Photoluminescence of p-doped quantum wells with strong spin splitting

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Thank you all

- **MBE growth**
  M. Bertolini[1], S. Tatarenko[1]
- **Spectroscopy and analysis**
  D. Ferrand[1], J. Cibert[1,4], P. Kossacki[1,2,3], J.A. Gaj[1,2]
- **Time resolved PL**
  V.Ciulin[3], B. Deveaud-Pledran[3]
- **Transmission at high magnetic fields**
  M. Potemski[5]

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2 Institute of Experimental Physics, Warsaw University – POLAND

3 Institute of Quantum Electronics and Photonics, EPFL – SWITZERLAND

4 Laboratoire Louis Néel, CNRS, Grenoble - FRANCE

5 High magnetic field laboratory, CNRS, Grenoble - FRANCE

Outline

I Material and samples

(Cd,Mn)Te based p-type modulation doped QW

II PL versus spin splitting

- PL at vanishing hole density
  - Switching from **X^+** to **X**
- PL at large hole density
  - Switching from **X^+** to (D_{hi} ,D_{low})
  - **X^+** transition and hole gas polarization

III Characteristic energies

IV Back to the hole density determination

V Conclusion

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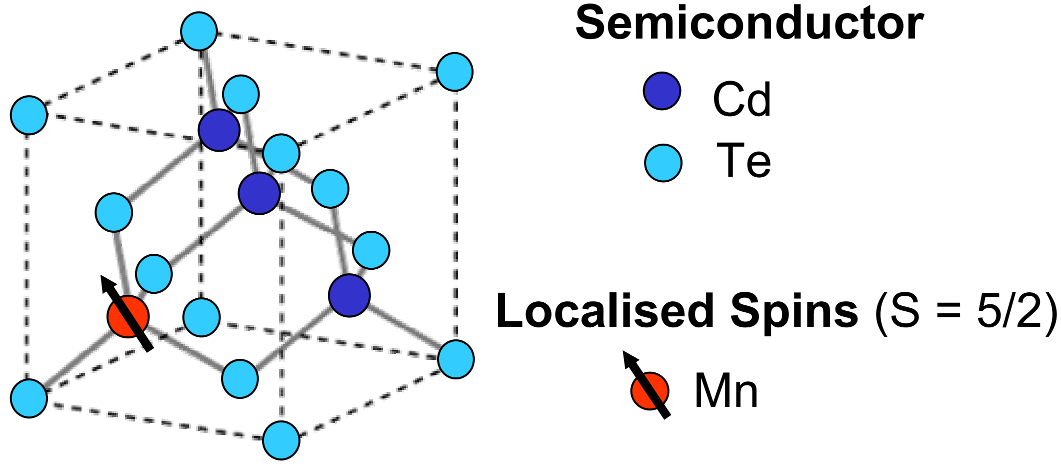
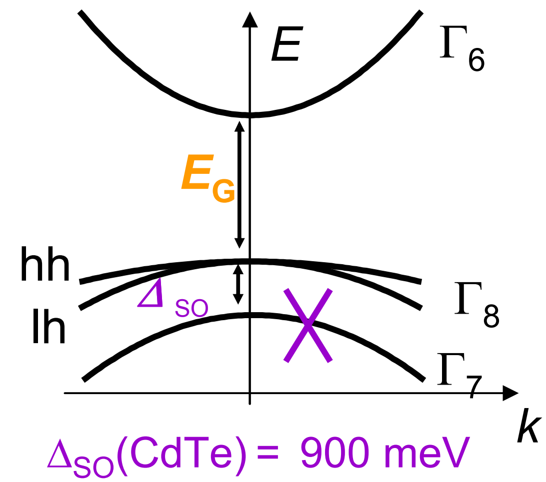
Diluted magnetic semiconductor: (Cd,Mn)Te

•Randomly distributed localised spins (Mn)

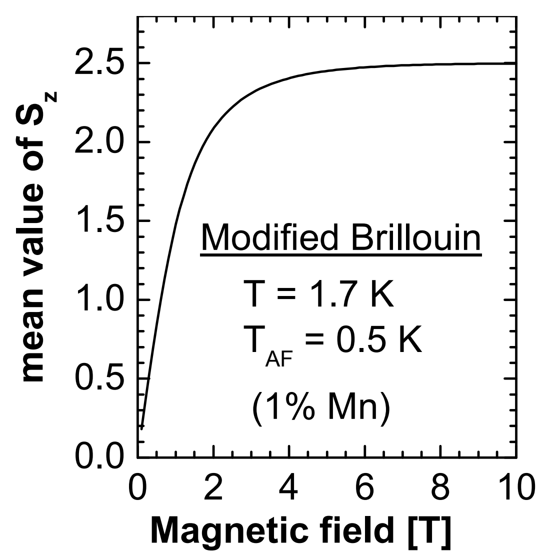




Modified Brillouin function

$$M = \frac{5}{2} g \mu_B N_0 x_{eff} B_{\frac{5}{2}}\left(\frac{\frac{5}{2} g \mu_B B}{k_B (T + T_{AF})} \right)$$

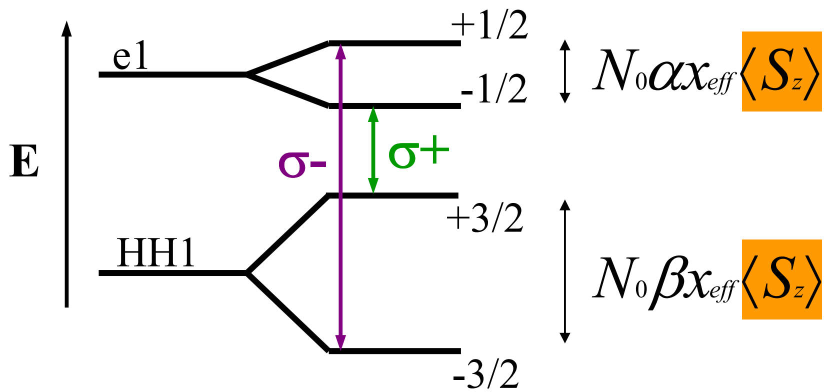
$$= g \mu_B N_0 x_{eff} \langle S_z \rangle$$

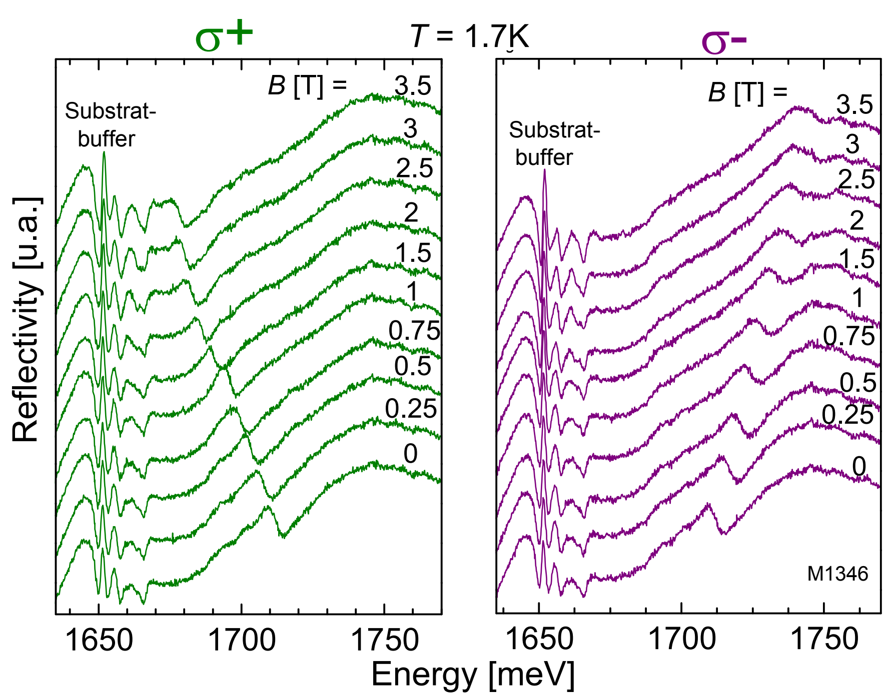


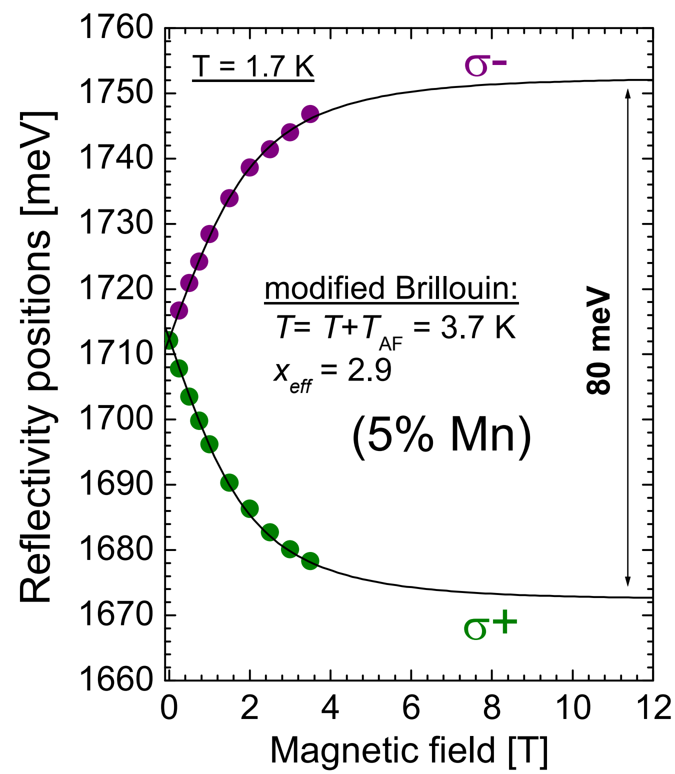
Diluted magnetic semiconductor: (Cd,Mn)Te

•**Exchange interaction:** 3d *Mn states – s,p states of the semiconductor matrix*

Giant Zeeman splitting

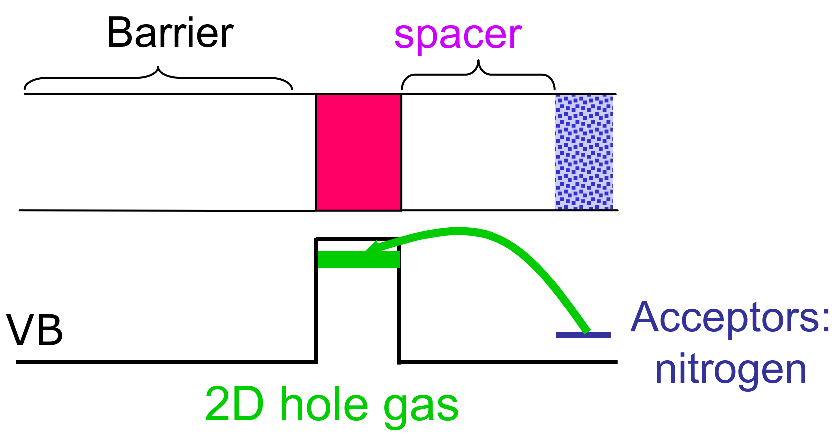






P-type doping and control

•Modulation doped



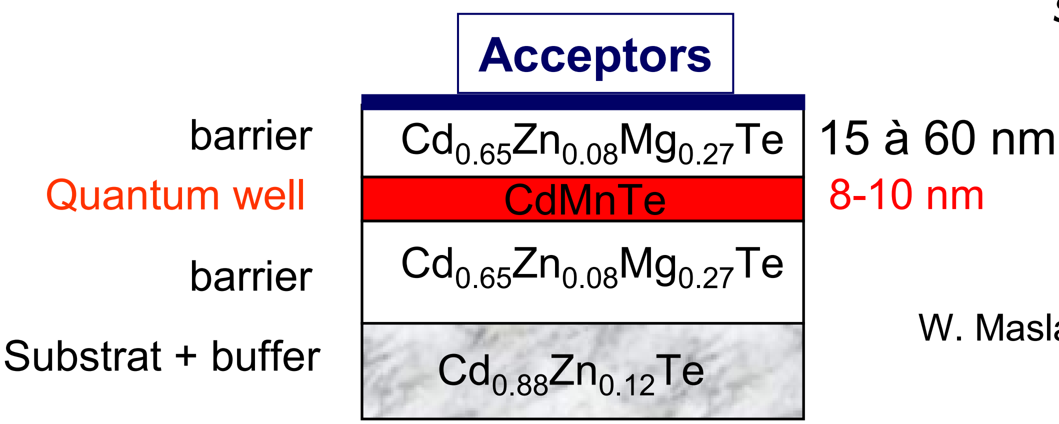
Control :

spacer thickness
acceptor concentration

•Surface doped

Control:

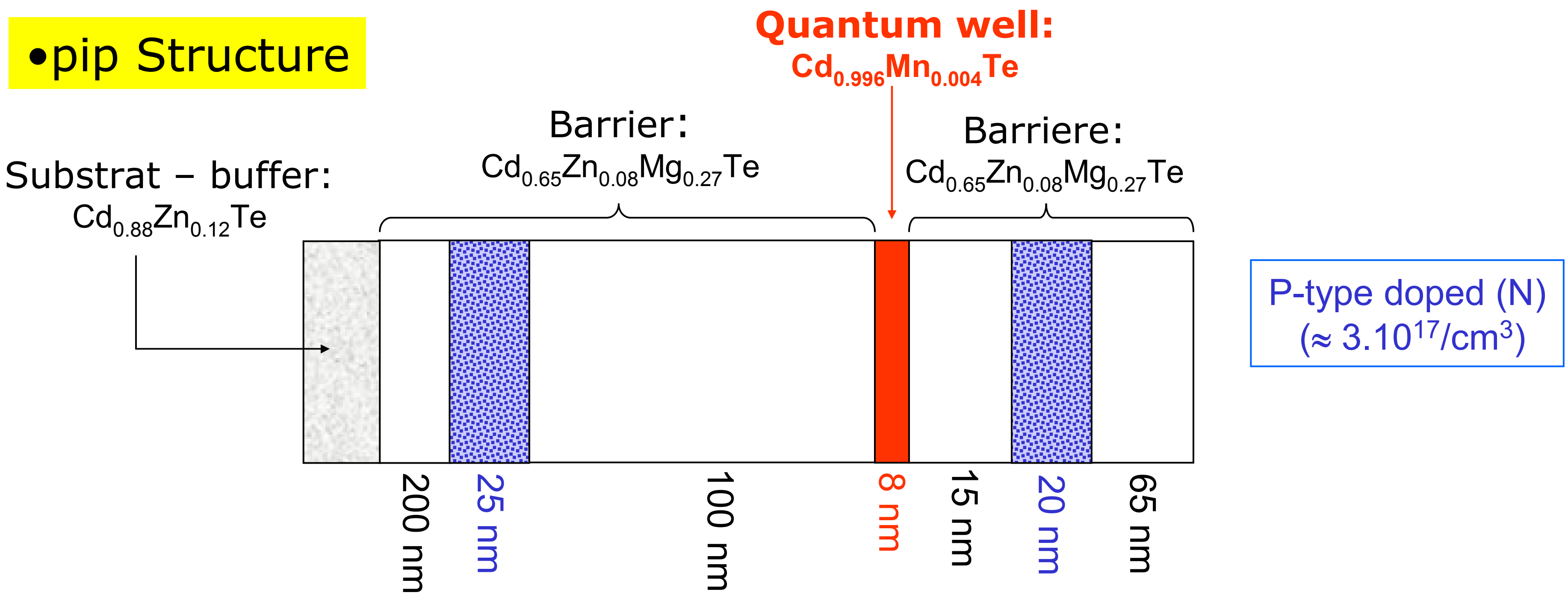
surface/quantum well Distance



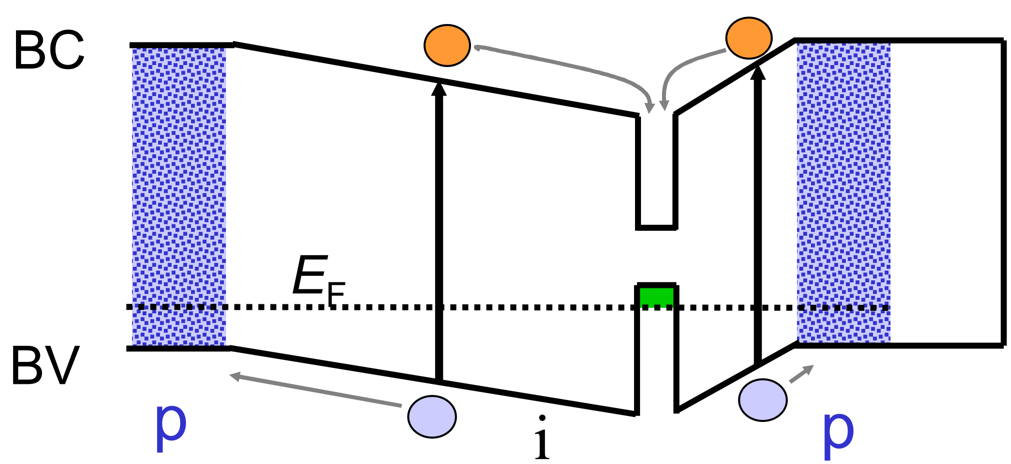
W. Maslana *et al., Appl. Phys. Lett.* ***82***, *1875 (2003)*

Optical control

•pip Structure



•Above barrier illumination

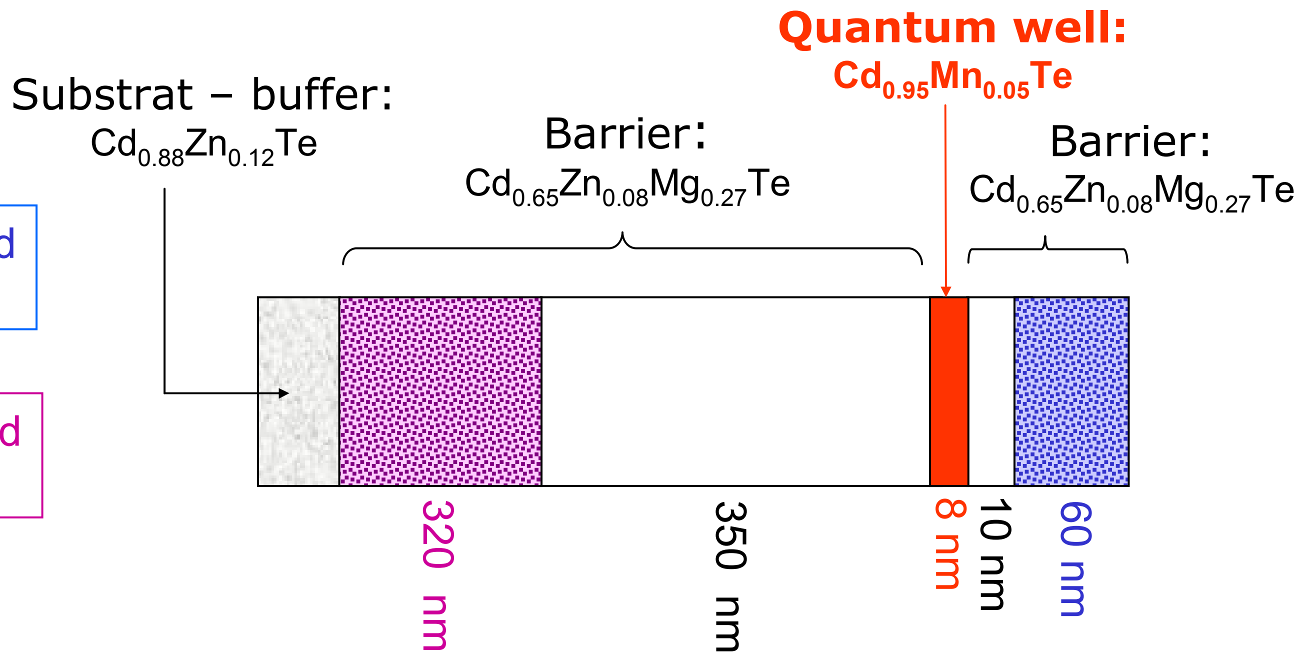


Electrical control of the hole density

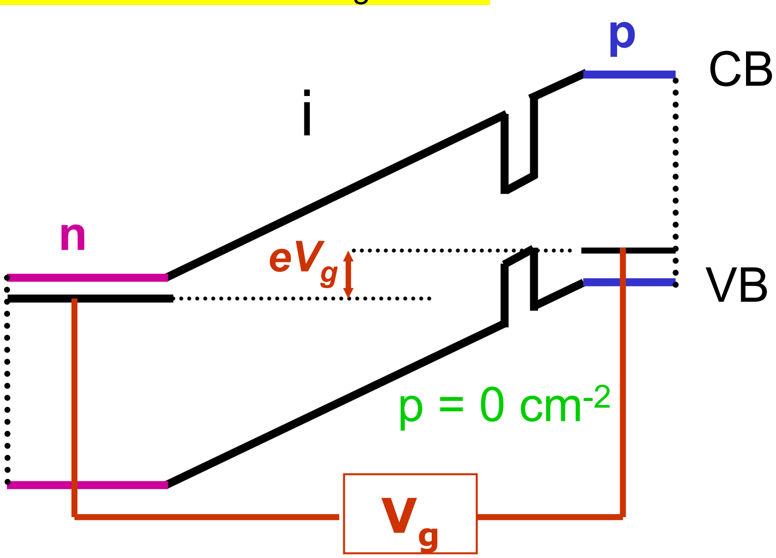
•pin diode

p-type Nitrogen doped
(≈ $3.10^{17}/cm^3$)

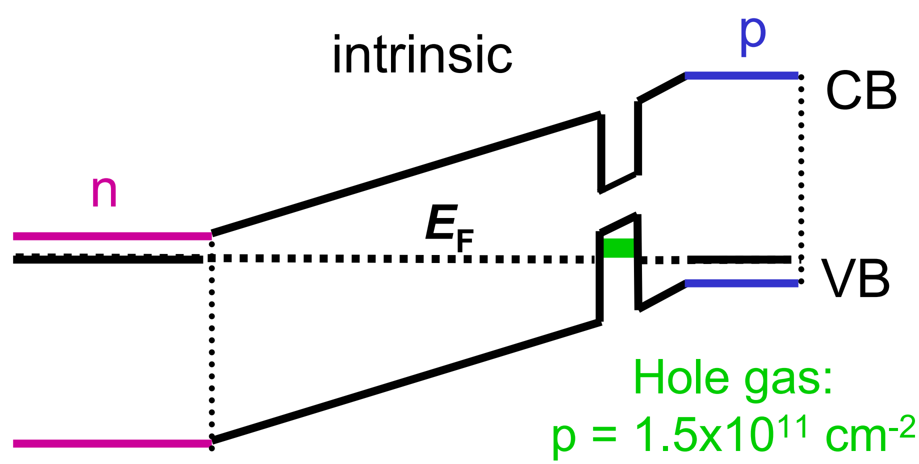
n-type Aluminium doped
(≈ $3.10^{18}/cm^3$)



•Reverse bias: $V_g < 0$



•Band structure at equilibrium

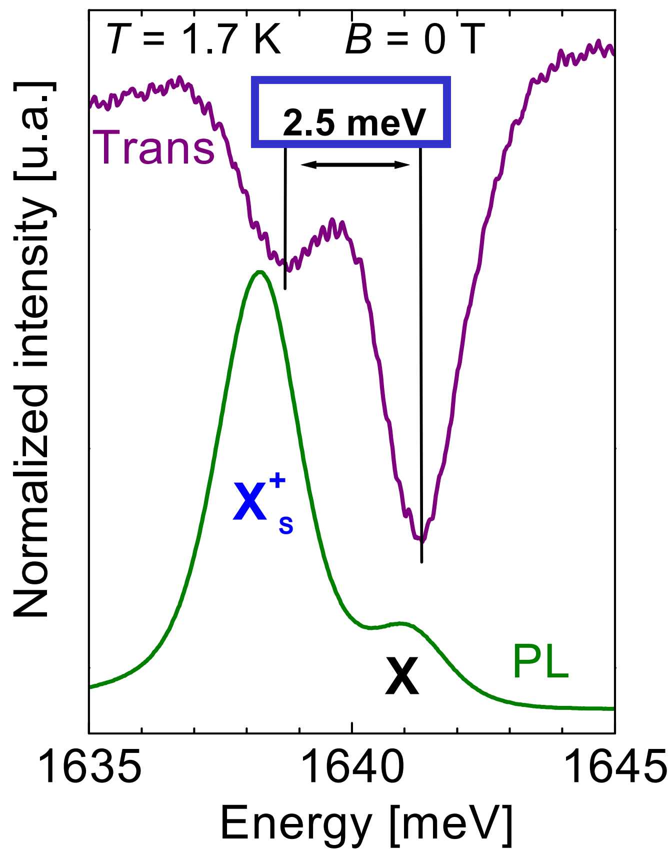


Important energies

Hole gas Fermi energy:

Max: E_F = 3 meV

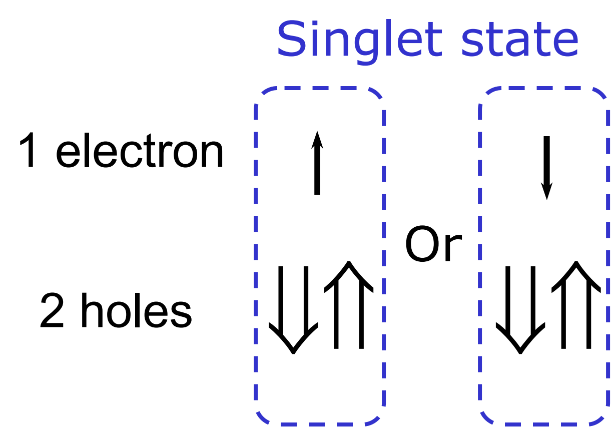
8 nm $Cd_{0.996}Mn_{0.004}Te$/(Cd,Zn,Mg)Te QW



Exciton binding energy: **X**

$E_b(X) \approx$ **20 meV**

Positively charged exciton: X_s^+



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  $\mathbf{X^+}$ transition and hole gas polarization

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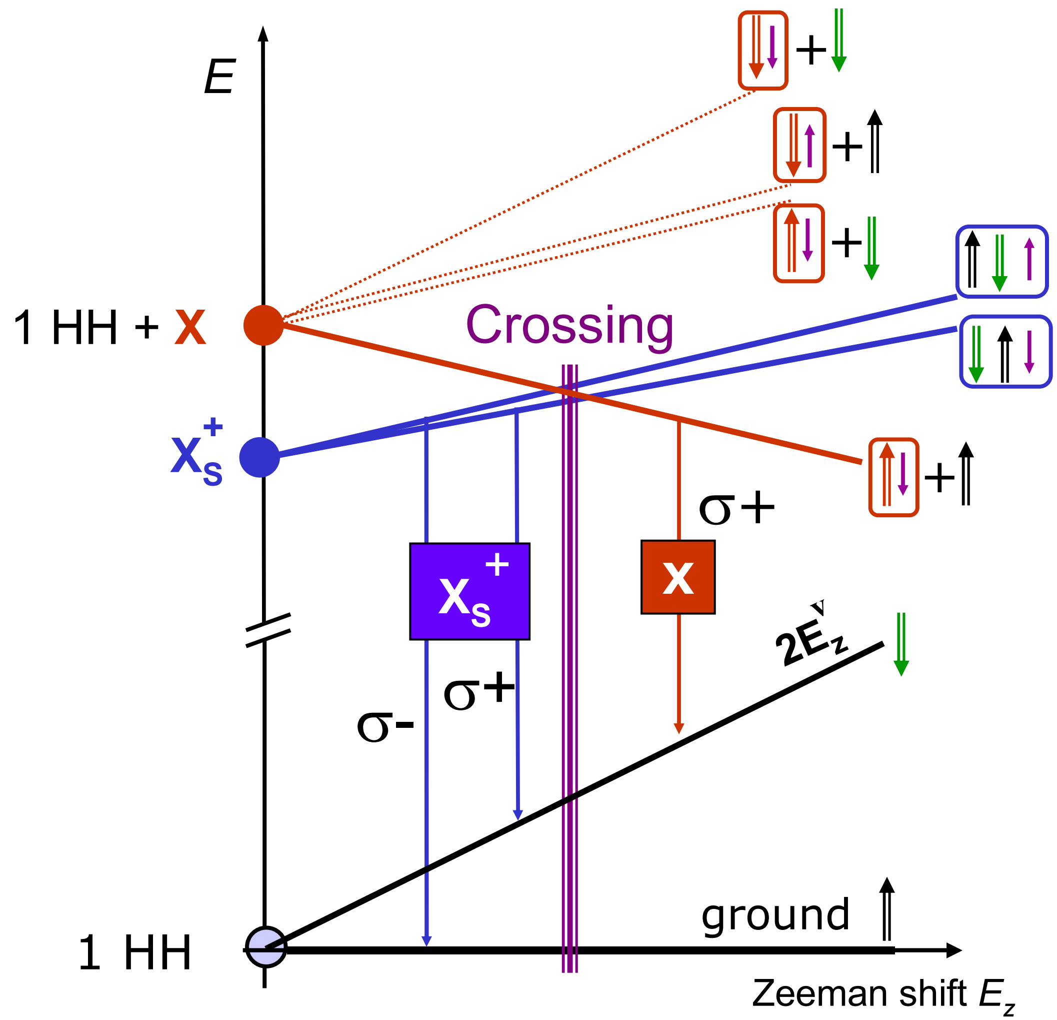
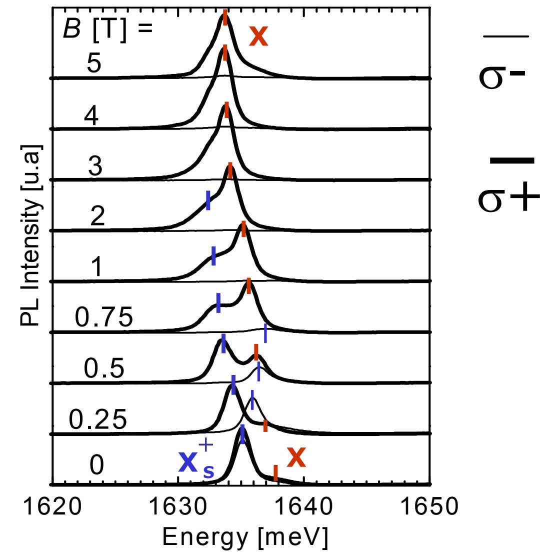
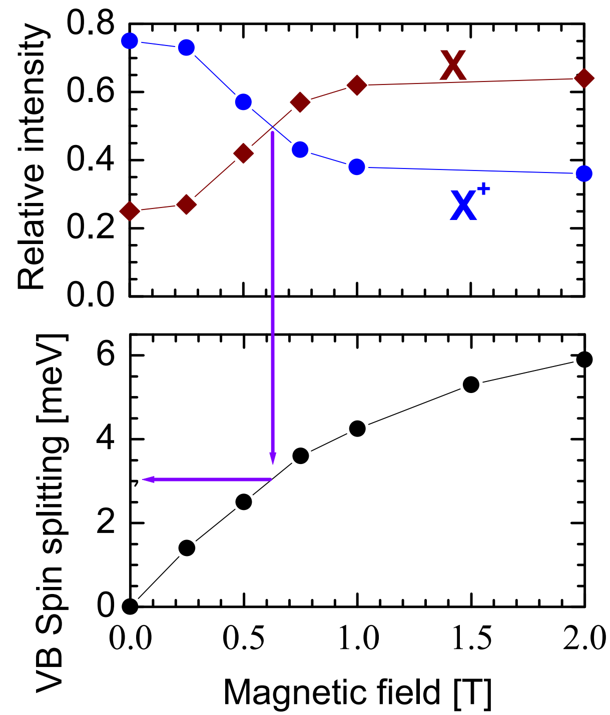
PL at vanishing hole density

•$p \leq 2 \times 10^{10}$ cm^{-2}







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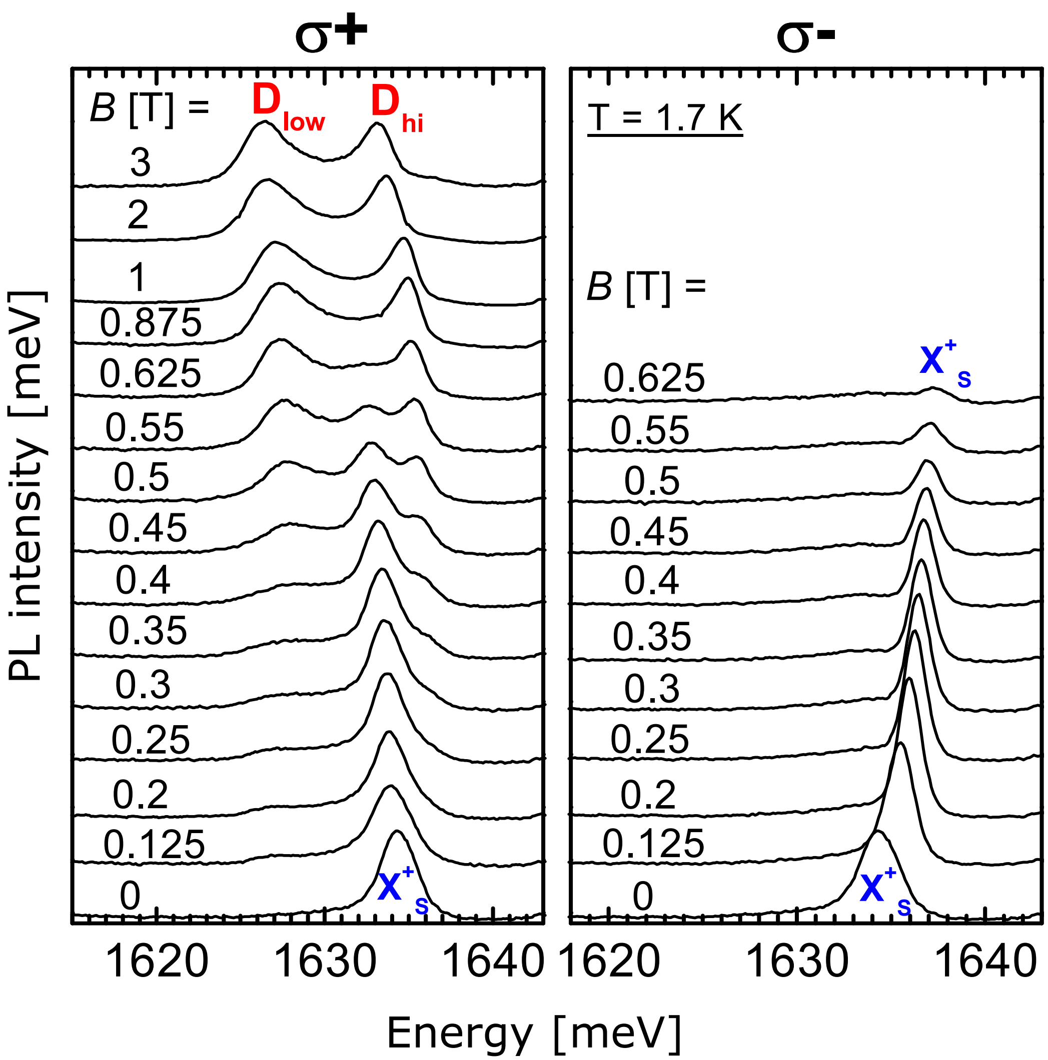
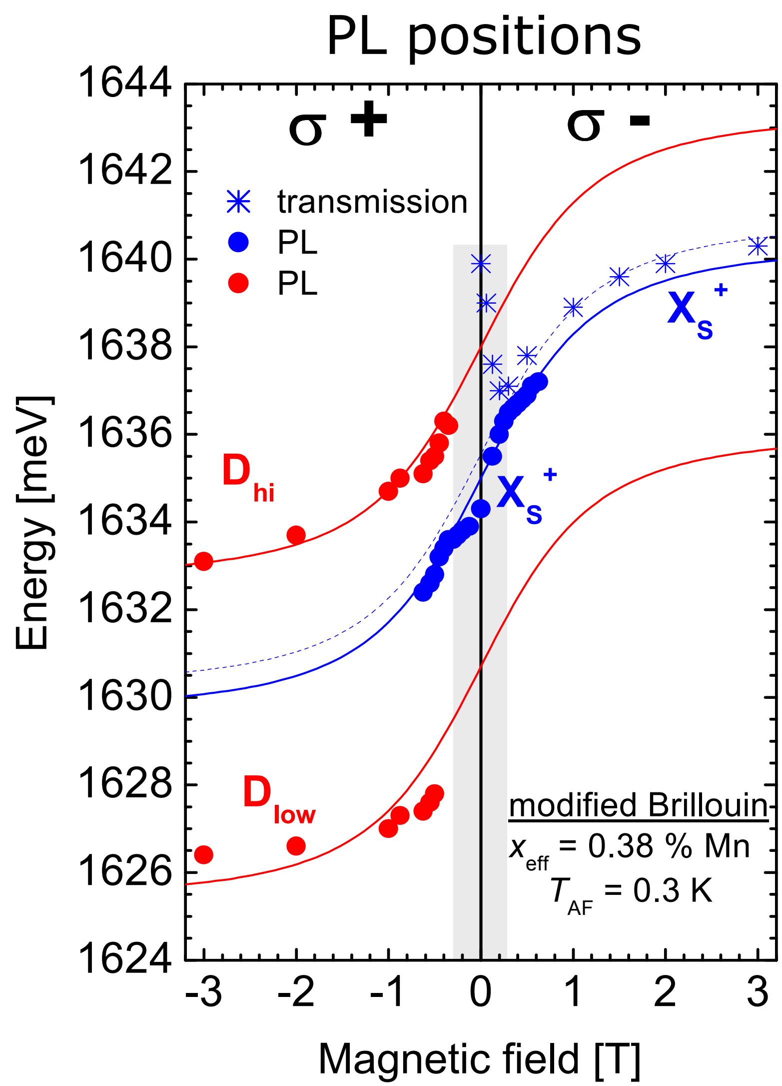
PL at larger hole density

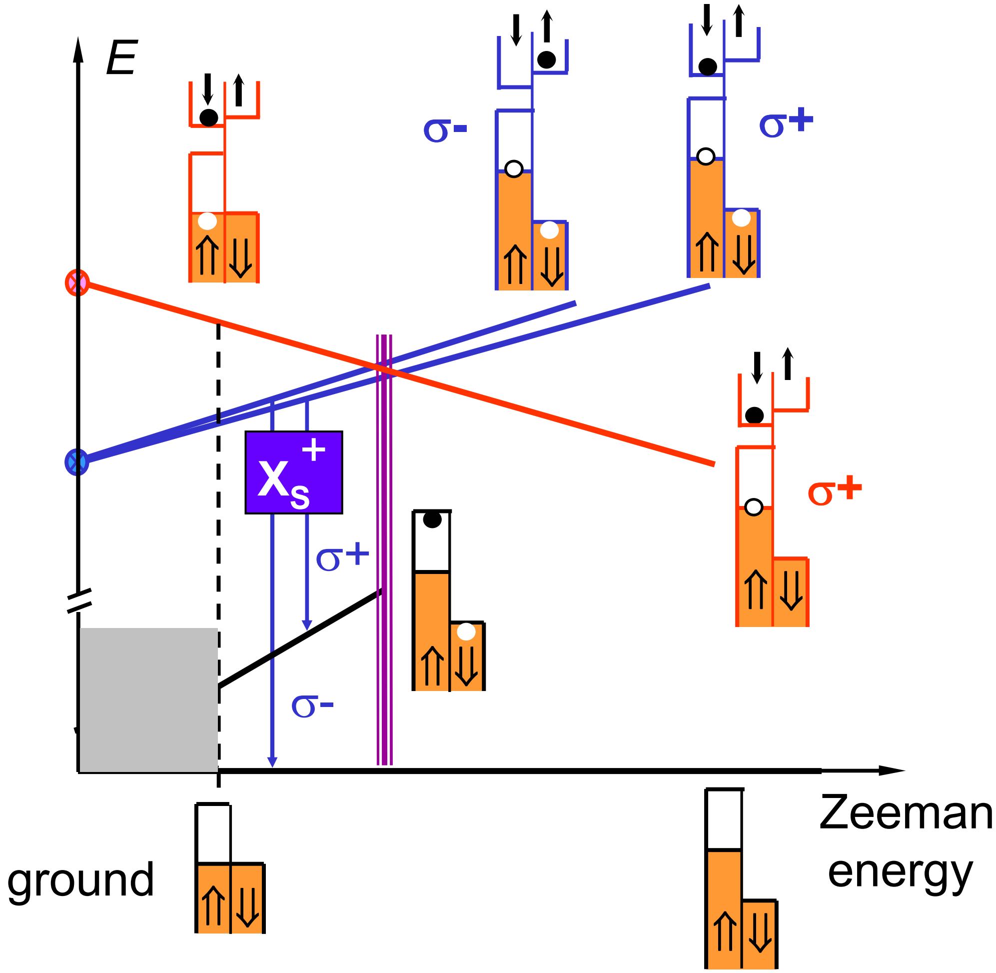
•p = 2.6x10^{11} cm^{-2}

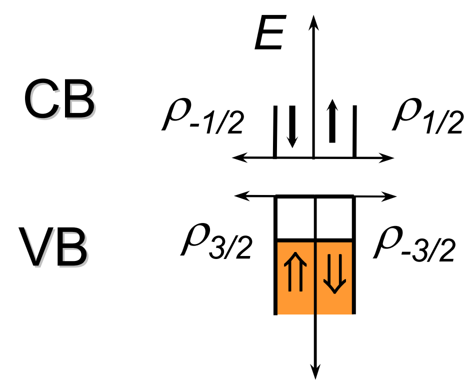
pip structure





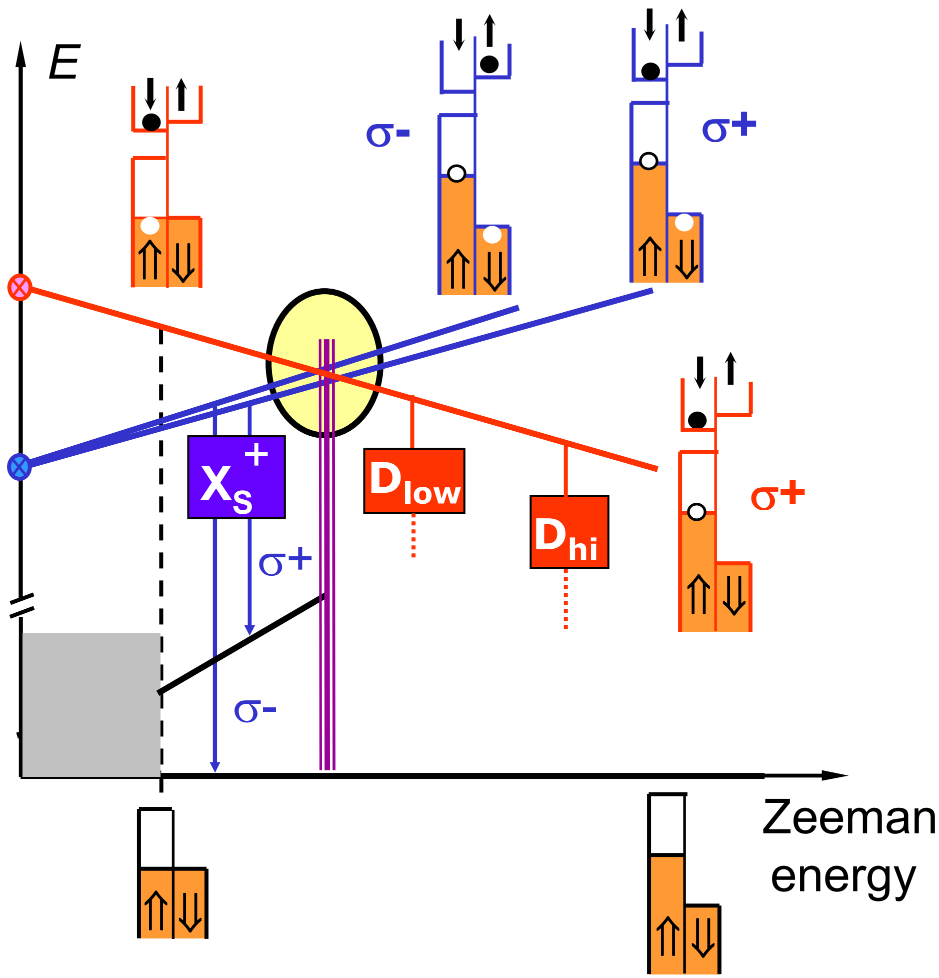
Destabilization of the singlet X⁺

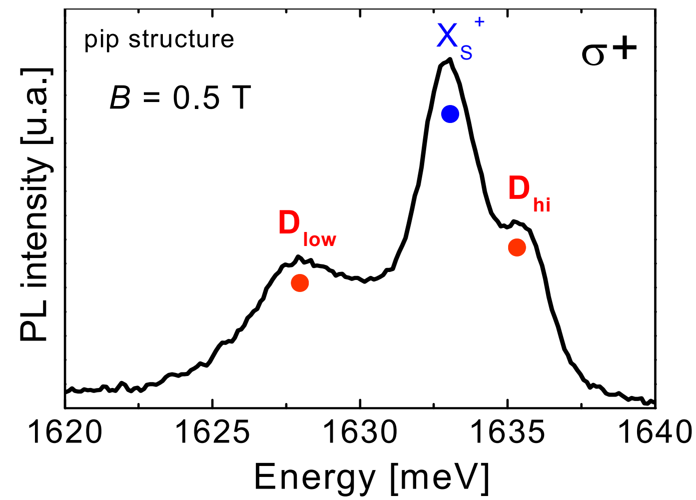


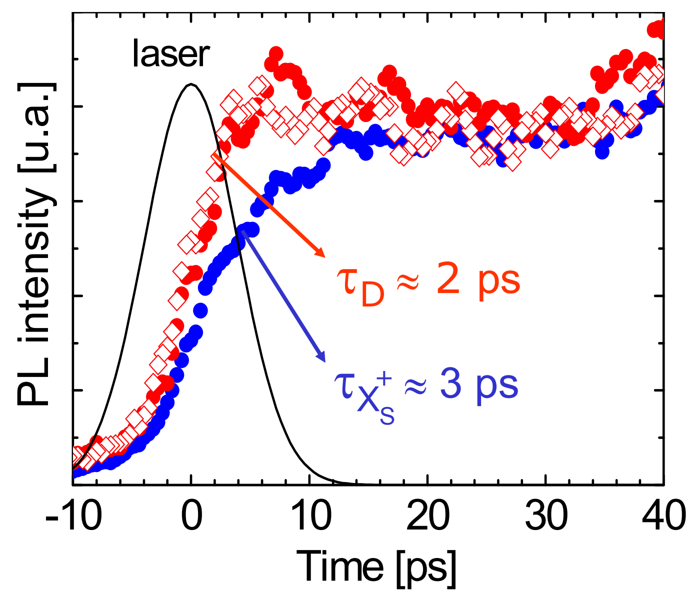


D_{hi} and D_{low} : the same initial state

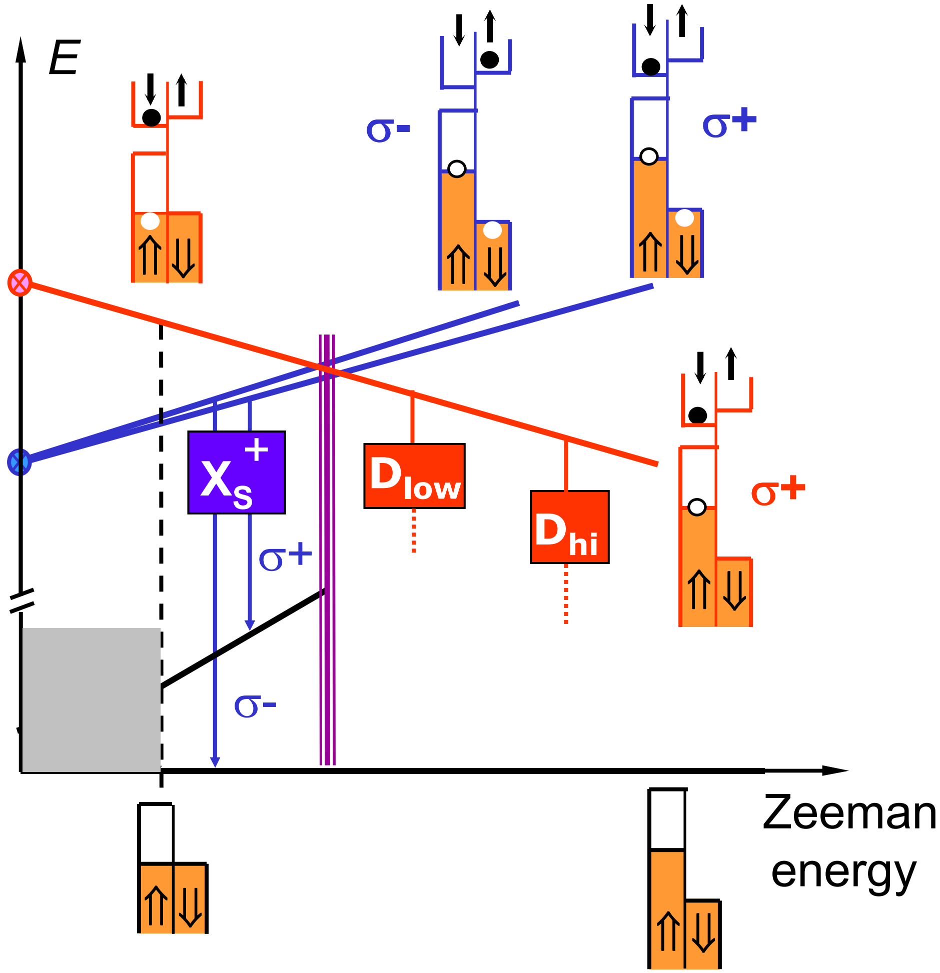
•At the crossing point

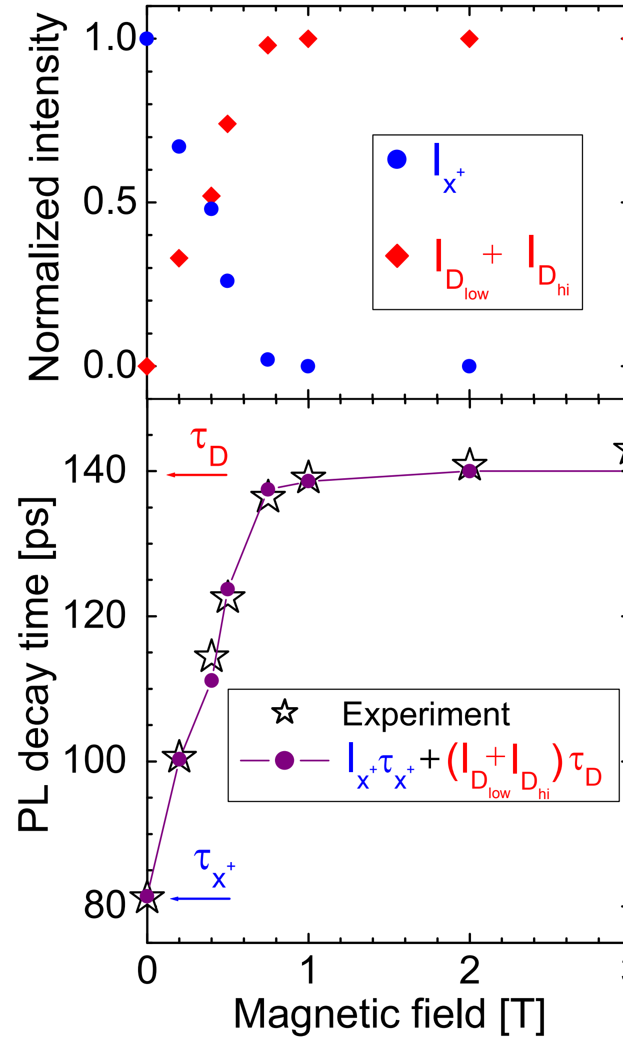






D_{hi} and D_{low} initial state – identification !

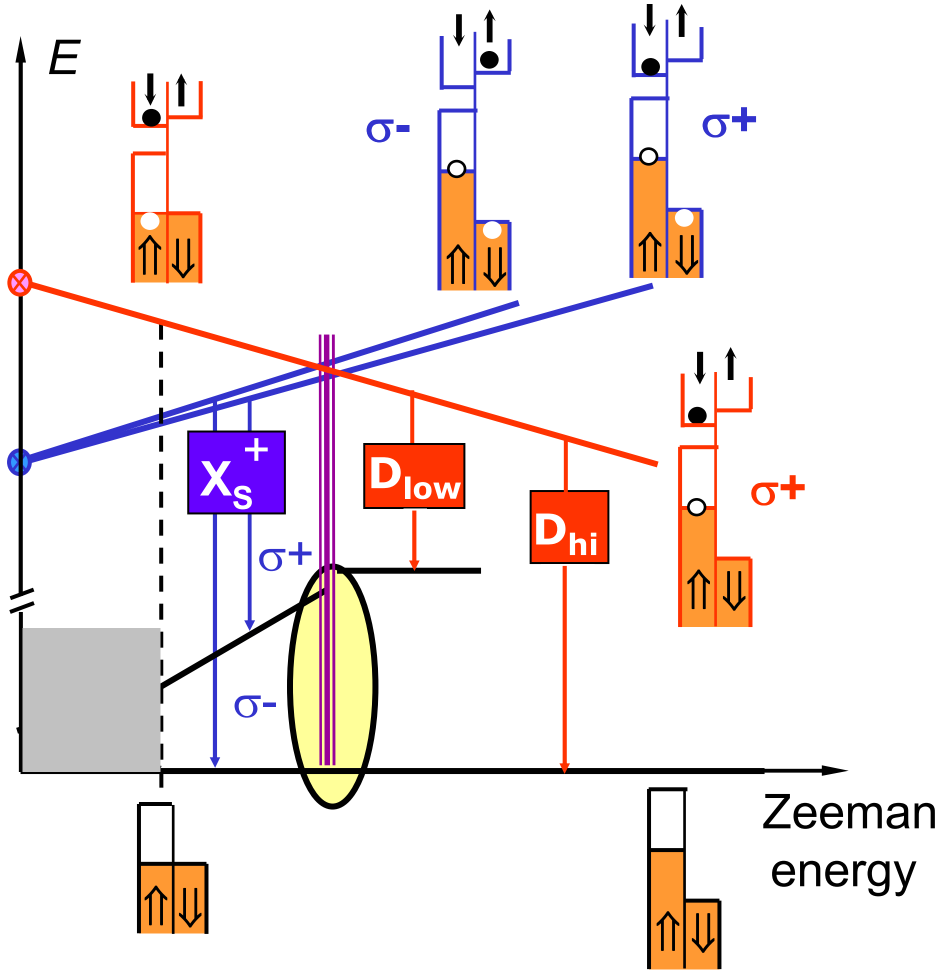


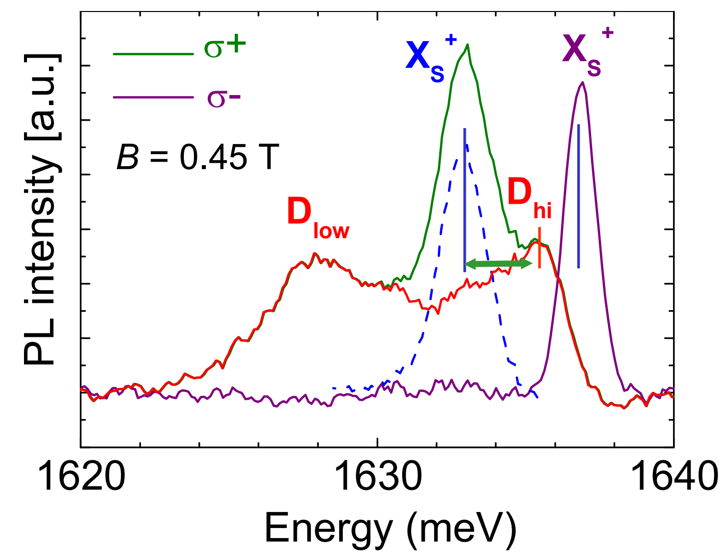


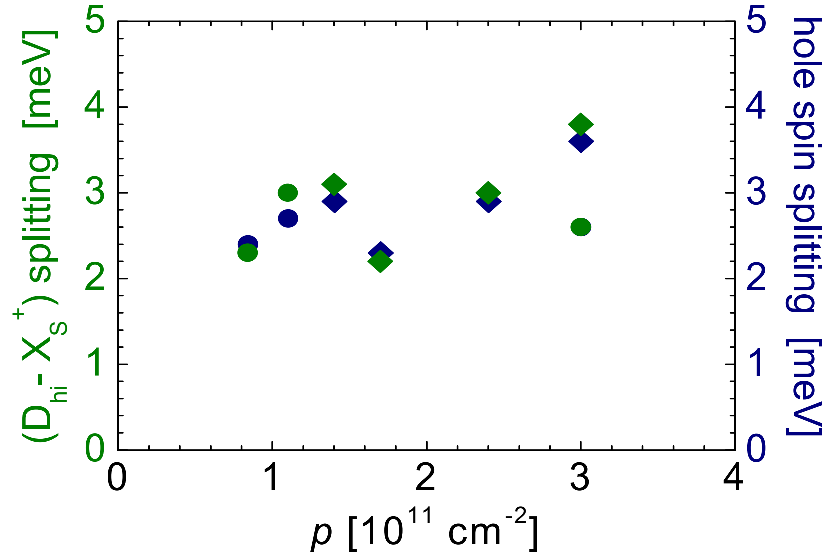
Transfert of oscillator strength from X^+ to a state with less correlated particles

D_{hi} and D_{low} final states

•At the crossing point



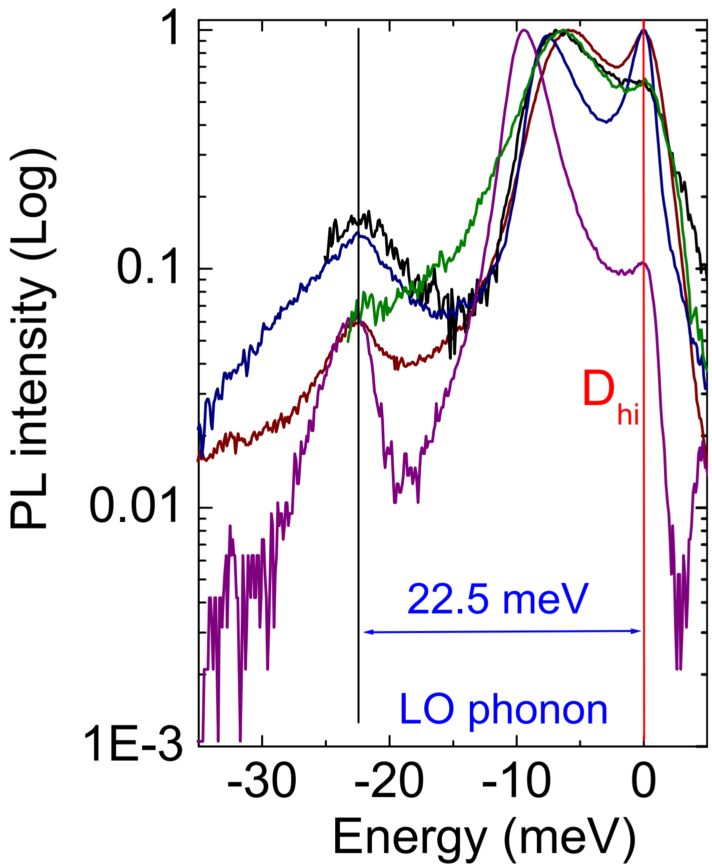


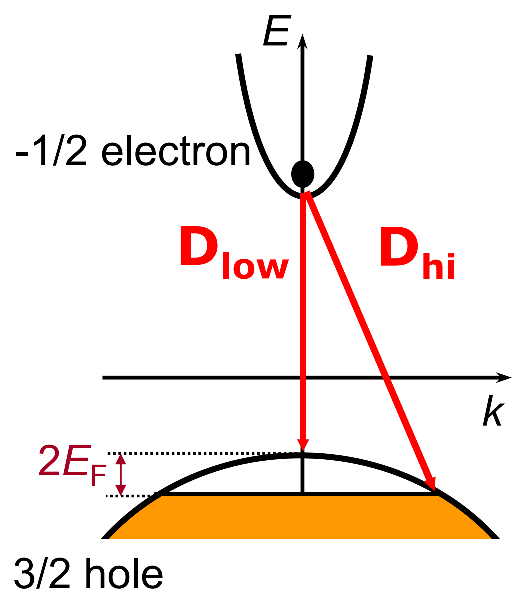


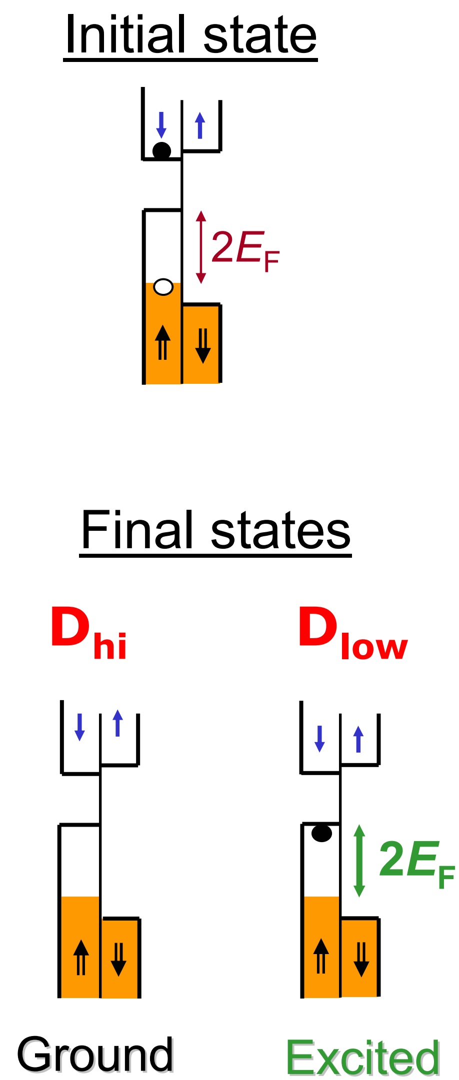
D_{hi} and D_{low} : indirect and direct transitions

σ^+ transitions

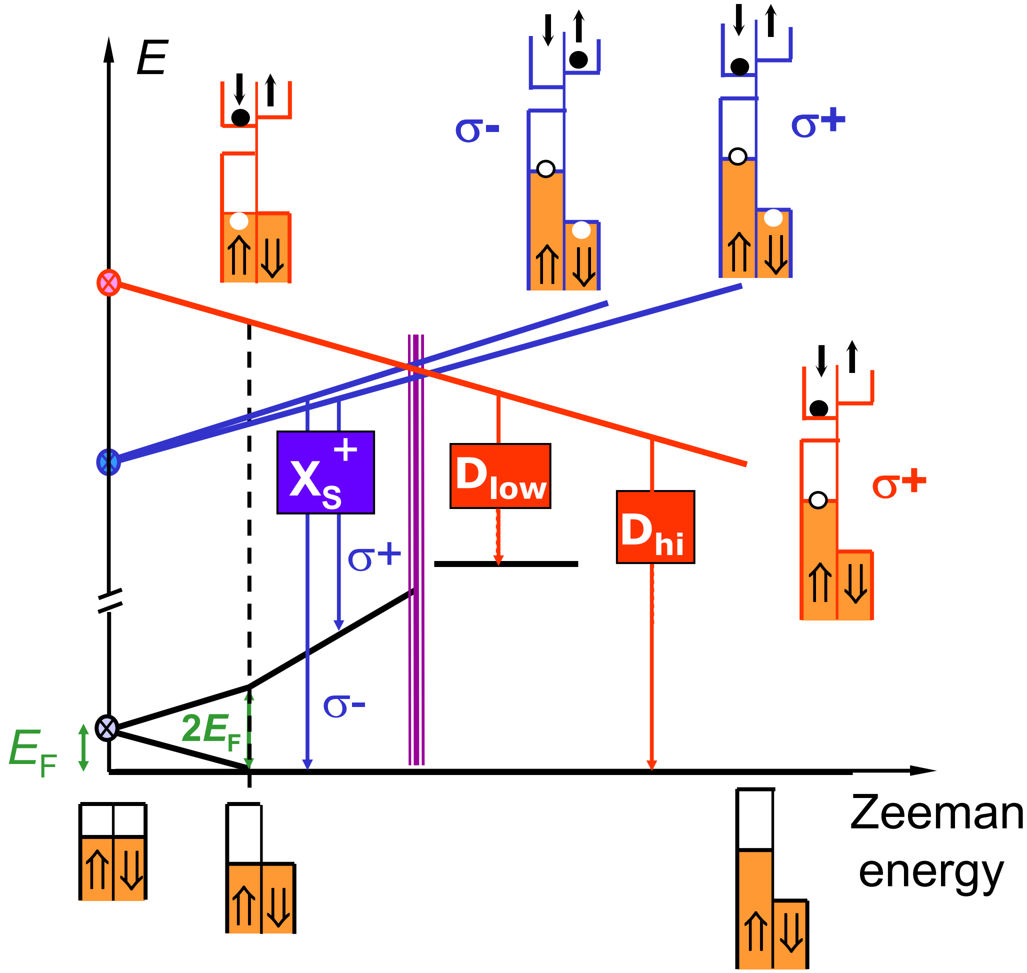
Phonon replica only associated to D_{hi}

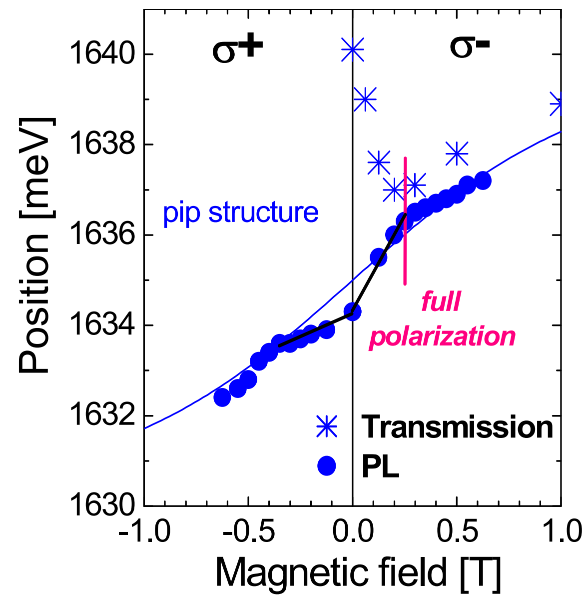




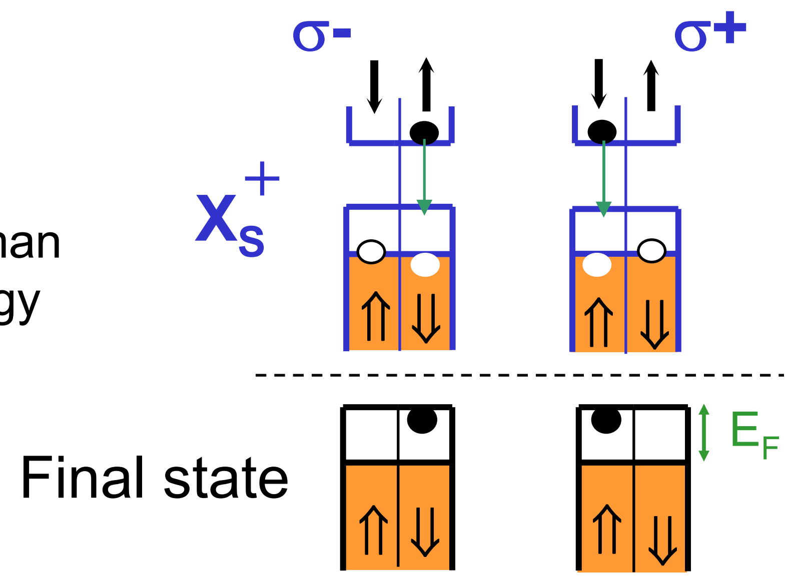


Small spin splitting: Polarization of the hole gas





At zero magnetic field



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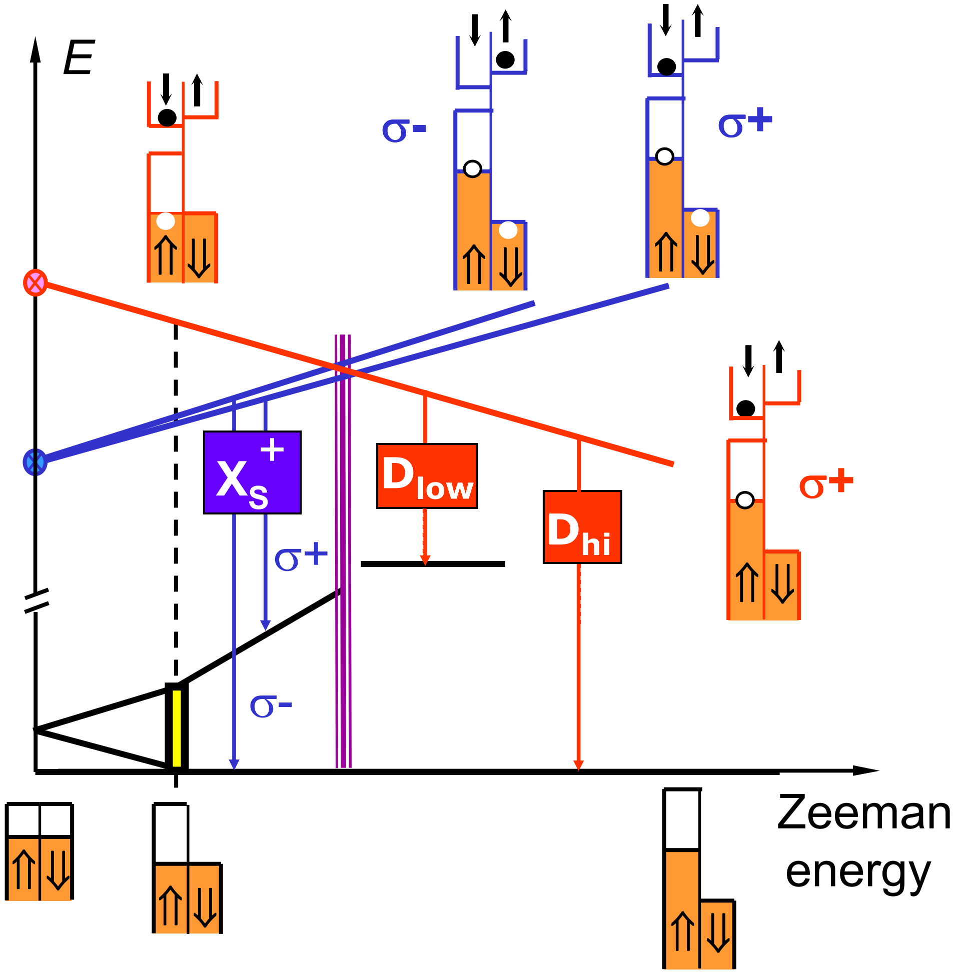
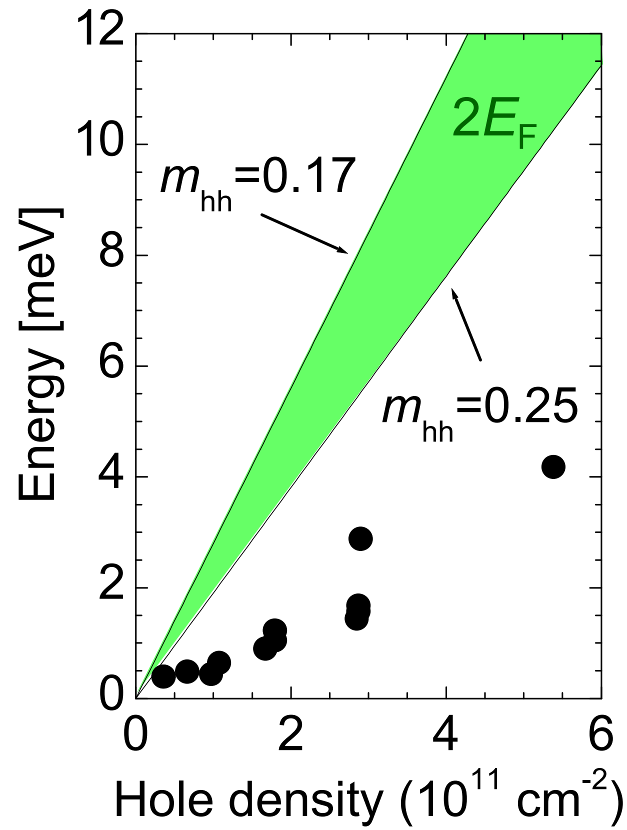
Spin splitting at full polarization

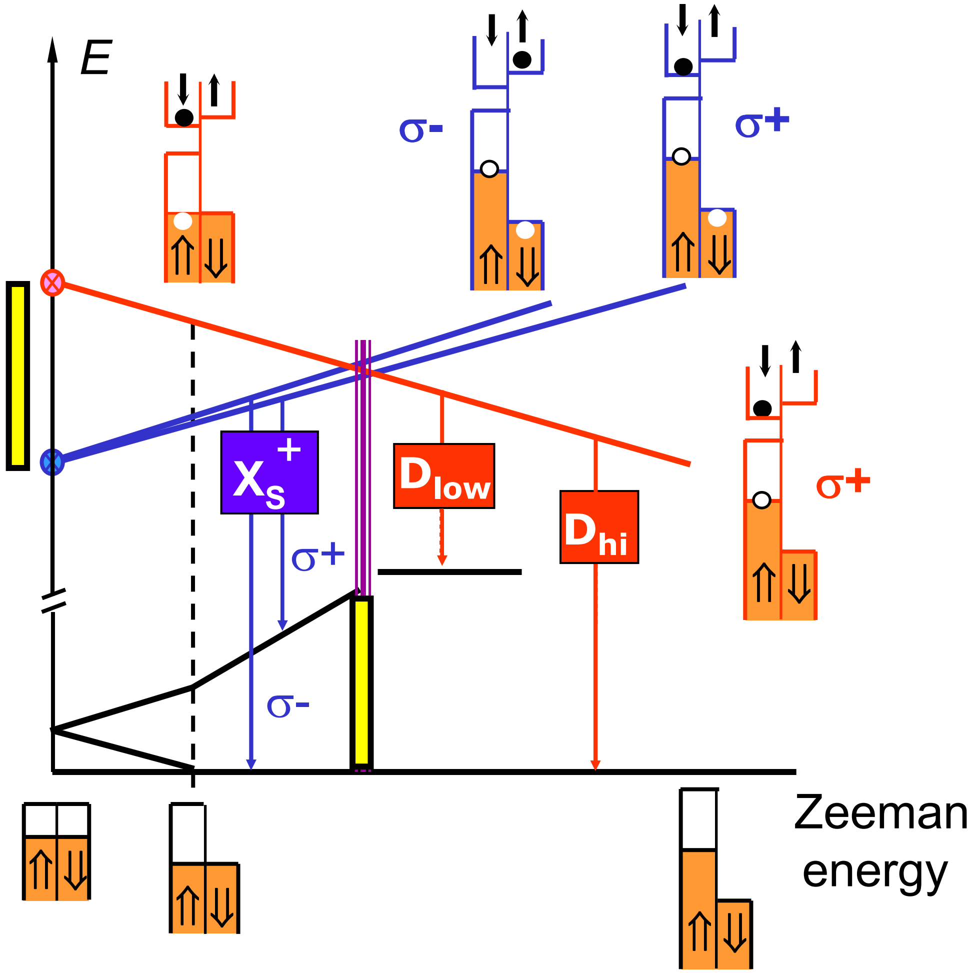


VB splitting at full polarization

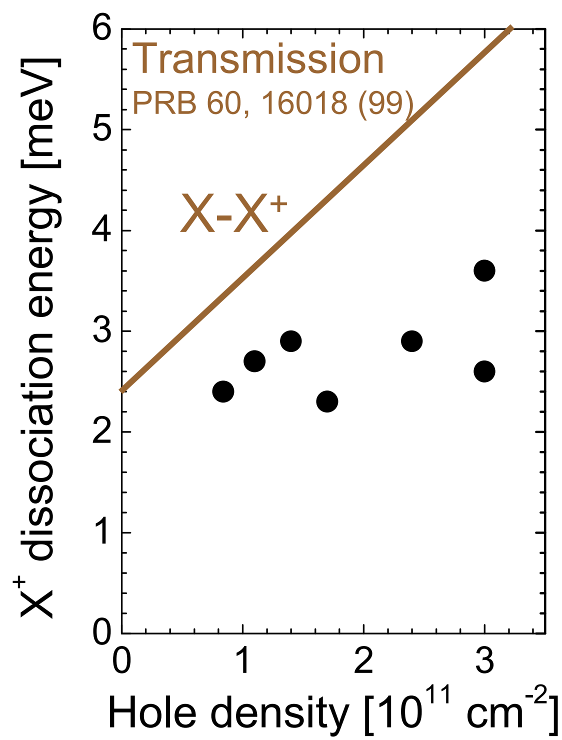


Hole-hole interactions !

Spin splitting needed to destabilize the singlet X^+



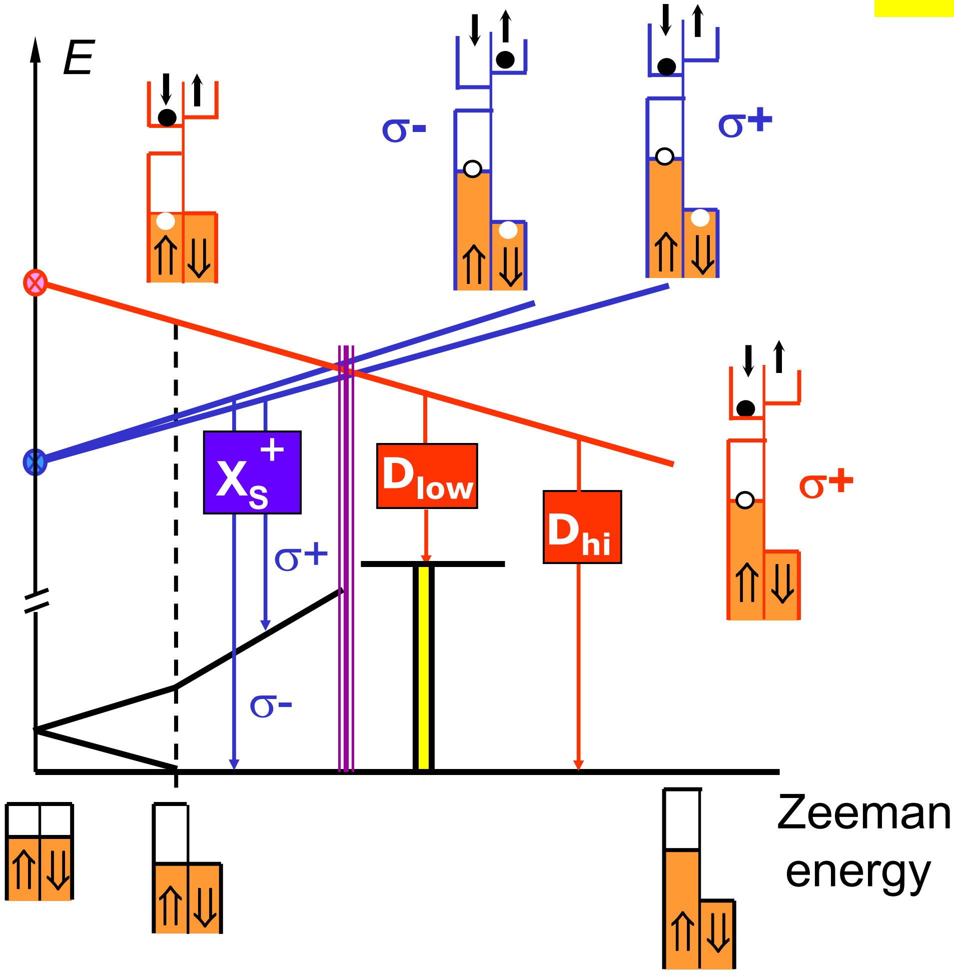
VB splitting at crossing point

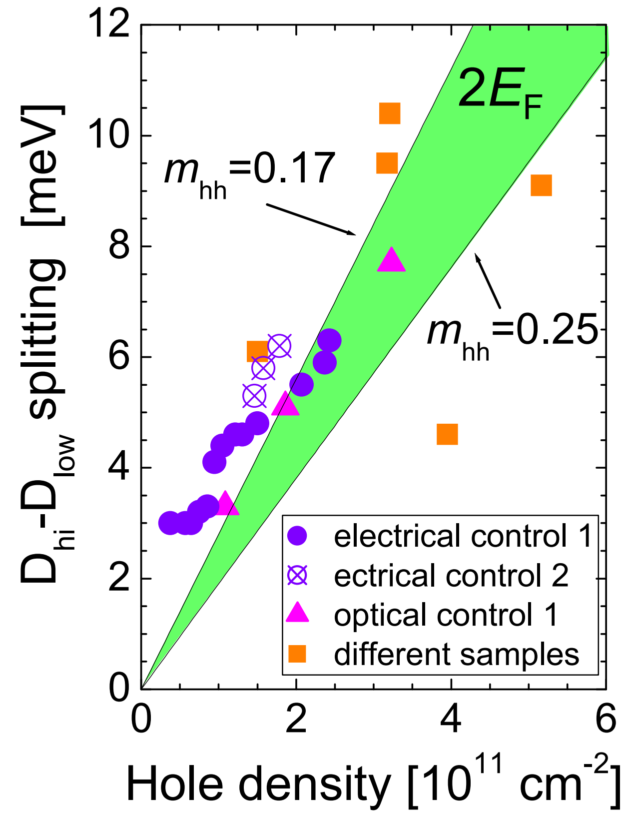


Binding energy !

Hole gas excitation

A measure of the energy left in the gas





Nature of the excitations !

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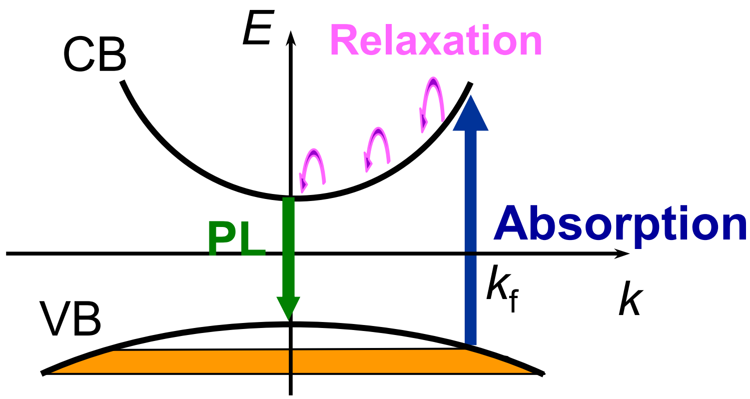
In the band-to-band regim

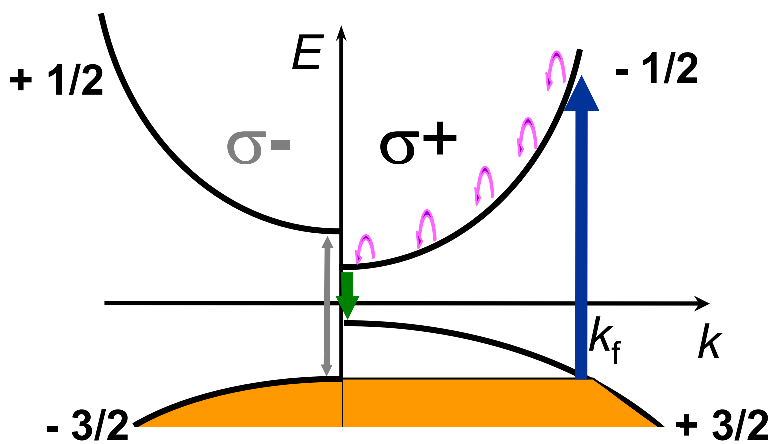
Moss-Burstein shift

Zero magnetic field



includes Stockes shift

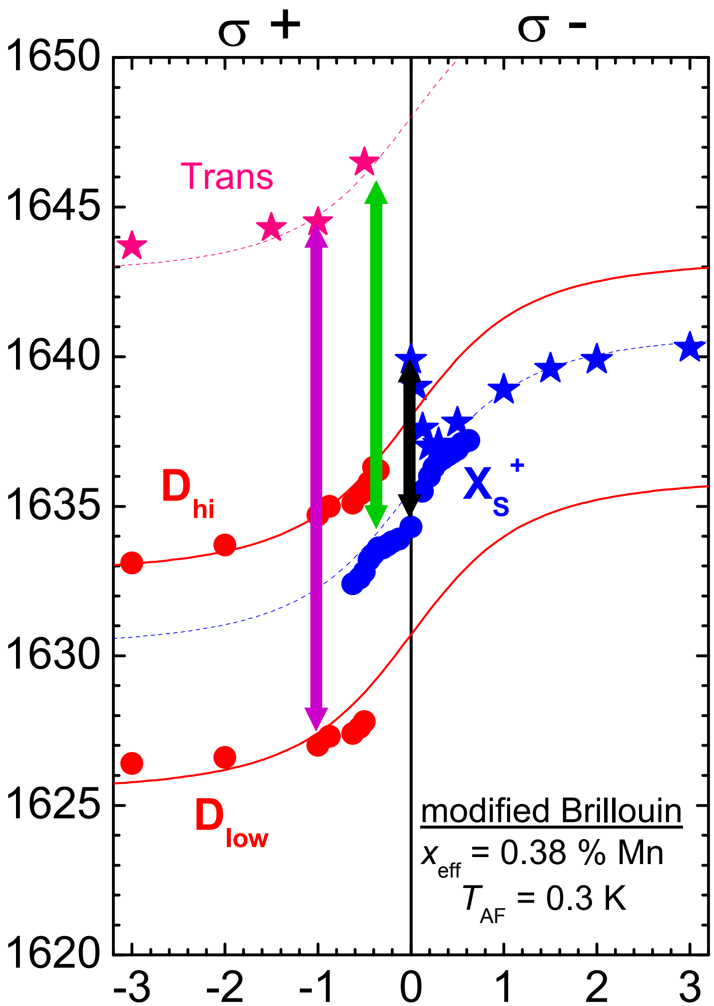
At the limit of full polarization



Enhance accuracy

- *2 times larger E_F*
- *Extract the Stockes shift in σ-*

Moss-Burstein and X⁺ ?

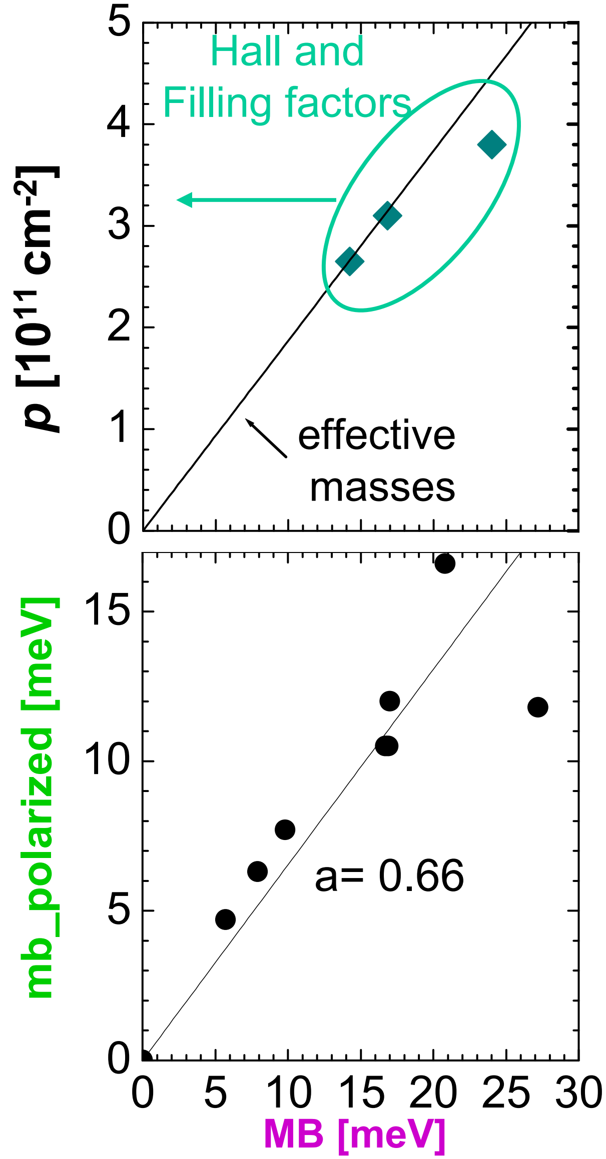


mb

mb_polarized

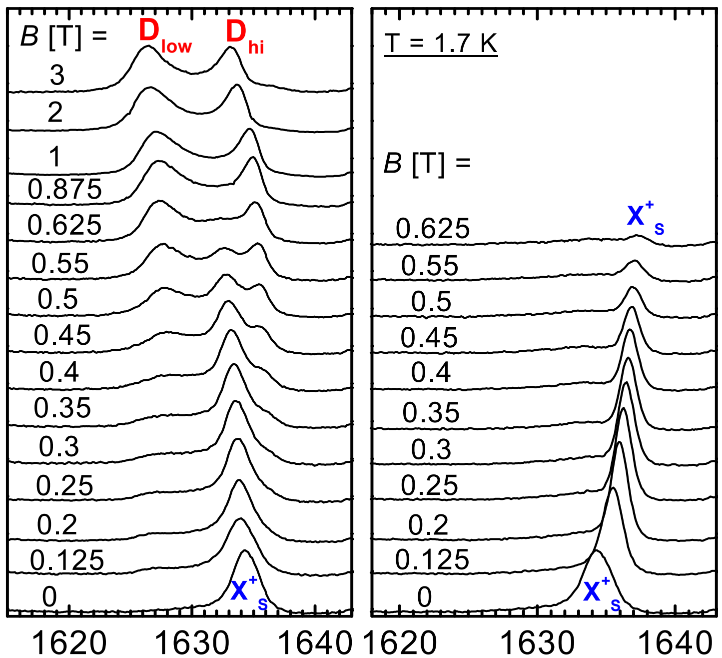
MB

Calibration

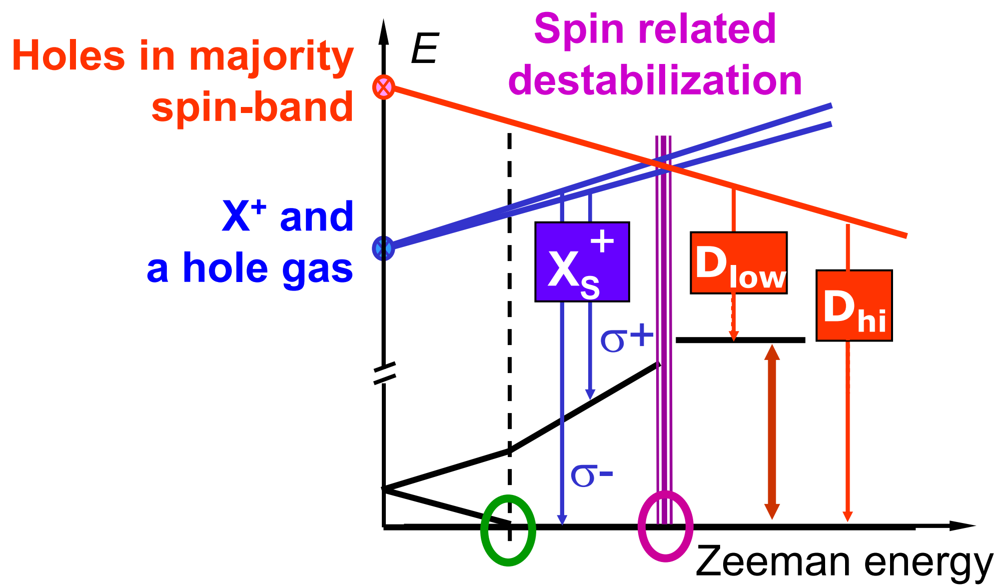


Conclusion

•A novel PL feature: (D_{hi} ,D_{low})



•A mechanism to understand it



•Characteristic energies

- Spin splitting at full gas polarization -- **Hole-hole interactions !**
- X^+ destabilization ------------------------- **Binding energy !**
- Hole gas excitation ----------------------- **Nature of the excitation ?**

•Quantitative understanding:
would need some more work from the theory side …