



The Abdus Salam
International Centre for Theoretical Physics



SMR 1666 - 14

**SCHOOL ON QUANTUM PHASE TRANSITIONS
AND
NON-EQUILIBRIUM PHENOMENA IN COLD ATOMIC GASES**

11 - 22 July 2005

To higher dimensions...

... and beyond!

Presented by:

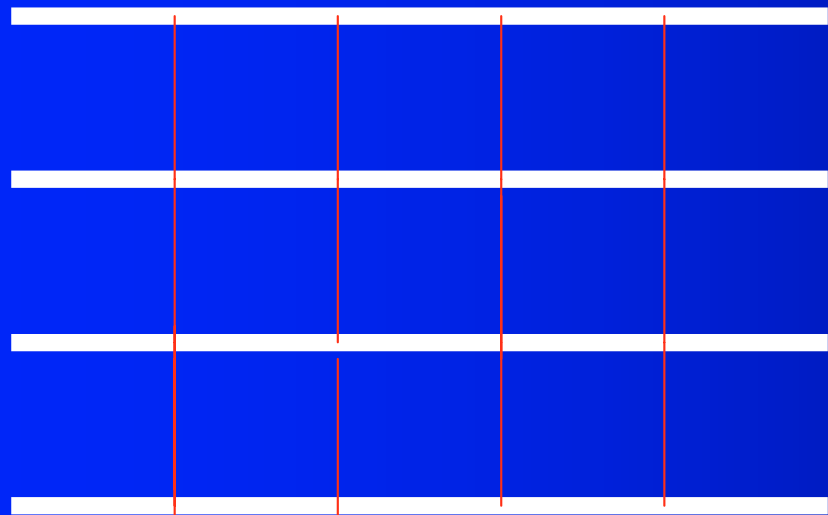
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To higher dimensions...

... and beyond !

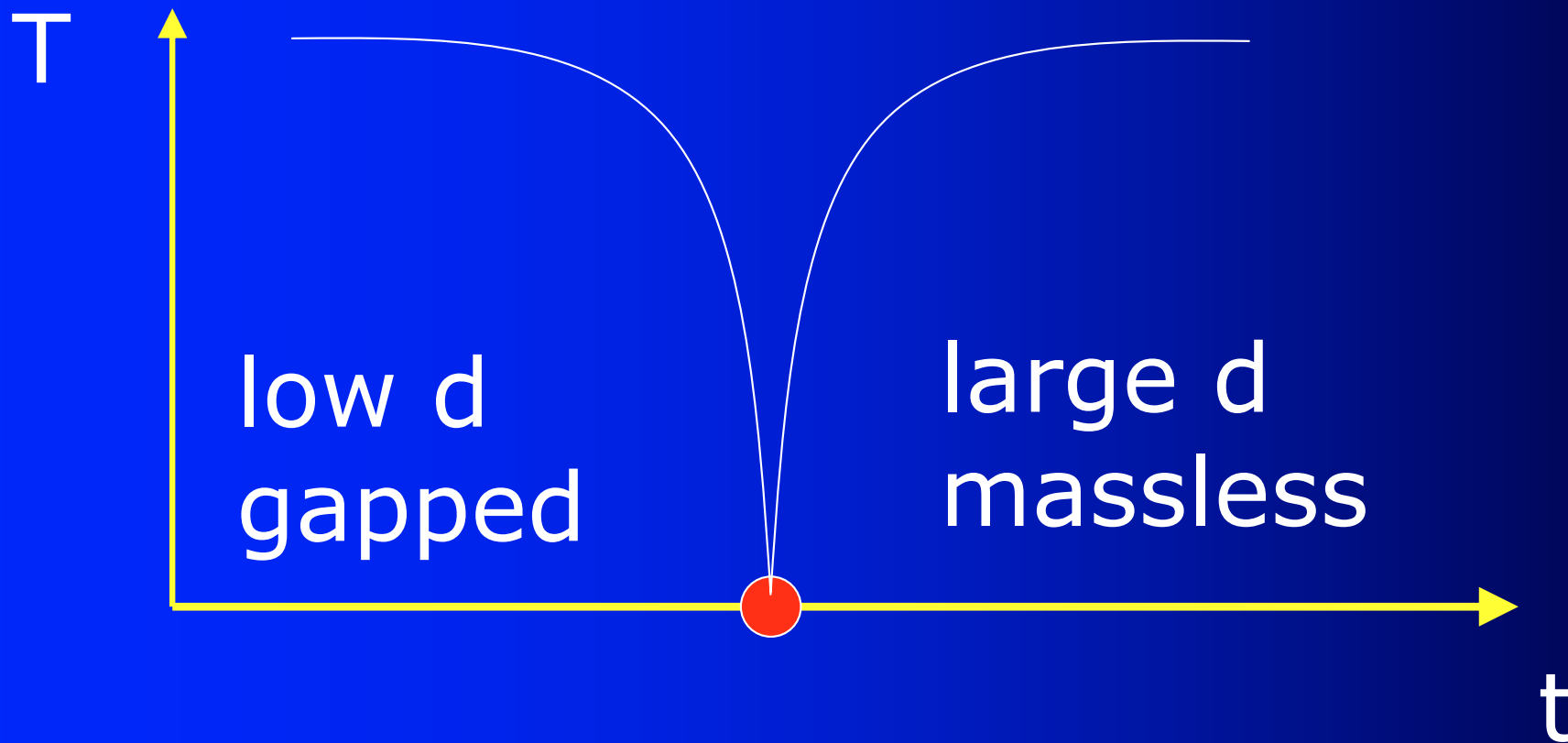
- Interaction effects vary enormously with dimension



Dimensional
Crossover



- Even more interesting : lower dimensional phase gapped



Quantum phase transition :
deconfinement

- Generic scenario for many physical systems
- Questions :
- Nature of the transition ?
- Physical properties in the critical regime
- Impact of the low-d phase on the massless phase

Boson Interchain hopping

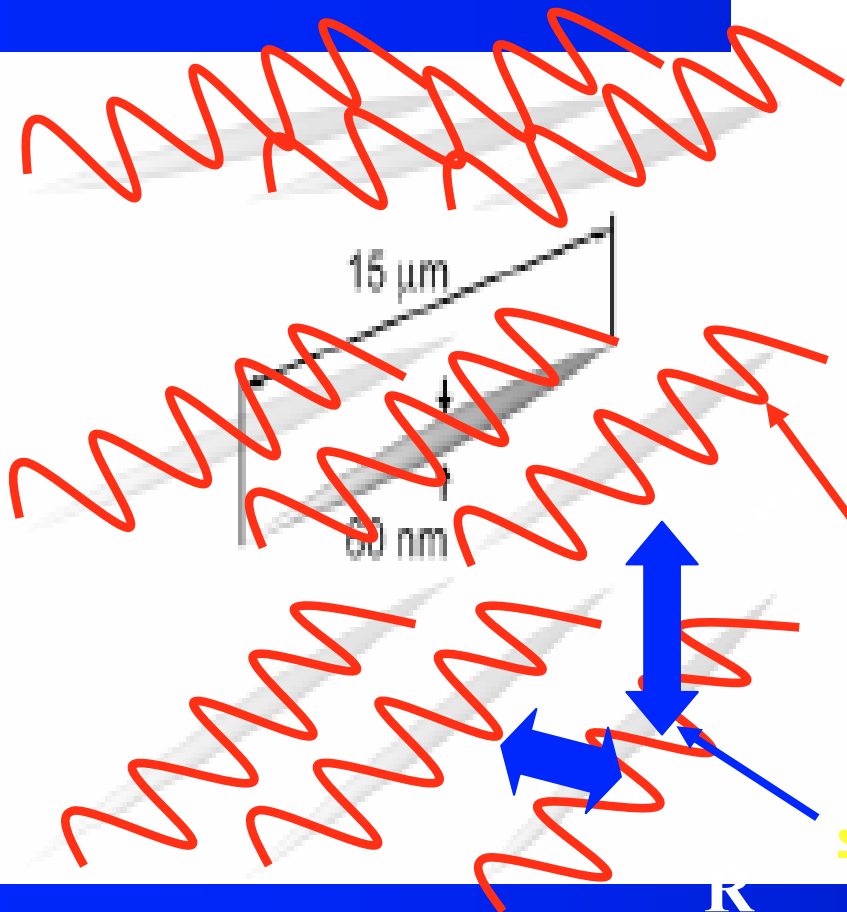
$$-t_{\perp} \sum_{\langle \alpha, \beta \rangle} \int dx \psi_{\alpha}^{\dagger}(x) \psi_{\beta}(x) = -t_{\perp} \rho_0 \int dx e^{i(\theta_{\alpha}(x) - \theta_{\beta}(x))}$$

Wants to order θ on each chain

Competes with Mott potential that wants to order ϕ

Mott vs. Josephson

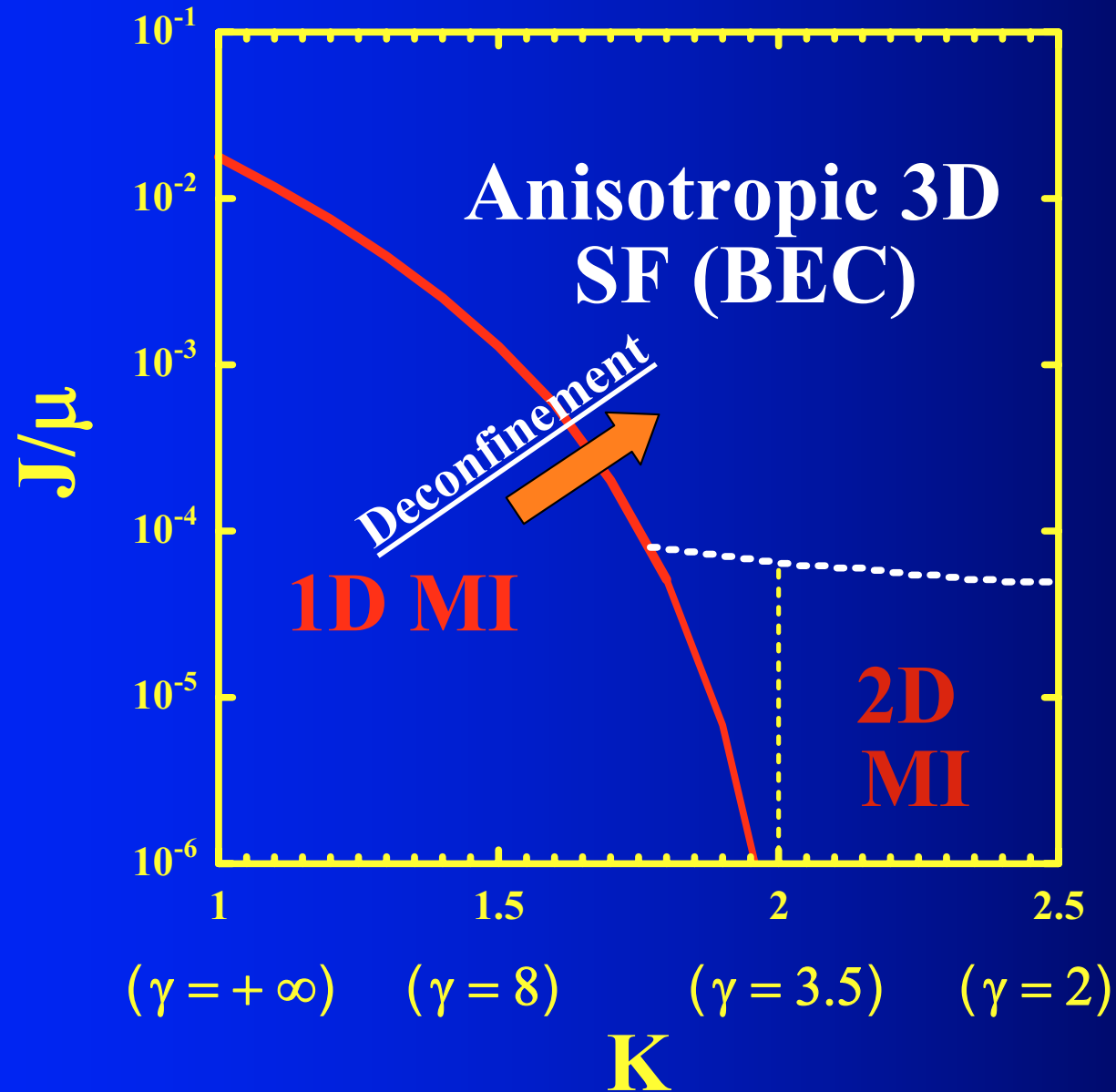
$$\begin{aligned}
 H_{\text{eff}} = & \frac{\hbar v_s}{2\pi} \sum_{\mathbf{R}} \int_0^L dx \left[\frac{1}{K} (\partial_x \phi_{\mathbf{R}}(x))^2 + K (\partial_x \theta_{\mathbf{R}}(x))^2 \right] \\
 & + \frac{\hbar v_s g_u}{2\pi a^2} \sum_{\mathbf{R}} \int_0^L dx \cos(2\phi_{\mathbf{R}}(x) + \delta\pi x) \\
 & - \frac{\hbar v_s g_J}{2\pi a^2} \sum_{\langle \mathbf{R}, \mathbf{R}' \rangle} \int_0^L dx \cos(\theta_{\mathbf{R}}(x) - \theta_{\mathbf{R}'}(x)) \quad (1)
 \end{aligned}$$



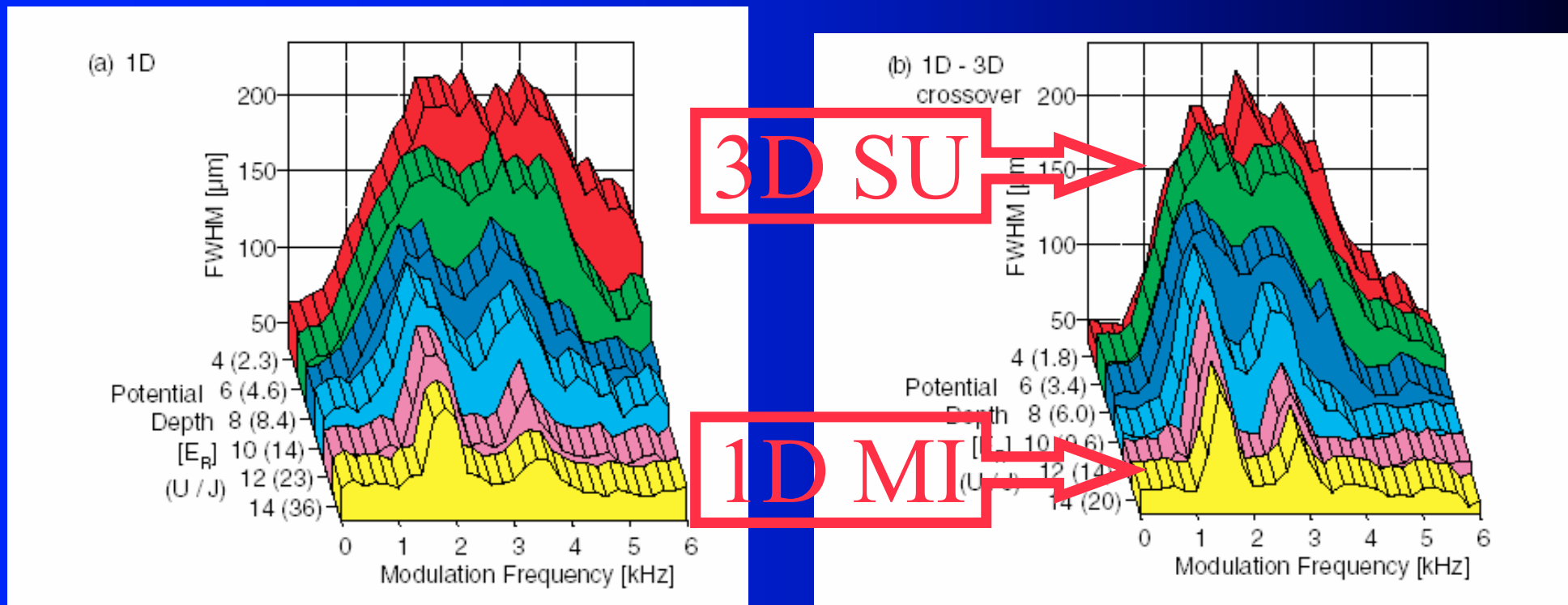
“Mott” potential: localizes atoms

Josephson coupling: delocalizes atoms

Phase diagram for finite tubes



Experiments



T. Stoferle *et al.* PRL 92 130403 (2004)

Coupled fermionic tubes

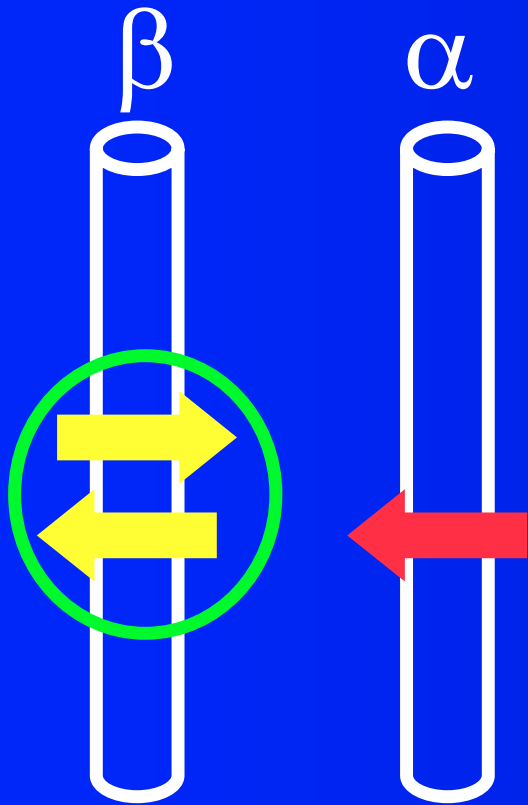
- Very difficult theoretically:

$$H_{\perp} = -t_{\perp} \sum_{\alpha, \beta} \int dx \psi_{\alpha}^{\dagger}(x) \psi_{\beta}(x)$$

- Single particle hopping relevant

(organics, quantum wires etc.)

Spin gap simpler



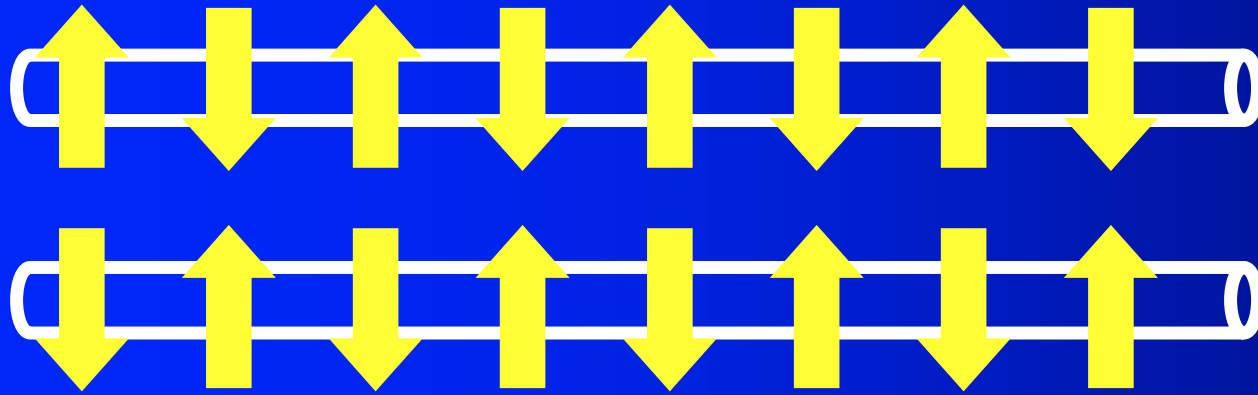
~~$$t_{\perp} \psi_{\alpha, \uparrow}^{\dagger}(x) \psi_{\beta, \uparrow}(x)$$~~

$$t_{\perp}^2 \psi_{\alpha, \uparrow}^{\dagger}(x) \psi_{\beta, \uparrow}(x) \psi_{\beta, \downarrow}^{\dagger}(x) \psi_{\alpha, \downarrow}(x)$$

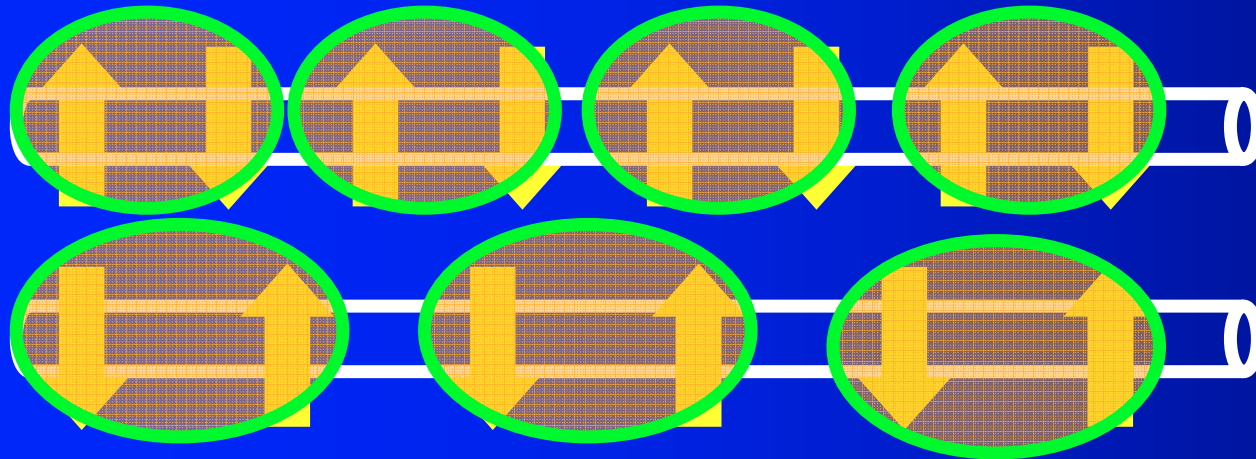
$$t_{\perp}^2 [\vec{S}_{\alpha}(x) \cdot \vec{S}_{\beta}(x) + \rho_{\alpha}(x) \rho_{\beta}(x)]$$

$$t_{\perp}^2 \psi_{\alpha, \uparrow}^{\dagger}(x) \psi_{\beta, \uparrow}(x) \psi_{\alpha, \downarrow}^{\dagger}(x) \psi_{\beta, \downarrow}(x)$$

$$t_{\perp}^2 [O_{\alpha, \text{SU}}^{\dagger} O_{\beta, \text{SU}}^{\dagger}]$$



AF
Order



μ_1

μ_2

Triplet superconductivity
(repulsive interactions)

Conclusions

- Cold atoms exciting systems to explore low dimensional physics
- Strong effects of interactions in 1D (Luttinger, Mott, Deconfinement)
- Exotic phases

Many open questions

- Physics remains to be probed
(correlation functions)
- Novel questions and possibilities:
Disorder, Dynamics, Dimensions
- The sky is the limit !!

