

BME Nanoelectronics

Szabolcs Csonka (Department of Physics, BME)

Exotic quantum states & Mesoscopic QED

~~Zero energy bound states in SC-Qdot system~~

HunQuTech workshop, Nokia Bell Labs, 30/05/2019

nanoelectronics.physics.bme.hu

Logos for funding agencies: AZ INNOVÁCIÓ LENDÜLET, AZ NKFÍI ALAPBól MEGVALÓSULÓ PROJEKT, QUANTERA ERA-NET CoNet in Quantum Technologies, FLAG-ERA European Research Council Executive Agency, Marie Curie Actions, ERC, Lendület program, and Százszáz tízezer főkötetűtől kezdődően.

Exotic quantum states

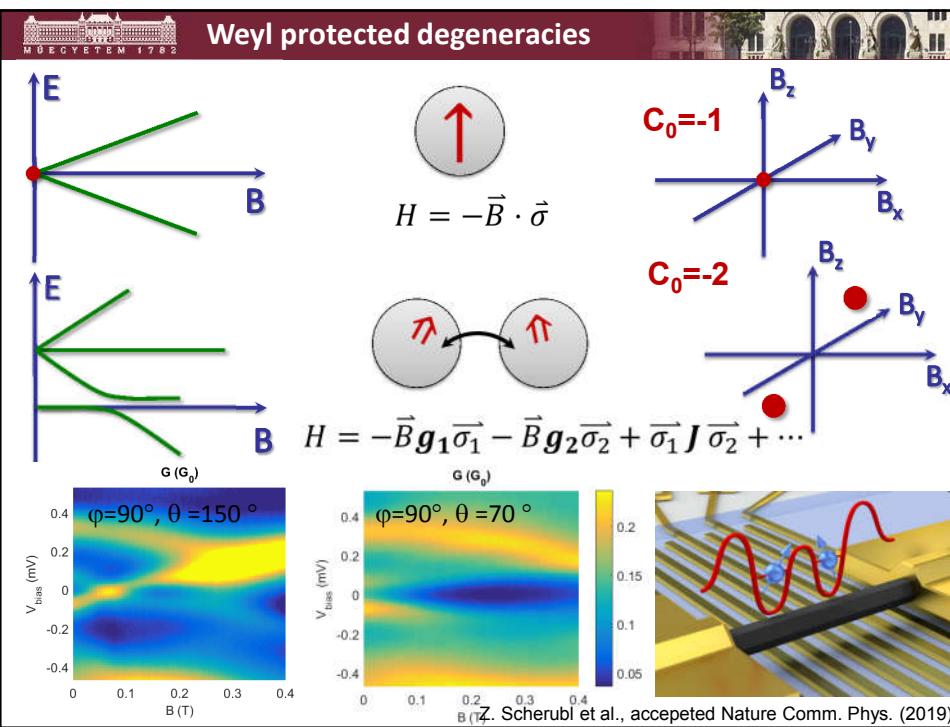
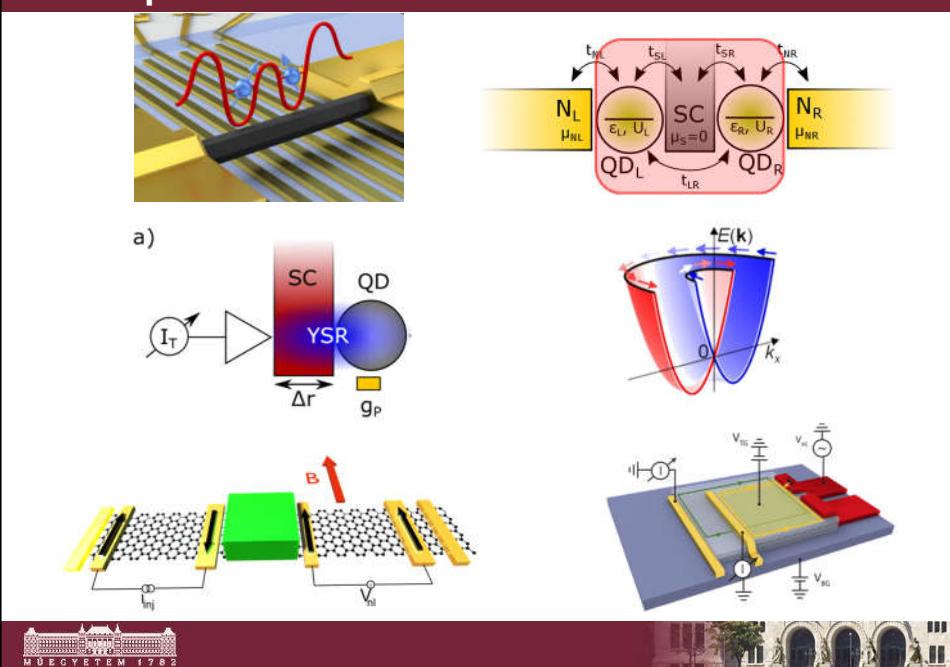
QUANTERA ERA-NET CoNet in Quantum Technologies, FLAG-ERA, European Union flag

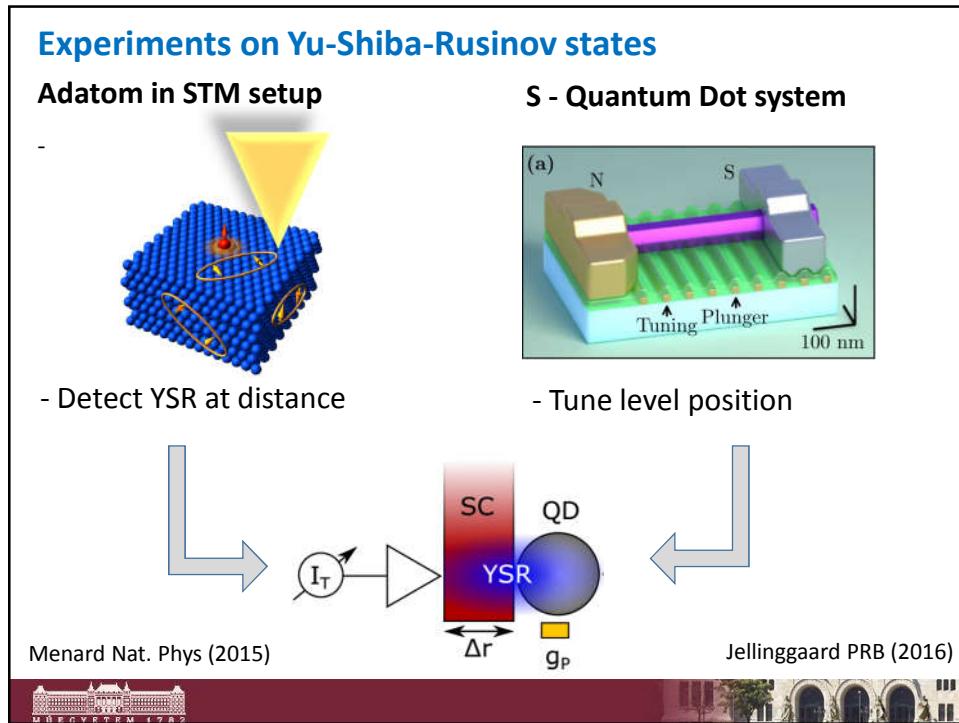
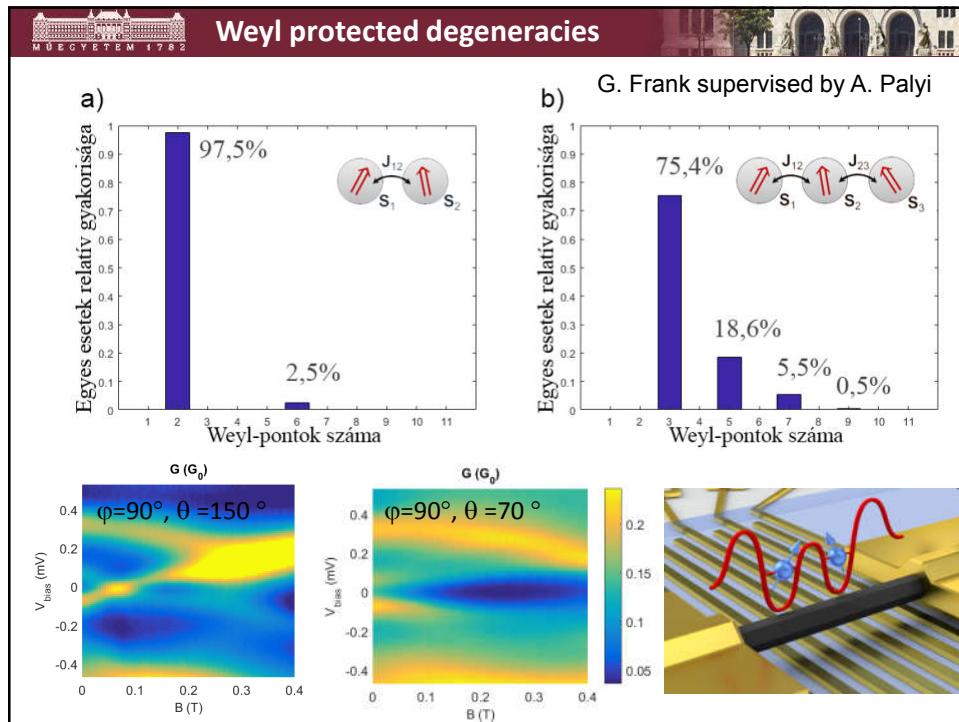
Mesoscopic quantum electrodynamics

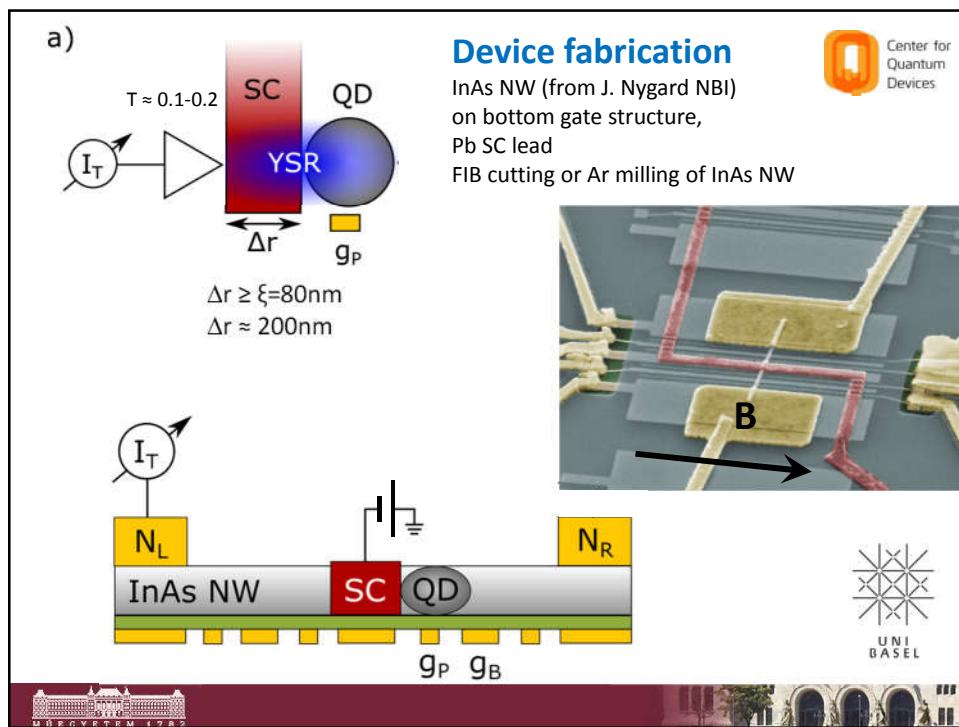
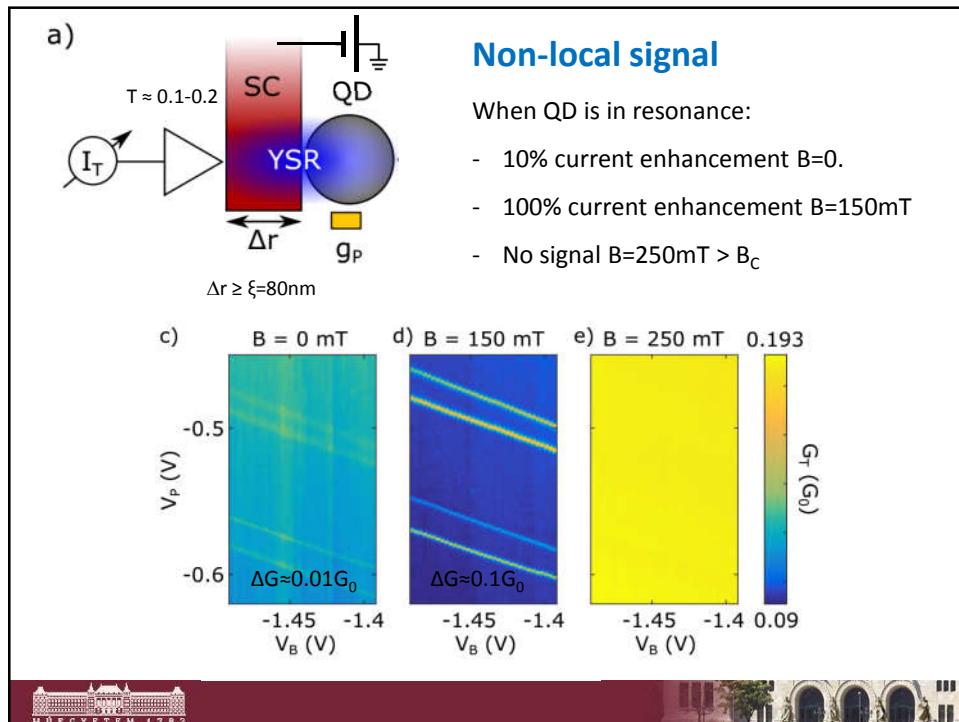
European Union flag

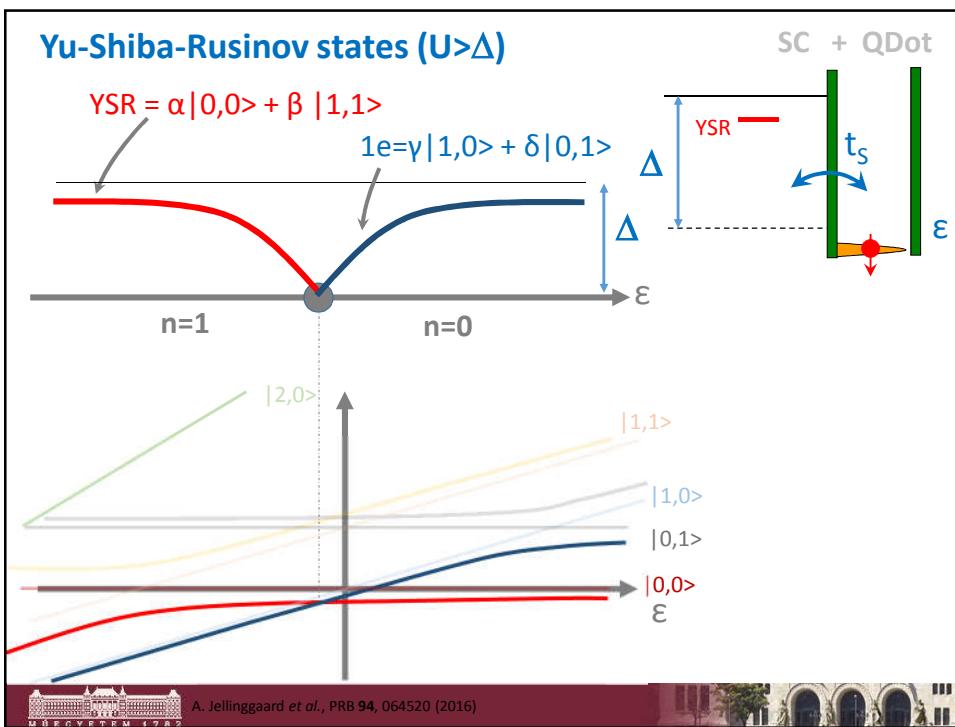
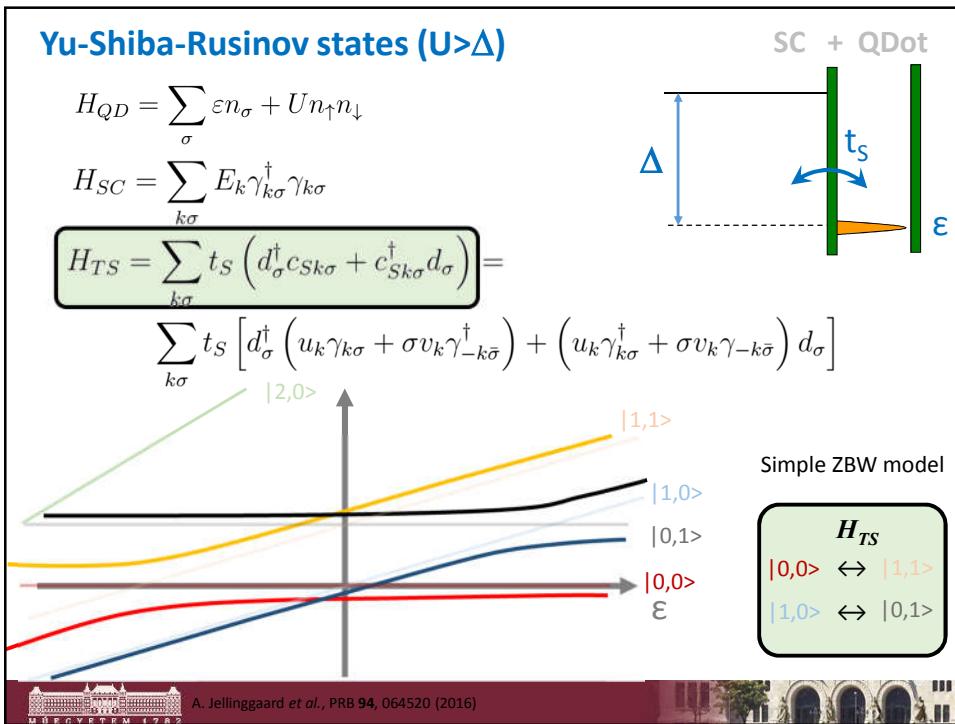
BME Nanoelectronics

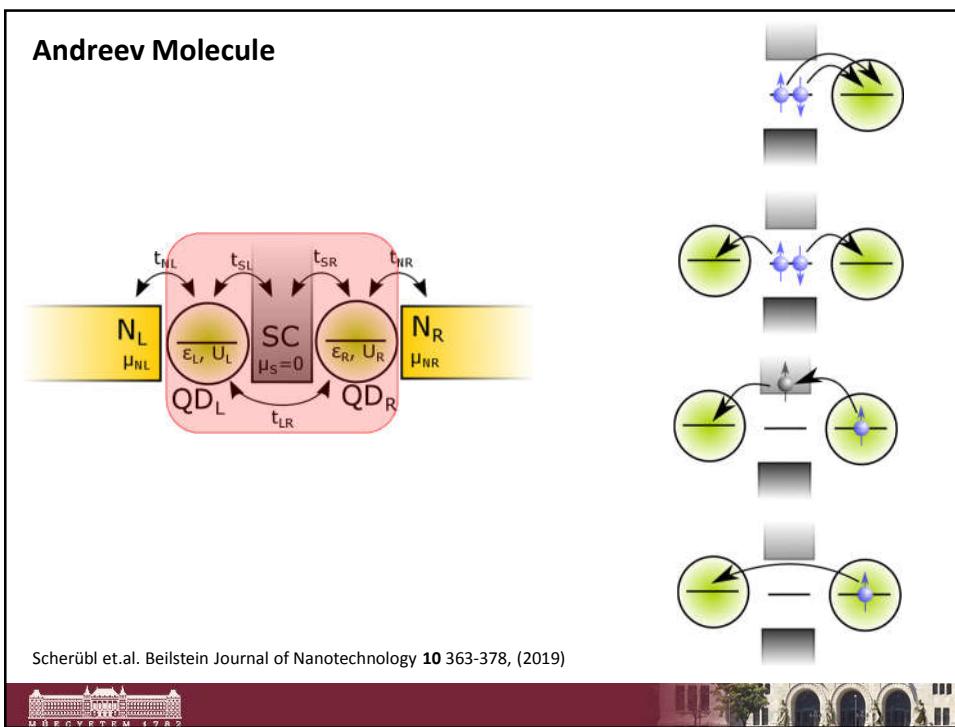
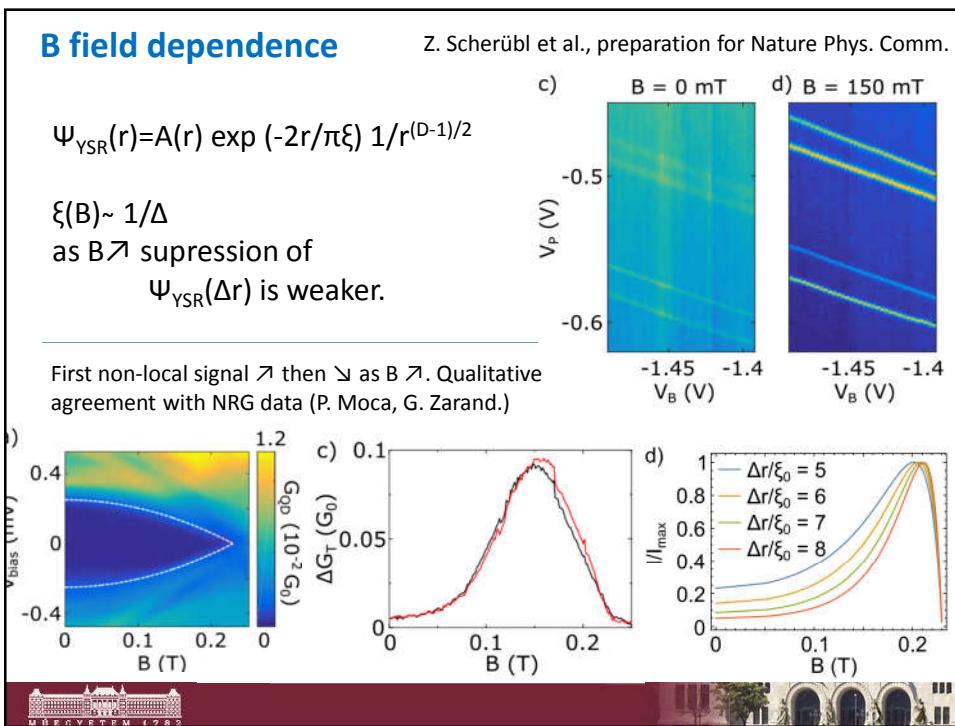
Exotic quantum states



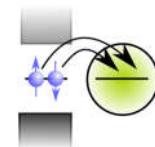




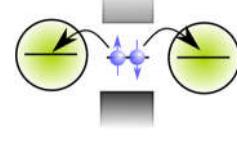




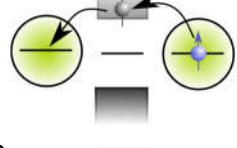
Local Andreev reflection
 $[H]_{(0,\downarrow)-(0,0)} \approx -\pi t_{SR}^2 \rho_0 =: \Gamma_{LAR,R}$



Crossed Andreev reflection
 $[H]_{(\uparrow,\downarrow)-(0,0)} \approx -\pi t_{SL} t_{SR} \rho_0 =: \Gamma_{CAR}$
 Exponential suppression with the distance
 $\Gamma_{CAR} = \sqrt{\Gamma_{LAR,L} \Gamma_{LAR,R}} \exp(-\Delta r/\xi)$

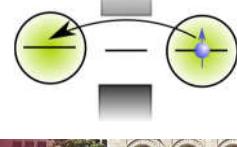


Elastic cotunneling
 $[H]_{(\uparrow,0)-(0,\uparrow)} \approx \frac{\Gamma_{CAR}}{\Delta} (\varepsilon_L + \varepsilon_R)$
 $\gamma_{EC} := \Gamma_{CAR}/\Delta$
Usually neglected

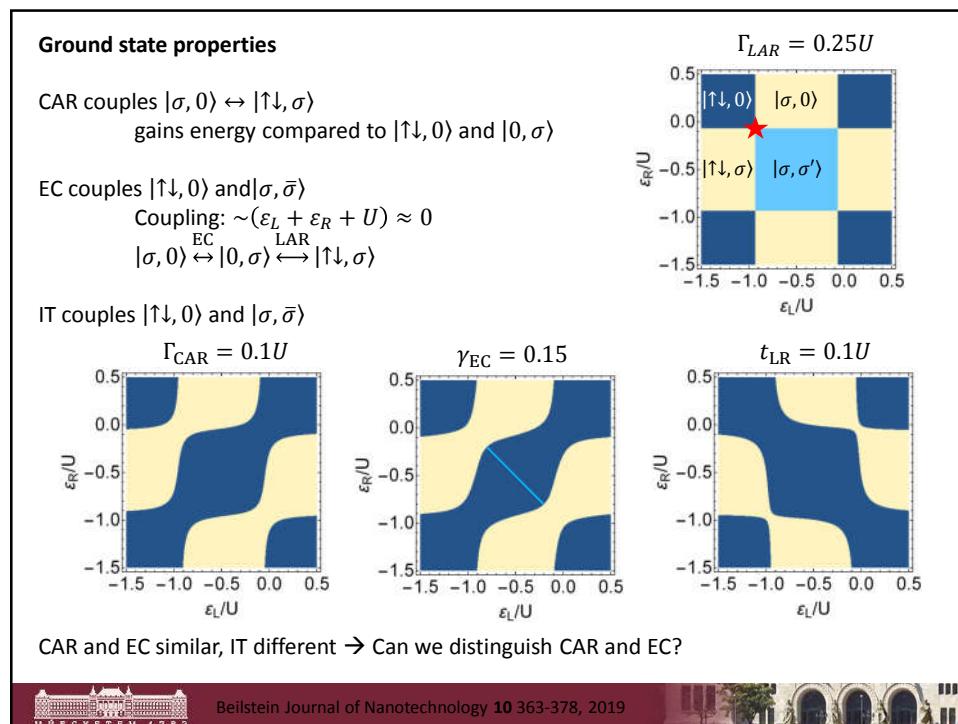


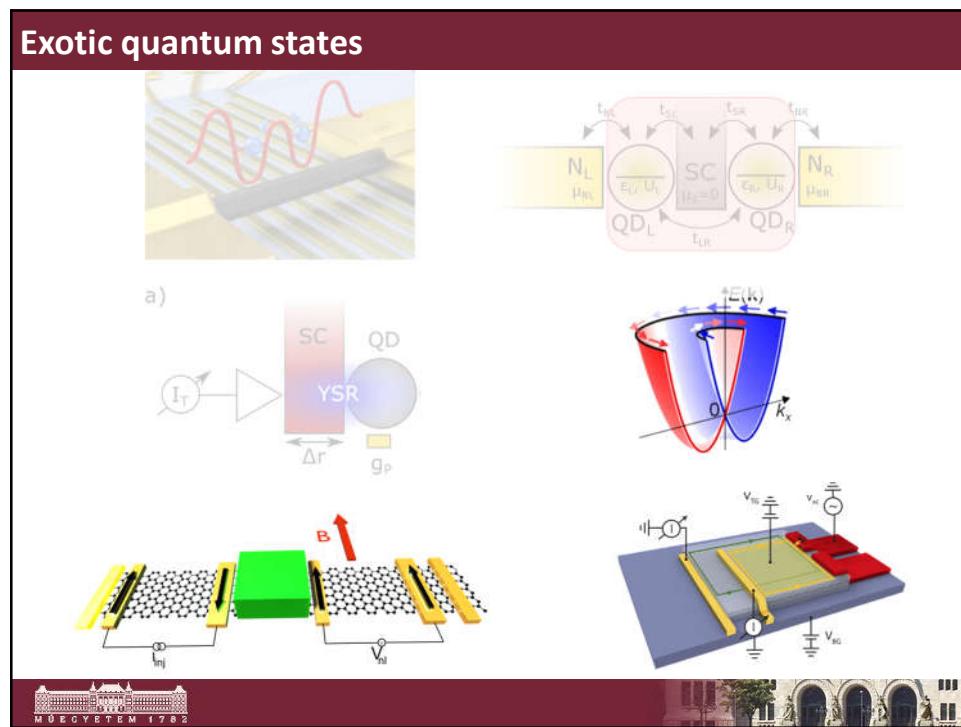
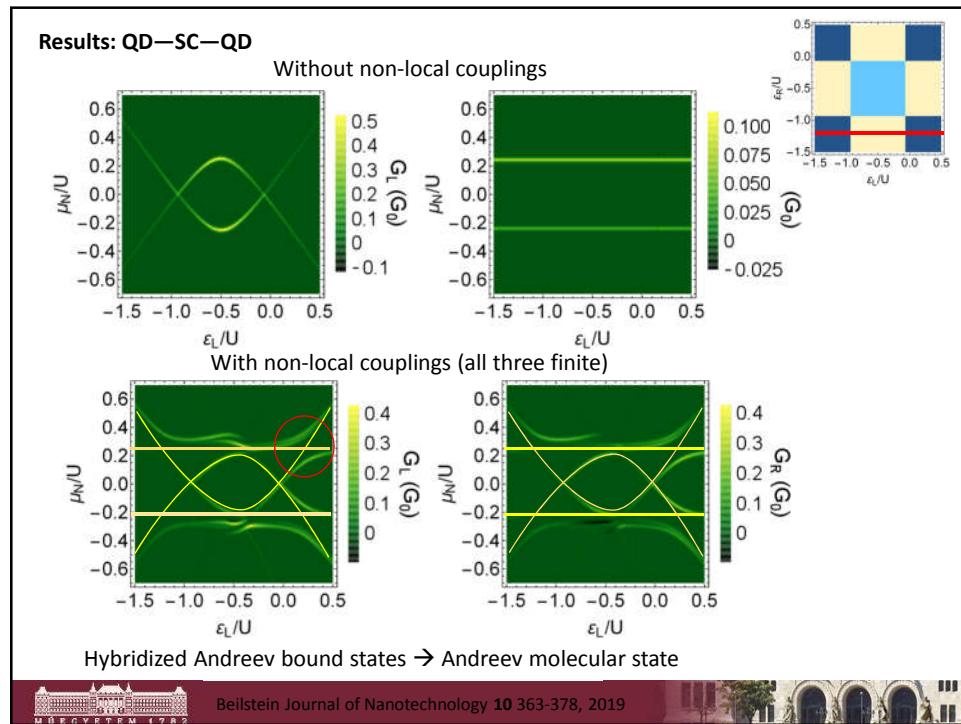
Interdot tunneling
 $[H]_{(\uparrow,0)-(0,\uparrow)} = t_{LR}$
 No energy dependence
 Parity is conserved

What is their effect?
 How to distinguish them?



Beilstein Journal of Nanotechnology 10 363-378, 2019





Exotic quantum states

Ionic liquid gating of giant Rashba material, BiTeBr

$J(E) \neq J(-E) \quad B \neq 0$

$V = IR_0(1 + IB_\perp\gamma)$

$\gamma \propto \frac{1}{n^2}$

M. Kocsis in collab. Justin Ye Groningen

Theory

$\gamma [T^{-1}A^{-1}m]$

$n [cm^{-3}]$

$1e-13$

Exotic quantum states

Induced spin-orbit interaction in graphene

(a) Schematic of a graphene device with a magnetic field B_y applied along the z-axis. Current I flows through the top contact, and voltage V is measured across the bottom contact.

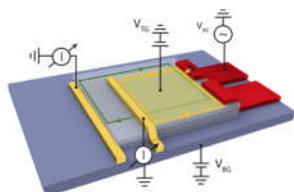
(b) Schematic of the same device with a voltage V applied across the top contact, and current I measured across the bottom contact.

(c) Plot of V_N (μV) versus B_y (mT) for $I = -40 \mu A$. The plot shows oscillatory behavior with a period of approximately 10 mT.

(d) Plot of V_N (μV) versus B_y (mT) for $I = -60 \mu A$. The plot shows a similar oscillatory behavior with a slightly different period.

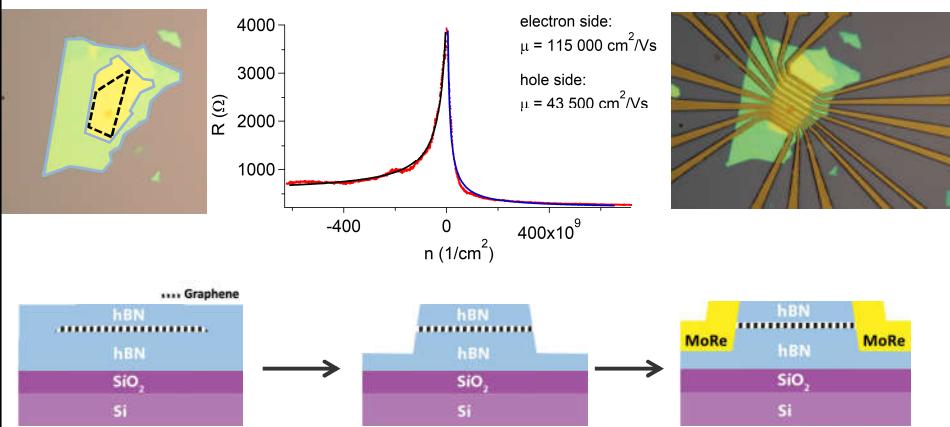
Z. Kovacs-Krausz, prep. for Nature Comm. (2019)

Exotic quantum states



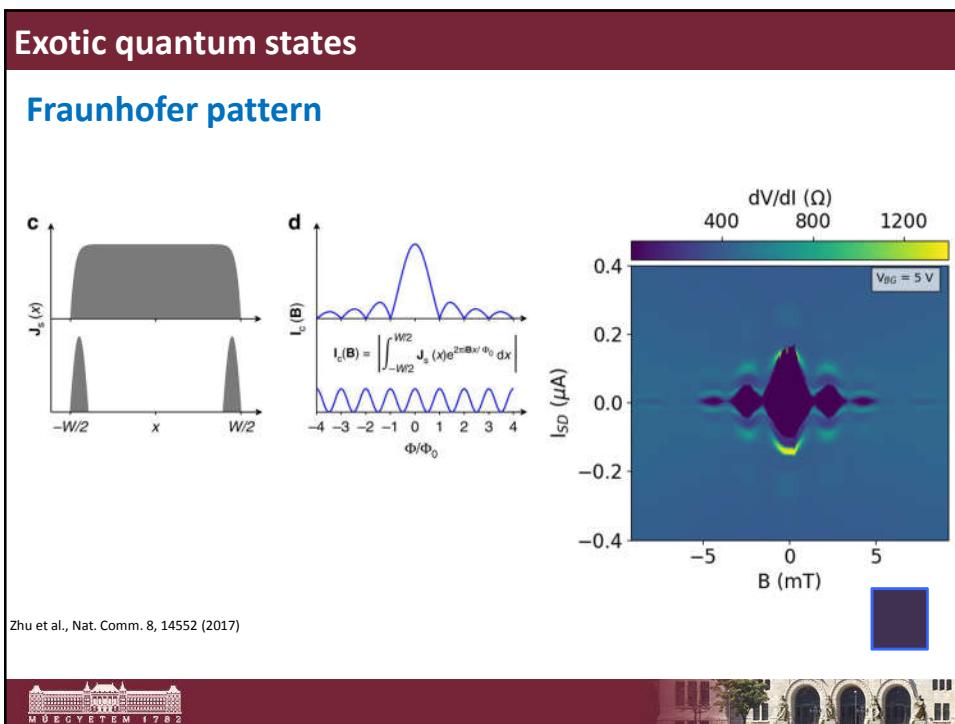
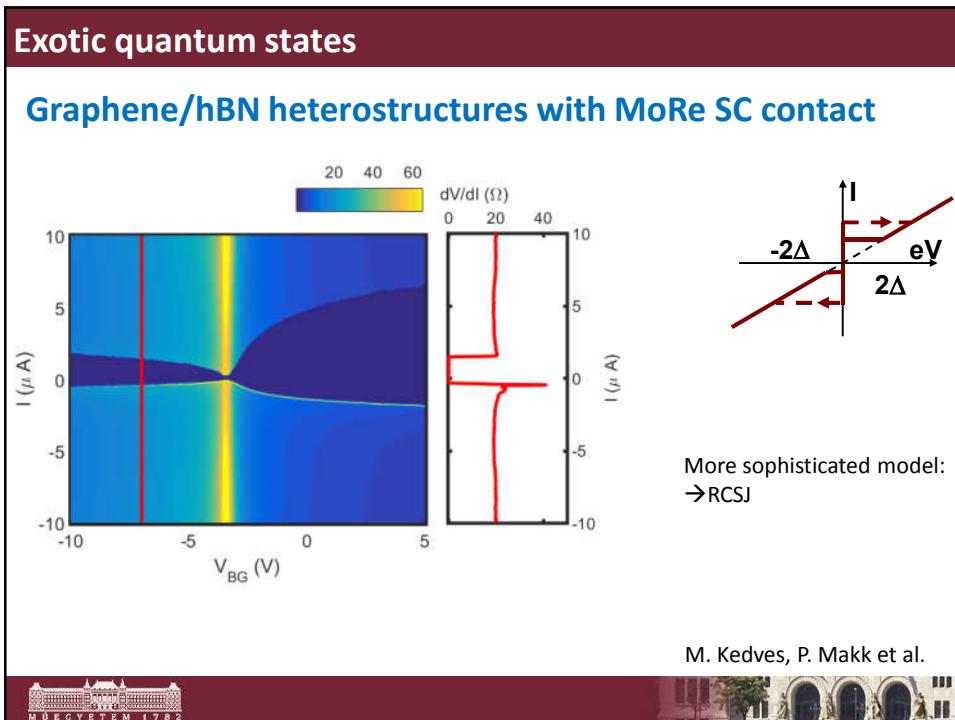
Exotic quantum states

High quality graphene/hBN heterostructures



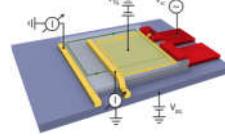
M. Kedves, P. Makk et al.





Exotic quantum states

- Coupling Supra to high quality graphene ✓
- Development of supra lead compatible with high B ✓
- New nanodevices with quantum dots ✓



Mesoscopic quantum electrodynamics



Public procurement finished. Contract is signed on 26/05/2019

Instruments



Zürich Instruments UHFLI



Zürich Instruments HF2LI



Zürich Instruments MFLI



Zürich Instruments HDAWG



Rohde&Schwarz ZNB



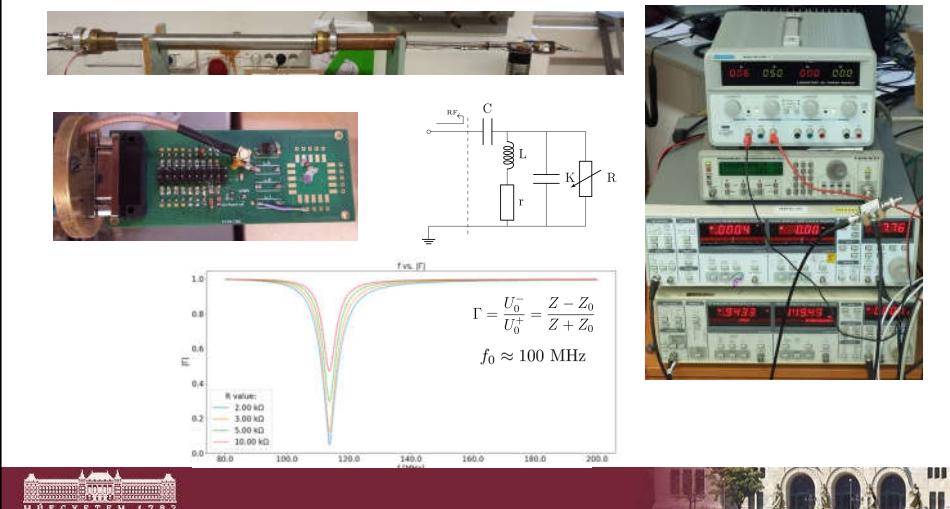
Rohde&Schwarz SGS100A



Mesoscopic quantum electrodynamics

MHz-range reflectometry: setup

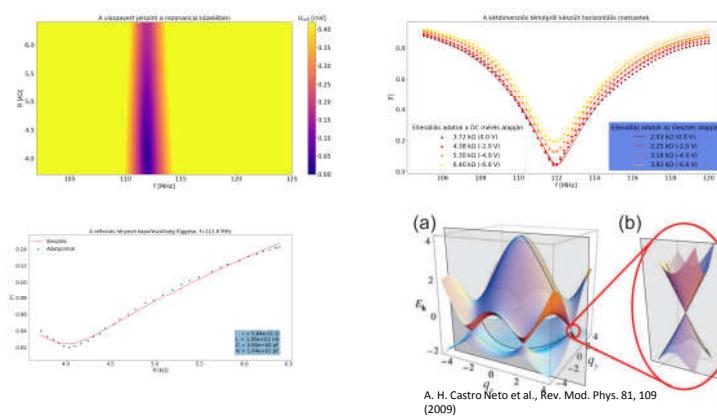
- BSc work of Tamás Kalmár (supervised by Péter Makk, Gergő Fülöp)



Mesoscopic quantum electrodynamics

MHz-range reflectometry: results

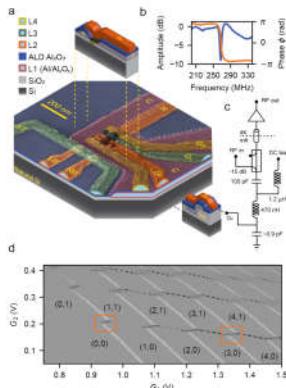
- Sample: graphene junction



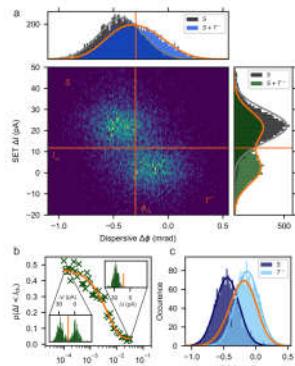
Mesoscopic quantum electrodynamics

MHz-range reflectometry: outlook

- Qubit readout



Gate-based single-shot spin readout characterisation



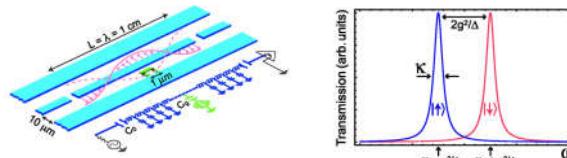
A. West et al., Nature Nanotechnology 14, 437–441 (2019)



Mesoscopic quantum electrodynamics

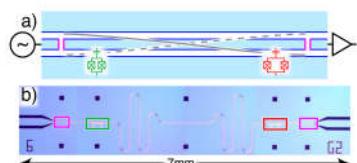
Microwave measurement probe (4 K)

- Building block: superconducting resonator
 - Qubit readout (qubit-resonator coupling)



A. Blais, PRA 69, 062320 (2004)

- Quantum bus (qubit-qubit coupling)



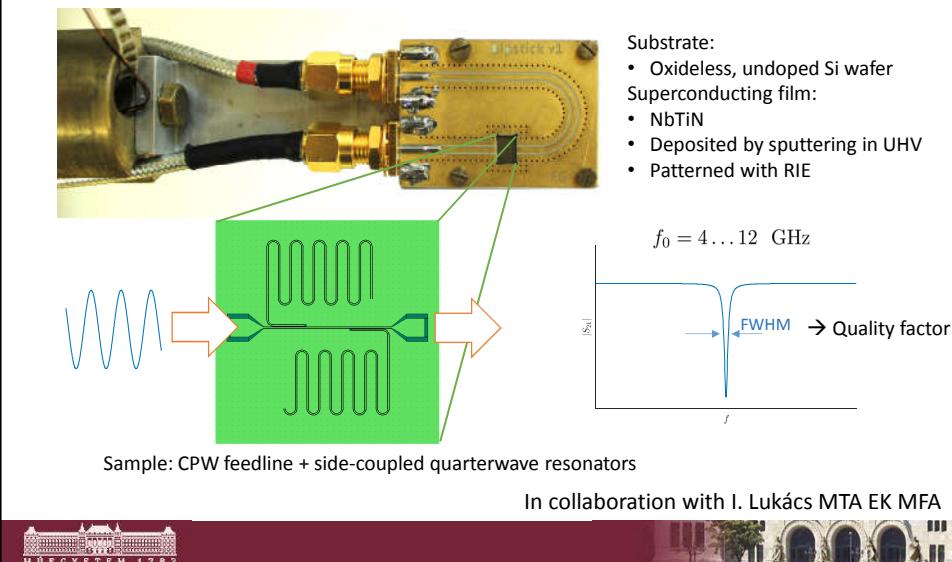
J. Majer et al., Nature 449, 443–447

In collaboration with I. Lukács MTA EK MFA



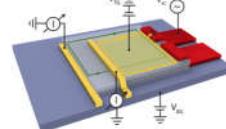
Mesoscopic quantum electrodynamics

Microwave measurement probe (4 K)



Exotic quantum states

- Coupling Supra to high quality graphene
- Development of supra lead compatible with high B
- New nanodevices with quantum dots



Mesoscopic quantum electrodynamics

- New fridge, GHz setup ,
- Development of coplanar resonators (Al, Nb, NbTiN)
- Characterization of resonators
- New reflectometry setup
- Test SC in high magnetic field



