Magnetic Circular Dichroism vs Excitonic Zeeman Splitting in (Ga,Fe)N

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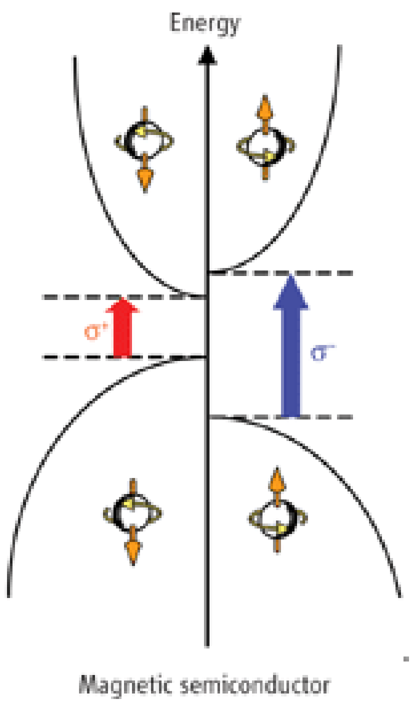
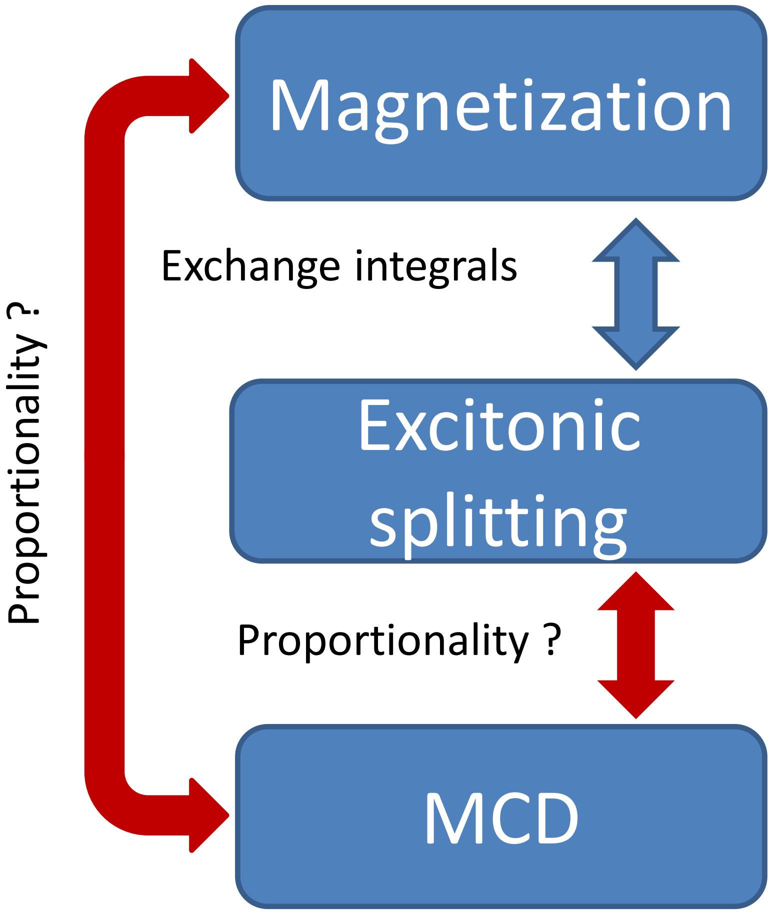
Motivation

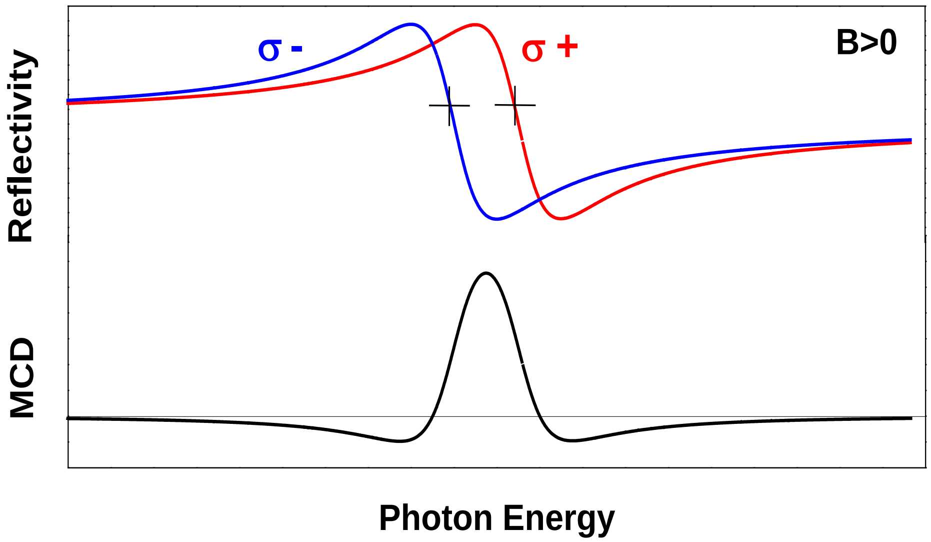
- MCD as a measure of magnetization



K. Ando

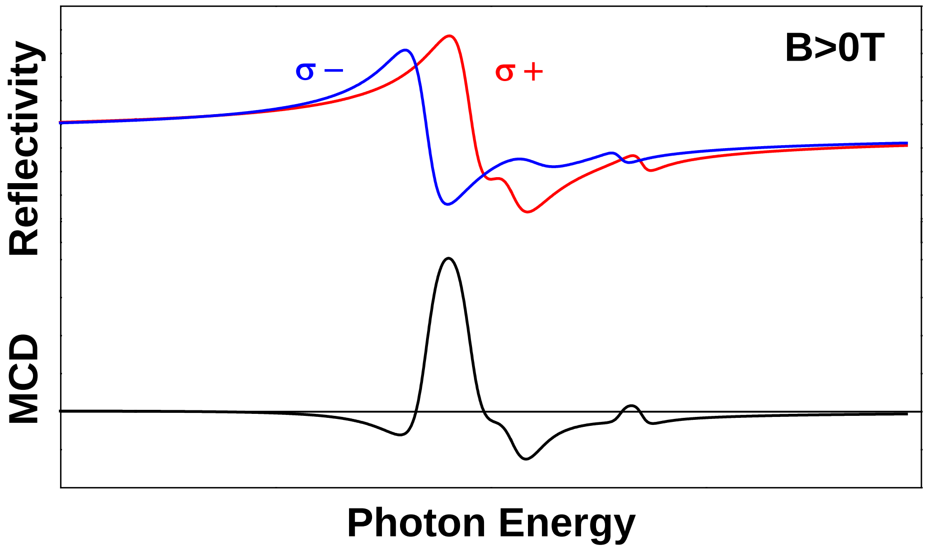


Motivation



- Typical semiconductor:
  - Single exciton transition

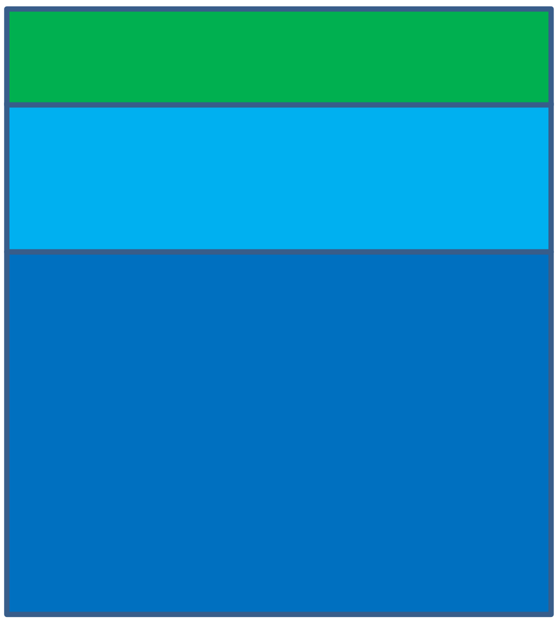
  → straightforward interpretation of MCD



- Wurztite structure DMS
  - Three excitonic transitions
  - Mutually compensating excitonic contributions

→ Interpretation of MCD ?

The sample



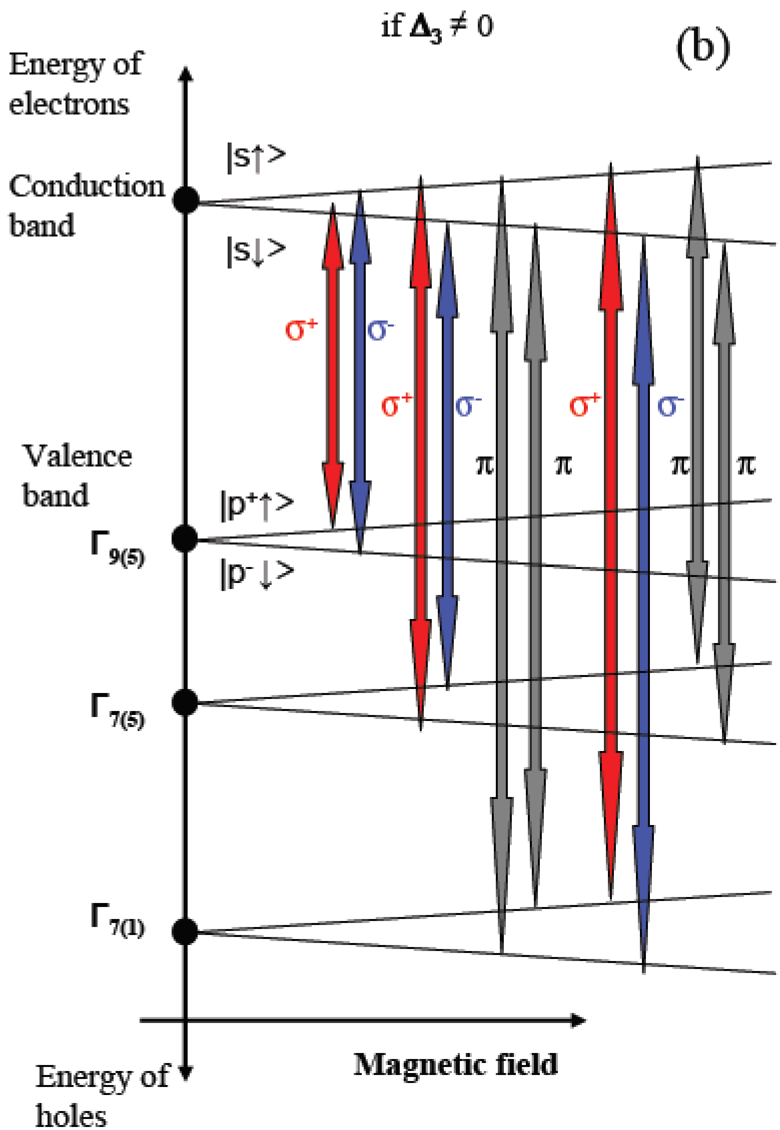
(Ga,Fe)N layer (~ 900 nm), x_{Fe}=0.20%

GaN buffer (1μm)

Sapphire substrate

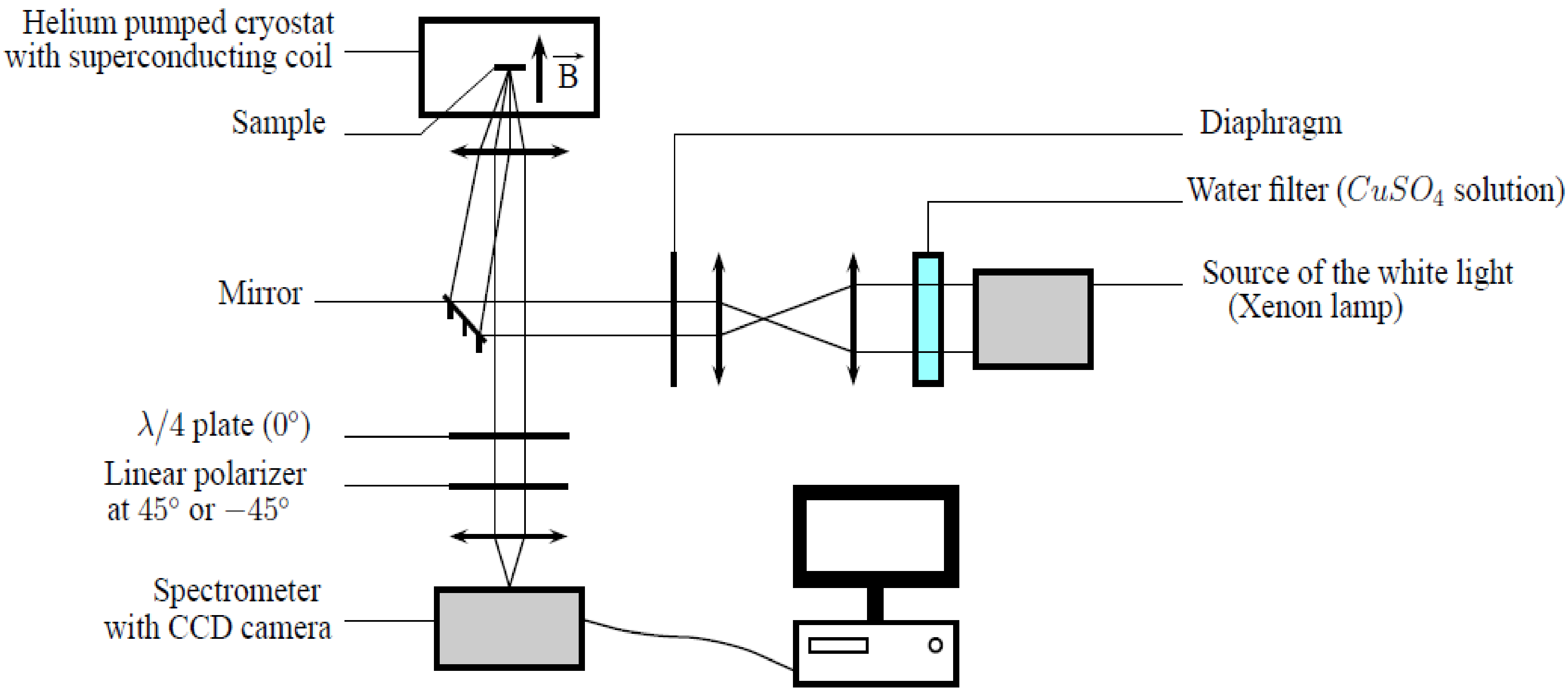
Grown by MOVPE at J.K. University - Linz

Energy diagram

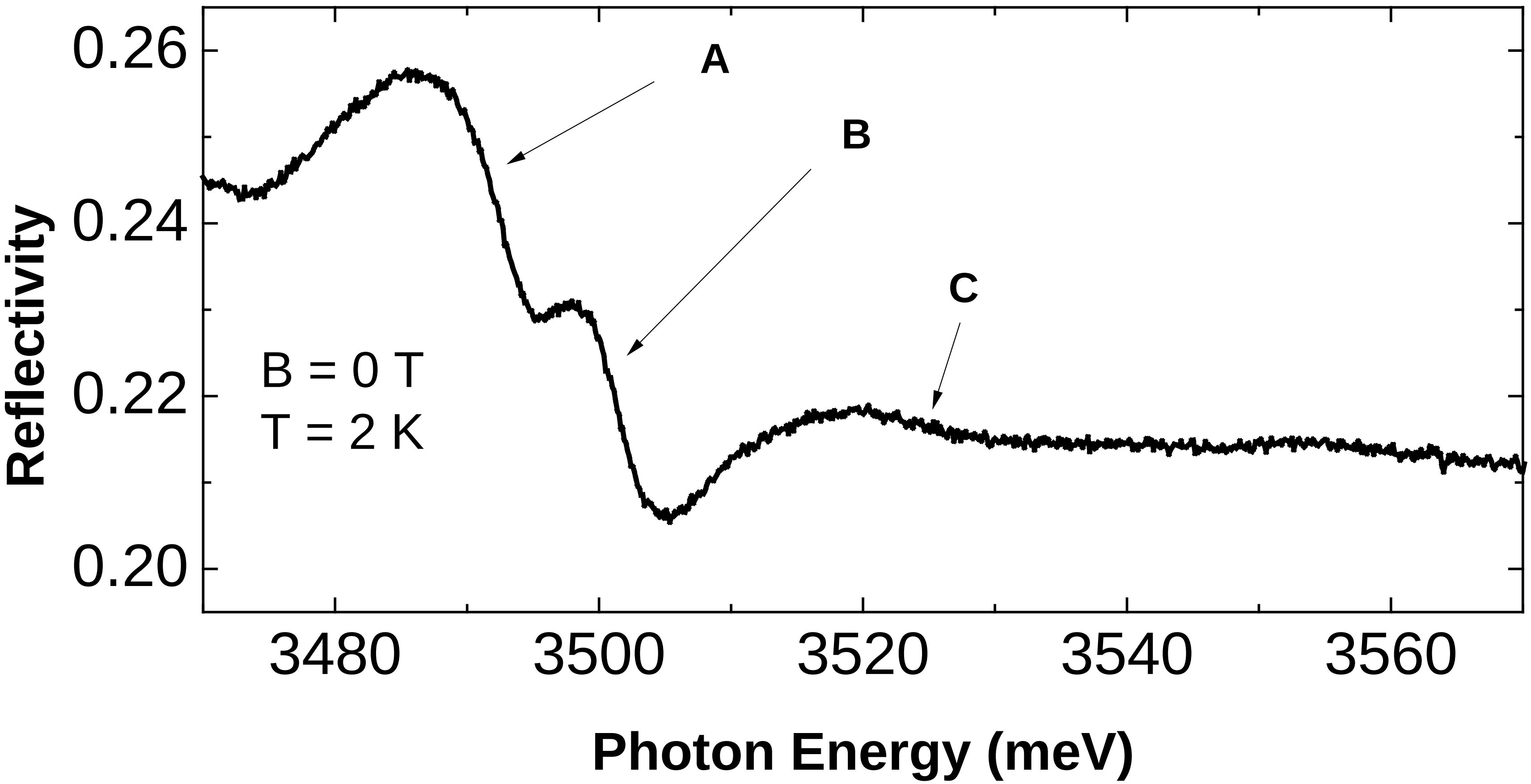


After W. Pacuski – chapt. in ``*Introduction to the Physics of Diluted Magnetic Semiconductors*`` (2010)

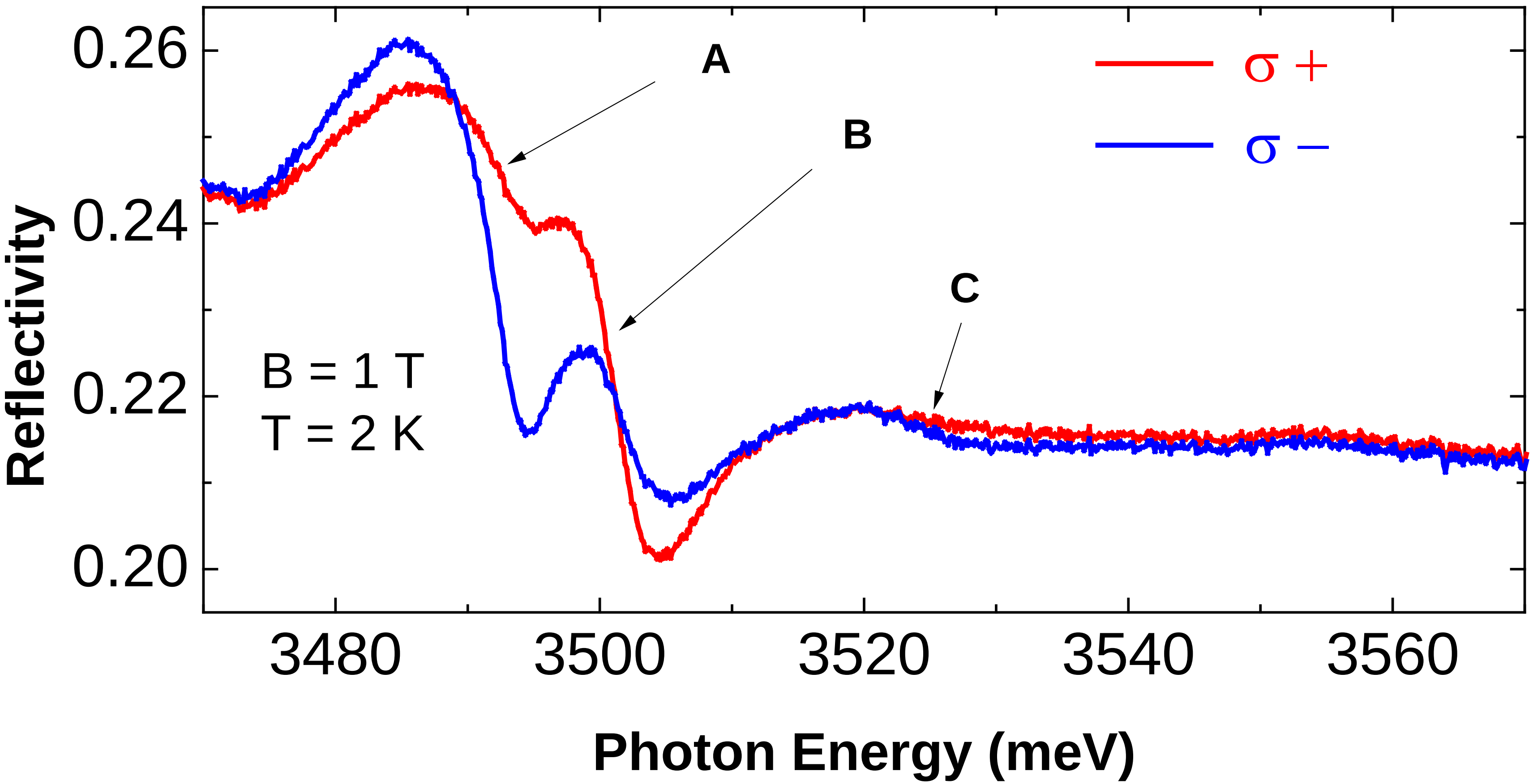
Experimental setup



Reflectivity Measurements



Reflectivity Measurements



Excitons A and B split toward opposite directions in magnetic field

Modelling of the experimental spectra

Contributions to dielectric function ε(ω) from:

Fundamental A, B and C excitonic transitions

Excited states of excitons

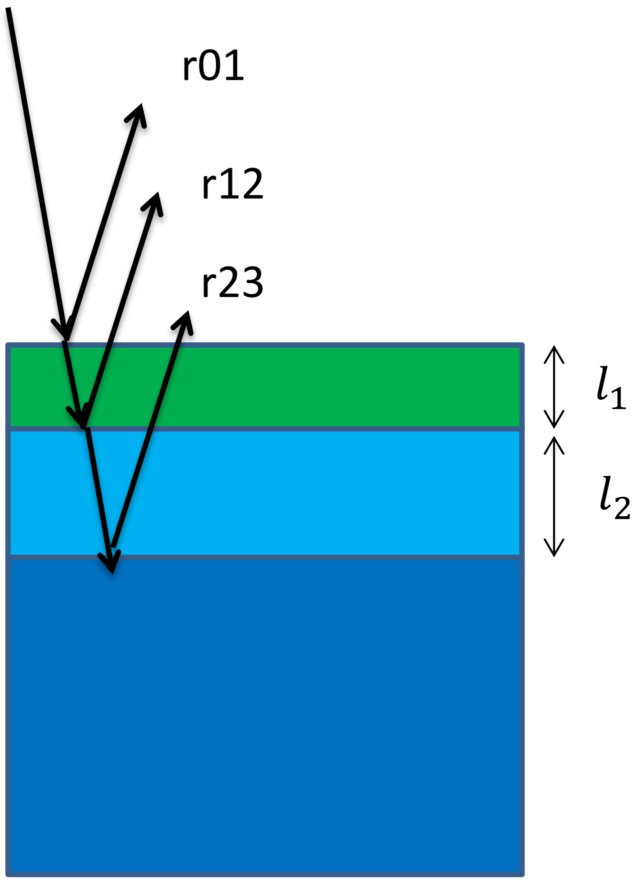
Unbound states

ε(ω)=

$$\varepsilon 0 + \sum_{n=A,B,C} \left(\frac{4\pi\alpha\alpha_{0,n}\omega_n}{\omega^2 n \quad -\omega^2 - i\omega\Gamma_n} + \sum_{j=2}^{\infty} \frac{4\pi\alpha\alpha_{0,n}\omega_{n,j}}{j^3} \frac{{\omega_{n,j}}^2}{{\omega_{n,j}}^2 - \omega^2 - i\omega\Gamma_{n,j}} + \varepsilon_{n,unbound} \right)$$

Modelling of the experimental spectra

Fabry Perot interferences in a multi layered structure:



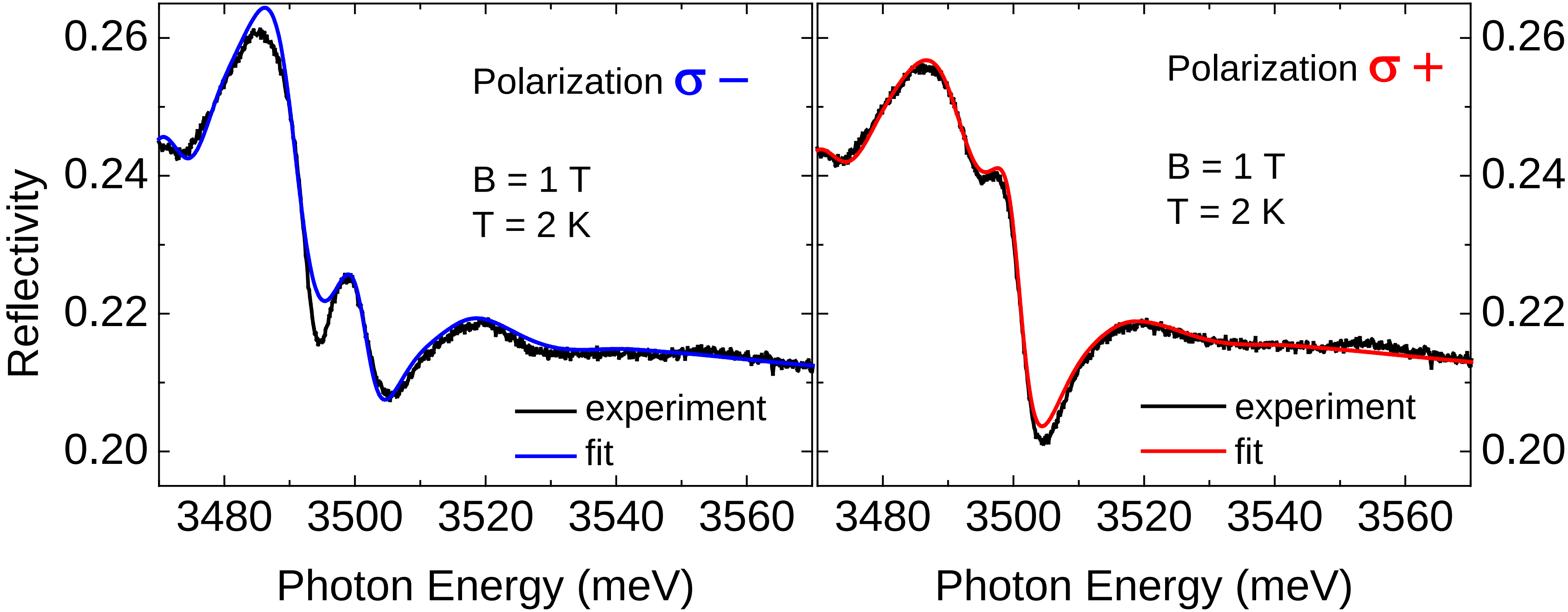
$$r = \frac{r_{12} + r_{23}e^{2i\beta 2}}{1 + r_{12}r_{23}e^{2i\beta 2}}$$

With:

$$r_{i,i+1} = \frac{\sqrt{\varepsilon_i} - \sqrt{\varepsilon_{i+1}}}{\sqrt{\varepsilon_i} + \sqrt{\varepsilon_{i+1}}}$$

$$\beta_i = \frac{\omega}{c} l_i \sqrt{\varepsilon_i}$$

Fit of the reflectivity spectra



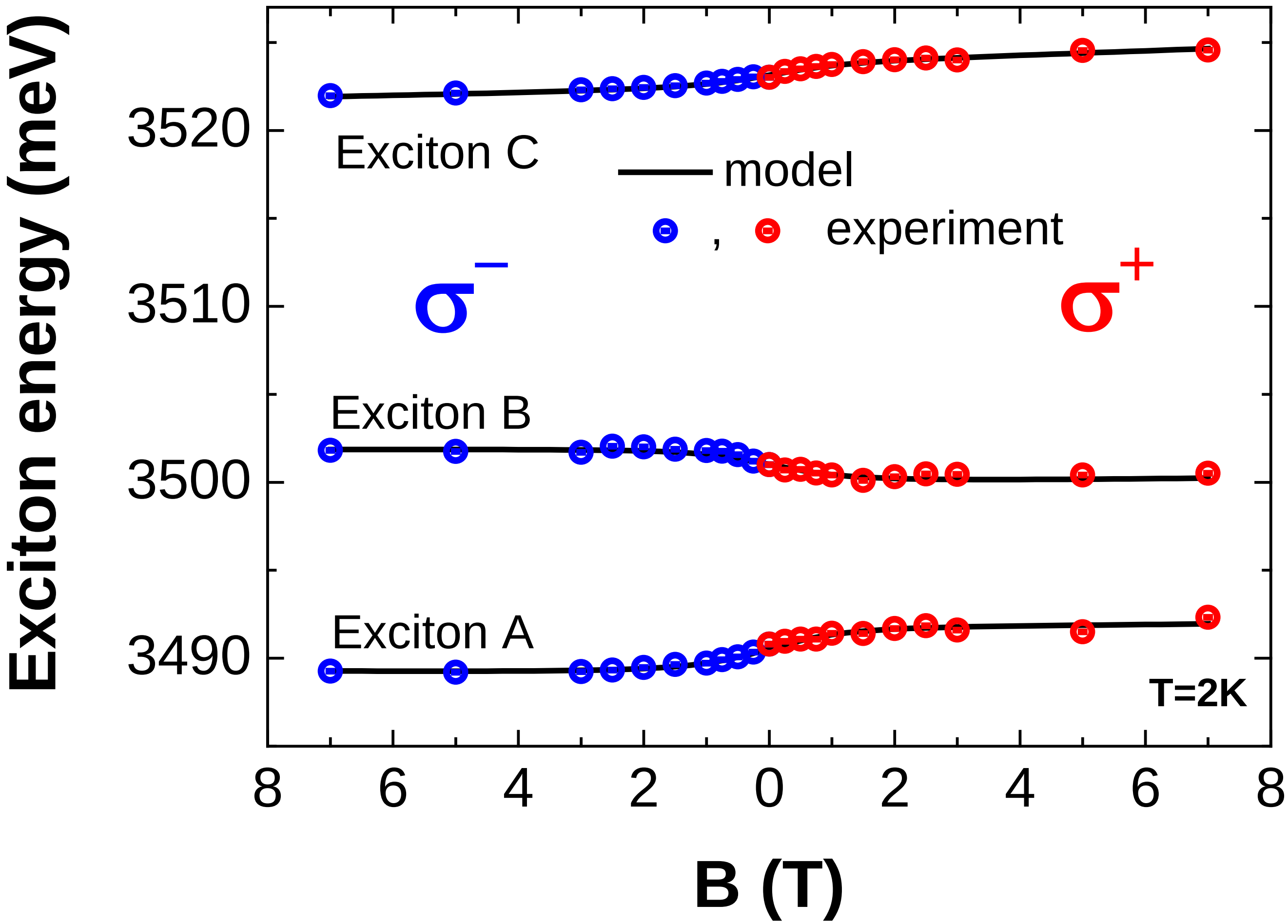
Successful description with the assumed model

Excitonic splitting vs magnetic field

- Hamiltonian: $H = E_0 + H_v + H_{e\text{-}h} + H_{sp\text{-}d} + H_z + H_{dia}$

  - E_0 → Energy gap
  - H_v → Valence band (s-o + crystal field)
  - $H_{e\text{-}h}$ → Electron- hole interaction within the exciton
  - $H_{sp\text{-}d}$ → Exchange interaction Between Fe ions and carriers
  - H_z → Linear Zeeman splitting
  - H_{dia} → Diamagnetic shift

Excitonic splitting vs magnetic field



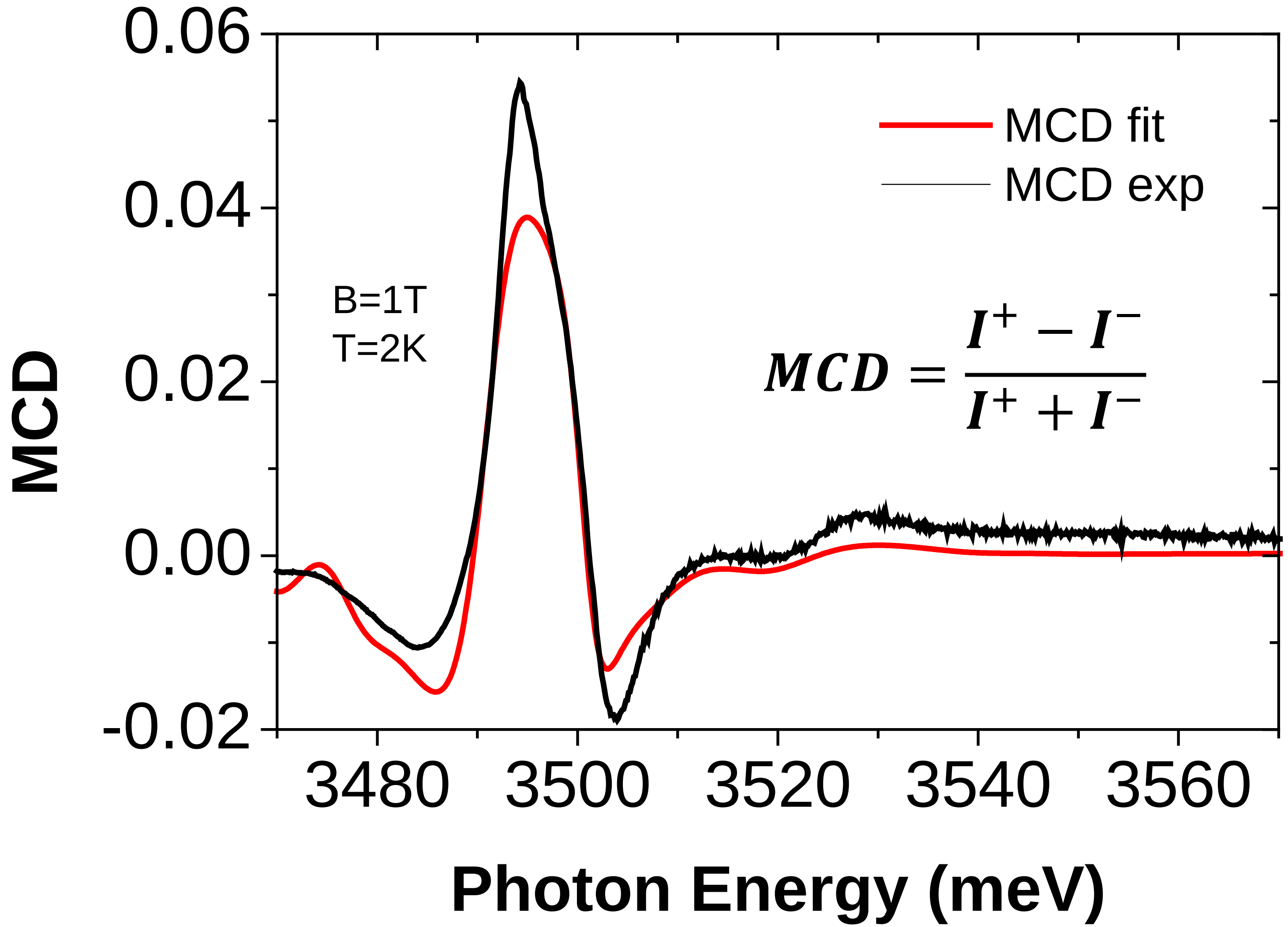
Apparent exchange constants determined from the fit :

Conduction band: $N_0\alpha^{(app)}$ = - 0.05±0.1 eV => **surprisingly low**

Valence band: $N_0\beta^{(app)}$ = + 0.5±0.1 eV => **unexpected sign**

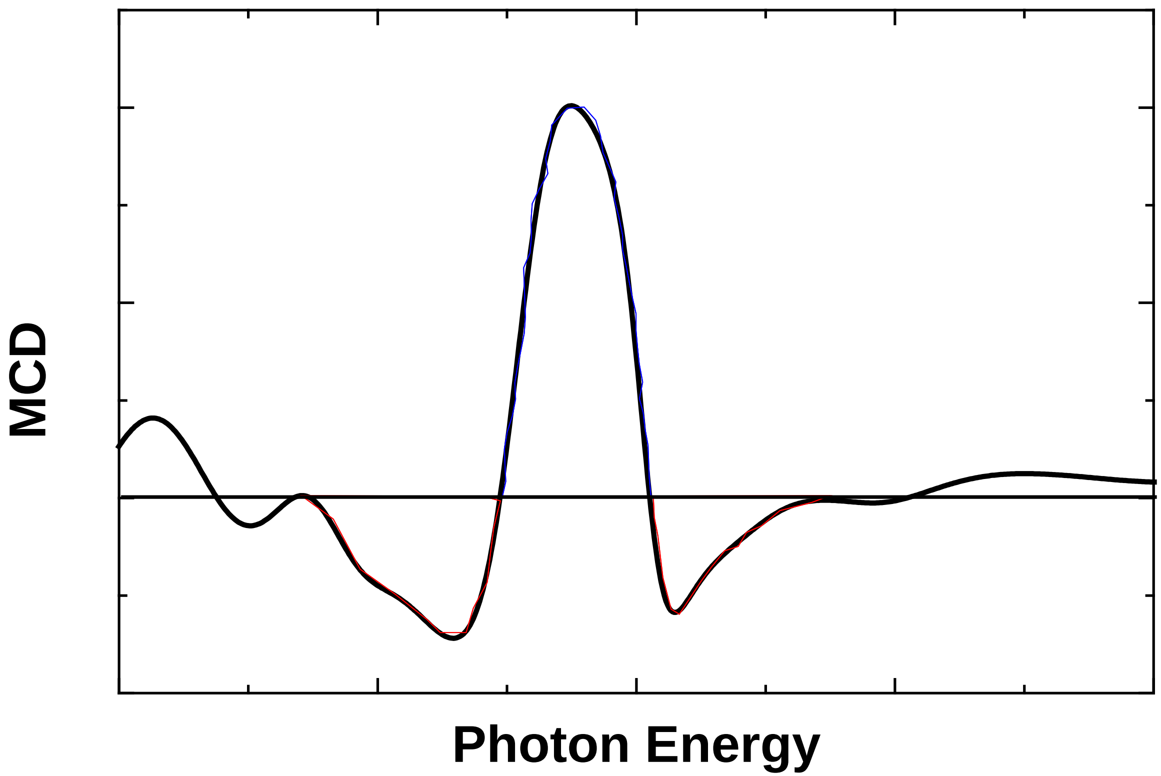
T.Dietl PRB 2008 – W.Pacuski et al. PRL 2008

MCD based on experimental and fitted spectra



MCD and magnetization

- What parameter of the MCD spectrum is linearly proportional to the excitonic splitting?



- Integrated signal?

MCD and magnetization

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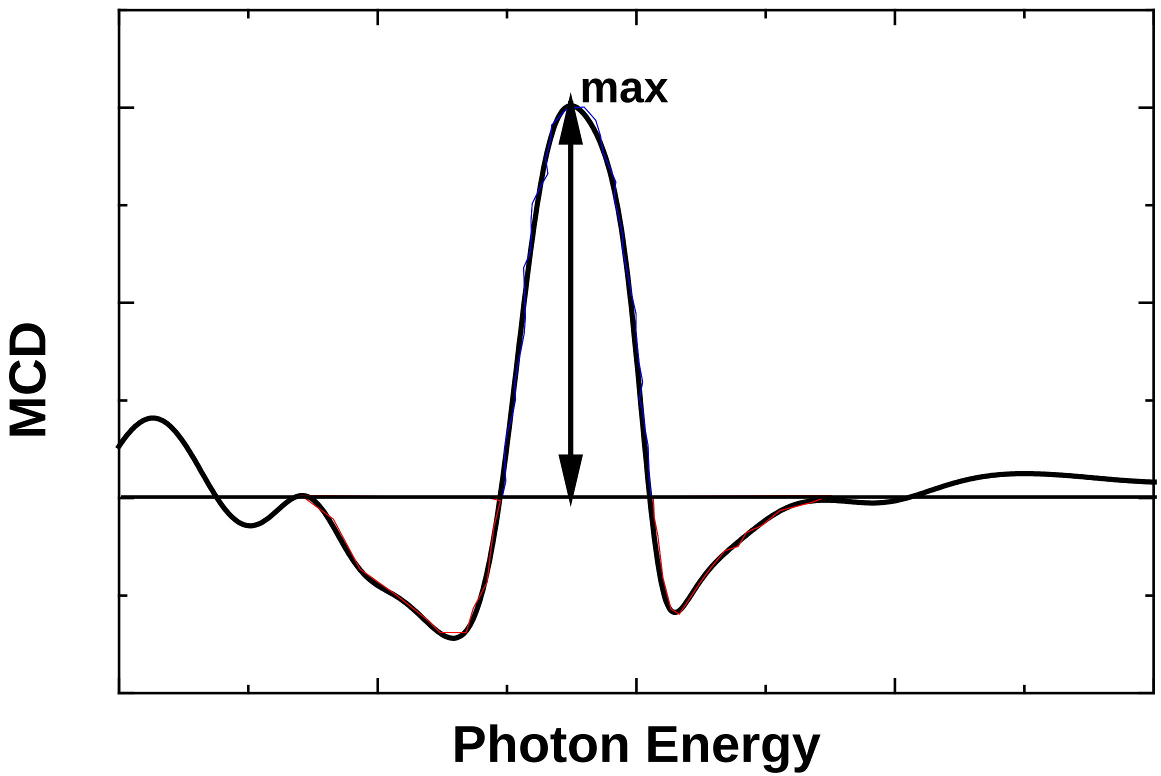

- Integrated signal?
- Amplitude (max)?

MCD and magnetization

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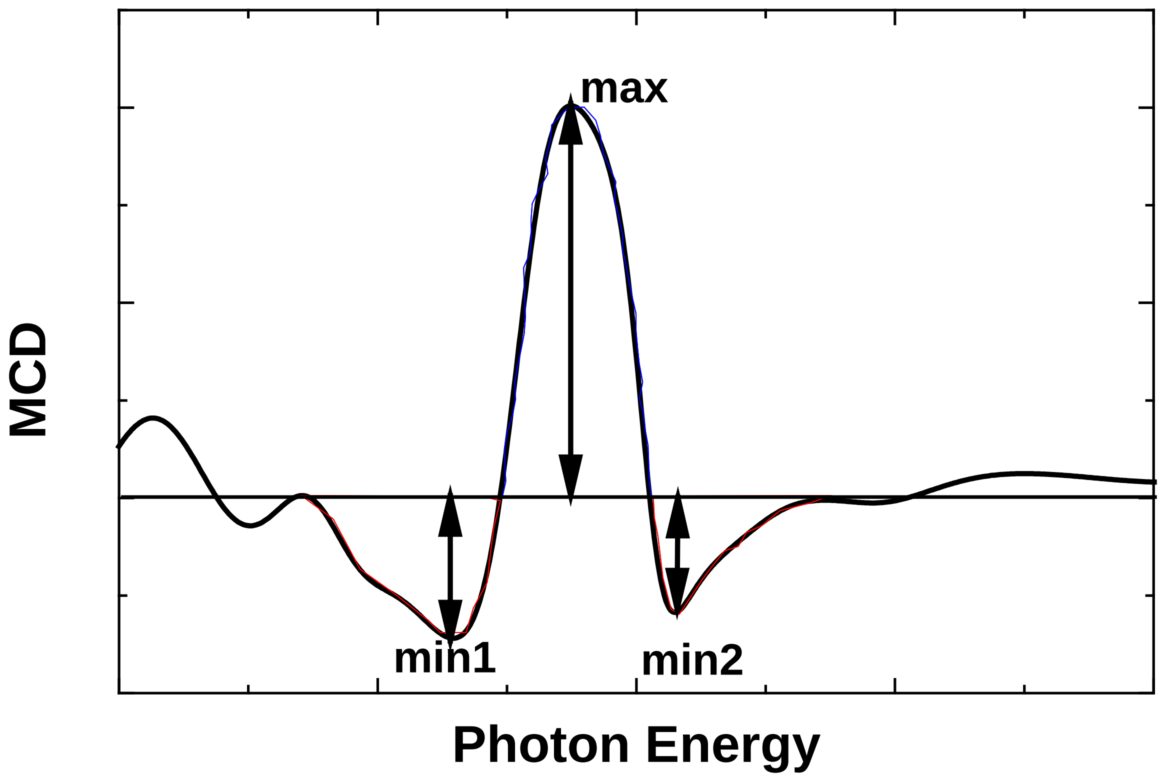
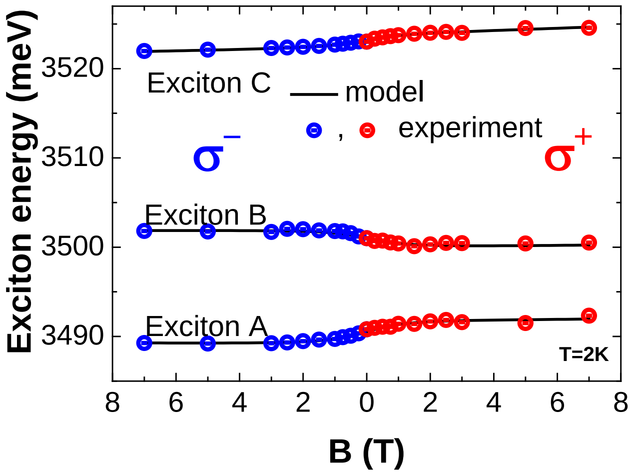


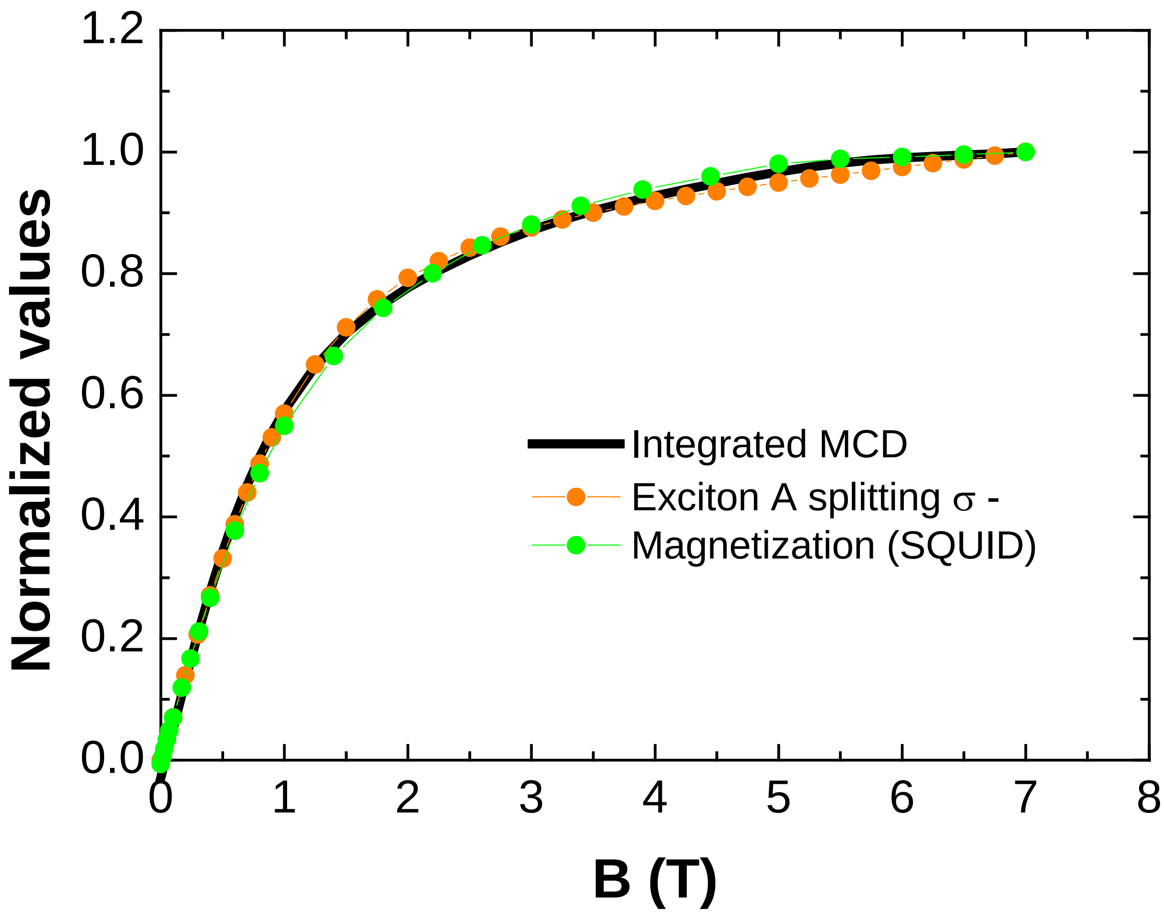
- Integrated signal?
- Amplitude (max)?
- Sum of extrema (max – min1 – min2)?

Comparison: integrated MCD, excitonic splitting and magnetization (SQUID)



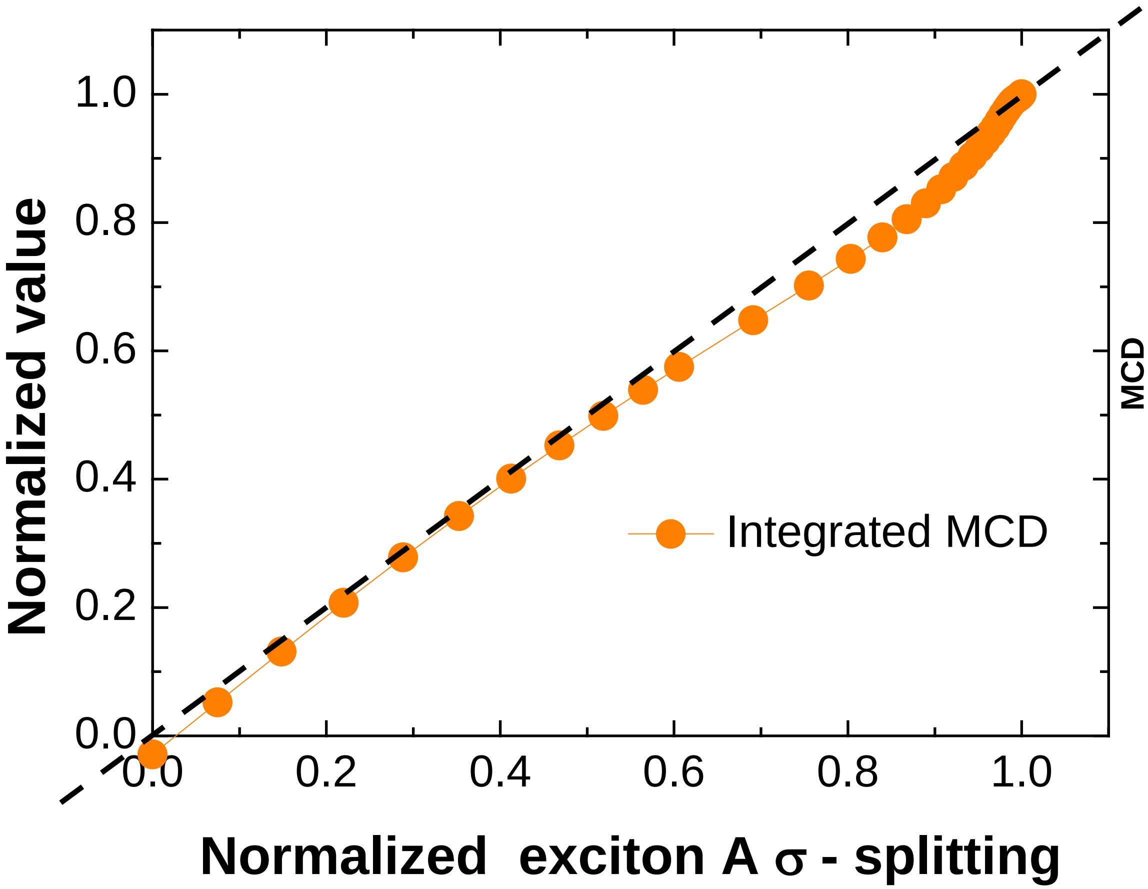
Normalization:

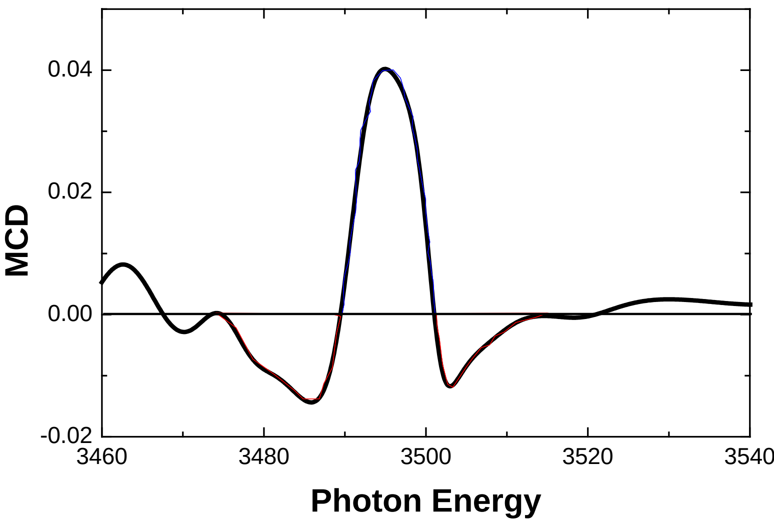
$$\frac{value\ (B)}{value\ (B = 7\ T)}$$



Brillouin function shape and good agreement between all three quantities

Correlation: MCD – exciton A σ - splitting





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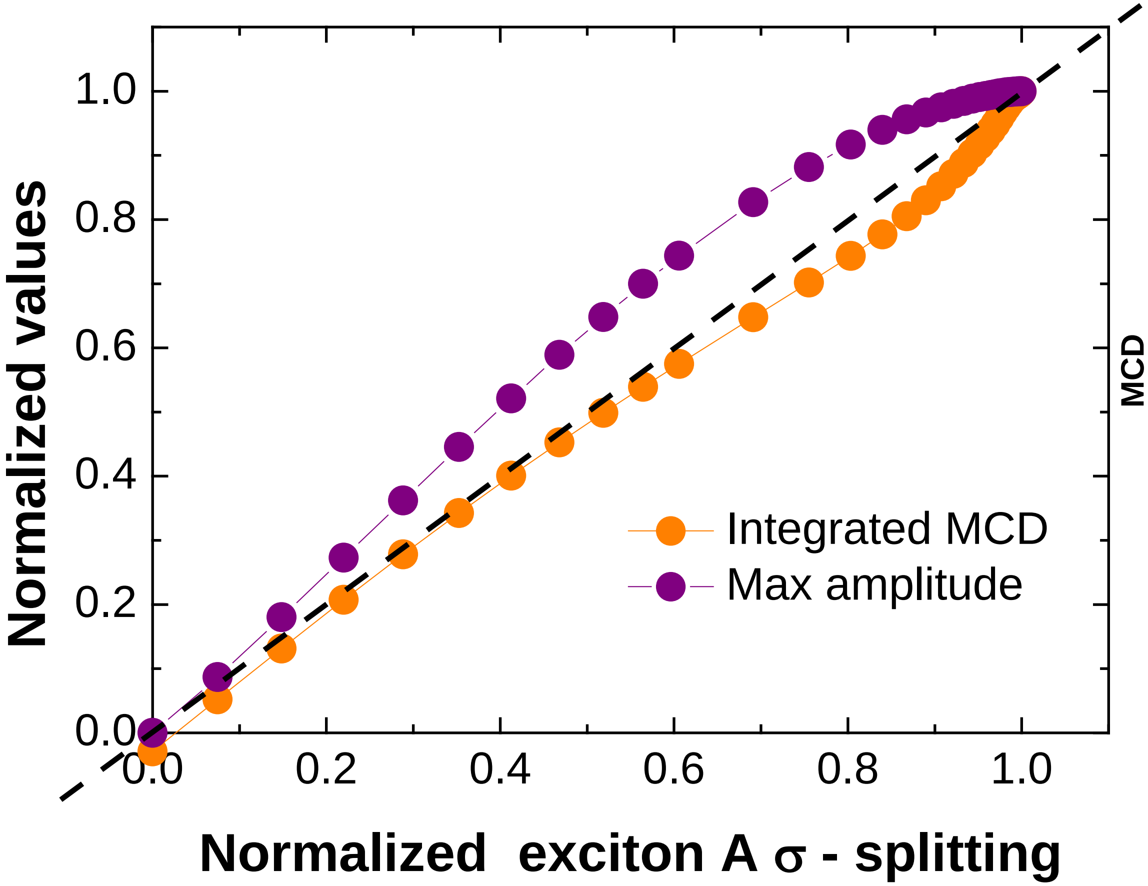
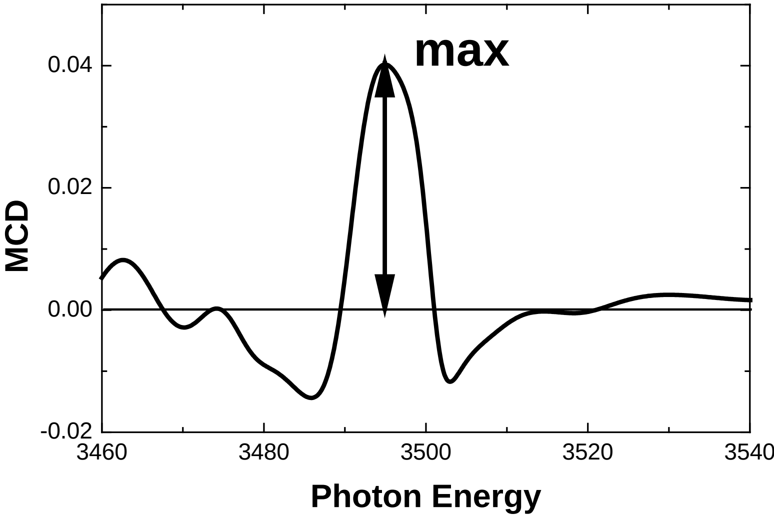
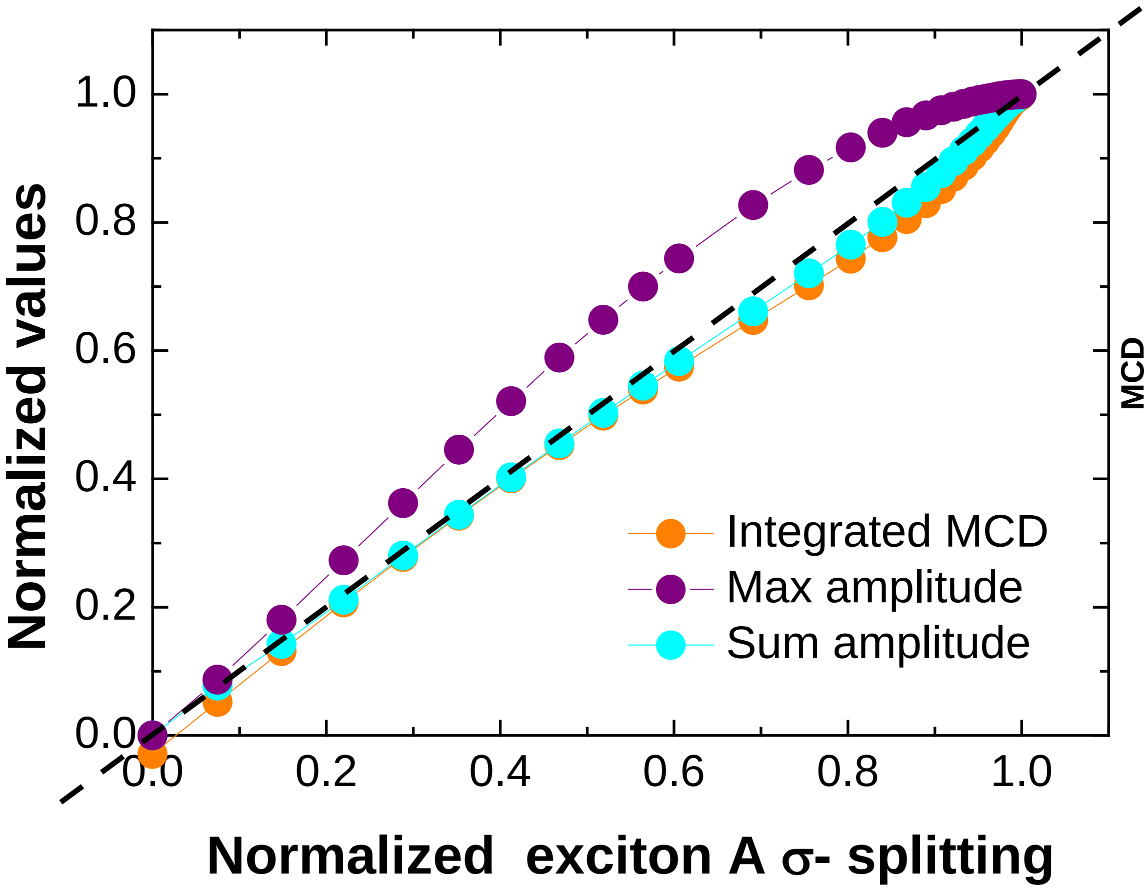
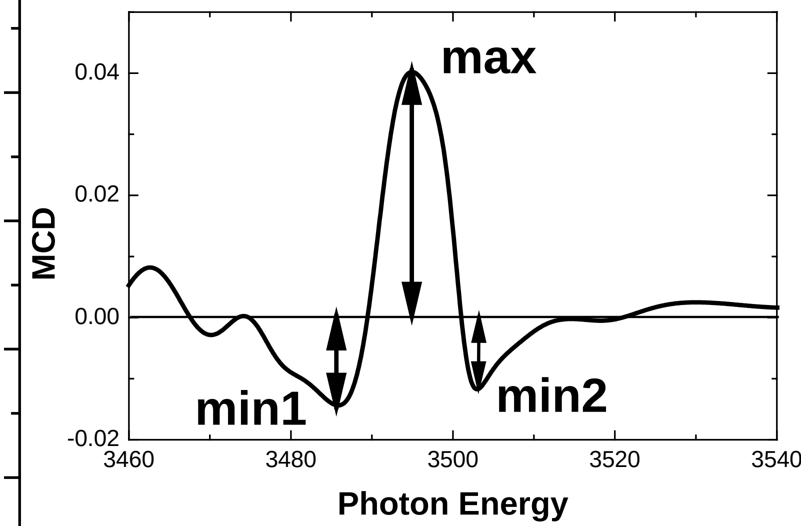




Correlation: MCD – exciton A σ - splitting

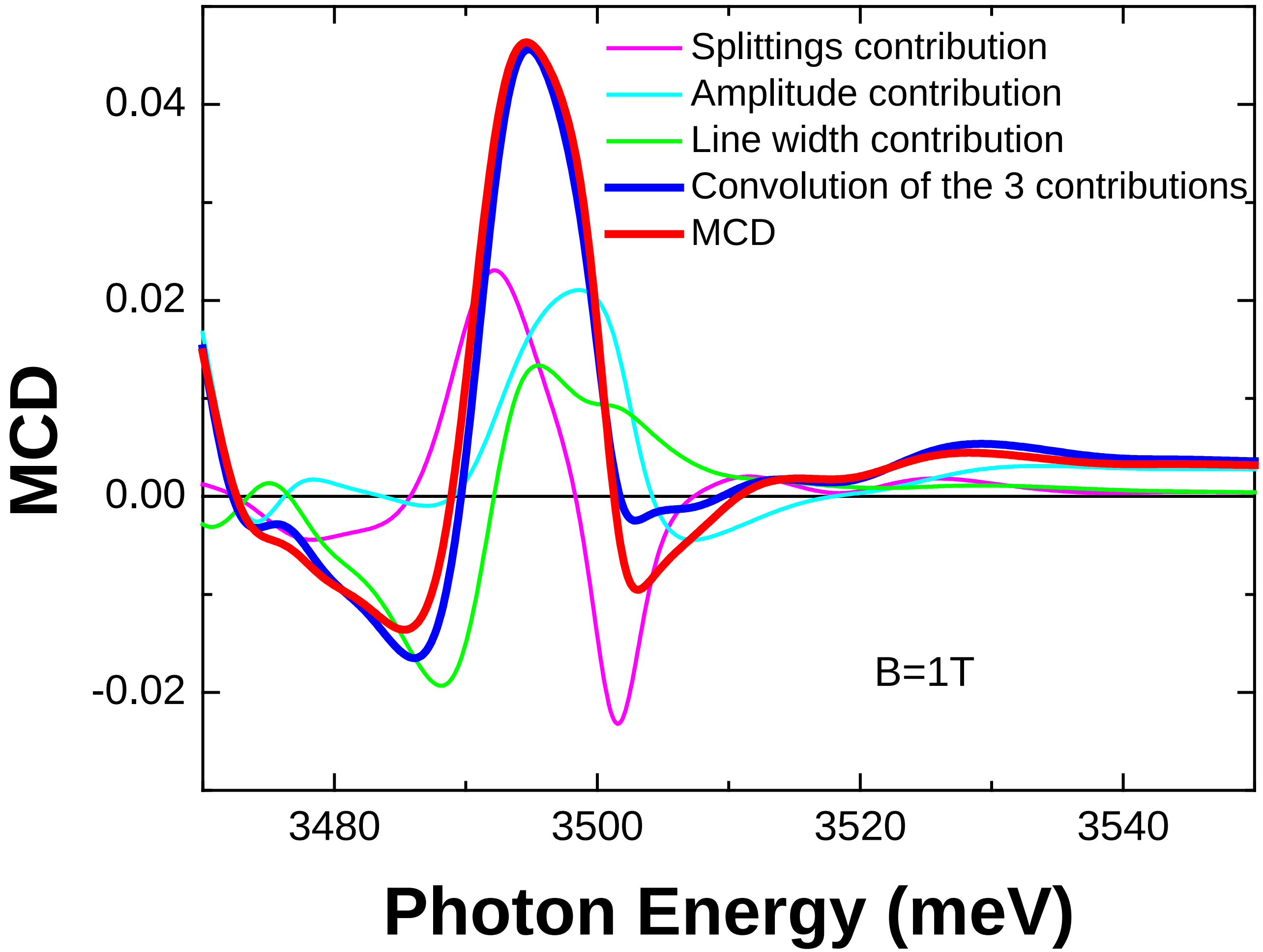




Splitting of Exciton A σ- (magnetization) well correlated with

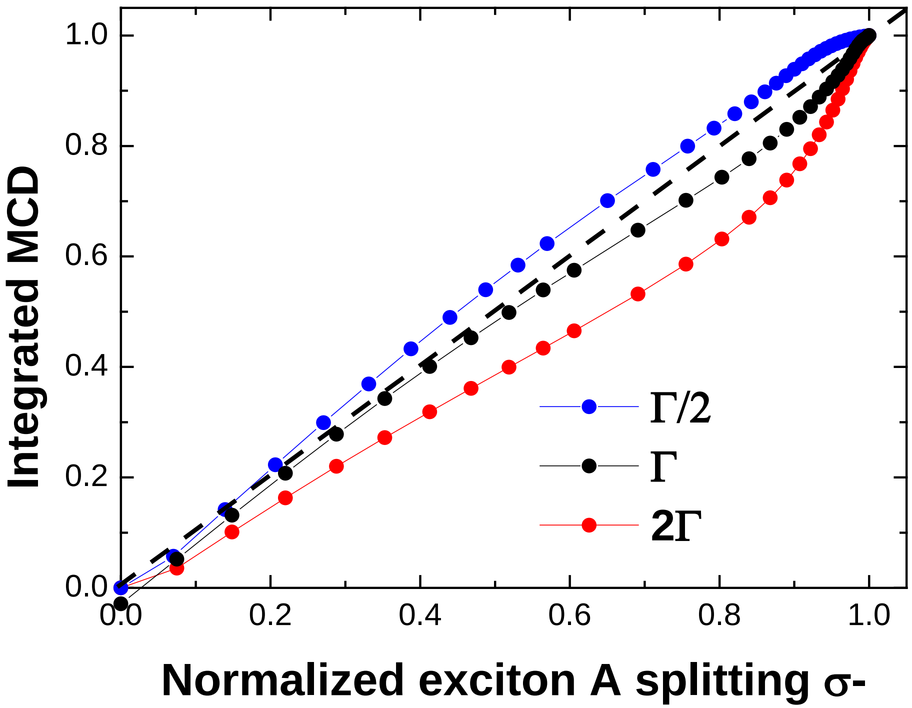
- **integrated MCD**
- **and sum of extrema**

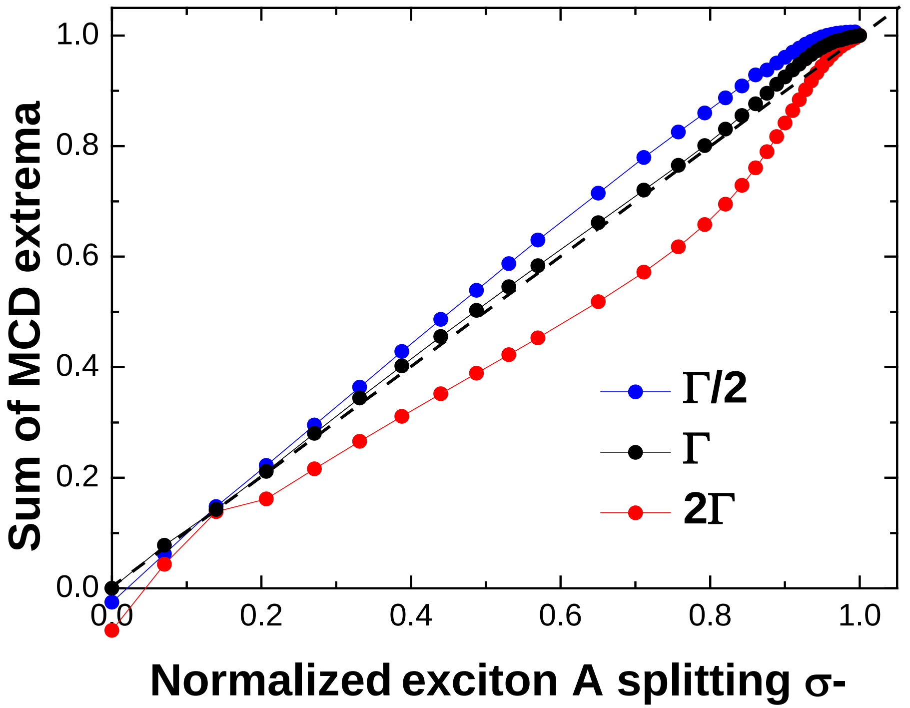
Separate contributions to MCD



- Each parameter of the excitonic transition contributes to MCD
- Separate contributions sum to result in MCD spectrum

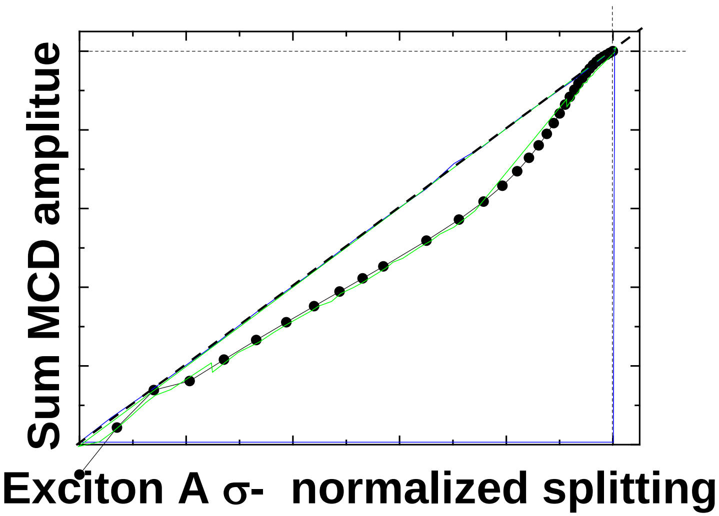
Influence of the excitonic width Γ





Similar dependence in both cases: integrated MCD and sum of MCD extrema.

Influence of the exciton width Γ

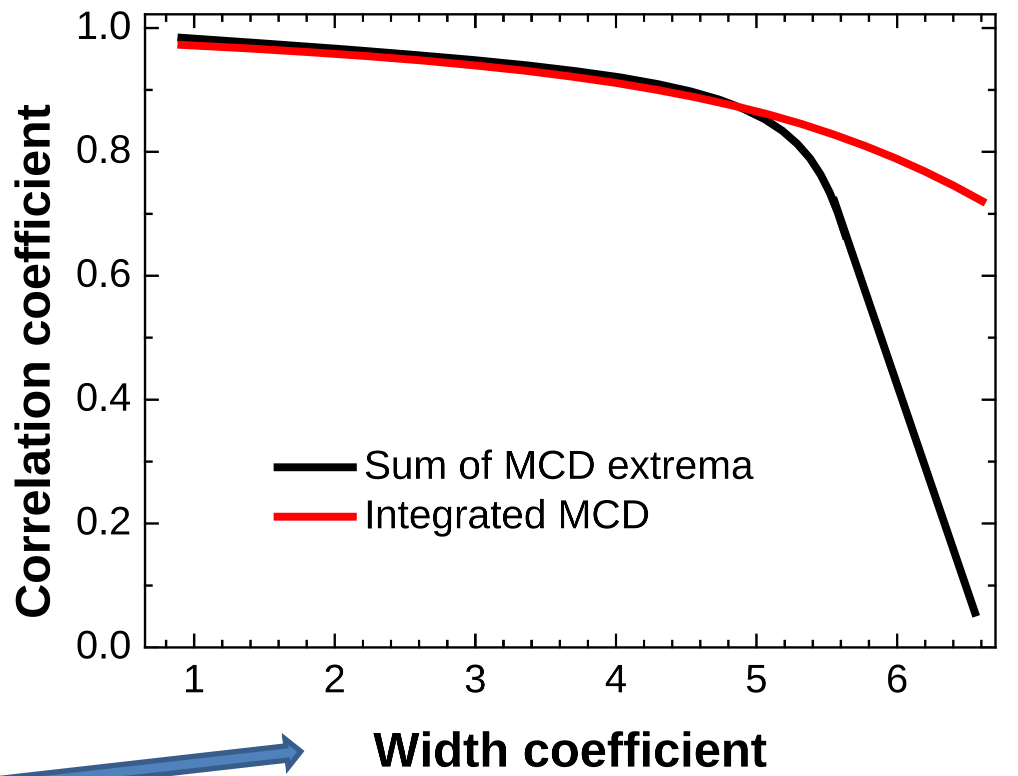


Correlation coefficient:

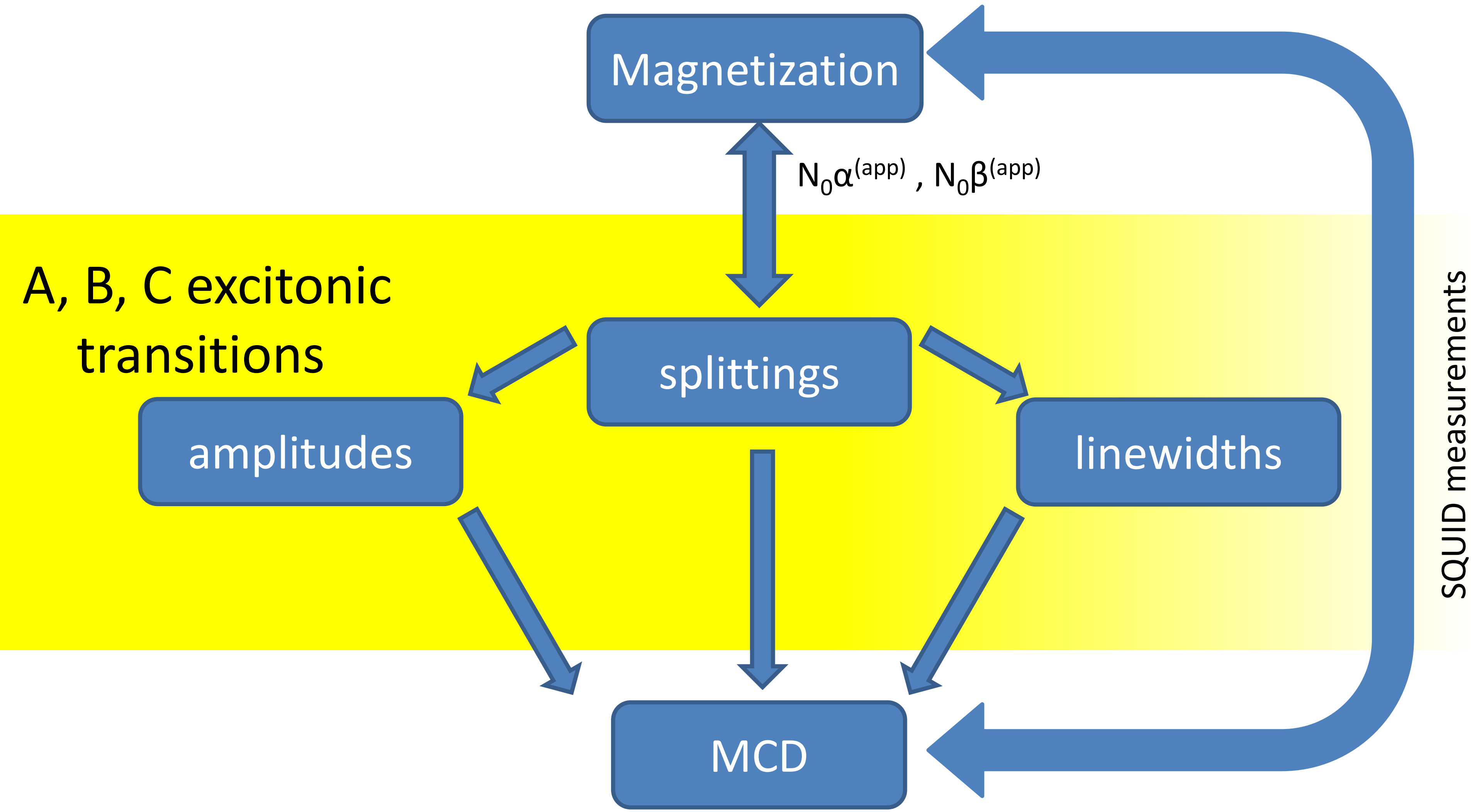
$$\rho = 1 - \frac{\sum \sqrt{(x-y)^2}}{\sum x}$$

Width coefficient:

$$W = \left(\frac{\Gamma_A}{E_{A-B}}\right)_{B=0T}$$



- **MCD not correlated to magnetization when exciton linewidth increased**
- **A better magnetization description with Integrated MCD**



Magnetization
N0α(app) , N0β(app)
A, B, C excitonic transitions
splittings
amplitudes
linewidths
MCD
SQUID measurements

Conclusions

- Reflectivity and excitonic splitting of excitons in (Ga,Fe)N succesfully described
- Determination of $N_0\alpha^{(app)}$ = -0.05 ± 0.1 eV and $N_0\beta^{(app)}$ = +0.5 ± 0.1 eV
- Justification of magnetization description by MCD in the case of wurtzite (Ga,Fe)N
- A crucial parameter deciding on the suitability of the description: exciton width