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Vienna Center for Quantum Science and Technology

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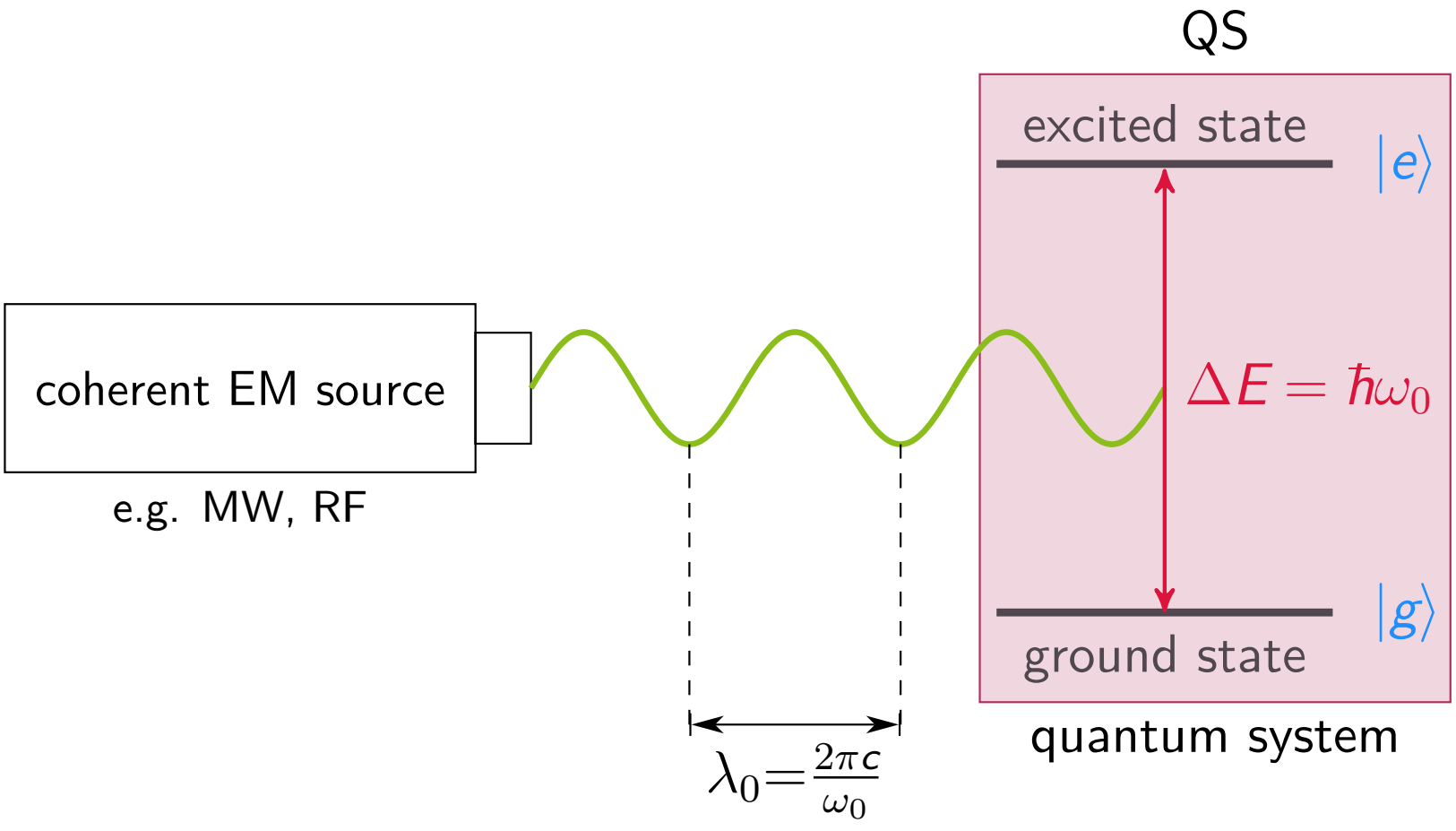
ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

Towards Driving Quantum Systems with the Non-Radiating Near-Field of a Modulated Electron Beam

Thomas Weigner
Philipp Haslinger group at Technische Universität Wien

SAMOP 2023, 07.03.2023

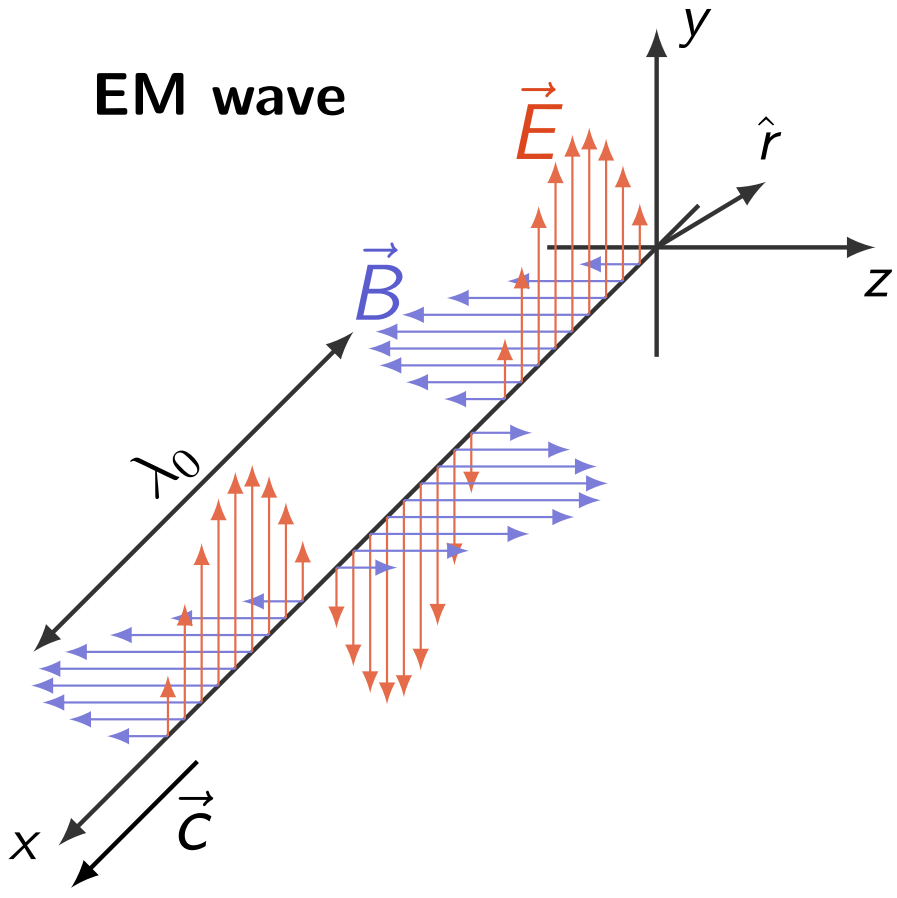
Driving a Quantum System with an Electromagnetic Wave



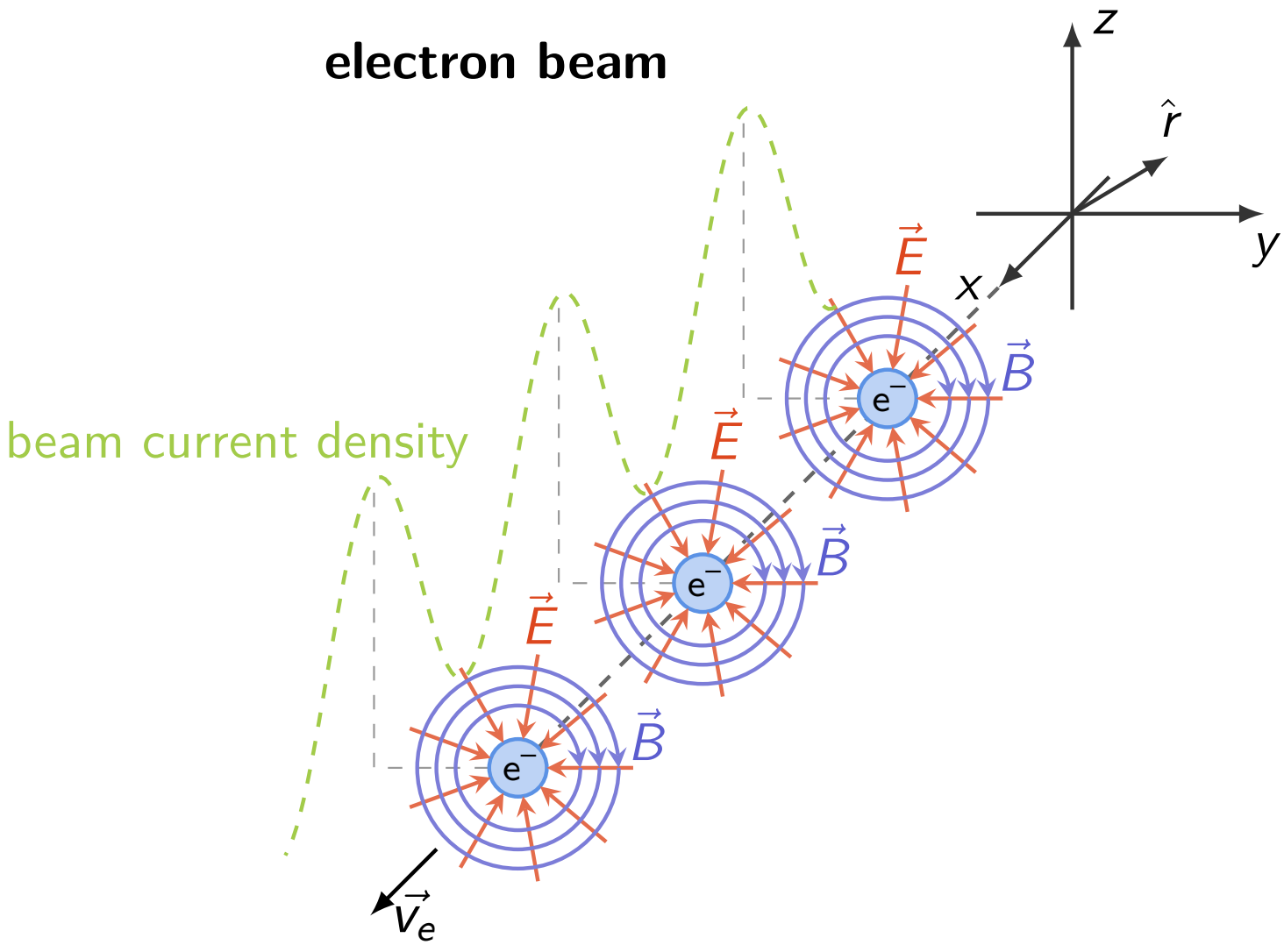
- Spatial resolution is diffraction limited $\approx \frac{\lambda_0}{2} \Rightarrow$ mm – km
- EM wave is dipole radiation

$\Rightarrow$ Idea: use modulated electron-beam instead

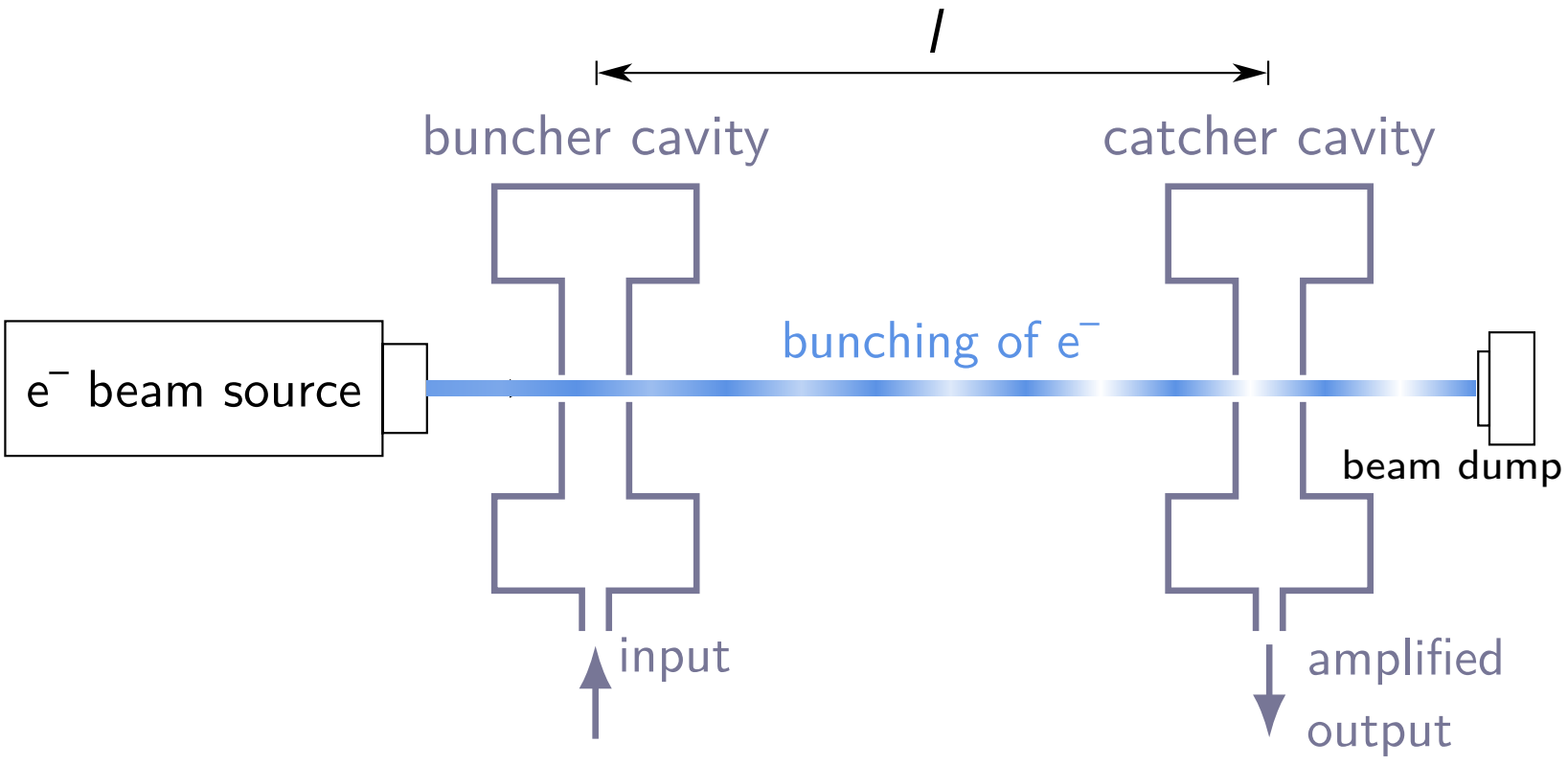
Electromagnetic Wave vs Modulated Electron Beam



Electromagnetic Wave vs Modulated Electron Beam

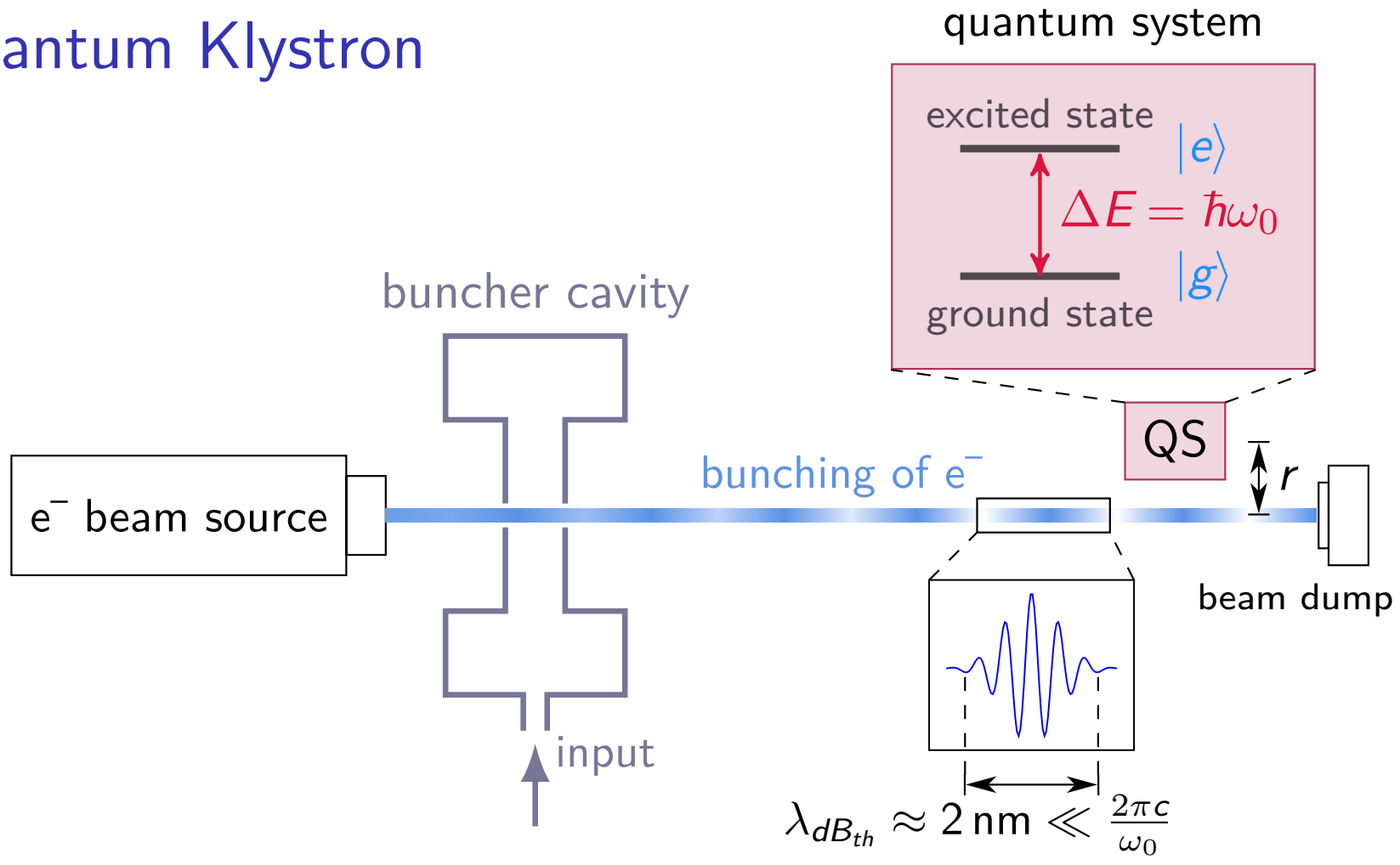


Klystron



- Technology to amplify RF or MW
- Accelerating of e^- in buncher cavity
- Bunches of e^- formed in drift space *l* couple coherently to catcher cavity

Quantum Klystron



- Coherent coupling of non-radiative near-field of e^- to QS[1][2]
- negligible back action on beam $\delta P \ll \Delta p$

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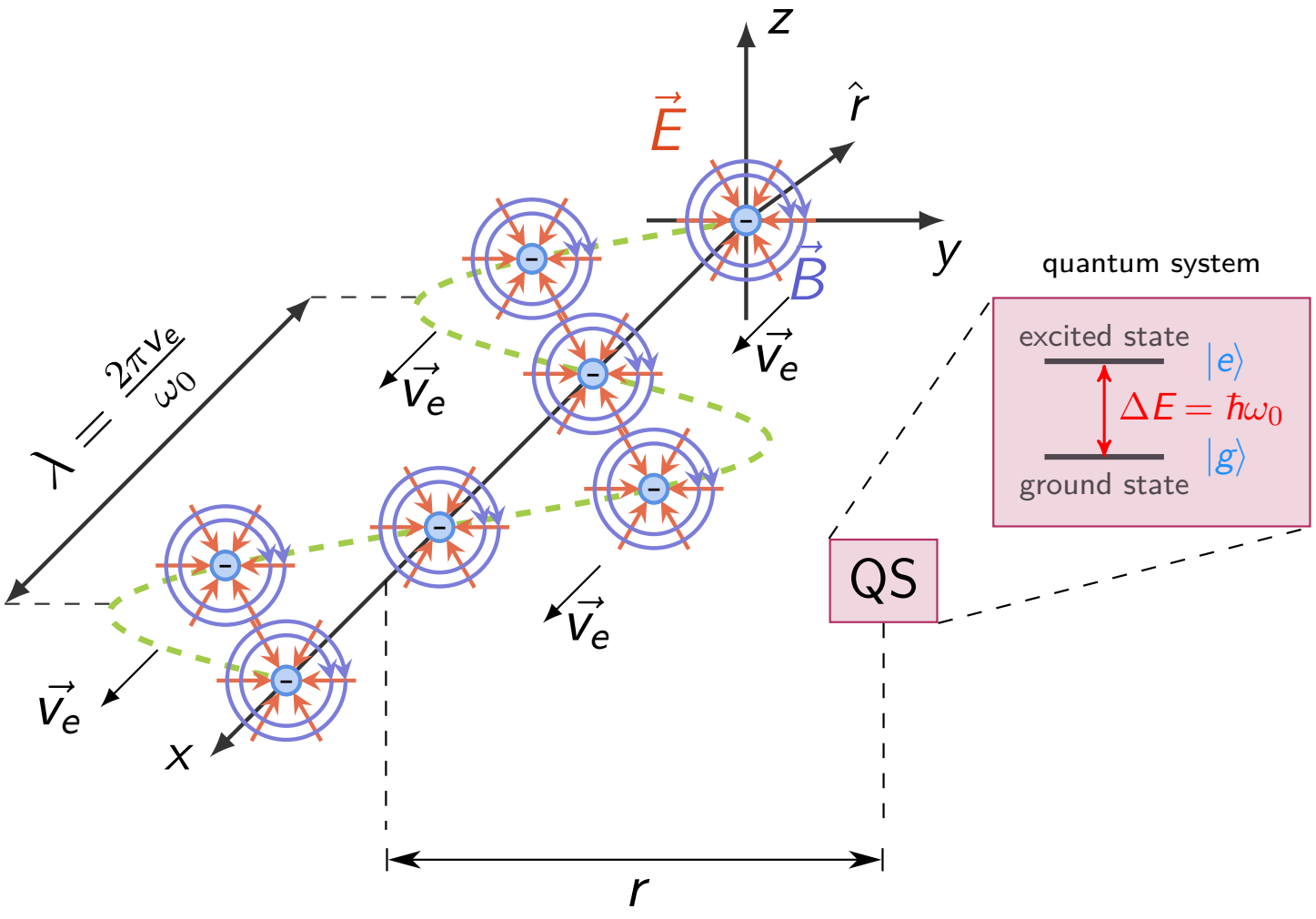
[1] Rätzel, D. et al., Physical Review Research, 2021.

[2] Gover, A. et al., Physical Review Letters, 2020.

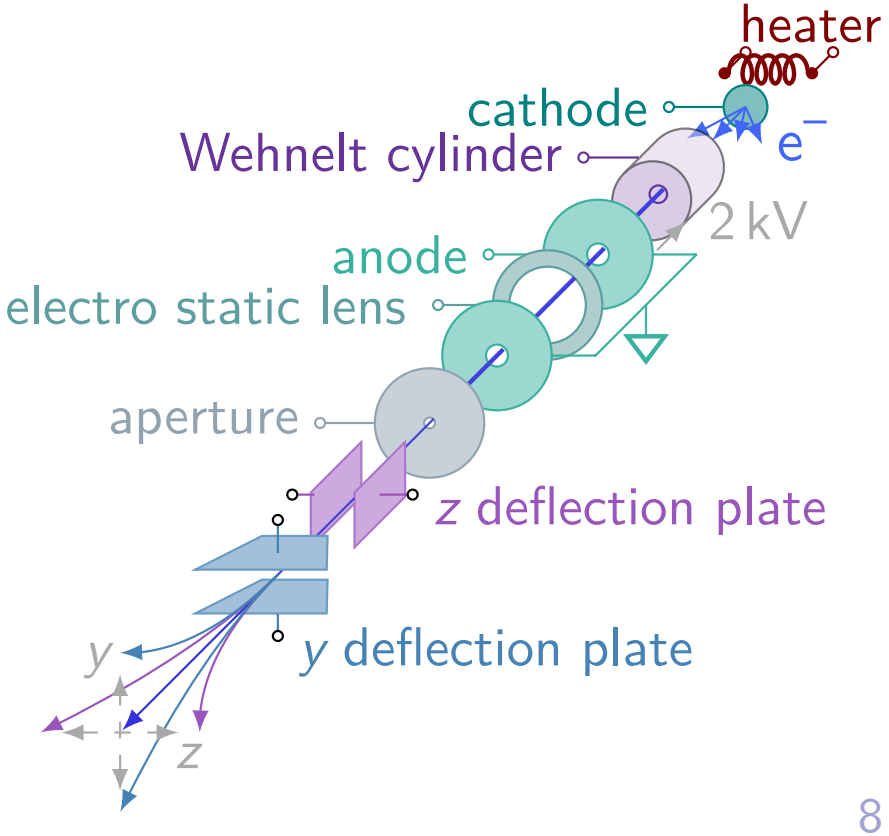
Spatially Modulated Electron Beam



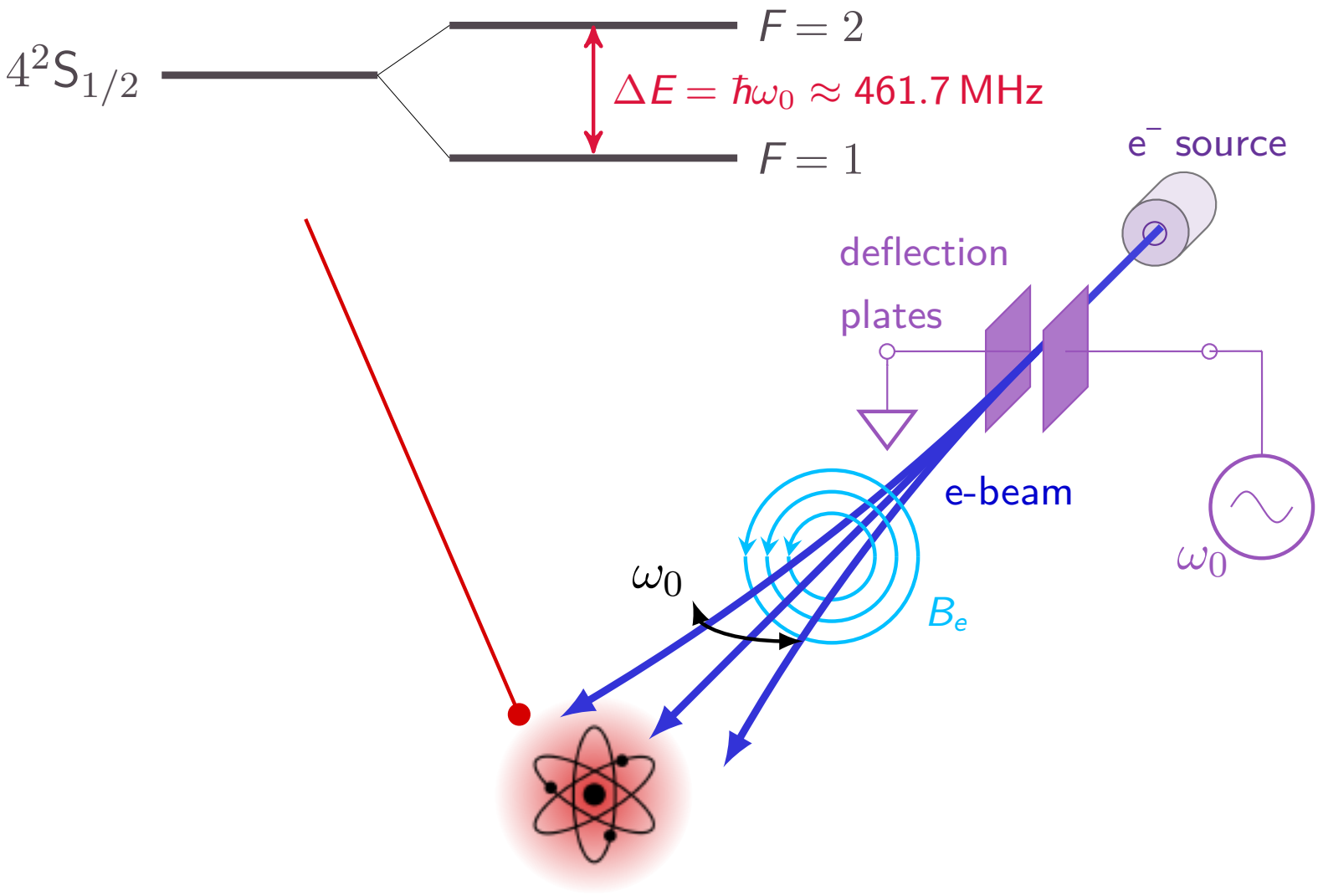
Spatially Modulated Electron Beam

$\Rightarrow$ Cathode Ray Tube (CRT) from analogue oscilloscope

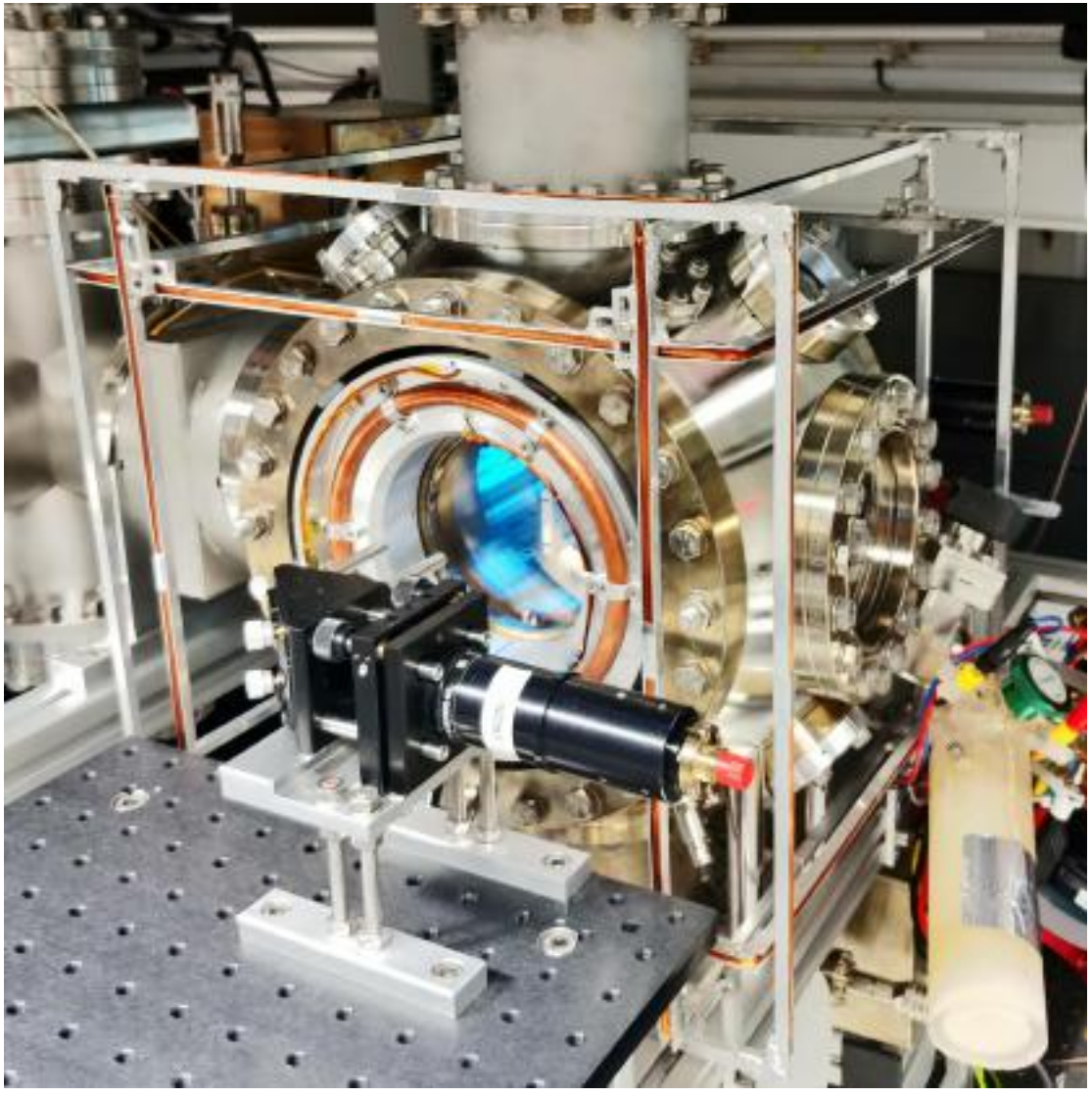
- Beam current $\backsim$ 100 µA
- Beam focus $\backsim$ 100 µm
- Established technology of electron microscopes

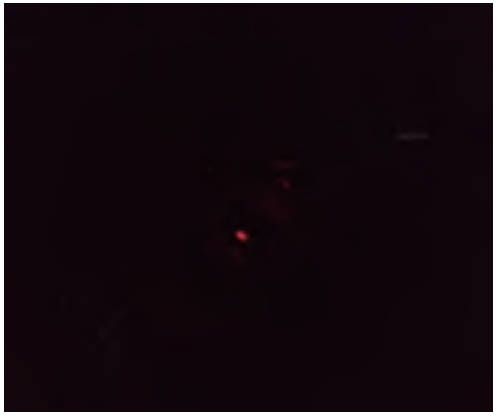


Hyperfinetransition of ^{39}K Ground State



^{39}K Ground-State Experiment Status



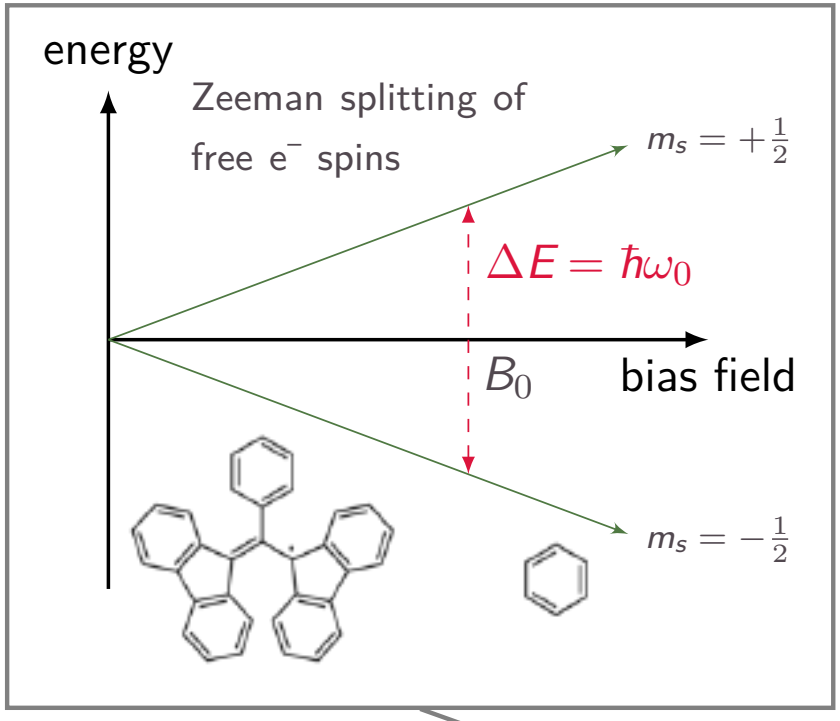


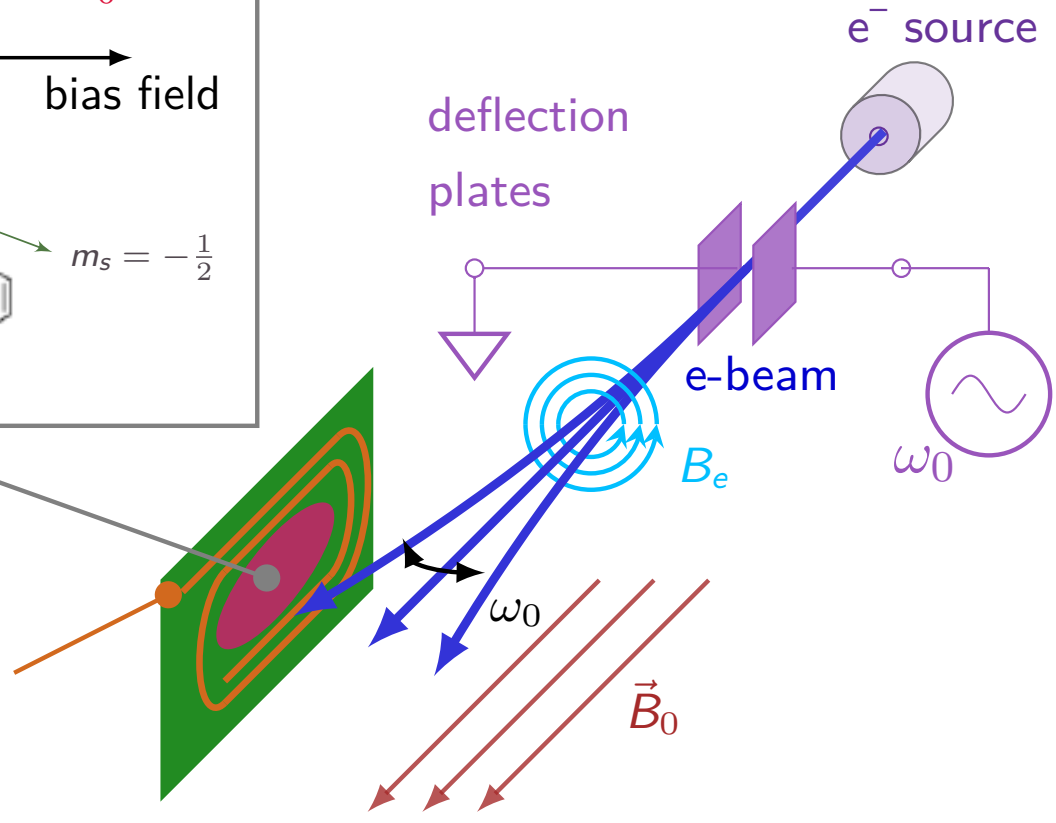
3D MOT

e^- beam in vaccum chamber

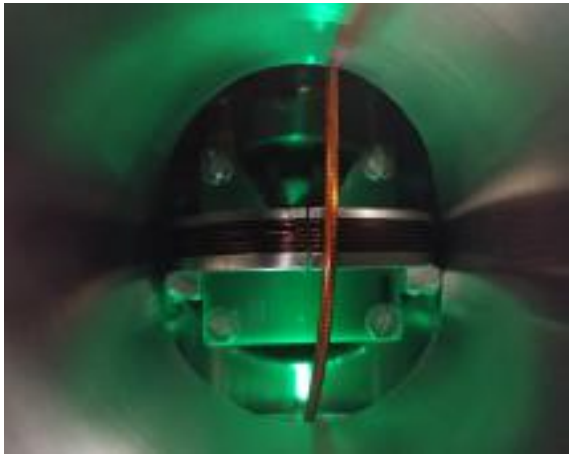
Electron Spin Resonance

BDPA (α, γ-Bisdiphenylen-β-phenylallyl)





Electron Spin Resonance Experiment Status

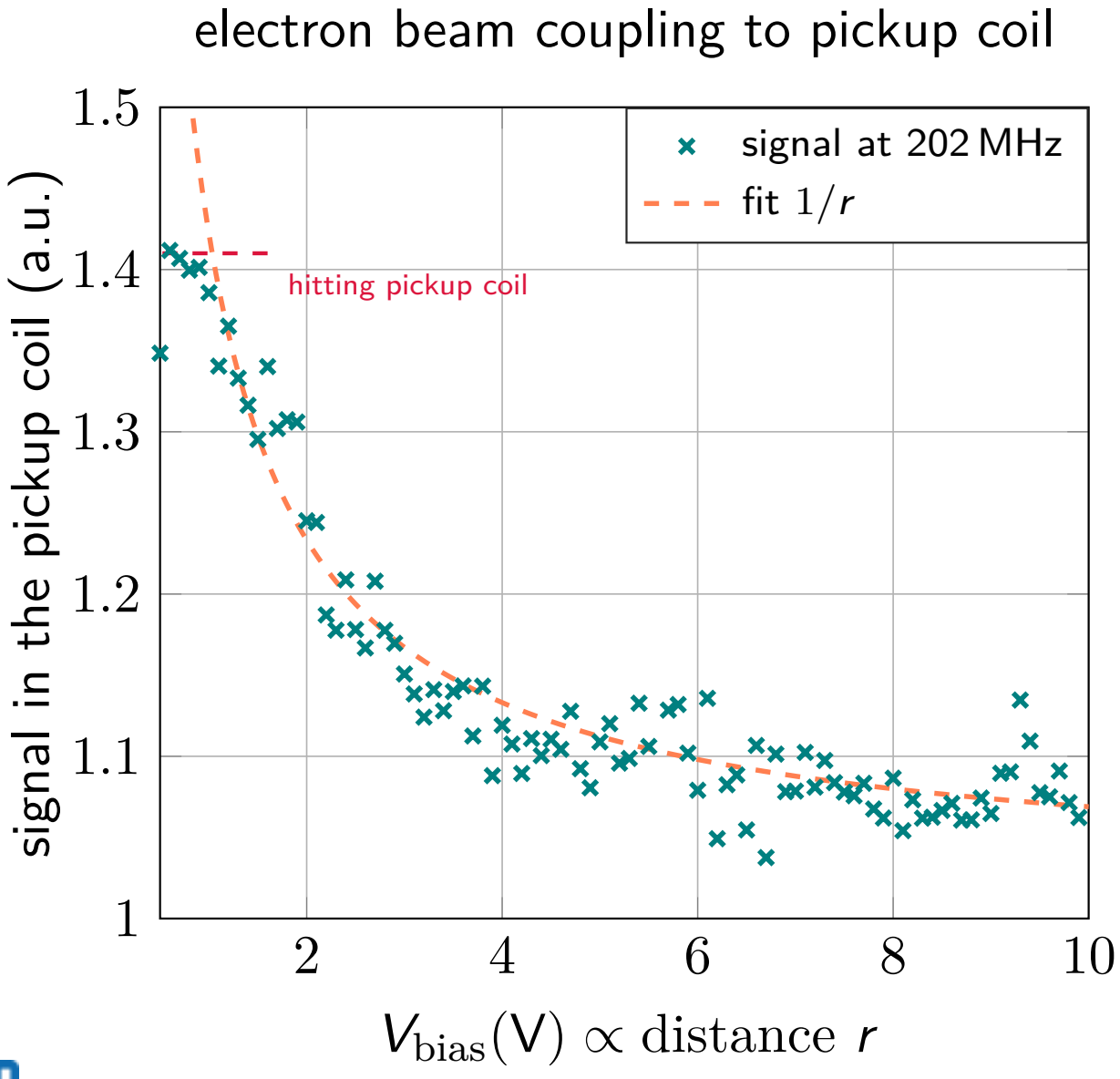


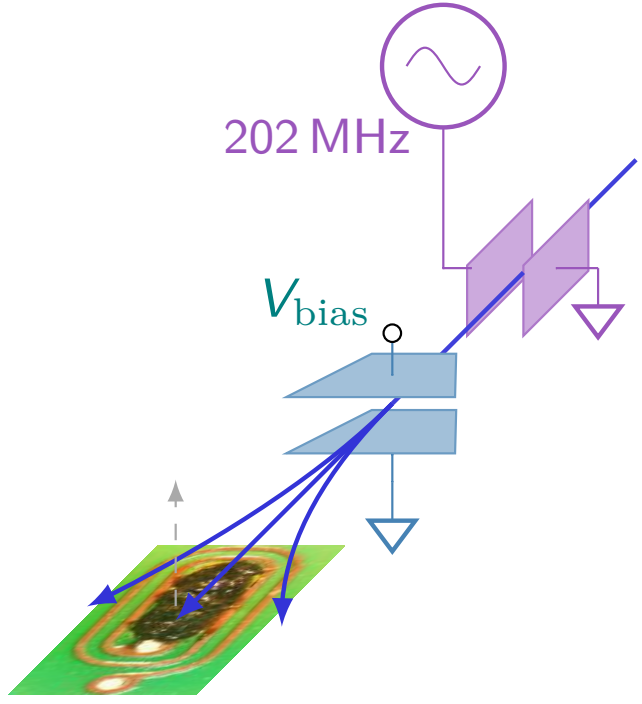
e^- beam in vaccum chamber

pickup coil with sample

e^- gun

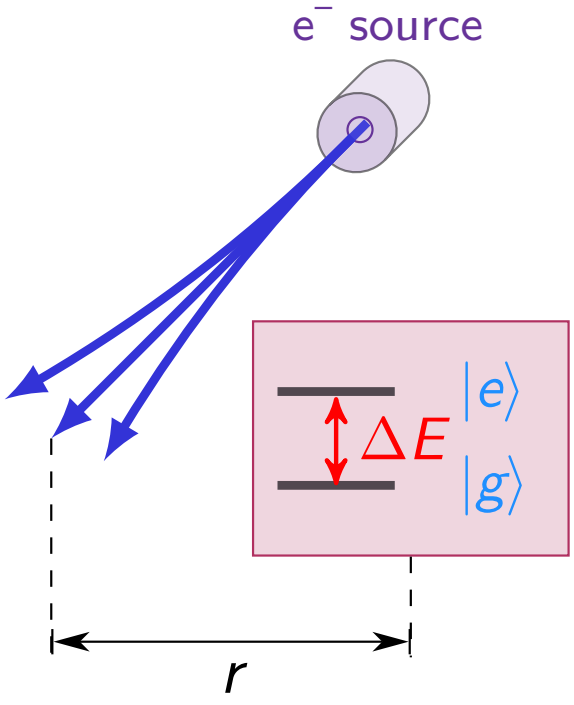
Preliminary Measurements





Summary and Outlook

- Novel technique to coherently drive quantum transitions beyond diffraction limit
- Spatial or temporal e^- -beam modulation
- Two prove of principle setups
- Preliminary measurement of the near-field of an electron beam
  - Cool spin sample
  - Drive ^{39}K ground-state
  - Paint potentials



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ESQ Discovery Programme

Thank you for your attention!

[1] D. Rätzel, D. Hartley, O. Schwartz, and P. Haslinger, "A Quantum Klystron – Controlling Quantum Systems with Modulated Electron Beams", Physical Review Research **3**, 023247 (2021).

[2] A. Gover and A. Yariv, "Free-Electron–Bound-Electron Resonant Interaction", Physical Review Letters **124**, 064801 (2020).

Haslinger Group (f.l.t.r):
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Matthias Kolb
Thomas Spielauer
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Dominik Hornof
Philipp Haslinger (PI)

Former Members:
Daniel Hartley
Samuel Rind
Johann Toyfl

Giovanni Boero; *EPFL, Lausanne*

Dennis Rätzel (Theory); *ZARM, University of Bremen*

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Open Positions (Postdoc, Phd, Master, Bachelor)

Hasl

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Giovanni Boero; *EPFL, Lausanne*

Dennis Rätzel (Theory); *ZARM, University of Bremen*

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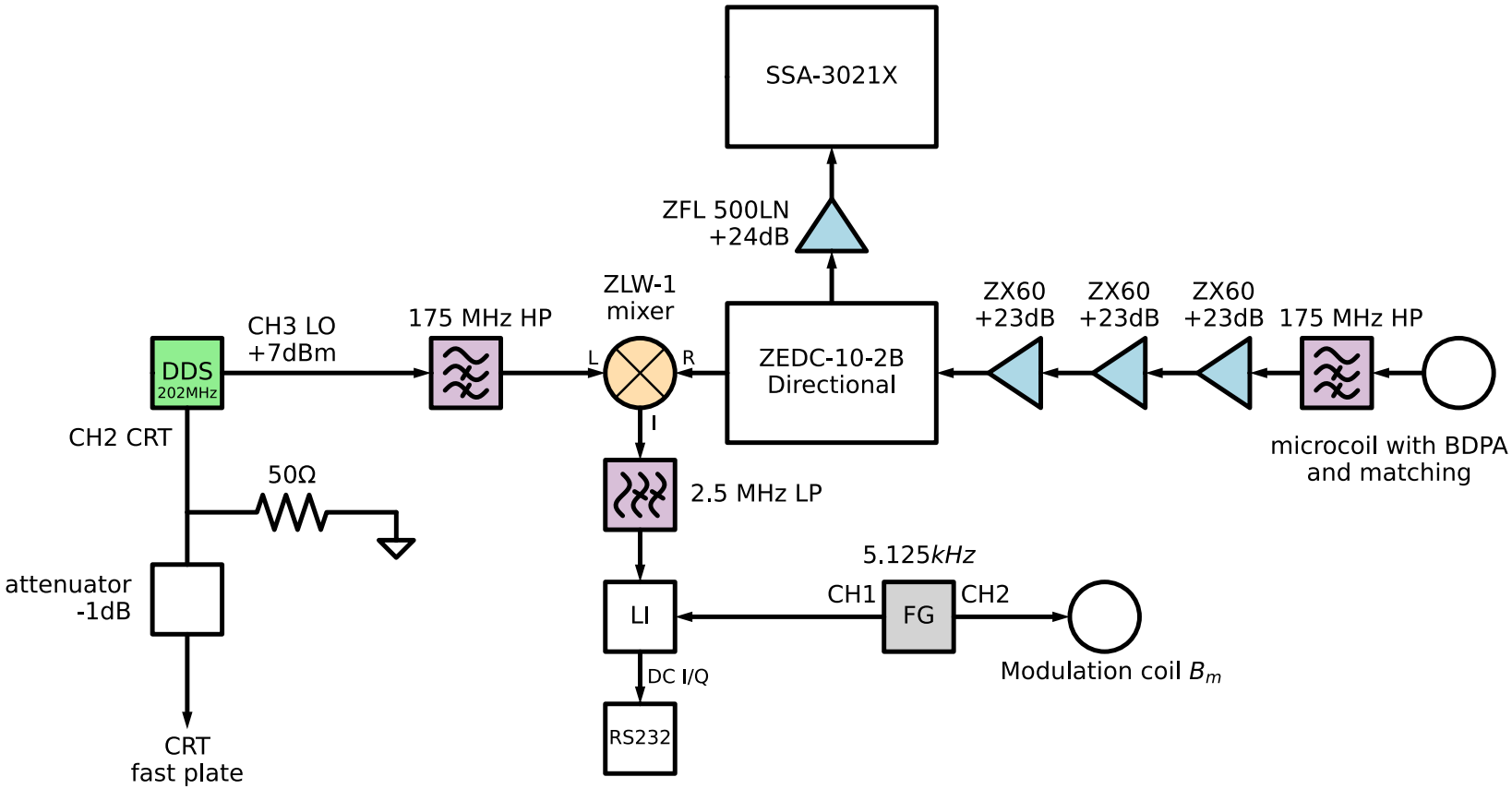
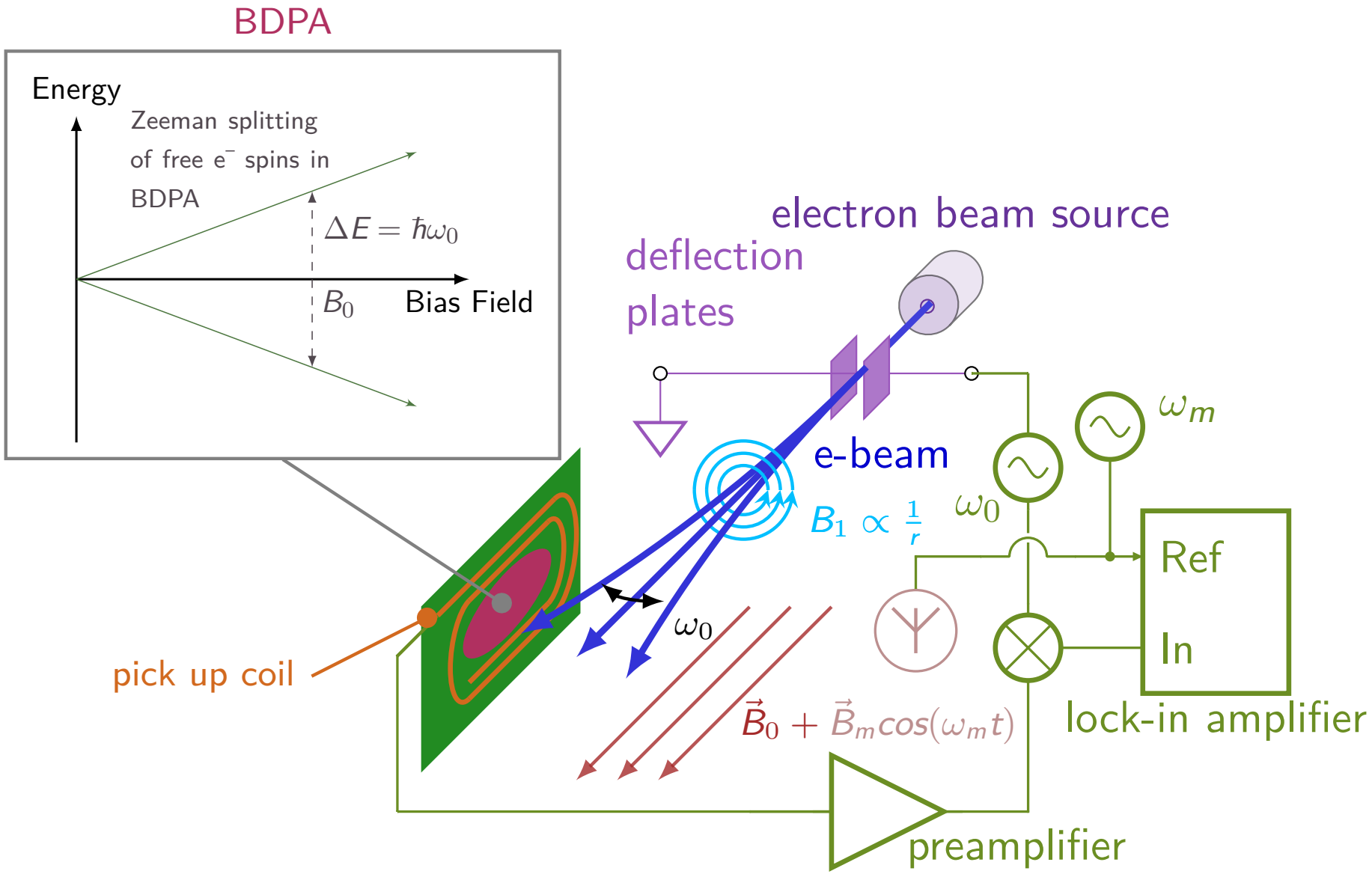
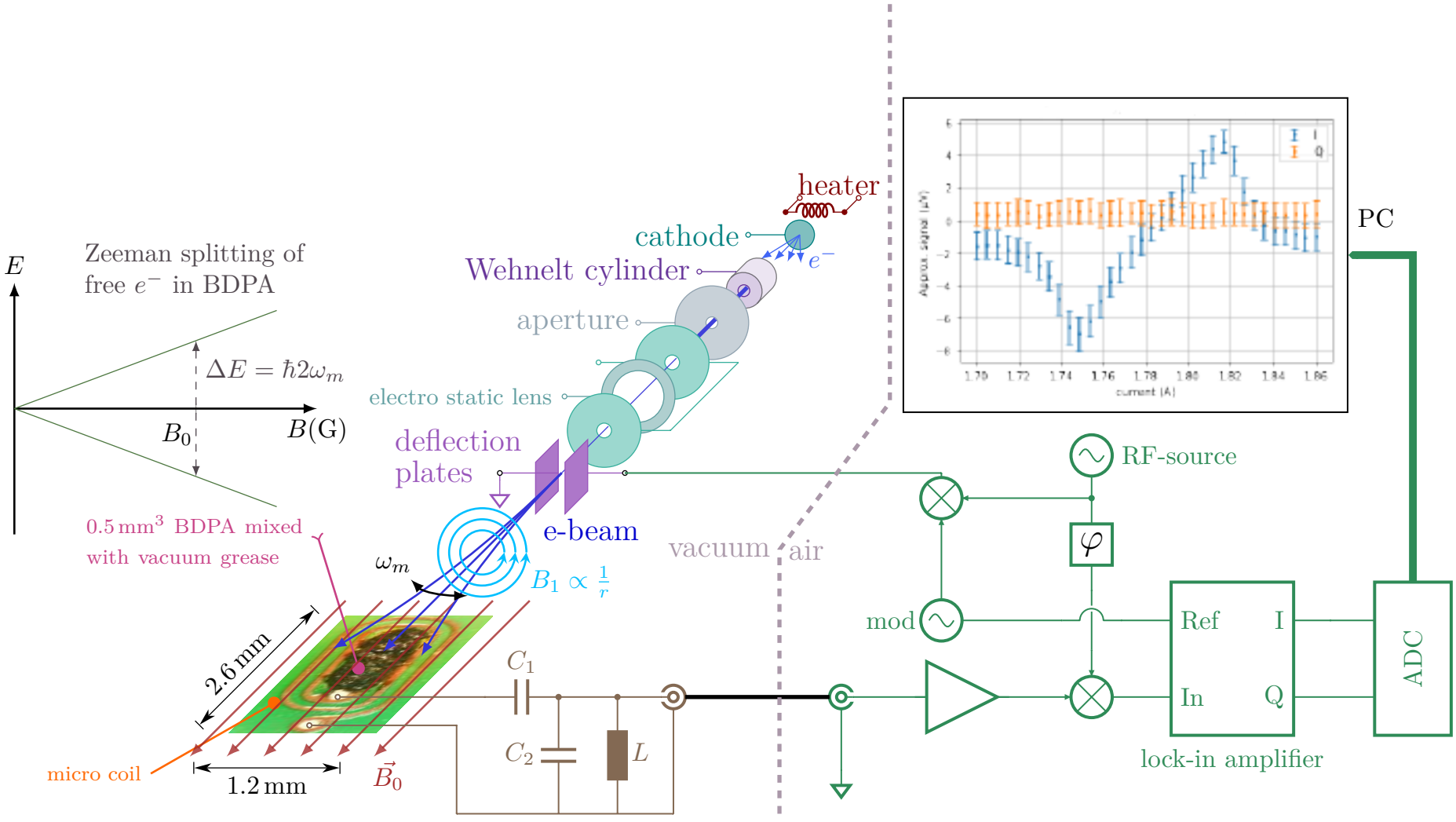
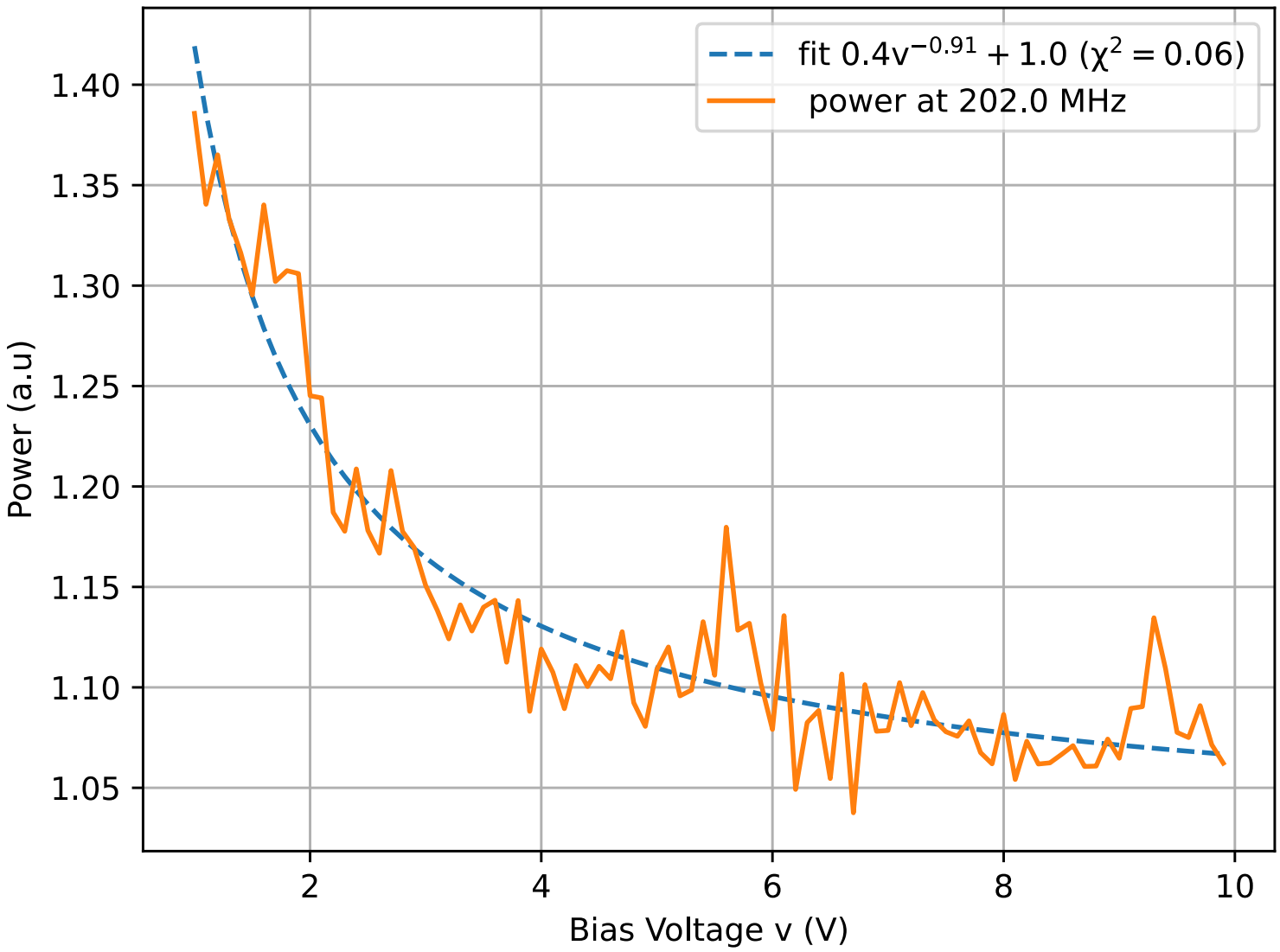
RF-Setup

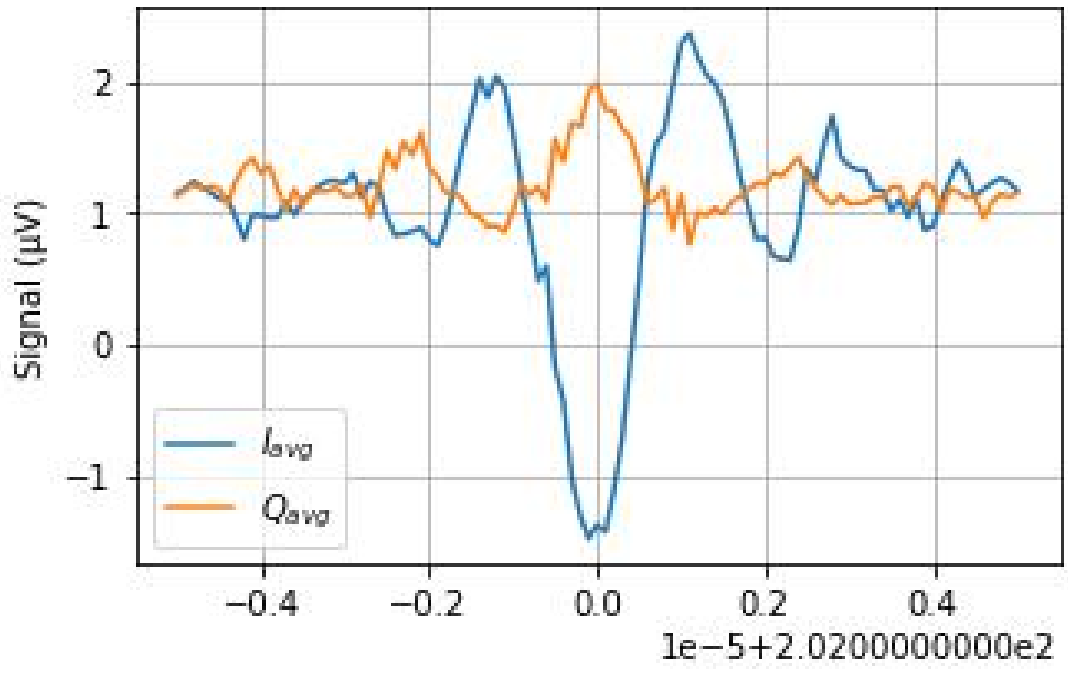

SSA-3021X
ZFL 500LN
+24dB
ZLW-1
mixer
ZX60
+23dB
ZX60
+23dB
ZX60
+23dB
175 MHz HP
CH3 LO
+7dBm
175 MHz HP
DDS
202MHz
L
R
ZEDC-10-2B
Directional
I
microcoil with BDPA
and matching
CH2 CRT
50Ω
2.5 MHz LP
5.125kHz
attenuator
-1dB
CH1
FG
CH2
LI
Modulation coil B_m
DC I/Q
RS232
CRT
fast plate

Detailed Experiment Setup




E
Zeeman splitting of
free e^- in BDPA
$\Delta E = \hbar 2\omega_m$
B_0
B(G)
heater
cathode
e^-
Wehnelt cylinder
aperture
electro static lens
deflection
plates
e-beam
$B_1 \propto \frac{1}{r}$
ω_m
0.5 mm^3 BDPA mixed
with vacuum grease
2.6 mm
1.2 mm
micro coil
$\vec{B}_0$
C_1
C_2
L
vacuum
air
RF-source
φ
mod
Ref
I
In
Q
lock-in amplifier
ADC
PC


Fit
fit $0.4v^{-0.91} + 1.0$ ($\chi^2 = 0.06$)
power at 202.0 MHz
Power (a.u)
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
2
4
6
8
10
Bias Voltage v (V)

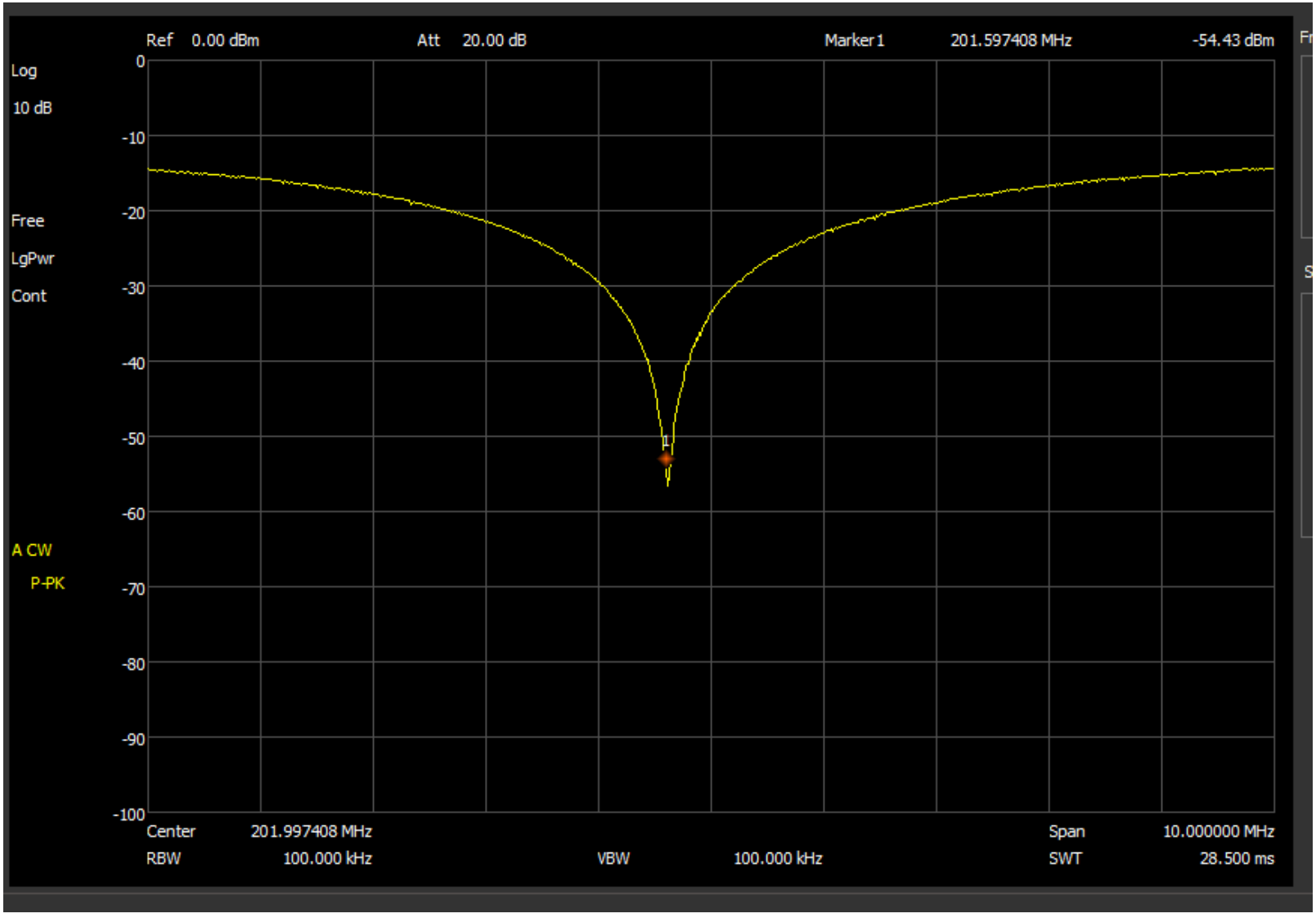

Signal (μV)
2
1
0
−1
I_{avg}
Q_{avg}
−0.4
−0.2
0.0
0.2
0.4
1e−5+2.0200000000e2

Only small impact on momentum

$$\Delta p_z \gg \delta p$$

$$\delta p = \frac{h}{\lambda_0} \qquad \Delta p_z = \frac{\hbar}{2\Delta z}$$

$\lambda \approx 13.8\,\text{cm},\ \lambda_{dB} \approx 26\,\text{pm}$


Ref 0.00 dBm
Att 20.00 dB
Marker 1 201.597408 MHz
-54.43 dBm
Log
10 dB
Free
LgPwr
Cont
A CW
P-PK
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
1
Center 201.997408 MHz
RBW 100.000 kHz
VBW 100.000 kHz
Span 10.000000 MHz
SWT 28.500 ms