Spin Currents in a 2D Electron Gas

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UBC

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Thanks to:

My group

Sergey Frolov (postdoc)
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Heterostructures

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Motivations

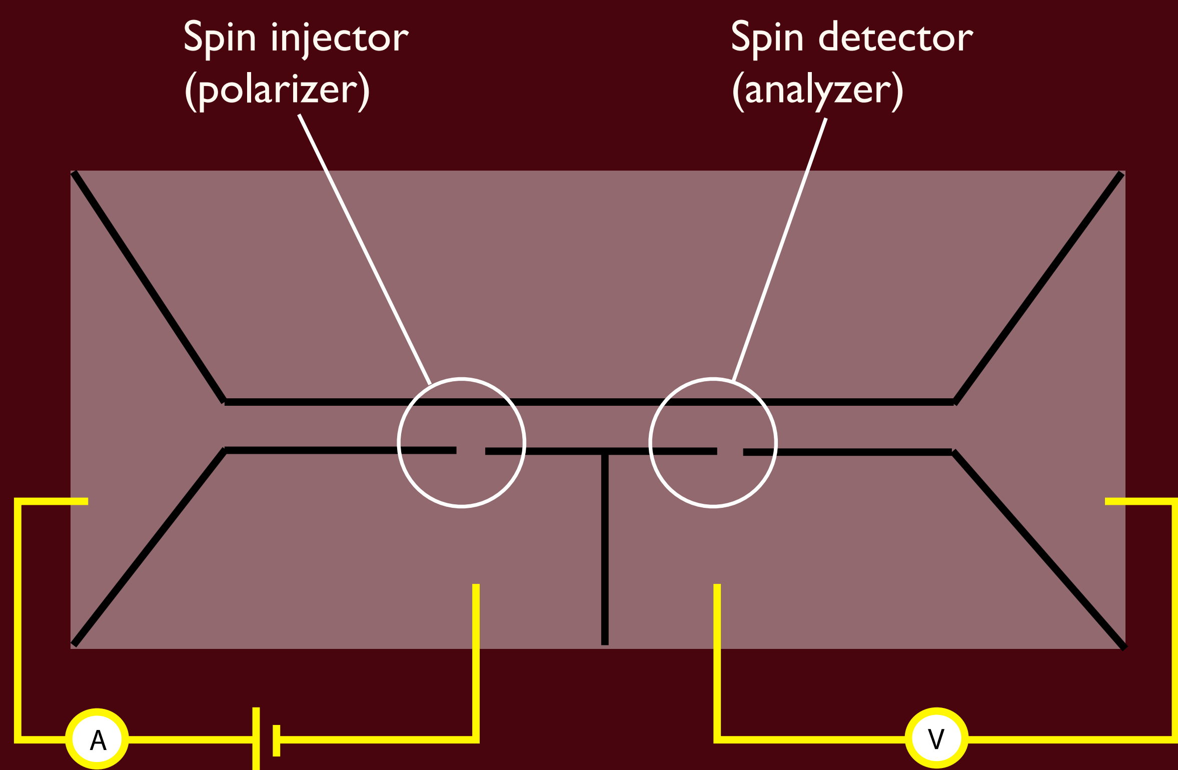
Why measure spin current?

- Spintronics (quantum and classical)
- Hard to infer spin physics from charge transport

Why measure in semiconductors (vs metals)?

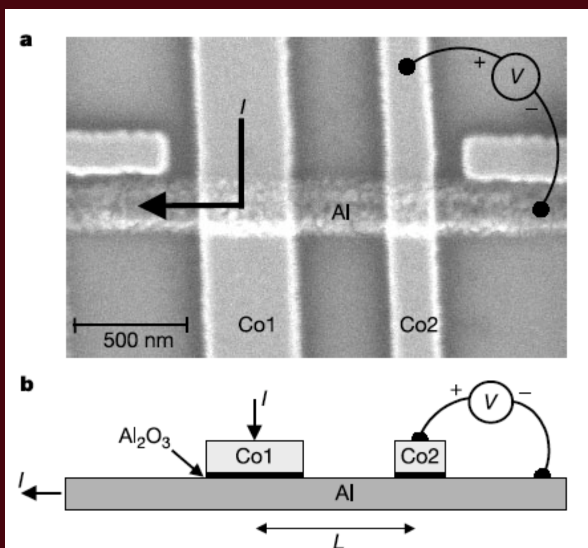
- Spin physics of interacting electrons
- Exquisite control of material system
- Electrical control of spin

Measuring spin currents electrically: a polarizer/analyzer geometry

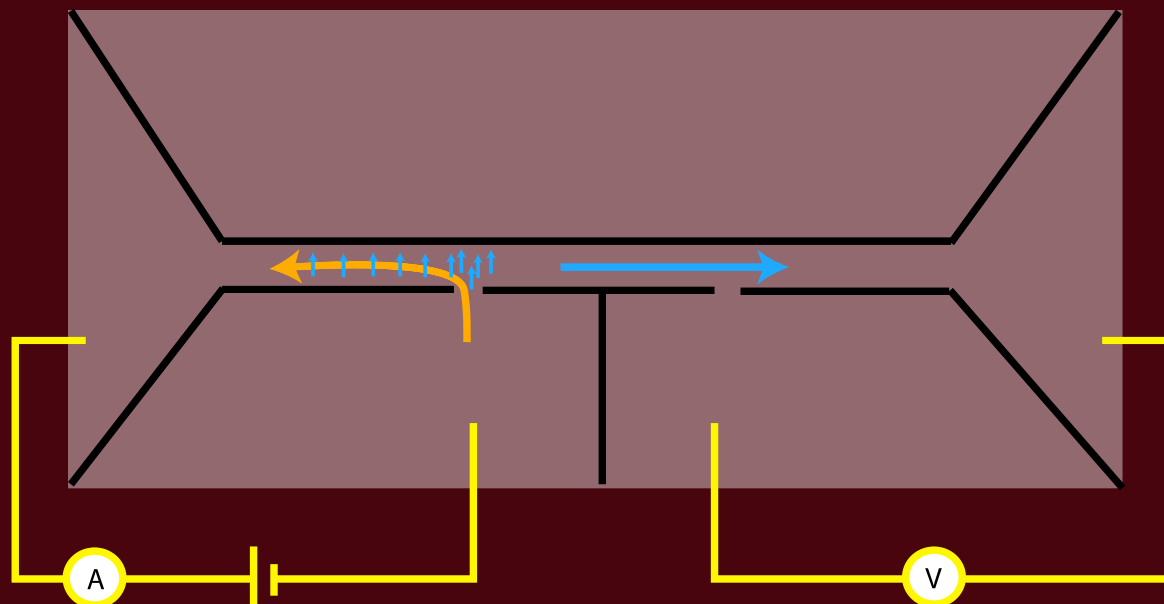


Nonlocal geometry generates pure spin currents

(spin currents without charge currents)

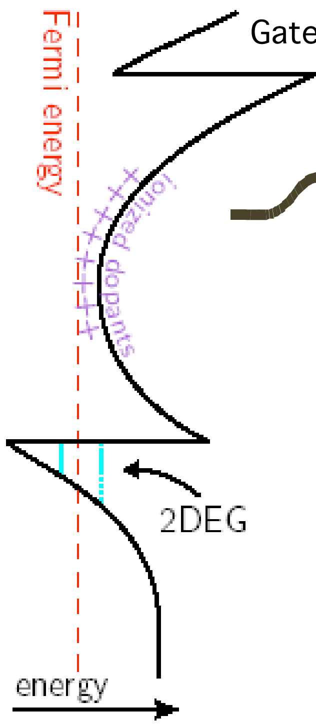


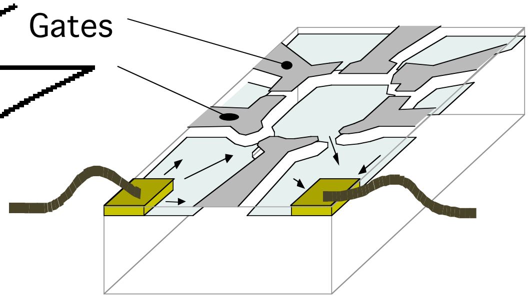
Jedema, van Wees et al, Nature 2002; see also Johnson and Silsbee, PRL 1985.



Charge current flows to left, spin current to right

Nanostructures in GaAs/AlGaAs electron gas



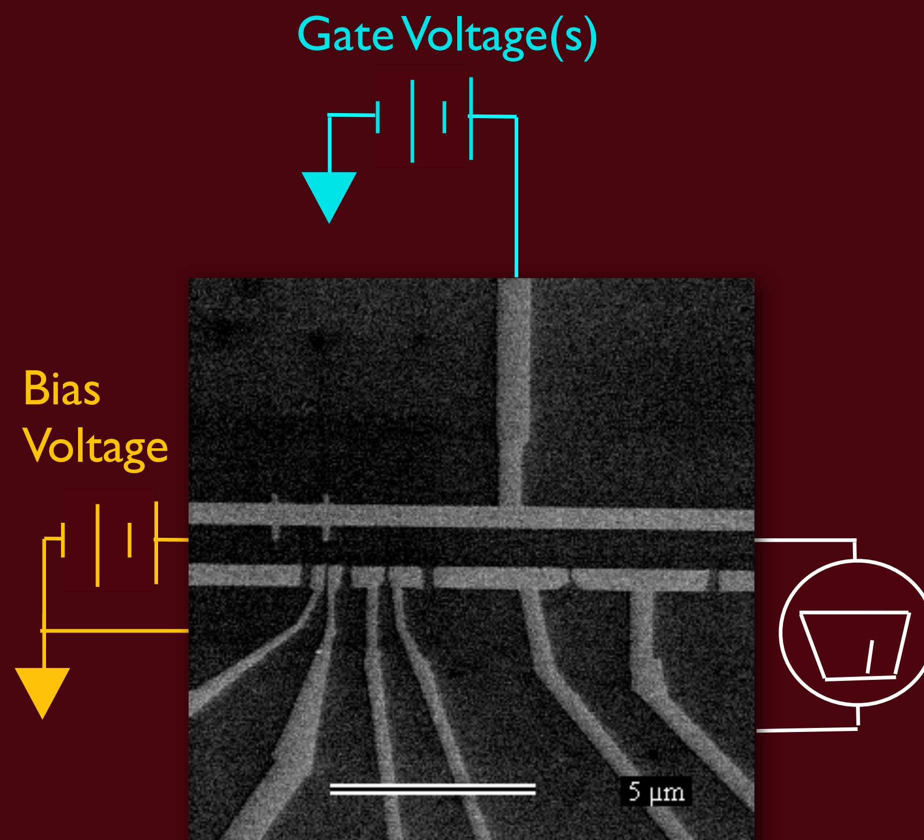


This material:

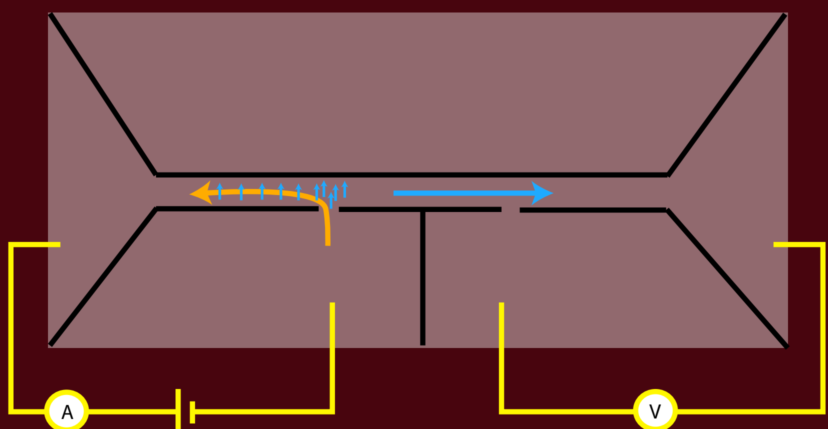
$$n_e = 1.4 \times 10^{11} cm^{-2}$$

$$\mu = 4 \times 10^{6} cm^{2}/Vs$$

$$\rightarrow mfp \sim 50\mu m$$



Device geometry



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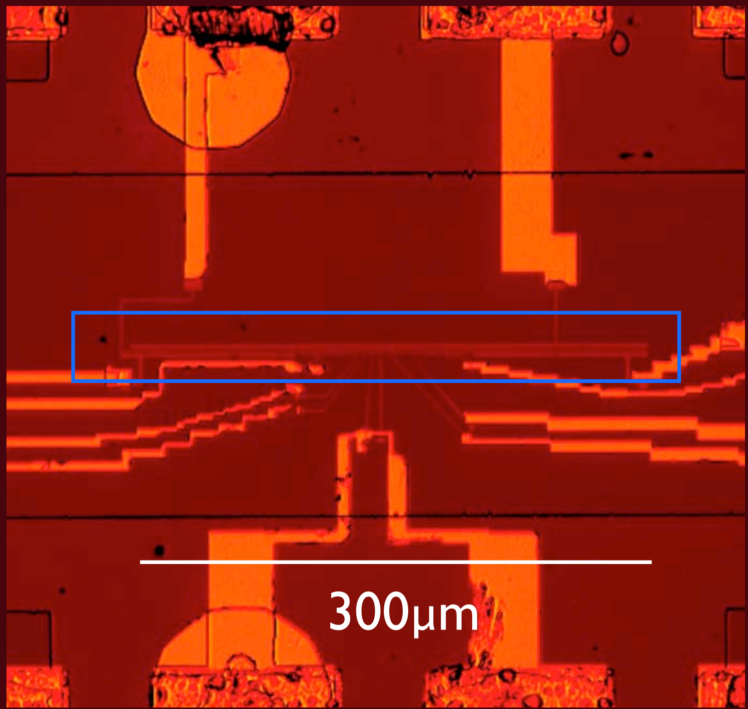

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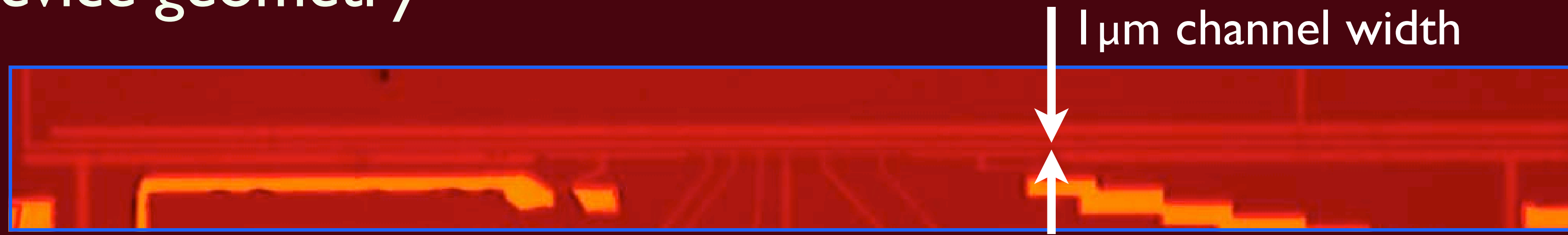

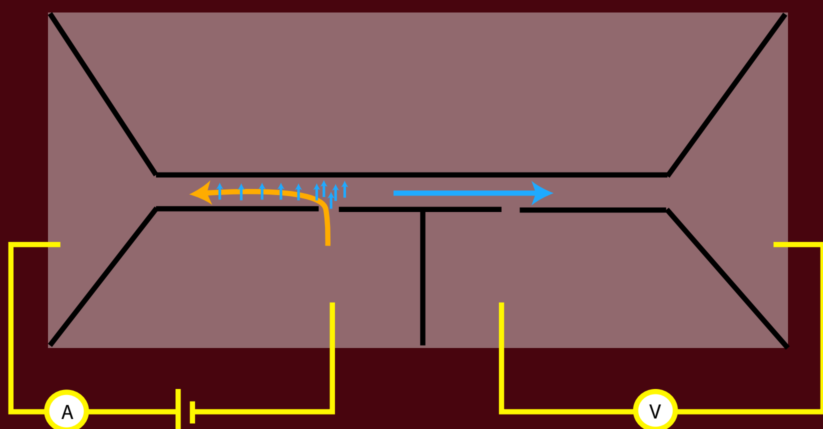

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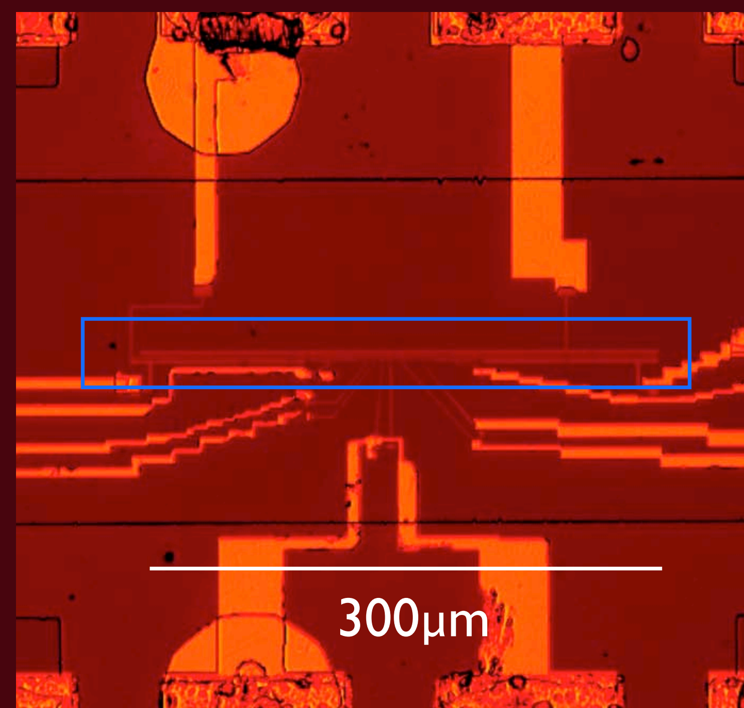
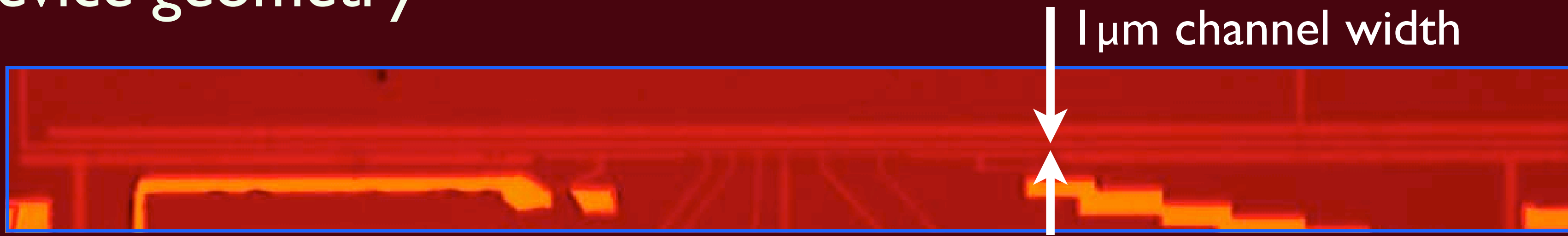
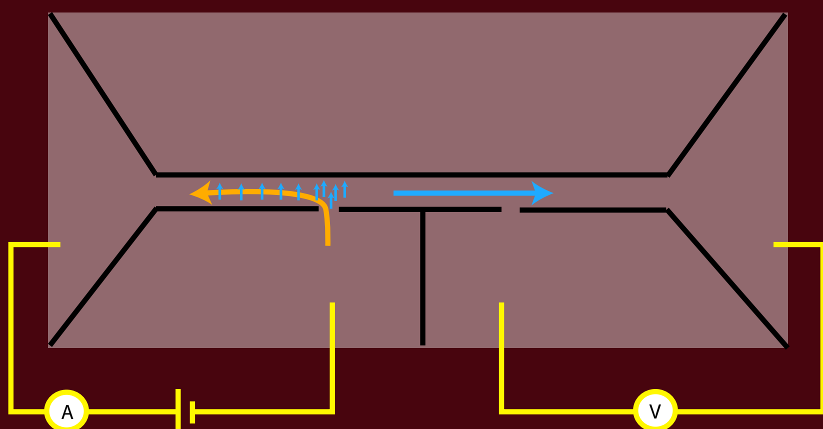


Device geometry



Quasiballistic: momentum relaxation length ~ 20um, >> channel width



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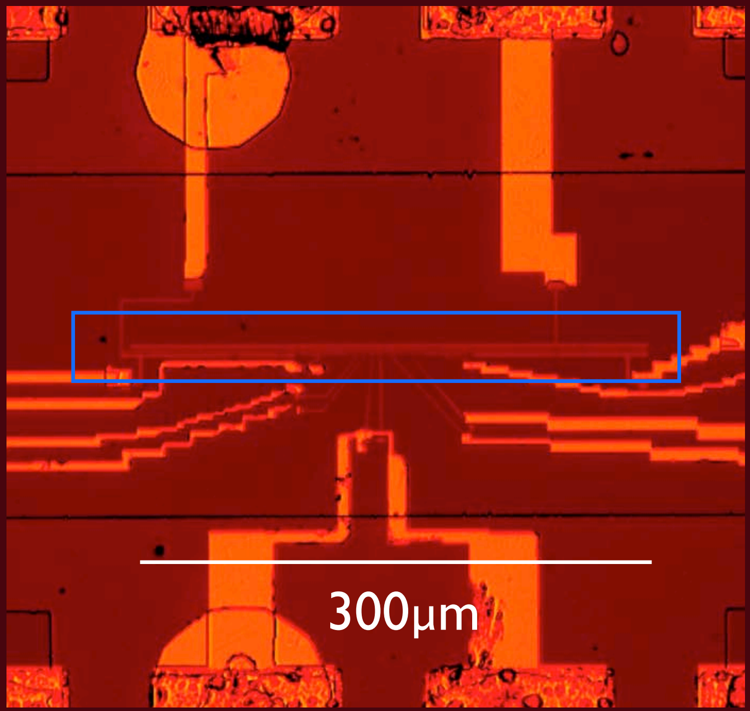
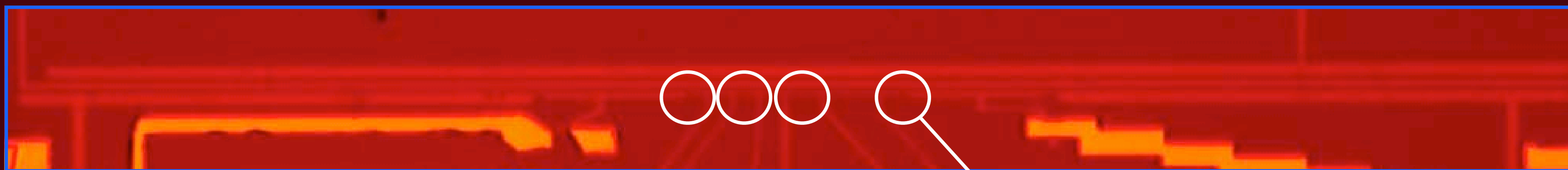
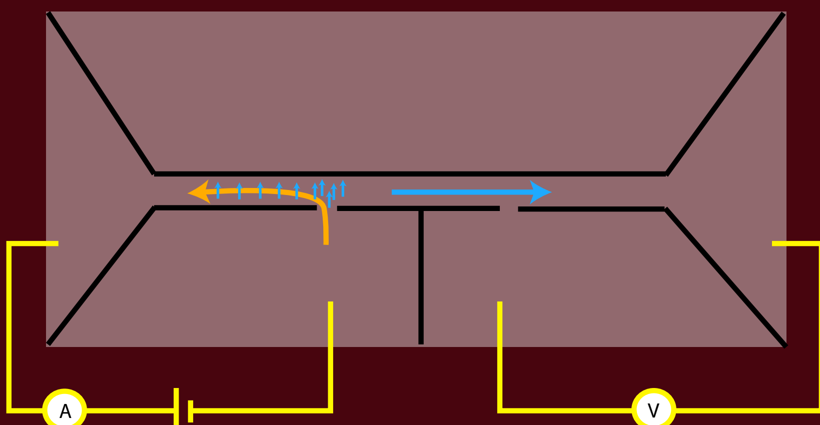


Device geometry





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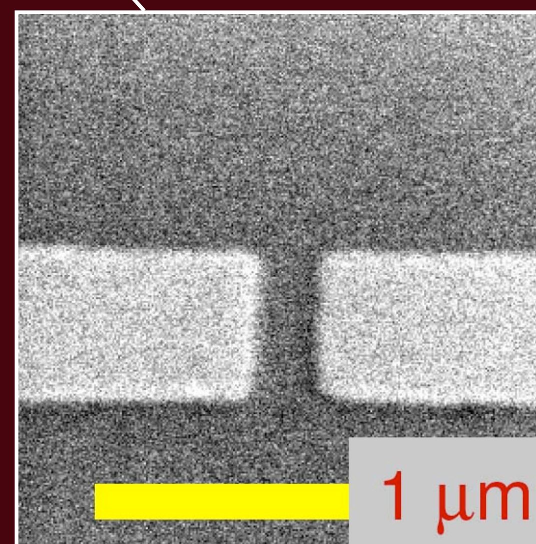
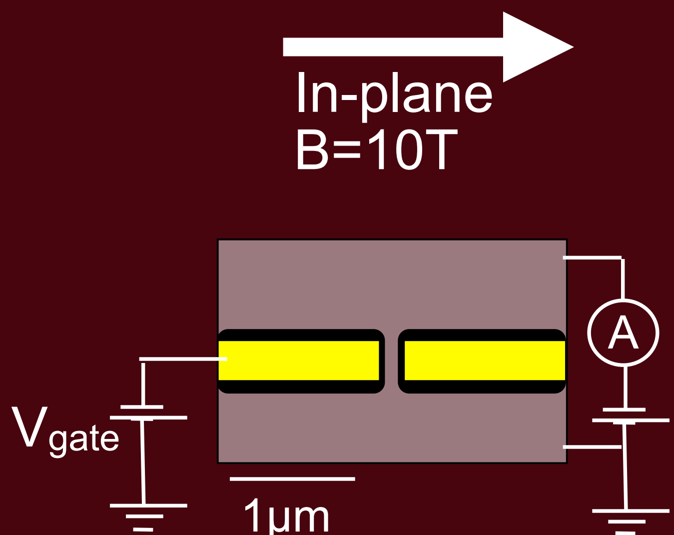
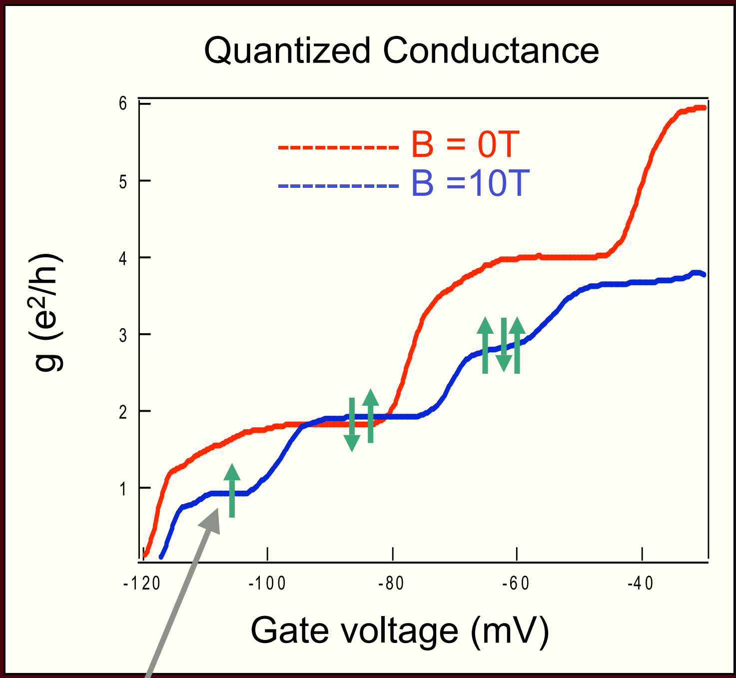


Point contact injector/detectors

Quantum point contact:

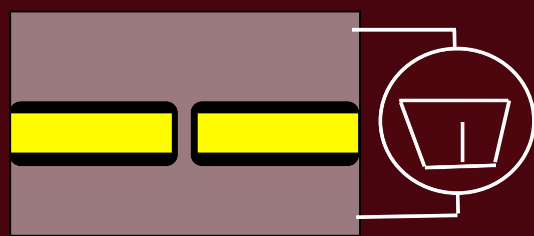
A spin injector without ferromagnets



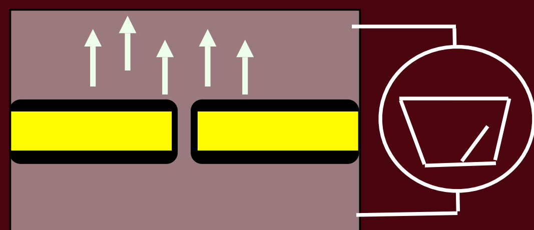


Spin-resolved plateau, transmits only spin up

Spin injectors are spin detectors too

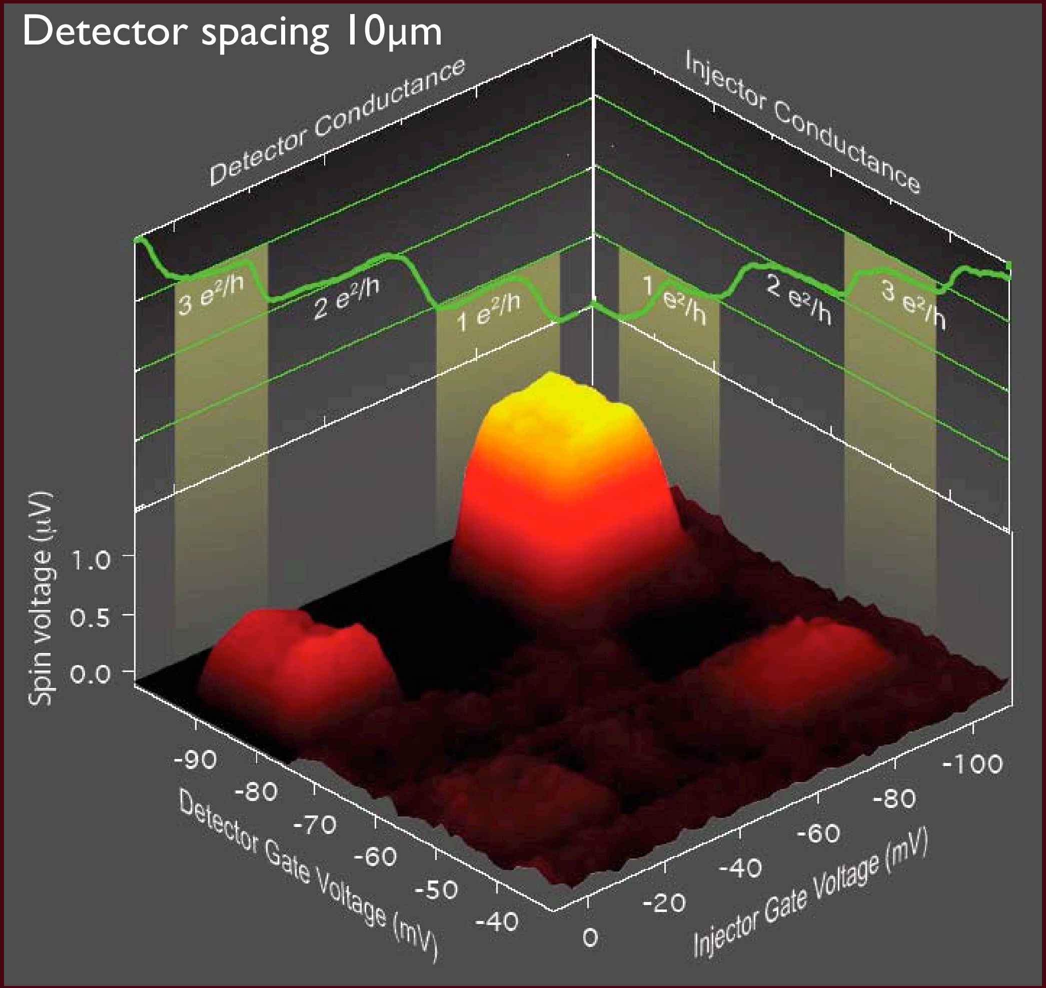


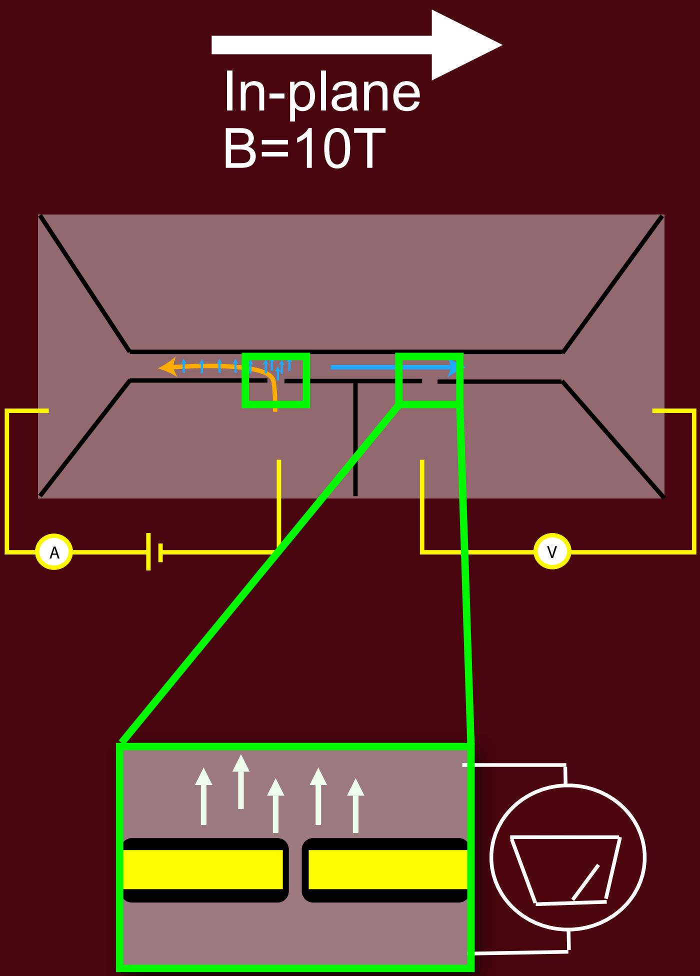
Equilibrium spin population
→ No voltage detected



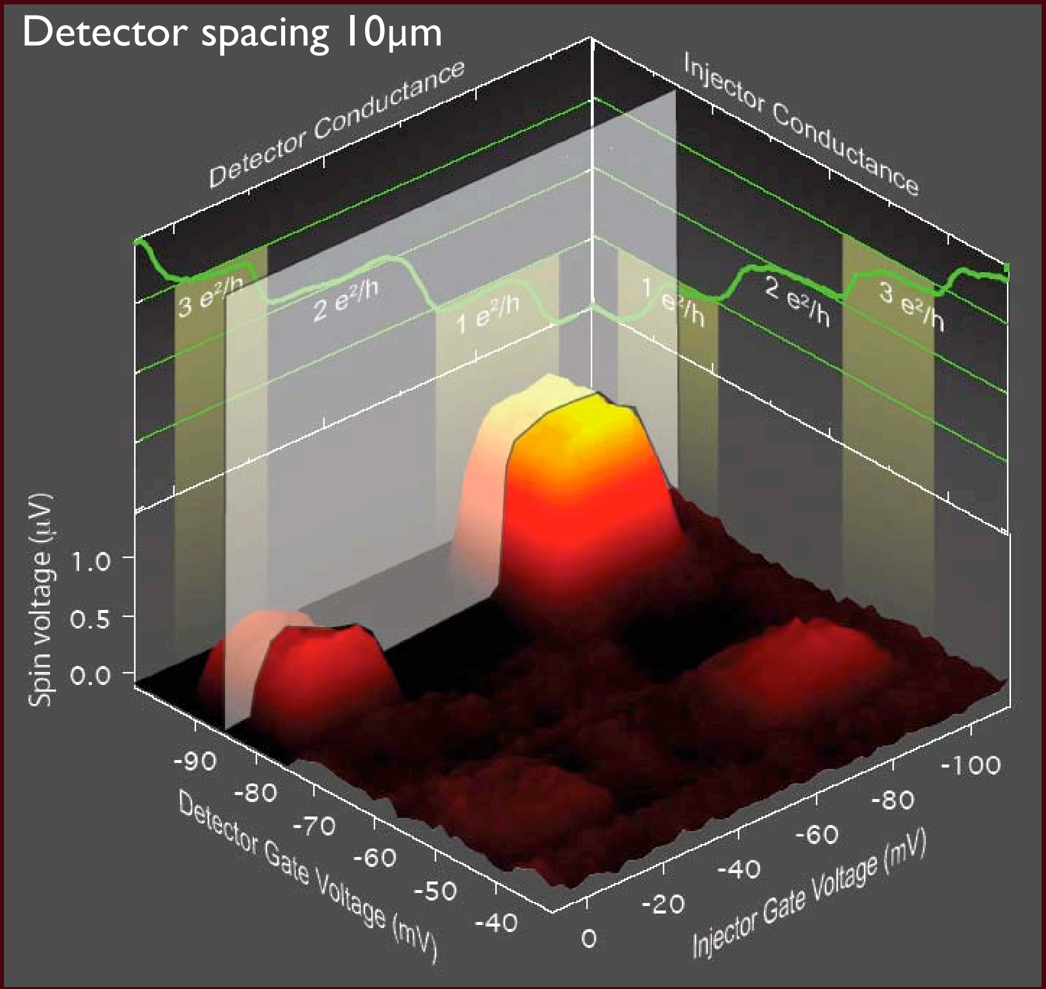
Nonequilibrium spin population
→ Voltage records μ_{up} - μ_{down}
when spin selective

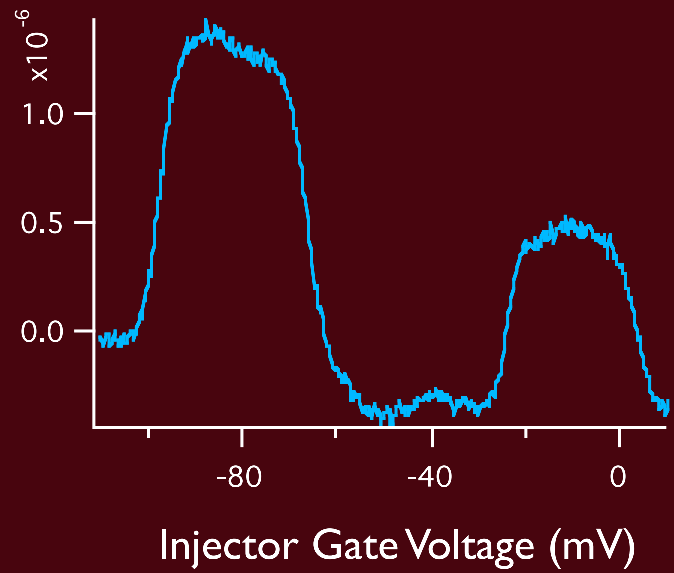
Detecting spin currents





Detecting spin currents





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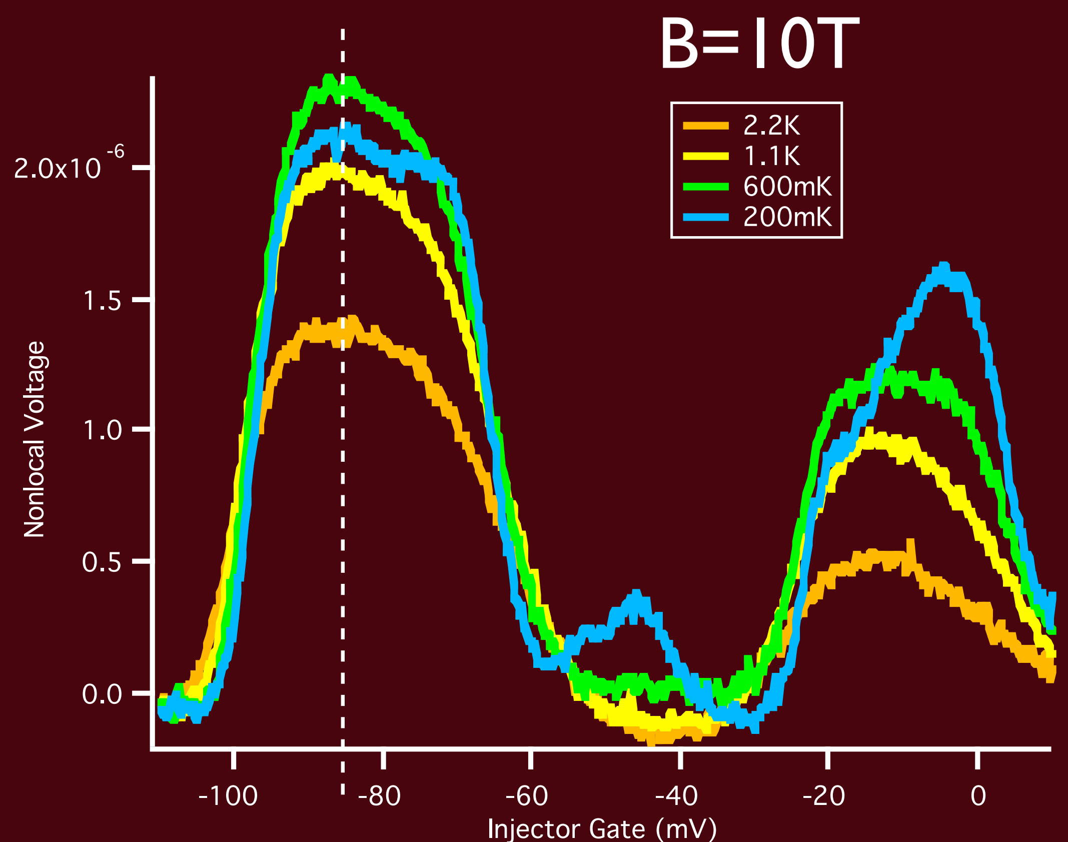
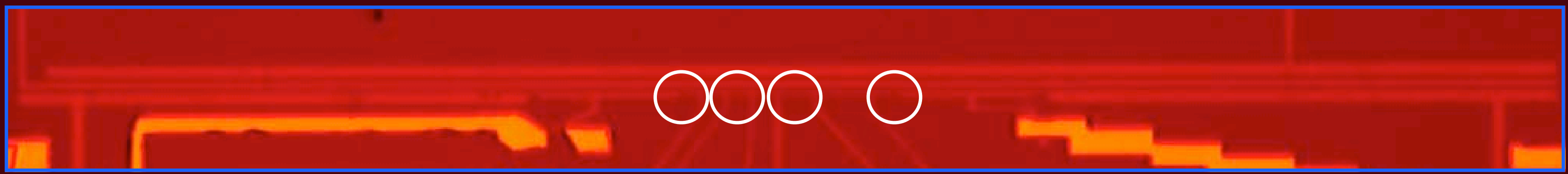
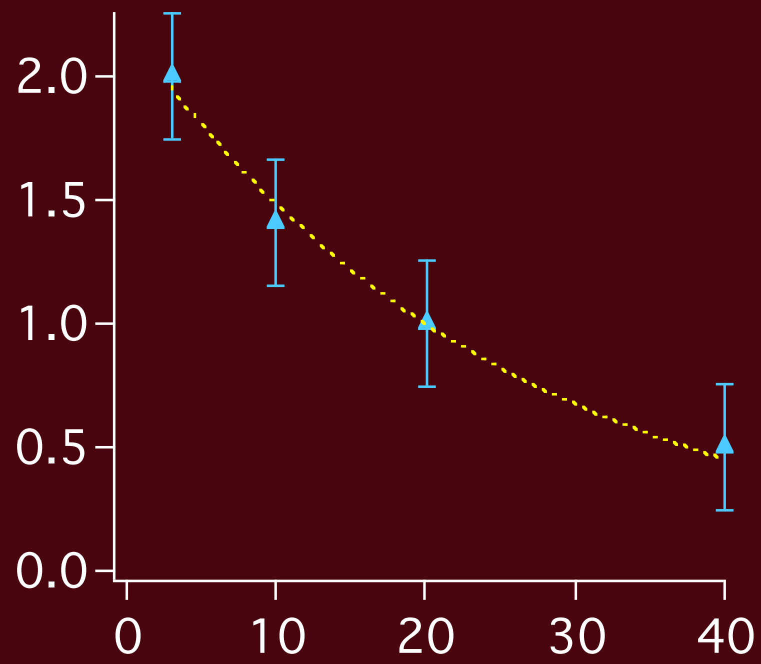
Temperature Dependence



Enhanced g factor in low density QPC ⇒ spin current still significant at T=2.2K!

Diffusion Length



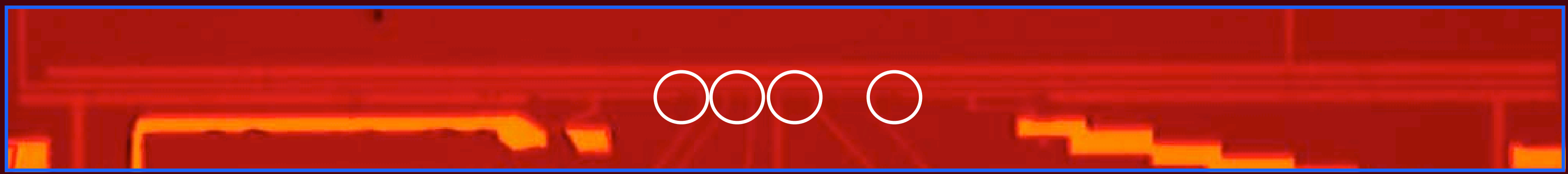


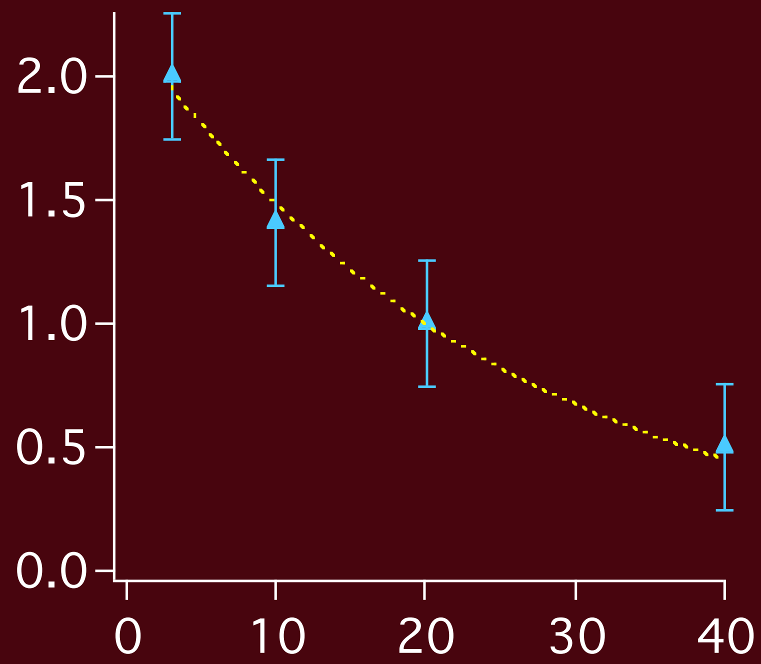
$$V_{spin}(x) \propto \lambda_s e^{\frac{-x}{\lambda_s}}$$

$$\lambda_s = 50\mu m$$

Assumes constant detector polarization.

Diffusion Length



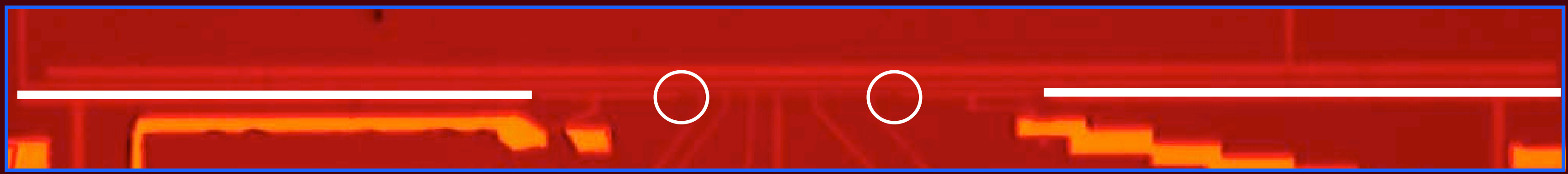


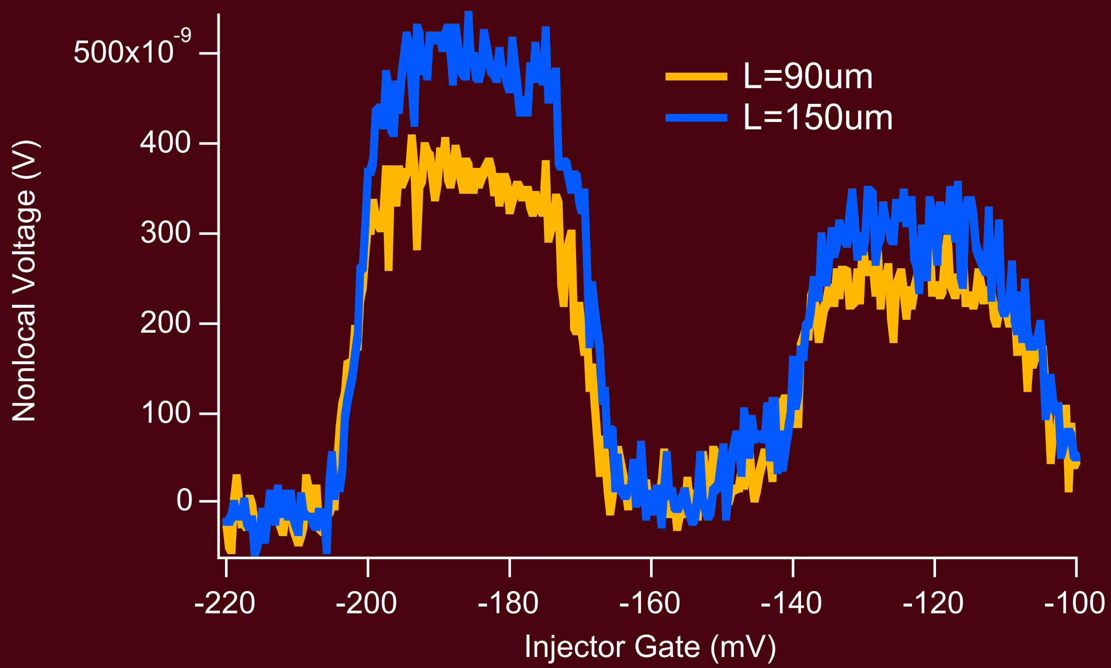
$$V_{spin}(x) \propto \lambda_s e^{\frac{-x}{\lambda_s}}$$

Assumes infinite channels

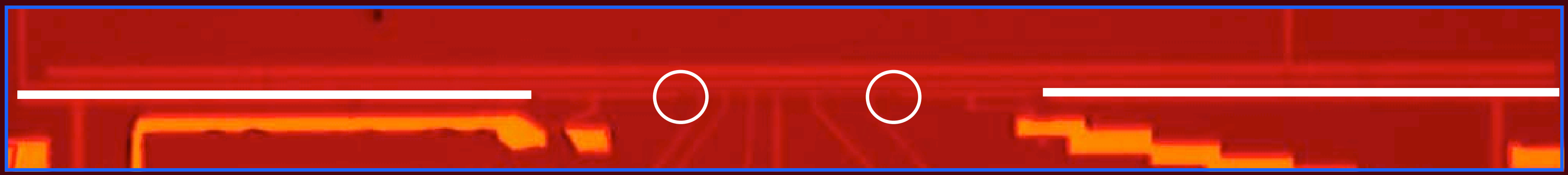
(channel length >> λ_s)

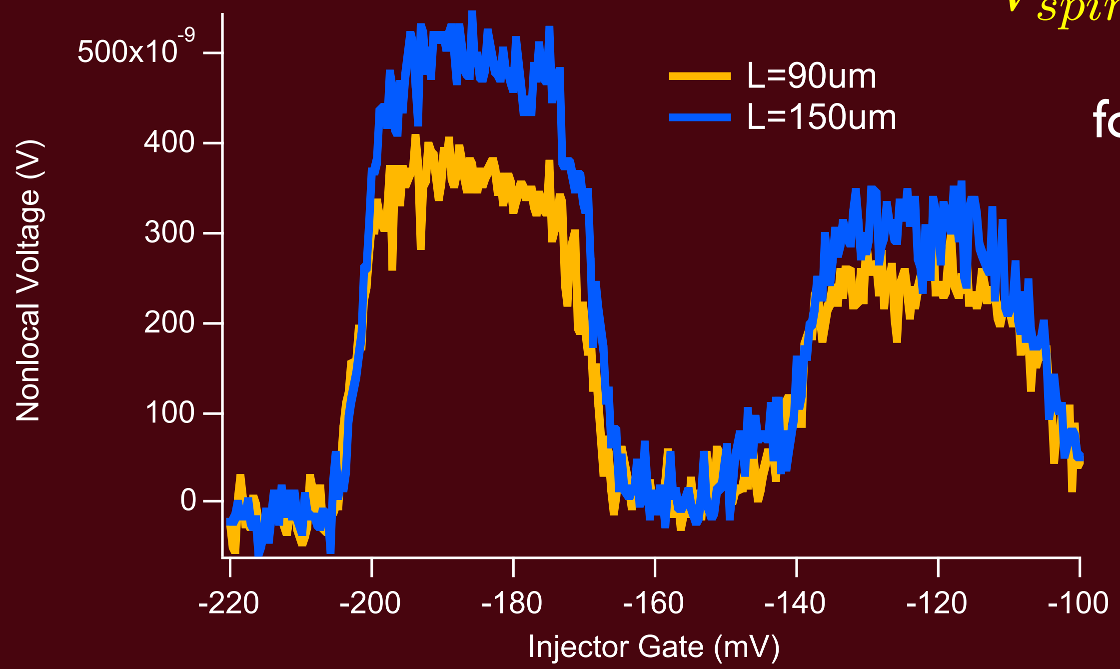
Finite channels





Finite channels

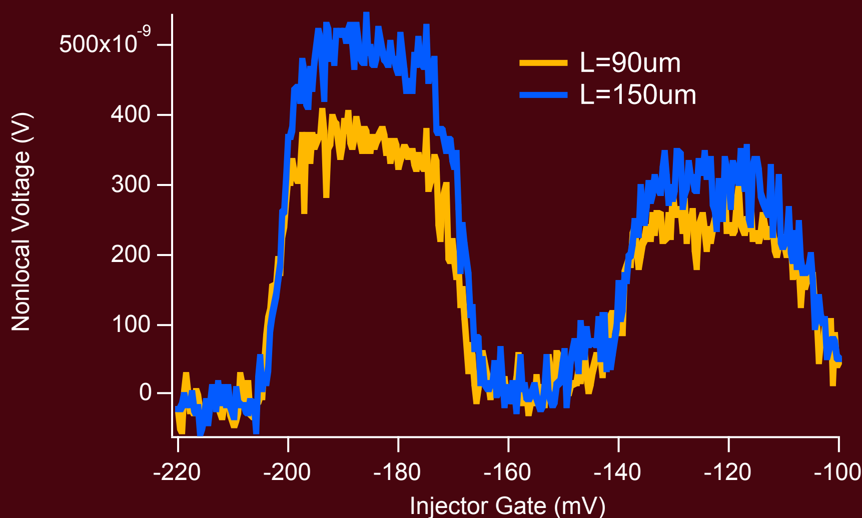




$$V_{spin}(x) \propto \lambda_s \frac{sinh(\frac{L-x}{\lambda_s})}{e^{\frac{L}{\lambda_s}}}$$

for channel length L

Finite channels



$$V_{spin}(x) \propto \lambda_s \frac{sinh(\frac{L-x}{\lambda_s})}{e^{\frac{L}{\lambda_s}}}$$

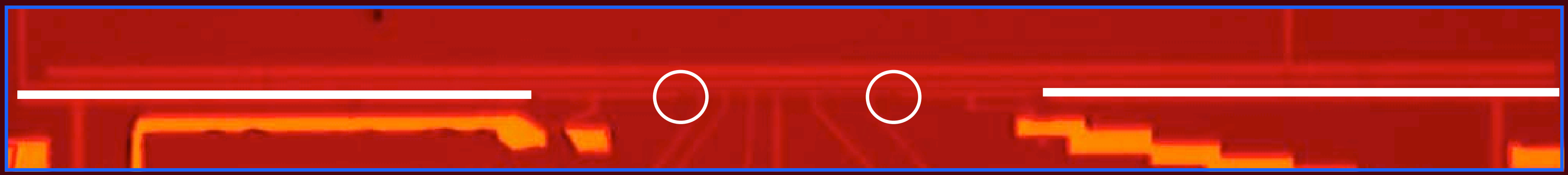
for channel length L

also gives

$$\lambda_s = 50\mu m$$

independent of contact polarization

Spin relaxation time



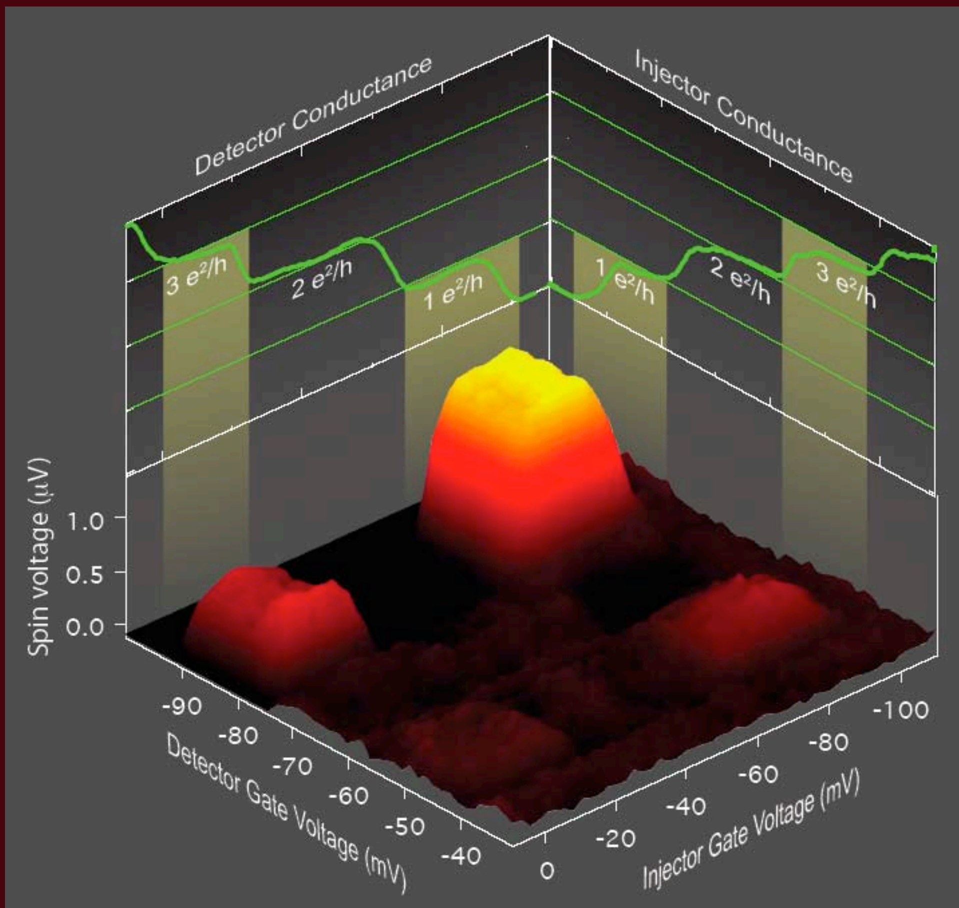
Total channel resistance implies 20um momentum relaxation length

$$\lambda_s = 50\mu m \;\Leftrightarrow\; \tau_s \sim 1ns$$

How does this depend on:

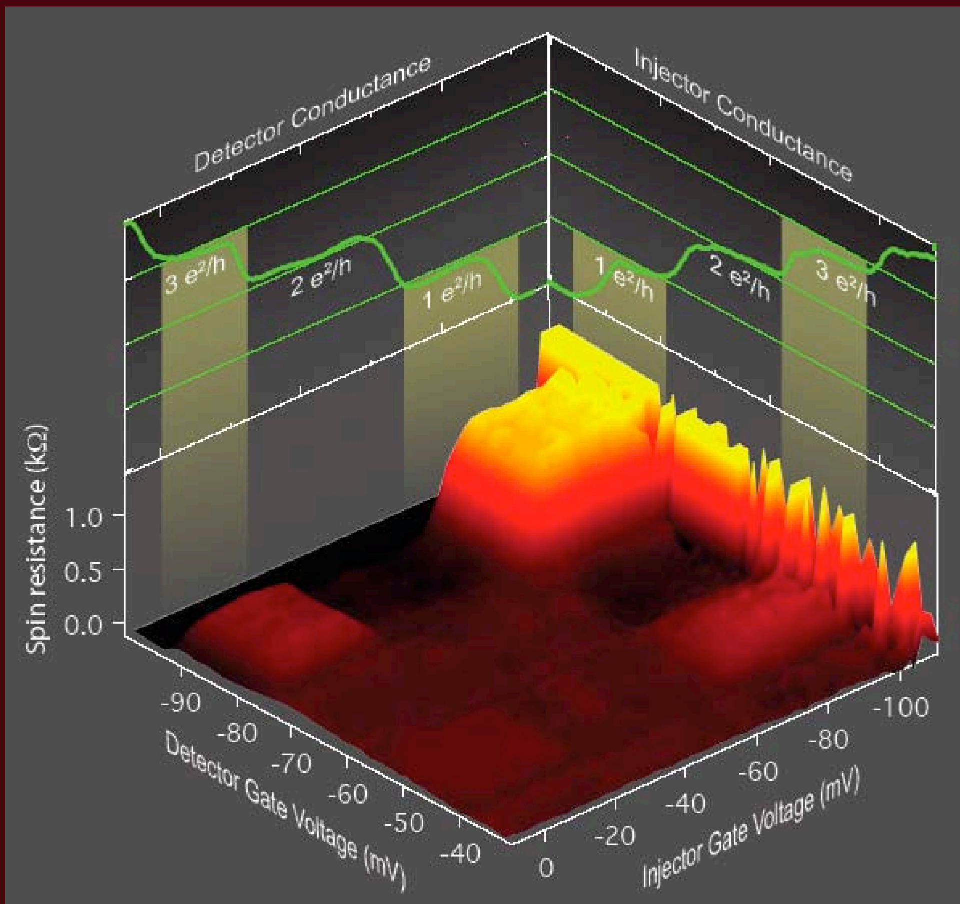
- Magnetic field?
- Electron-electron interactions?
- Nonequilibrium chemical potential?

Contact Polarization



$$V_{spin}(x) \sim I_{inj} \frac{R}{2L} P_{inj} P_{det} \lambda_s e^{\frac{-x}{\lambda_s}}$$

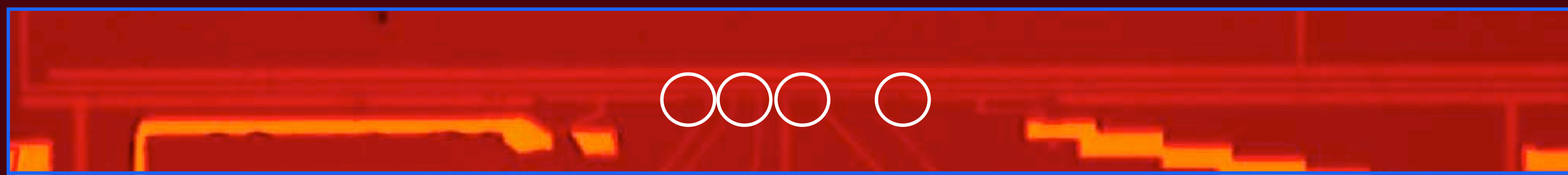
Contact Polarization

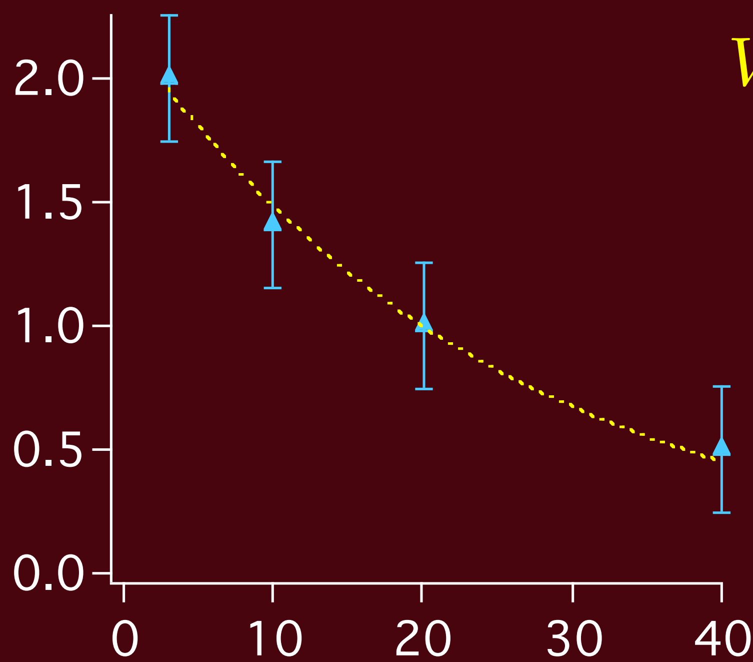


$$V_{spin}(x) \sim I_{inj}\frac{R}{2L}P_{inj}P_{det}\lambda_s e^{\frac{-x}{\lambda_s}}$$

$$R_{spin} = \frac{V_{spin}}{I_{inj}} \propto P_{inj}P_{det}$$

Absolute magnitude of spin signal





$$V_{spin}(x) \sim I_{inj} \frac{R}{2L} P_{inj} P_{det} \lambda_s e^{\frac{-x}{\lambda_s}}$$

Spin current flows to the left and right. Absolute magnitude depends on device details (not fully diffusive!).

E.g. perpendicular field of 50-100mT can strongly enhance or suppress spin current

Other Nonlocal Signals

Thermoelectric Voltage (?)

Lockin measurement

$$V \propto P \propto I^2$$
$$= (I_{dc} + I_0 sin(\omega t))^2$$
$$= I_{dc}^2 + \boxed{2I_{dc}I_0 sin(\omega t)} + sin^2(\omega t)$$

Other Nonlocal Signals

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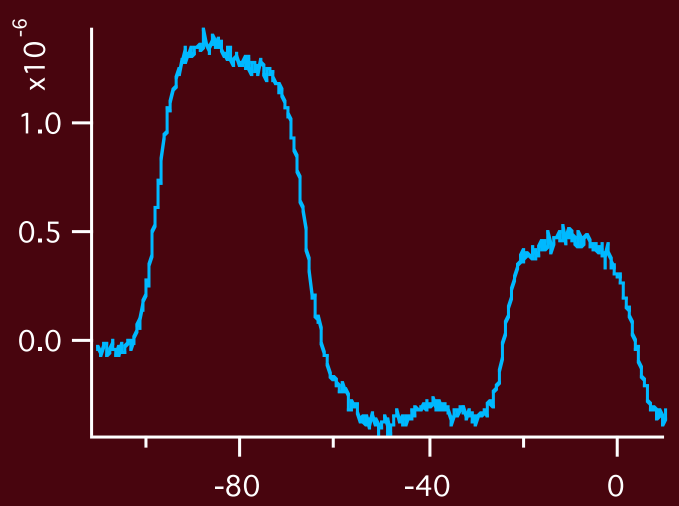

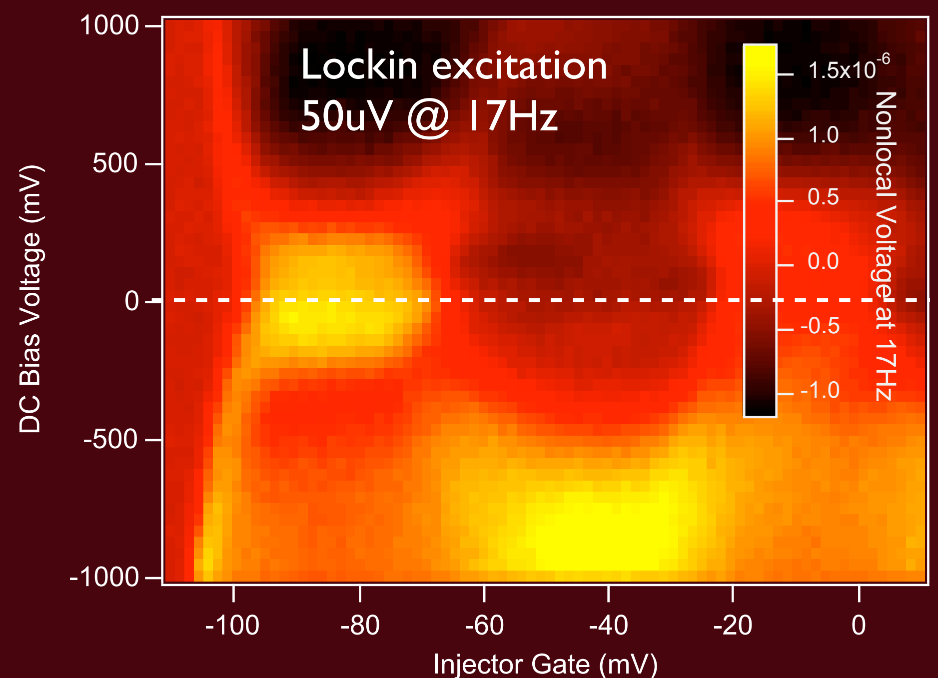

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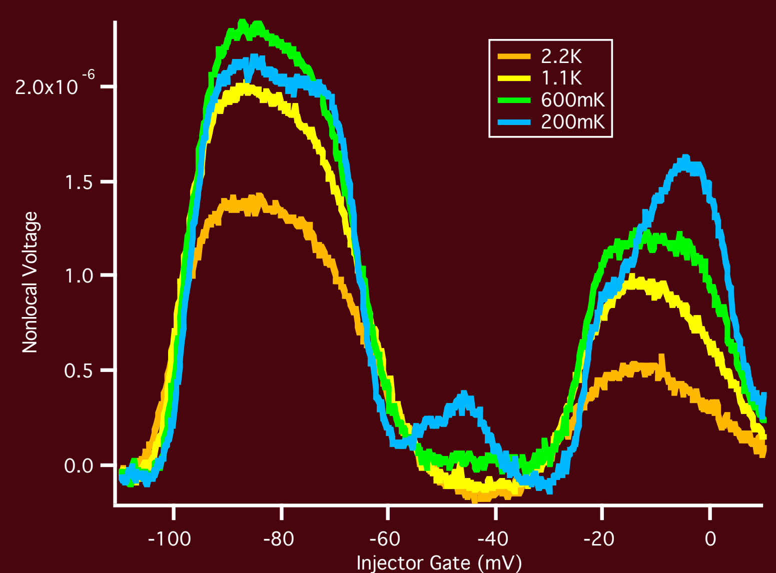
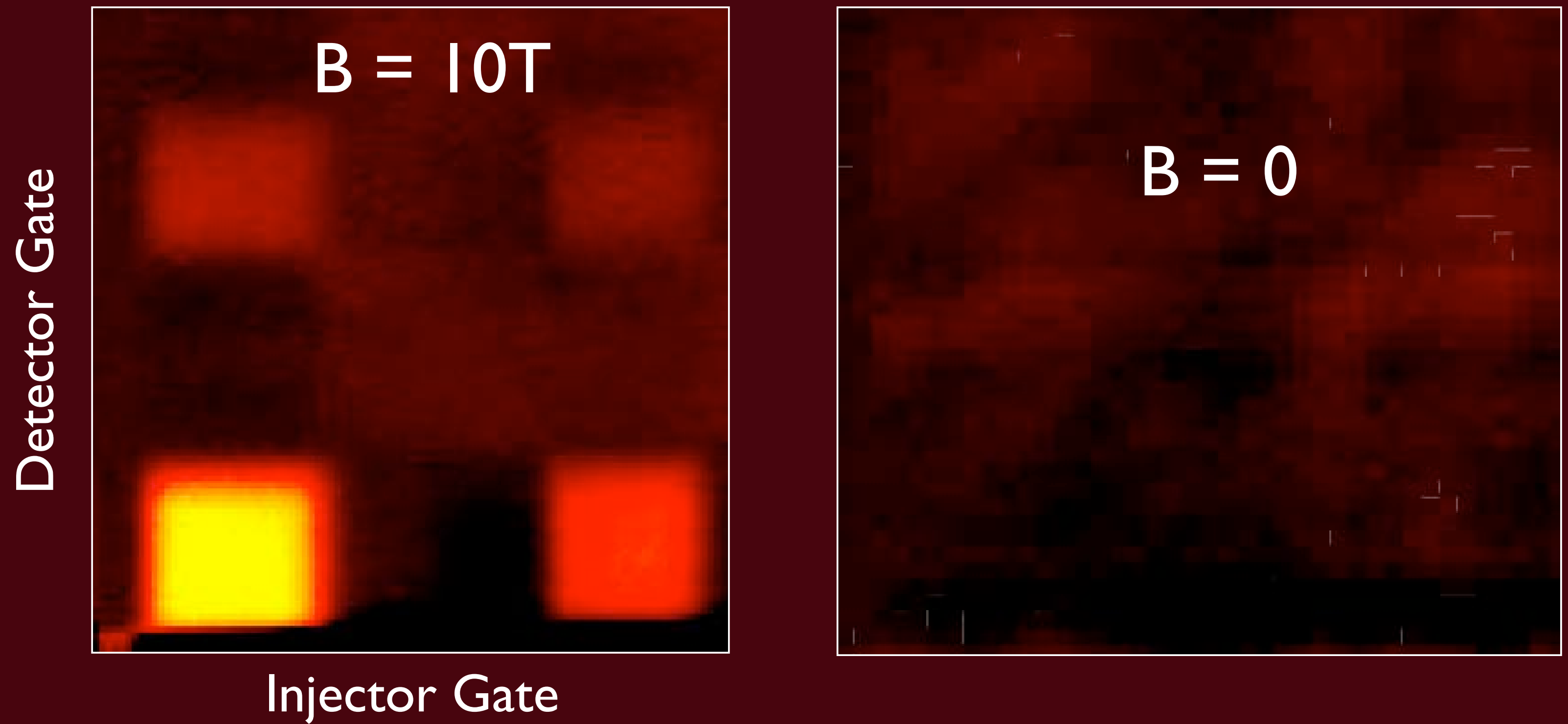
Phase coherent effects (nonlocal UCF)



see also Lerescu, van Wees et al

Other Nonlocal Signals



Spin signal dominates over other nonlocal signals, and most other signals disappear for T>500mK

Conclusions:

- Electrical generation and detection of spin currents
- Long mean free path enables spin transfer over long distances
- Spin relaxation length can be determined independent of contact polarization characteristics
- Flexibility of gated channel geometry in 2D electron gas provides a tool to study spin relaxation over a wide range of parameters (temperature, field, density, # of modes in