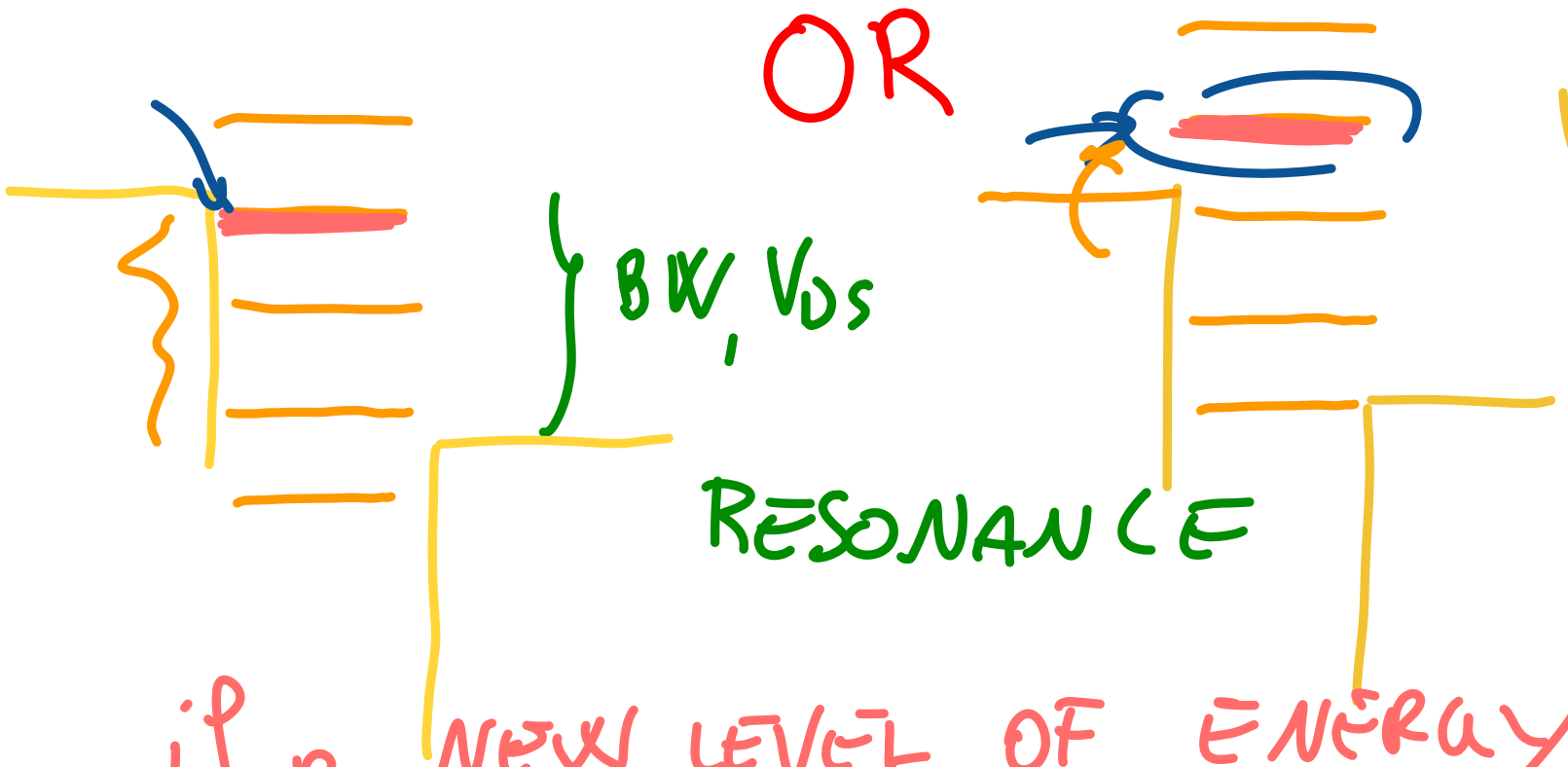
A NEW LEVEL ENTERS IN THE B.W.

↓

A NEW ELECTRON JUMPS IN THE CHANNEL

← NEGATIVE CHARGES ENTERS

THE Ts SHIFTS TOWARD LOWER ENERGIES



V_{DS} ↓ or ↑

BW. ↓ or ↑

if a NEW LEVEL OF ENERGY

EXITS FROM THE CHANEL

↓

1EL JUMPS OUT

↓

NEW POSITIVE CHARGE

TS SHIFT TOWARD HIGER ENERGIS

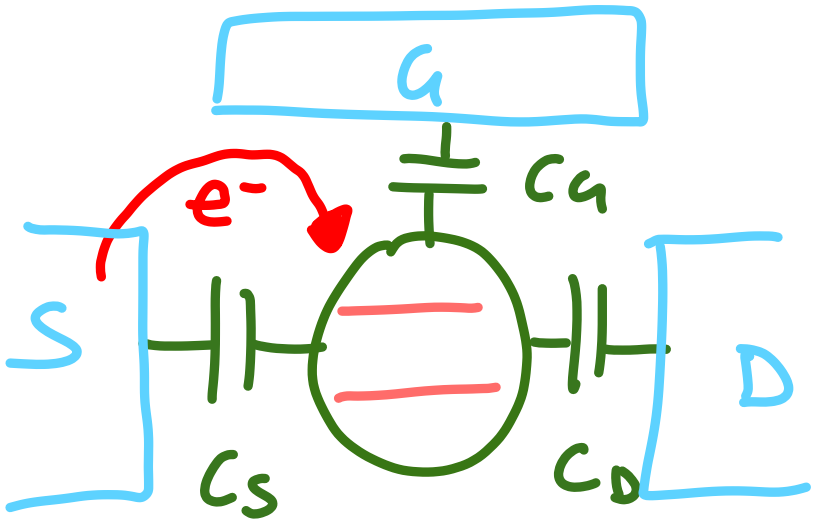
RECAP

I_{DS}

- ELECTROSTATIC CONTRIBUTION
- CHARGING EFFECT CONTRIBUTION (W/O or W RESONANCE)

HOW IS THIS TAKEN INTO ACCOUNT IN THE MODEL ?

CAPACITIVE MODEL OF QDOT



$$C_{ES} = C_S + C_D + C_G$$

$$U_{DOT} = -qV_{DS}\frac{C_D}{C_{ES}} - qV_{GS}\cdot\frac{C_G}{C_{ES}} + \frac{q^2}{E_S}\cdot(N - N_0)$$

N: ACTUAL No OF e^- IN THE DOT

N_0: No of $\bar{e}$ @ Eq.

$$N(V_{GS}, V_{DS}) = \sum_{i=1}^{M} \int \frac{2}{\gamma_{i,1} + \gamma_{i,2}} \cdot D_{EL}(E - U_{DOT}) \cdot$$

$$\cdot \left[\gamma_{i,1} f(E_L, E_{TS}) + \gamma_{i,2}(E_L, E_{FD}) \right] dE$$

TO CORRECTLY EVALUATE N

SCF → SELF CONSISTENT FIELD

→ SEE NEXT SECTION OF THE LESSON

NOW LET'S FOCUS ON KEY POINTS

KEY POINTS

$V_{DS} \uparrow \rightarrow \Delta Q_n = -q\Delta N$ VARIATION OF CHARGE IN CHANNEL

$\Delta V_{CHARGE} = \frac{-q\Delta N}{C_{ES}}$ → MODEL WITH CAP.

$U_{CHARGE} = -q\Delta V_{CHARGE} = \frac{q^2}{C_{ES}}\Delta N$

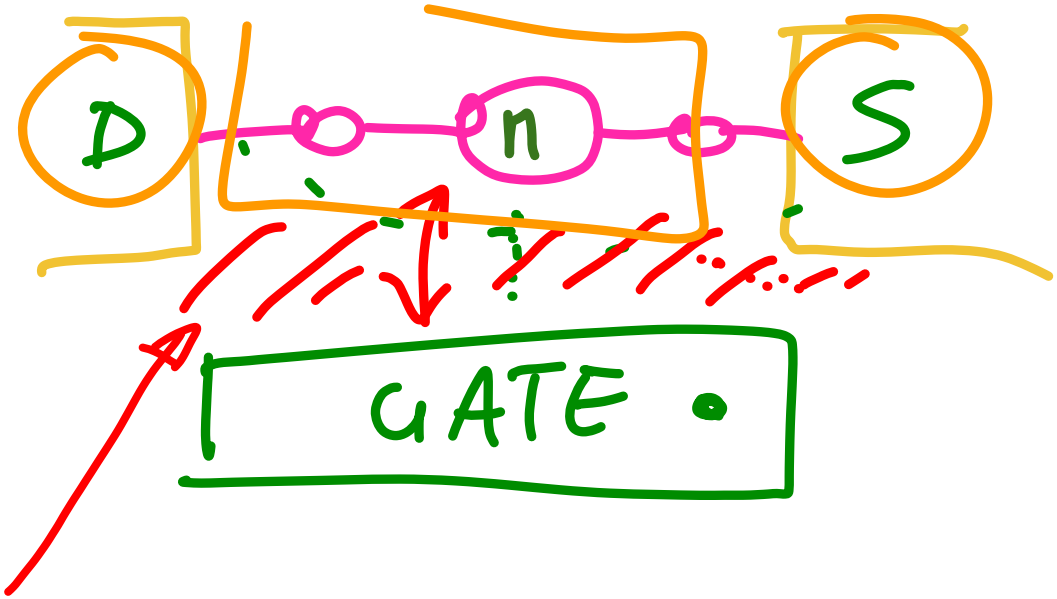
→ $V_{DS} \uparrow \rightarrow \Delta N \rightarrow U \alpha (\Delta N) \rightarrow D \alpha (E,U)$

→ $T(E,U) \alpha D$ $I_{DS} \propto T(E,U)$

C) EFFECT OF GATE

- GENERAL
- BENZENE
- OPV7
- PCP

EFFECT OF GATE



A CERTAIN MATERIAL AND DISTANCE DETERMINES THE COUPLING FACTOR

V_{GS} APPLIED

↓ COUPLING FACTOR ←

D - M - S

SYSTEM CHANGES

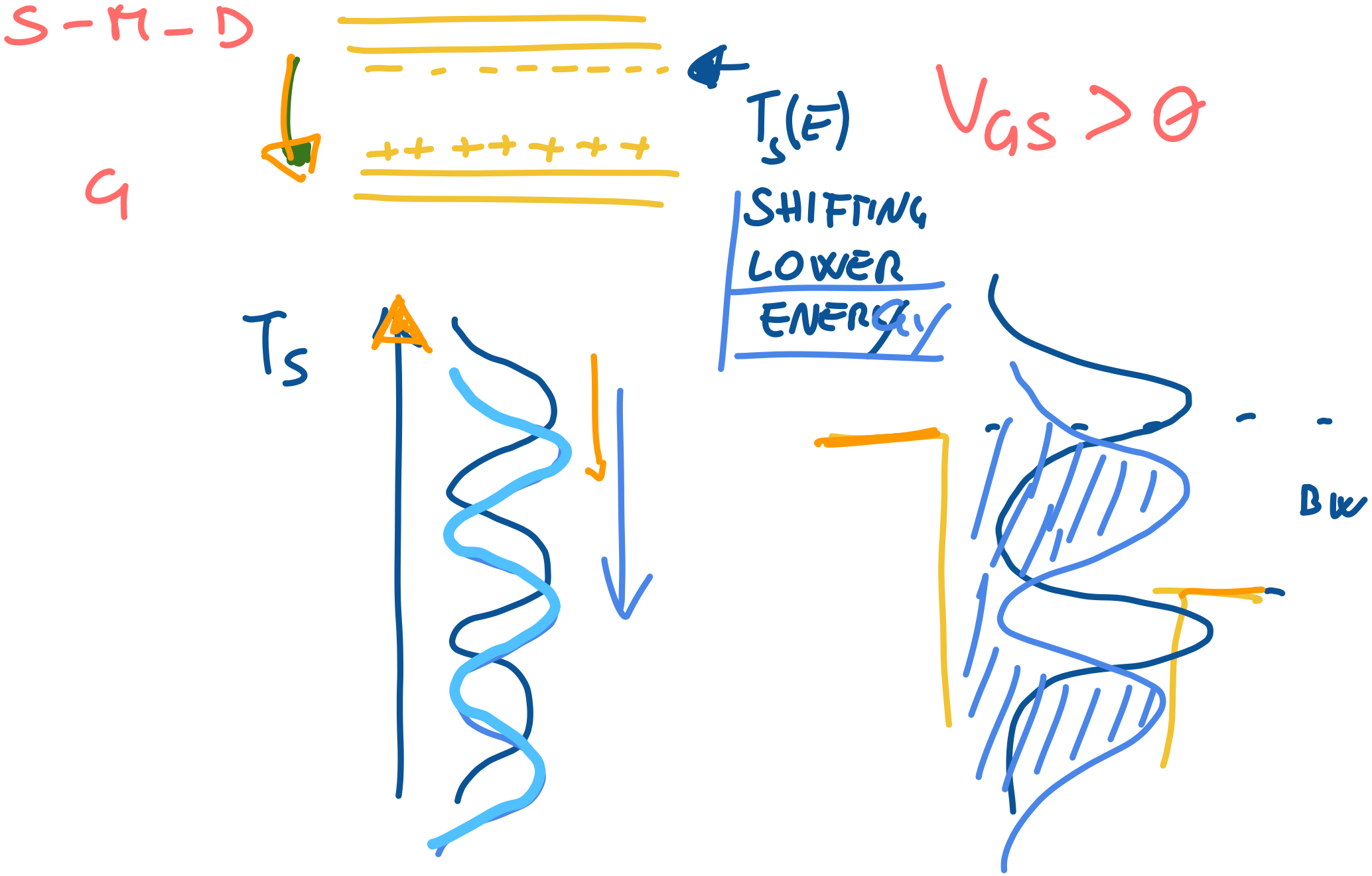
POTENTIAL ENERGY

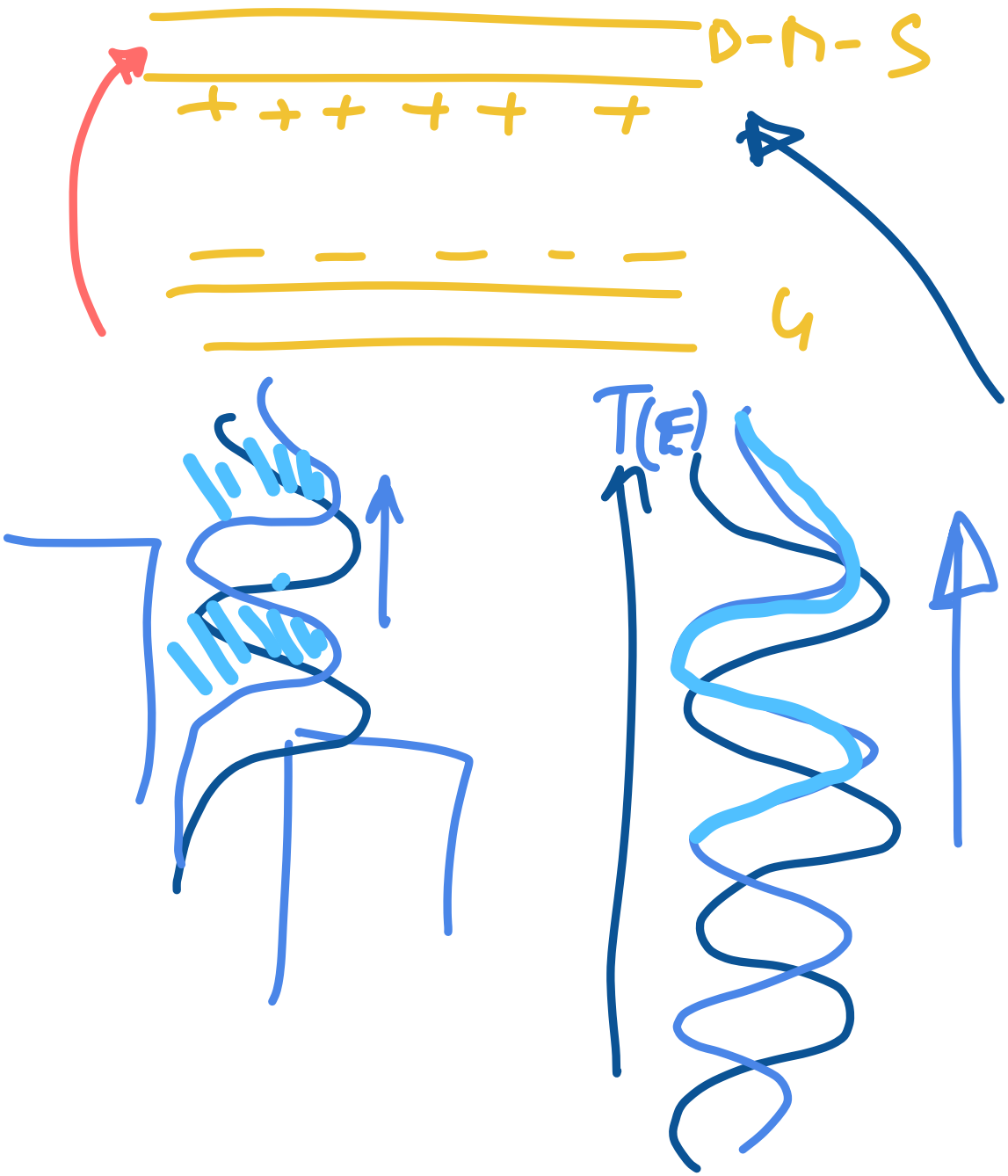
U

↓

T(E) CHANGES

THE STRUCTURE CAN BE SEEN AS A CAPACITOR

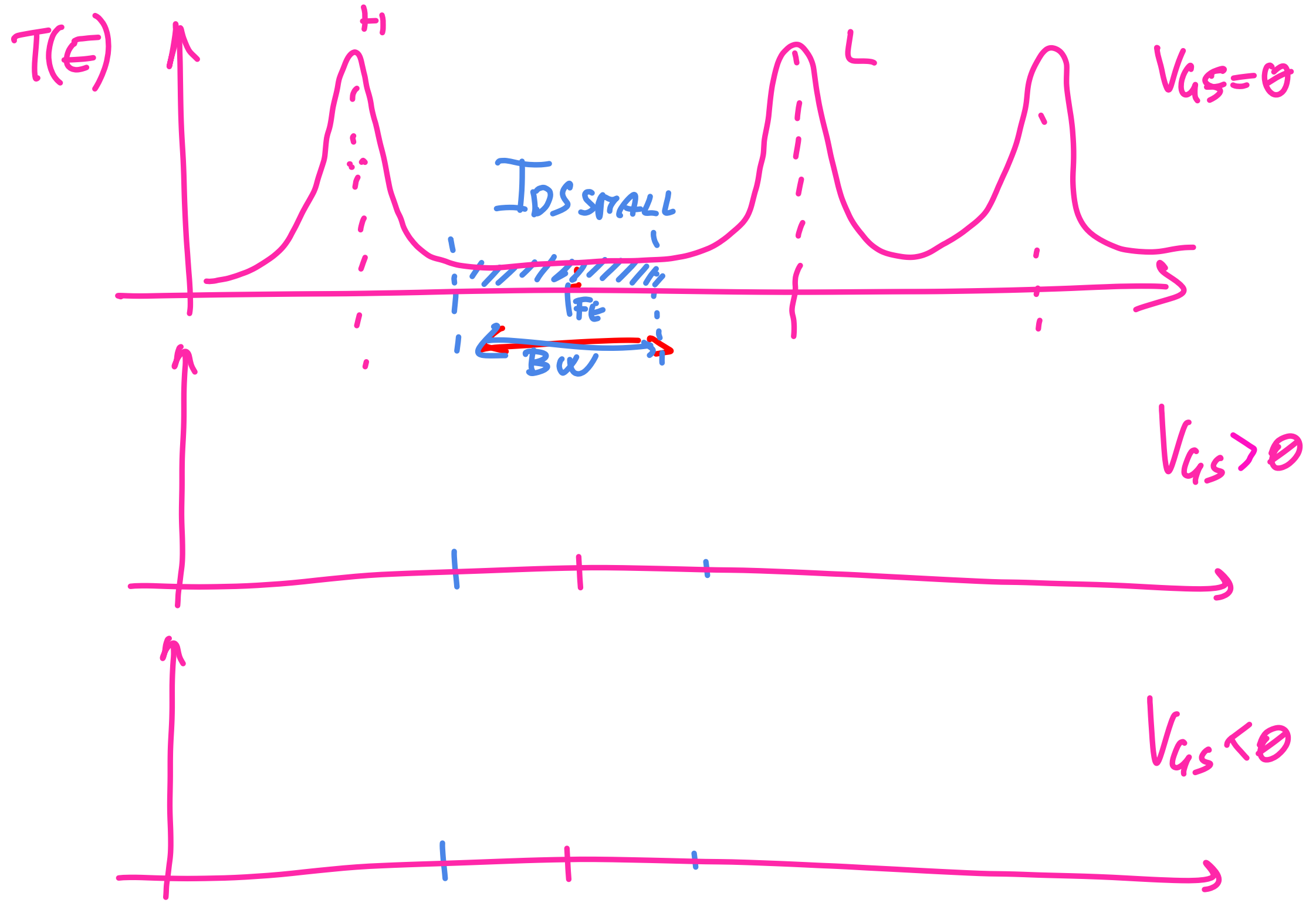


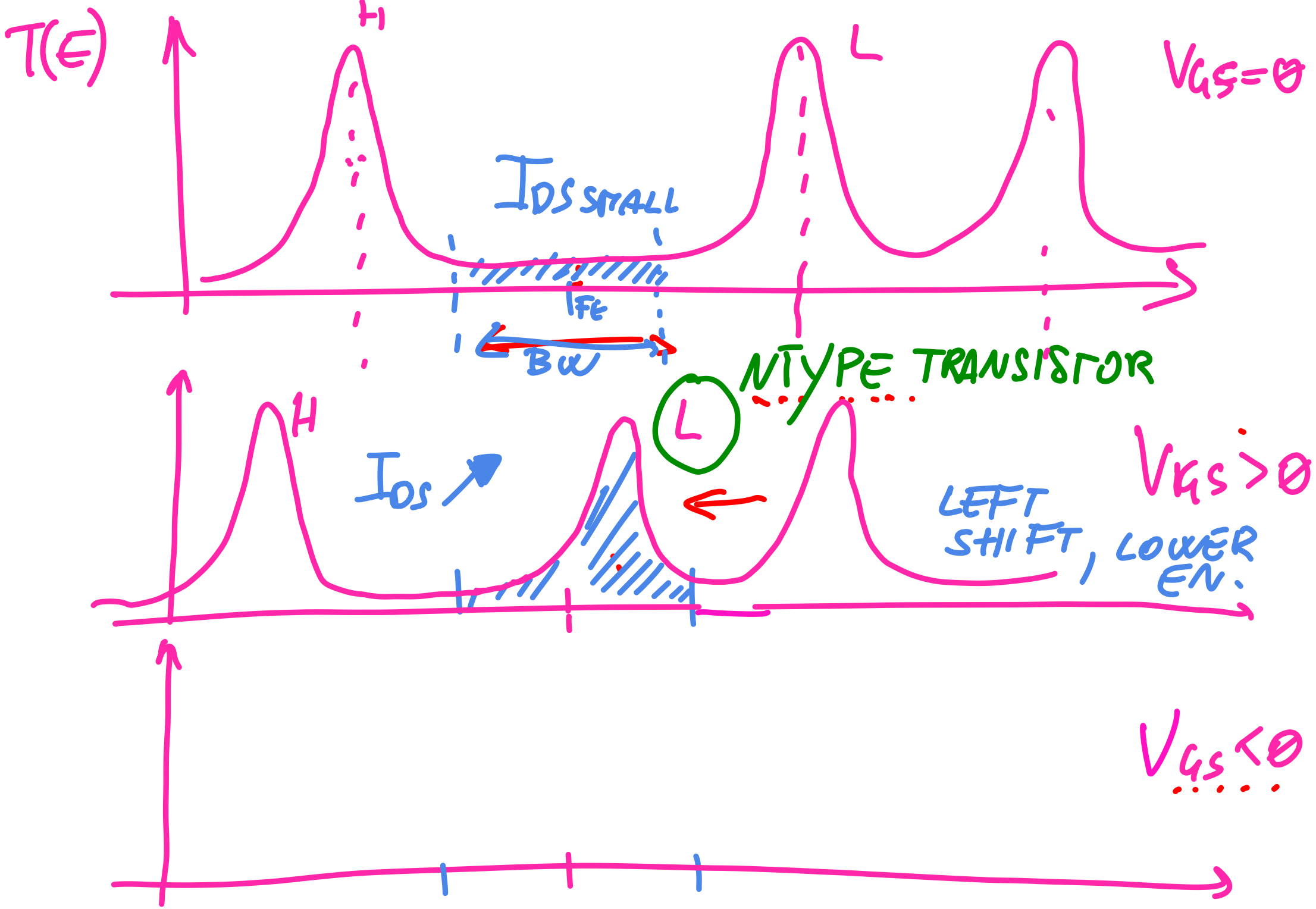


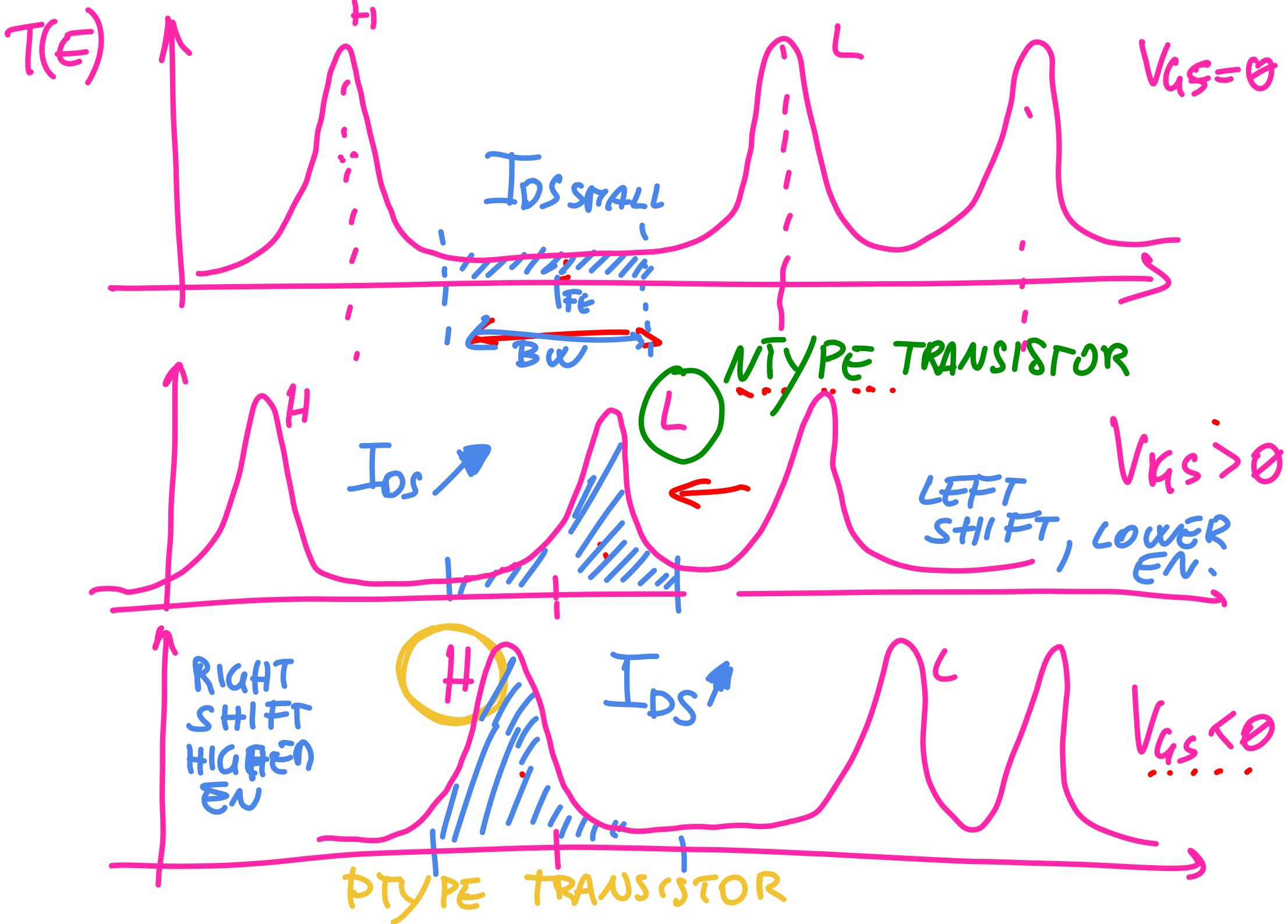
$V_{GS} < 0$

POSITIVE CHARGE

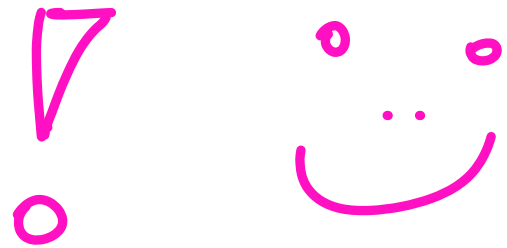
$T_S(E)$ SHIFT TOWARD HIGHER ENERGIES


T(E)
H
L
$V_{GS}=0$
$I_{DS\,SMALL}$
f_E
BW
$V_{GS}>0$
$V_{GS}<0$

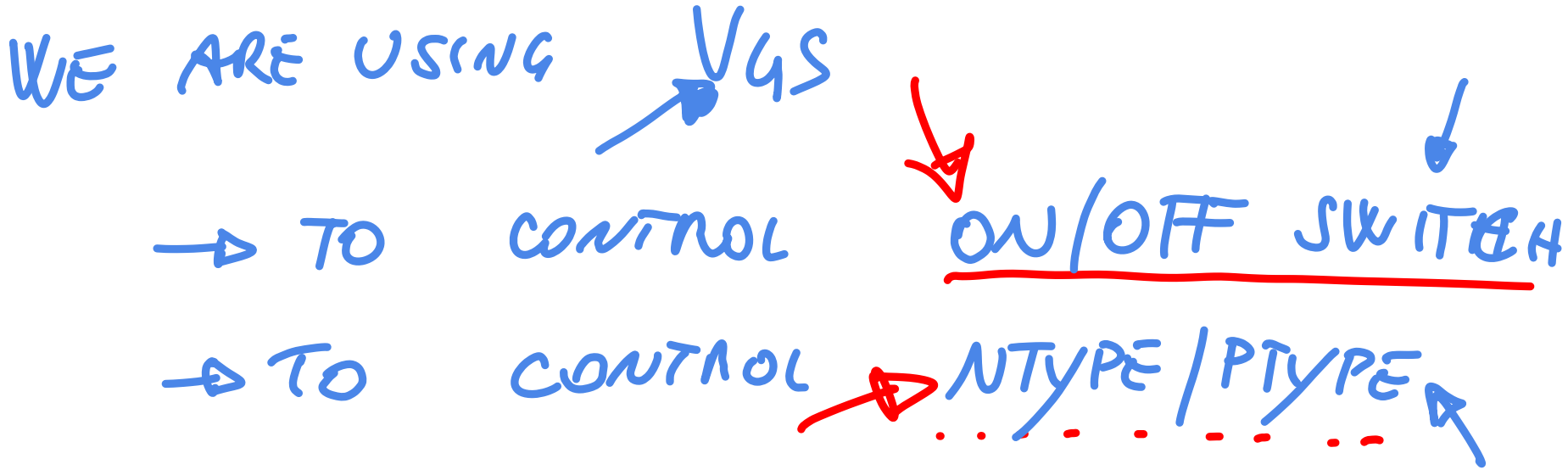

T(E)
H
L
$V_{GS}=0$
I_{DS} SMALL
E_F
BW
NTYPE TRANSISTOR
H
L
I_{DS}
$V_{GS}>0$
LEFT SHIFT, LOWER EN.
$V_{GS}<0$


T(E)
H
L
$V_{GS}=0$
I_{DS} SMALL
E_F
BW
NTYPE TRANSISTOR
H
L
I_{DS}
$V_{GS}>0$
LEFT SHIFT, LOWER EN.
RIGHT SHIFT HIGHER EN
H
I_{DS}
L
$V_{GS}<0$
PTYPE TRANSISTOR

WE CAN USE V_{GS} TO SWITCH ON/OFF THE TRANSISTOR !



BUT WE ARE ACTUALLY DOING SOMETHING MORE.... WHAT ?

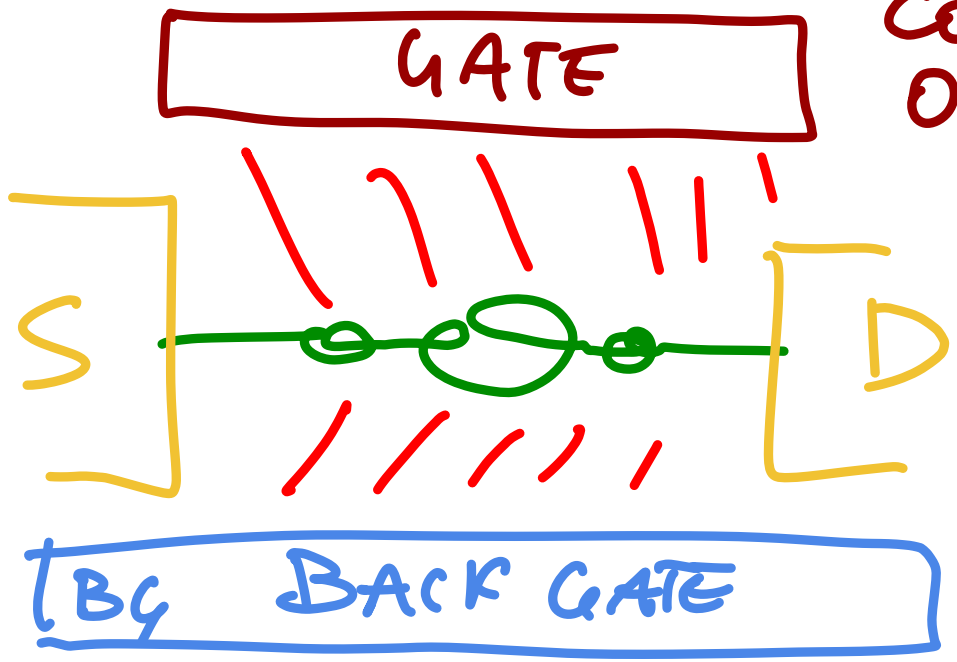

WE ARE USING VGS
→ TO CONTROL ON/OFF SWITCH
→ TO CONTROL NTYPE/PTYPE

WE ARE USING V_{GS}

→ TO CONTROL ON/OFF SWITCH

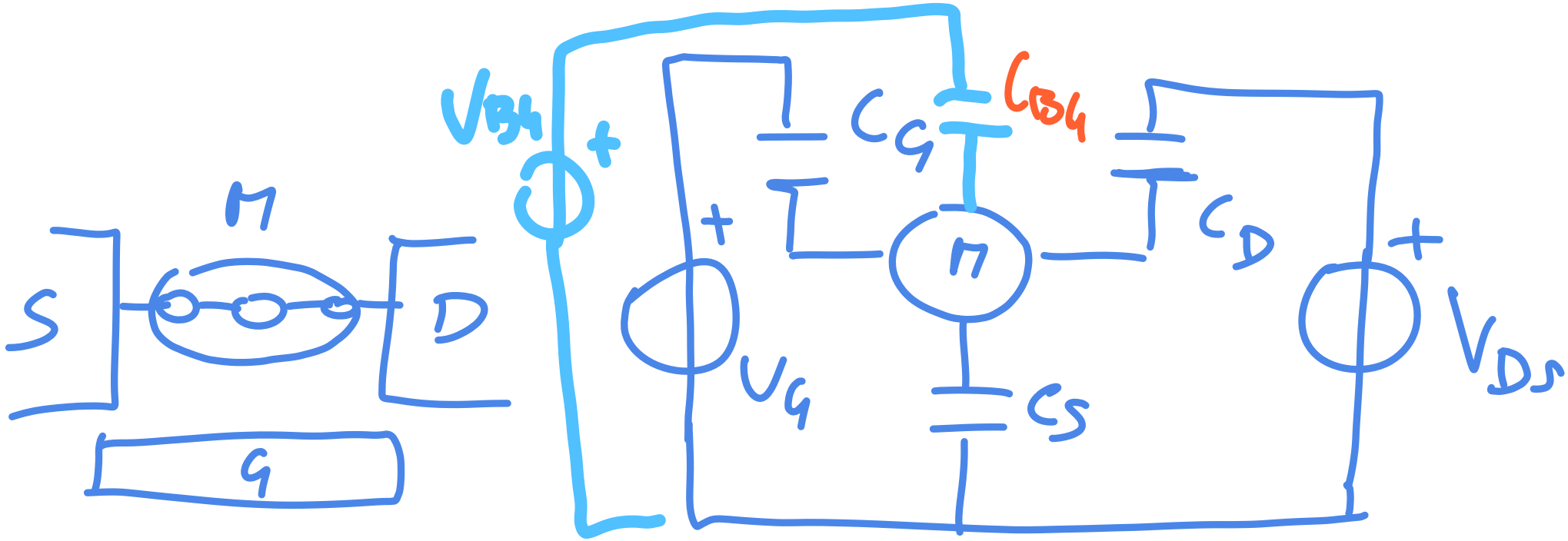
→ TO CONTROL → NTYPE / PTYPE

COMBINE GATE, BG



WHAT IN THE MODEL ?

CAPACITIVE MODEL OF Q. DOT



$$C_{ES} = C_G + C_S + C_D + C_{BG}$$

$$U = U_{VDS} + U_{C.E} + UV_{GS} + UV_{BG}$$

$$U \begin{cases} U_{VDS} = -q \dfrac{C_D}{C_{ES}} V_{DS} \\ U_{VGS} = -q \dfrac{C_G}{C_{ES}} V_{GS} \\ U_{BG} = -q \dfrac{C_G}{C_{ES}} V_{BG} \\ U_{C.E.} = \dfrac{q^2}{C_{\Sigma S}} \cdot \Delta N \end{cases}$$

$V_{BG} > 0$ $V_{GS} > 0$ → U SHIFTS LOWER ENERGY

$V_{GS} < 0$ $V_{BG} < 0$ → U SHIFTS HIGHER ENERGY

$$\Delta N = N - N_0 \leftarrow \begin{matrix} \text{No el.} \\ \text{EQ.} \end{matrix}$$

U_{SCF} SELF CONSISTING FIELD

NEXT SECTION FOR MODELING

THE GATE & BG

$$V_{VGS} = -q\left(\frac{C_G}{C_{ES}}\right)V_{GS}$$

$$V_{VBG} = -q\left(\frac{C_{BG}}{C_{ES}}\right)V_{BG}$$

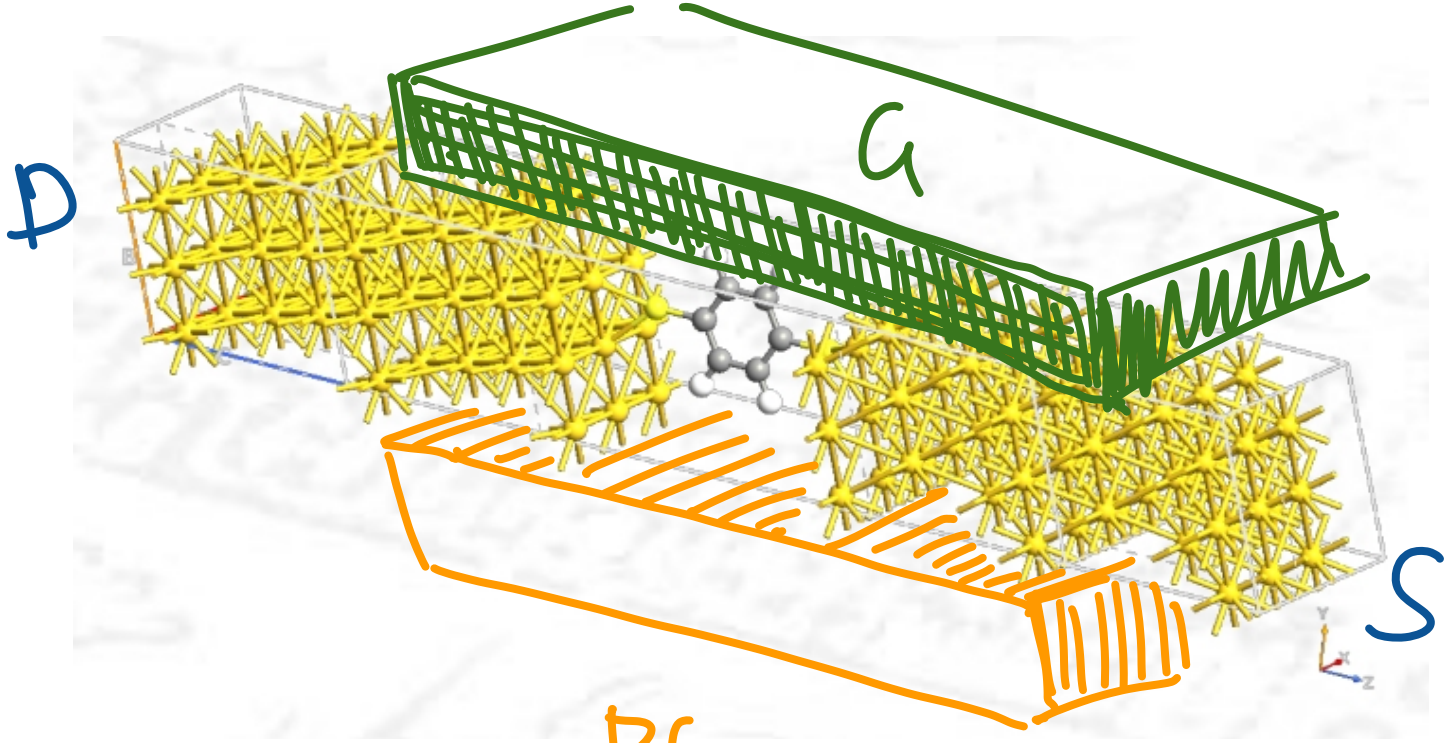
α COUPLING FACTOR

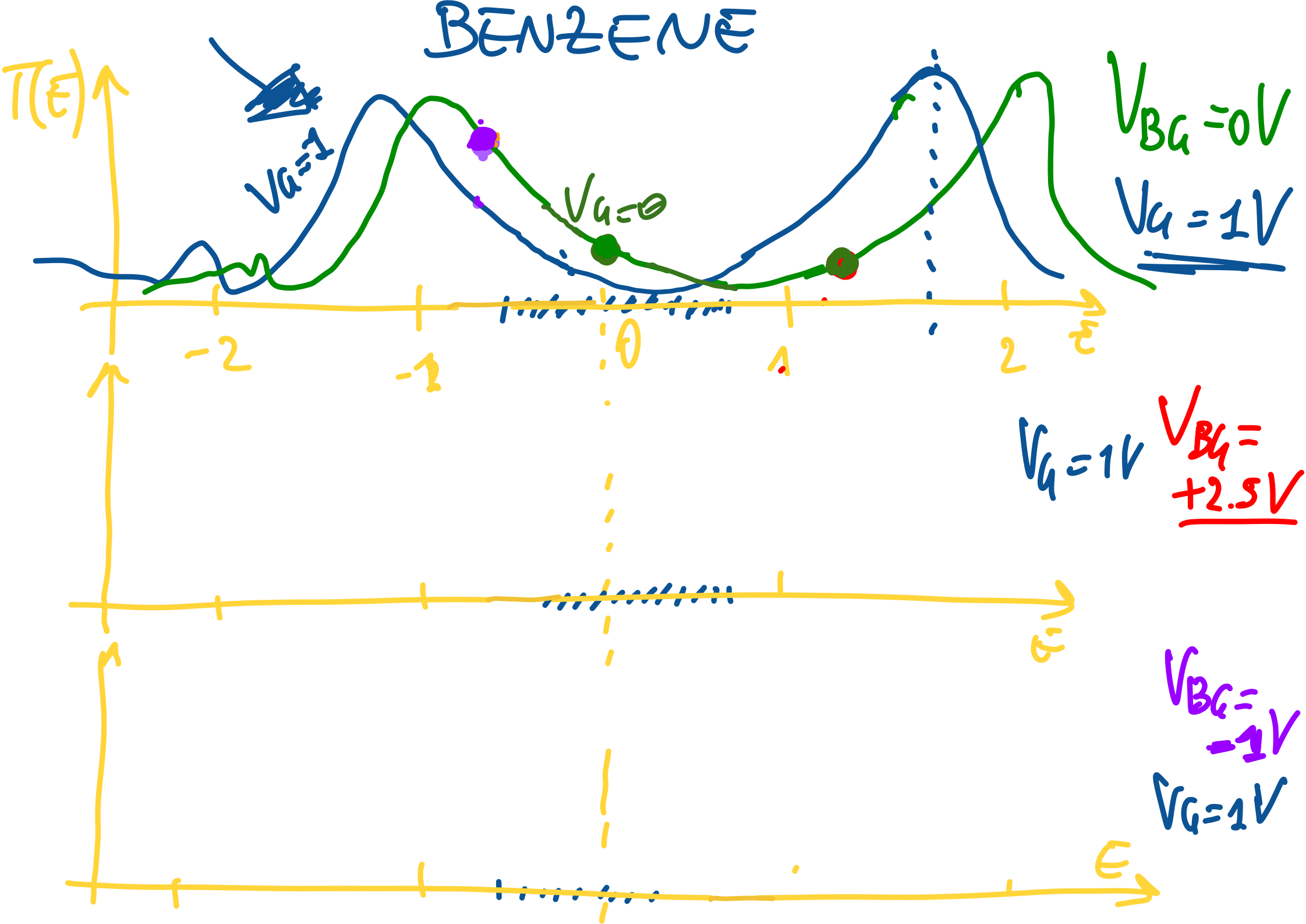
β BG COUPLING FACTOR

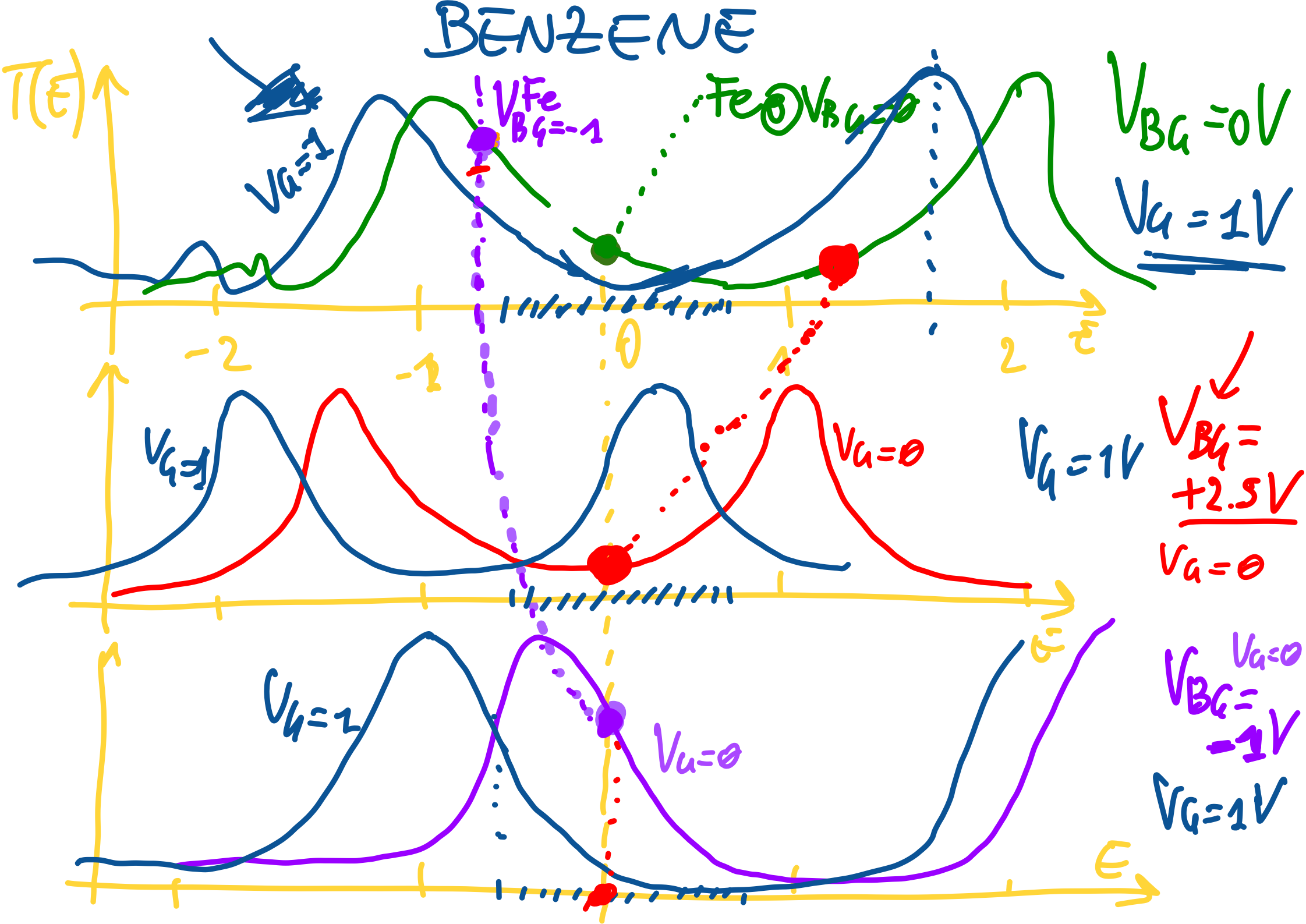
NOTE 1. in the example ⊙ THEORY $\alpha = 0.5$ but this depends on GATE ELECTRODE distance and COUPLING MEDIUM

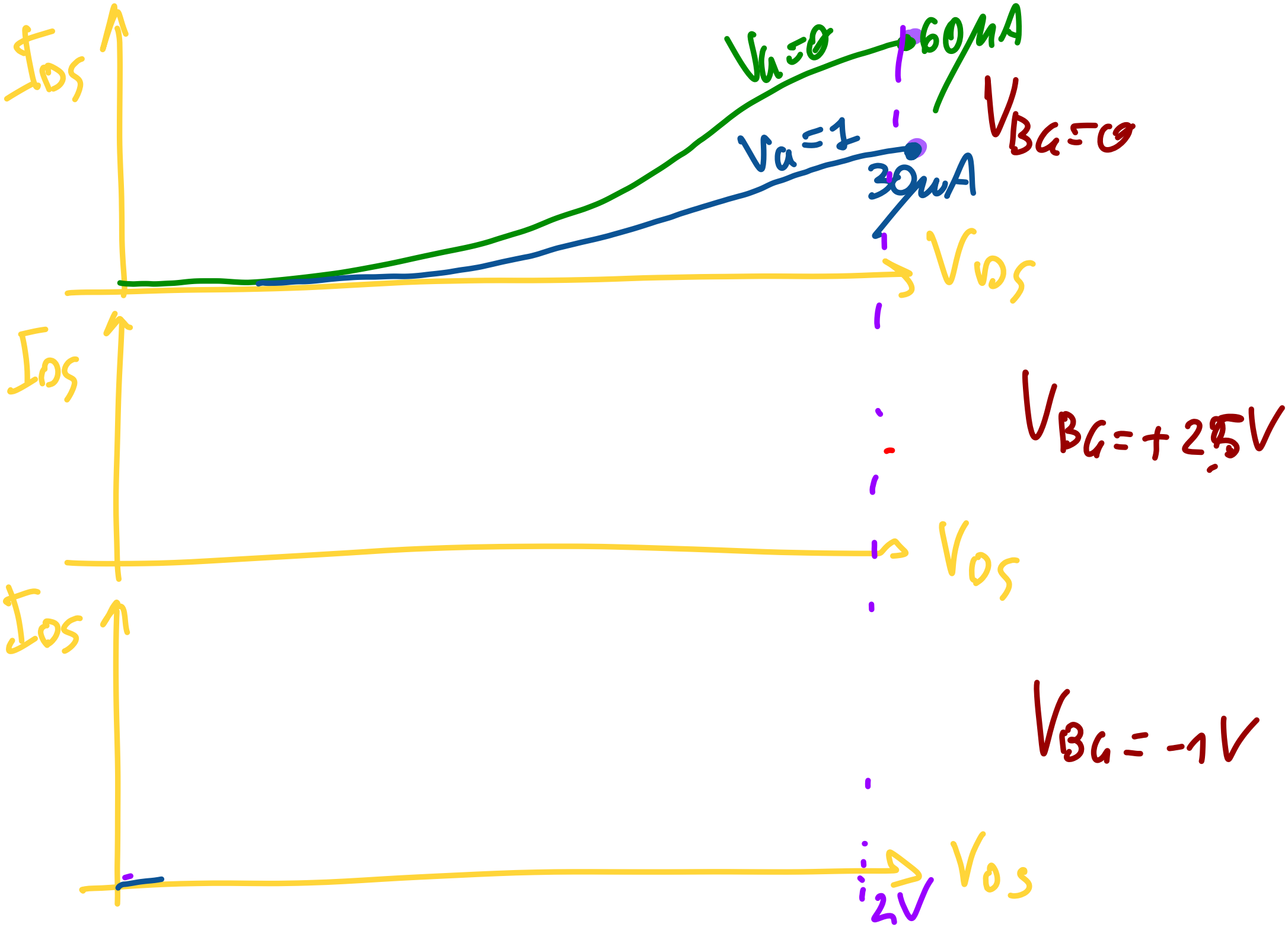
NOTE 2. α and β could be different

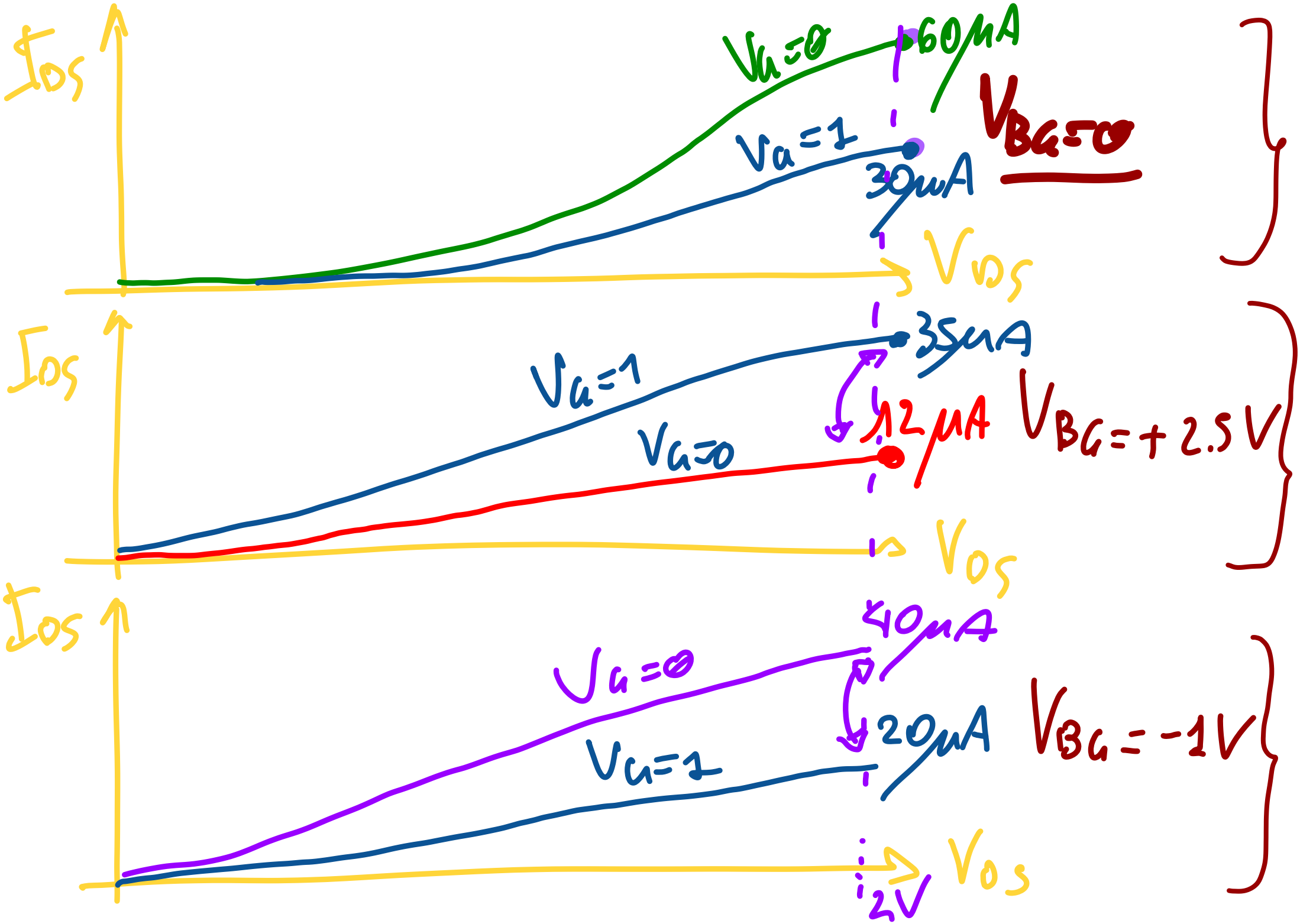
BENZENE




BENZENE
T(E)
$V_G=1$
$V_G=0$
$V_{BG}=0V$
$V_G=1V$
-2
-1
0
1
2
E
$V_G=1V$
$V_{BG}=+2.5V$
E
$V_{BG}=-1V$
$V_G=1V$
E


BENZENE
T(E)
VFe
VBG=-1
Fe @ VBG=0
VBG=0V
VG=1
VG=1V
-2
-1
0
1
2
E
VG=1
VG=0
VG=1V
VBG=
+2.5V
VG=0
VG=2
VG=0
VG=0
VBG=
-1V
VG=1V
E


I_{DS}
$V_{th}=0$
60mA
$V_{BG}=0$
$V_{th}=1$
30mA
V_{DS}
I_{DS}
$V_{BG}=+2.5V$
V_{DS}
I_{DS}
$V_{BG}=-1V$
V_{DS}
2V

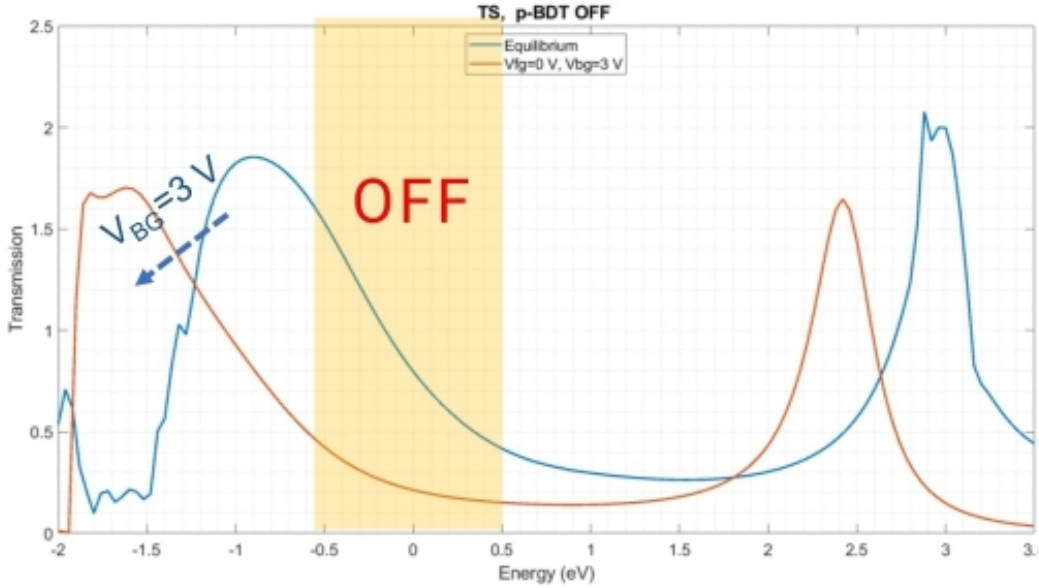

IDS
VG=0
60μA
VG=1
30μA
VBG=0
VDS
IDS
VG=1
35μA
VG=0
12μA
VBG=+2.5V
VDS
IDS
40μA
VG=0
20μA
VG=1
VBG=-1V
VDS
2V

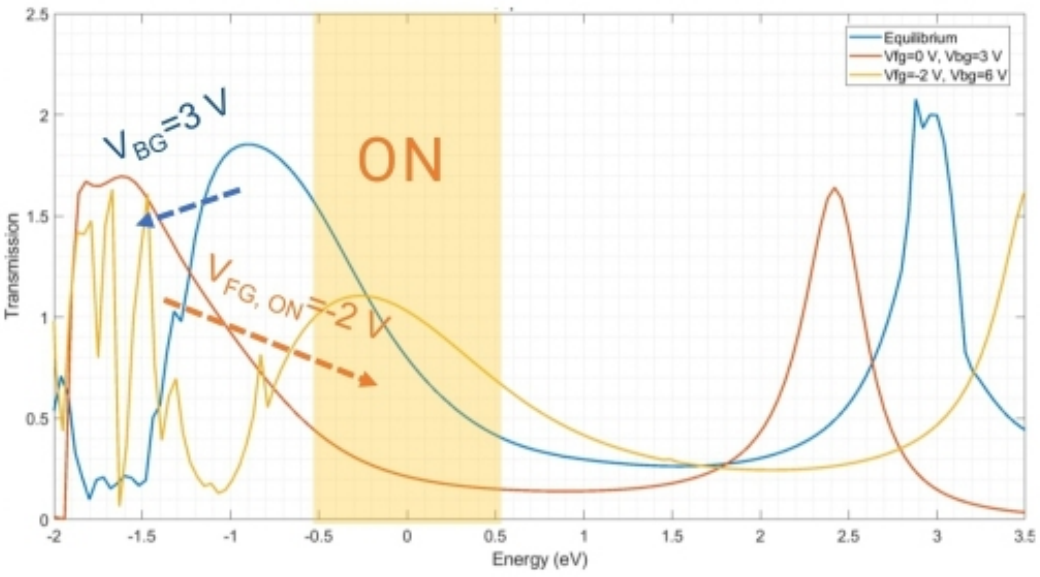
BENZENE, ANOTHER POSSIBLE EXAMPLE OF V_{BG}

V_{FG} = FRONT GATE, i.e. GATE FOR ON/OFF

HOMO conduction (p-type)

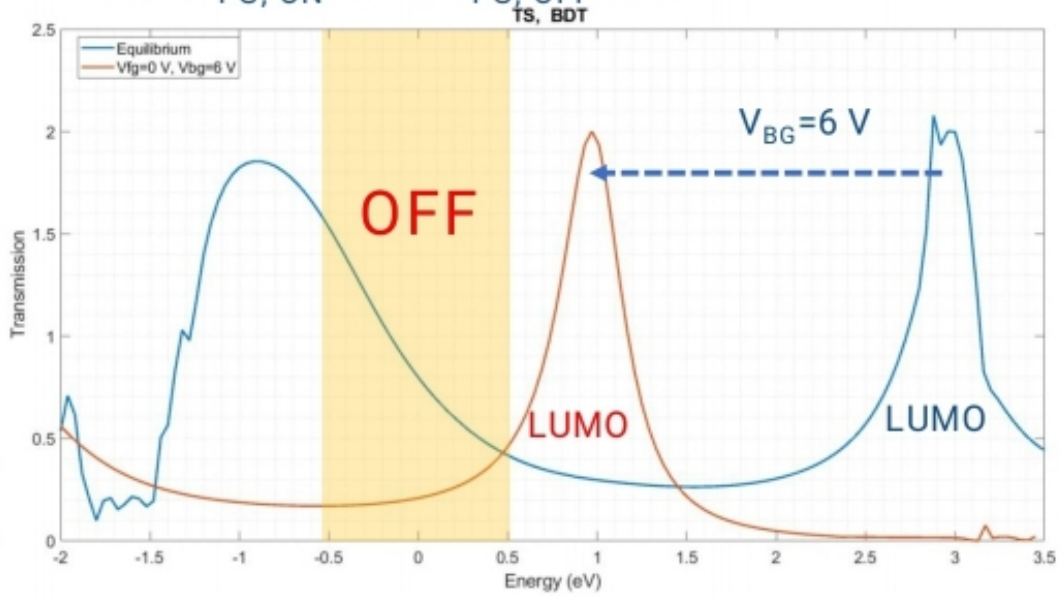
- $V_{FG,\,ON}$=-2 V, $V_{FG,\,OFF}$=0 V

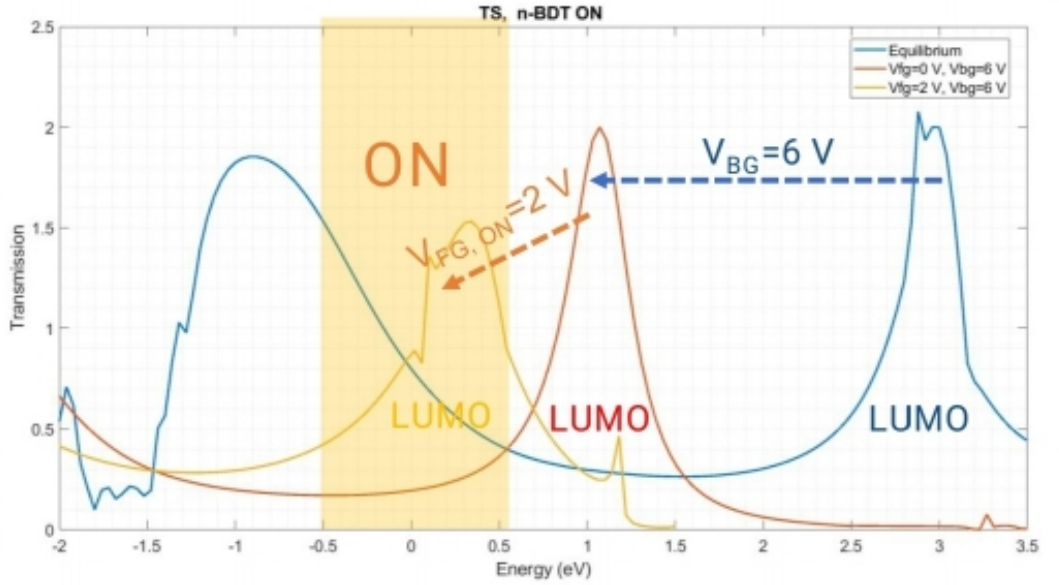




LUMO conduction (n-type)

- $V_{FG,\,ON}$=2 V, $V_{FG,\,OFF}$=0 V





FOR THE LAST CASE BENZENE

PTYPE

$I_{ON} = 40\mu A$

$I_{OFF} = 10\mu A$

NTYPE

$I_{ON} = 40\mu A$

$I_{OFF} = 7\mu A$

@1V

CONSIDERATION ON BENZENE

- CAN BE USED AS PTYE & NTYPE
- THERE IS AN APPRECIABLE DIFFERENCE BW I_{ON} AND I_{OFF}

→ BUT

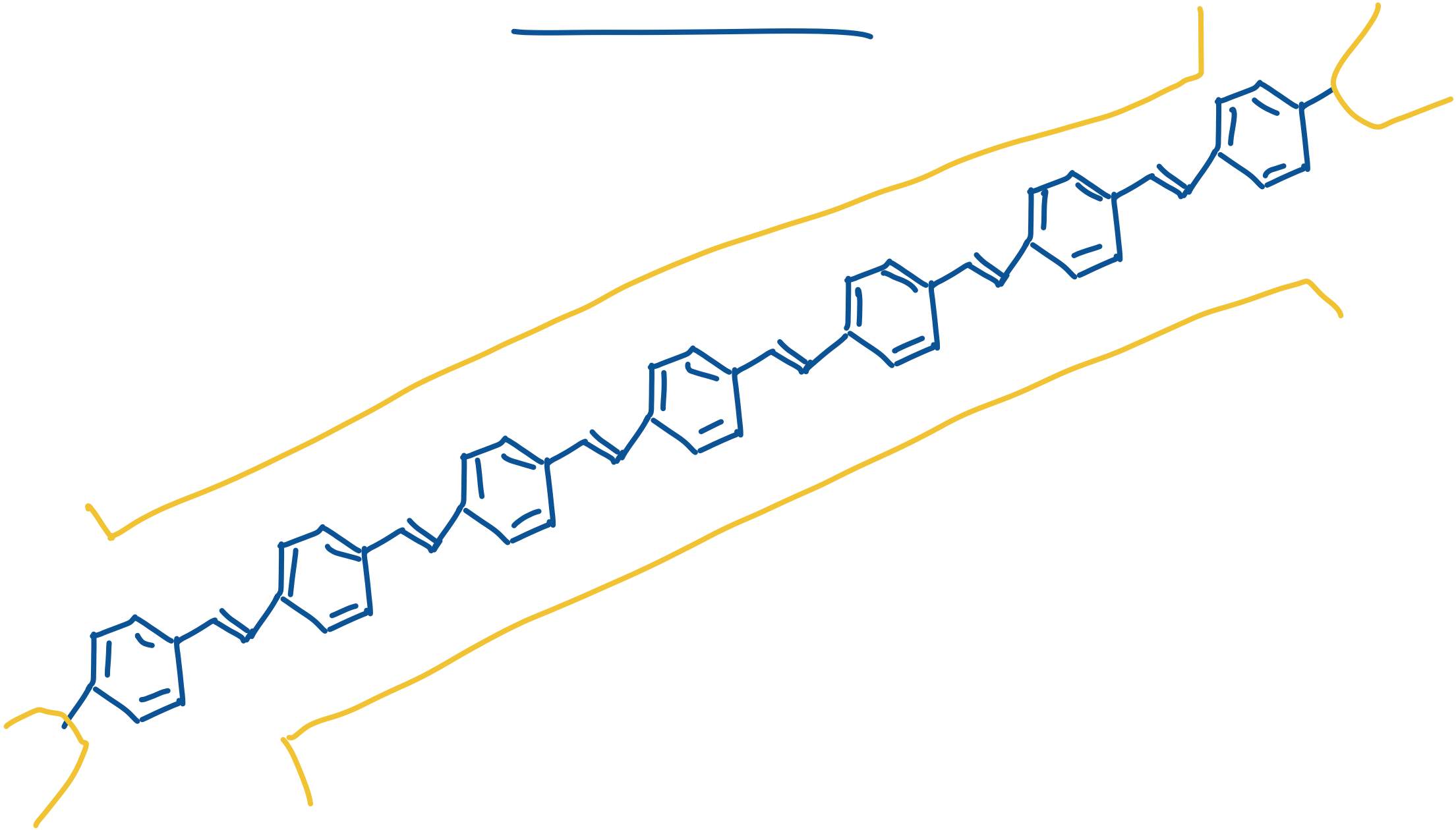
- I_{OFF} IS NOT SMALL → POWER!!
- $\frac{I_{ON}}{I_{OFF}}$ IS POOR FOR DIGITAL APP

WE CAN DO BETTER!

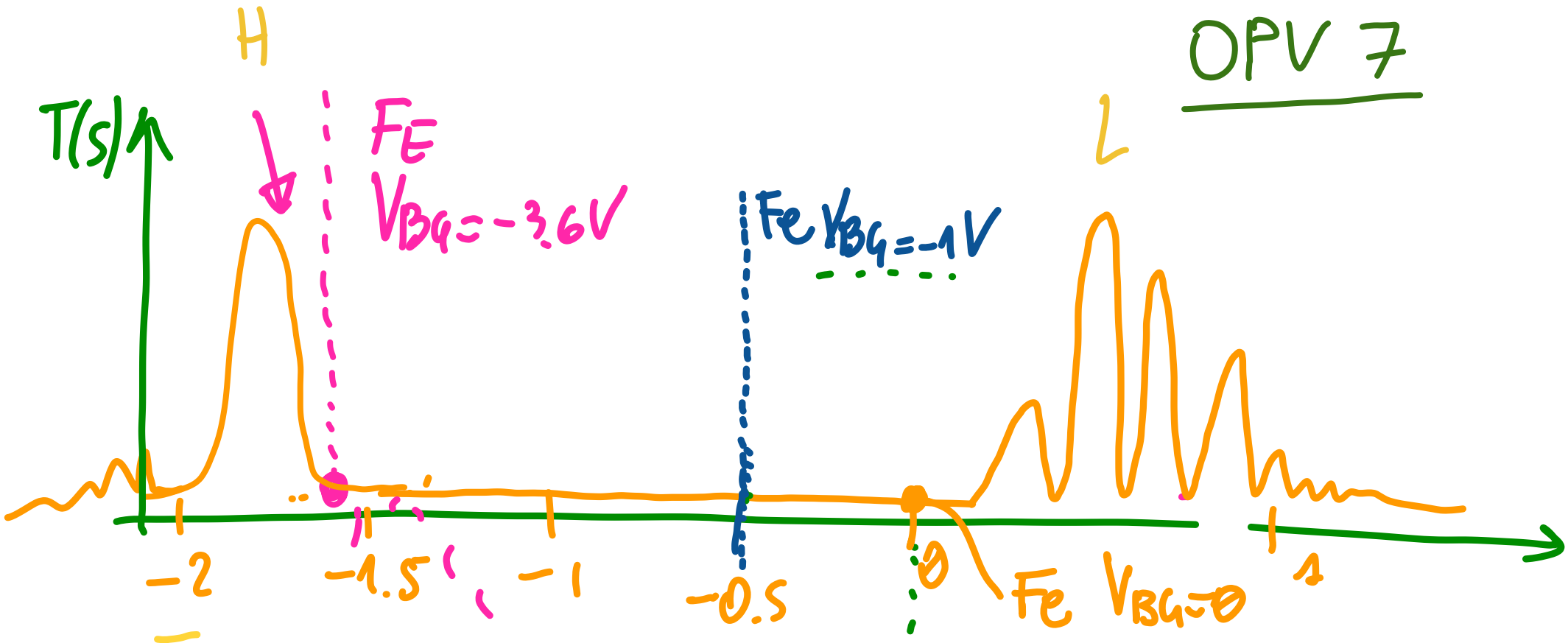
- CASE 1 OPV7
- CASE 2 PCP

NOTE: V_{BG1} and V_{BG2} could have different β, either by necessity or by choice; different β complicate tech.

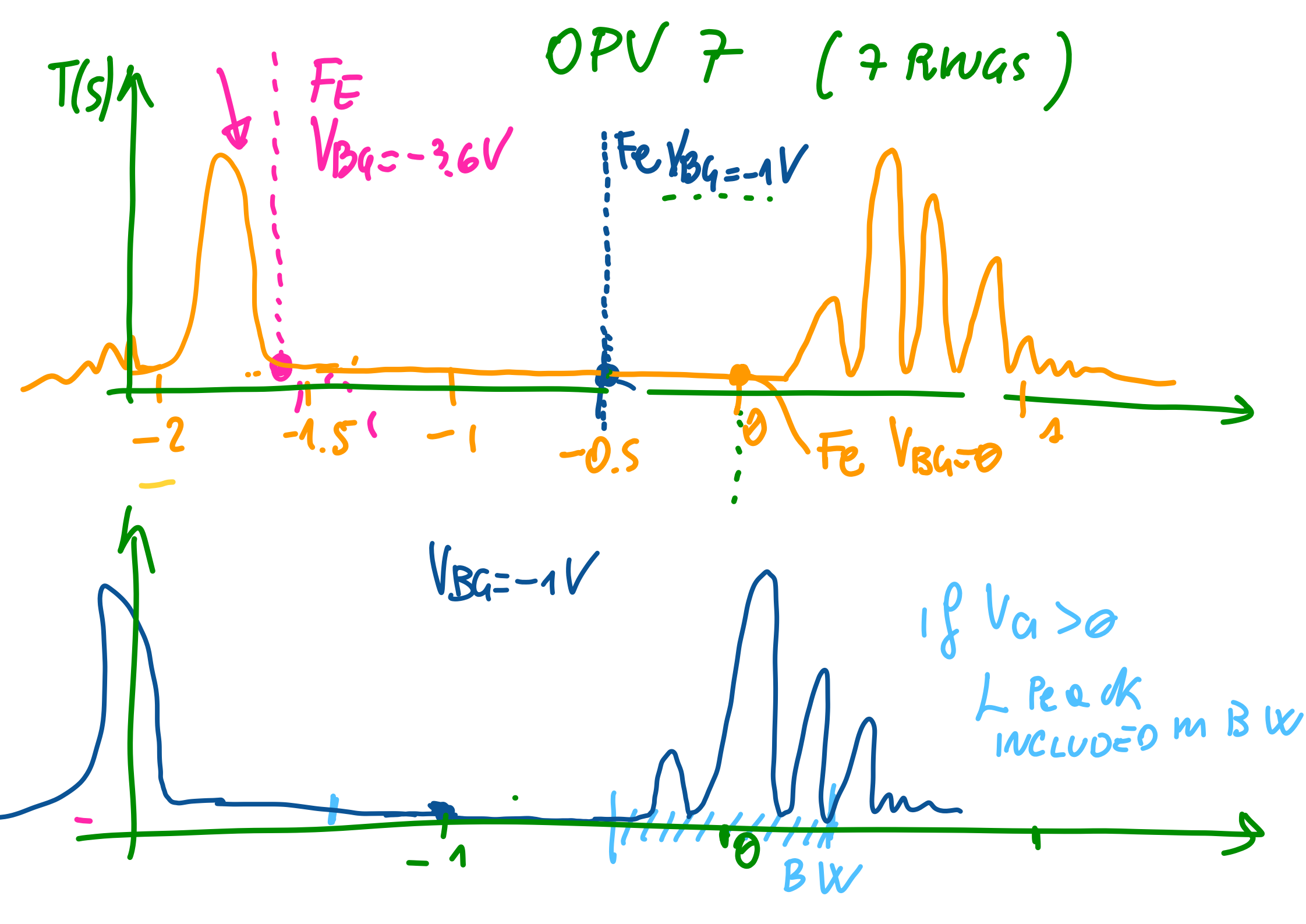
OPV 7

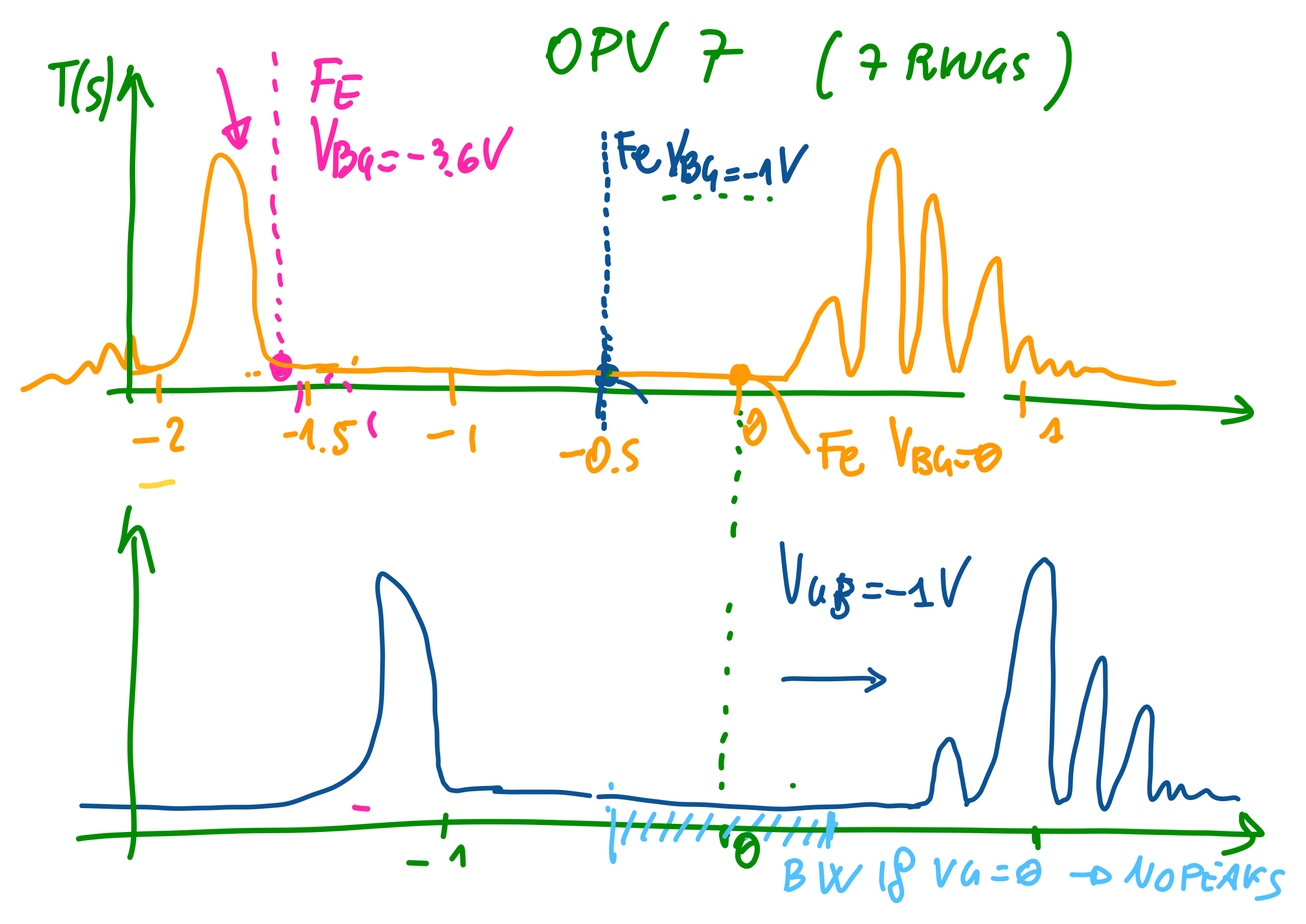


OPV 7

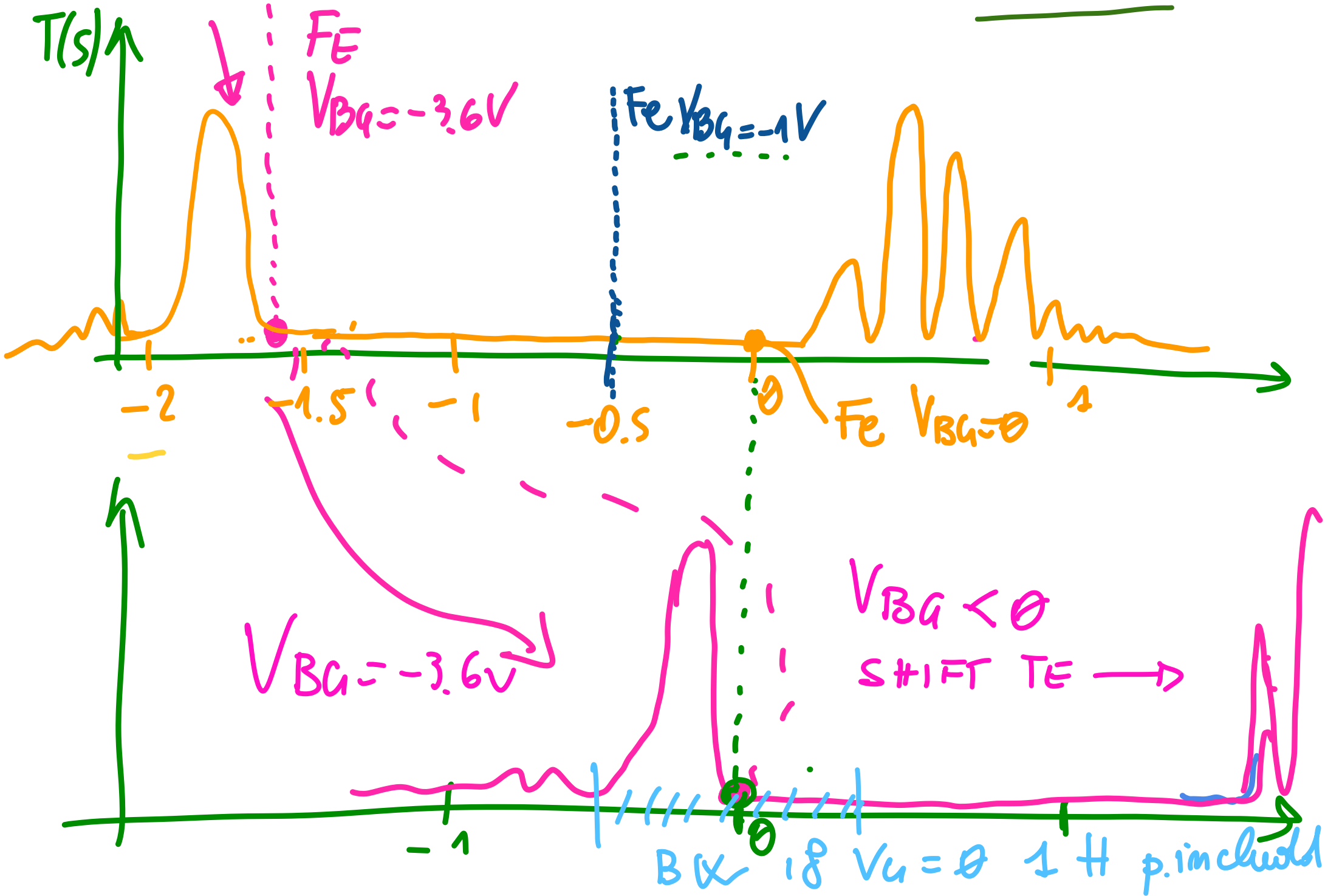


→ USE V_{BG} TO CHOOSE THE PEAK TO INCLUDE WHEN V_G "ACTIVE"

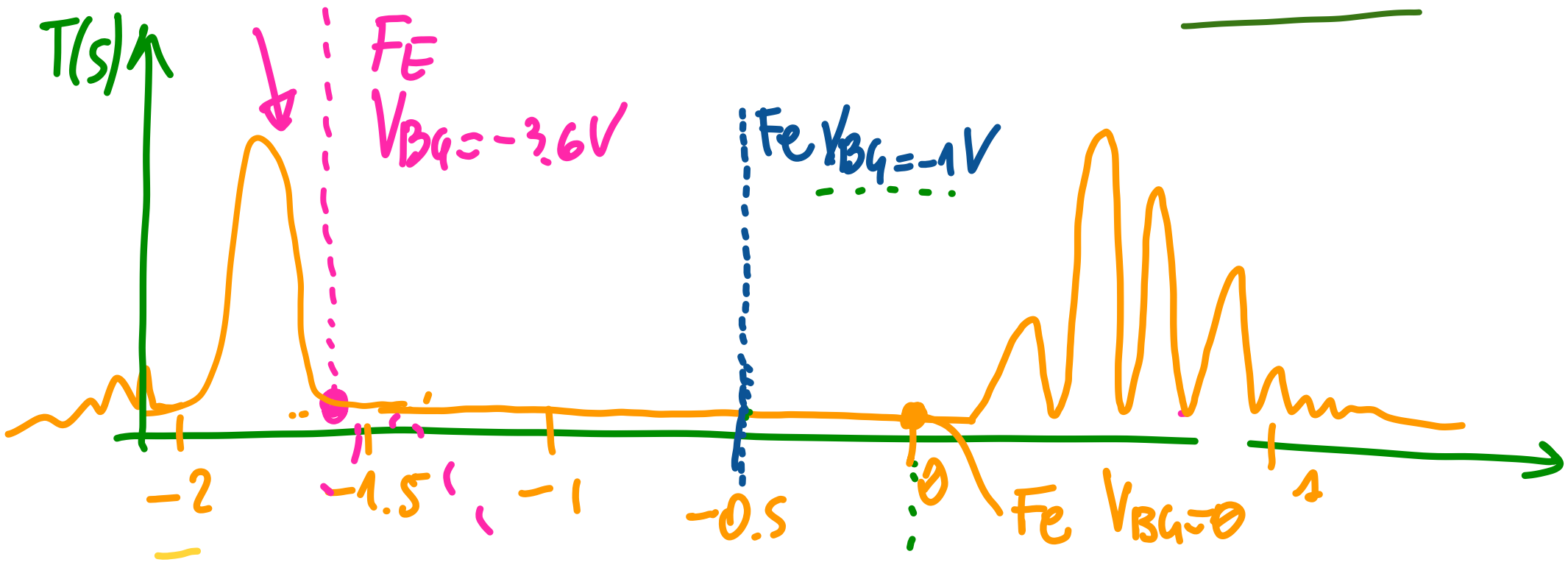

OPV 7 (7 RINGS)
T(s)
FE
VBG=-3.6V
Fe VBG=-1V
-2
-1.5
-1
-0.5
0
Fe VBG=0
1
VBG=-1V
if Va >0
Lpeak
INCLUDED in BW
-1
0
BW

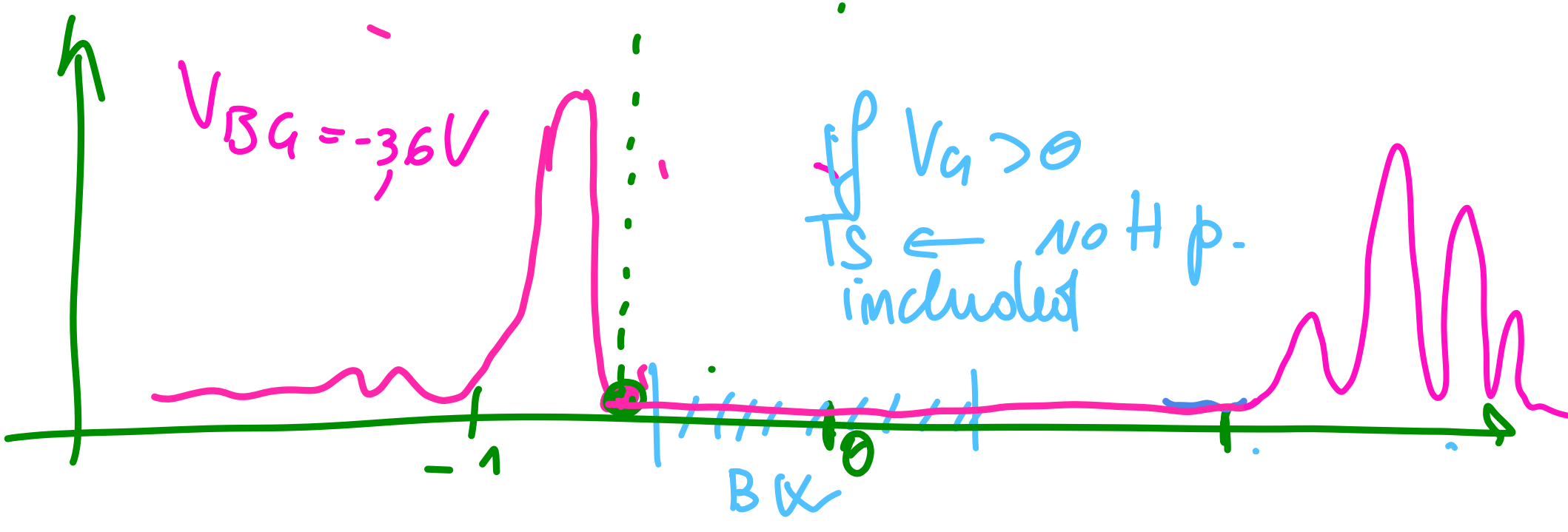

OPV 7 (7 RINGS)
T(s)
FE
$V_{BG}=-3.6V$
Fe $V_{BG}=-1V$
-2
-1.5
-1
-0.5
0
Fe $V_{BG}=0$
1
$V_{BG}=-1V$
-1
0
BW if $V_G=0$ → NO PEAKS

OPV 7

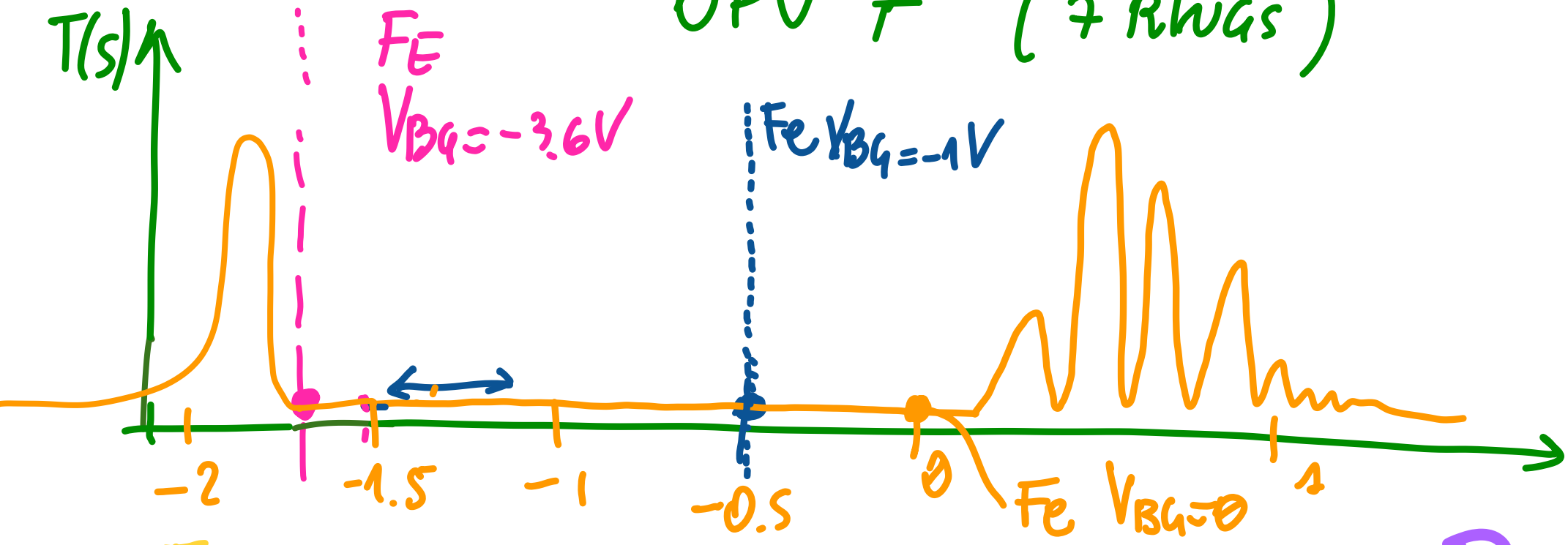

T(s)
FE
$V_{BG}=-3.6V$
Fe $V_{BG}=-1V$
-2
-1.5
-1
-0.5
0
Fe $V_{BG}=0$
1
$V_{BG}=-3.6V$
$V_{BG}<0$
SHIFT TE
-1
0
BK 18 $V_G=0$ 1H p.in cluster

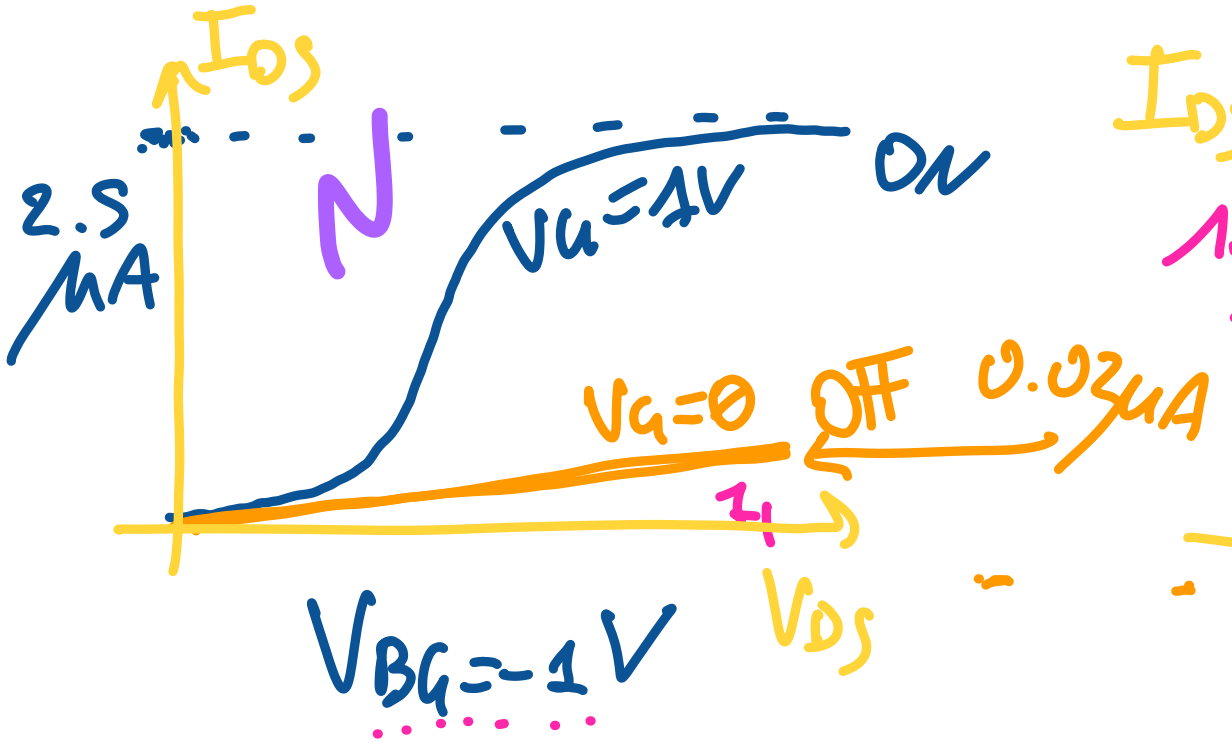
OPV 7

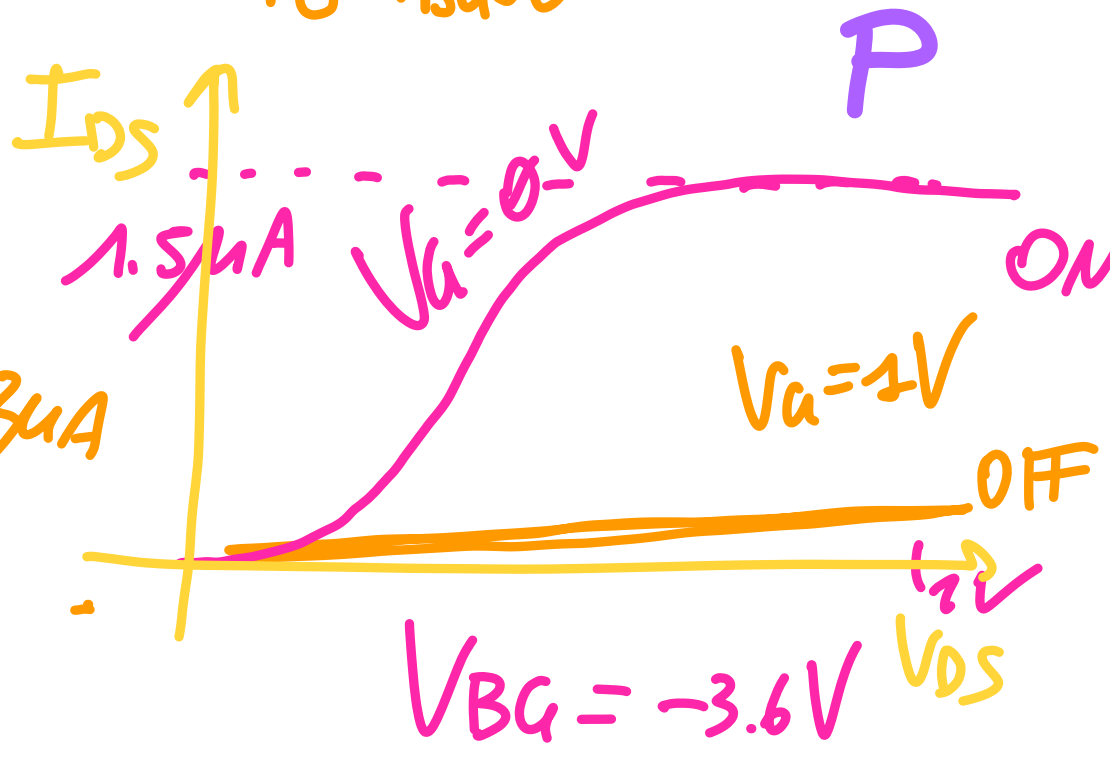

T(s)
FE
$V_{BG}=-3.6V$
Fe $V_{BG}=-1V$
-2
-1.5
-1
-0.5
0
Fe $V_{BG}=0$
1


$V_{BG}=-3,6V$
if $V_G>0$
Ts ← no Hp. included
-1
0
B (x

OPV 7 (7 RINGS)

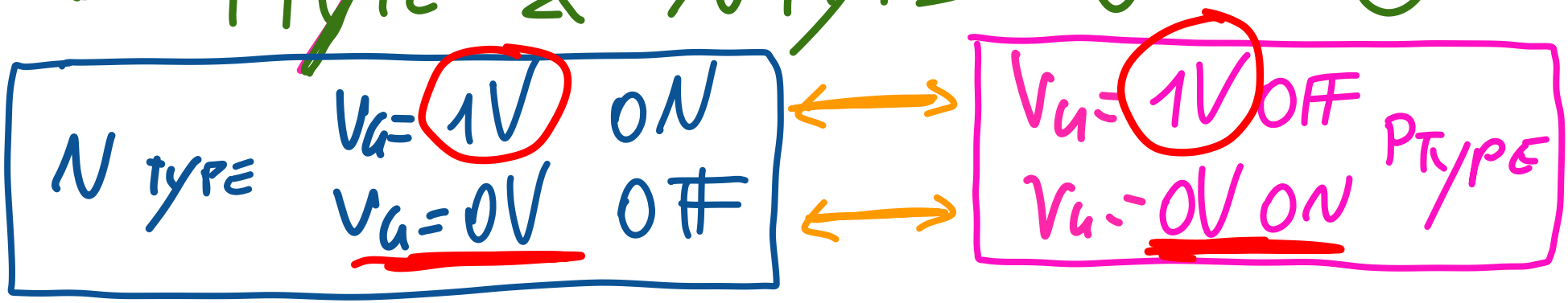

T(s)
FE
$V_{BG}=-3.6V$
Fe $V_{BG}=-1V$
-2
-1.5
-1
-0.5
0
Fe $V_{BG}=0$
1


I_{DS}
N
2.5 μA
$V_G=1V$
ON
$V_G=0$ OFF
0.02μA
1
V_{DS}
$V_{BG}=-1V$


P
I_{DS}
1.5μA
$V_G=0V$
ON
$V_G=1V$
OFF
1V
V_{DS}
$V_{BG}=-3.6V$

OPV 7

- PTYPE & NTYPE OK ☺



COMPLEMENTARY BEHAVIOUR

- GOOD $\frac{I_{ON}}{I_{OFF}}$

N - $\frac{I_{ON}}{I_{OFF}} \sim 12$ ..

P $\frac{I_{ON}}{I_{OFF}} \sim 54$.

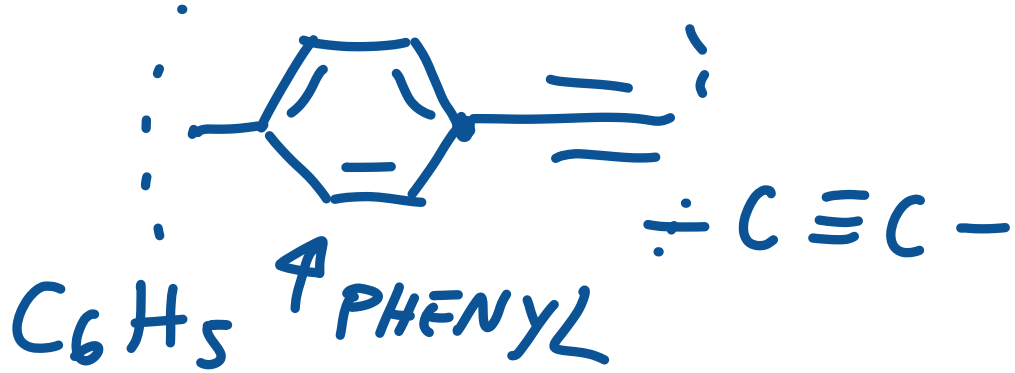
∴ I_{OFF} NOT SO STAL ↓ PCP!!!

BETER THAN BENZENE

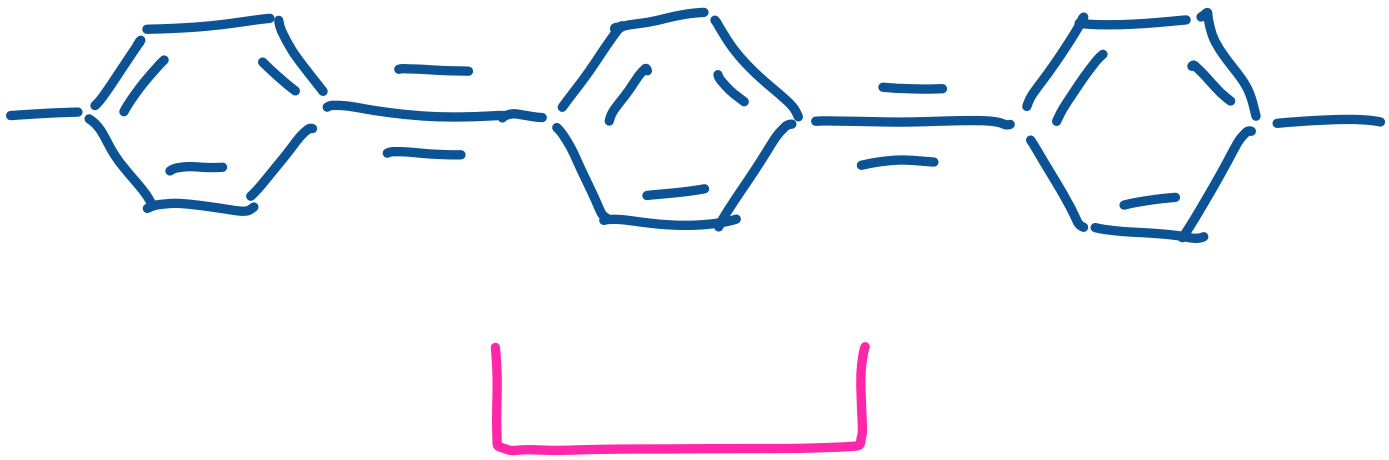
CASE PCP PARACYCLOPHANE

BASED ON OPE

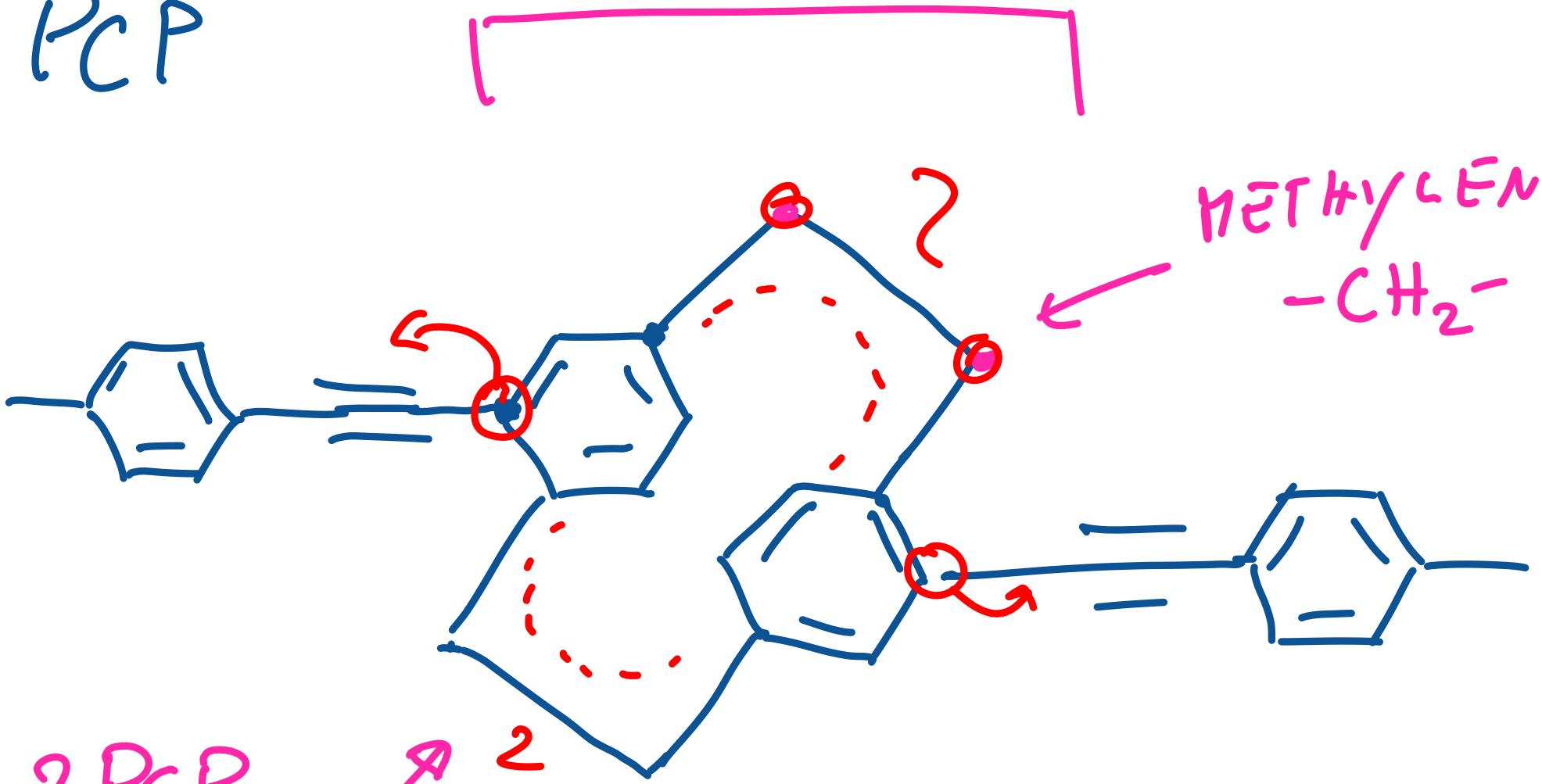
OPE



OPE3



PCP

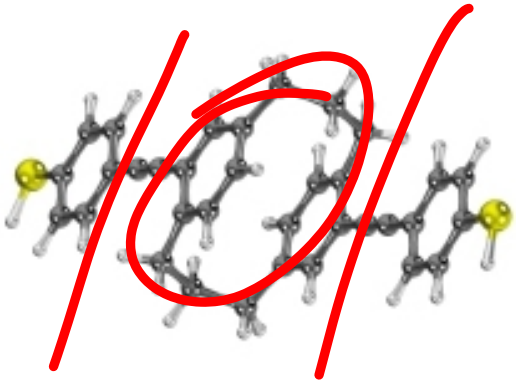


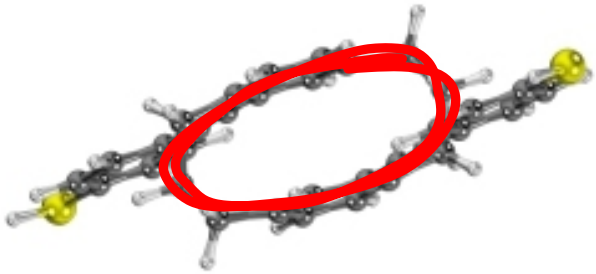
2,2 PCP

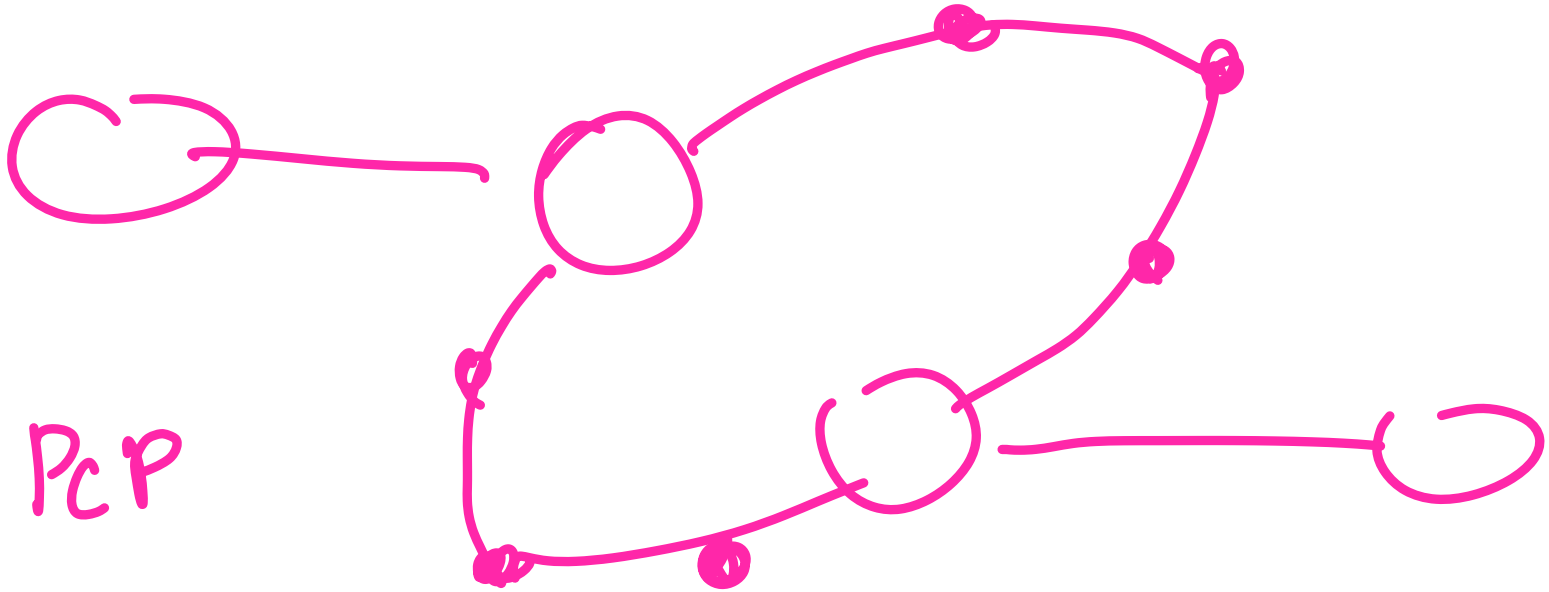
BRIDGE WITH A CHAW OF 2 METHYLEN.

3,3 PCP → BRIDGE 3 METH...

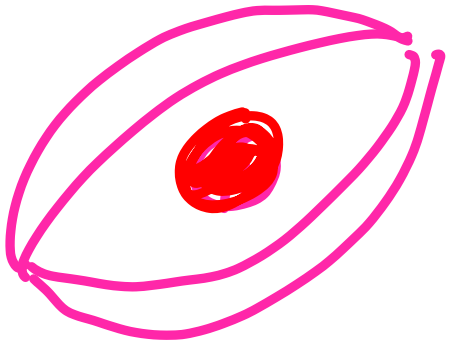
2,2 PCP







3,3 PCP



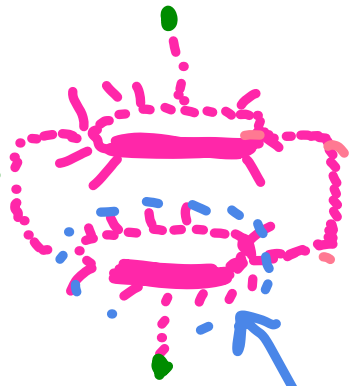
BOAT LIKE ORG.

CAN BE USED AS A SENSOR

2,2 PCP

THE BRIDGE INFLUENCE THE CONJ. SYSTEM

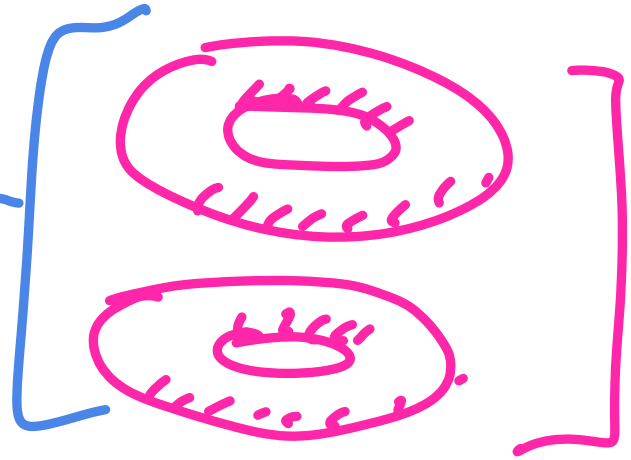
TOP VIEW



each RING CONJUGATED SYSTEM OF π OR BITALS

2 RINGS FACED :

2 FACED CONJ. SYSTEMS



1 RING

1 CURRENT PATH IN π-π OVERLAP BW THE 2 FACED RINGS I_C

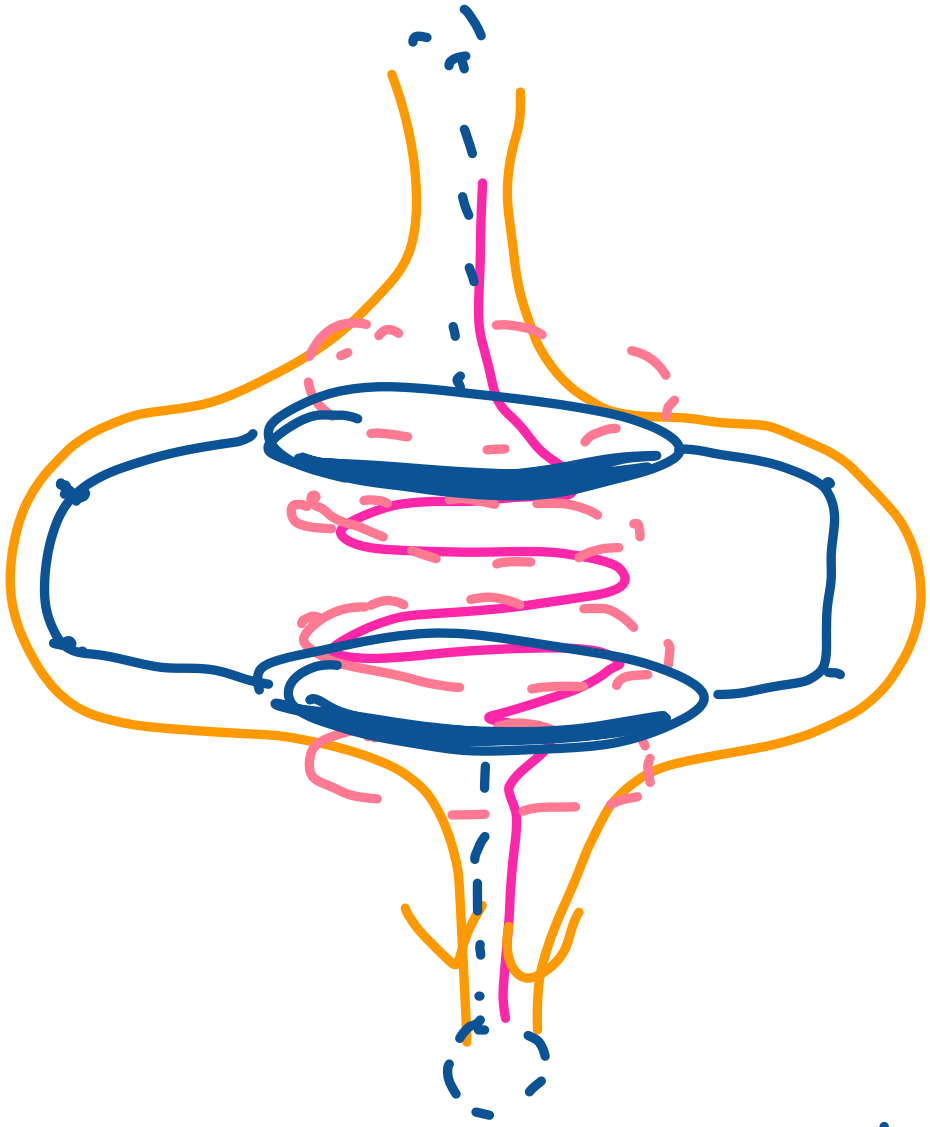
1 CURRENT PATH THROUGH 4 BRIDGES I_B

↳ IN PARALLEL → GENERATE

DESTRUCTIVE QUANTUM INTERFERENCE

↳ QI

HOMO & HOMO-1

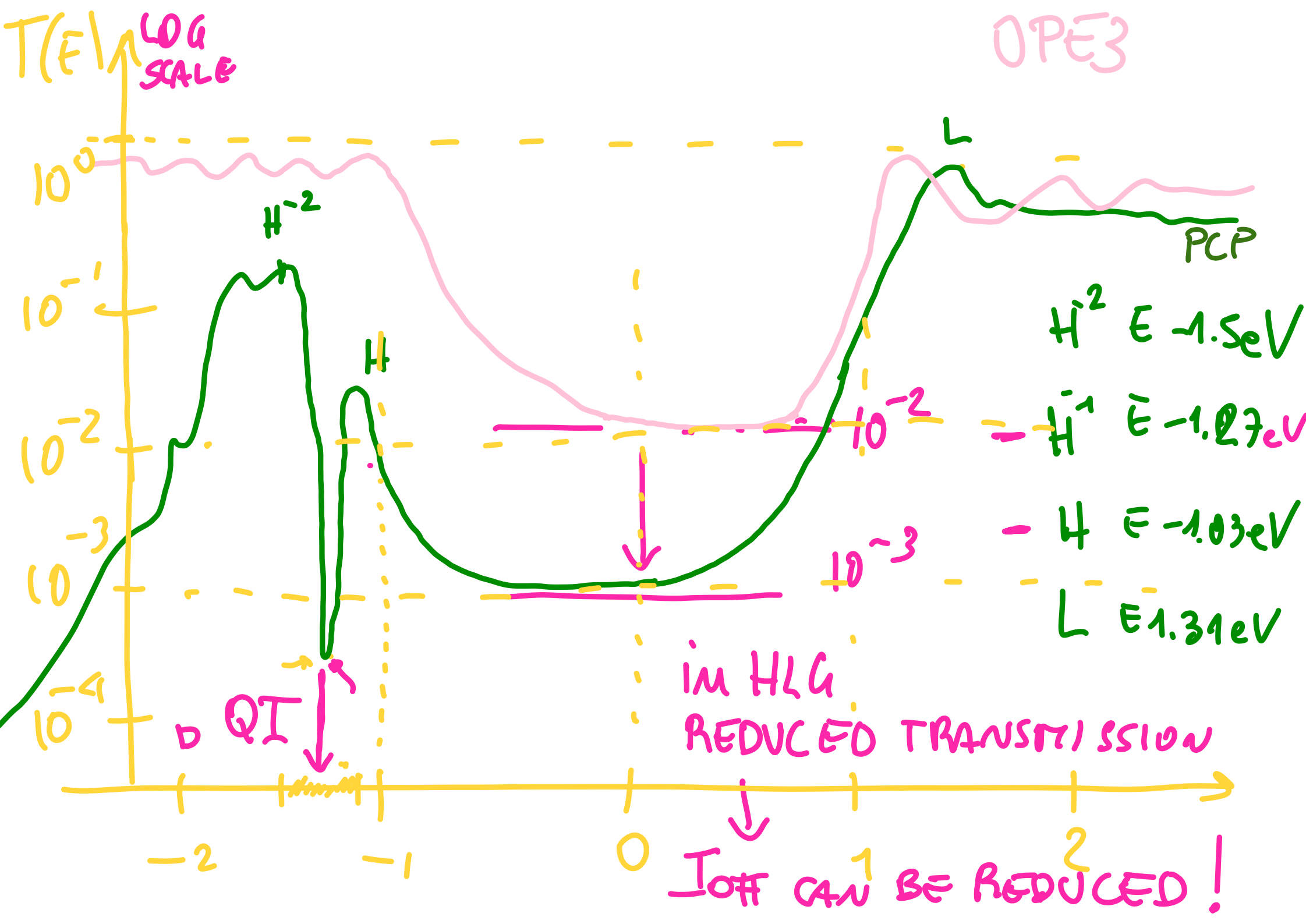


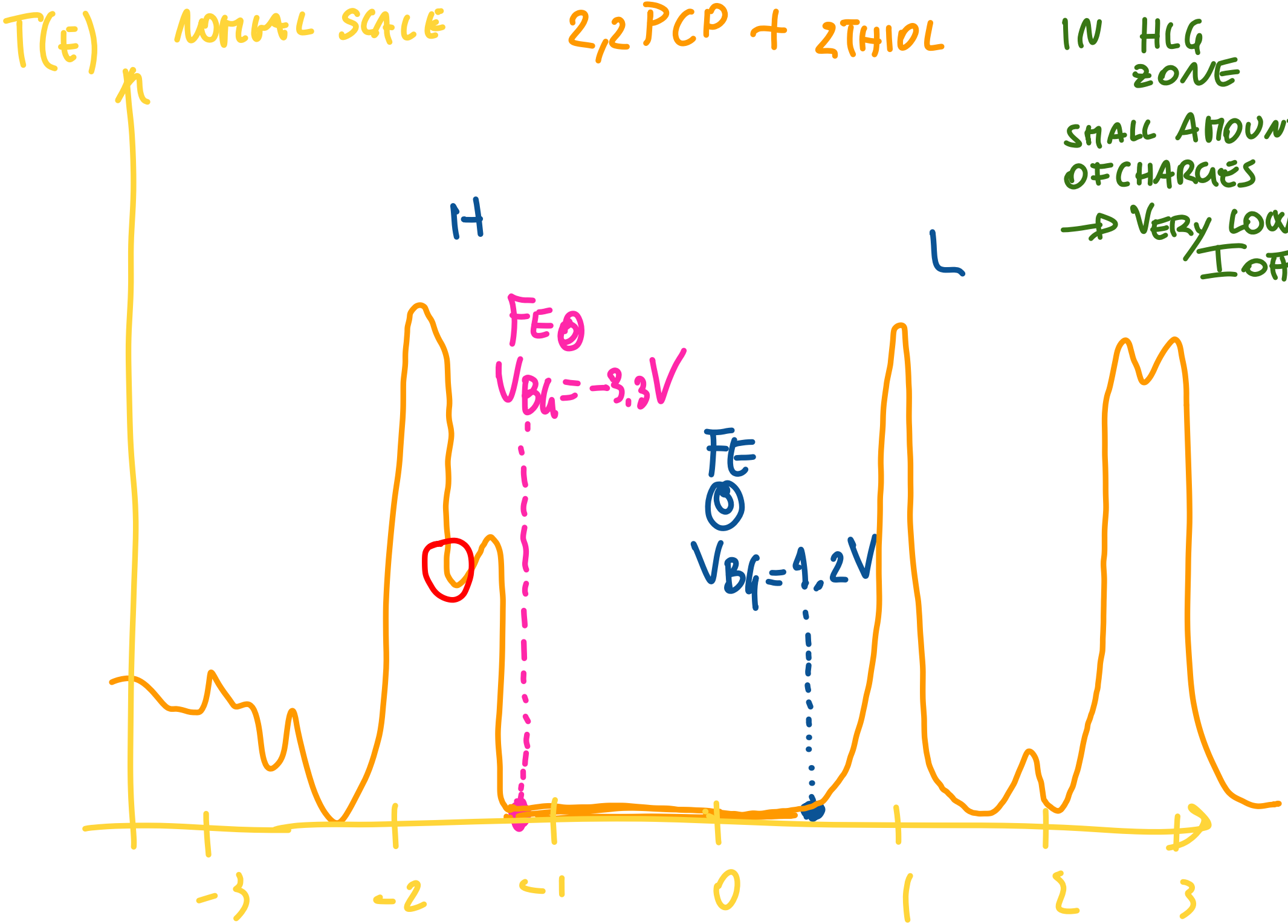
I_C —

I_B —

for some ENERGIES INTERFERE DESTRUCTIVELY

D (QI)


T(E)
LOG SCALE
OPE3
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
H^{-2}
H
L
PCP
10^{-2}
10^{-3}
H^{-2} E -1.5eV
H^{-1} E -1.27eV
H E -1.03eV
L E1.31eV
D QI
IM HLG
REDUCED TRANSMISSION
I_{OFF} CAN BE REDUCED!
-2
-1
0
1
2


T(E)
NORMAL SCALE
2,2 PCP + 2THIOL
IN HLG ZONE
SMALL AMOUNT OF CHARGES
→ VERY LOW I OFF
H
L
FE
$V_{BG} = -3.3V$
FE
$V_{BG} = 1.2V$
-3
-2
-1
0
1
2
3

NTYPE $V_{BG} = 12V$

ON $V_G = 1V$

OFF $V_G = -1V$

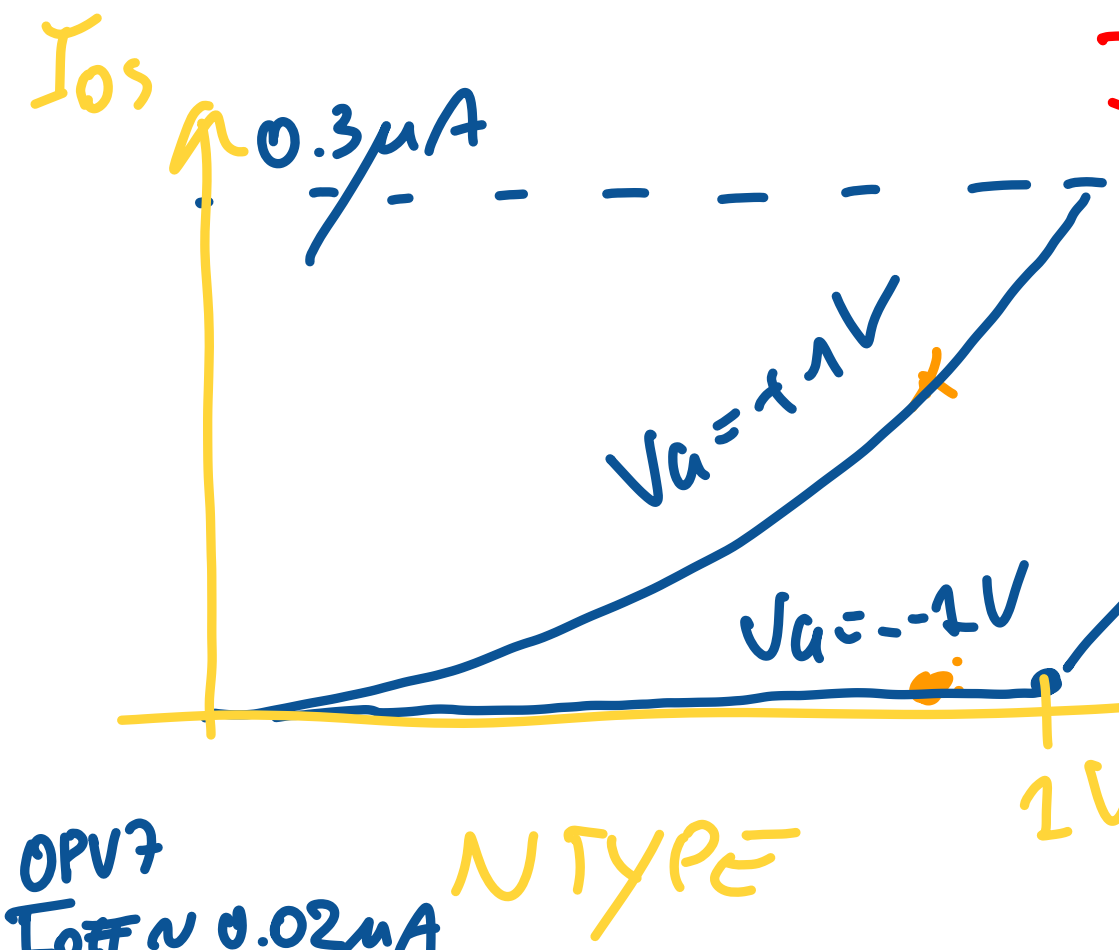
AMBIPOLAR

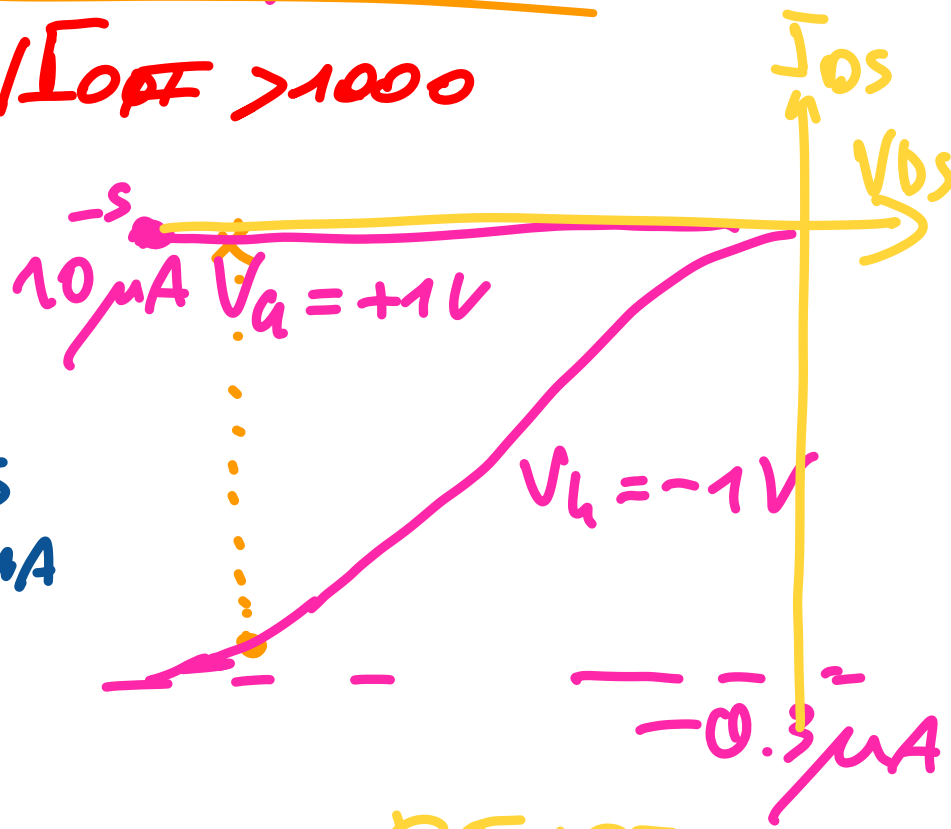
PTYPE $V_{BG} = -3.3V$

ON $V_G = -1V$

OFF $V_G = 1V$

$I_{ON}/I_{OFF} > 1000$





OPV7

$I_{OFF} \approx 0.02\mu A$

NTYPE

PTYPE

→ GOOD AMBIPOLAR BEHAVIOR
(DISTINCT PEAKS, VERY CLEAR)

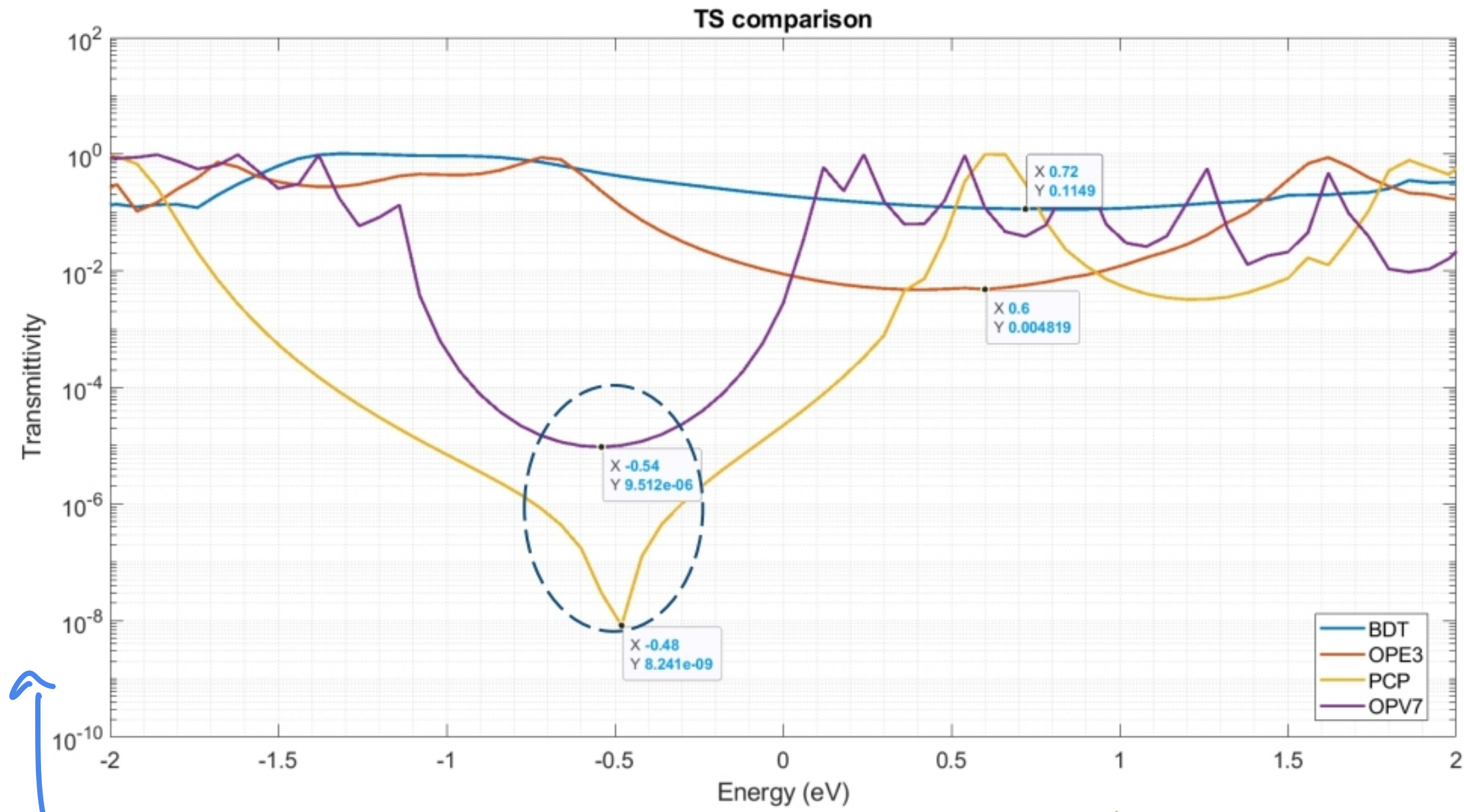
→ VERY LOW I_{OFF} → GOOD $\frac{I_{ON}}{I_{OFF}}$

→ V.R.T. OPV7

$I_{OFF}\big|_{OPV7} \sim 2 \cdot 10^{-2}\,\mu A$ $\quad I_{OFF}\big|_{PCP_{2,12}} \sim 10^{-5}\,\mu A$

⇒ LOWER POWER ⇒ BETTER BEHAVIOR IN A LOGIC GATE (NEXT SECTION)

BDT OPE3 OPV7 PCP



LOG SCALE

QI FUNDAMENTAL FOR GOOD I_{ON}/I_{OFF} RATIO

CRISTALLIZATION

a) CHARGING EFFECT & RESONANCE

b) EFFECT OF GATE

- GENERAL
- BENZENE
- OPV3
- PCP & Q.D.