Circuit Quantum Electrodynamics with Semiconductor Quantum Dots

Anna Stockklauser, Andreas Landig, Pasquale Scarlino, Matthias Beck, Jerome Faist, Werner Wegscheider, Thomas Ihn, Klaus Ensslin, Andreas Wallraff (ETH Zurich)

Markus Buttiker (Geneva), Alexandre Blais (Sherbrooke)

www.qudev.ethz.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

FNSNF
Swiss National Science Foundation

erc

QSIT Quantum Science and Technology
National Centre of Competence in Research

Acknowledgements

www.qudev.ethz.ch

Former group members now
Faculty/PostDoc/PhD/Industry

A. Abdumalikov (Gorba AG)
M. Allan (Leiden)
M. Baur (ABB)
J. Basset (U. Paris Sud)
S. Berger (AWK Group)
R. Bianchetti (ABB)
D. Bozyigit (MIT)
C. Eichler (Princeton)
A. Fedorov (UQ Brisbane)
A. Fragner (Yale)
S. Filipp (IBM Zurich)
J. Fink (IST Austria)
T. Frey (Bosch)
M. Goppl (Sensirion)
J. Govenius (Aalto)
L. Huthmacher (Cambridge)
D.-D. Jarausch (Cambridge)
K. Juliusson (CEA Saclay)
C. Lang (Radionor)
P. Leek (Oxford)
P. Maurer (Stanford)
J. Mlynek (Siemens)
G. Puebla (IBM)
A. Safavi-Naeini (Stanford)
L. Steffen (AWK Group)
A. van Loo (Oxford)
S. Zeytinoğlu (ETH Zurich)

Collaborations with (groups of):

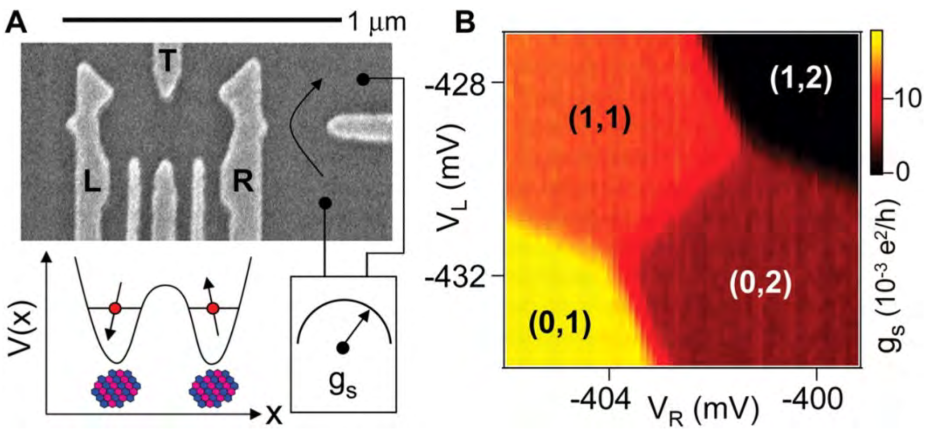
A. Blais (Sherbrooke)
C. Bruder (Basel)
M. da Silva (Raytheon)
L. DiCarlo (TU Delft)
K. Ensslin (ETH Zurich)
J. Faist (ETH Zurich)
J. Gambetta (IBM)
K. Hammerer (Hannover)
T. Ihn (ETH Zurich)
F. Merkt (ETH Zurich)
L. Novotny (ETH Zurich)
T. J. Osborne (Hannover)
B. Sanders (Calgary)
S. Schmidt (ETH Zurich)
R. Schoelkopf (Yale)
C. Schoenenberger (Basel)
E. Solano (UPV/EHU)
W. Wegscheider (ETH Zurich)

FNSNF Swiss National Science Foundation
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
QSIT Quantum Science and Technology National Centre of Competence in Research
QED Circuit and Cavity Quantum Electrodynamics
SOLID
erc
Seventh Framework Programme
GEOMDISS
aqute
scaleQIT

Circuit QED with Quantum Dots: Motivation

Interconnect the worlds of semiconductor and superconductor based quantum circuits

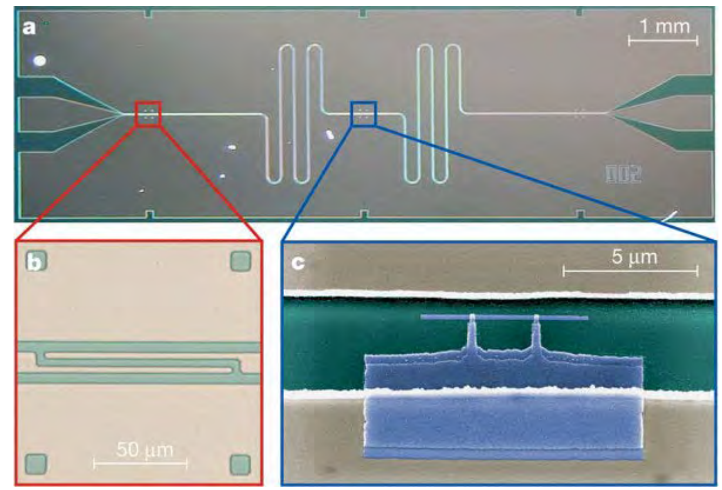
Spin qubits in quantum dots



Science 309, 2180 (2005)

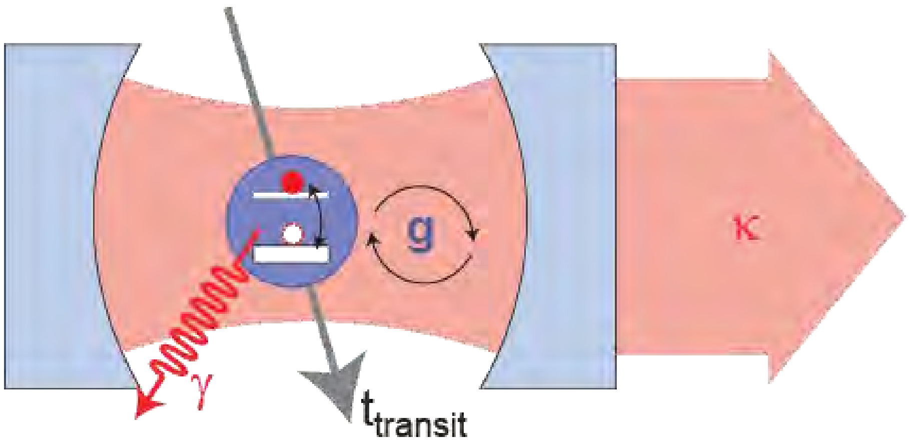
&

Circuit quantum electrodynamics



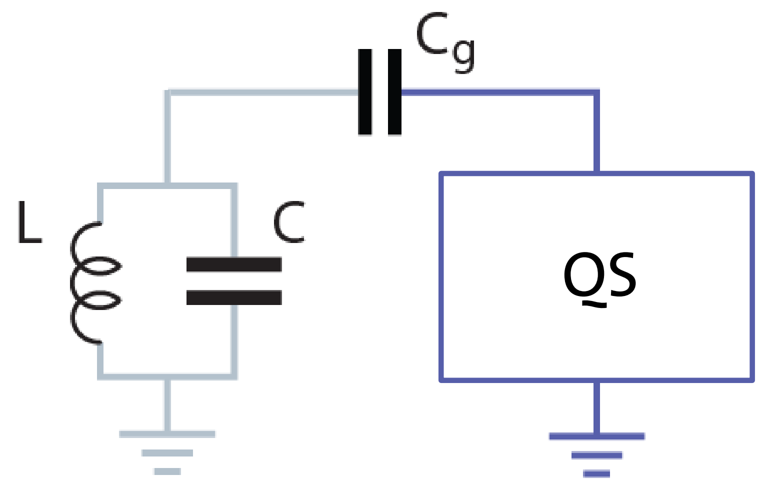
Nature 431, 162 (2004)

Attractive Features of Cavity/Circuit QED



coherent quantum mechanics
with individual photons and qubits ...

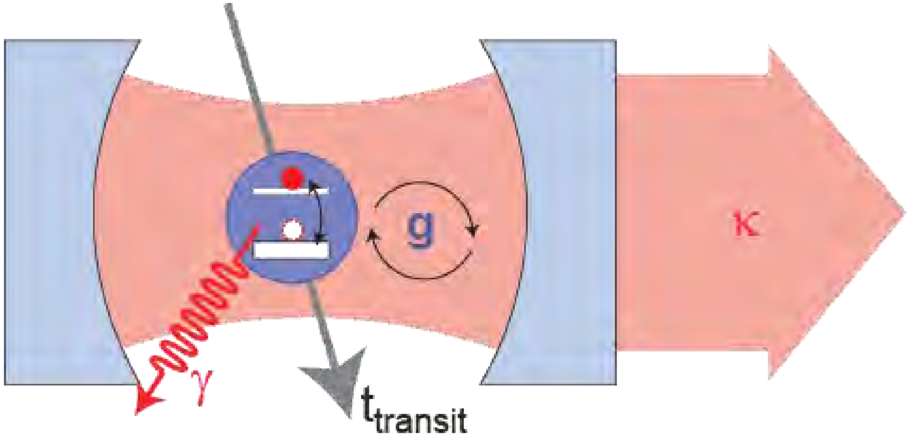
... basic approach in circuits:



What is this good for?

- Isolate quantum system (QS) from its environment
- Maintain addressability of QS
- Read out the state of QS
- Couple QSs to each other
- Convert state of stationary QS into mobile photon

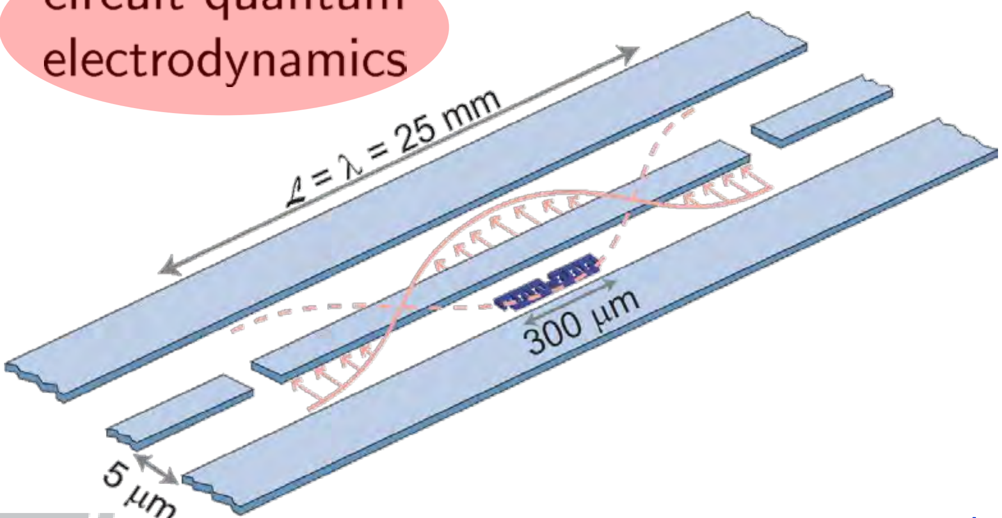
Cavity QED with Superconducting Circuits



coherent interaction of photons with quantum two-level systems ...

J. M. Raimond *et al., Rev. Mod. Phys.* 73, 565 (2001)
S. Haroche & J. Raimond, *OUP Oxford* (2006)
J. Ye., H. J. Kimble, H. Katori, *Science* 320, 1734 (2008)

circuit quantum electrodynamics



Features:

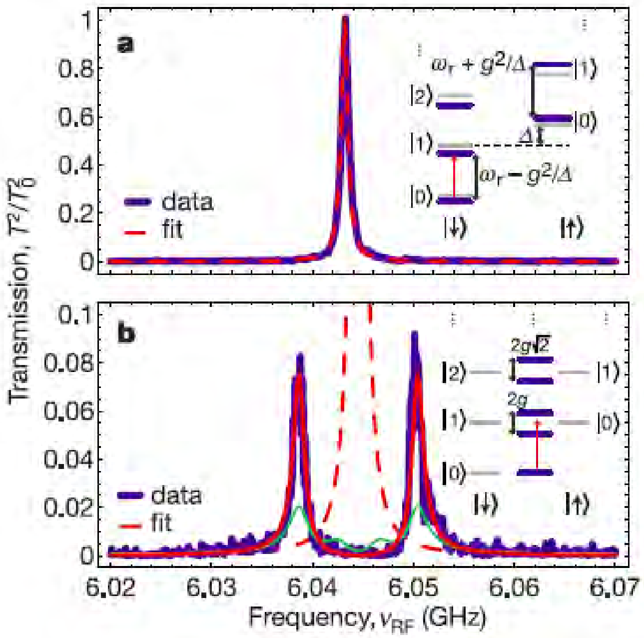
- strong coupling in solid state sys.
- 'easy' to fabricate and integrate

Research directions:

- quantum optics
- quantum information
- hybrid quantum systems

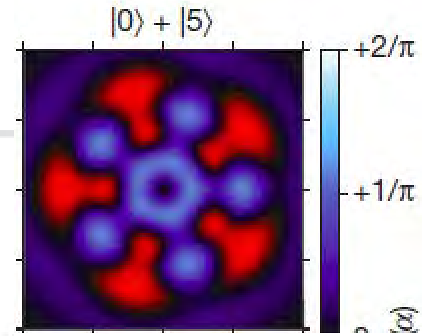
A. Blais, *et al., PRA* 69, 062320 (2004)
A. Wallraff *et al., Nature (London)* 431, 162 (2004)
R. J. Schoelkopf, S. M. Girvin, *Nature (London)* 451, 664 (2008)

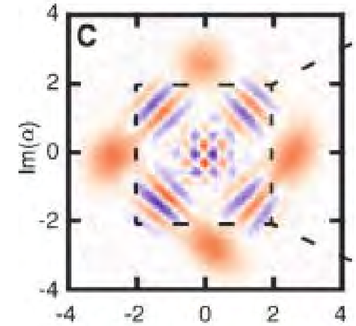
Quantum Optics



Strong Coherent Coupling

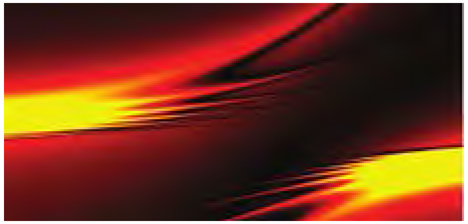
Chiorescu *et al.*, *Nature* 431, 159 (2004)
Wallraff *et al.*, *Nature* 431, 162 (2004)
Schuster *et al.*, *Nature* 445, 515 (2007)





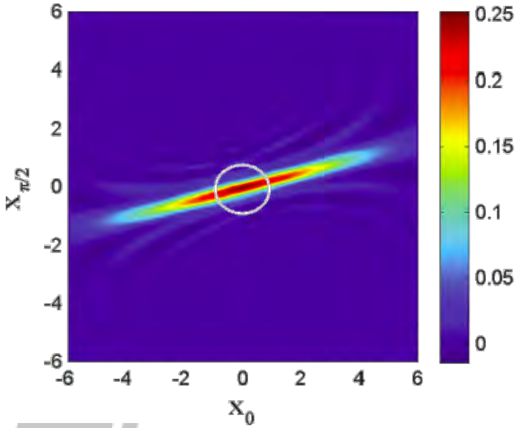
Root n Nonlinearities

Fink *et al.*, *Nature* 454, 315 (2008)
Deppe *et al.*, *Nat. Phys.* 4, 686 (2008)
Bishop *et al.*, *Nat. Phys.* 5, 105 (2009)



Microwave Fock and Cat States

Hofheinz *et al.*, *Nature* 454, 310 (2008)
Hofheinz *et al.*, *Nature* 459, 546 (2009)
Kirchmair *et al.*, *Nature* 495, 205 (2013)
Vlastakis *et al.*, *Science* 342, 607 (2013)

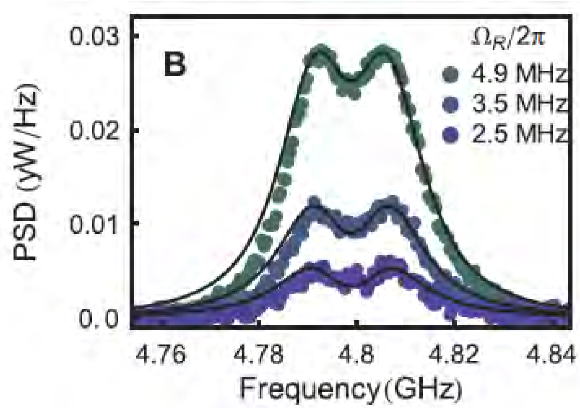


Parametric Amplification & Squeezing

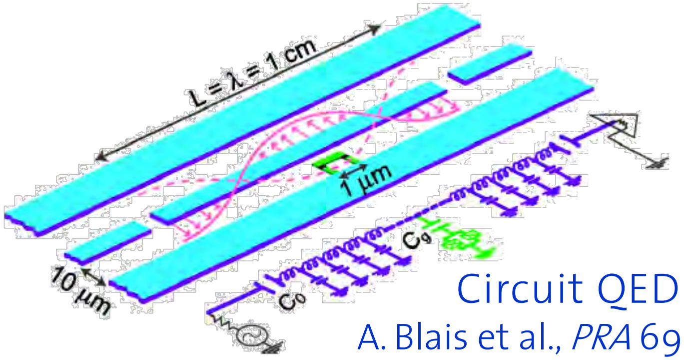
Castellanos-Beltran *et al.*, *Nat. Phys.* 4, 928 (2008)
Abdo *et al.*, *PRX* 3, 031001 (2013)

Waveguide QED – Qubit Interactions in Free Space

Astafiev *et al.*, *Science* 327, 840 (2010)
van Loo *et al.*, *Science* 342, 1494 (2013)

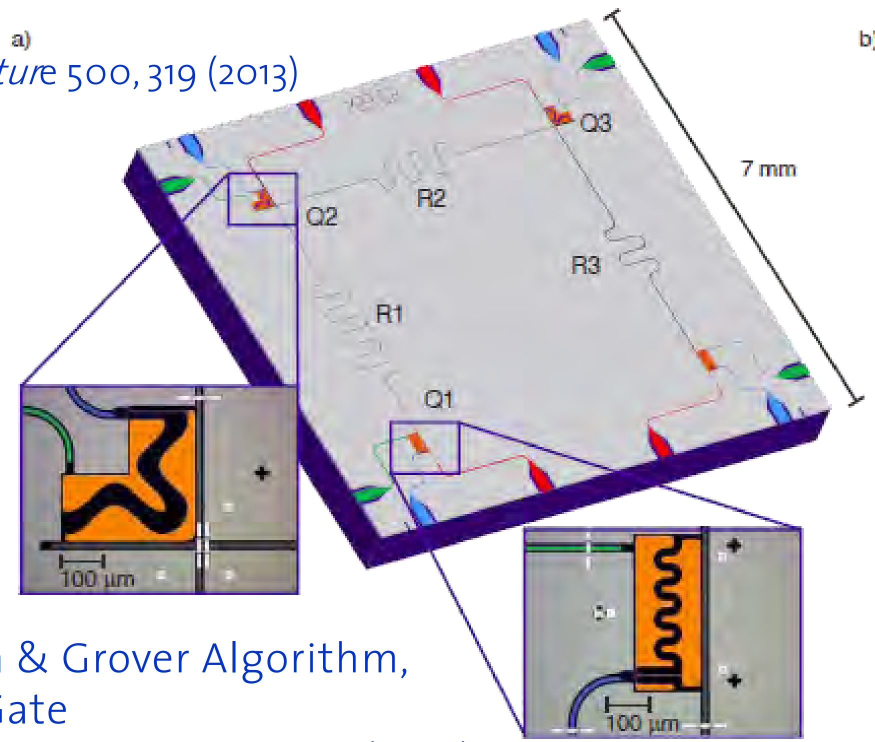


Quantum Computation



Teleportation

L. Steffen *et al., Nature* 500, 319 (2013)



Circuit QED Architecture

A. Blais et al., *PRA* 69, 062320 (2004)

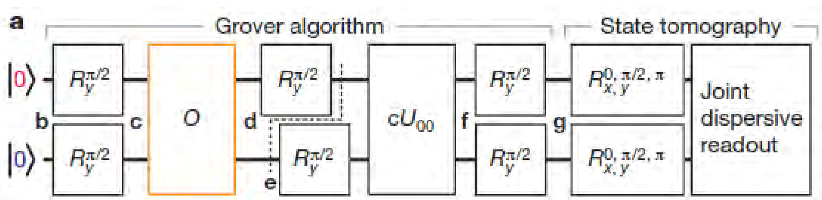
A. Wallraff *et al., Nature* 431, 162 (2004)

M. Sillanpaa *et al., Nature* 449, 438 (2007)

H. Majer *et al., Nature* 449, 443 (2007)

M. Mariantoni *et al., Science* 334, 61 (2011)

R. Barends *et al., Nature* 508, 500 (2014)



Deutsch & Grover Algorithm, Toffoli Gate

L. DiCarlo *et al., Nature* 460, 240 (2009)

L. DiCarlo *et al., Nature* 467, 574 (2010)

A. Fedorov *et al., Nature* 481, 170 (2012)

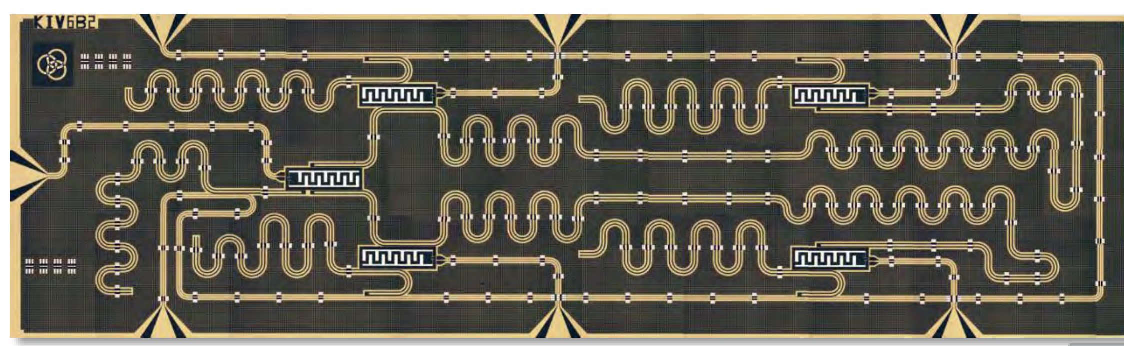
Error Correction & Logical Qubits

M. Reed *et al., Nature* 481, 382 (2012)

Corcoles et al., *Nat. Com.* 6, 6979 (2015)

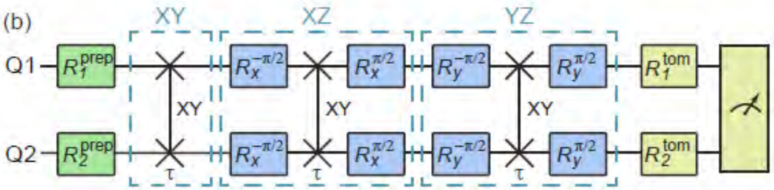
Ristè et al., *Nat. Com.* 6, 6983 (2015)

Kelly et al., *Nature* 519, 66-69 (2015)



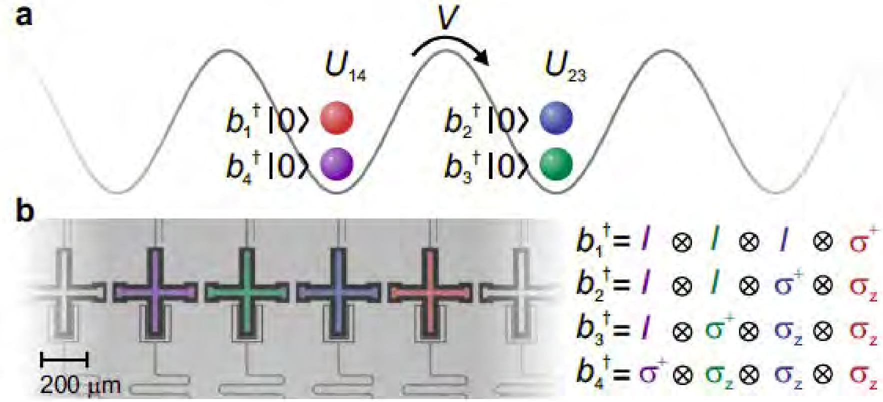
Quantum Simulation

Digital simulation of exchange, Heisenberg, Ising spin models



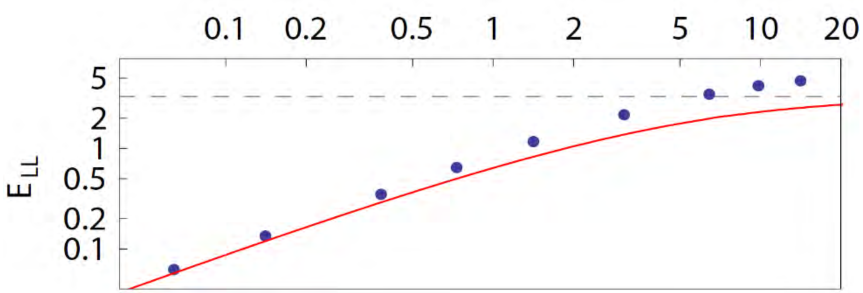
Salathe *et al.*, *PRX* 5, 021027 (2015)

... two-mode fermionic Hubbard models



Barends *et al.*, *Nat. Com.* 6, 7654 (2015)

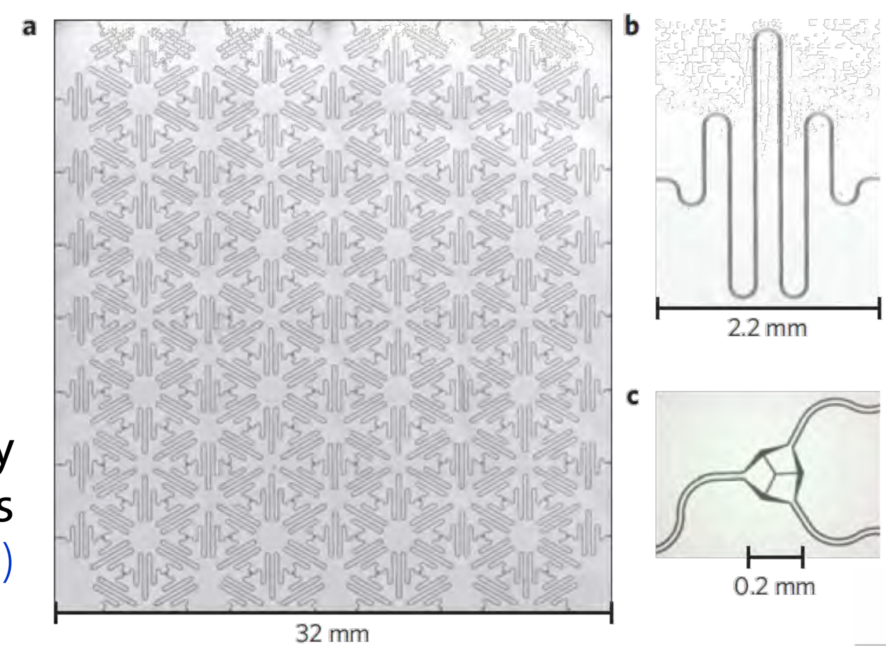
Quantum simulation of correlated systems with variational Ansatz based on MPS



Eichler *et al.*, *Phys. Rev. X* 5, 041044 (2015)

Analog simulations with cavity and/or qubit arrays

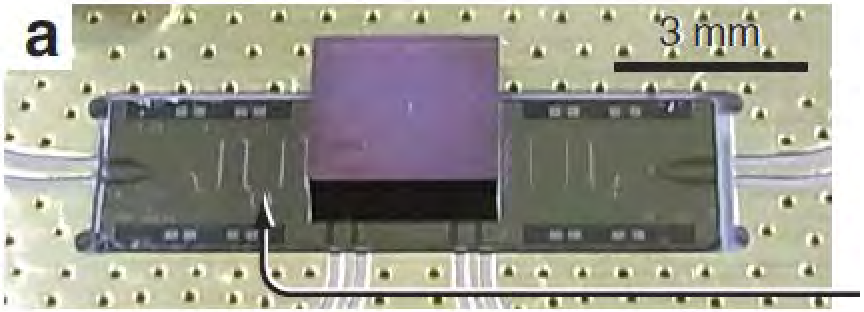
Houck *et al.*, *Nat Phys.* 8, 292 (2012)



Hybrid Systems with Superconducting Circuits

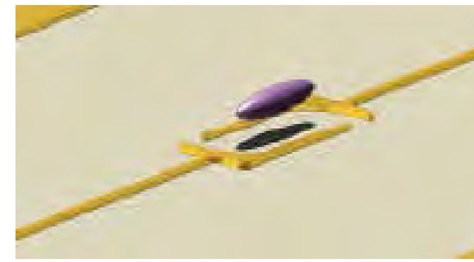
Spin Ensembles: e.g. NV centers

D. Schuster *et al.*, *PRL* 105, 140501 (2010)
Y. Kubo *et al.*, *PRL* 105, 140502 (2010)



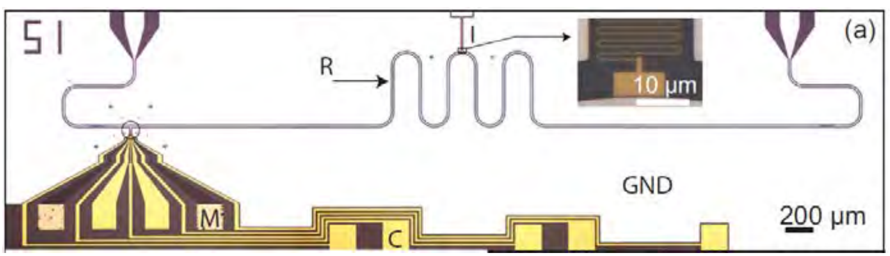
Polar Molecules, Rydberg, BEC

P. Rabl *et a*l, *PRL* 97, 033003 (2006)
A. Andre *et a*l, *Nat. Phys.* 2, 636 (2006)
D. Petrosyan *et al*, *PRL* 100, 170501 (2008)
J. Verdu *et al*, *PRL* 103, 043603 (2009)



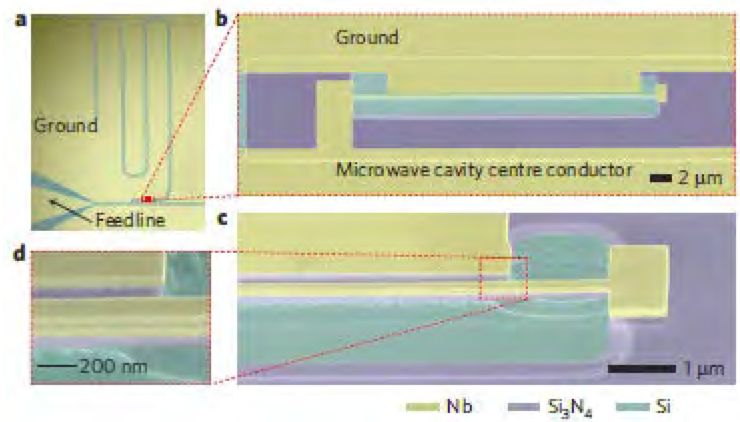
CNT, Gate Defined 2DEG, or nanowire Quantum Dots

M. Delbecq *et al.*, *PRL* 107, 256804 (2011)
T. Frey *et al.*, *PRL* 108, 046807 (2012)
K. Petersson *et al.*, *Nature* 490, 380 (2013)



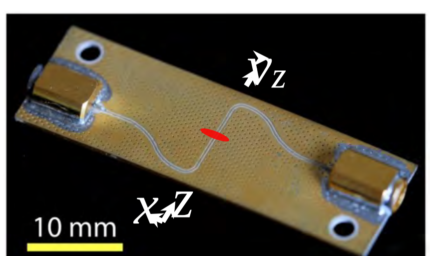
Nano-Mechanics

J. Teufel *et al.*, *Nature* 475, 359 (2011)
X. Zhou *et al.*, *Nat. Phys.* 9, 179(2013)



Rydberg Atoms

S. Hogan *et al.*, *PRL* 108, 063004 (2012)

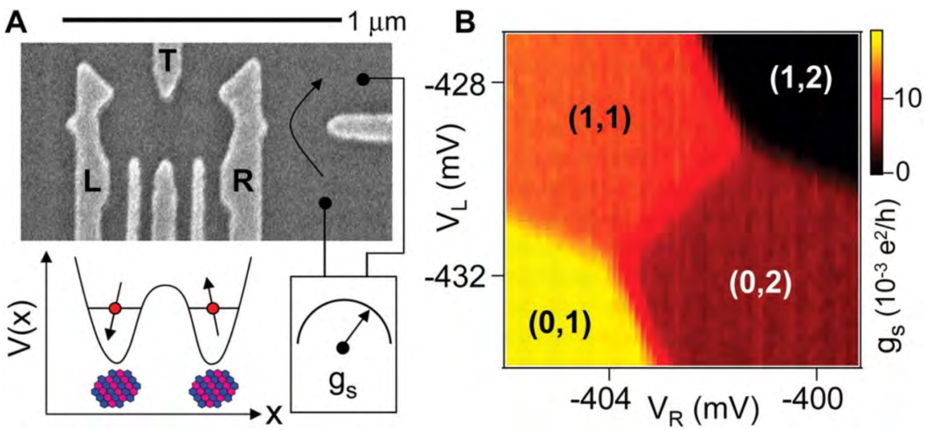


... and many more

Circuit QED with Quantum Dots: Motivation

Interconnect the worlds of semiconductor and superconductor based quantum circuits

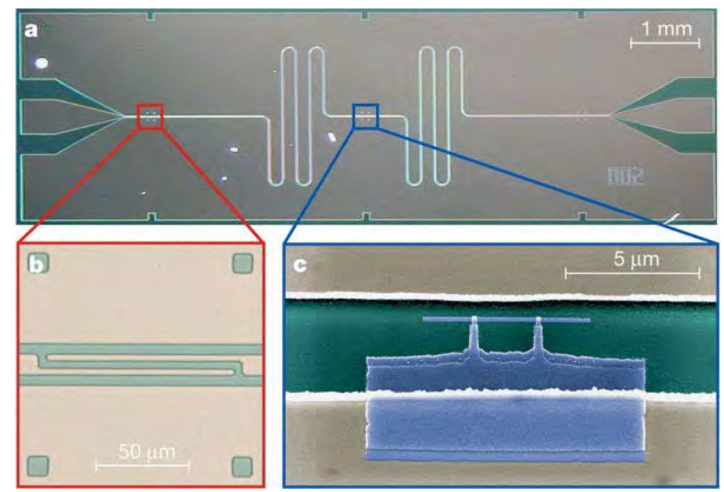
Spin qubits in quantum dots



Science 309, 2180 (2005)

&

Circuit quantum electrodynamics



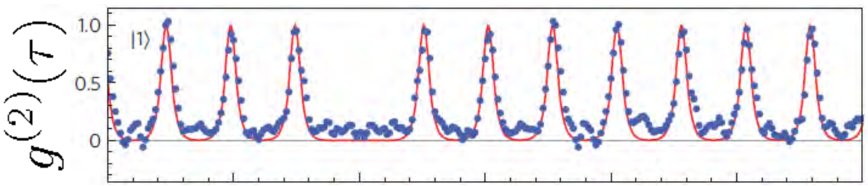
Nature 431, 162 (2004)

Potential benefits:

- realize interfaces between quantum systems
- allow for coherent control while isolating from environment
- achieve long distance coupling
- implement alternative measurement/read-out schemes
- explore correlations between charge transport and radiation emission

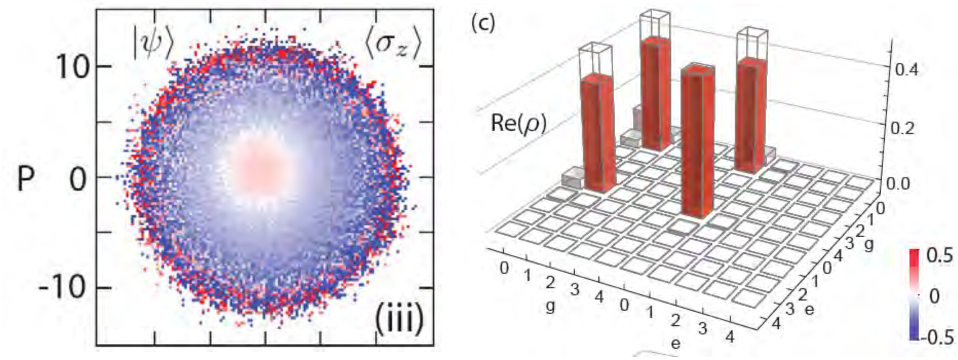
Experiments with Propagating Quantum Microwaves

Single photon sources and their anti-bunching



Houck *et al.*, *Nature* 449, 328 (2007)
Bozyigit *et al.*, Nat. Phys 7, 154 (2011)
Lang *et al.*, *PRL* 107, 073601 (2011)

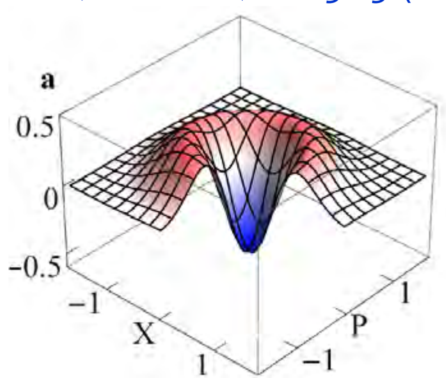
Creation and characterization of entanglement of qubits with propagating photons



Eichler *et al.*, *PRL* 109, *240501* (2012)
Eichler *et al.*, *PRA* 86, 032106 (2012)

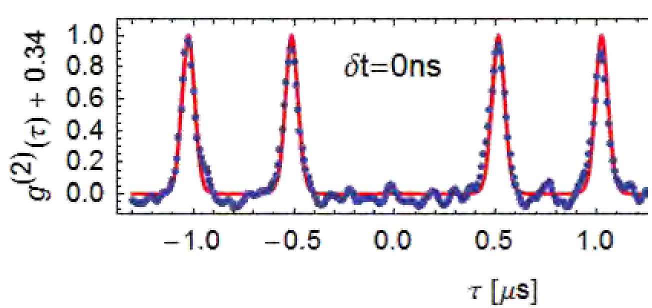
Full state tomography and Wigner functions of propagating photons

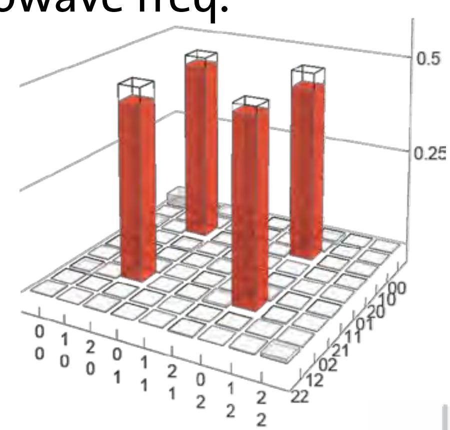
Eichler *et al.*, *PRL* 106, 220503 (2011)



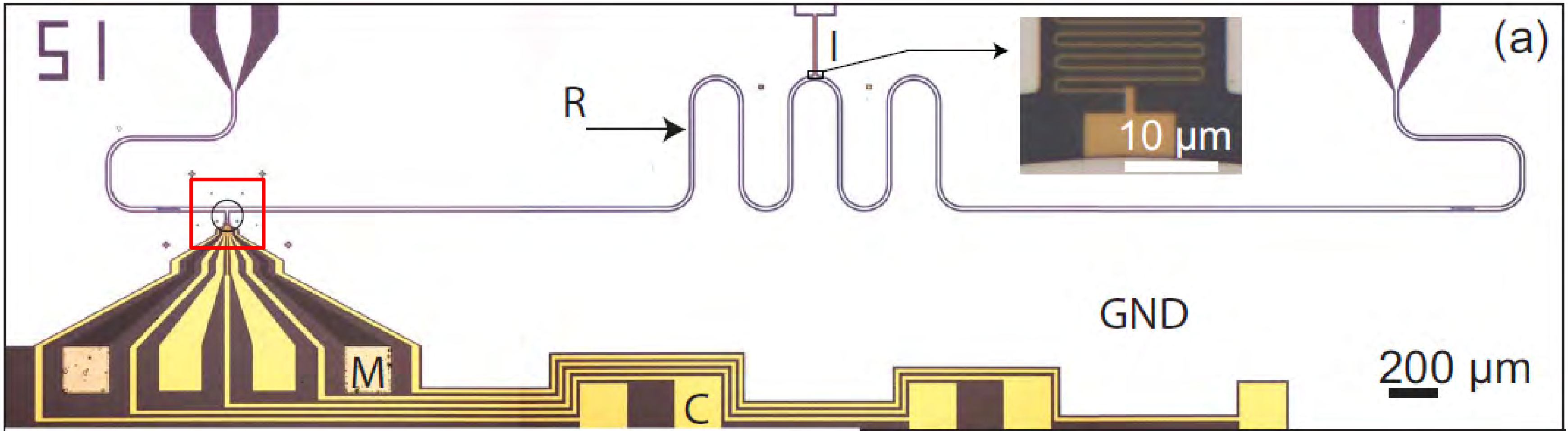
Hong-Ou-Mandel: Two-photon interference incl. msrmnt of coherences at microwave freq.

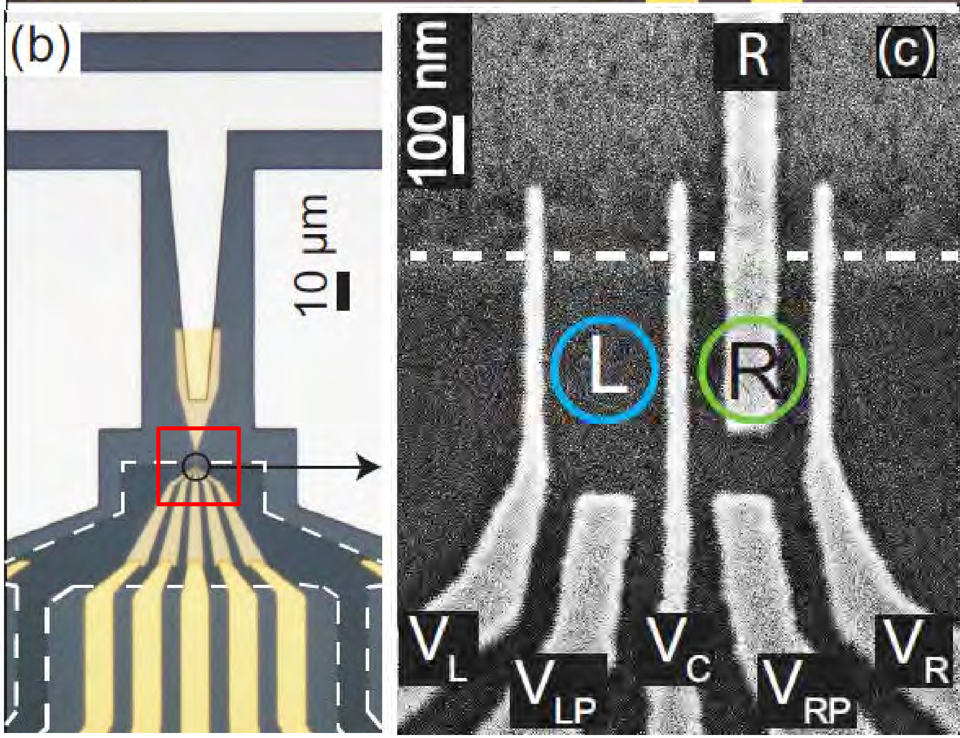
Lang *et al.*, *Nat. Phys.* 9, 345 (2013)





Hybrid Quantum Dot / Circuit QED Device





resonator circuit:
superconducting aluminium
f_0 = 6.75 GHz (28 µeV, 280 mK)

quantum dot based on standard Ga[Al]As heterostructure with 2D electron gas

Frey *et al.*, *PRL* 108, 046807 (2012)

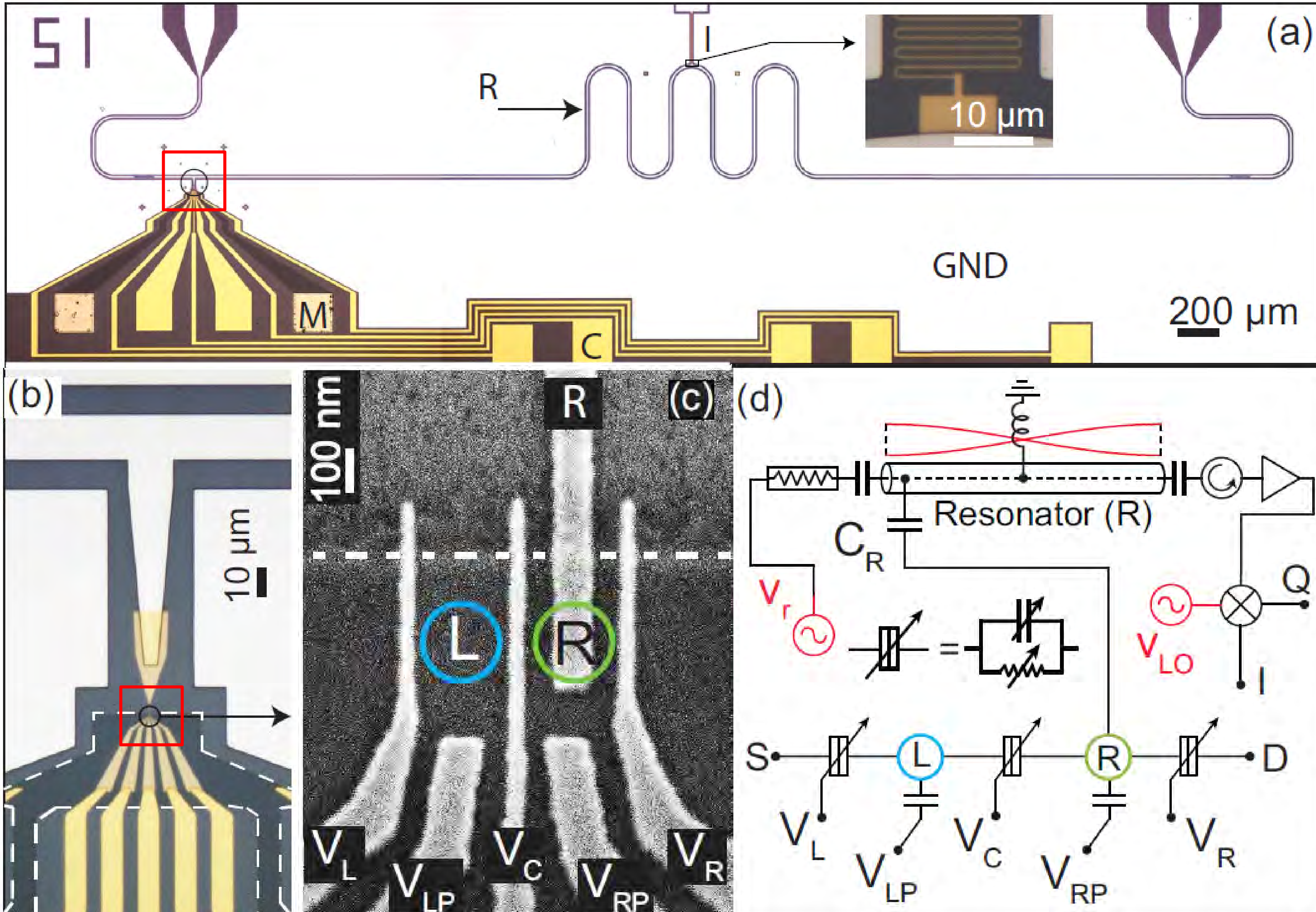
related work:

Delbecq *et al.*, *PRL* 107, 256804 (2011)

Petersson *et al.*, *Nature* 490, 380 (2012)

Toida *et al.*, *PRL* 110, 066802 (2013)

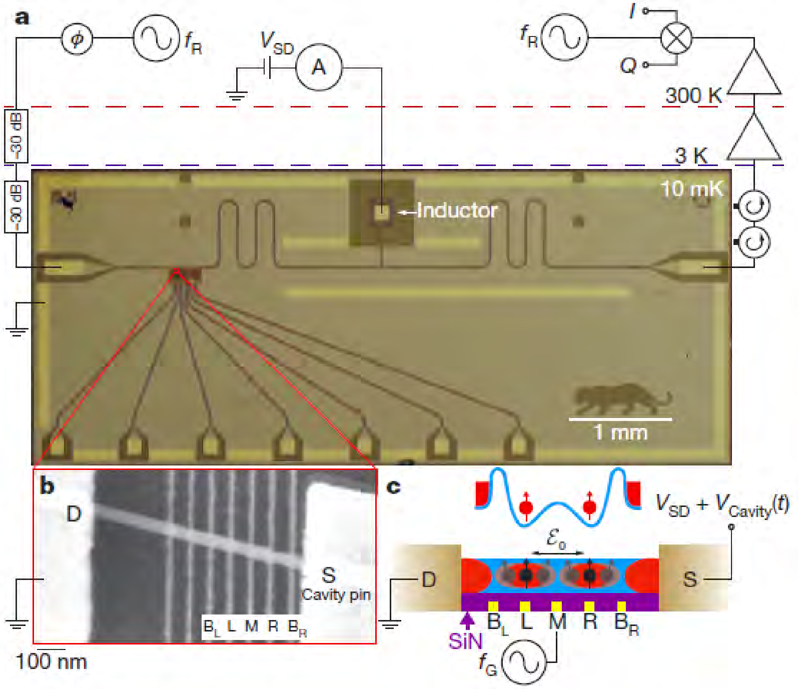
Hybrid Quantum Dot / Circuit QED Device



T. Frey *et al.*, *PRL* 108, 046807 (2012)

Semiconductor Circuit QED Hybrid Systems

InAs nano-wire quantum dots:



K. D. Petersson et al., *Nature* 490, 380-383 (2012)

Liu *et al.*, *PRL* 113, 036801 (2014)

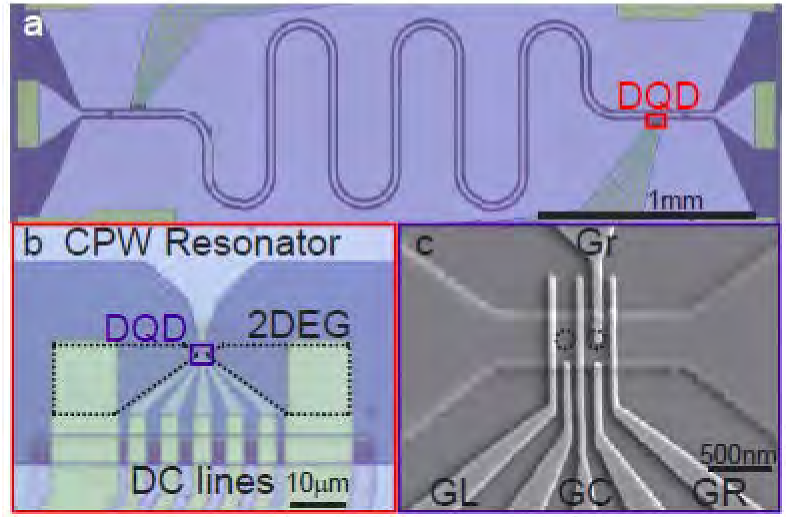
Liu *et al.*, *Science* 347, 285-287 (2015)

Carbon nanotube quantum dots:

M. Delbecq et al., *PRL* 107, 256804 (2011)

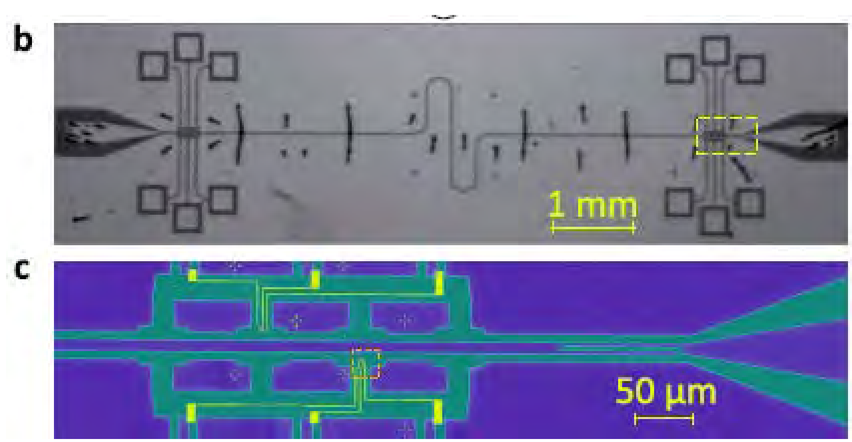
J. Viennot et al., *Science* 349, 408 (2015)

GaAs quantum dots:

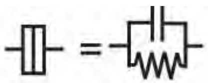


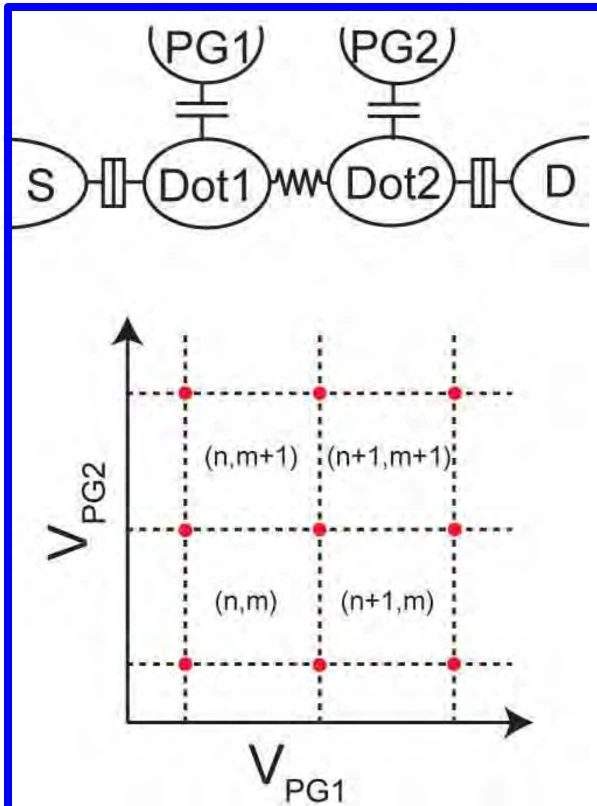
H. Toida et al., *PRL* 110, 066802 (2013)

A. Wallraff et al., *PRL* 111, 249701 (2013)

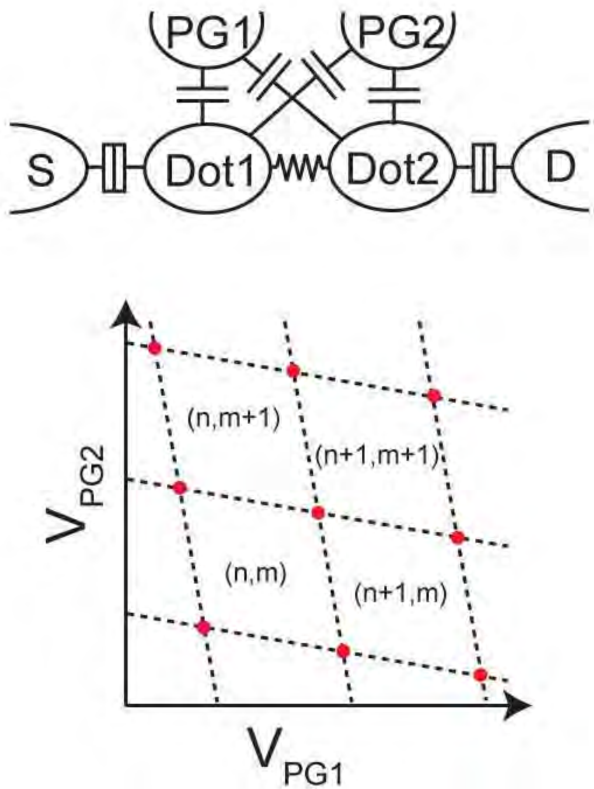


Double Dot Charge Stability Diagram

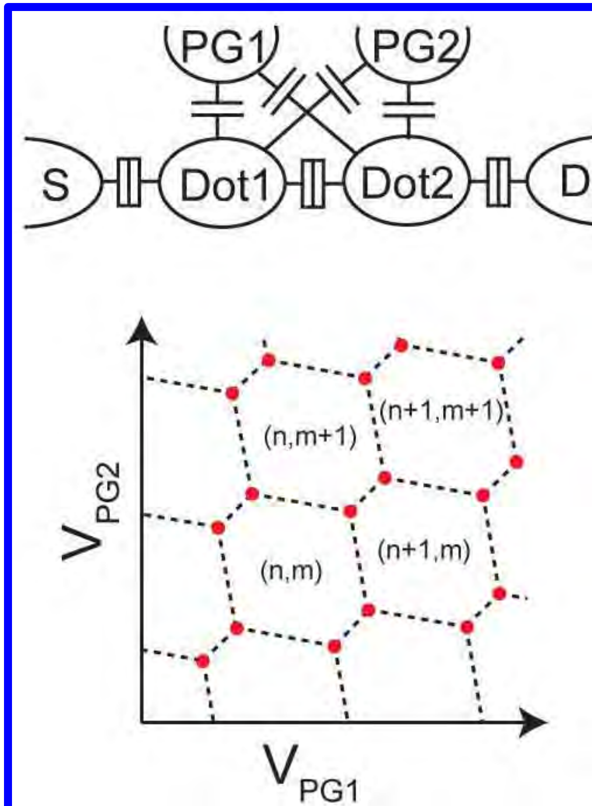




each dot coupled only to its gate



each dot coupled to both gates



both dots coupled to each other

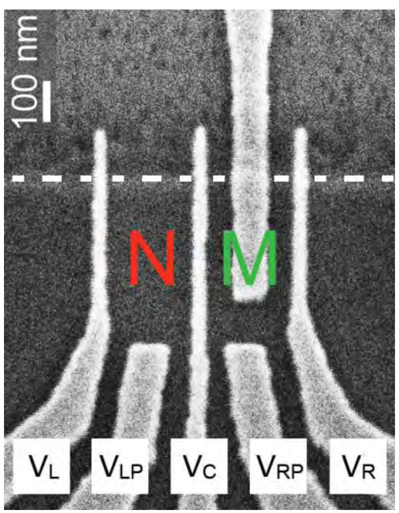
Double Dot Current and Resonator Transmission

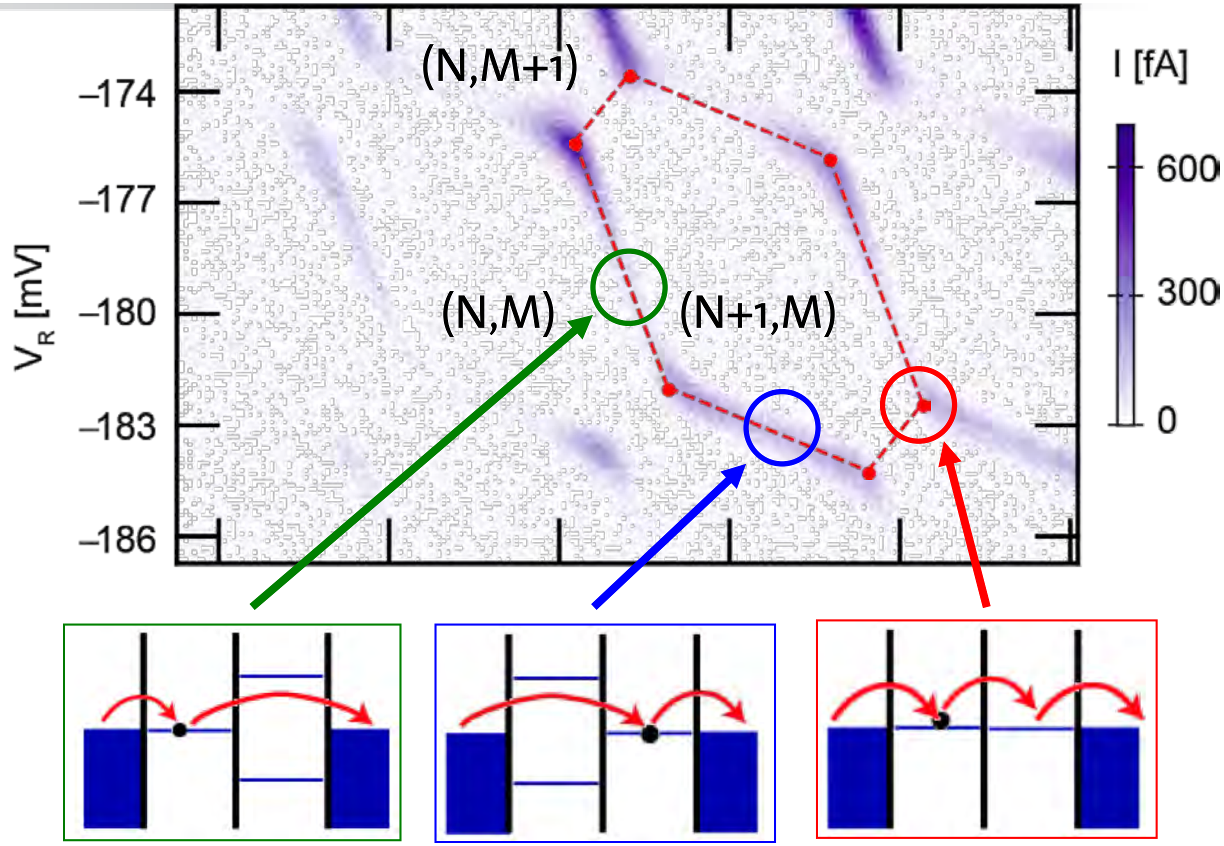
Transport measurements:

- Charging diagrams

dot properties:

- many electron regime
- large charging energy
- consider two-level approx.





co-tunneling

sequential tunneling

T. Frey *et al.*, *PRL* 108, 046807 (2012)

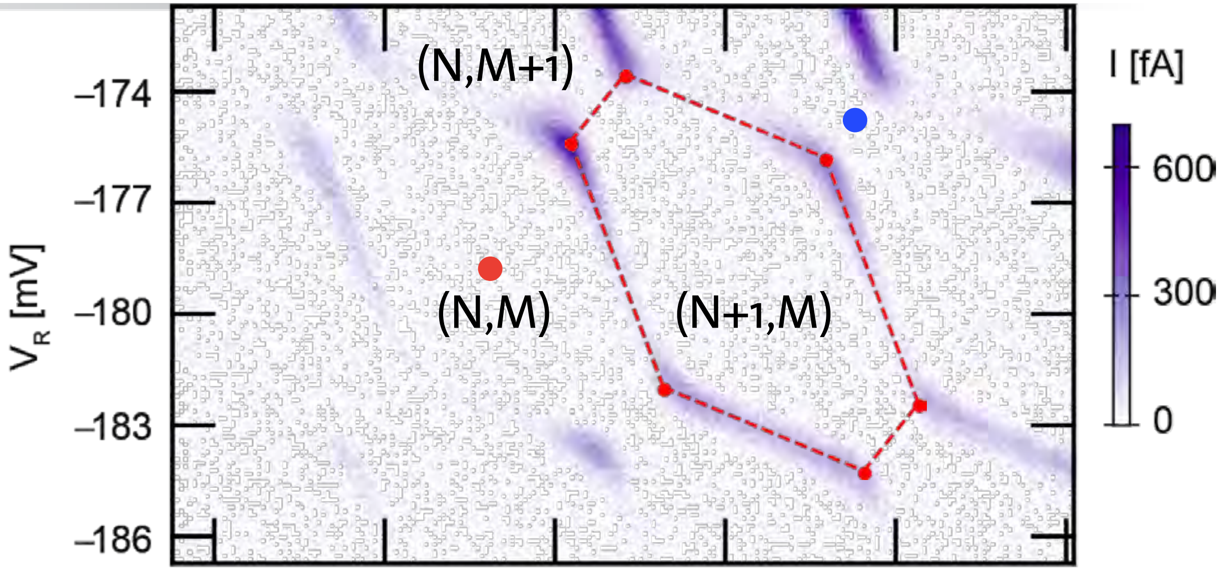
Double Dot Current and Resonator Transmission

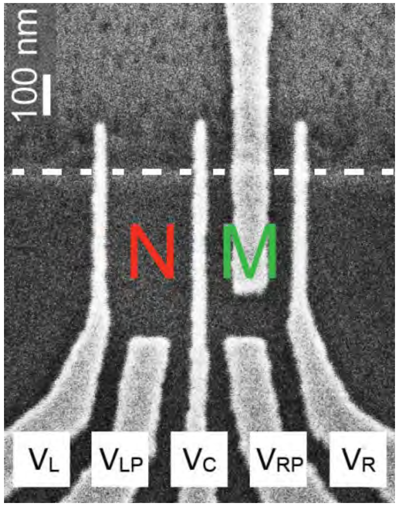
Transport measurements:

- Charging diagrams

dot properties:

- many electron regime
- large charging energy
- consider two-level approx.





T. Frey *et al.*, *PRL* 108, 046807 (2012)

Double Dot Current and Resonator Transmission

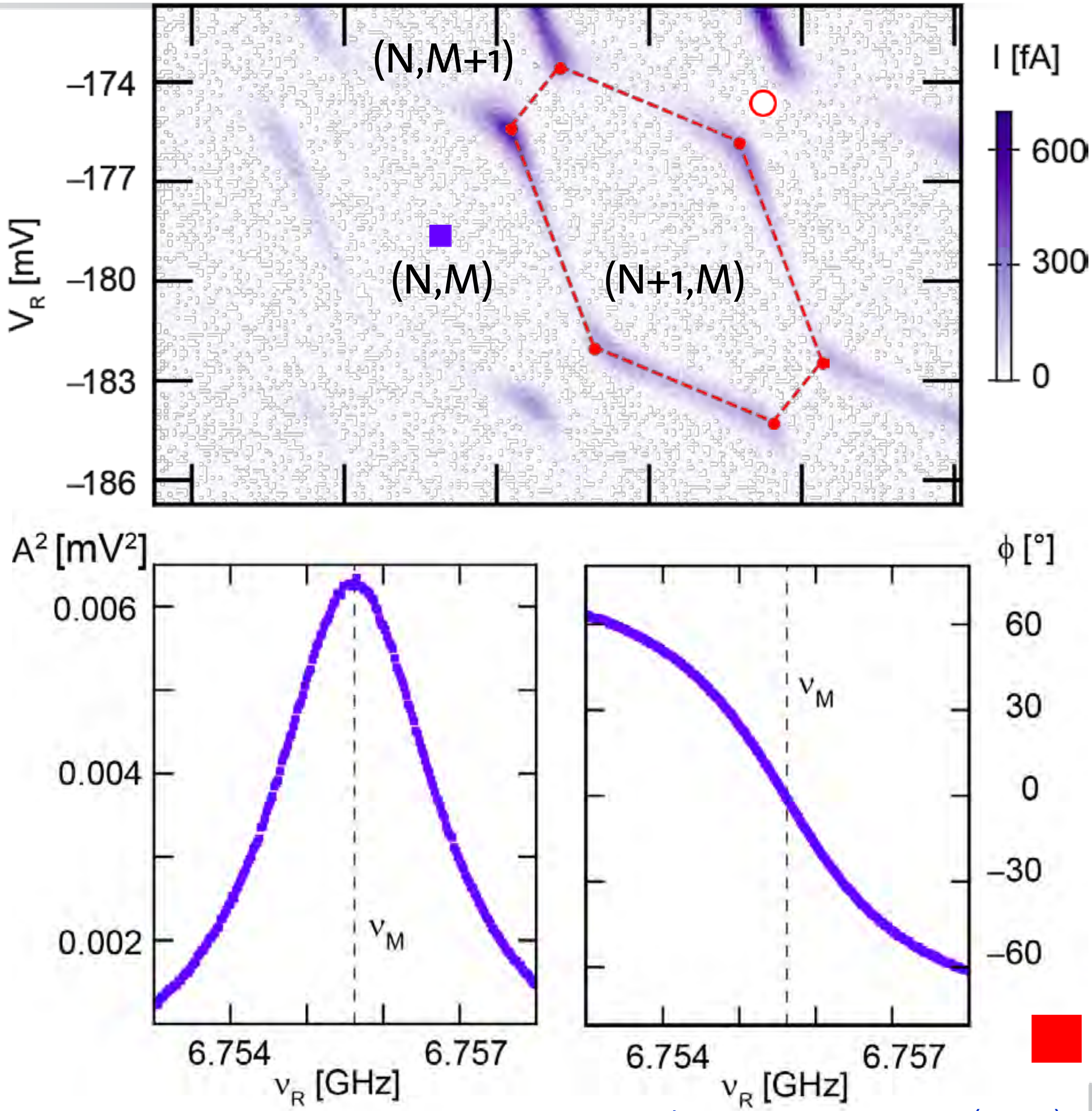
Transport measurements:

- Charging diagrams

dot properties:

- many electron regime
- large charging energy
- consider two-level approx.

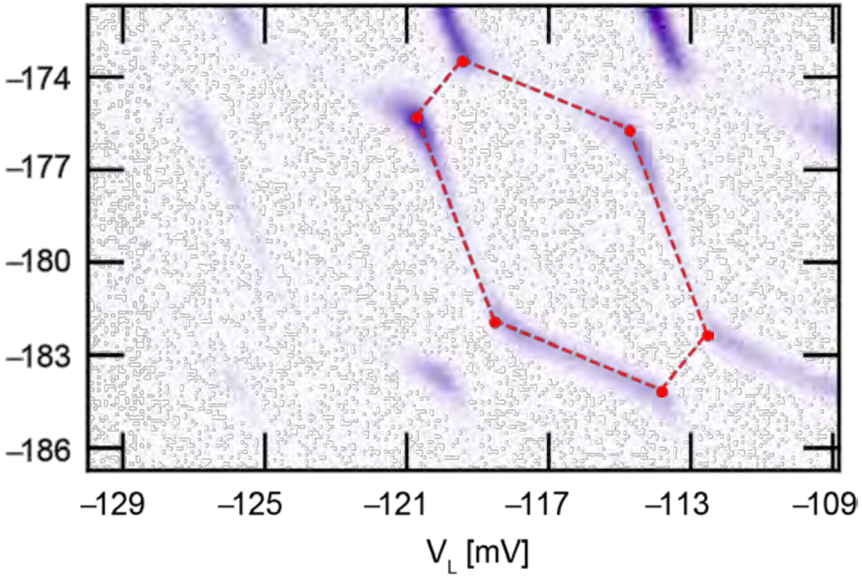
Resonator transmission:



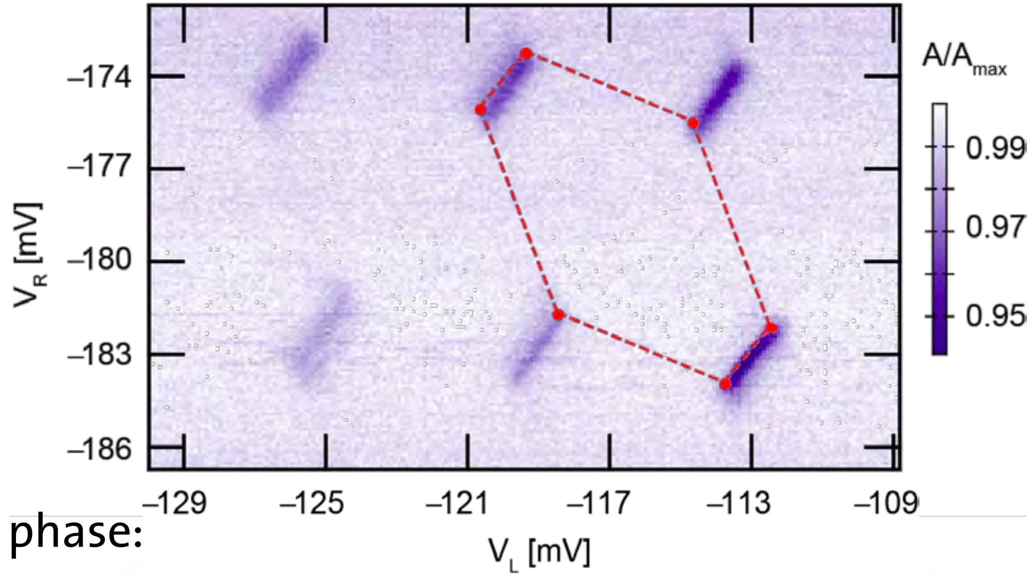
T. Frey *et al.*, *PRL* 108, 046807 (2012)

Charging Diagrams in Current, Amplitude and Phase

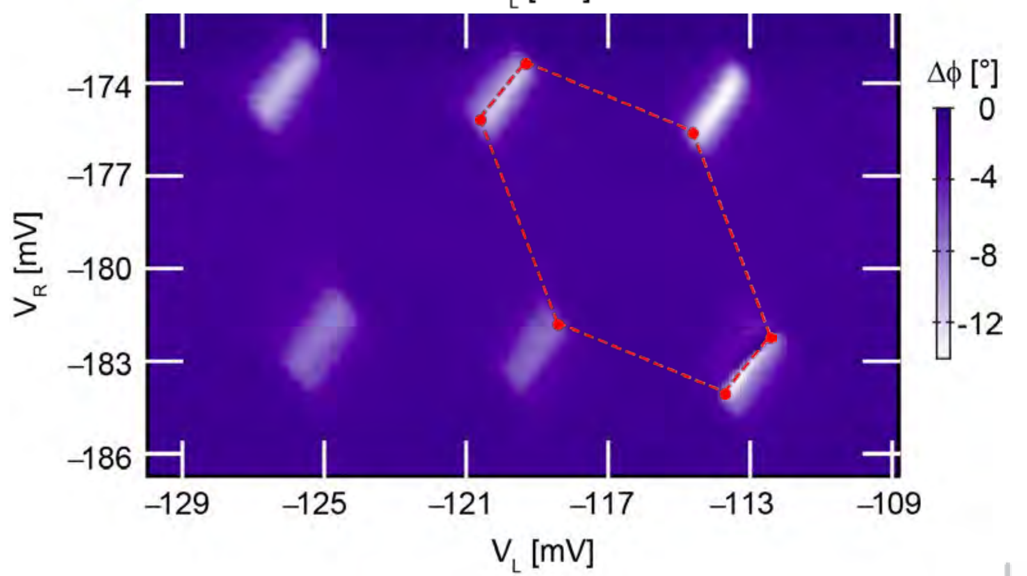
current:



amplitude:



phase:

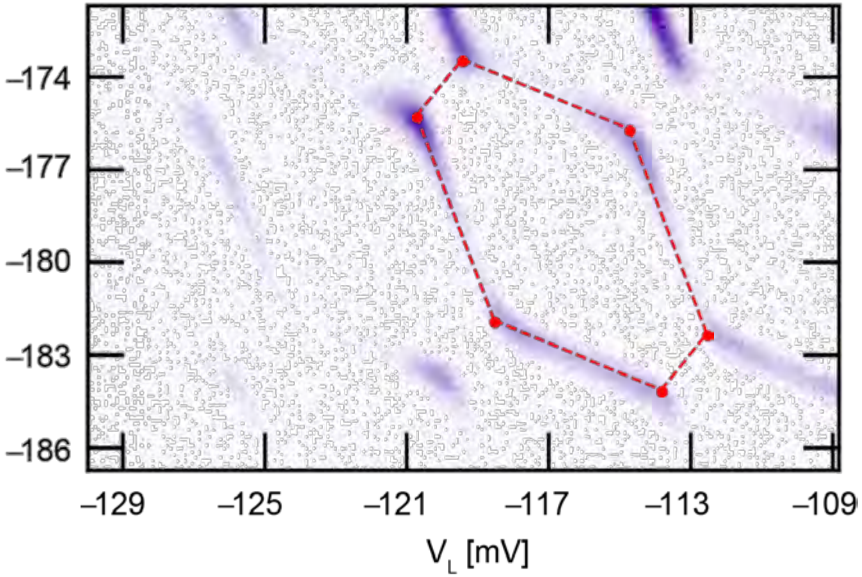


- systematic changes in transmission amplitude and phase
- equivalent charging diagrams ...
- ... but different physical origin of signal

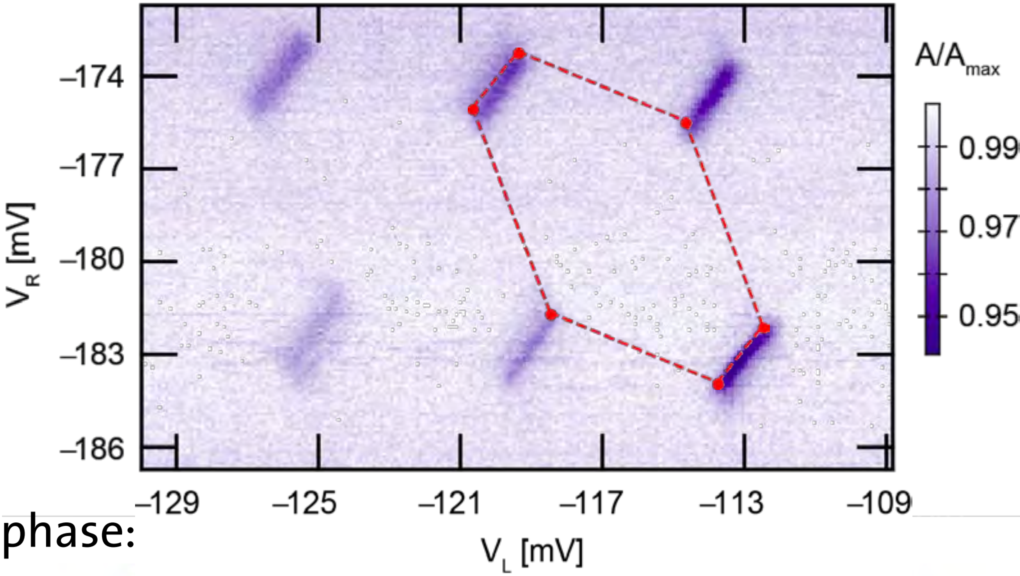
T. Frey *et al.*, *PRL* 108, 046807 (2012)

Charging Diagrams in Current, Amplitude and Phase

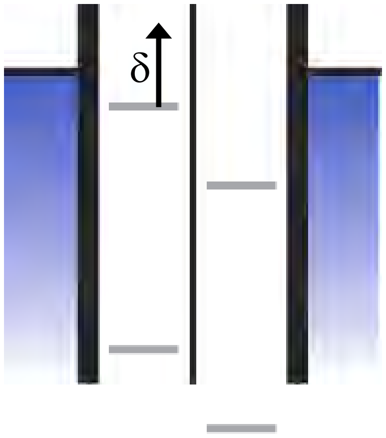
current:



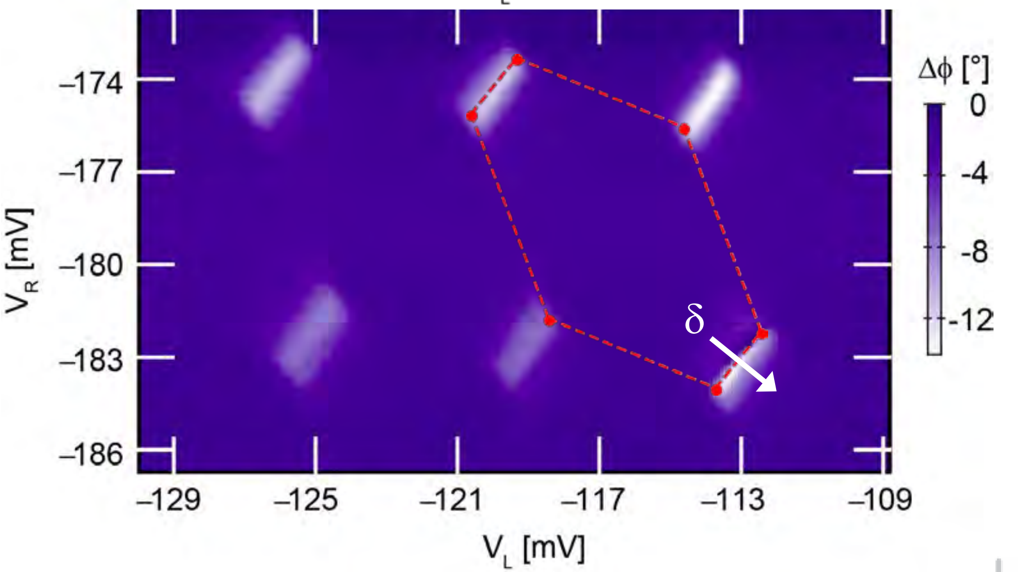
amplitude:



detuning δ:



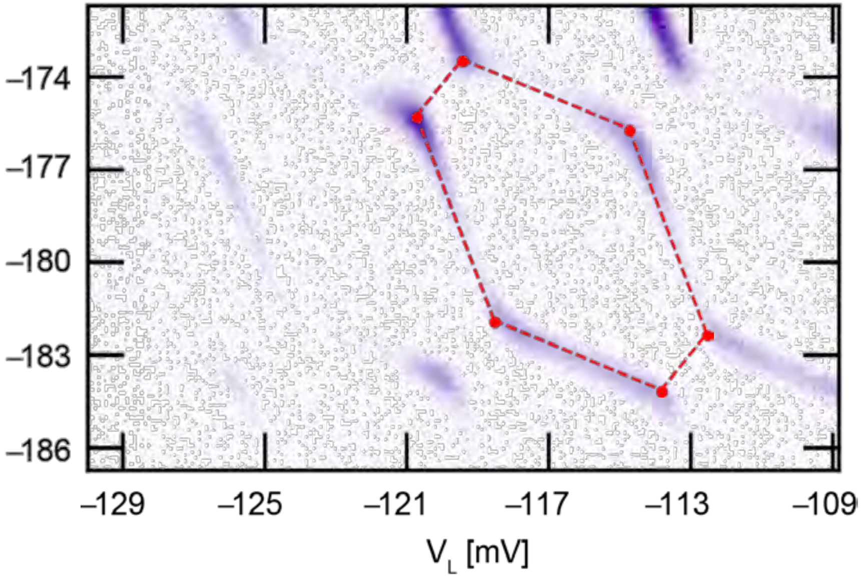
phase:



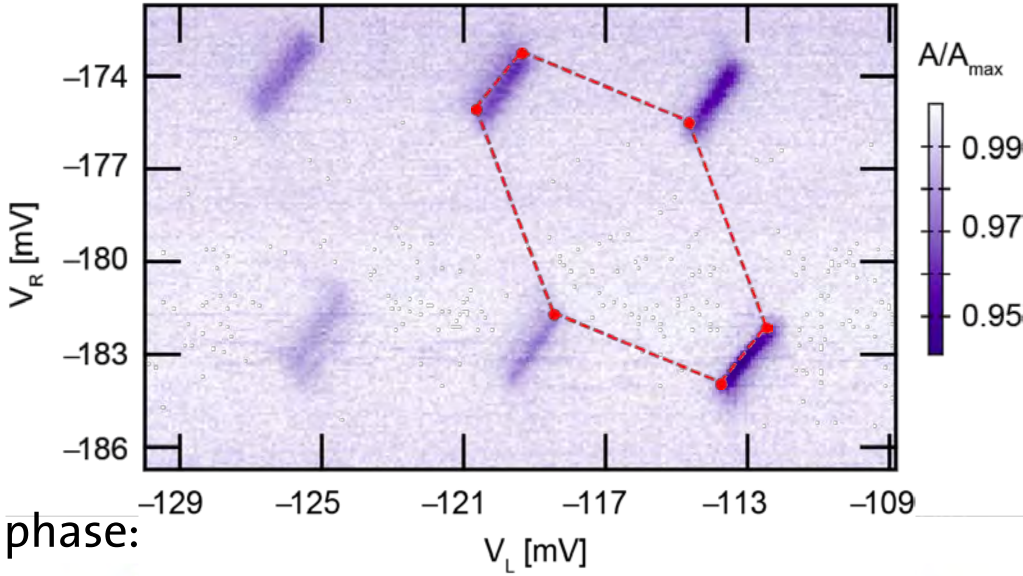
T. Frey *et al.*, *PRL* 108, 046807 (2012)

Charging Diagrams in Current, Amplitude and Phase

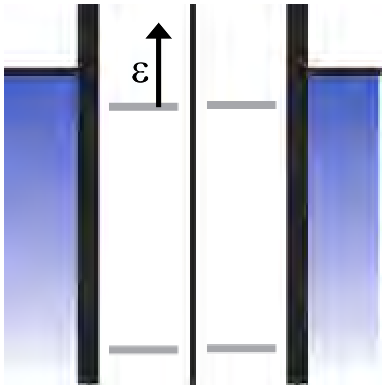
current:



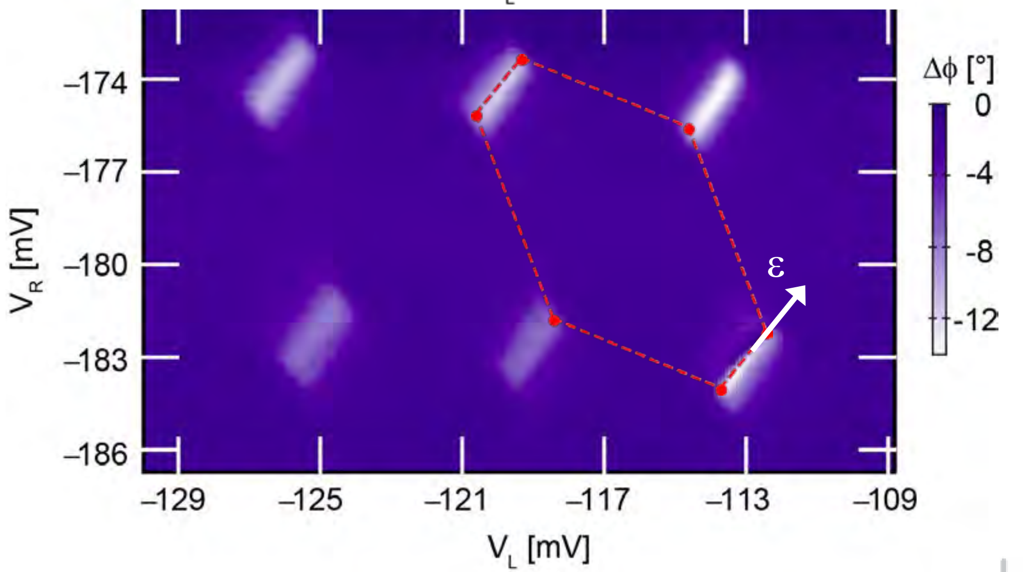
amplitude:



total energy ε:



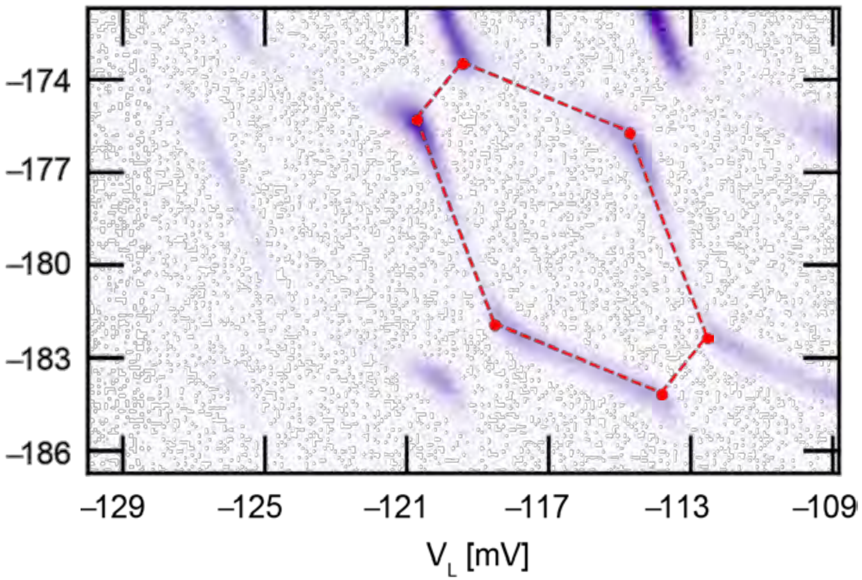
phase:



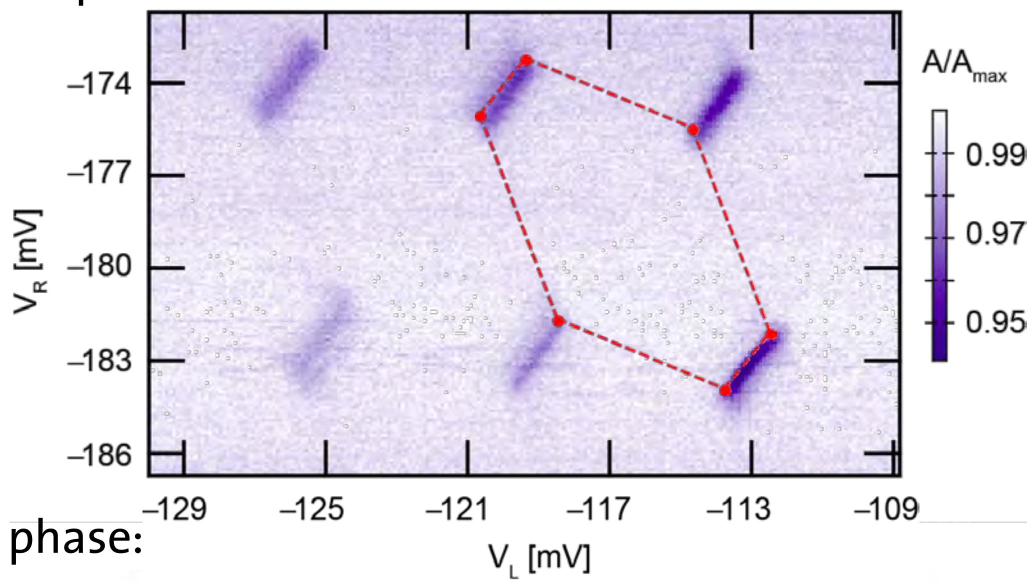
T. Frey *et al.*, *PRL* 108, 046807 (2012)

Charging Diagrams in Current, Amplitude and Phase

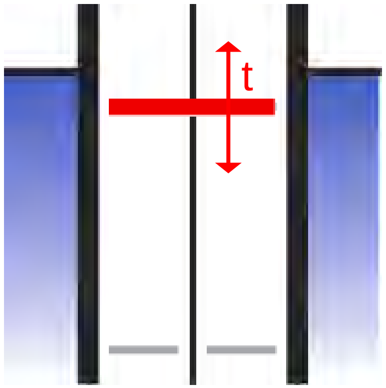
current:



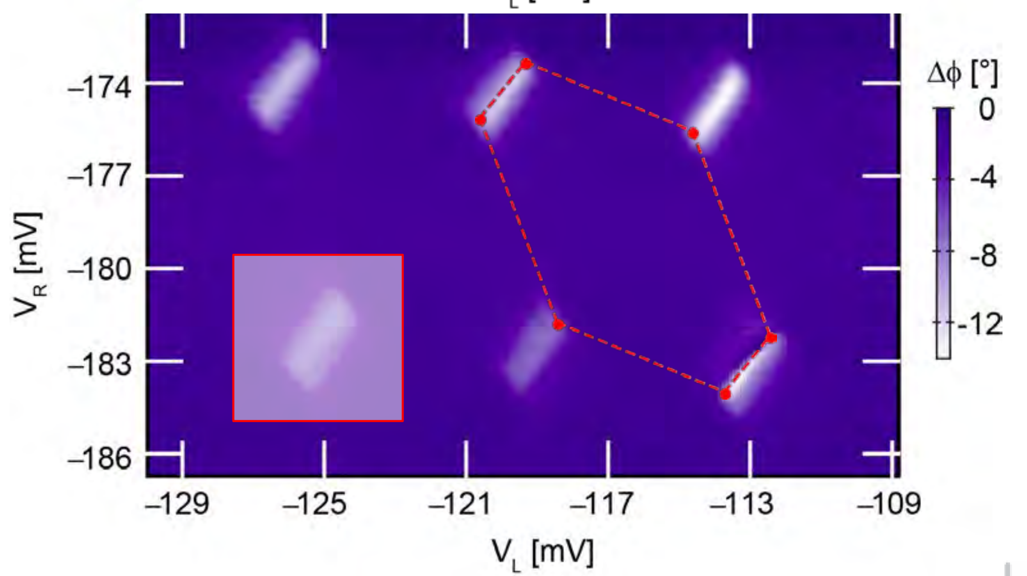
amplitude:



tunnel coupling t :



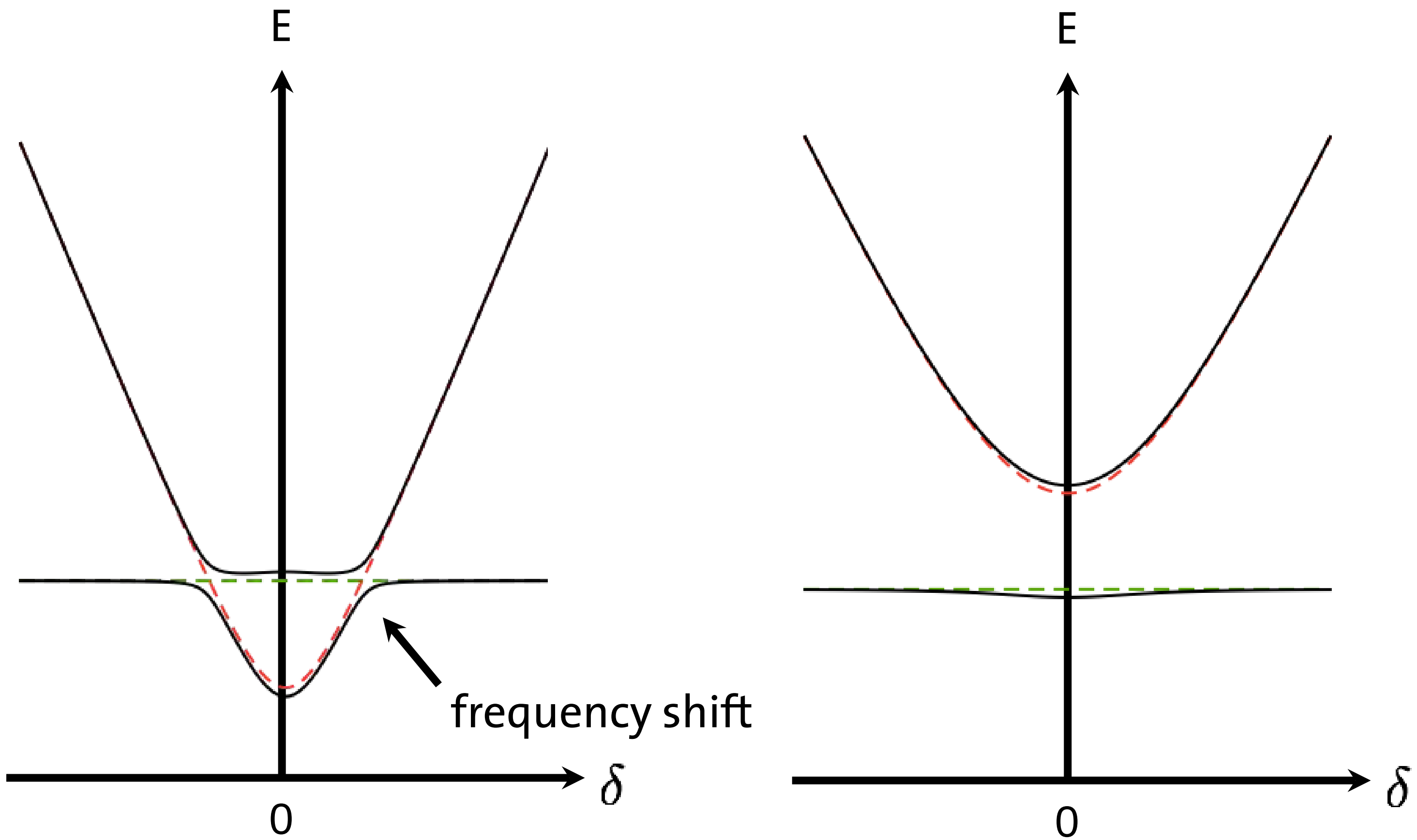
phase:



T. Frey *et al.*, *PRL* 108, 046807 (2012)

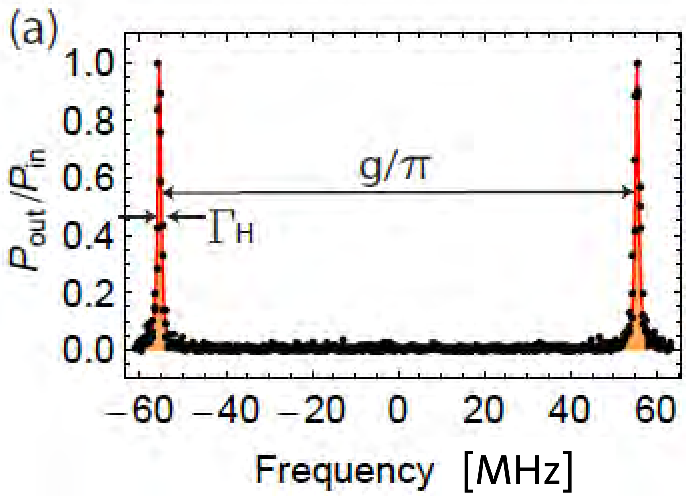
Model of the Coupled Resonator–Dot System

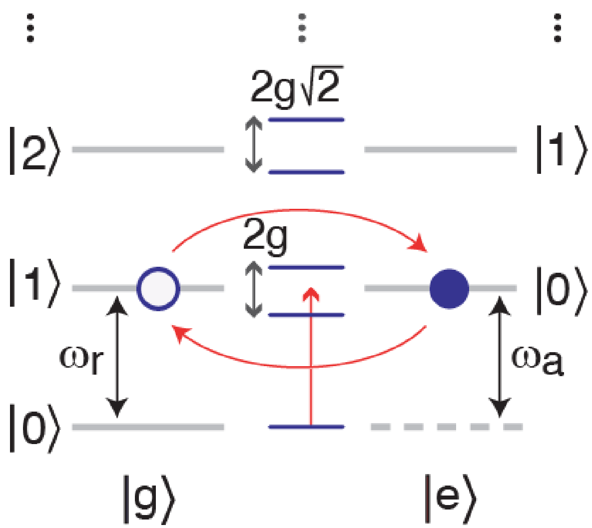
$$H = \underbrace{h\nu_0(\hat{n} + \frac{1}{2})}_{\text{resonator}} + \underbrace{\frac{h\nu_\mathrm{q}}{2}\hat{\sigma}_\mathrm{z}}_{\text{qubit}} + \underbrace{\hbar g \sin\theta(\hat{a}^\dagger\hat{\sigma}^- + \hat{a}\hat{\sigma}^+)}_{\text{coupling}}$$



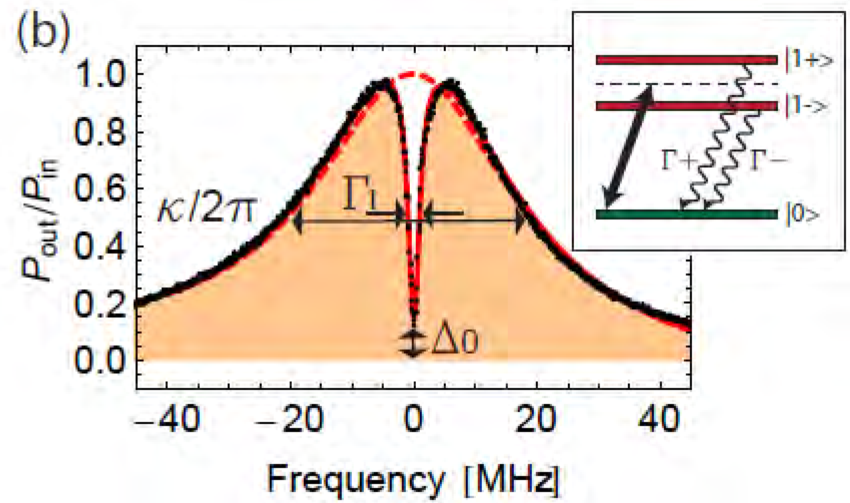
Regimes of Resonant Circuit/Cavity QED

- strong coupling limit ($g > \kappa, \gamma$)

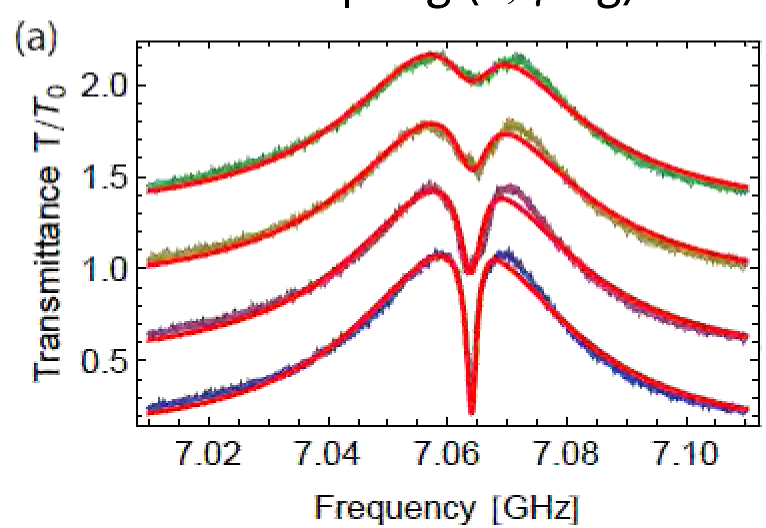




- bad (or fast) cavity limit ($\kappa > g > \gamma$)

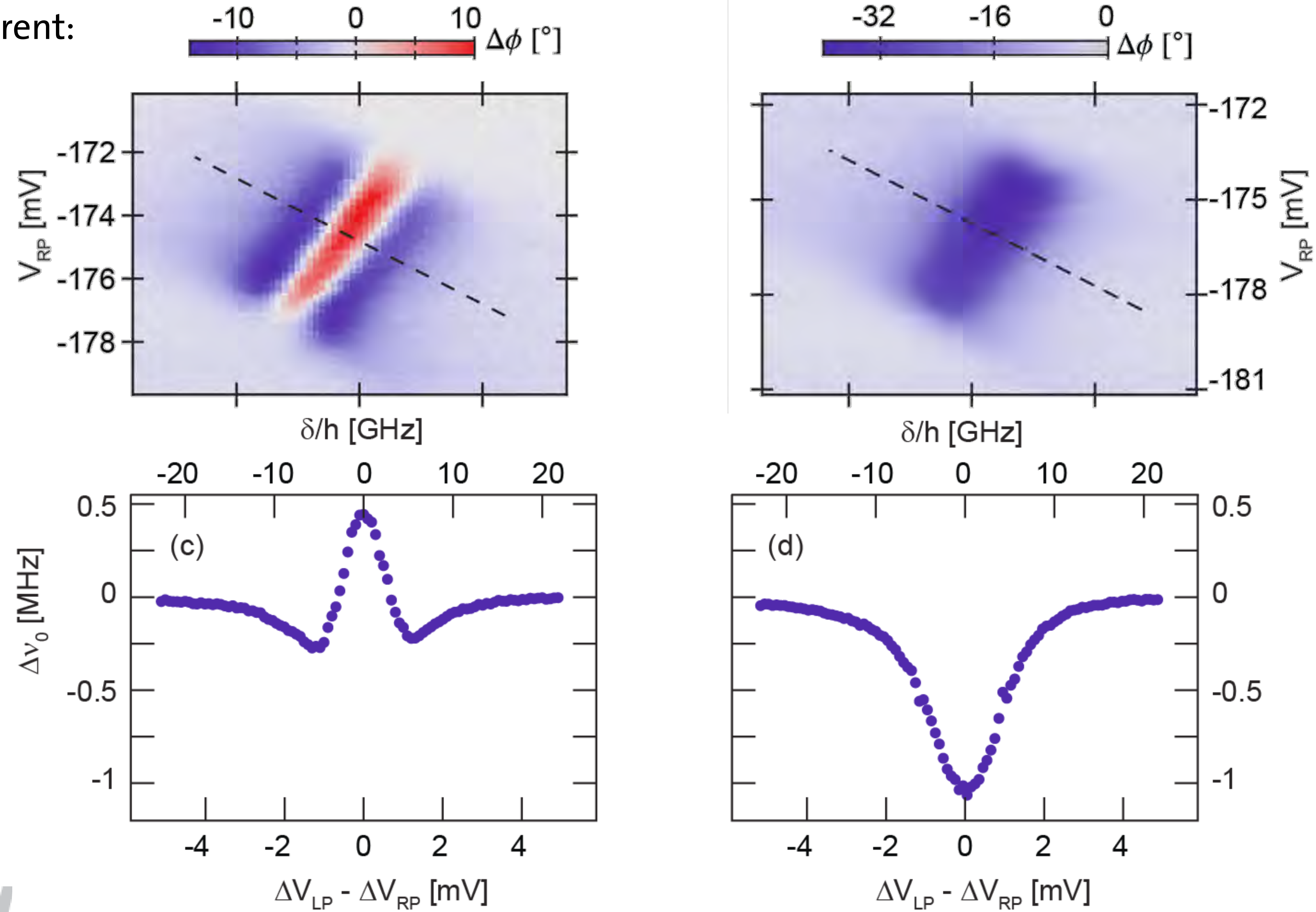


- weak coupling ($\kappa, \gamma > g$)



Resonator/Double-Dot Interaction

current:



T. Frey *et al.*, *PRL* 108, 046807 (2012)

Quantitative Evaluation of Dipole-Coupling

$$H = h\nu_0(\hat{n} + \frac{1}{2}) + \frac{h\nu_q}{2}\hat{\sigma}_z + \hbar g \sin\theta(\hat{a}^\dagger\hat{\sigma}^- + \hat{a}\hat{\sigma}^+)$$

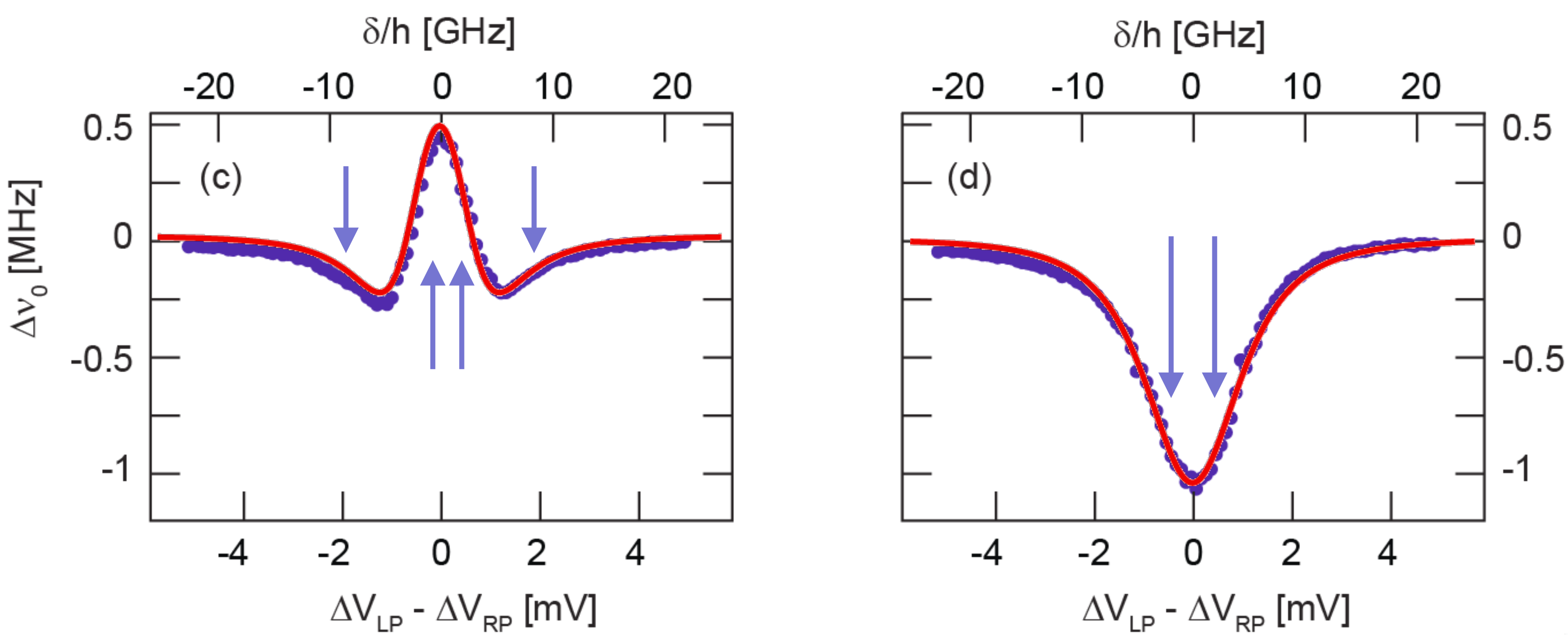
resonator | qubit | coupling

Coupling strength

$g/2\pi$ = 50 MHz

$2t/h$ = 6.1 GHz
$\gamma_\phi/2\pi$ = 3.3 GHz

$2t/h$ = 9.0 GHz
$\gamma_\phi/2\pi$ = 0.9 GHz

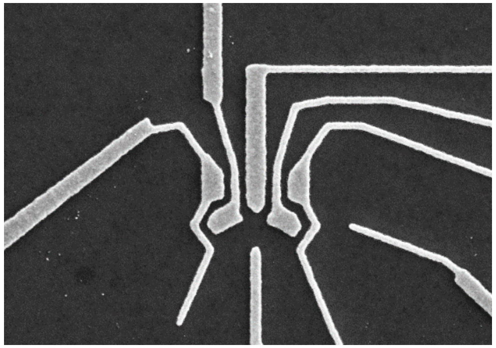


T. Frey *et al.*, *PRL* 108, 046807 (2012)

Single-Electron Regime

Optimized gate geometry for single electron regime of DQD coupled to resonator

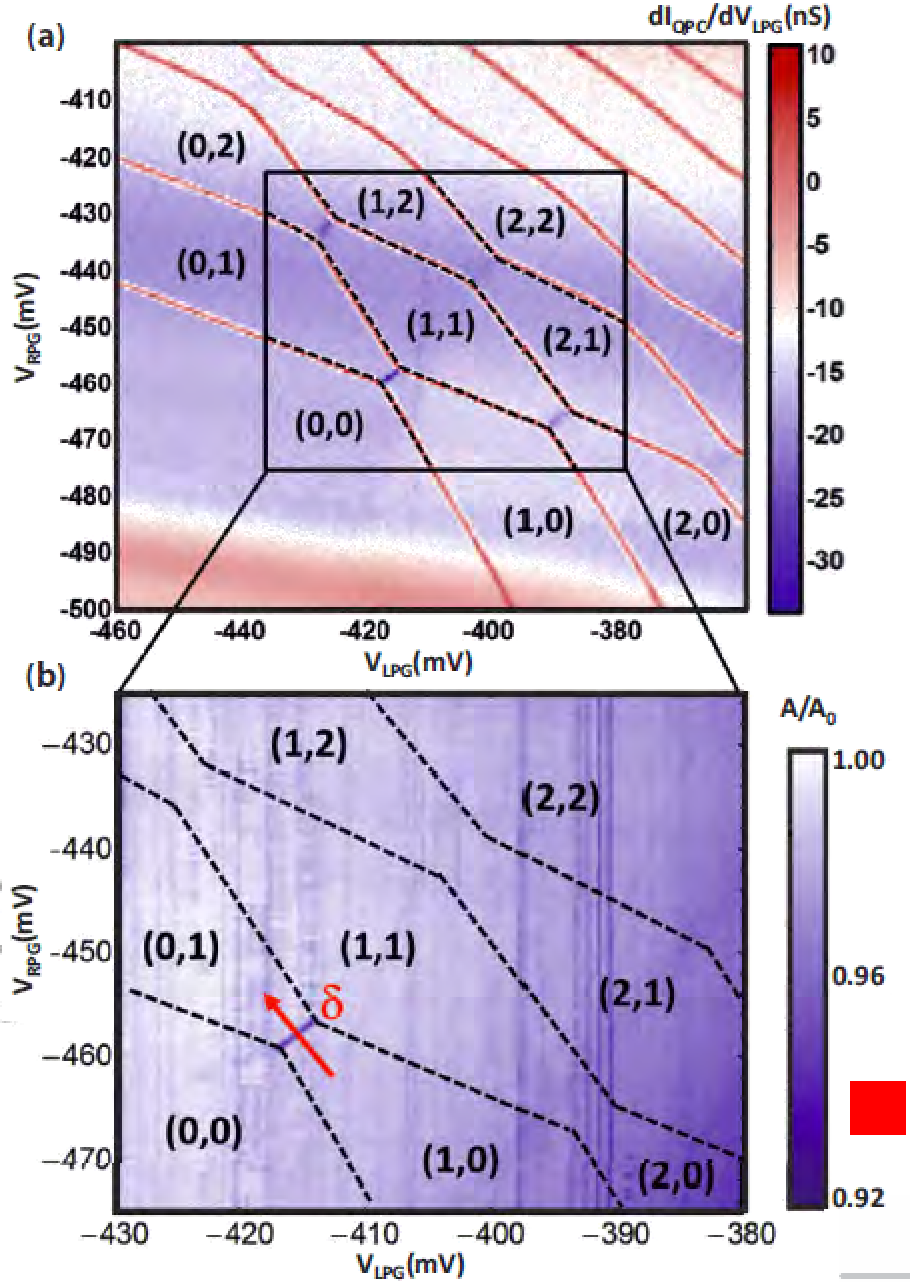
- Expectation: improved coherence



However:

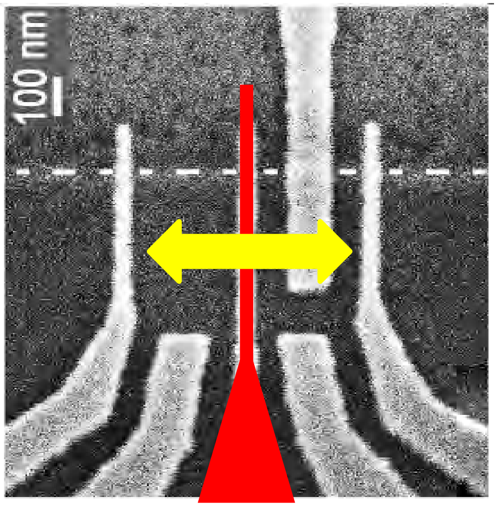
- same large dephasing ($\gamma \gg g$)
- similar dephasing rates in many (all?) other hybrid DQD experiments independent of material

J. Basset *et al.*, *Phys. Rev. B* 88, 125312 (2013)



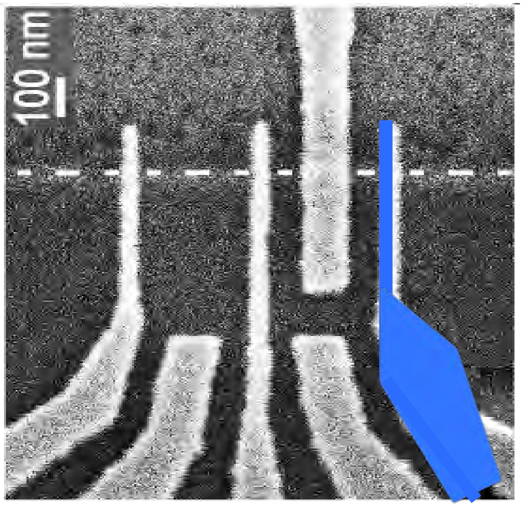
Quantum Dot Bias Regimes

tunnel coupling between dots



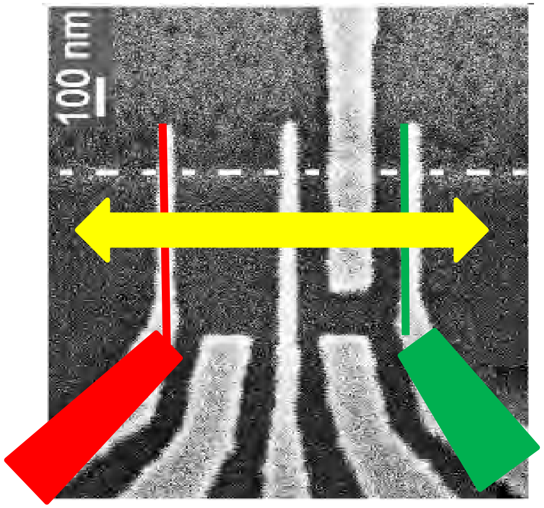
- tunnel coupling (t) similar to resonator frequency
- coupling to leads (Γ) small

tunnel coupling between lead and dot



- coupling to leads (Γ) similar to resonator frequency
- tunnel coupling (t) small

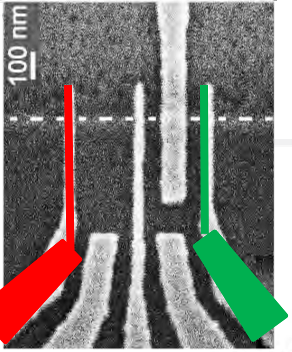
tunnel coupling to both leads

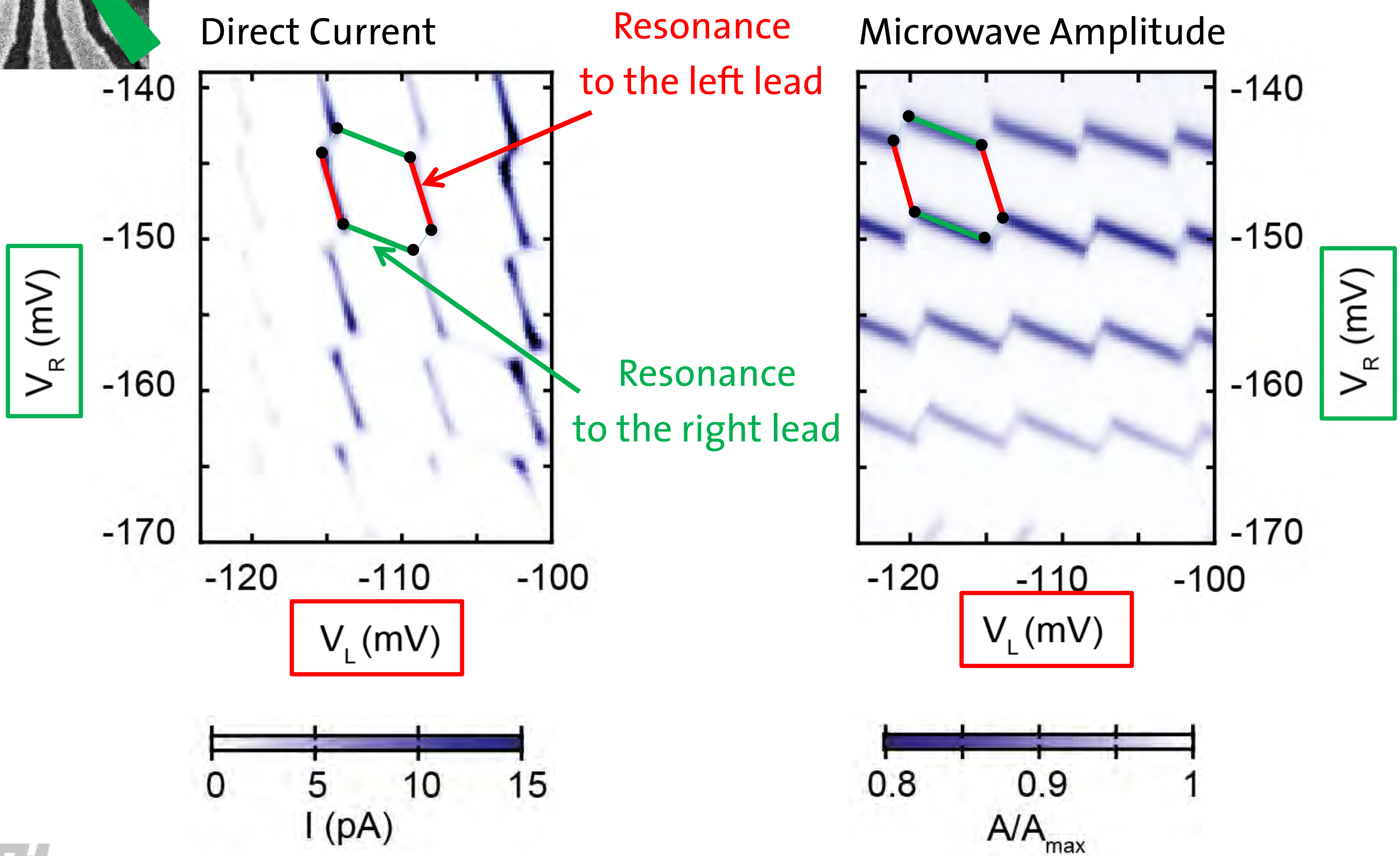


- coupling to leads (Γ) similar tunnel coupling (t) similar to resonator frequency

Investigation of tunnel coupling to leads at GHz frequencies: T. Frey *et al.*, *PRB* 86, 115303 (2012)

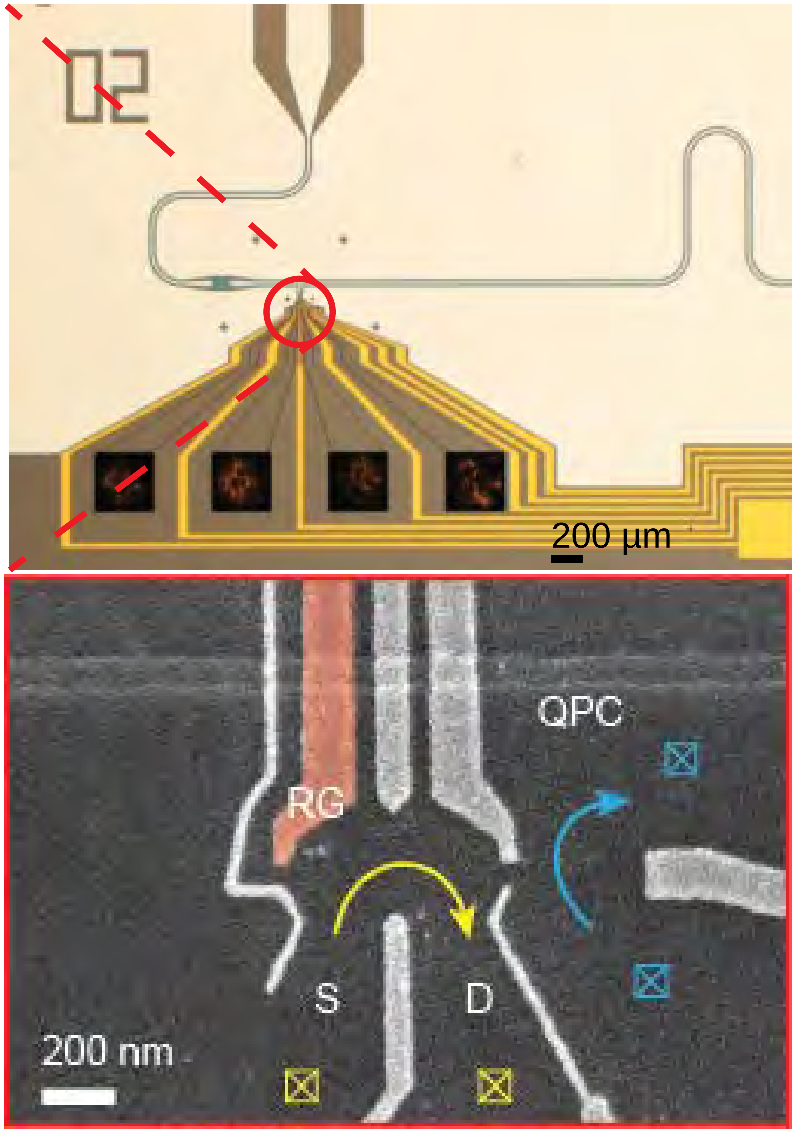
Charge Stability Diagram





T. Frey *et al.*, *PRB* 86, 115303 (2012)

Improved Cavity-Coupled GaAs Double Quantum Dot



Device design:

- iterated from previous versions
  T. Frey *et al.*, *PRL* 108, 046807 (2012)
- cavity frequency ν ~ 6.85 GHz (28 µeV)
- QD charging energies E_c ~ 200 GHz (1 meV)

improved charge coherence properties

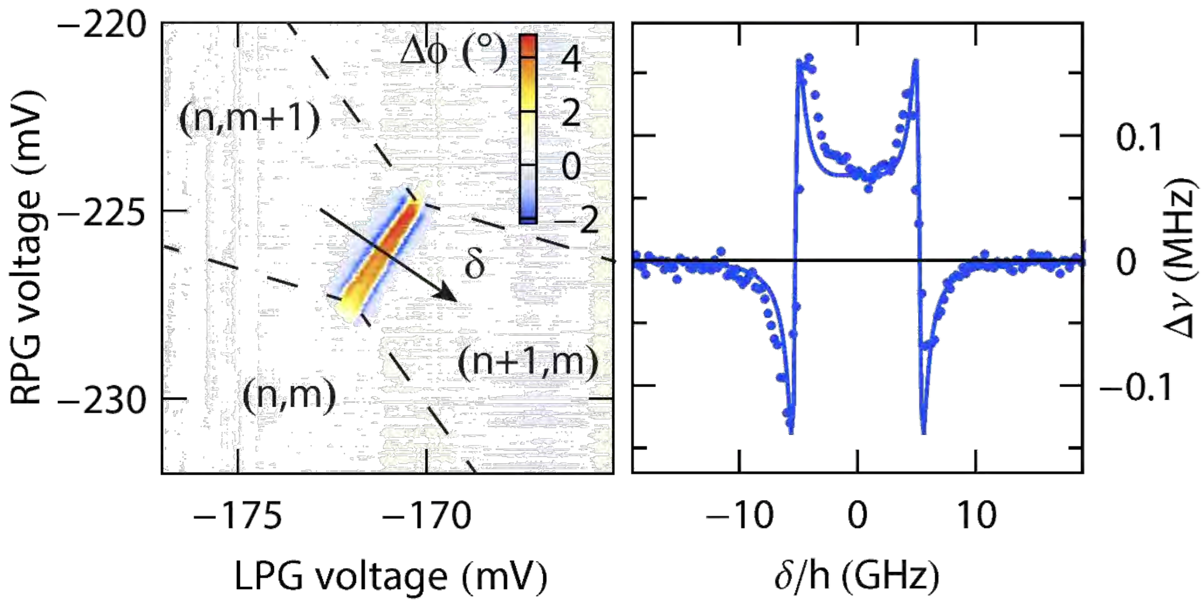
- γ_ϕ ~ 200 MHz
- previously several GHz

likely affected by:

- reduced overlap between gates and 2DEG
- different wafer material
- improved filtering

Device Characterization

dispersive resonator shift versus QD bias:



parameters:

- constant cavity coupling strength g ~ 13 MHz
- adjustable inter-dot coupling t ~ 1 to 10 GHz
- adjustable inter-dot detuning δ ~ 0 to 100's GHz
- approx. energy relaxation rate γ_1 ~ 100 MHz
- dephasing rate γ_ϕ ~ 0.2 to 1.2 GHz (depending on bias)
- approx. # charges (*n,m*) ~ 10

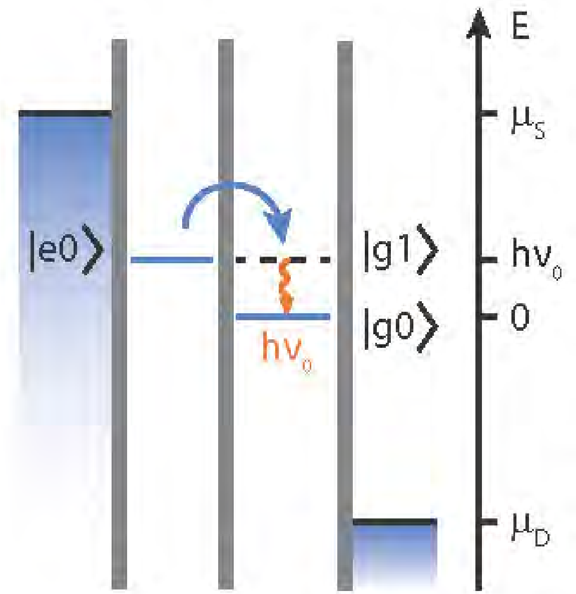
A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

Radiation Emission Experiments: Motivation

- explore radiation emission from semiconductor nanostructure
- investigate correlations between charge transport and radiation emission
- characterize inelastic tunneling processes

Approach:

- voltage bias DQD
- adjust DQD energy levels
- detect emitted radiation



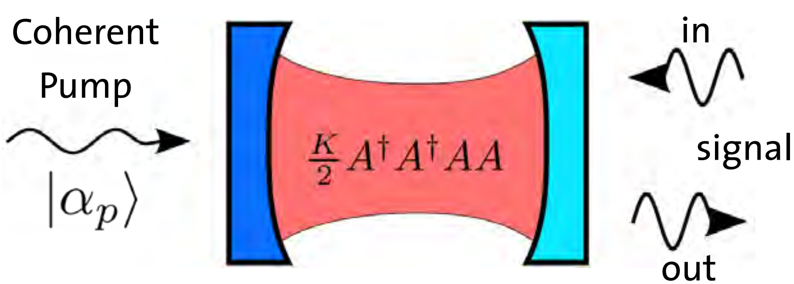
Use techniques known from circuit QED:

- sensitive parametric amplifiers
- quadrature amplitude measurements
- power measurements
- correlation function measurements

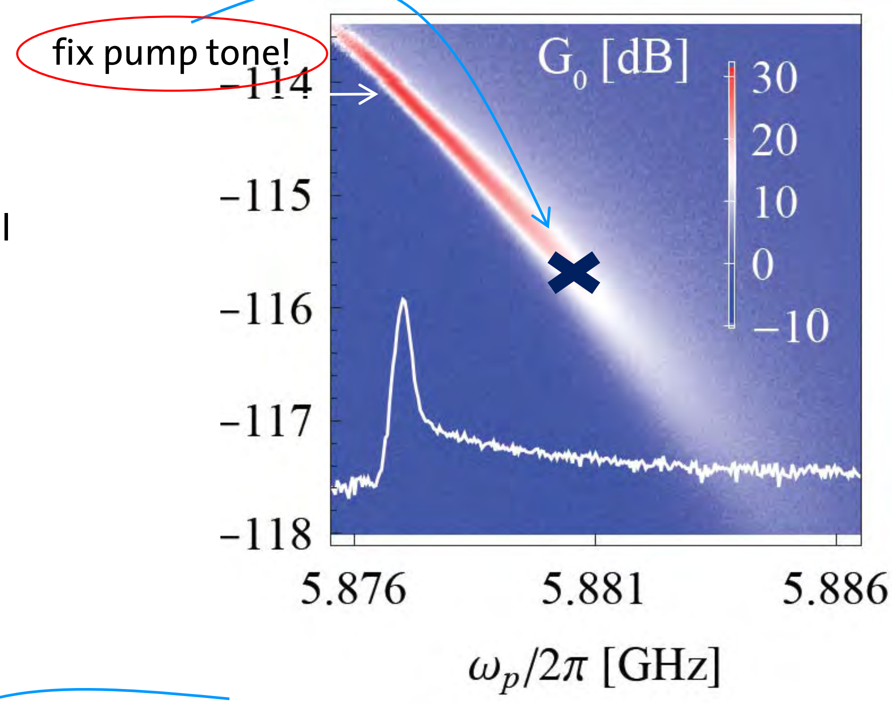
A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

Related work on radiation emission and micro-maser action
Liu *et al.*, *PRL* 113, 036801 (2014), *Science* 347, 285-287 (2015)

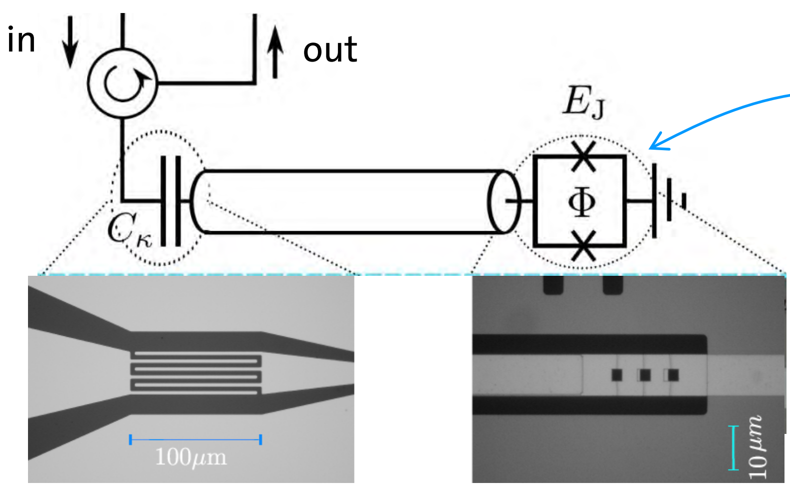
Parametric Amplifier



Measured Gain



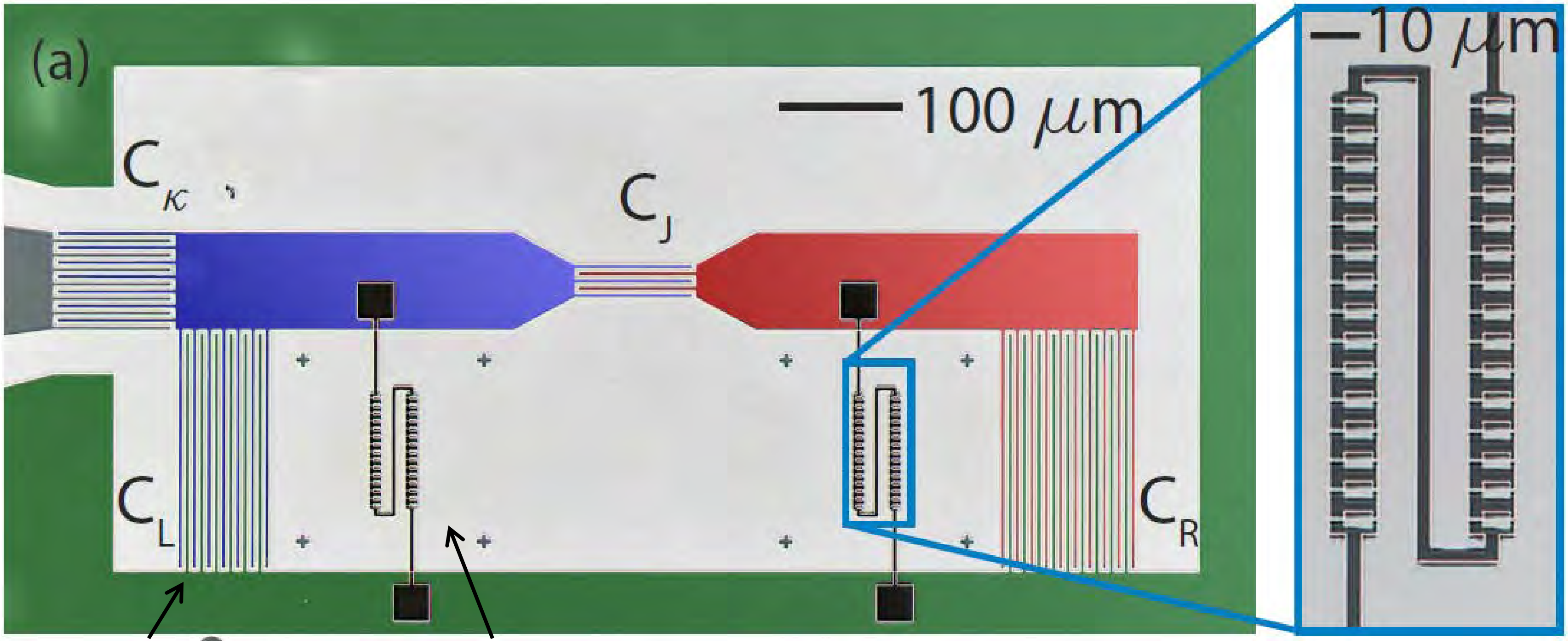
Circuit QED implementation:



SQUID provides nonlinearity!

Caves, *Phys. Rev. D* 26, 1817 (1982)
Yurke and Buks, *J. Lightwave Tech.* 24, 5054 (2006)
Castellanos-Beltran et al., *Nat. Phys.* 4, 929 (2008)
Eichler et al., *Phys. Rev. Lett.* 107, 113601 (2011)

JPD amplifier: implementation

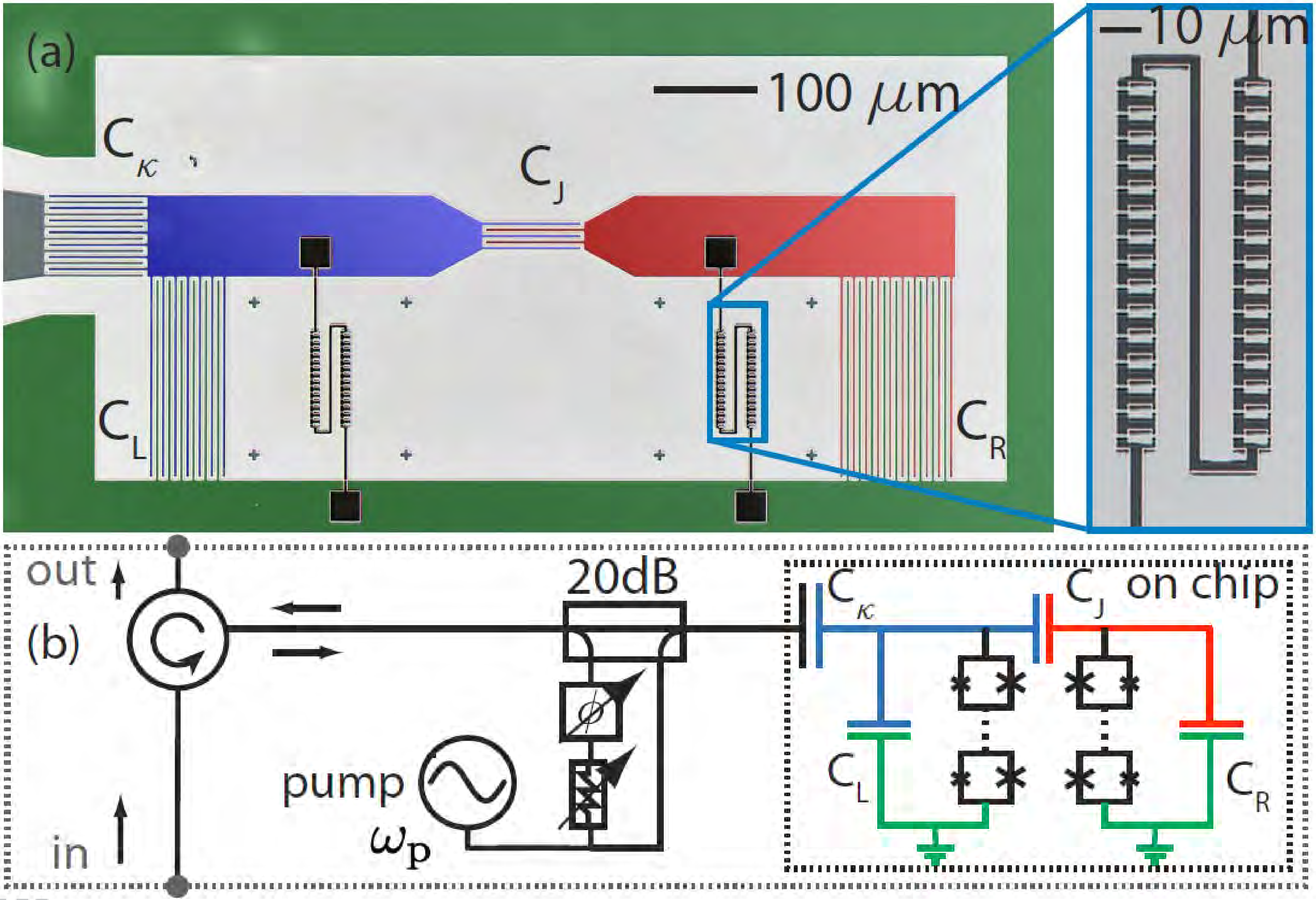


Features:

- Arrays with M SQUIDs to control nonlinearity: $U \sim E_c/M^2$
- asymmetric SQUIDs -> homogeneous coupling to external flux

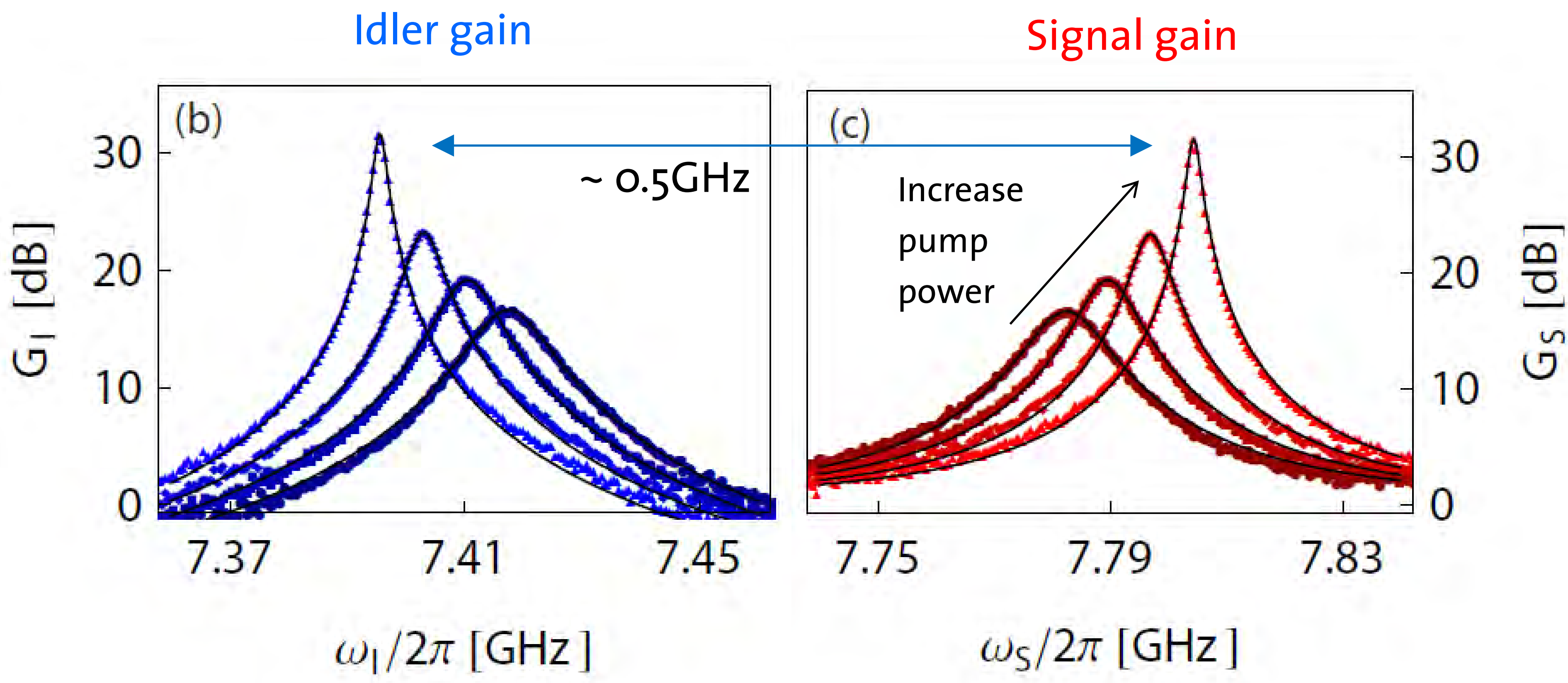
Eichler et al., *Phys. Rev. Lett.* 113, 110502 (2014)

JPD amplifier: implementation



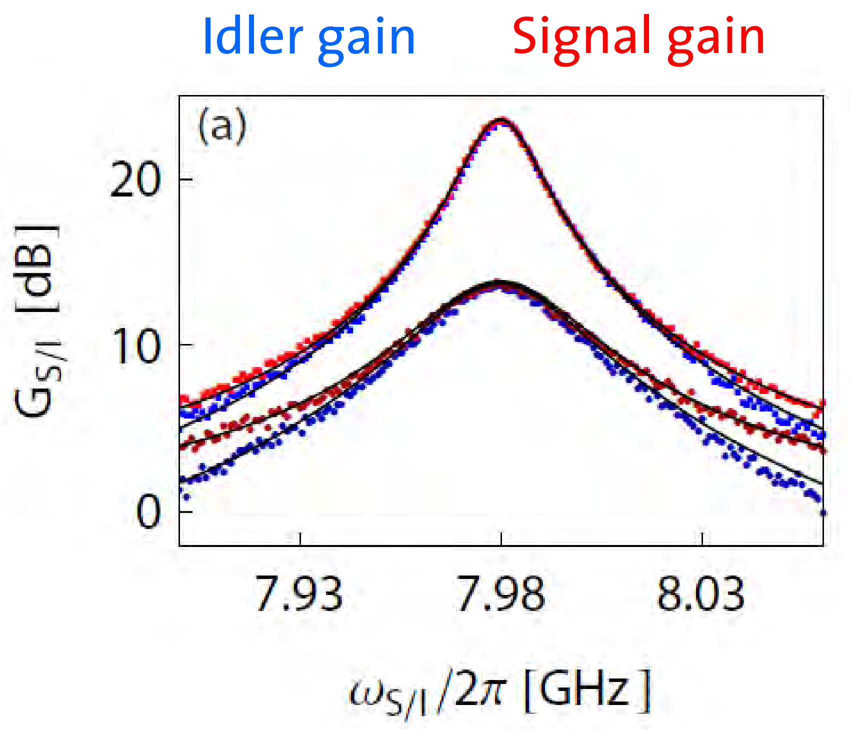
Eichler et al., *Phys. Rev. Lett.* 113, 110502 (2014)

JPD amplifier: non-degenerate operation



Eichler et al., *Phys. Rev. Lett.* 113, 110502 (2014)

JPD amplifier: degenerate operation

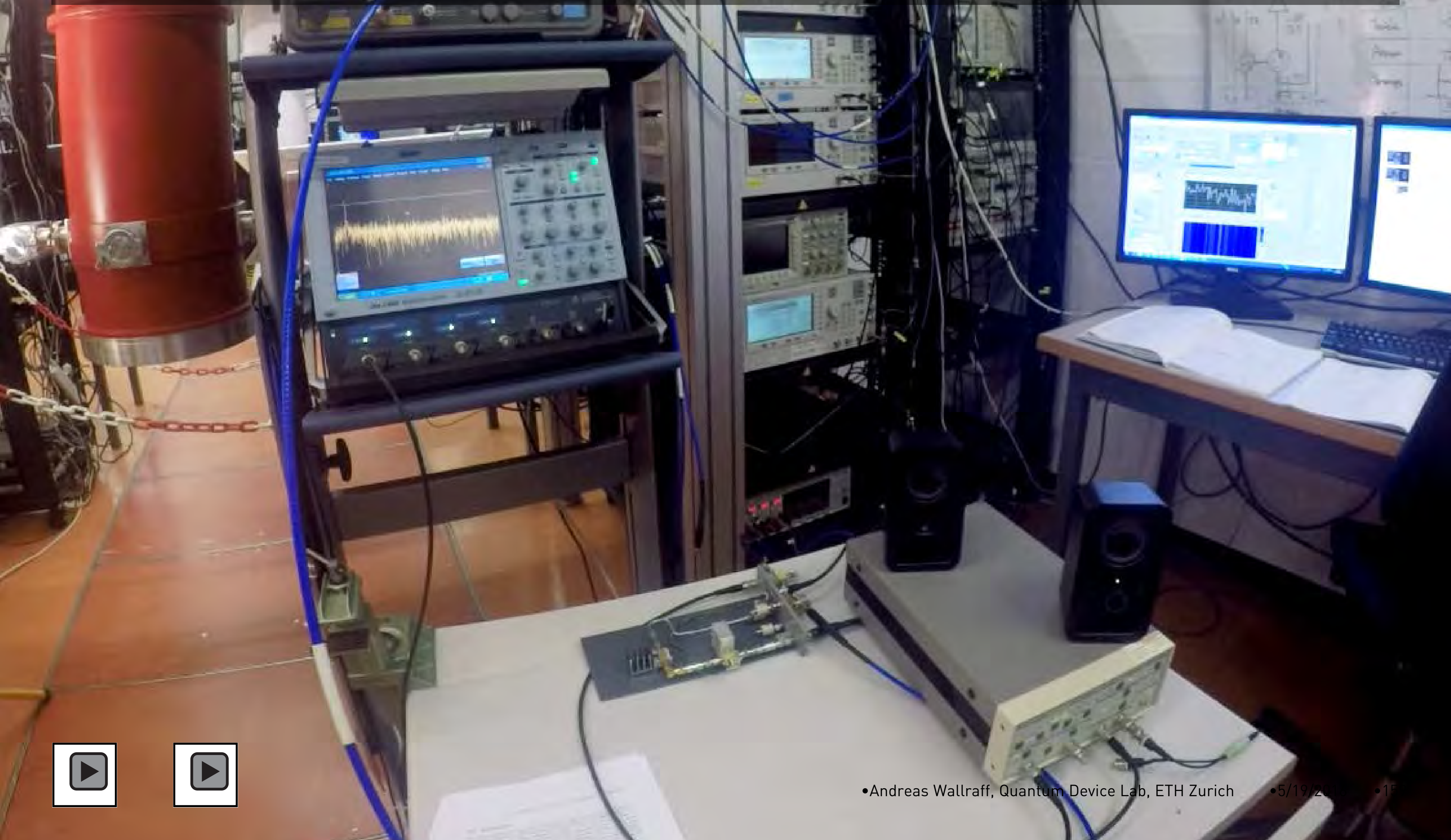


Eichler et al., *Phys. Rev. Lett.* 113, 110502 (2014)

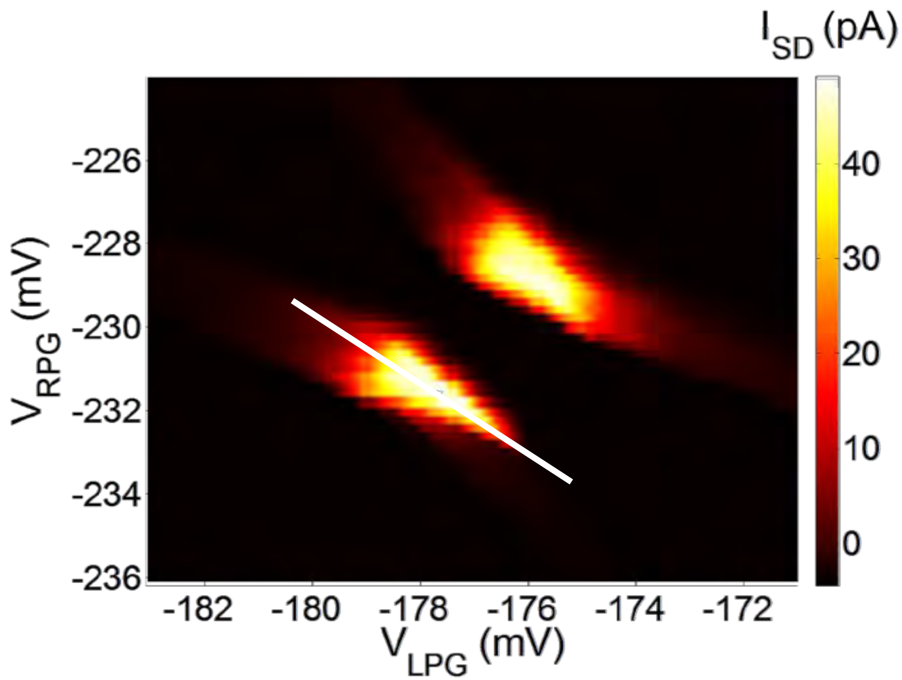
Control


UHF AWG
Arbitrary Waveform Generator
1.8 GSa/s, 14 bit, 600 MHz
Signal Input
1
Over
2
Over
50Ω / 1MΩ
max ±3.5V
Signal Output
1
On
2
On
50Ω
8dBm
Ref / Trigger
1
2
In: 50Ω ±2.5V / 1kΩ ±5V
Out: 50Ω 3.3V TTL
Aux Output
1
2
3
4
50Ω ±10V
Zurich
Instruments

Sensing Small Electromagnetic Signals

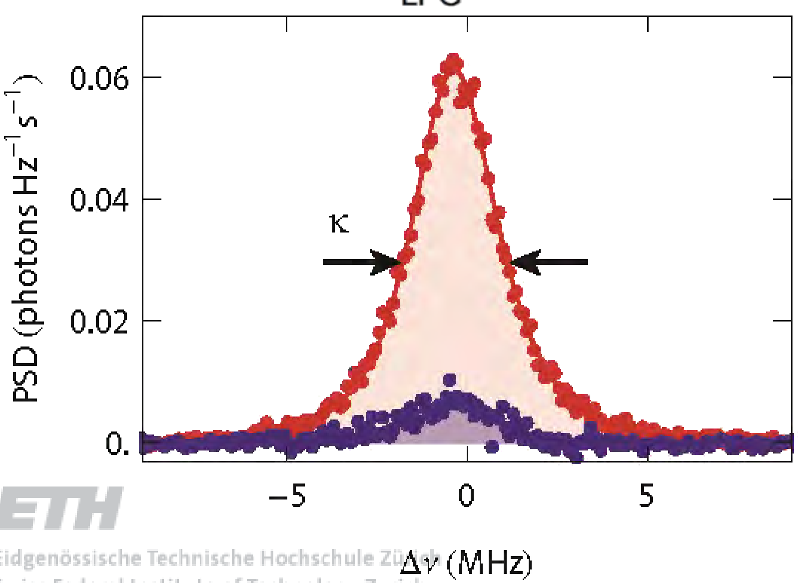


Radiation Emission at Finite Bias



measured source/drain current at bias voltage $V_{SD} = -200\ \mu V$ (~ 50 GHz)

- observation of finite bias triangles



measured power spectral density (PSD) as a function of inter-dot detuning δ

- line-width given by cavity $\kappa \sim 3.3$ MHz
- power is strongly δ–dependent

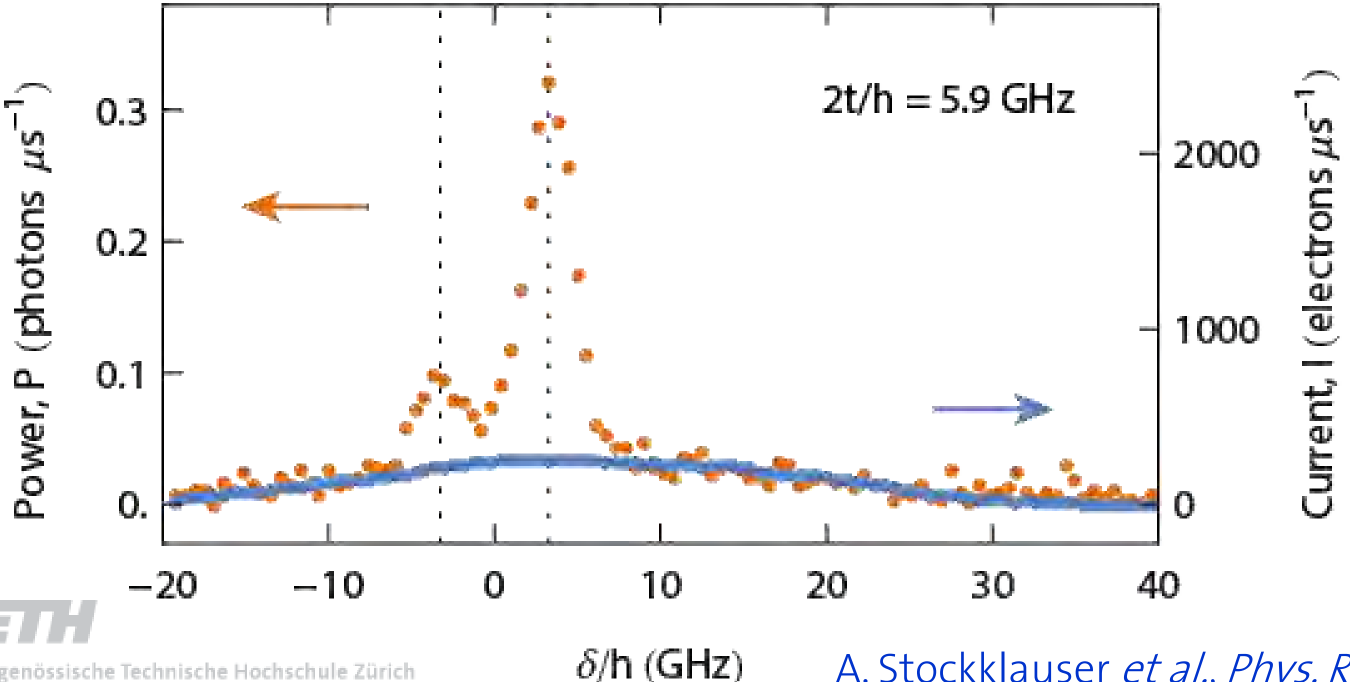
A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

Integrated Emitted Power *vs.* Inter-Dot Detuning

Observations:

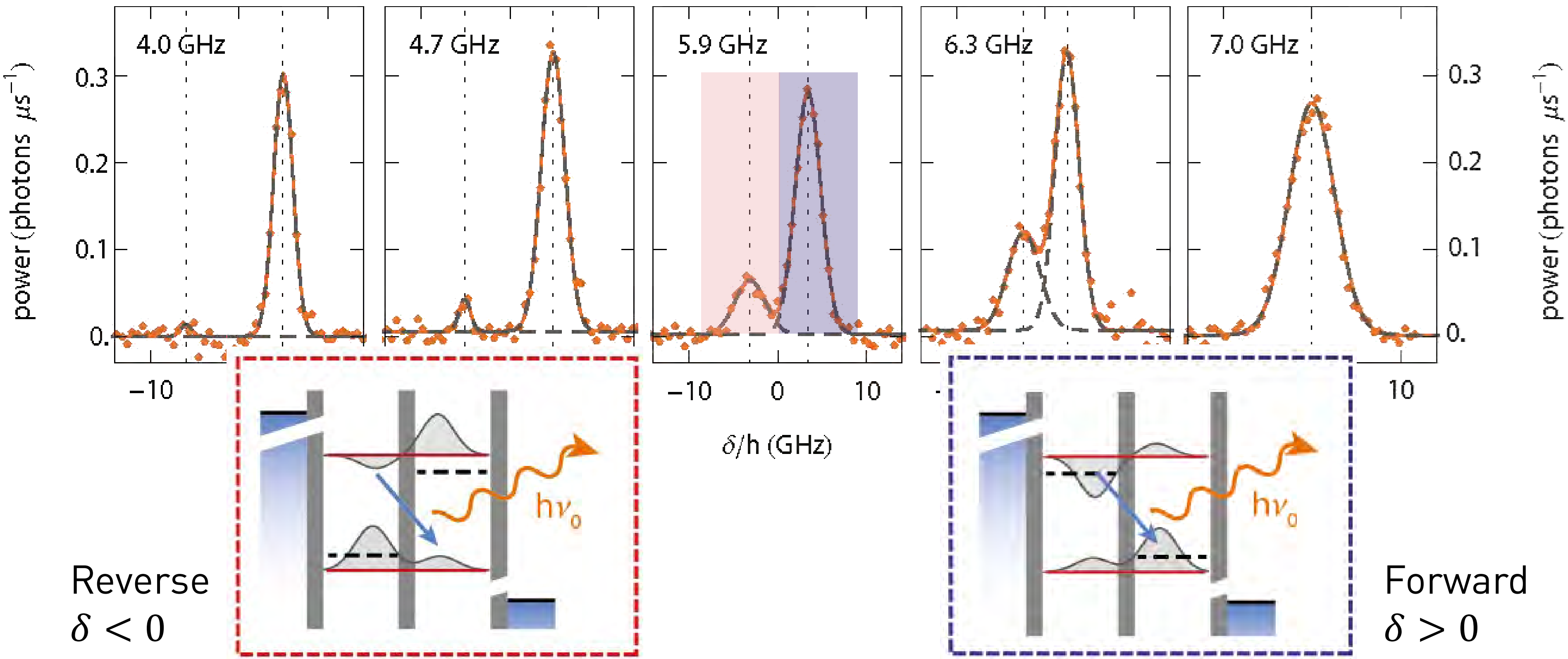
- weak emission over broad range in δ proportional to bias current
- emission rate: 10^{-4} photons per electron

- two pronounced maxima in emission symmetric around δ=0
- emission rate increased 10x



A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

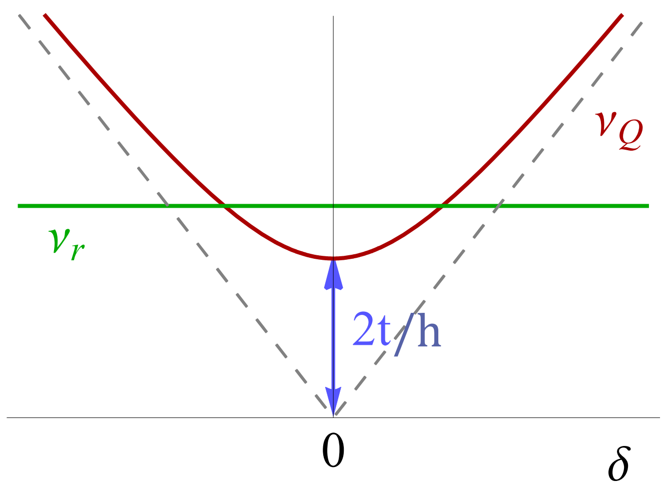
Emission Resonances vs. Inter-Dot Tunnel Coupling



- inter-dot tunneling t-independent background emission (subtracted)
- maxima in emission symmetric about inter-dot detuning δ = 0
- emission gaussian in detuning δ (FWHM ~ 1.5 GHz)
- large (approx. δ-independent) emission for forward bias δ > 0
- small (δ-dependent) emission for reverse bias δ < 0

Stockklauser *et al.*, *PRL* 115, 046802 (2015)

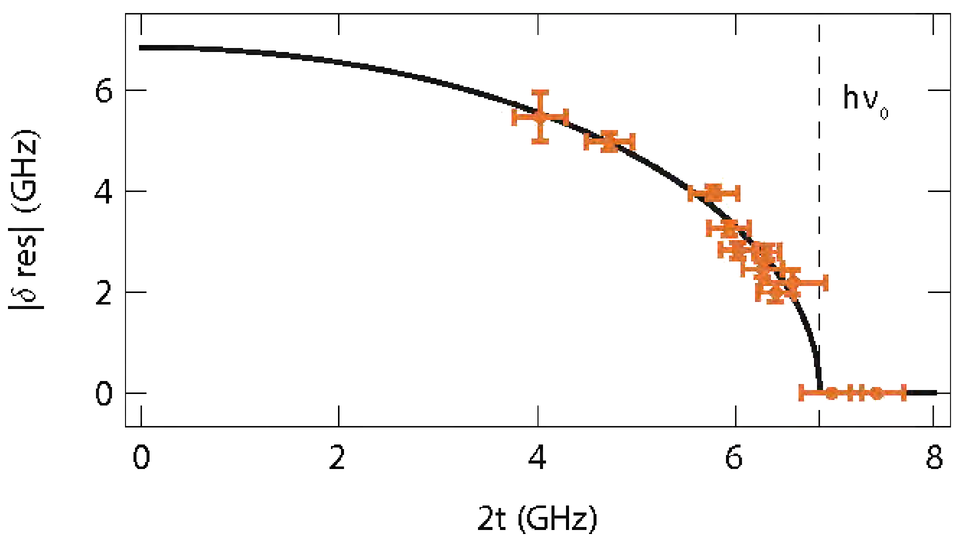
Tunnel-Coupling Dependence of Emission Maxima



Interpretation:

- Inter-dot detuning δ_r resonance with cavity depends on tunnel coupling *2t*

$$\delta = \pm\sqrt{(h\nu_r)^2 - (2t)^2}$$

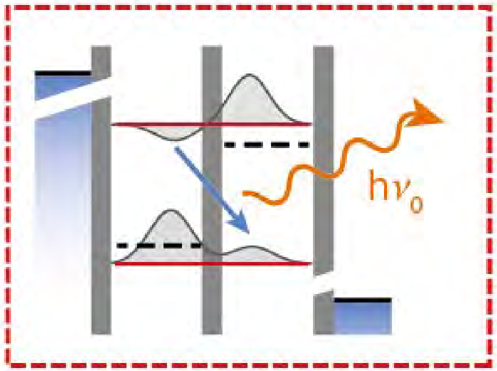


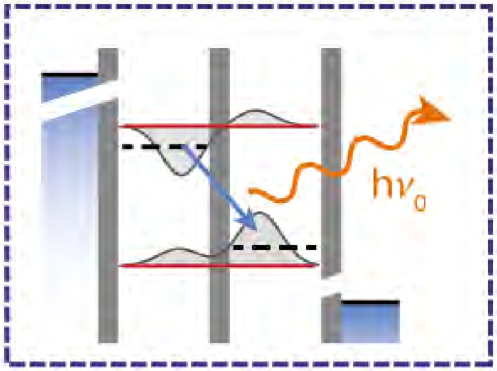
- good agreement with observed bias at emission maxima

A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

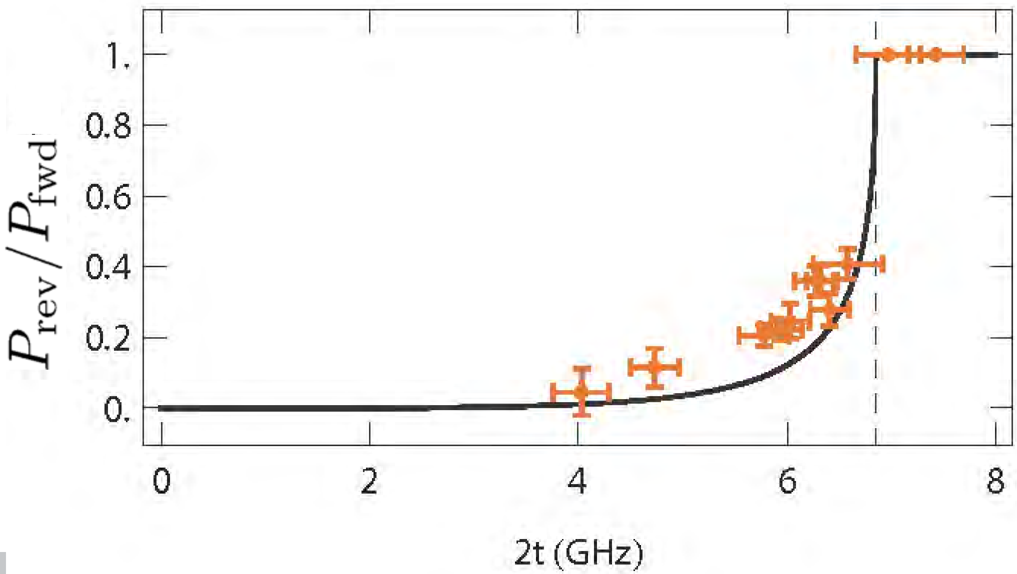
Scaling of Forward and Reverse Bias Emission with 2t

Reverse
$\delta < 0$





Forward
$\delta > 0$



Ratio of peak emission between reverse and forward bias

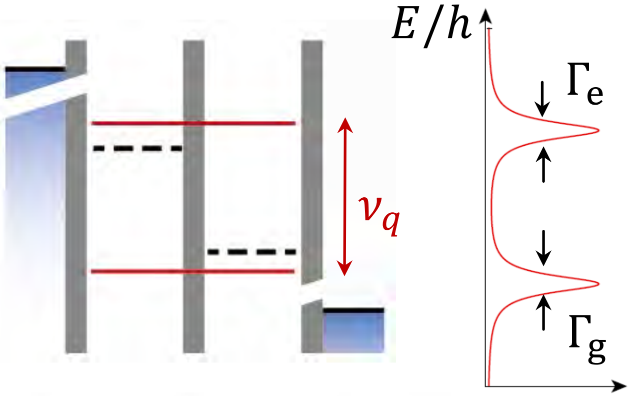
$$\frac{P_{rev}}{P_{fwd}} = \frac{\alpha^2}{(1-\alpha)^2}$$

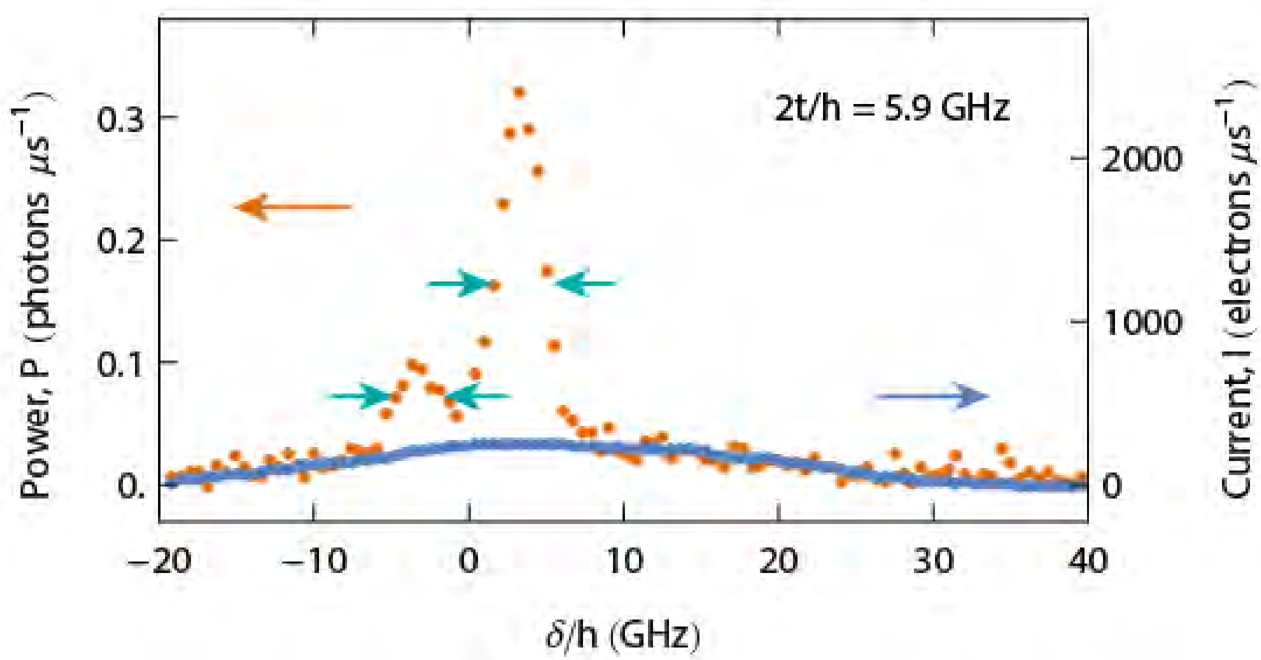
with $\alpha = \frac{1}{2}\left[1 + \sqrt{1 - \left(\frac{2t}{h\nu_r}\right)^2}\right]$

A. Stockklauser *et al.*, *Phys. Rev. Lett.* 115, 046802 (2015)

Dependence of Emission on Coupling to Leads

- Investigation of width of emission resonances in dependence on broadening of quantum dot levels due to coupling to leads



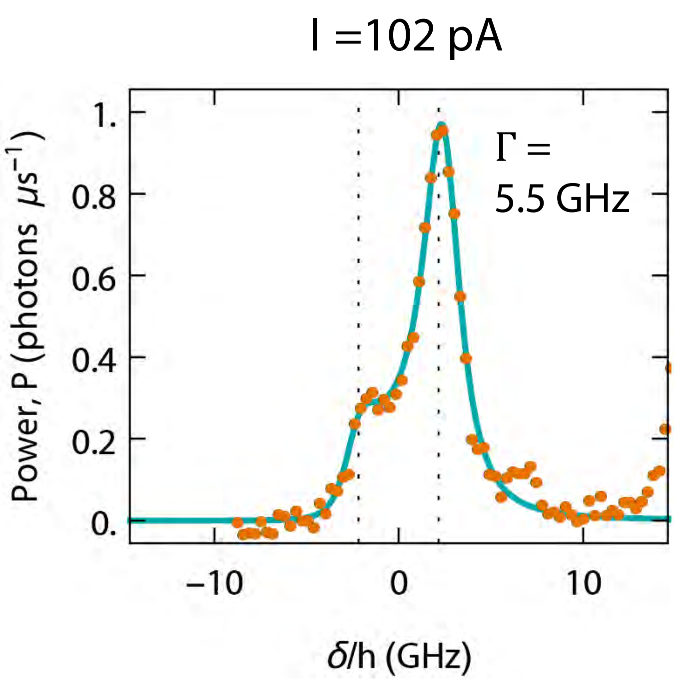


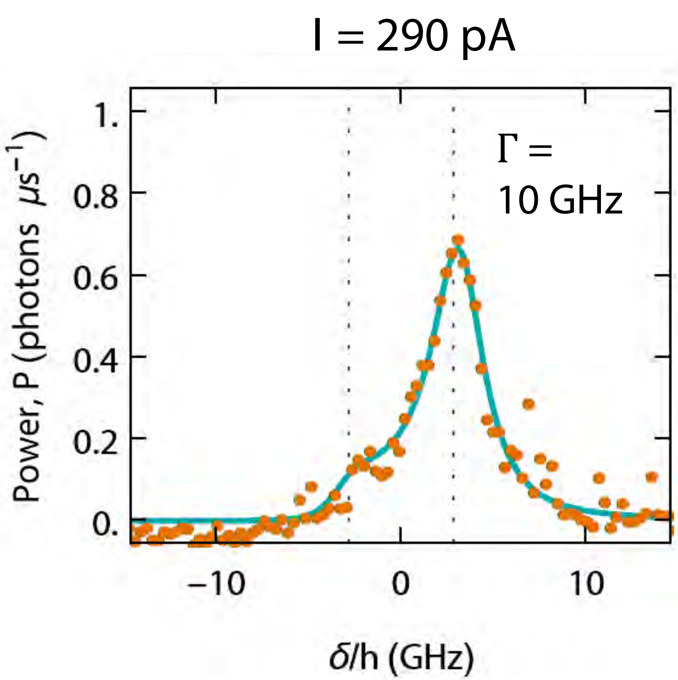
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

A. Stockklauser *et al.*, ETH Zurich *unpublished* (2016)

Dependence of Emission on Coupling to Leads

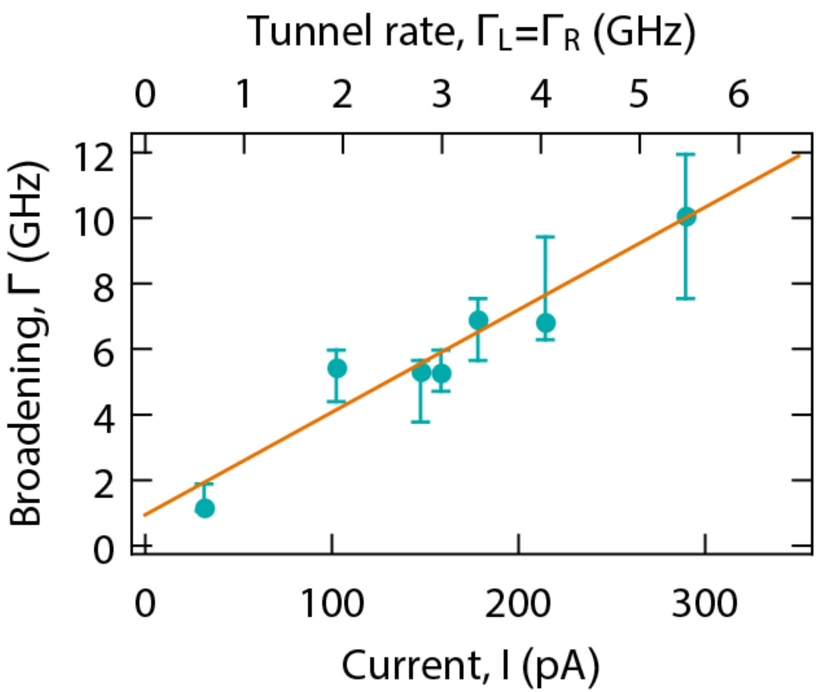
- Symmetric configuration $\Gamma_\mathrm{L} = \Gamma_\mathrm{R}$, constant t, V_SD
- Elastic current $I = I_{el} \propto \Gamma_R$
- Resonance width increases with $\Gamma_\mathrm{L}, \Gamma_\mathrm{R}$





A. Stockklauser *et al.*, ETH Zurich *unpublished* (2016)

Dependence of Emission on Coupling to Leads



- Approximately linear increase with the current
- Expected level broadening: $\Gamma = \Gamma_R + \tilde{\gamma}$
- $\gamma/2\pi \leq 250$ MHz in the entire range of source–drain coupling
- $I = I_{el}$ converted to tunnel rate $\Gamma_L = \Gamma_R$
- Emission linewidth and qubit level broadening proportional to tunnel rates to leads

A. Stockklauser *et al.*, ETH Zurich *unpublished* (2016)

Summary

- Performed photon emission measurements from semiconductor DQD
- Used circuit QED measurement techniques for characterization of emission
- Obtained good understanding of emission process

Outlook

- Investigate radiation emission using correlation function measurements
- Work towards strong coupling to charge (overcome 100 MHz scale dephasing rate)
- Use resonator as a coupling bus in semiconductor-based QIP

- Explore benefits of circuit QED in semiconductor structures

A. Stockklauser *et al., Phys. Rev. Lett.* 115, 046802 (2015)
J. Basset *et al., Phys. Rev. B* 88, 125312 (2013)
T. Frey *et al., Phys. Rev. B* 86, 115303 (2012)
T. Frey *et al., Phys. Rev. Lett.* 108, 046807 (2012)

The ETH Zurich Quantum Device Lab

incl. undergrad and summer students

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

QSIT Quantum Science and Technology
National Centre of Competence in Research

FNSNF Swiss National Science Foundation

scaleQIT

erc

Want to work with us?
Postdoc and PhD positions are available!