Spin dynamics in Microcavities

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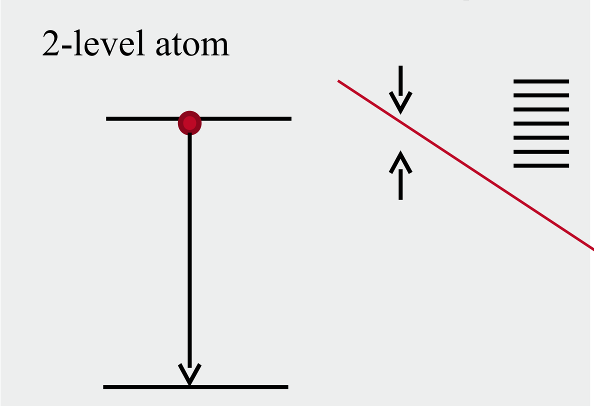
Outline

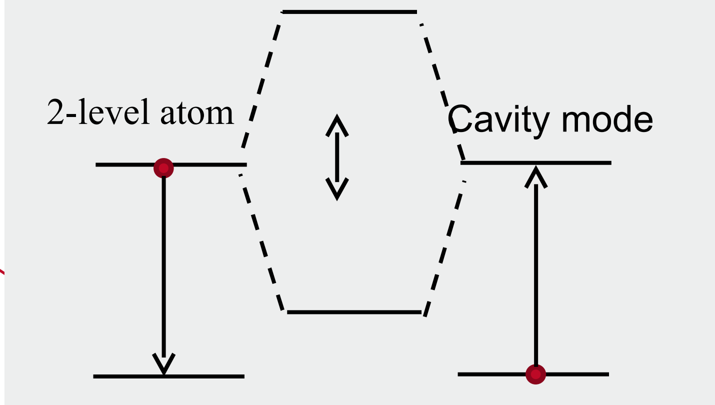
Vacuum field Rabi oscillation

Atom in free space



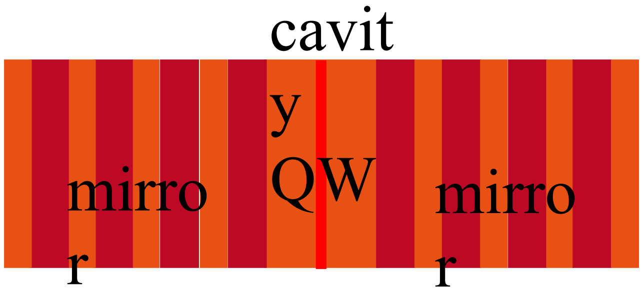
Spontaneous emission

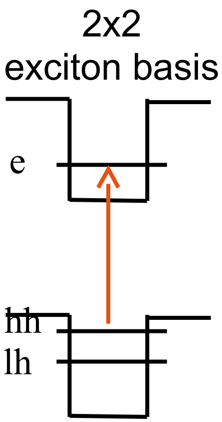
Atom in cavity

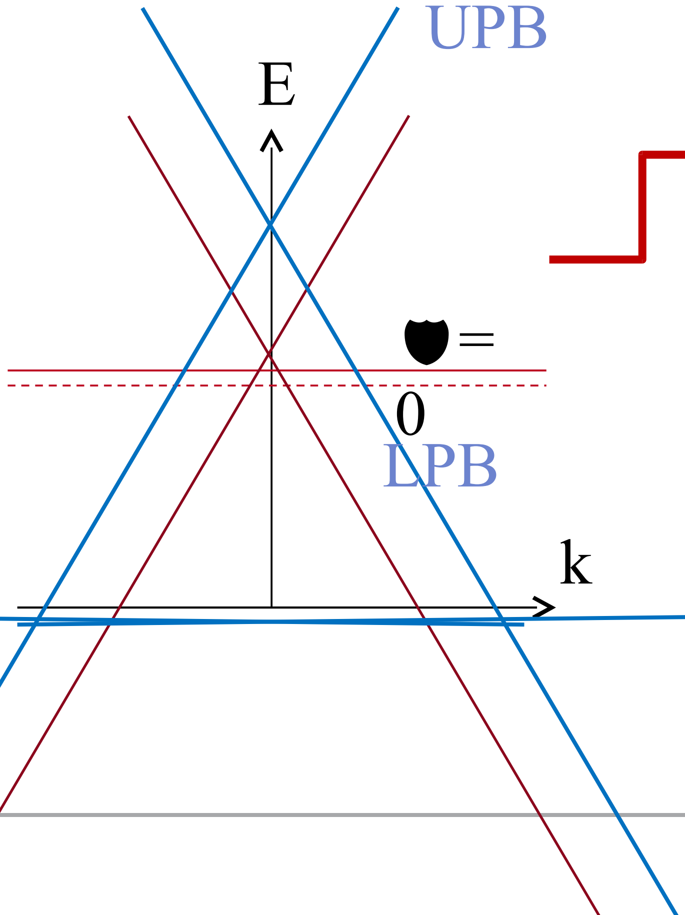


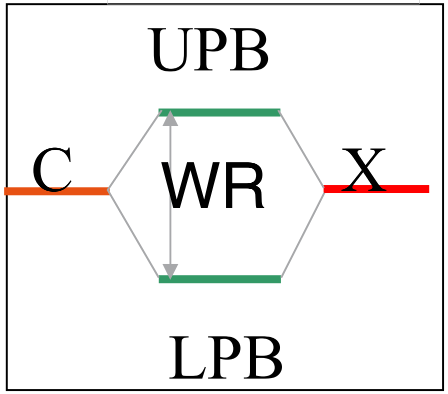
Vacuum field Rabi oscillation

Microcavity in the strong coupling regime

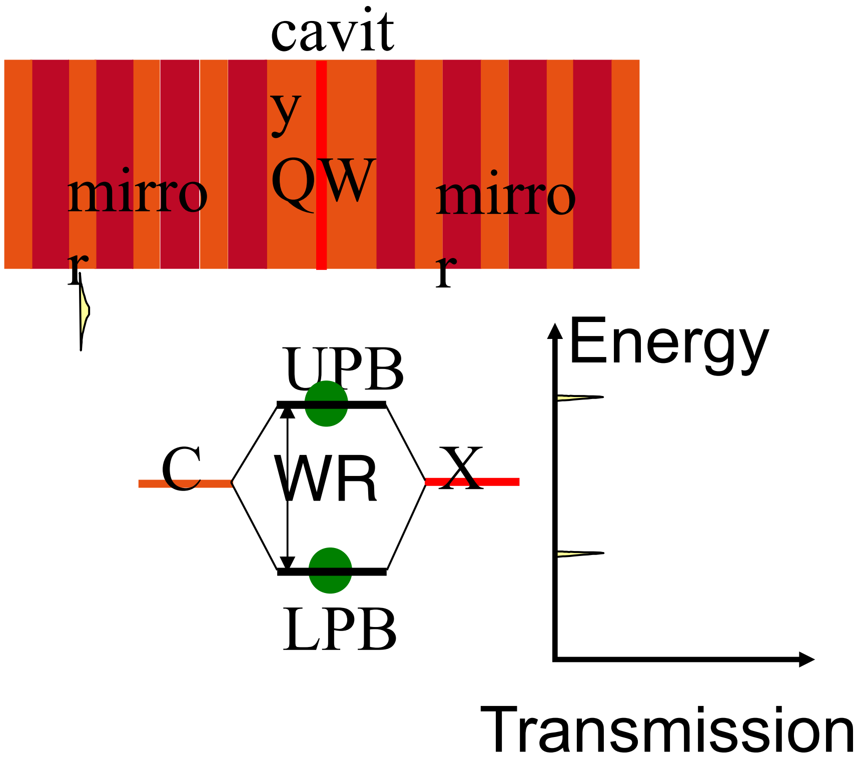




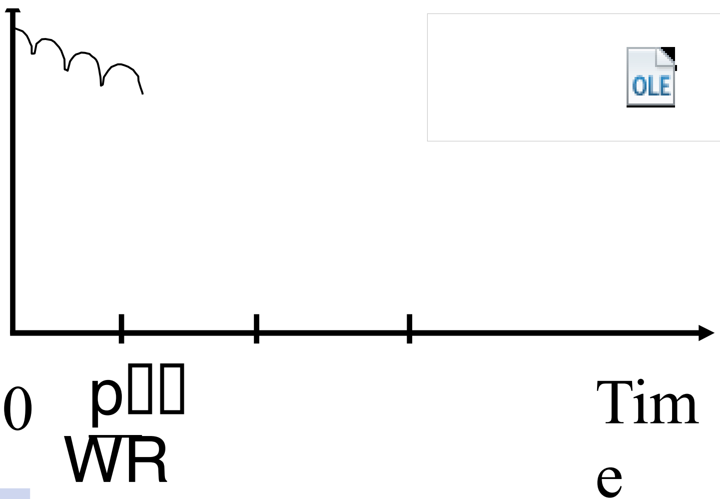


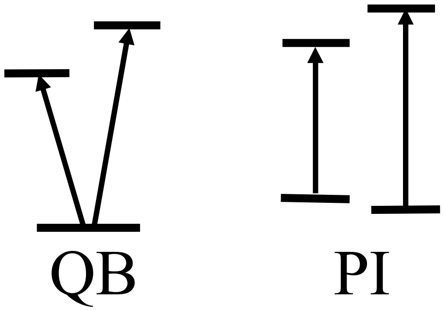


QW microcavity : time- resolved transmission of the light



Linear transmission

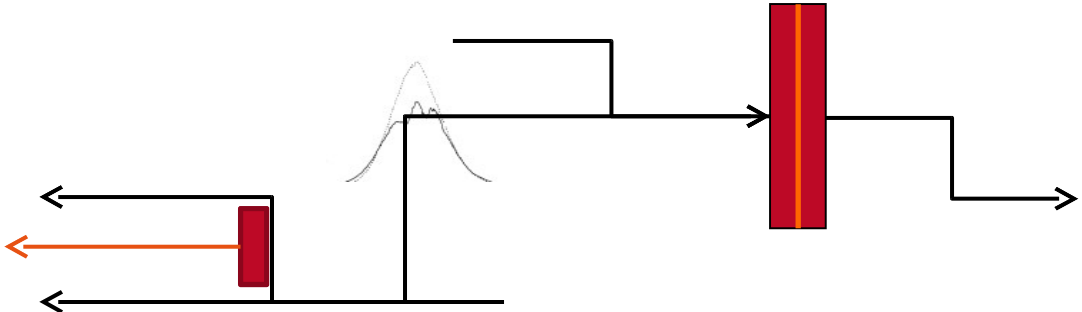




These oscillations can results either from polarization interference (PI) in the detector, or from quantum beats (QB) but cannot be distinguished in linear optics

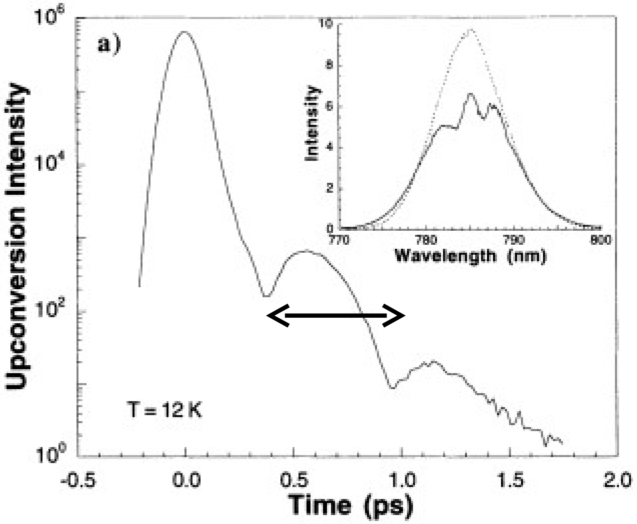
QW microcavity : time- resolved emission

Norris et al, PRB 1994

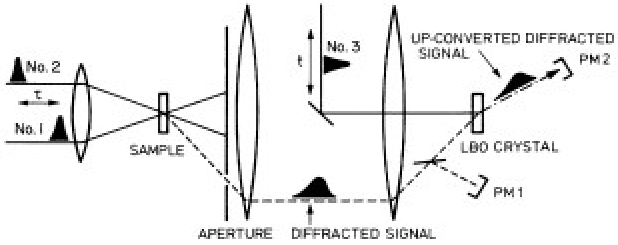


pump spectrum

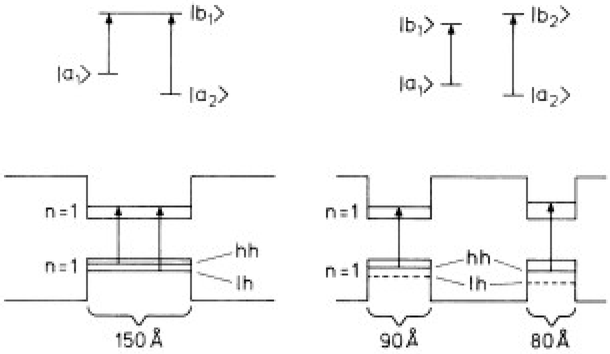
probe



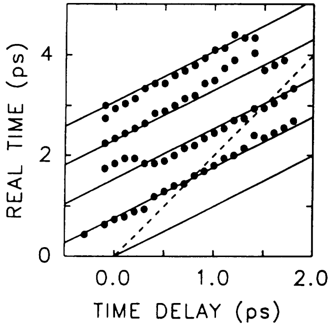
Distinction between QB and PI by time-resolved FWM



M. Koch et al, PRB (1993)
Two-pulse photon echo experiment

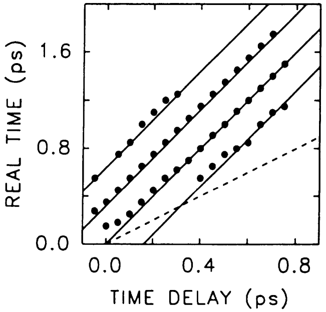


QB



maxima at t=t+nTB

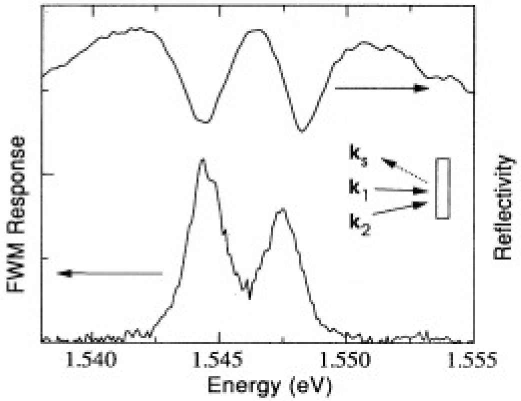
PI

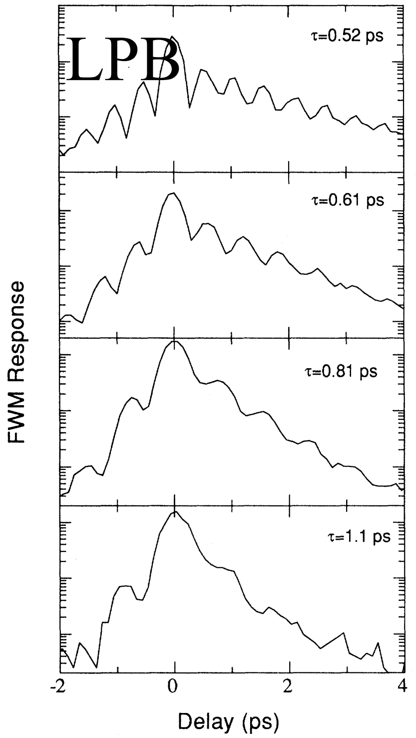


maxima at t=2t+nTB

M. Koch et al, PRL **69**, 3631 (1992)

Spectrally resolved FWM: GaAs-based microcavity



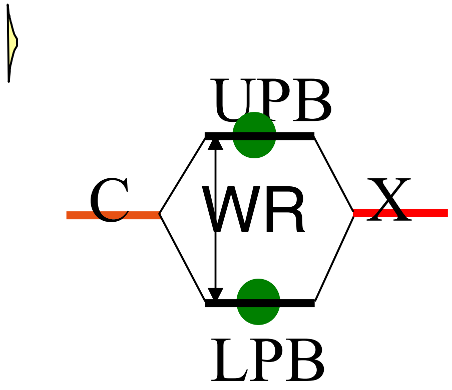


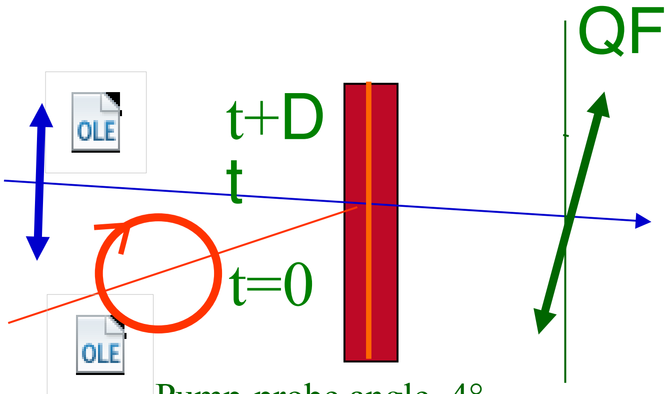
Spectral filtering of the signal prevents PI effects ☾ QBs are observed

QBs are observed even at large detunings: nonlinear response is due to excitonic part of the wavefunction

Wang et al, PR B **51**, 14713 (1994)

Time-resolved Faraday rotation

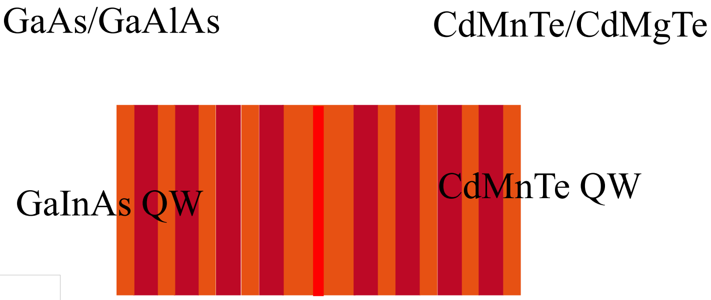




Pump-probe angle~4°

Samples

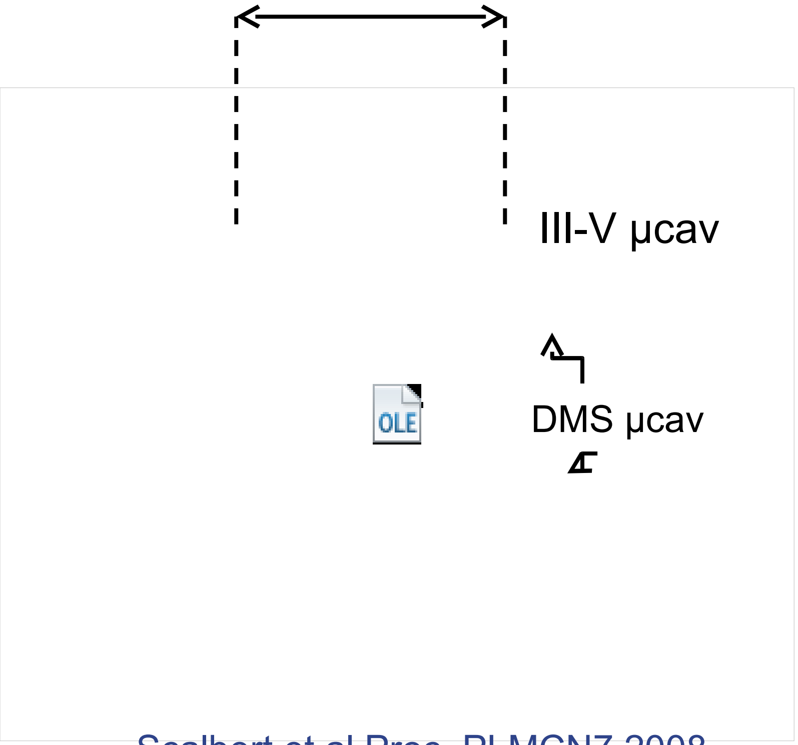
l/2 cavity



sample	QW	Lw (nm)	WR (meV)	Q	tc (ps)	TR (ps)
M1025	CdMn5%Te	7	6	400	0.25	0.6
M992	CdMn0.7%Te	6	10	400	0.25	0.4
11G20	GaIn5%As	8	3.5	2500	1.8	1.1

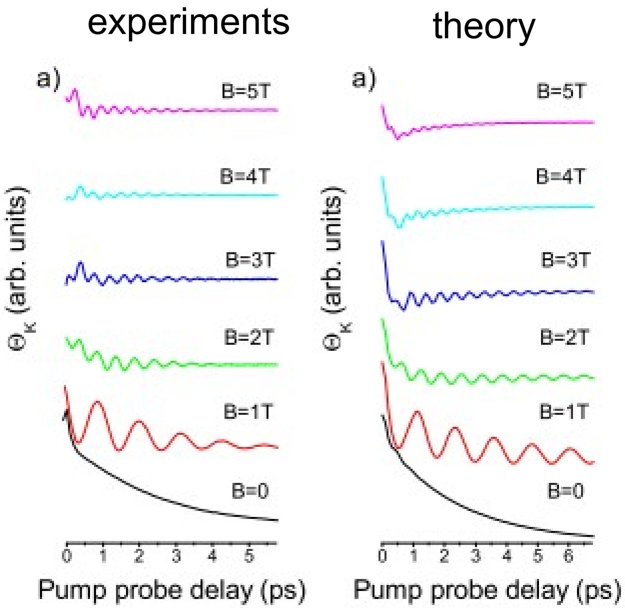
GaInAs MC : J. Bloch, LPN (Paris)
CdMnTe MC : R. André, LSP (Grenoble)

Spectrally integrated TRFR



Scalbert et al Proc. PLMCN7 2008

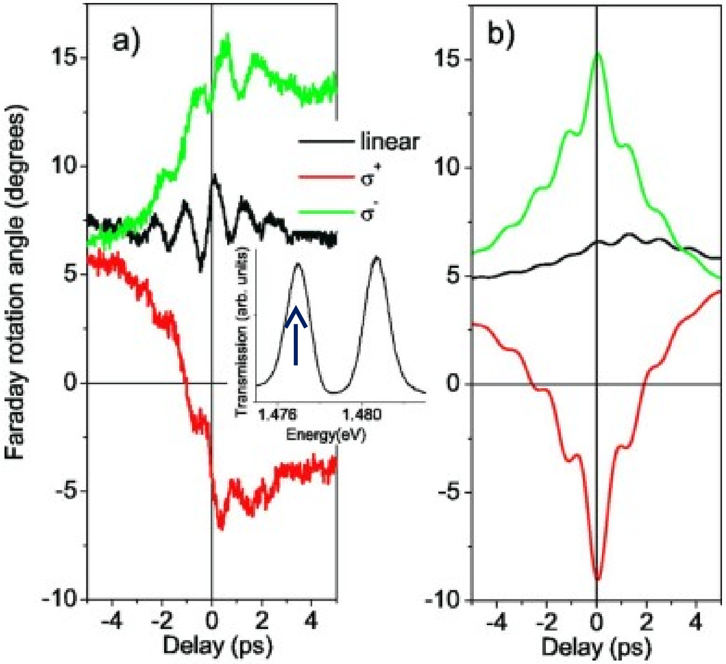
DMS µcav



Brunetti et al PRB 2006

- Rabi oscillations seen only in the µcavity with long enough cavity lifetime
- Oscillations better seen at negative delays
- Long living non oscillating decay probably due to spin polarized excitons from the reservoir
- PI effects not seen in Kerr rotation: but do we really see Rabi oscillations?

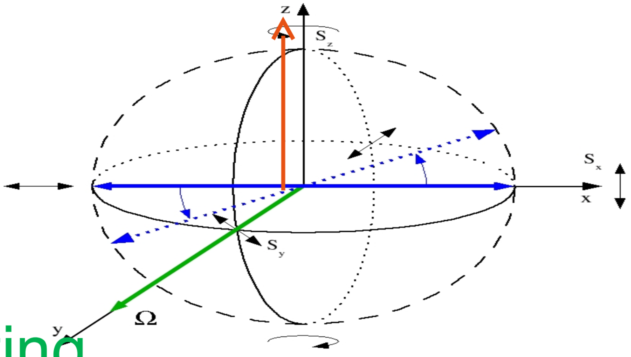
Spectrally-resolved photo-induced Faraday Rotation



- Faraday rotation exhibits beatings with Rabi period 1.25 ps
- Linear birefringence induces
  - rotation of probe polarization at negative delays
  - Existence of beatings for linear polarization of the pump

Brunetti et al, PRB 2006

Conversion from linear to circular polariton state due to linear splittings of polariton branches: Poincaré sphere representation



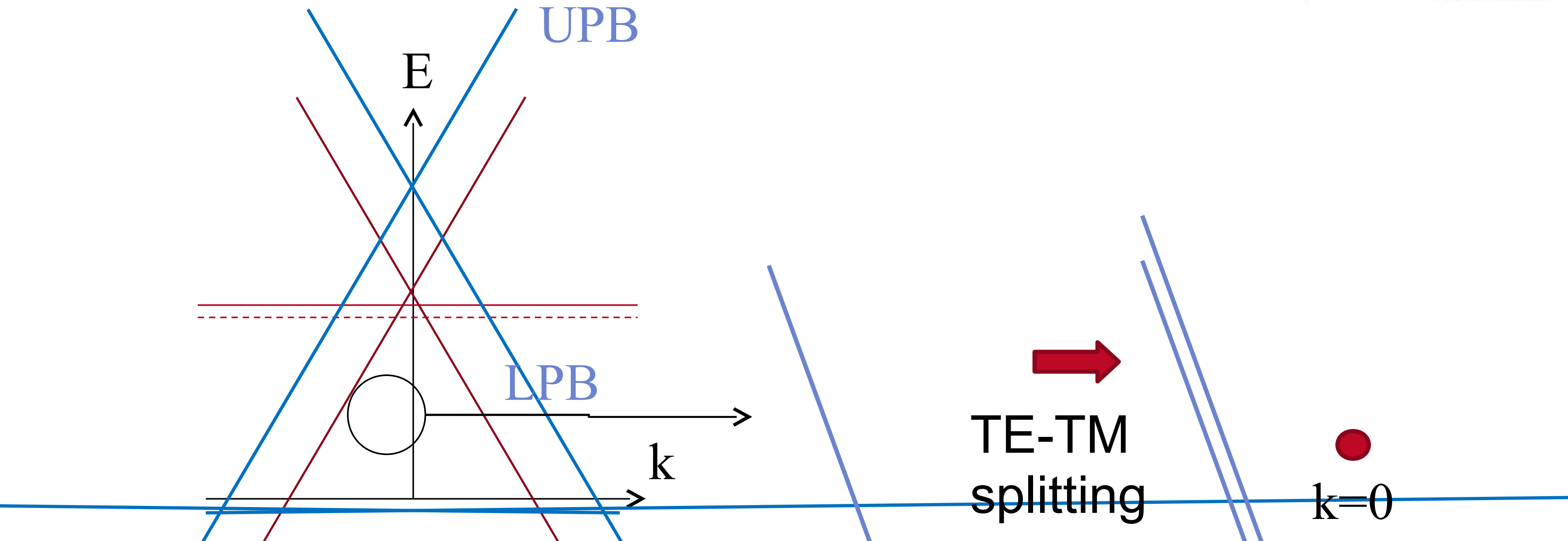
left-right splitting

linear splitting

See review by I. Shelykh, A. Kavokin, G. Malpuech PSS(b) 2005

Spin state of the condensate

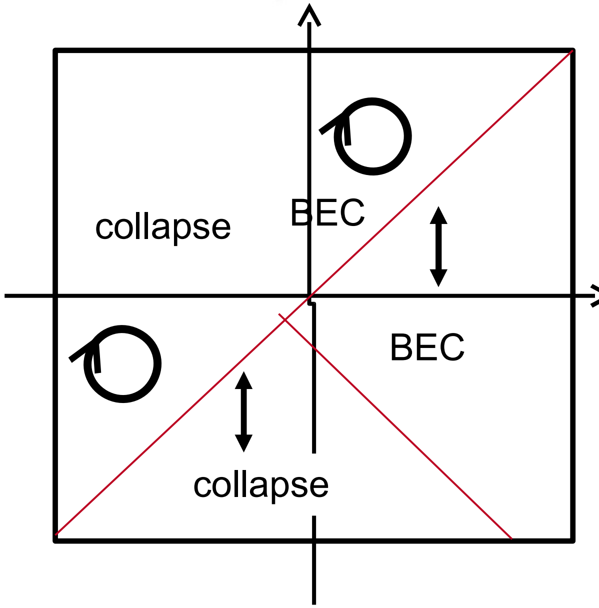
1) Ideal system (no splitting)

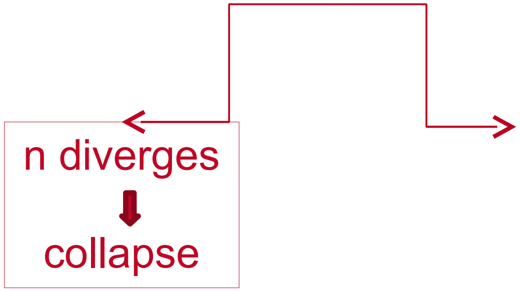


- Fundamental state is degenerate ☾ condensate must select a specific state among an infinity of states
- Spontaneous symmetry breaking with build-up of stochastic linear polarization is expected (Shelykh et al Semicond. Sci. Technol. 2010)

Free energy of the condensate

Minimize free energy

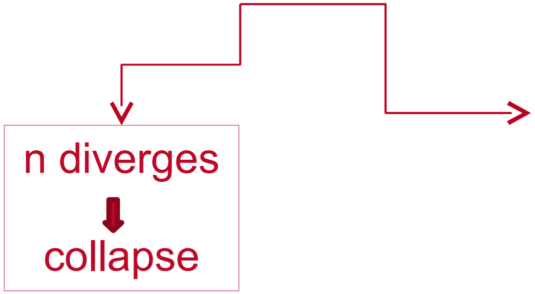




n diverges

⬇

collapse



n diverges

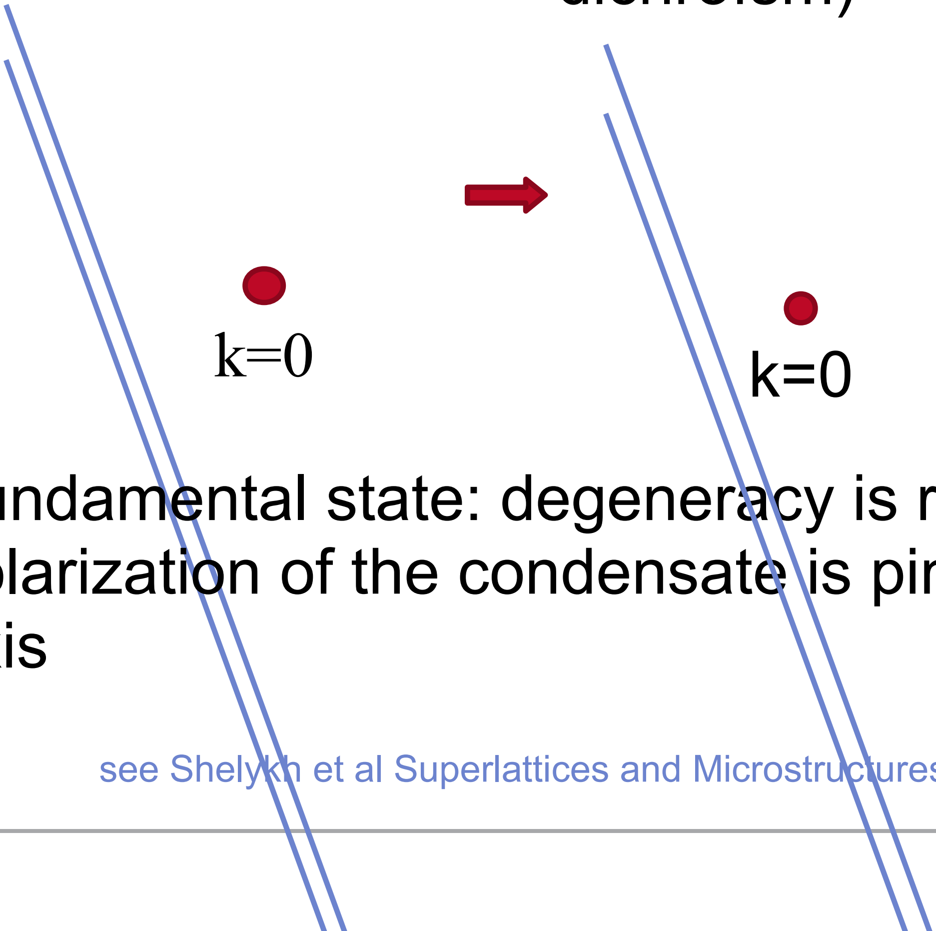
⬇

collapse

Spin state of the condensate

2) Real system

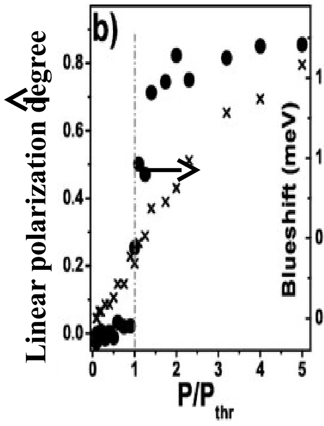
a) asymmetric QW
b) strain in the mirrors } ☾ lower symmetry (linear dichroïsm)



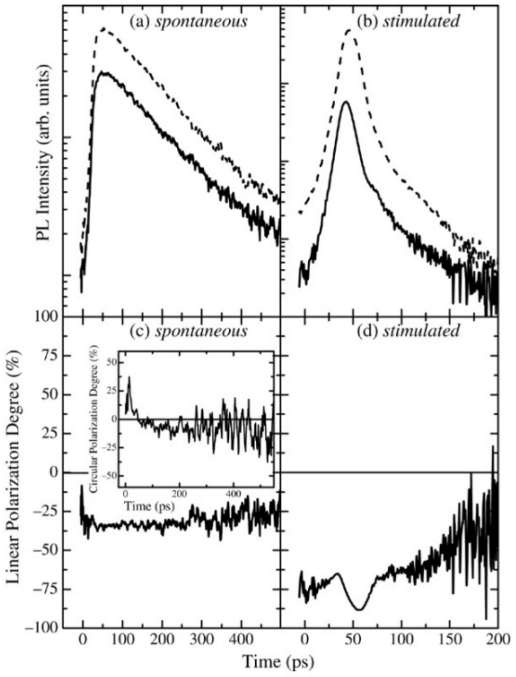
Fundamental state: degeneracy is removed ☾ polarization of the condensate is pinned to a fixed axis

see Shelykh et al Superlattices and Microstructures (2007)

Pinning of the polarization of light emitted by a microcavity



Kasprzak et al PRB 2007



Klopotowski *et al.*, *SSC* 2006

CdTe/CdMgTe µcav

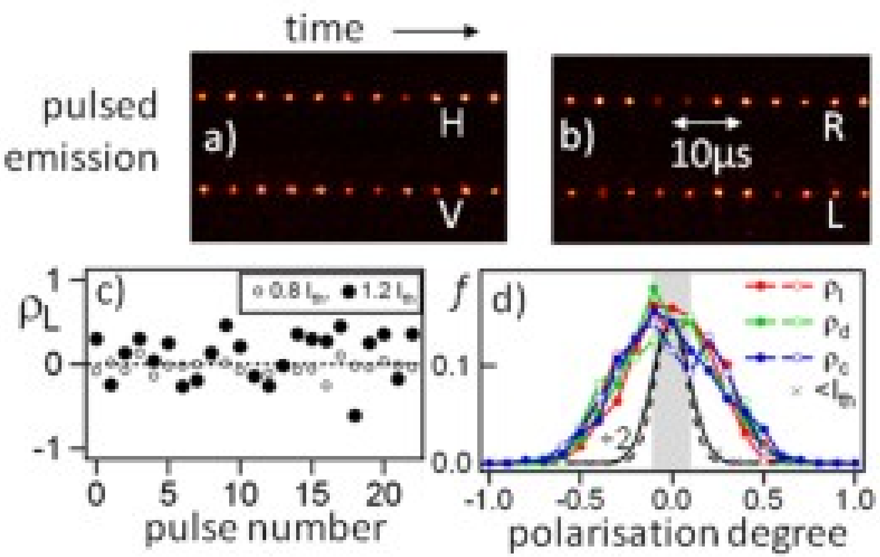
Non resonant excitation

Polarization fixed with respect to cristal axis

increases above threshold for stimulated emission

See also:
Kasprzak et al Nature 2006
Balili et al Science 2007

Spontaneous symmetry breaking in a BEC



Polarization resolved emission above threshold

Polarization histogram

Bulk GaN µcav:

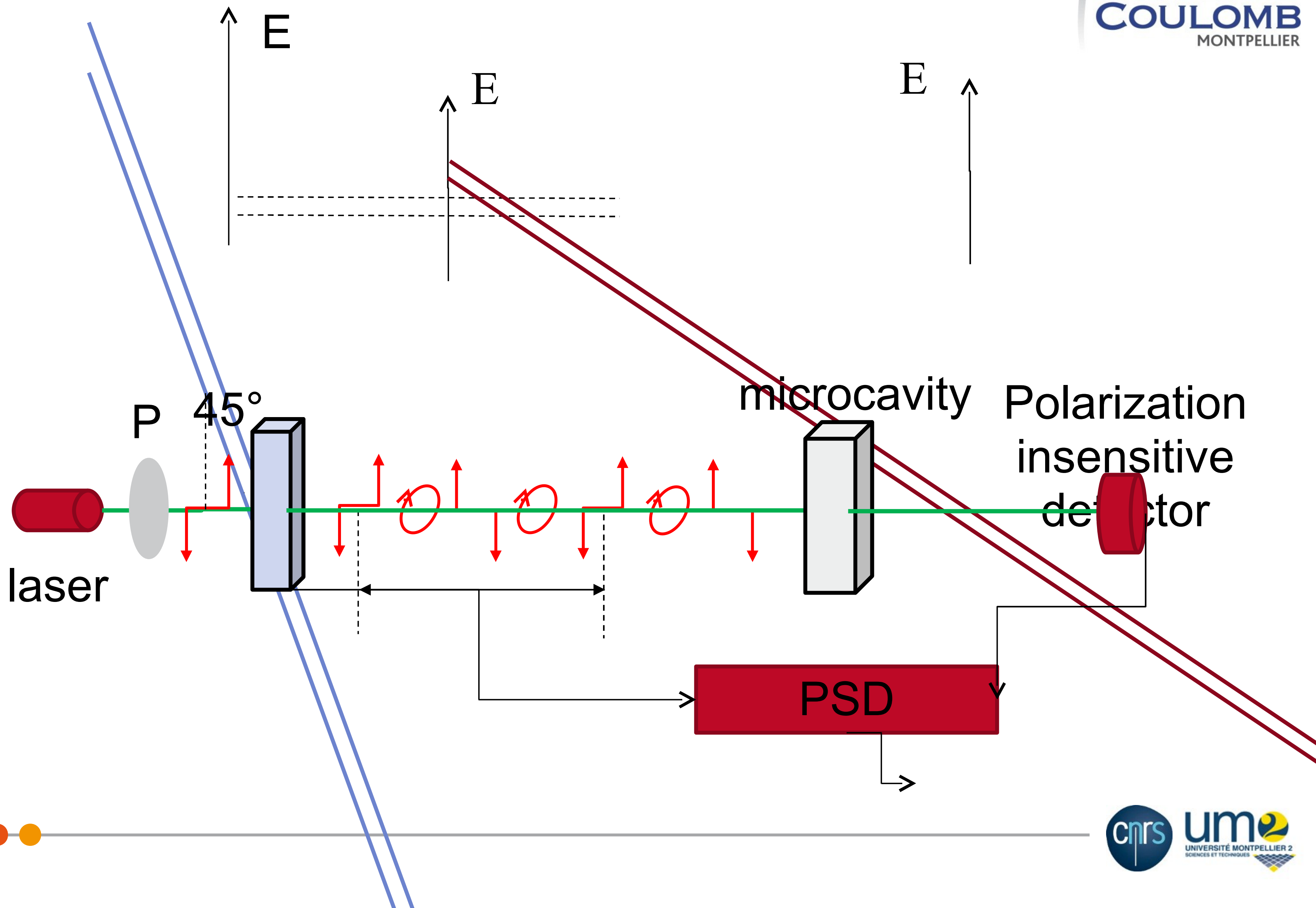
No strain-induced birefringence

spin-isotropic polariton-polariton interactions

Room-temperature

Baumberg et al, PRL 2008

Polarization resolved transmission



Linear dichroïsm: results

LPB UPB

(11G20)

Origin of the anomalous signal?

Non-linear optical effect

3rd order nonlinear polarization

Boyd, Nonlinear optics

Power dependence of signal

Conclusion

UPB : linear optical effect / linear dichroïsm dominates

LPB : nonlinear optical effect / mixed dichroïsm dominates

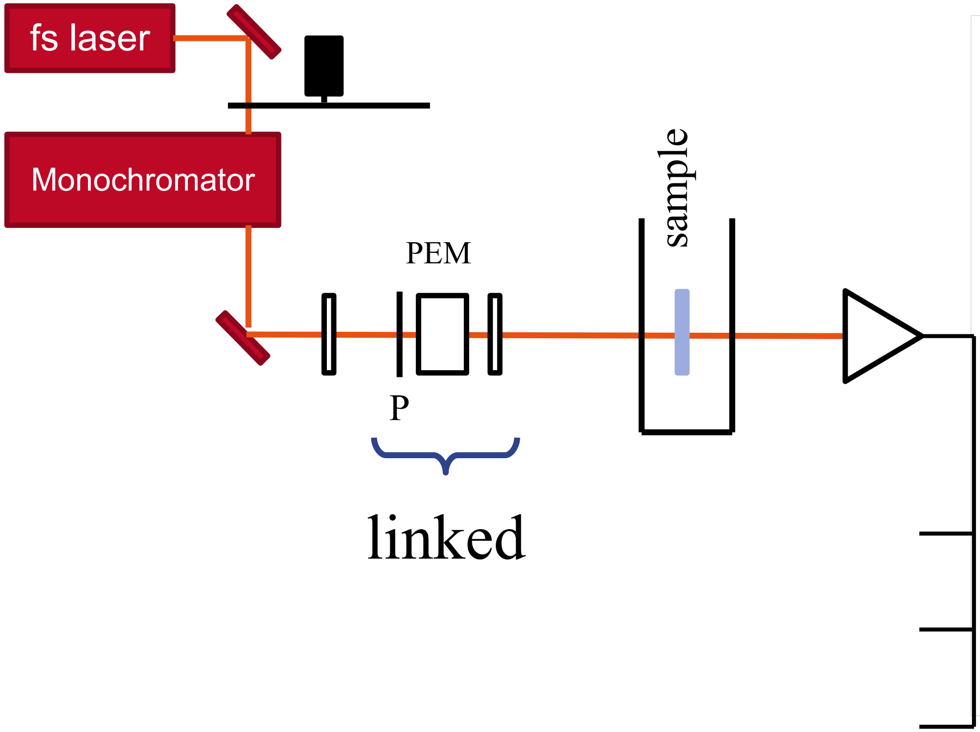
How to separate the 2 contributions?

New modulation scheme

linear dichroïsm

mixed dichroïsm

Simultaneous detection of linear and mixed dichroïsm



Linear and mixed dichroïsm do not spoil each other

Mixed dichroïsm also appears on UPB but with opposite sign

Lineshape of linear dichroïsm is different on LPB and UPB

LD of UPB is stronger than LD of LPB

principal axis of LD are different for UPB and LPB

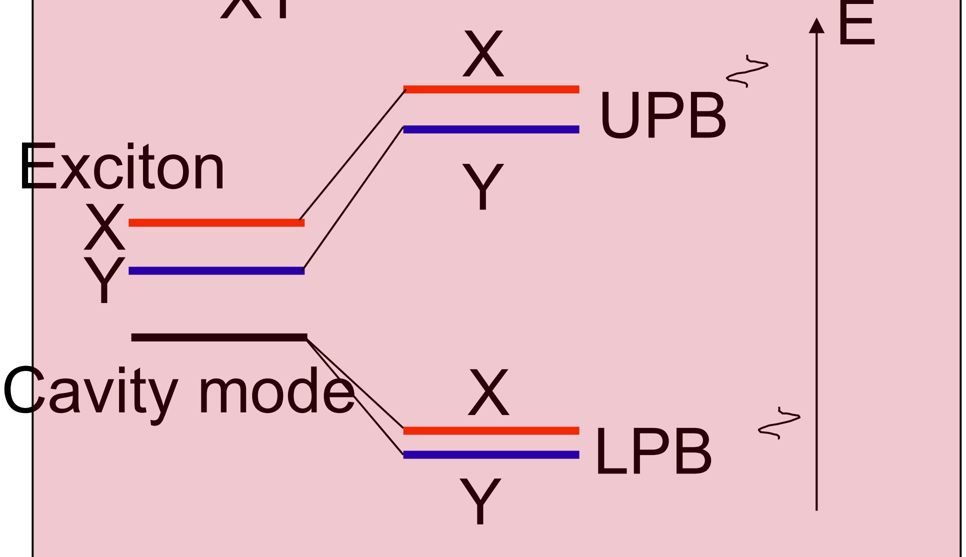
Linear dichroism : discussion

3 contributions to polariton linear splitting :

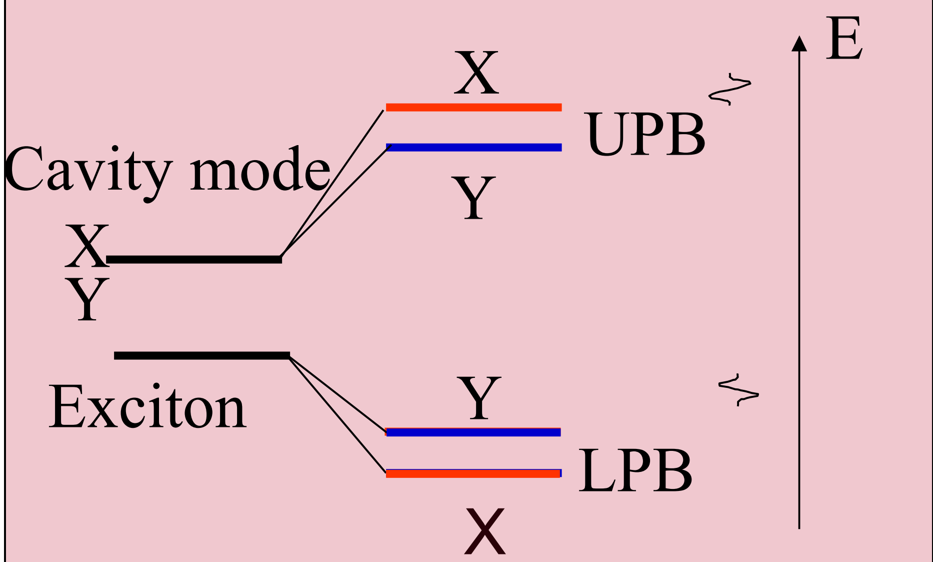
· Exciton splitting XY

· cavity mode splitting X'Y'

· Polarization dependent exciton oscillator strength XY



Mode splitting



Oscillator strength difference

Linear dichroism : results and discussion

C

X

C

X

- Exciton splitting ~15 meV
- Cavity mode splitting ~20 -30meV
- Polarization dependent Rabi splitting ~20 meV
- ~30° between dichroïsm axes for exciton and cavity mode
- splittings are smaller than those observed in PL experiments

Brunetti et al, PLMCN6 (2006)
Scalbert et al, PLMCN7 (2007

Pump –induced FR

Transmission difference up to 40%

Much stronger at LPB then at UPB

1mW ↔ 9·108 photons/cm2

LPB :Tc>Tl

Polarization resolved transmission

100µeV

185mW

no visible shift

LPB

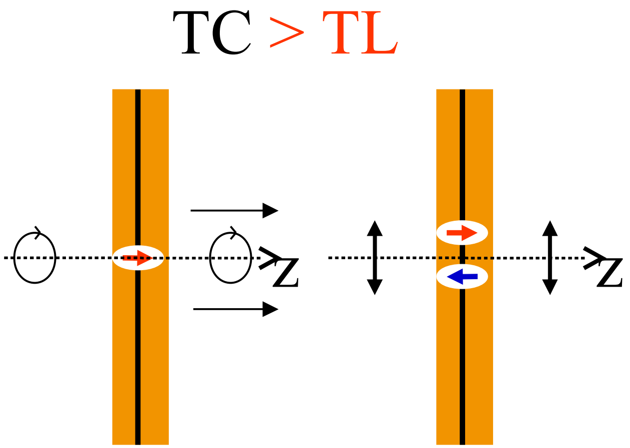
3mW

UPB

Line broadening :6%

Splitting : 100 meV

Main effect : transmission difference up to 40%



It may result from spin dependent polariton-polariton interactions

Microscopic origin of the optical nonlinearity?

dominant
contribution

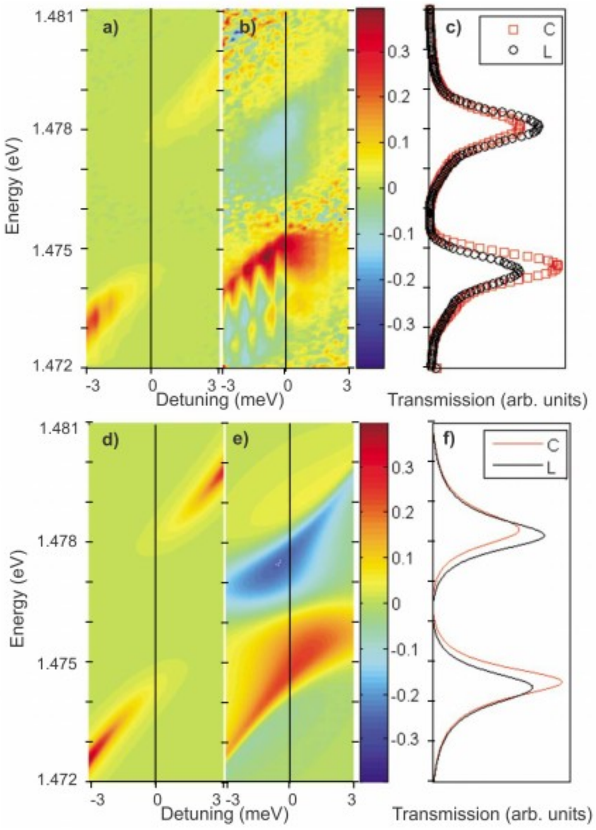
Phase-space filling

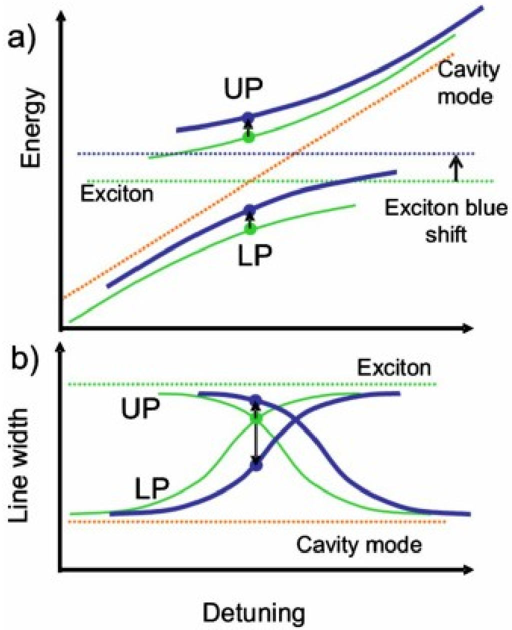
Exciton-exciton
interactions

LPB

In agreement with observed linear shifts

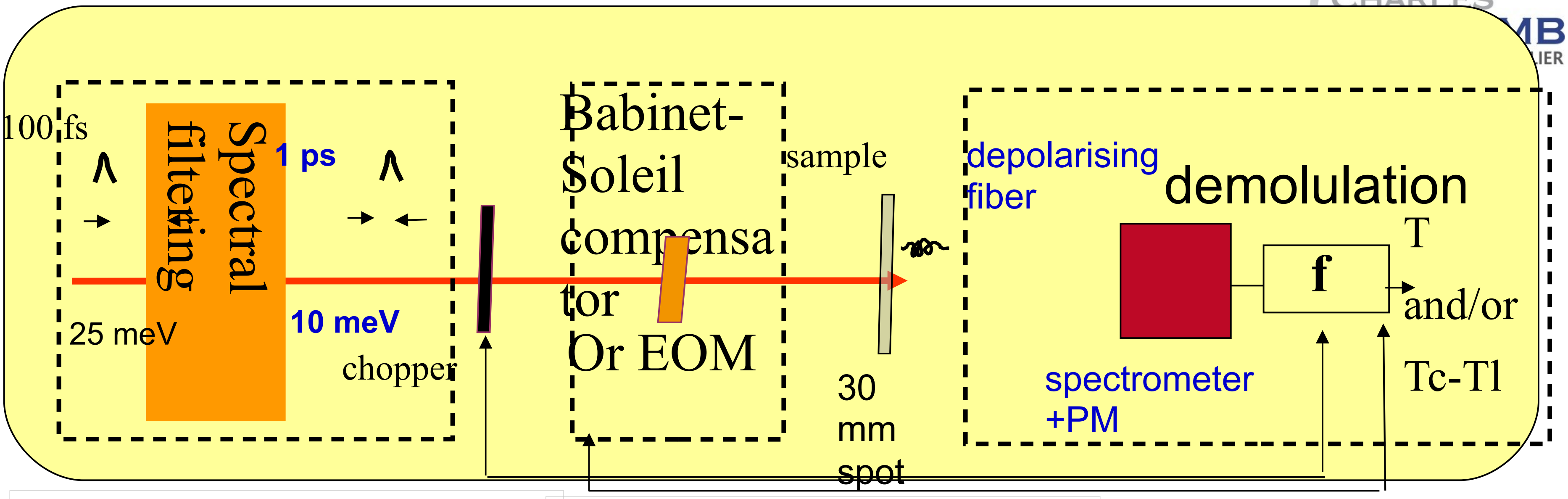
Interpretation of mixed dichroïsm: spin-dependent blue shift





Vladimirova et al, PRB 2009

Polariton energy shift from transmission experiments



100 fs

25 meV

Spectral filtering

1 ps

10 meV

chopper

Babinet-Soleil compensator

Or EOM

sample

30 mm spot

depolarising fiber

demolulation

spectrometer +PM

f

T

and/or

Tc-Tl

GaAs l/2 cavity,

In0.5Ga0.95As QW,

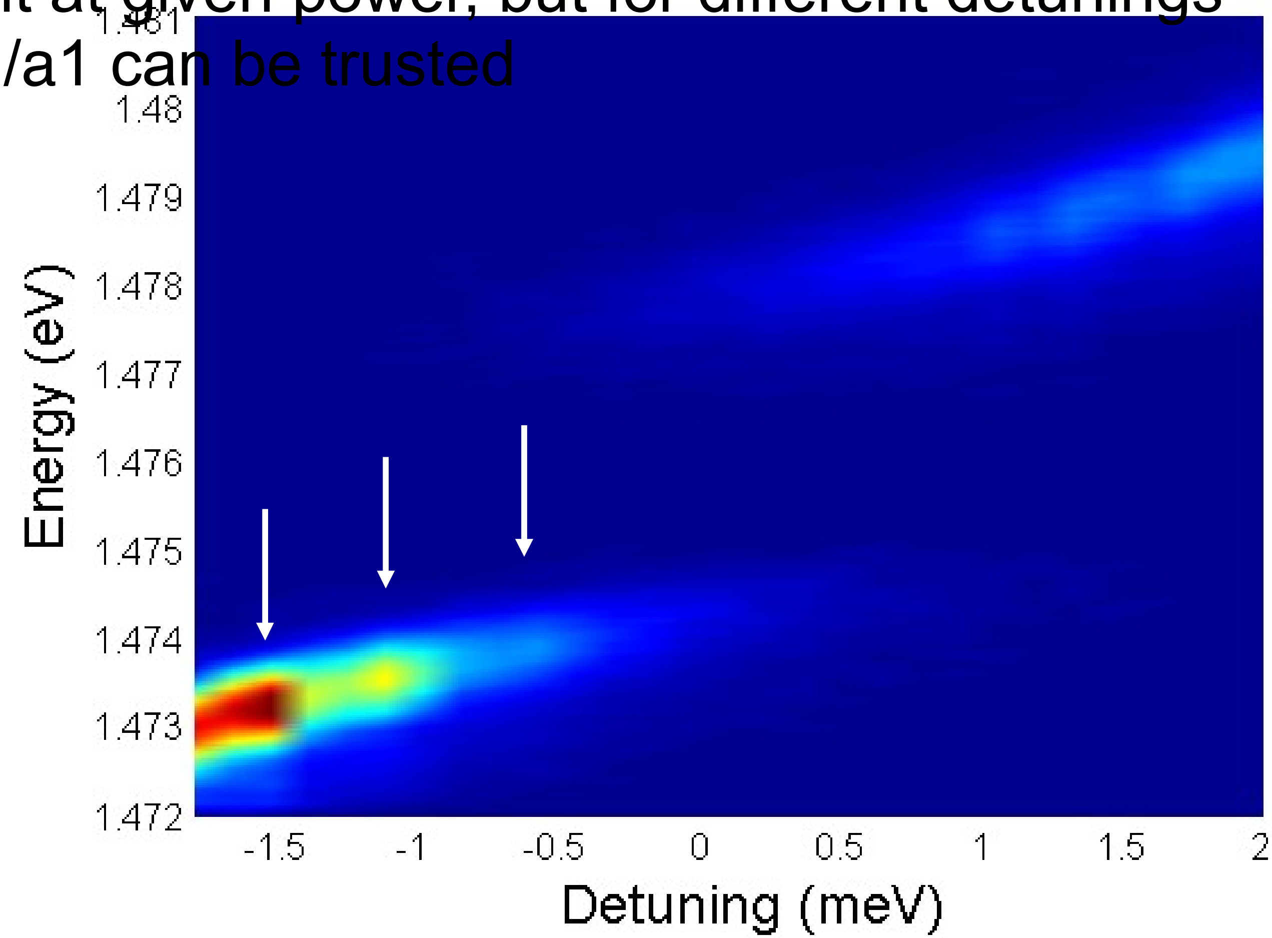
GaAs/Ga0.9Al0.1As Bragg mirrors

23 pairs/29pairs
WR=3.5 meV

for the power dependence of transmission in linear and circular pola

What limits the precision

- Even at very low density we have oscillations of the transmission intensity across the sample
- This means, that average polariton number may not be constant at given power, but for different detunings ☾ only ratio a2/a1 can be trusted



Measuring LPB shift

(T-T18 mW) / (T+T18 mW)

Red → linear

Black → circular

Blue shift, almost no broadening in both polarizations

Negligible shift and broadening in linear polarization

Ratio between interaction constants

Red → linear

Black → circular

ersion=poor precision at zero and strong negative detuning

DEL=n(a1+a2)/2

DEC=na1

- a2 and a1 have different sign
- |a2| increases when

Tentative explanation

ifferent contribution to the interaction constants a1 (↑ ↑) and a2 (↑ ↓)

Spin independent contributions:

1) Mean field electrostatic energy (Repulsion)

1) Van-der-Waals (dipole-dipole) interaction (Attraction)

$a1n=UCoulomb+UVdW+Uex\uparrow\uparrow$

$a2n=UCoulomb+UVdW+Uex\uparrow\downarrow+Ubi$

$DEC=a1n$

$DEL=(a1+a2)n/2$

Spin dependent contributions:

1) Exchange interaction (Repulsion for ↑ ↑ and Attraction for ↑ ↓)

1) Bi-exciton state (Attraction) ↑ ↓

measured → **a1n** = UCoulomb+UVdW ← Fit of DEC

calculated

\+ Uex↑↑

a2n = UCoulomb+UVdW + ← Fit of a2/a1

Uex↑↓ + Ubi

Uex↑
↑

UCoulomb

UVdW

Uex↑↓

Ubi

Comparison with other experiments

T. Lecomte :
polarization dependent parametric scattering in 3-coupled microcavities

P. Renucci and D. Solnyshkov:
polariton spin dynamics observed in time and polarization resolved PL (2 µcavities quite similar to ours)

strong disagreement at small negative detunings!

Conclusions

I. A. Shelykh et al, SST (2010)