2583-6

Workshop on Coherent Phenomena in Disordered Optical Systems

26 - 30 May 2014

Coherence Length of a Weakly Interacting One-dimensional Polariton Condensate

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Coherence Length of a Weakly Interacting One-dimensional Polariton Condensate

E. Durupt[1], S. Klembt[1], A. trichet[1,*], F. Médard[1,**], A. Minguzzi[2], S. Datta[2], Le Si Dang[1], M. Richard[1]

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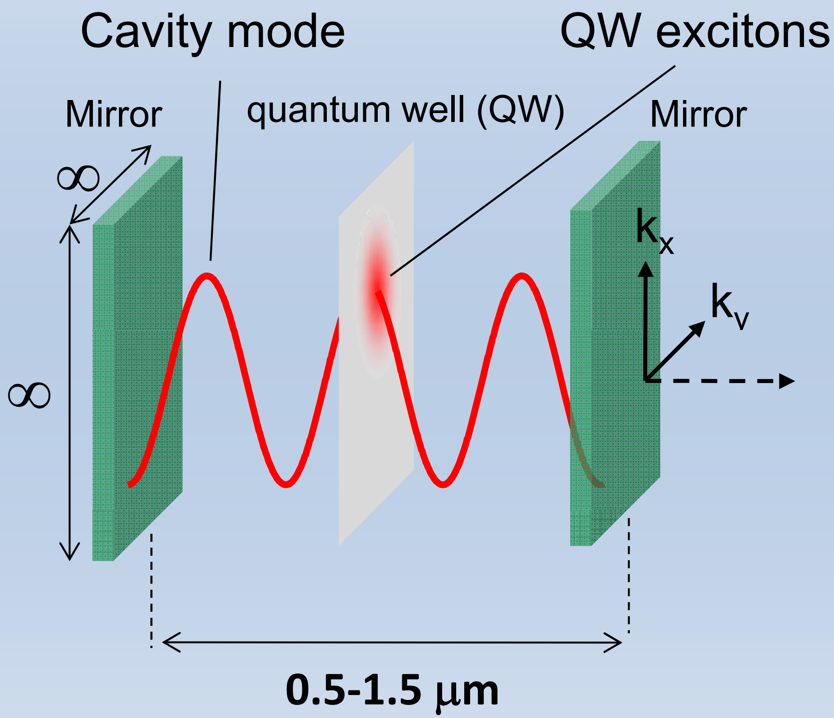
** Now at Université Blaise Pascal, Clermont-Ferrand, France

[2]*Laboratoire de Physique et Modélisation des Milieux Condensés* - CNRS, Grenoble, France

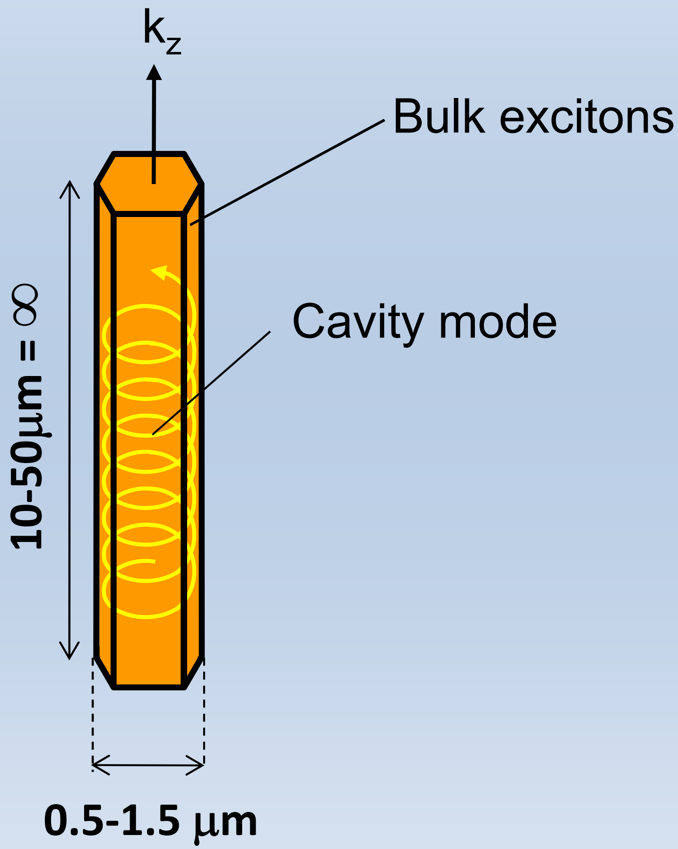
Microcavities in the strong coupling regime



Microcavity in the strong coupling regime with a **2-dimensional** degree of freedom (k_x,k_y)

+ *weak in-plane disorder*

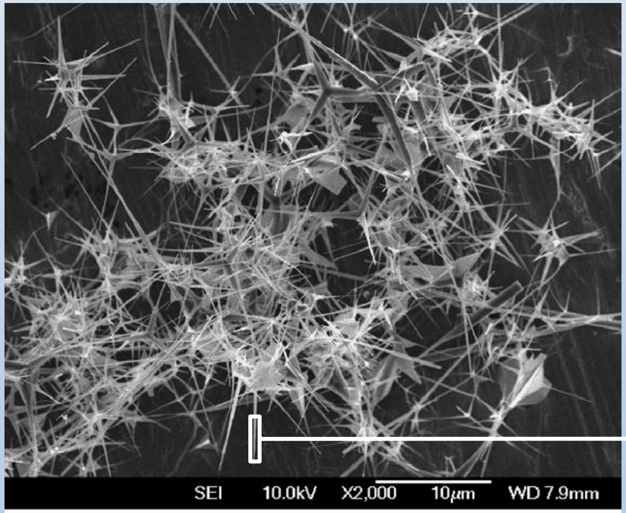
Microcavities in the strong coupling regime



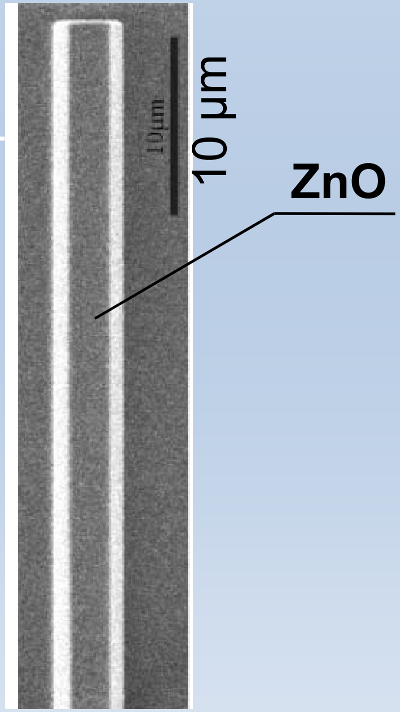
Microcavity in the strong coupling regime with a **1-dimensional** degree of freedom (k_z)

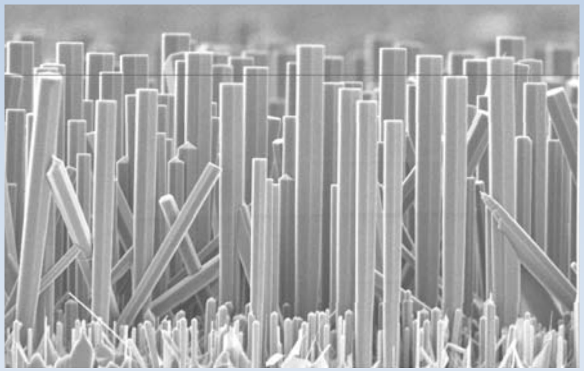
+ *weak in-line disorder*

ZnO microwires: an intrinsically one dimensional microcavity



VPE

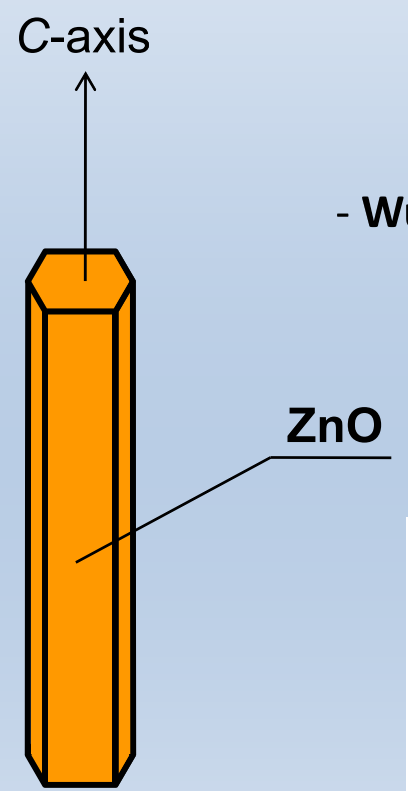




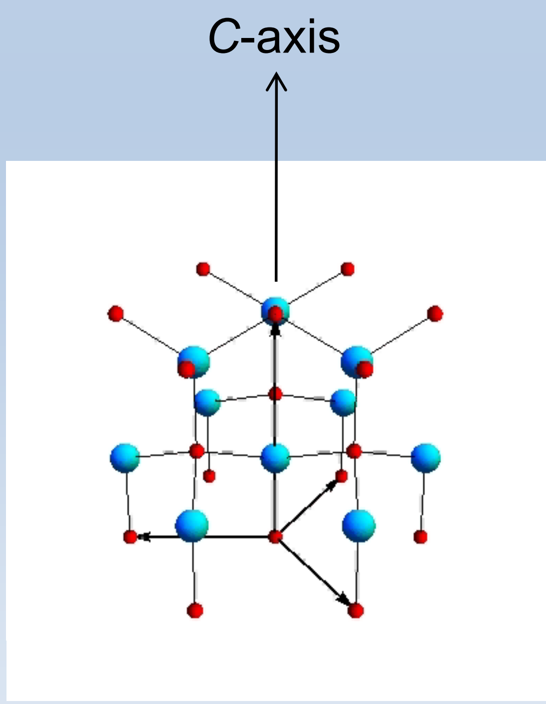
MOCVD

SEM Micrograph of a ZnO microwire

ZnO microwires: an intrinsically one dimensional microcavity



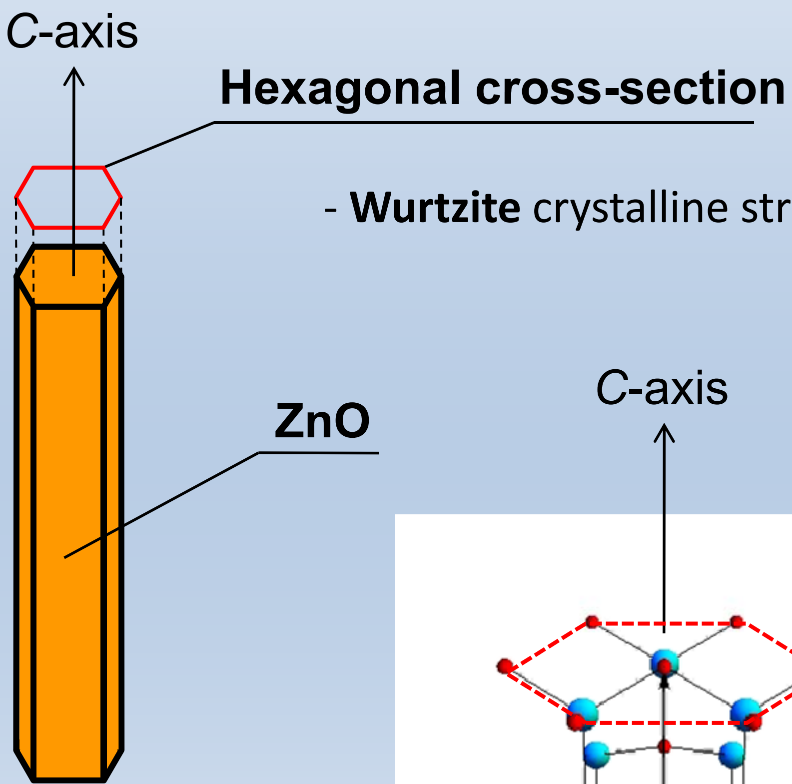
- **Wurtzite** crystalline structure



ZnO

- Bulk excitonic transition @ **3.31eV**
- Excionic binding energy of **60meV**
- Large E. dipole moment

ZnO microwires: an intrinsically one dimensional microcavity



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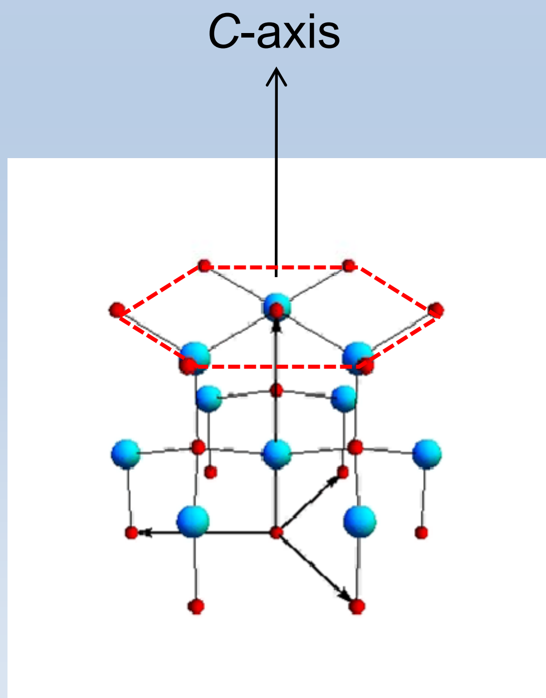

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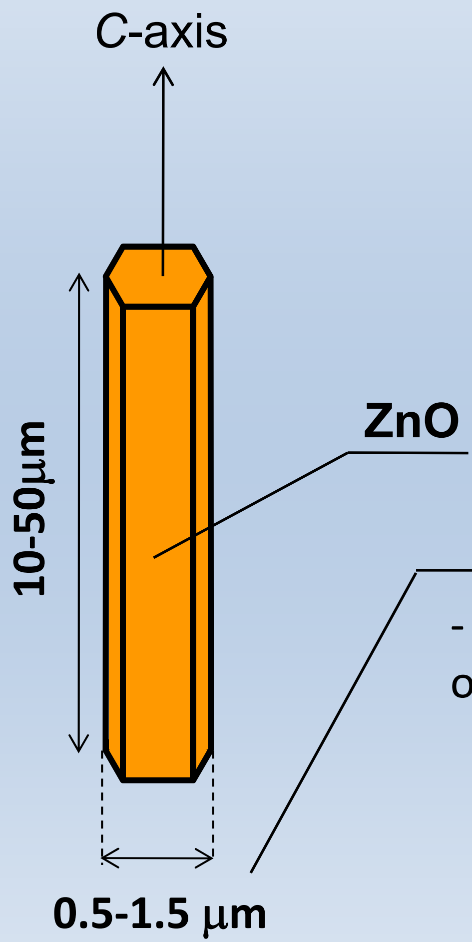
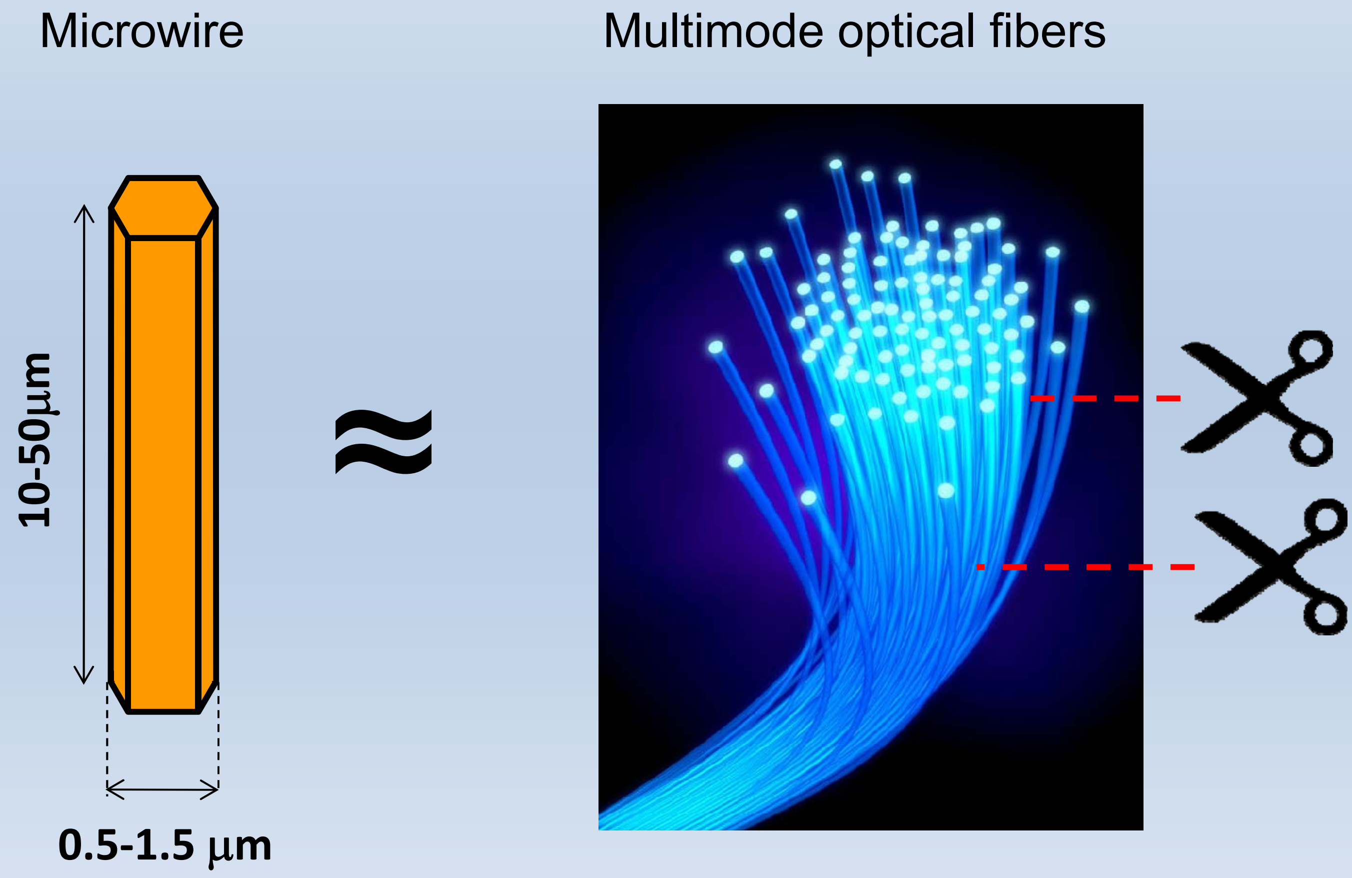


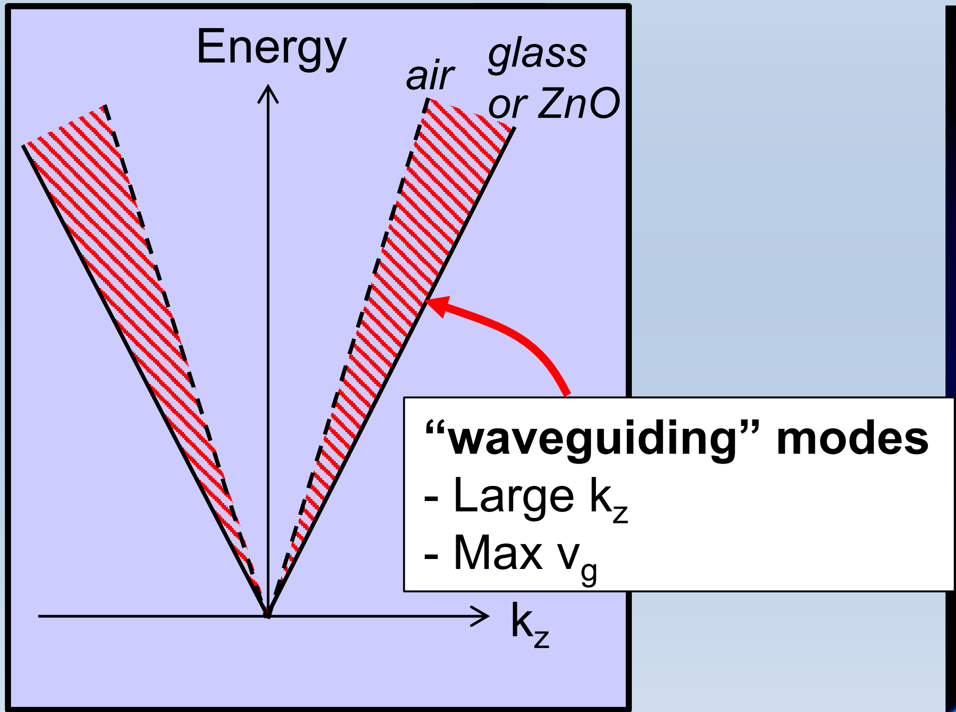
Micron scale

- Confinement of **light** not of electronic excitations

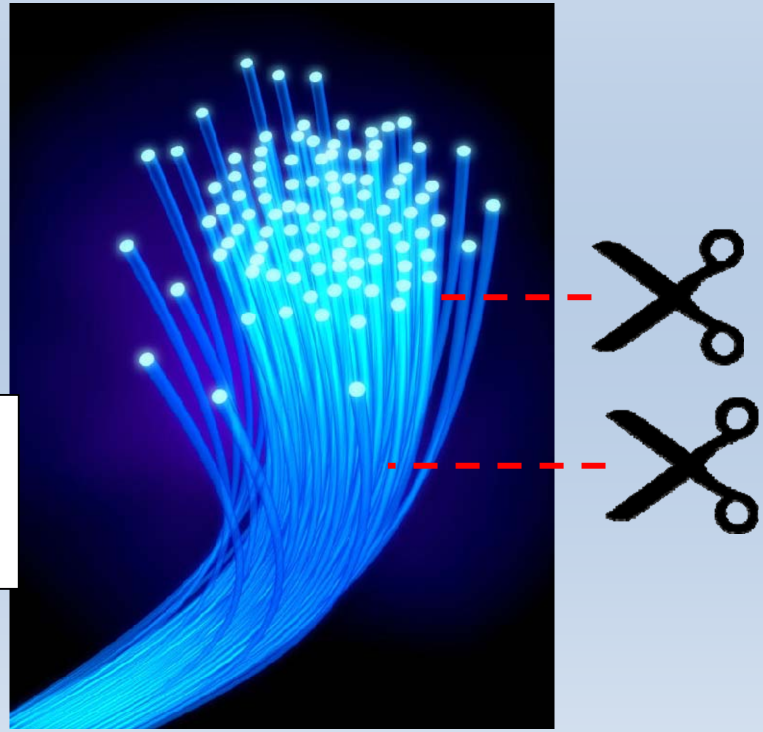
Optical properties of a ZnO Microwires



Optical properties of a ZnO Microwires

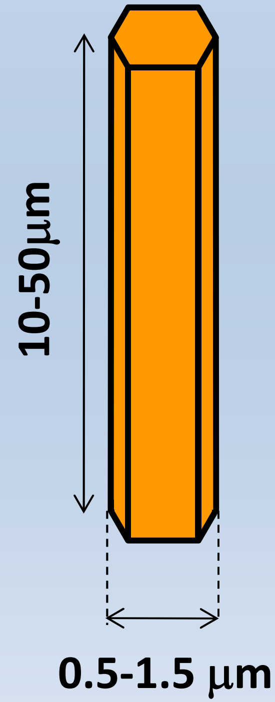


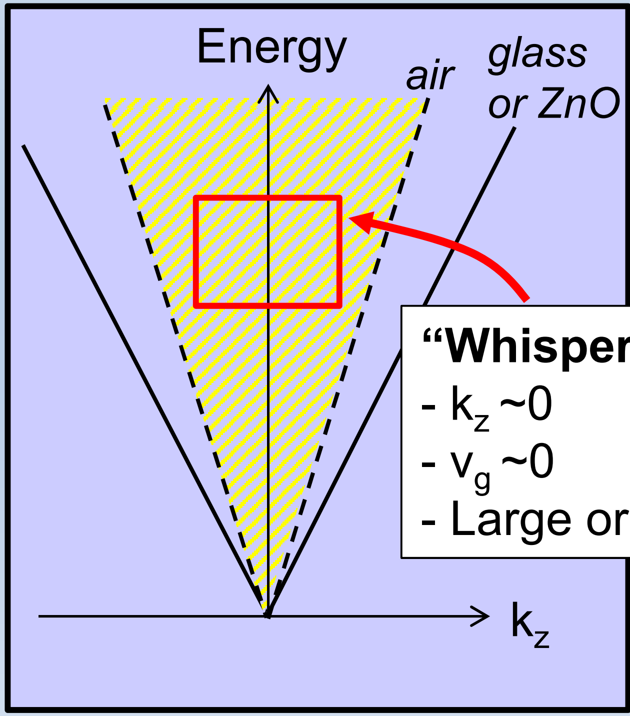
Multimode optical fibers



Optical properties of a ZnO Microwires

Microwire

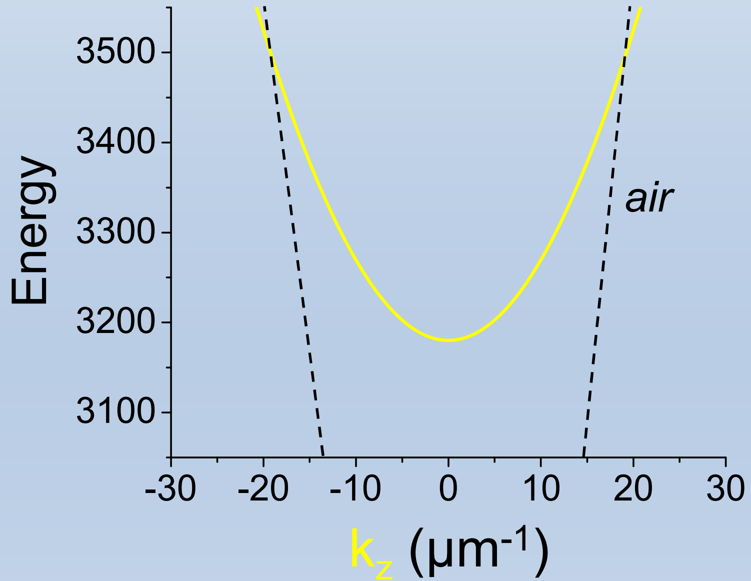


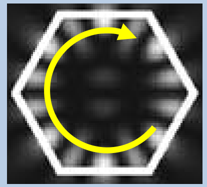


“Whispering gallery” modes

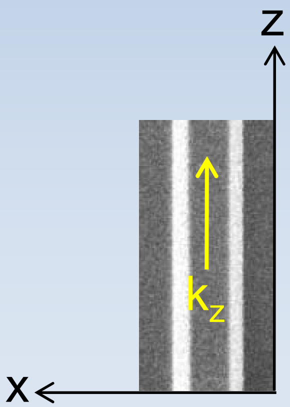
- $k_z \sim 0$
- $v_g \sim 0$
- Large orbital momentum

Optical properties of a ZnO Microwires



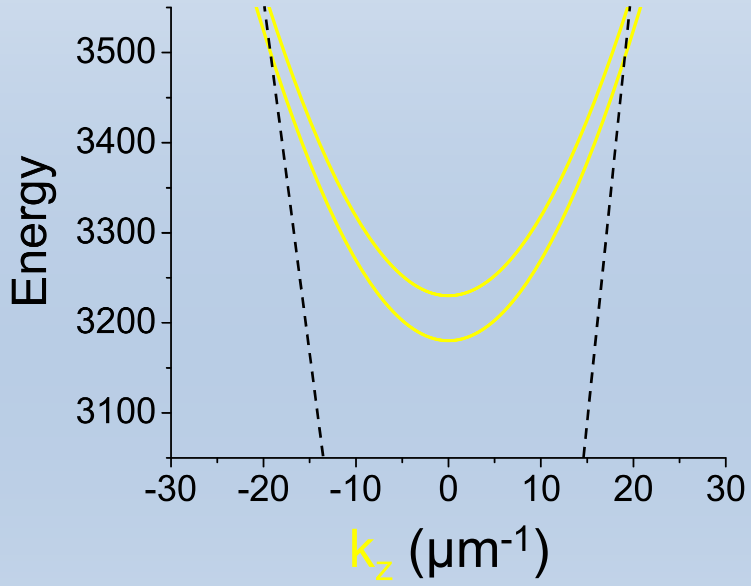


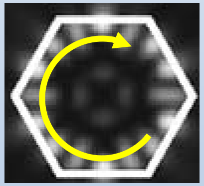
n, m
(WGM transverse numbers)



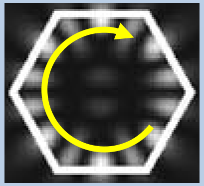
$$\omega_{n,m}(k_z) = \sqrt{\omega_{0n,m}^2 + \frac{c^2 k_z^2}{n_o^2}}$$

Optical properties of a ZnO Microwires





n, m+1



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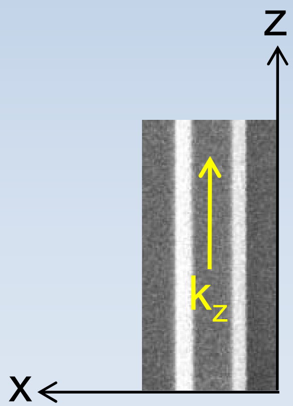
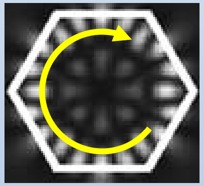
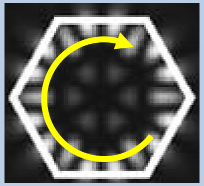


Optical properties of a ZnO Microwires

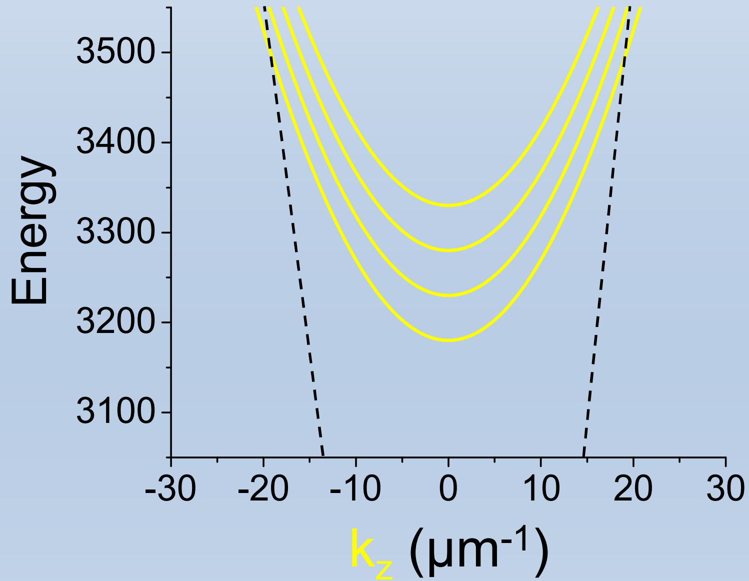


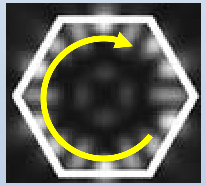
n, m+3



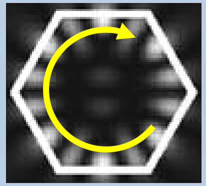
n, m+2

Etc…





n, m+1



n, m

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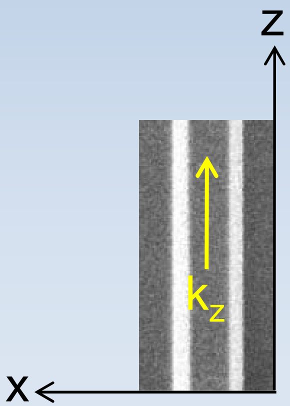
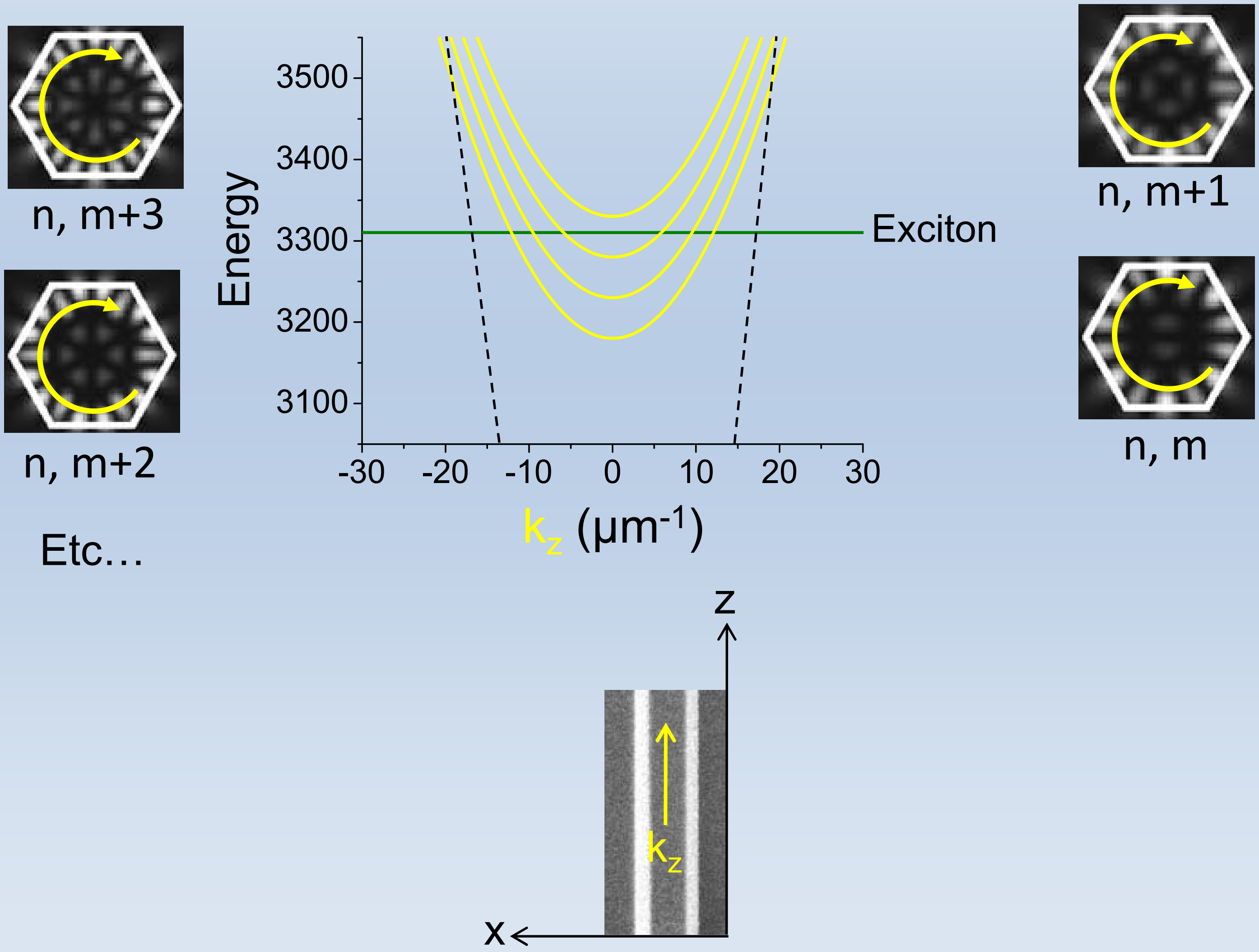
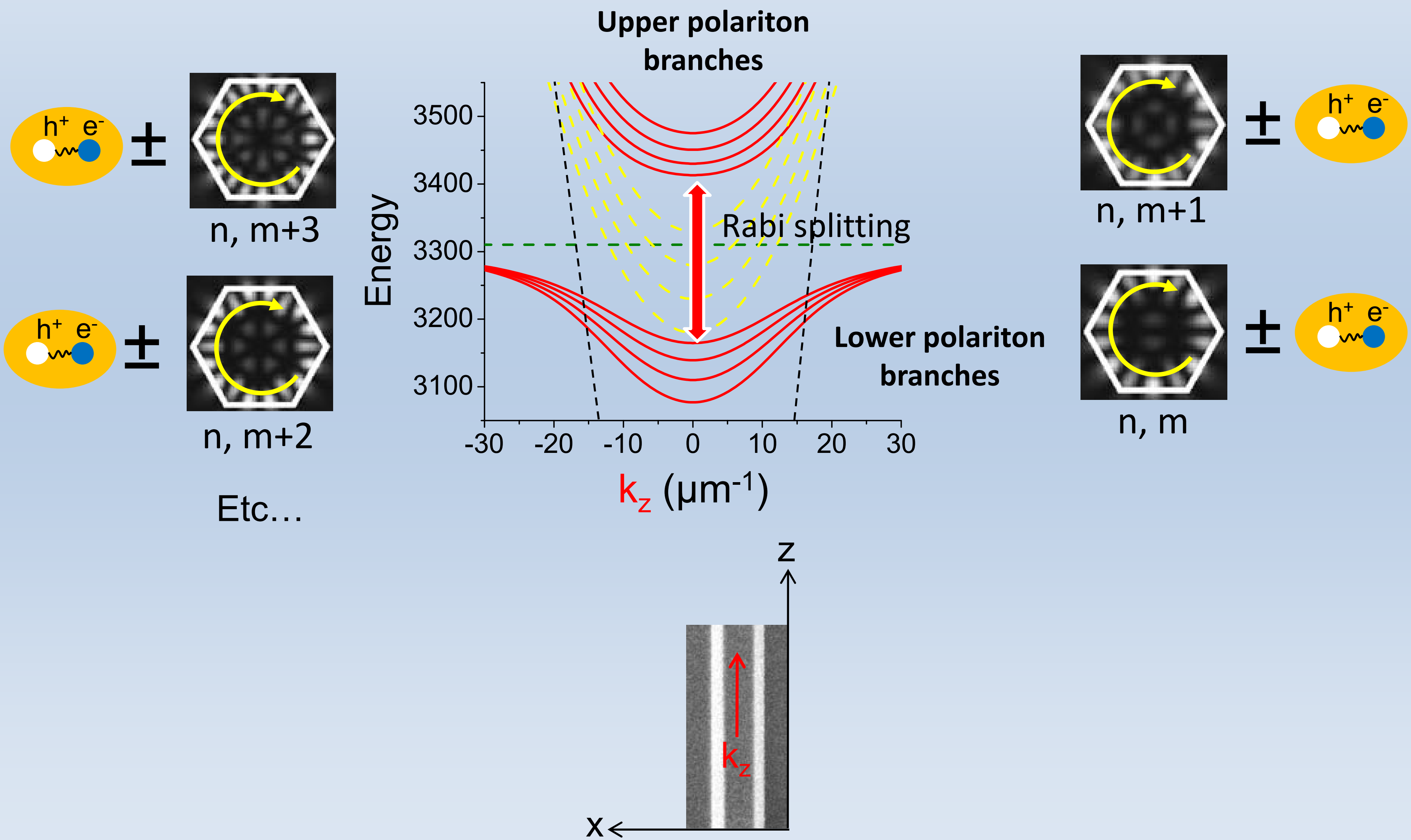


Optical properties of a ZnO Microwires



Polaritonic properties of a ZnO Microwires



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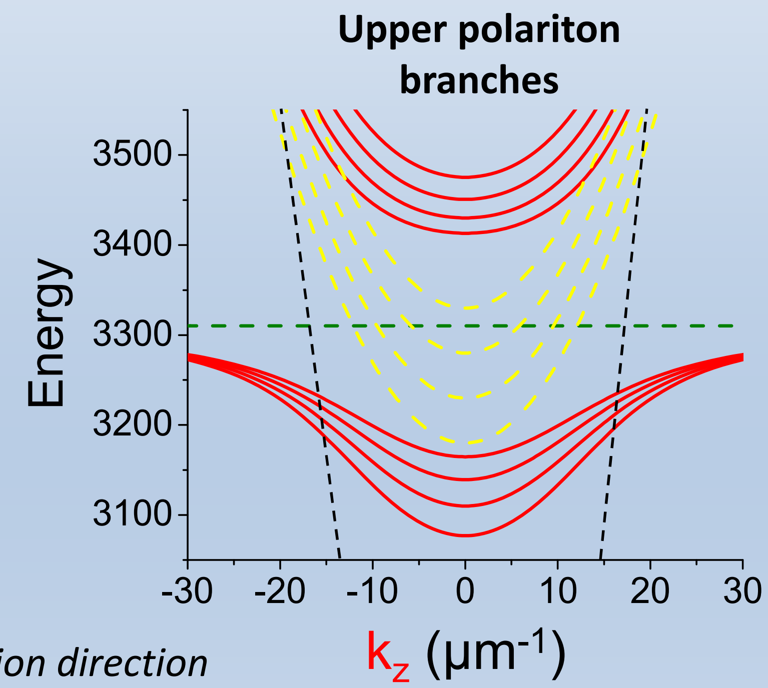
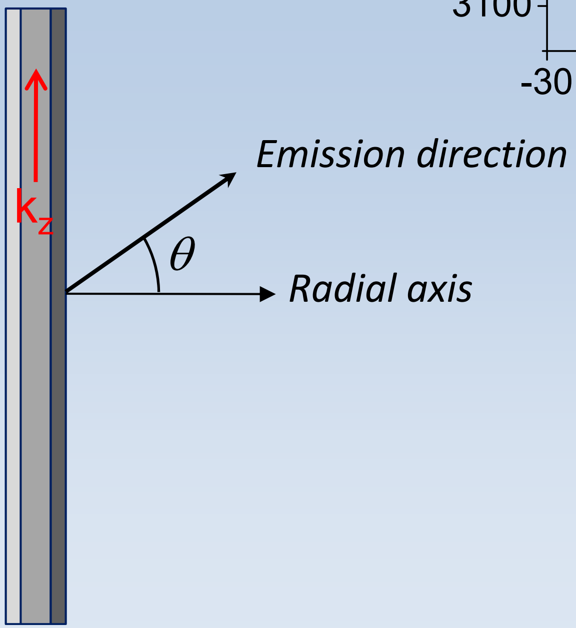


$$k_z = \frac{E}{\hbar c}\sin(\theta)$$



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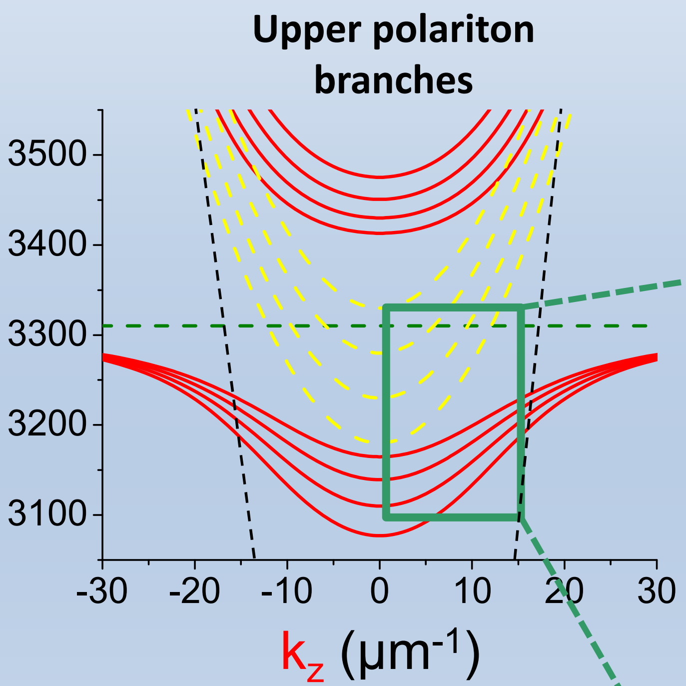

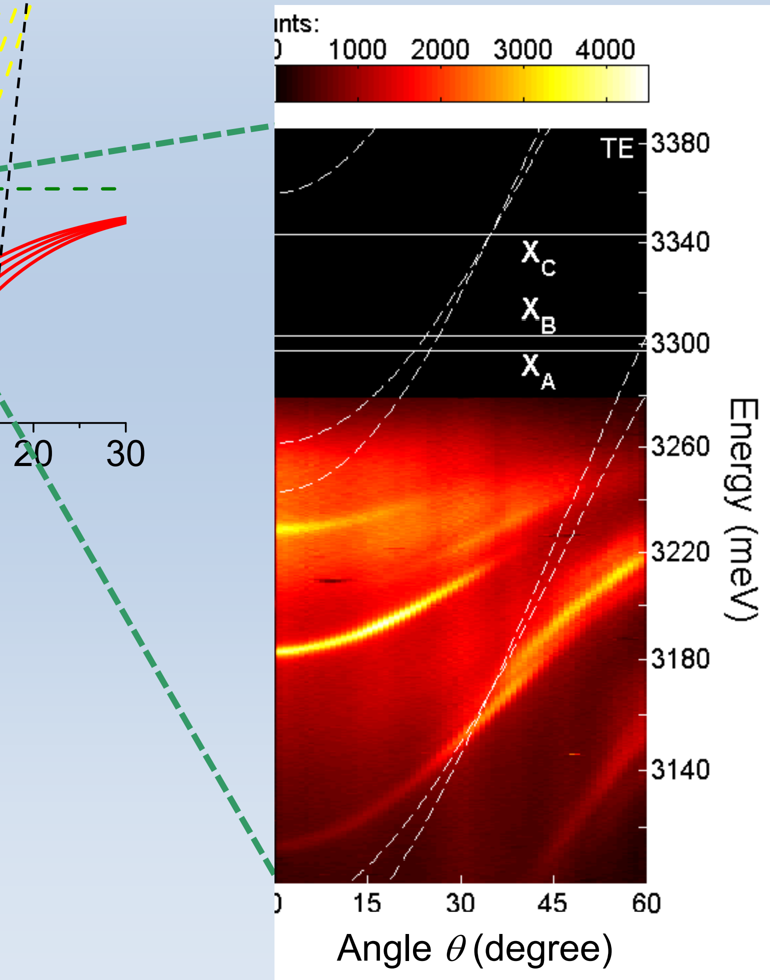

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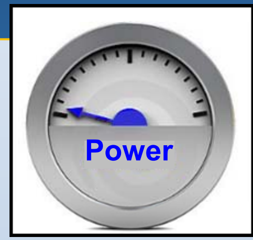
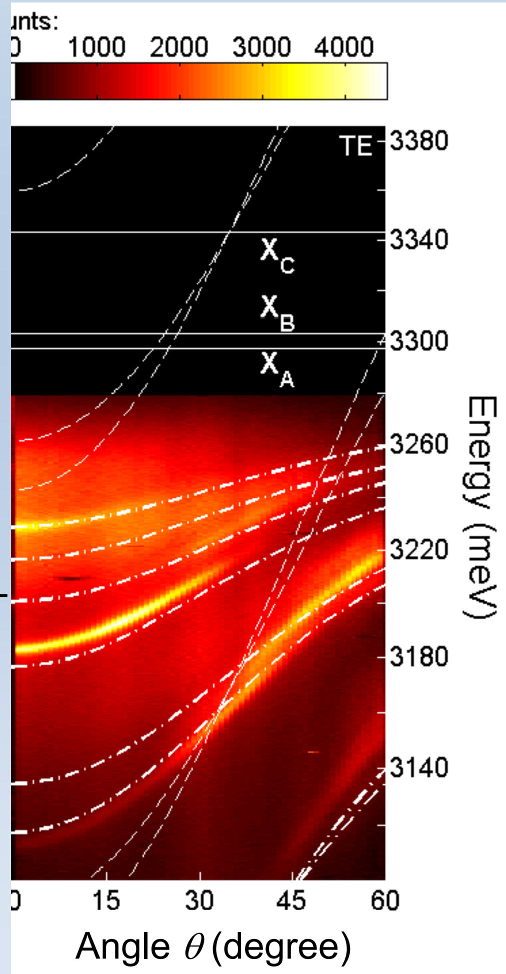


T=300K-

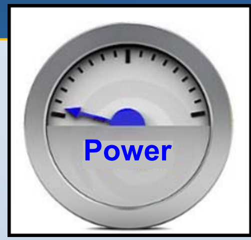
Good agreement with linear response theory [1]

→ Rabi splitting = 290meV
→ Q=800

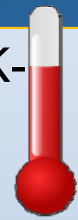


[1] Pavlovic *et al.*, *Phys. Rev. B*, **82** 195328 (2010)

Polaritonic properties of a ZnO Microwires



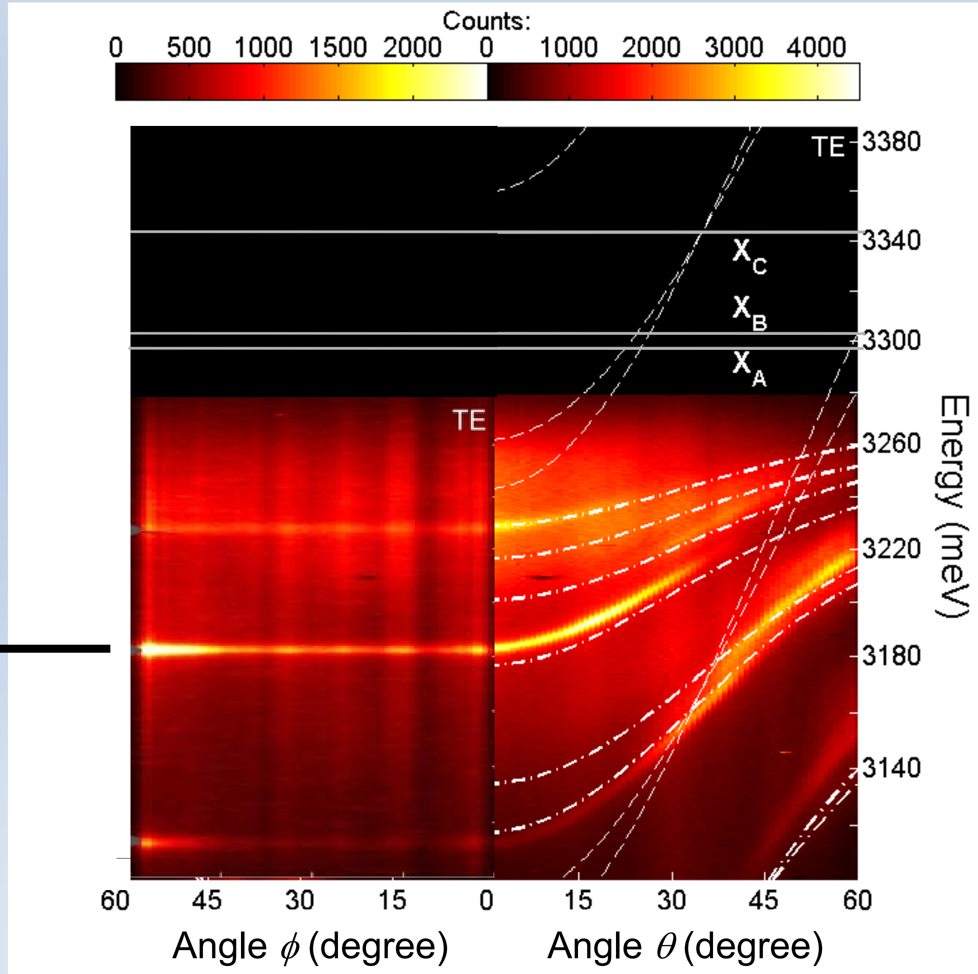
T=300K-

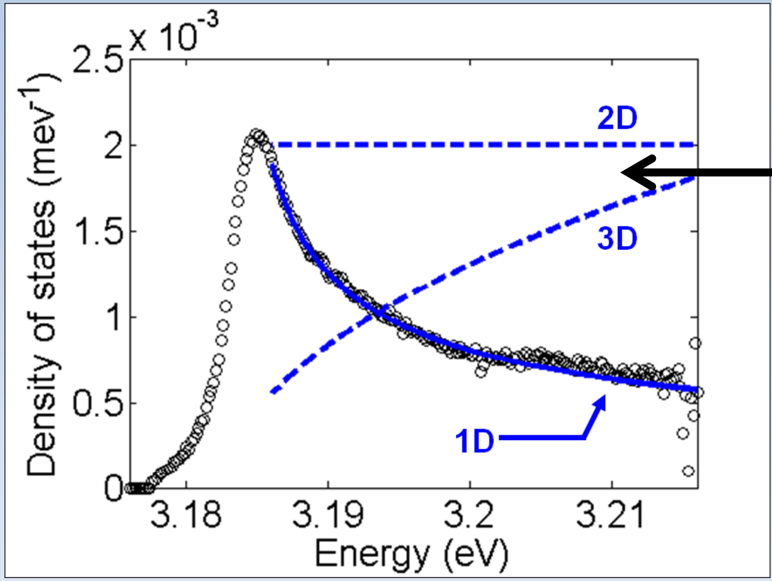


Complete knowledge of
E(k_x, k_y, k_z)

→Complete knowledge of **Density of states**

→ 1-Dimensional density of states





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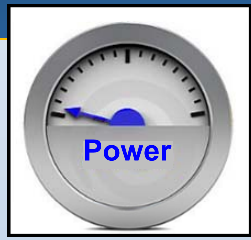

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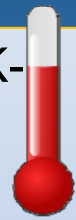
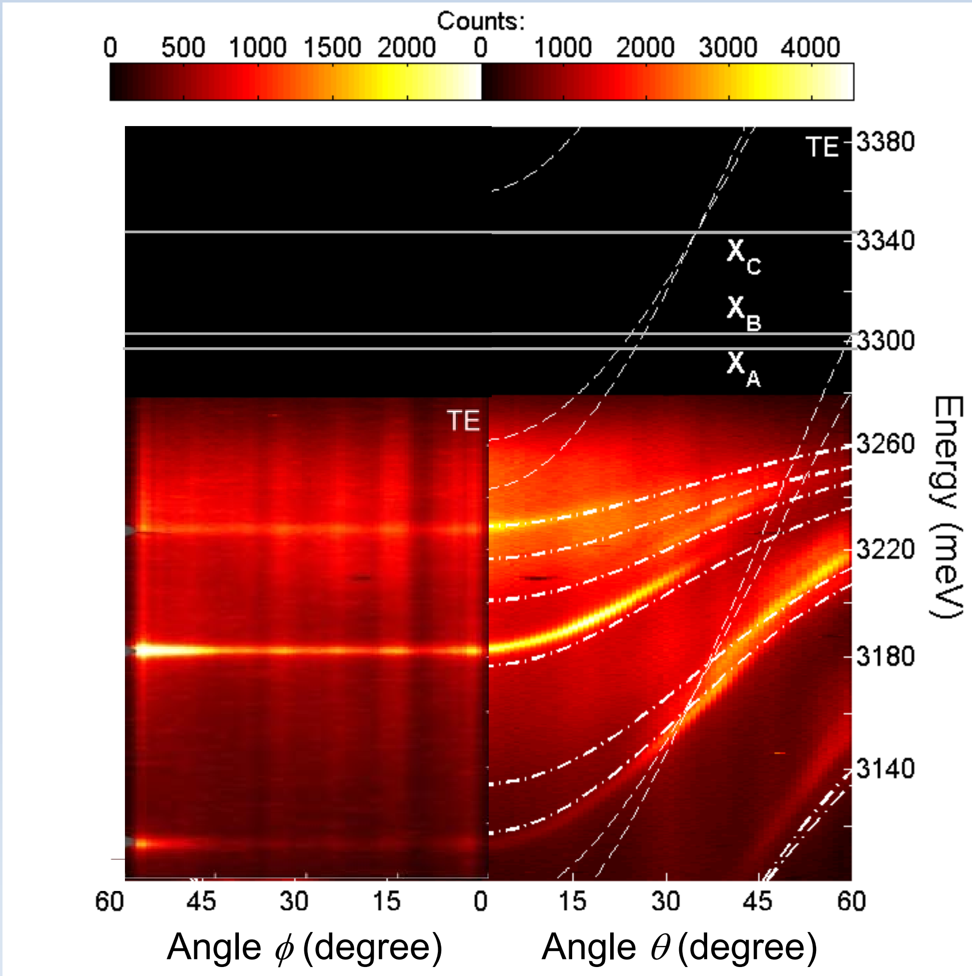


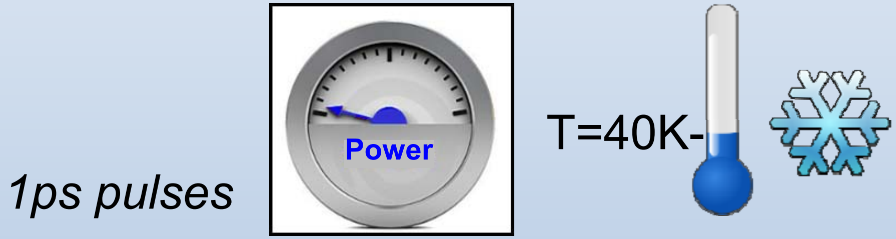


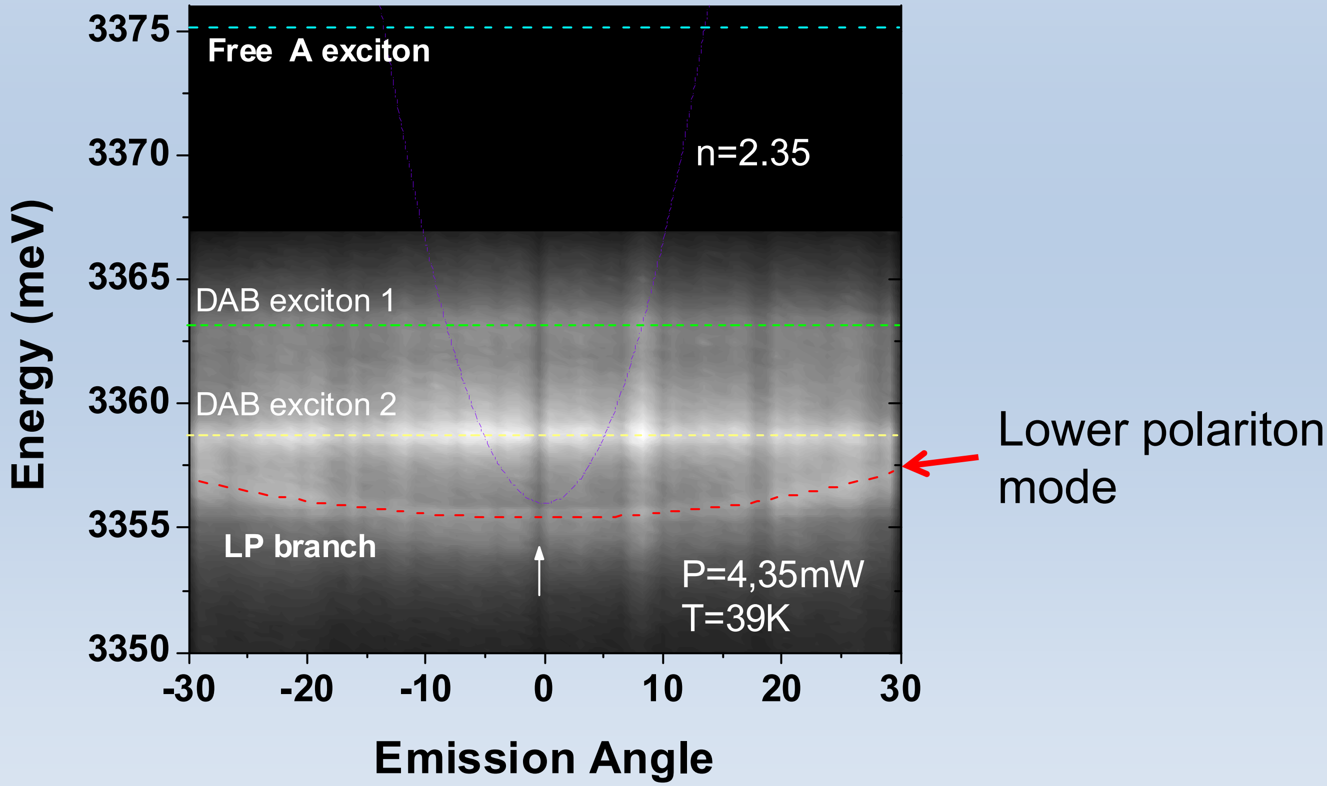
Quick summary [2]

- Rabi splitting = **290meV**
- Stable at **room temperature**
- Dimensionality = **1D**
- Q = 800

[2] A. Trichet *et al. Phys Rev B* **83** R041302 (2011)

Excitation of a transient condensate under pulsed excitations

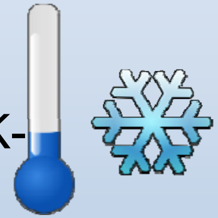


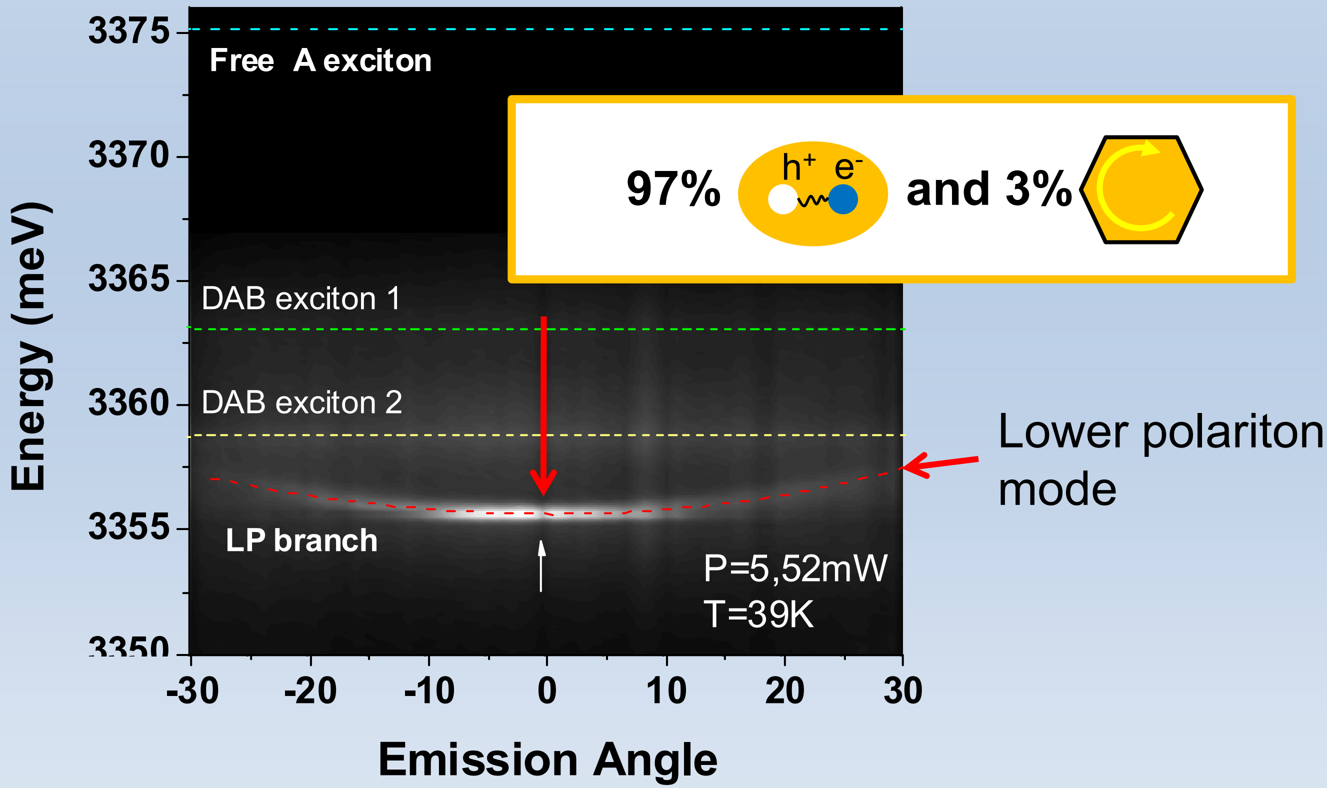


Excitation of a transient condensate under pulsed excitations

1ps pulses
P_{th}~ 0.3 W/ m

T=40K-





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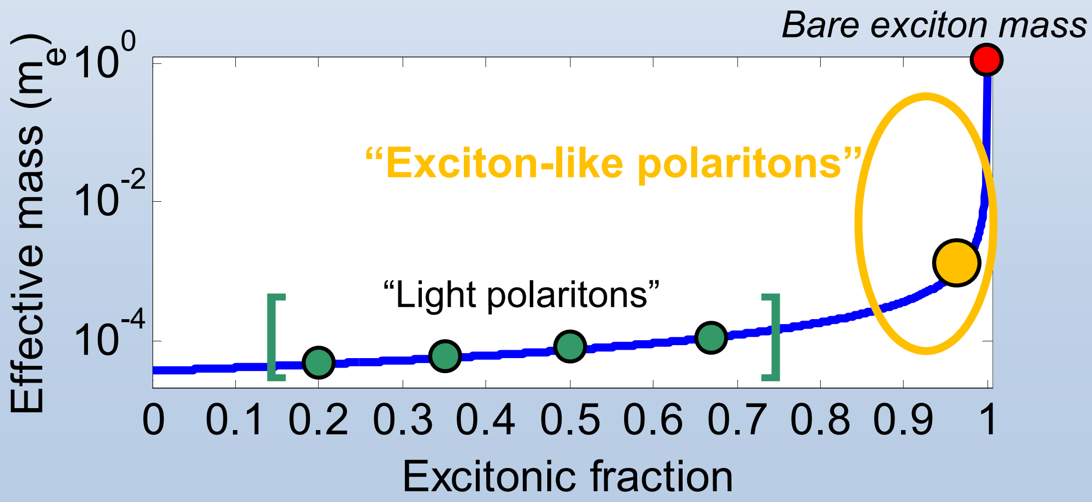
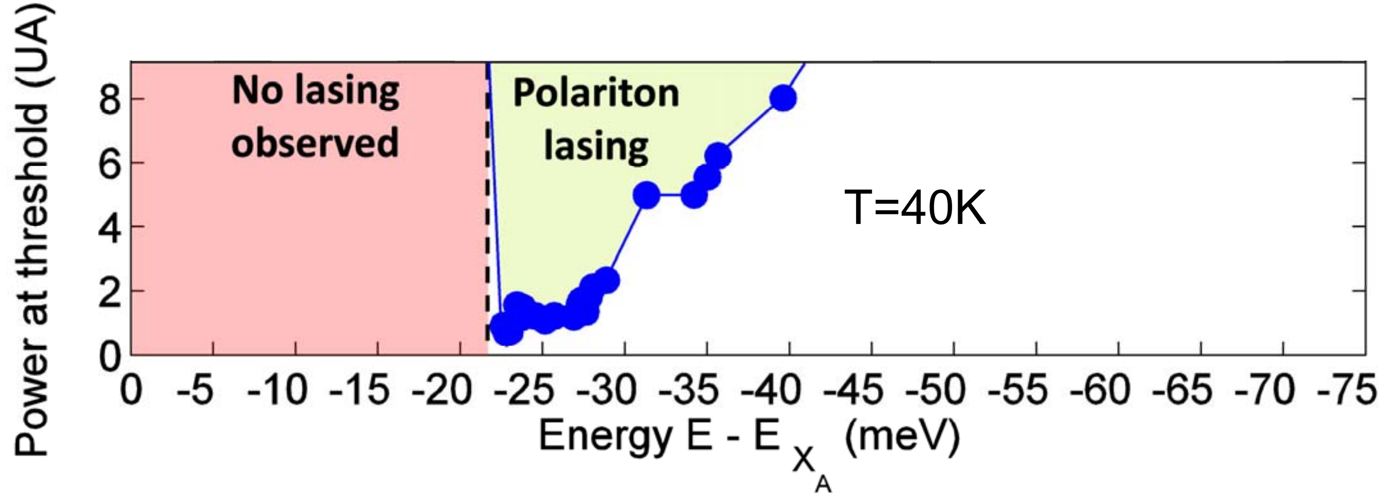
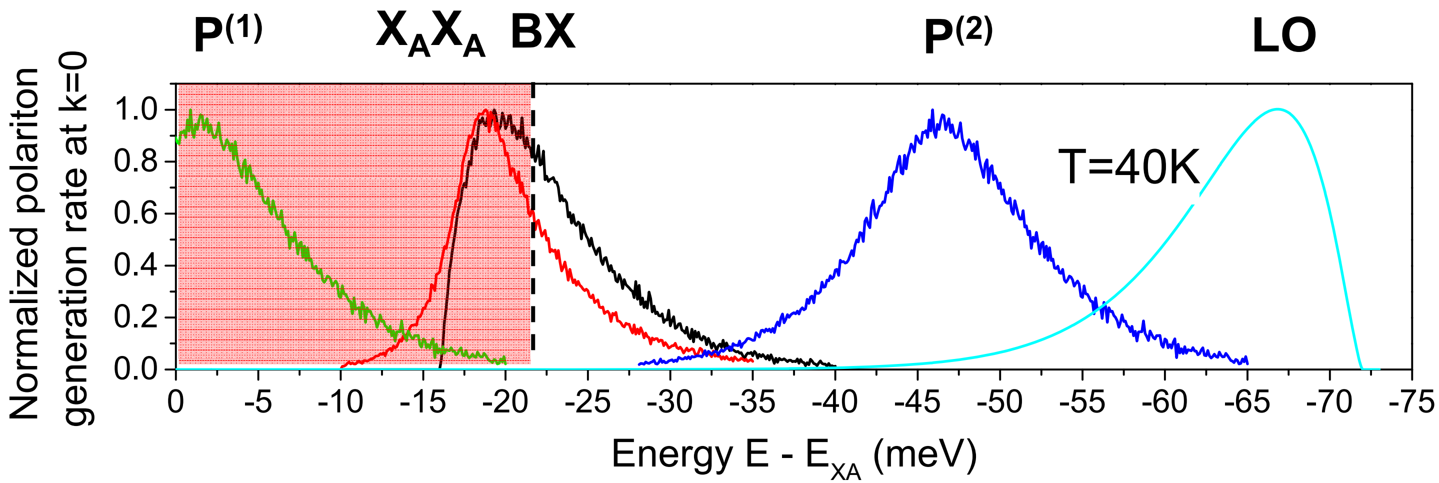


→ **Exciton-like polaritons :**

- >15x heavier than « light polaritons »
- Still 1000x lighter than exciton

Excitation of a transient condensate under pulsed excitations



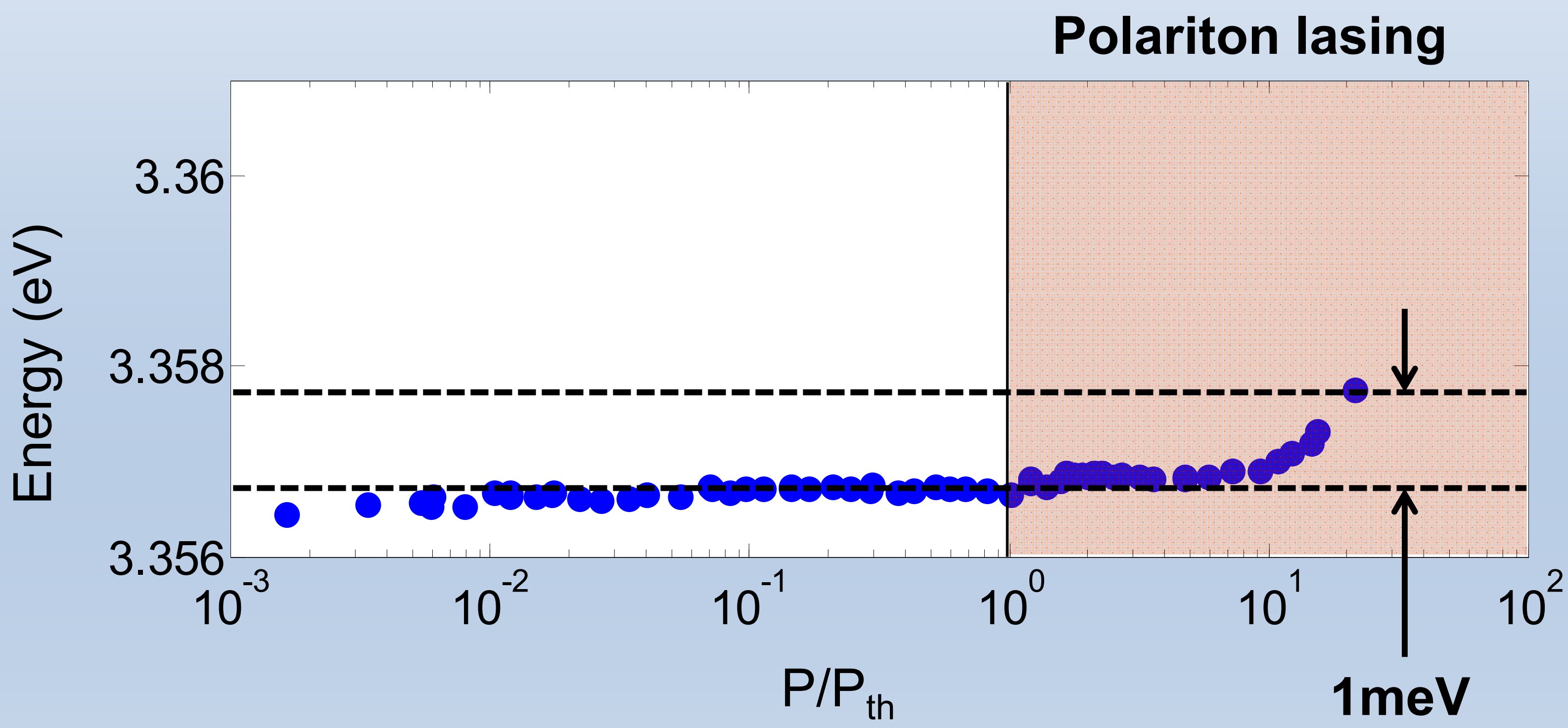


- Classical Monte-Carlo simulation to model 2-particles scattering within the reservoir

→ Free exciton scattering is excluded ($P^{(1)}$, $P^{(2)}$)

→ LO relaxation is excluded (LO)

Excitation of a transient condensate under pulsed excitations



<200µeV blueshift up to $10P_{th}$

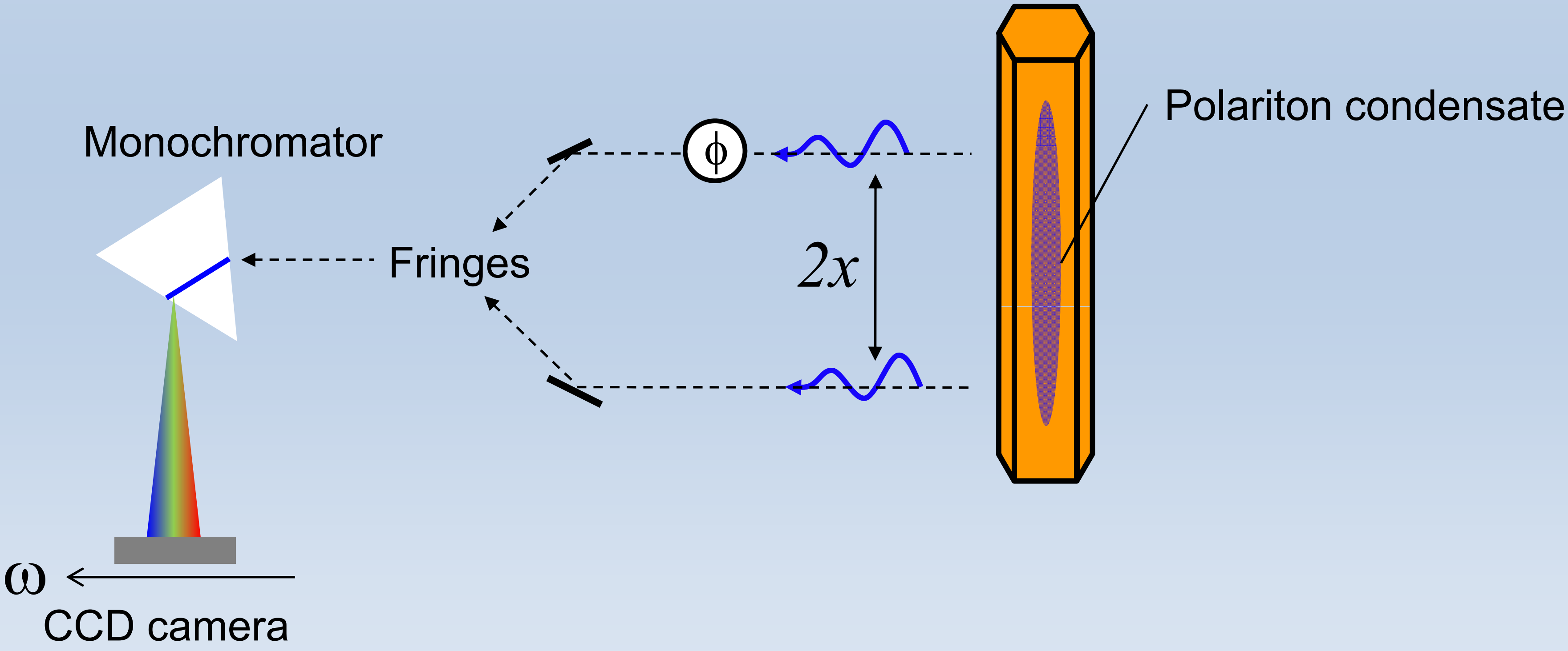
Large excitonic binding energy

Large excitonic medium volume

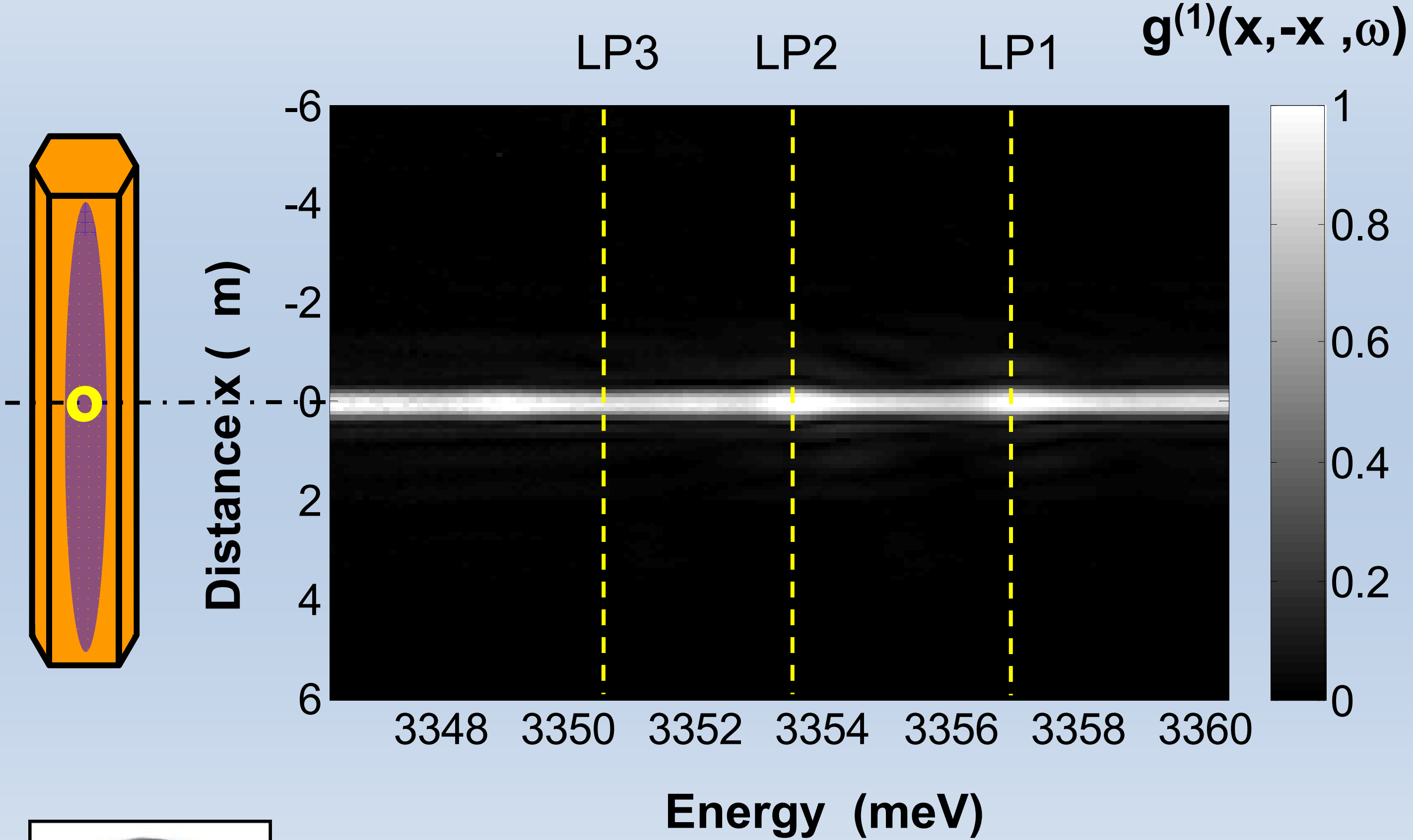
→ **Weak interactions**

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

Measurement of $g^{(1)}(x,-x,\omega)$
→ Imaging Michelson interferometer

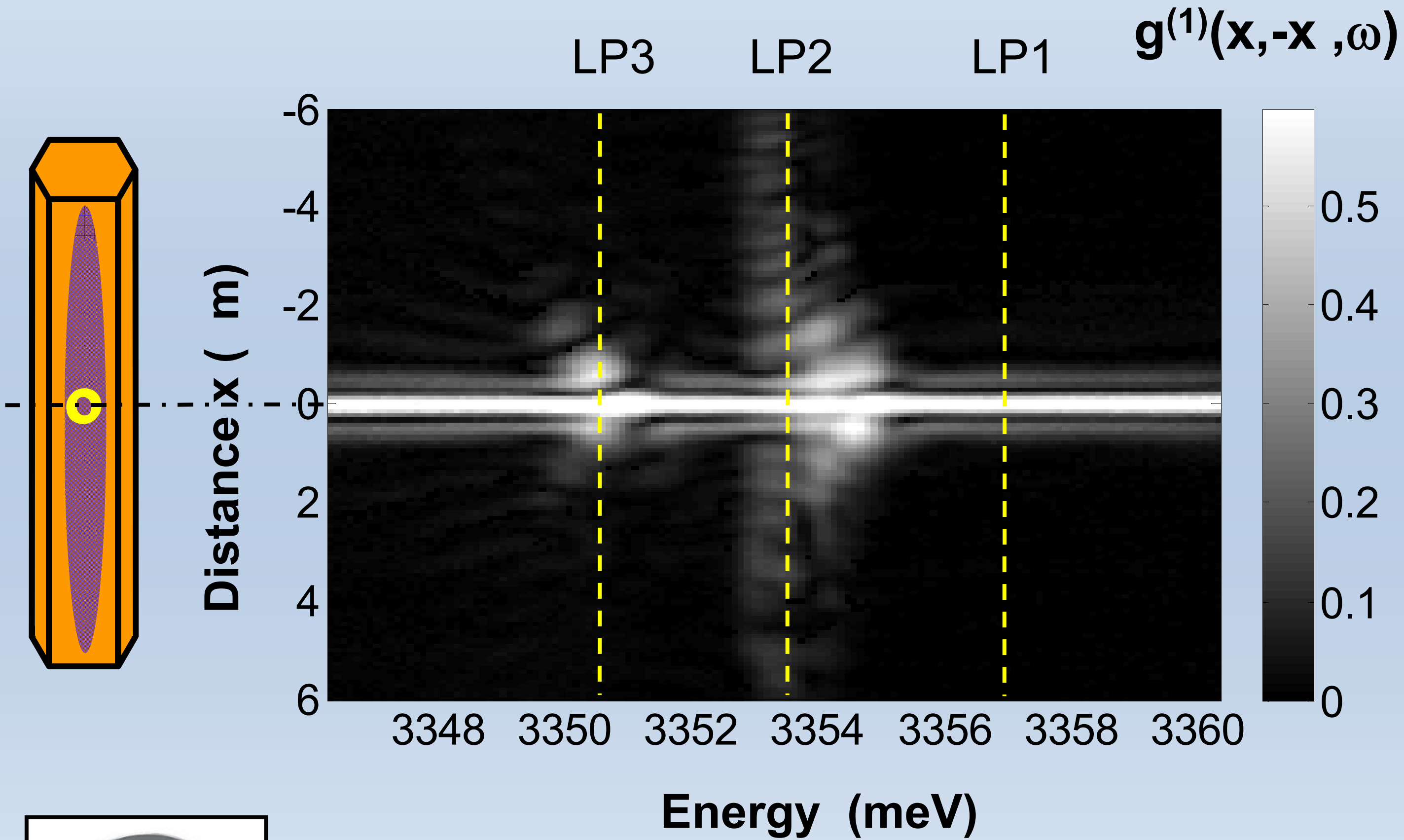


Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$



Below threshold

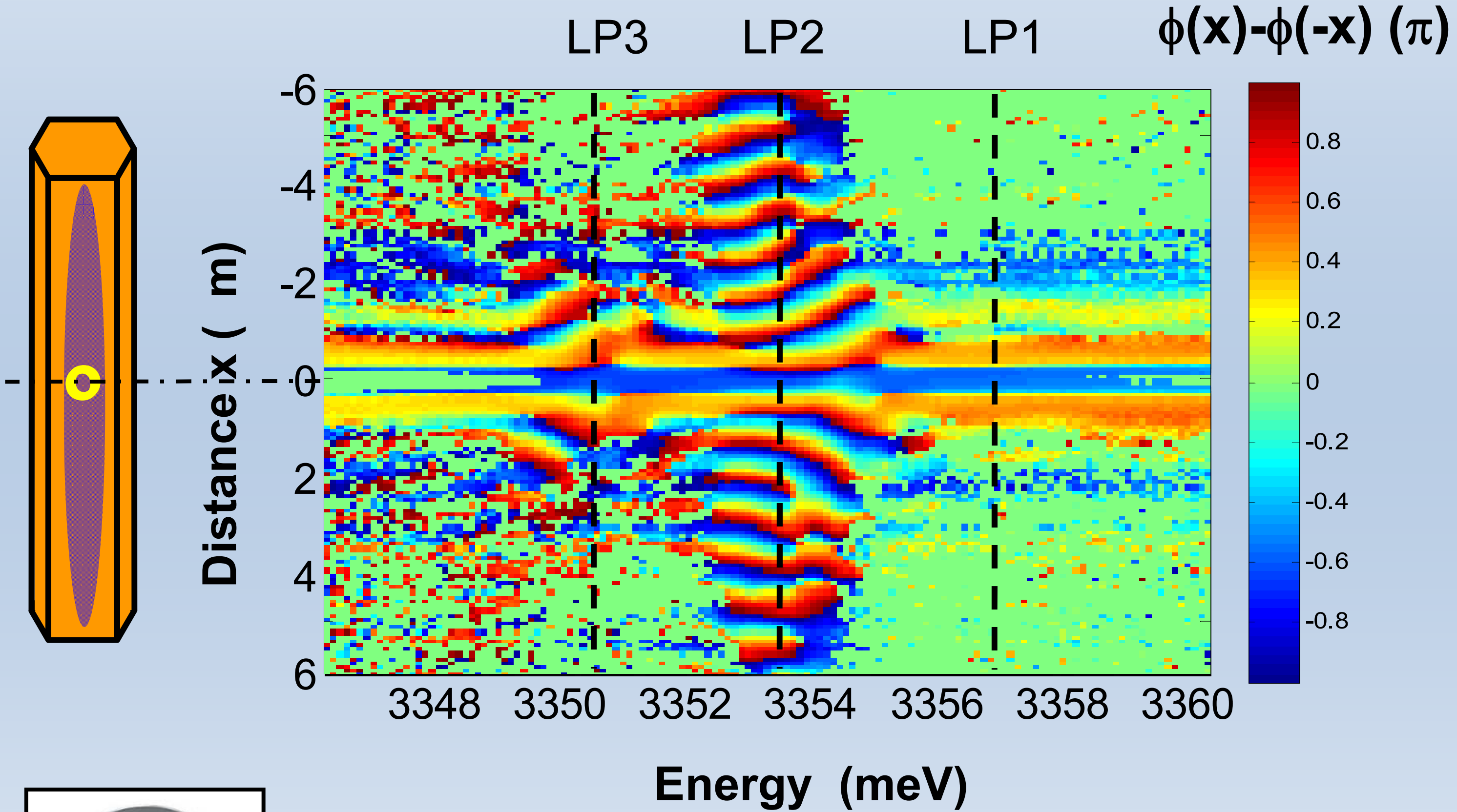
Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$



Above threshold

- Multimode condensate
- Long range correlations build up

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$



Above threshold

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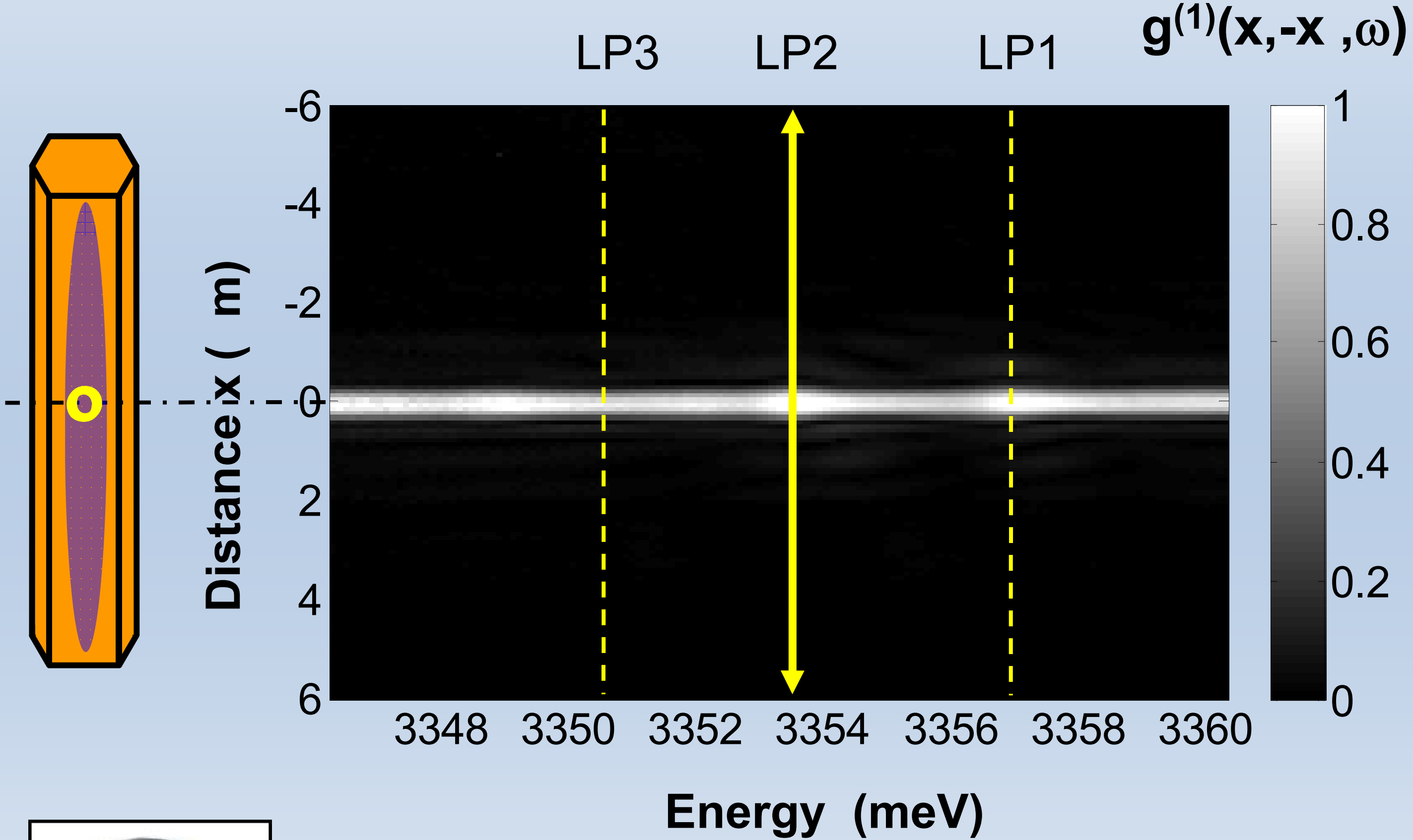

Below threshold

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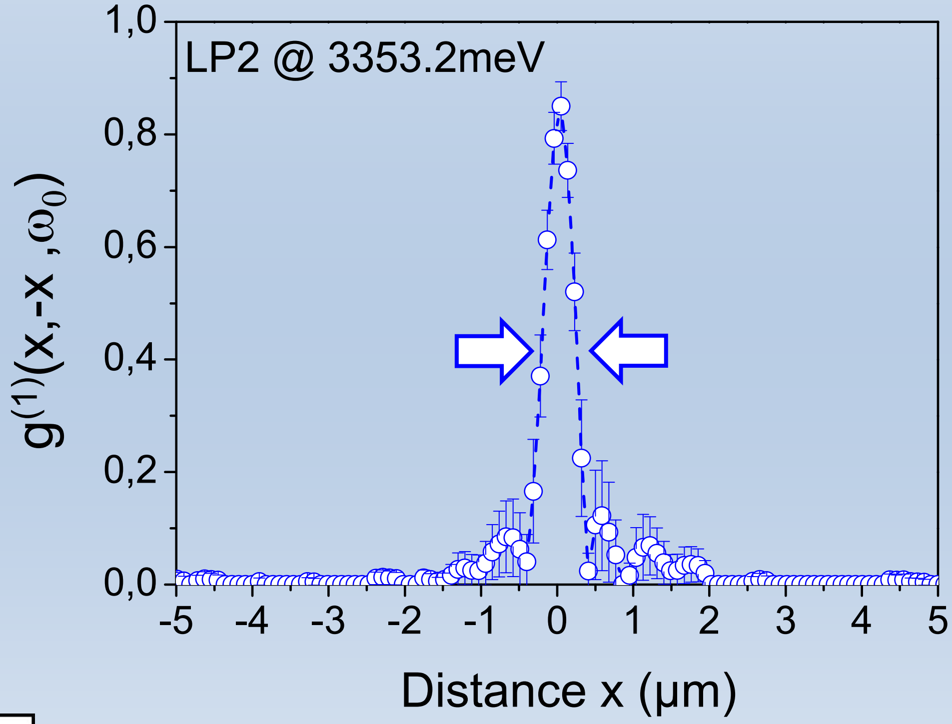
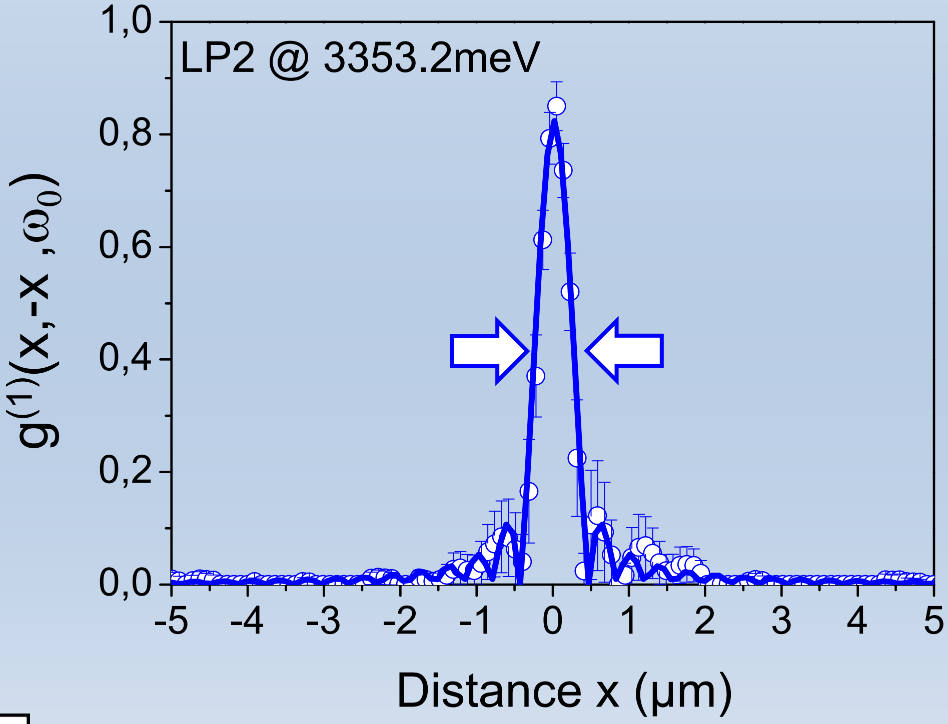


FWHM=0.45µm

Below threshold

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$



FWHM=0.45µm

Matches the objective point spread function :

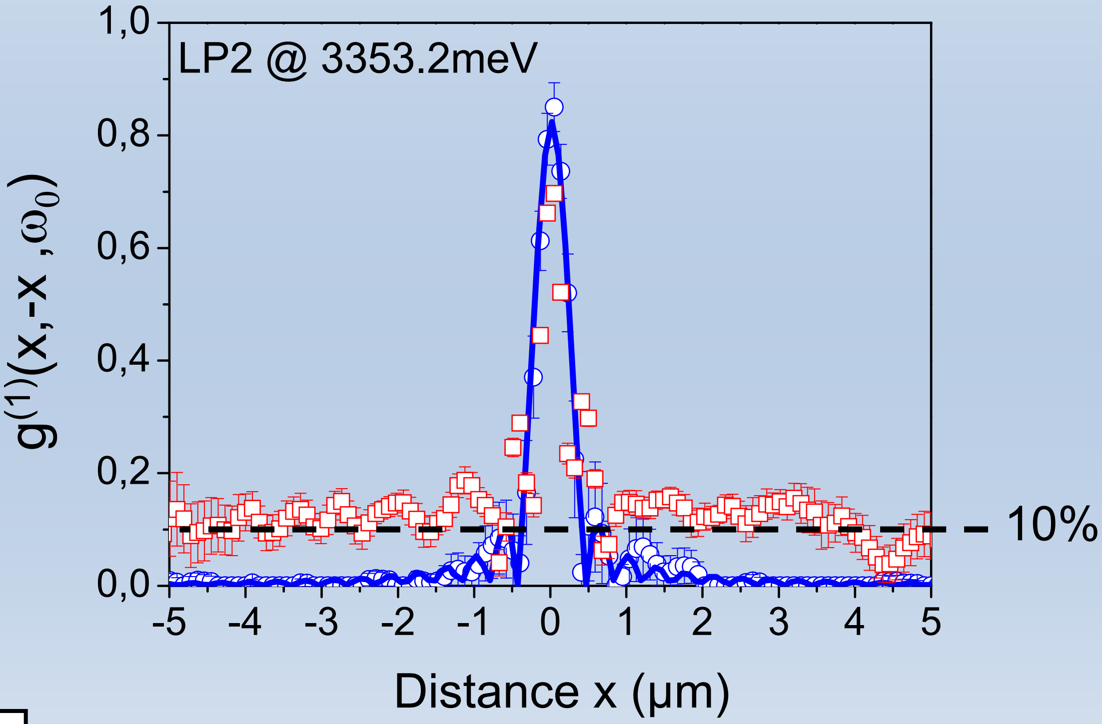
$$g_0^{(1)}(x,-x) = \frac{2\,J_1(2\pi x NA)}{2\pi x NA}$$

Below threshold

→ Coherence length < 0.45µm

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

~**10%** correlation build-up over **10µm** range
- Not limited by excitation spot



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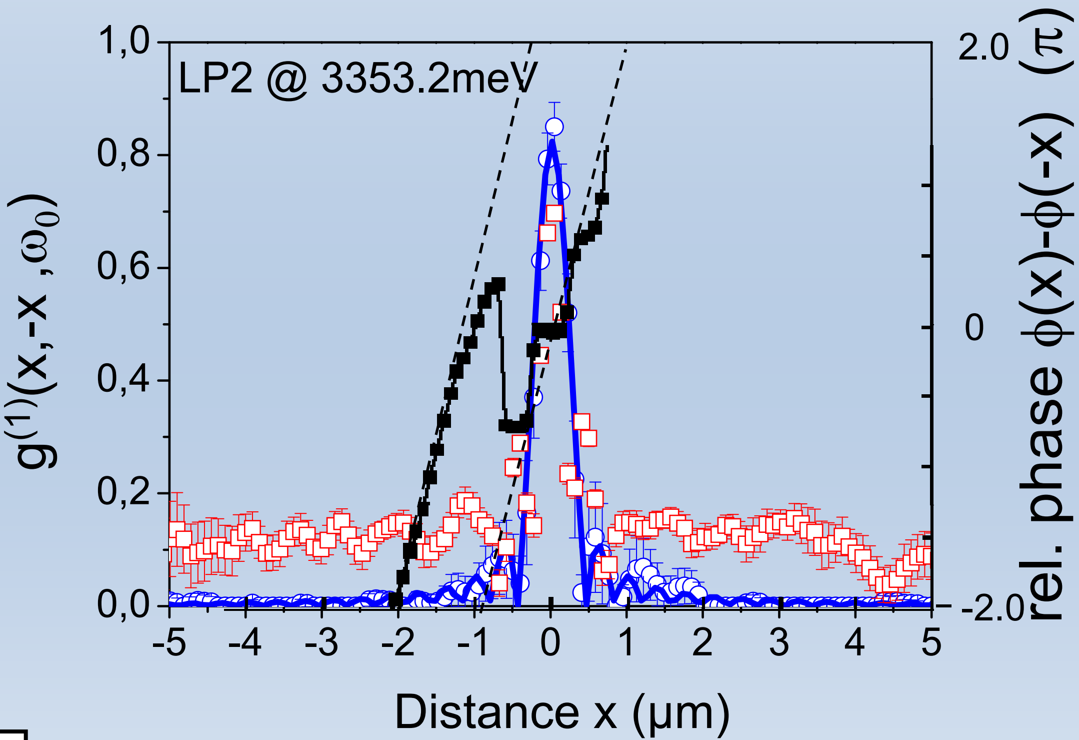
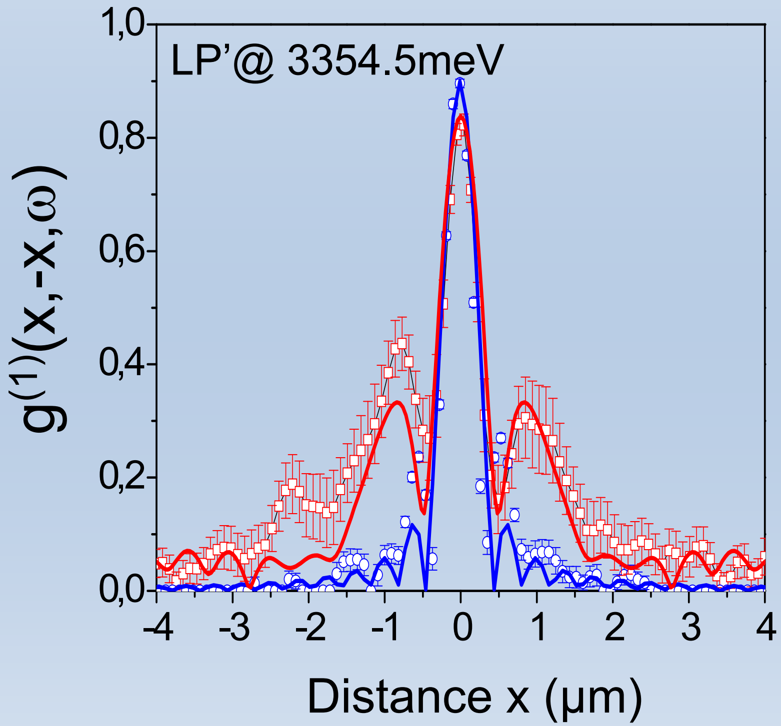


Above threshold

- $\phi(x)=\mathbf{k_a}x+f_{even}(x)$ → Condensate propagates with avg. momentum <**k**>=**3.2 rad. m^{-1}**
- Propagation driven by potential gradient

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

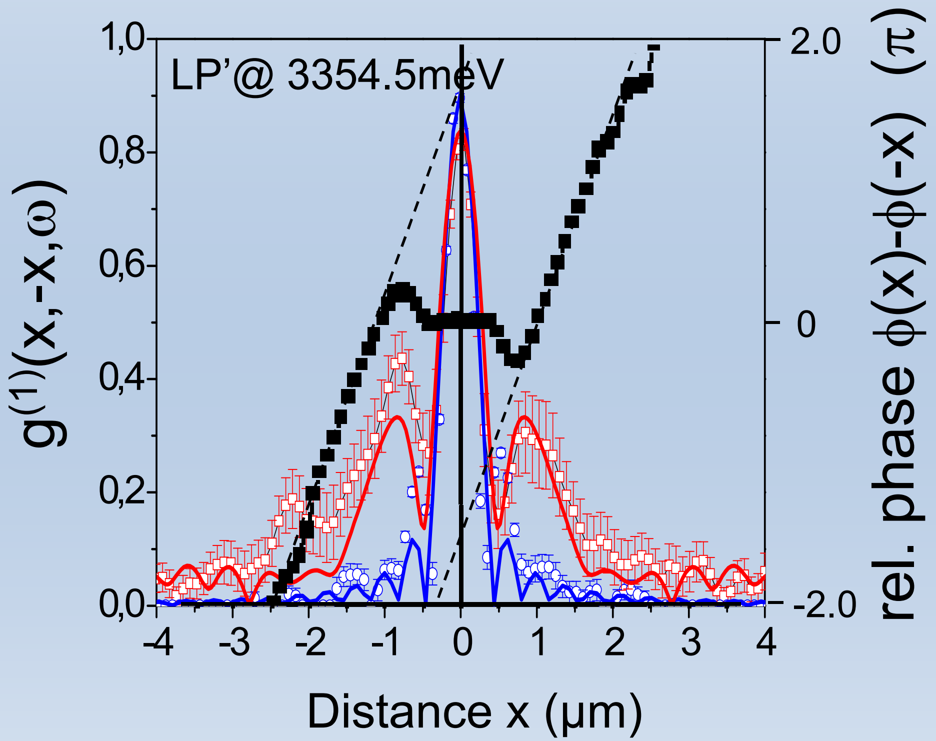
Another realization of disorder



Above threshold

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

Another realization of disorder

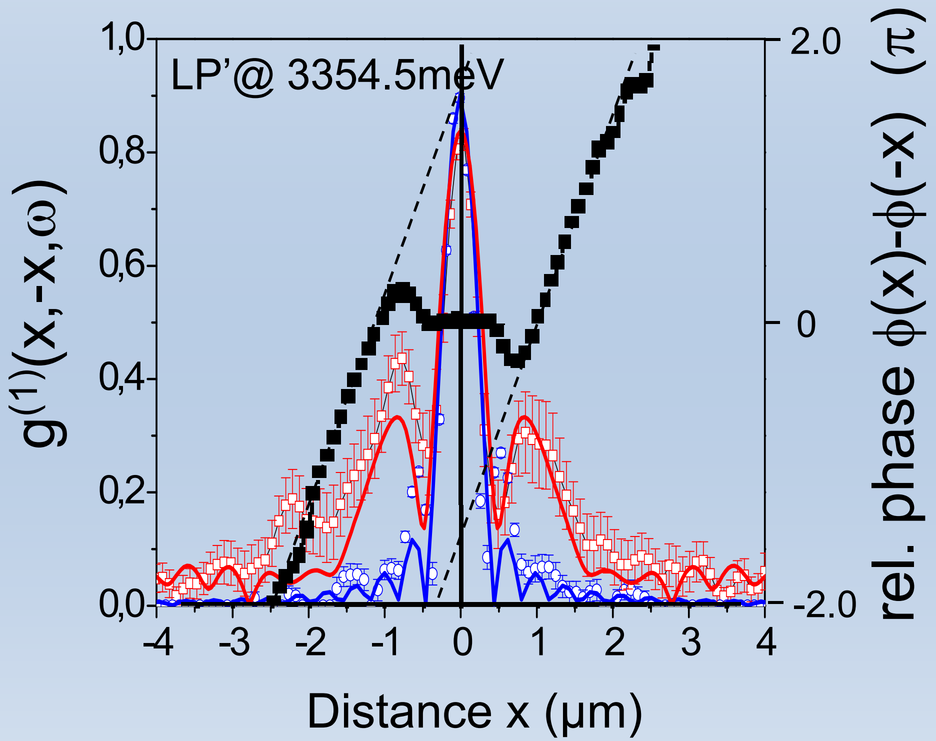


Above threshold

- $\phi(x)=\mathbf{k_a}x+f_{even}(x)$ → Condensate propagates with avg. momentum <**k**>=**2.25 rad. m^{-1}**
- Propagation driven by potential gradient

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

Another realization of disorder



Above threshold

Higher, shorter correlations due to slower propagation

Measurement of first order spatial correlations $g^{(1)}(x,-x,\omega)$

What is the physics governing the measured correlation function $g^{(1)}(x,-x,\omega)$ **?**

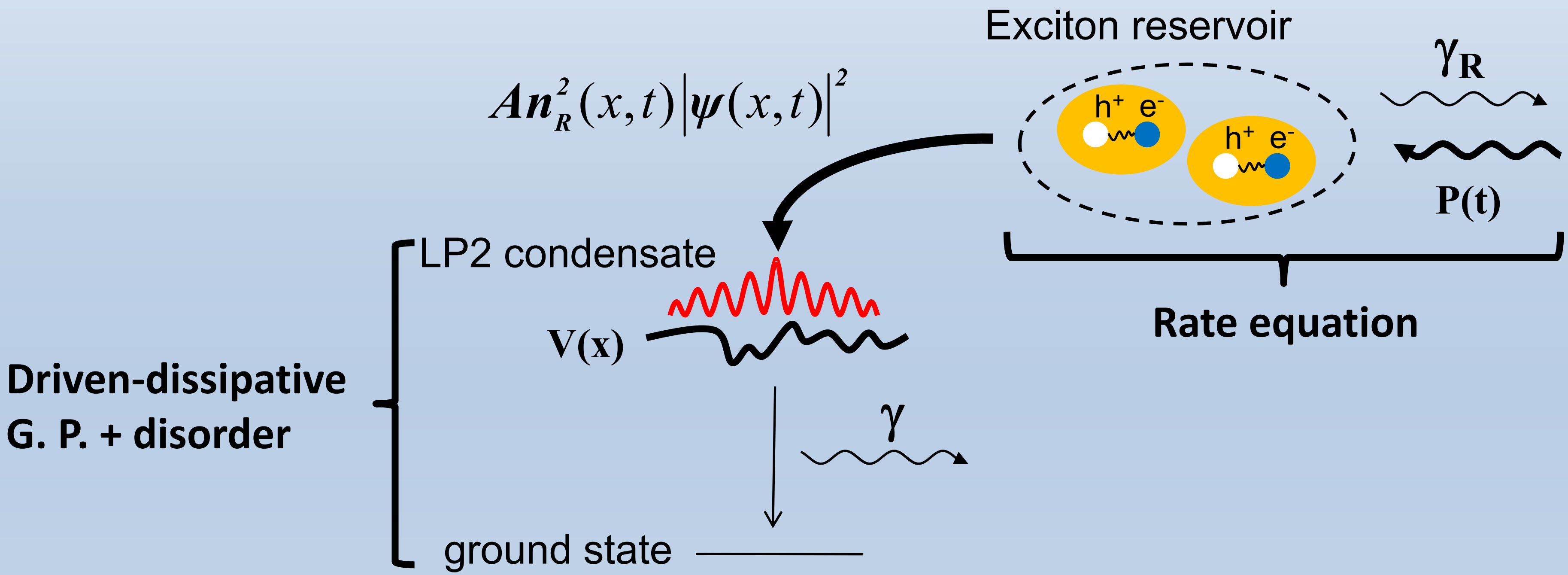
Cf. Talk by Michiel Wouters this afternoon

(1) Gain+loss noise in 1D in the low interaction limit [3,4] + disorder

→ **(2) Time-integrated motion in disorder + decay**

[3] V.N. Gladilin,K. Ji and M. Wouters arXiv:1312.0452v1
[4] A. Chiocchetta and I. Carusotto, EPL **102** 67007 (2013)

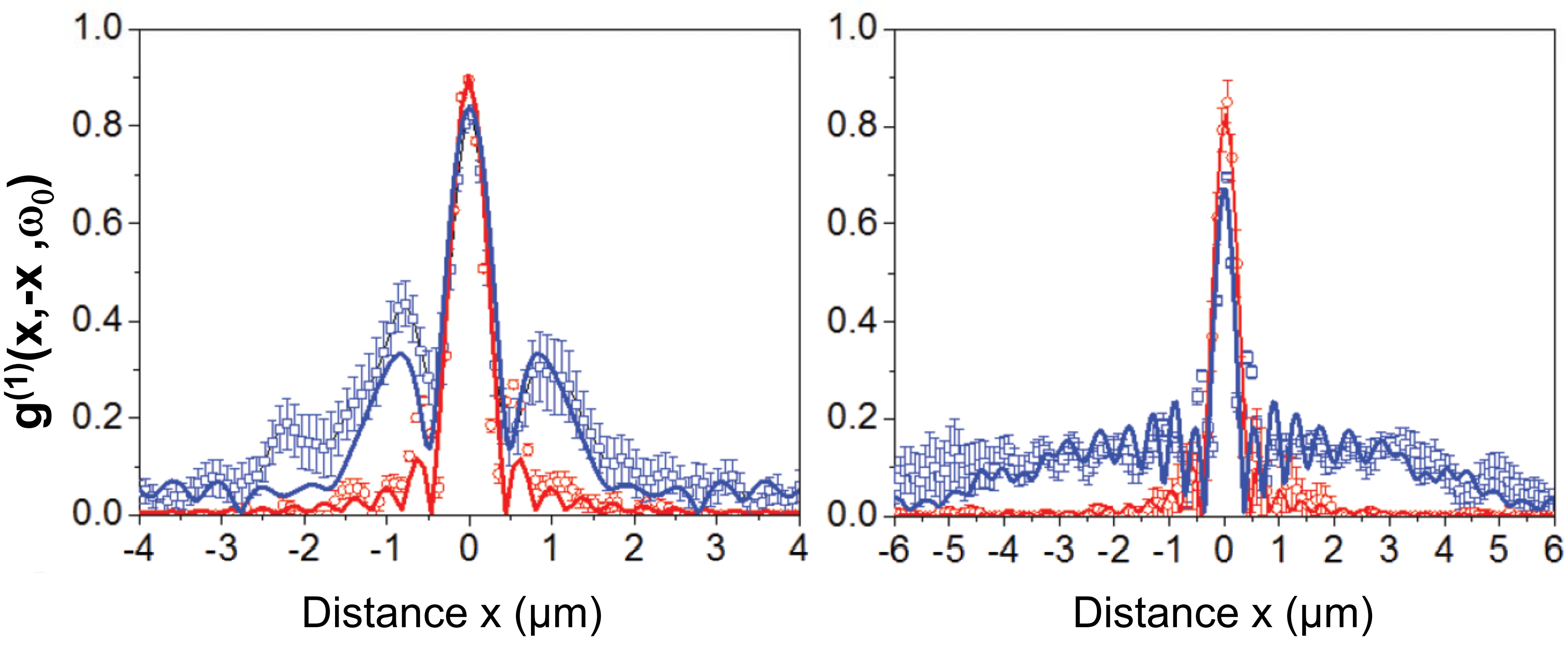
Model for time-integrated 1D condensate motion in disorder: mean-field approach



1D mean-field model [5]
- Pulsed excitation
→ Time integrated correlations

[5] M. Wouters and I. Carusotto, Phys. Rev. Lett. **99** 140402 (2007)

Model for time-integrated 1D condensate motion in disorder: mean-field approach



Decay fixed by :

- Condensate motion in disorder

- **Negligible** interactions
- Disorder **dominates over lifetime**

Conclusion

- Generation of a **transient quasi-excitonic 1D condensate**
- **10µm correlation length** at threshold in spite of much heavier polaritons.
- Spatial phase correlation properties mostly determined by **time-integrated propagation in disorder**.
- Vanishing interactions at threshold.

Perspective :

- Look for signature of gain/loss induced noise in the correlation decay
- Enter the steady-state 1D interacting regime

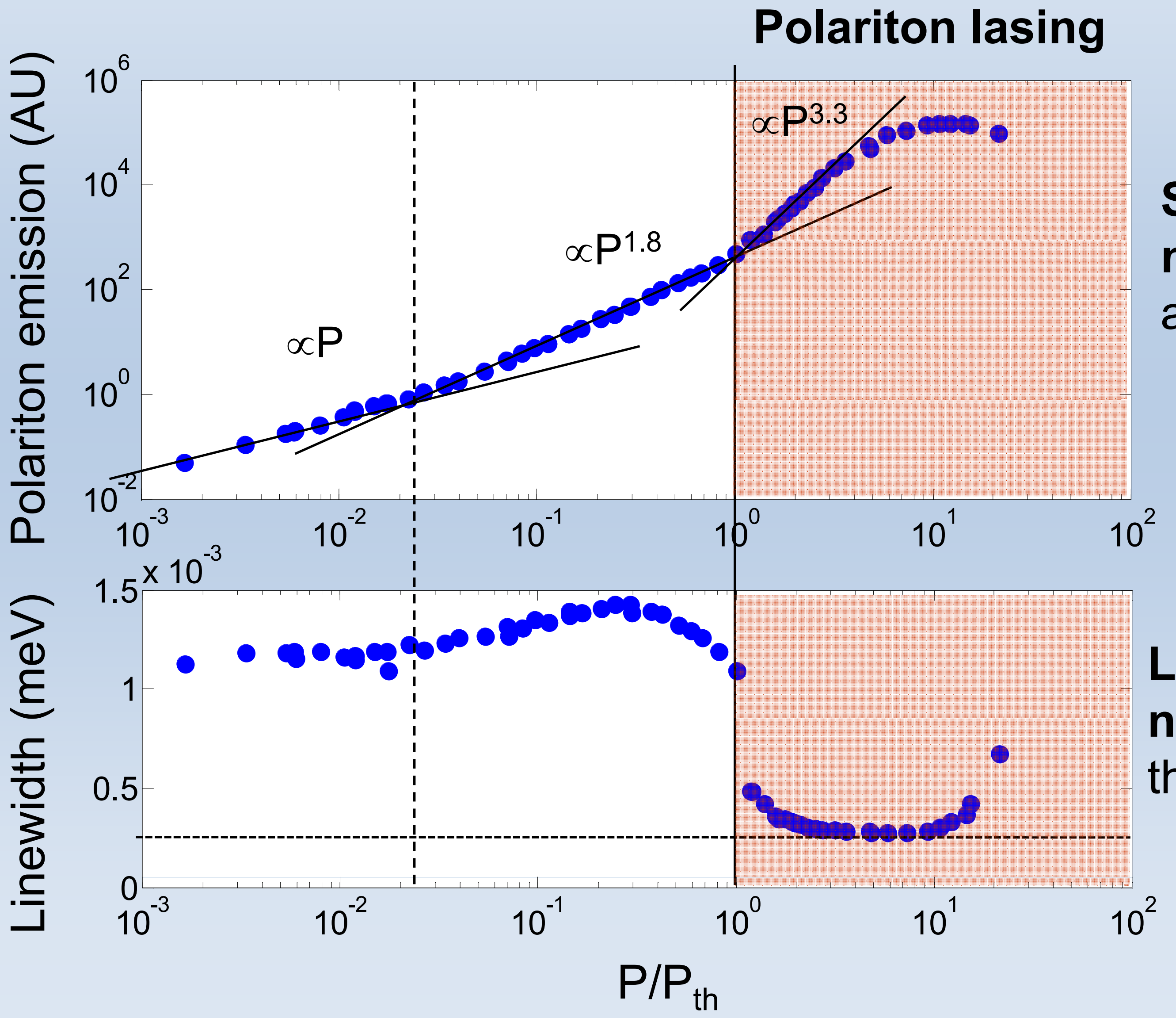
Acknowledgments

F. Médard

A. Trichet

S. Datta

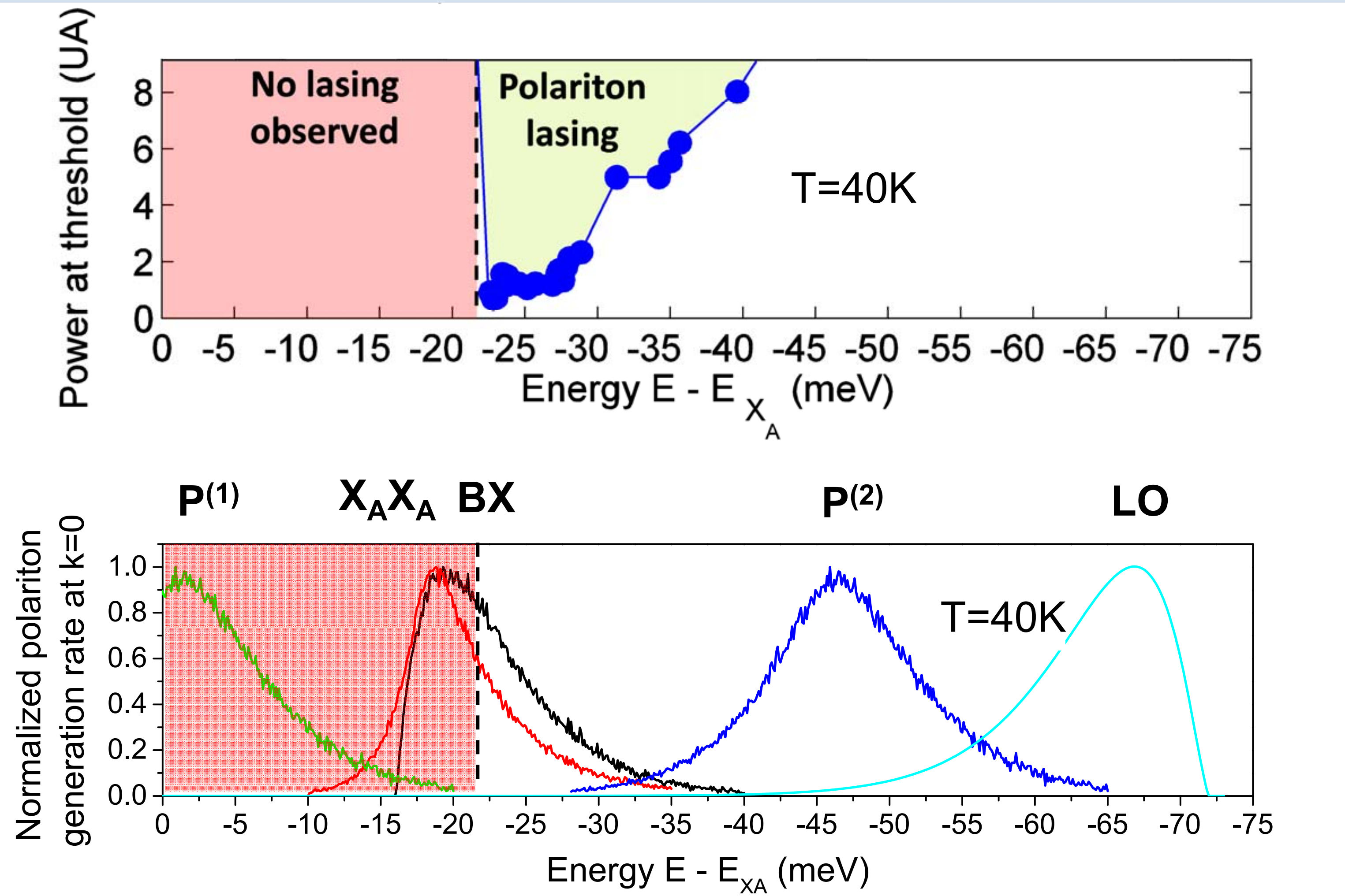
Excitation of a transient condensate under pulsed excitations



Strong nonlinearity at threshold

Linewidth narrowing at threshold

Gain mechanism

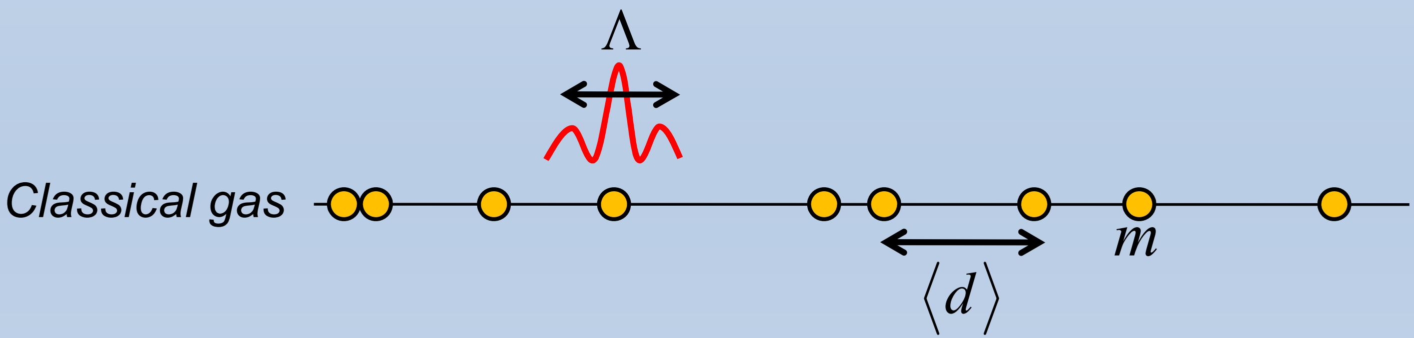


- Classical Monte-Carlo simulation to model scattering within the reservoir
- Free exciton scattering is excluded ($P^{(1)}$, $P^{(2)}$)
- LO relaxation is excluded (LO)

Quantum degeneracy of Bose gases

- Criterion at thermodynamic equilibrium

Interparticle distance $\langle d \rangle \approx \dfrac{h}{\sqrt{2\pi m k T}} = \Lambda_{dB}$



Quantum degeneracy of Bose gases

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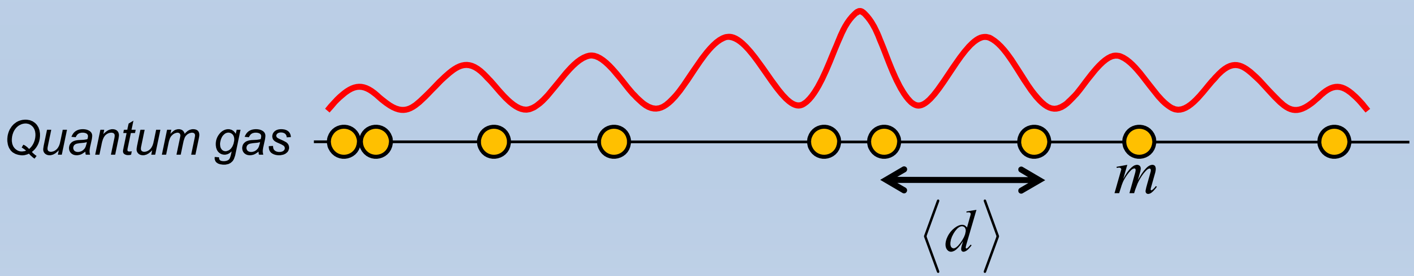
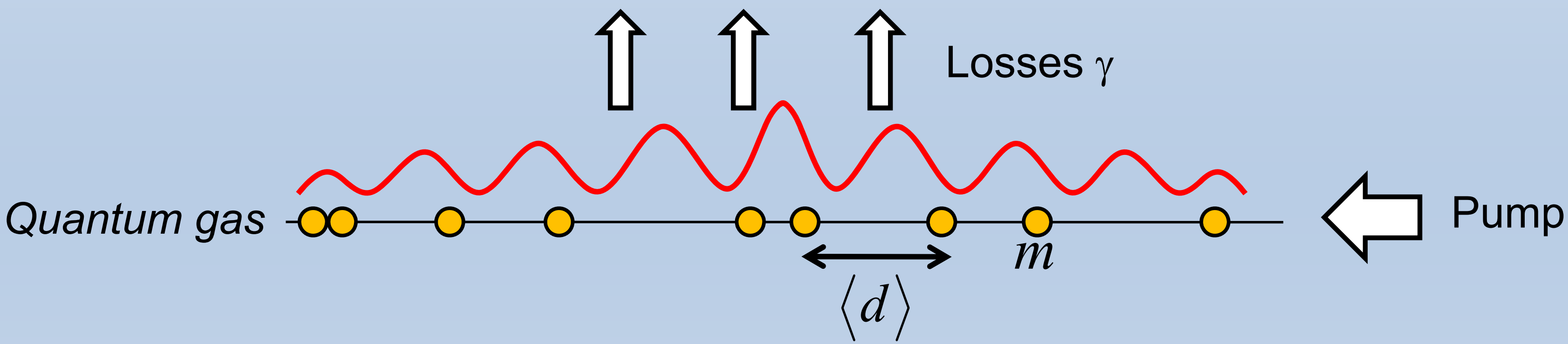


Quantum degeneracy achieved for
- **Low mass**
- low temperature
- Large density

Quantum degeneracy of Bose gases

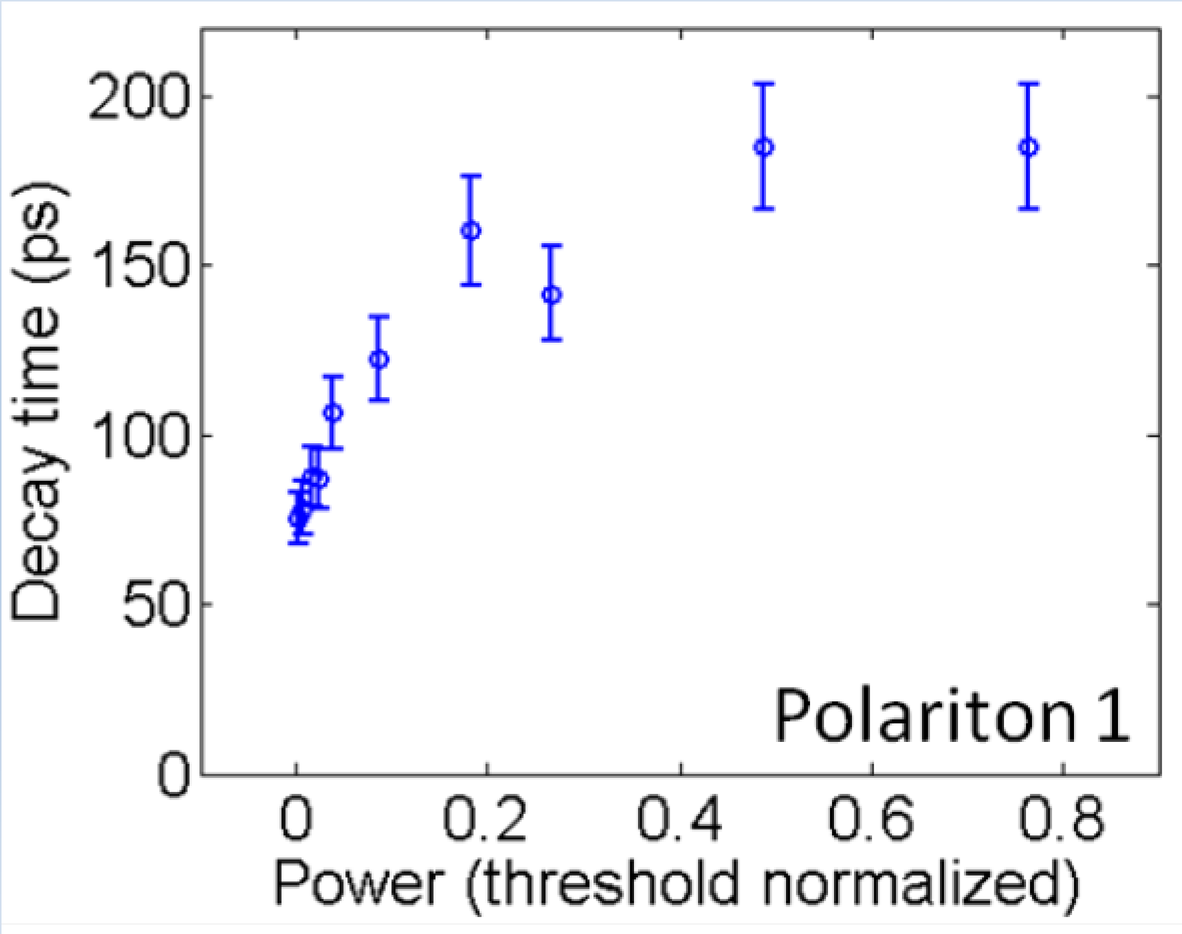
- **Driven-dissipative** condensate (laser) in k=0

$$\Lambda_{DD} = 1.3 \frac{h}{\sqrt{2\pi m \gamma}}$$



→ Quick summary
At *or* out-of-equilibrium, mass always matters

Quantum degeneracy achieved for
- **Low mass**
- long lifetime
- Large density


Decay time (ps)
200
150
100
50
0
0
0.2
0.4
0.6
0.8
Power (threshold normalized)
Polariton 1

Brève discussion

→ La position  est la source du condensat :
Preuve : en positionnant un petit spot dessus on genere toute la partie propagative
À contrario si on place le spot sur la partie propagative on n'excite rien
→ La direction de propagation n'est donc pas ambigue

→La propagation du condensat se fait à vitesse finie
Preuve : le comportement de l'inclinaision des franges sur l'image de phase:
le délai entre les points z et –z vaux tau=(z-z0)/vg(z)-(-z-z0)/vg(-z) où z0 est le point d'autocorrelation. on observe des franges *spectrales* de periode infini en z0 (gradient de phase purement selon z), et de periode de plus en plus courte quand (z-z0) augmente (i.e. gradient de phase selon lambda augmente avec z-z0). On peut en déduire le DeltaVg entre paires de points (z-z0) et (-z-z0) du condensat

→ L'impulsion k_z du condensat est non-nulle mais pas nécessairement constante
Preuve : 1- observation direct dans l'espace des kz.
2– observation directe par l'interferogramme. Par contre dans ce cas là on n'accède qu'à la difference de phase entre les points z-z0 et -z-z0, on peut donc rajouter n'importe quelle fonction (approximativement) paire F à la phase du condensat : i.e. phi(z)=k_z(z-z0)+F(z-z0). Les résultats sont donc compatible avec l'hypothèse de la remontée d'un potentiel (i.e. k_z pas constant mais diminuant au cours de la propagation).