Quantum Cryptography & Quantum Hacking

Hacking the „un-hackable“

Lecturer: Vinzenz Vogel, Viola Hansjakob

- Paper by Lars Lydersen et. al. 2010:
  Hacking commercial quantum cryptography systems by tailored bright illumination

- Two commercial systems hacked: Clavis2 (ID Quantique), QPN 5505 (MagiQ Technologies)

- Trojan Horse attack

Outline

- Introduction
- A basic QKD protocol: BB84
- How can QKD be hacked?
- Example: The Trojan Horse attack
- Conclusion

Introduction

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	A	**A**	**Q**	**J**	**K**	**cipher text**

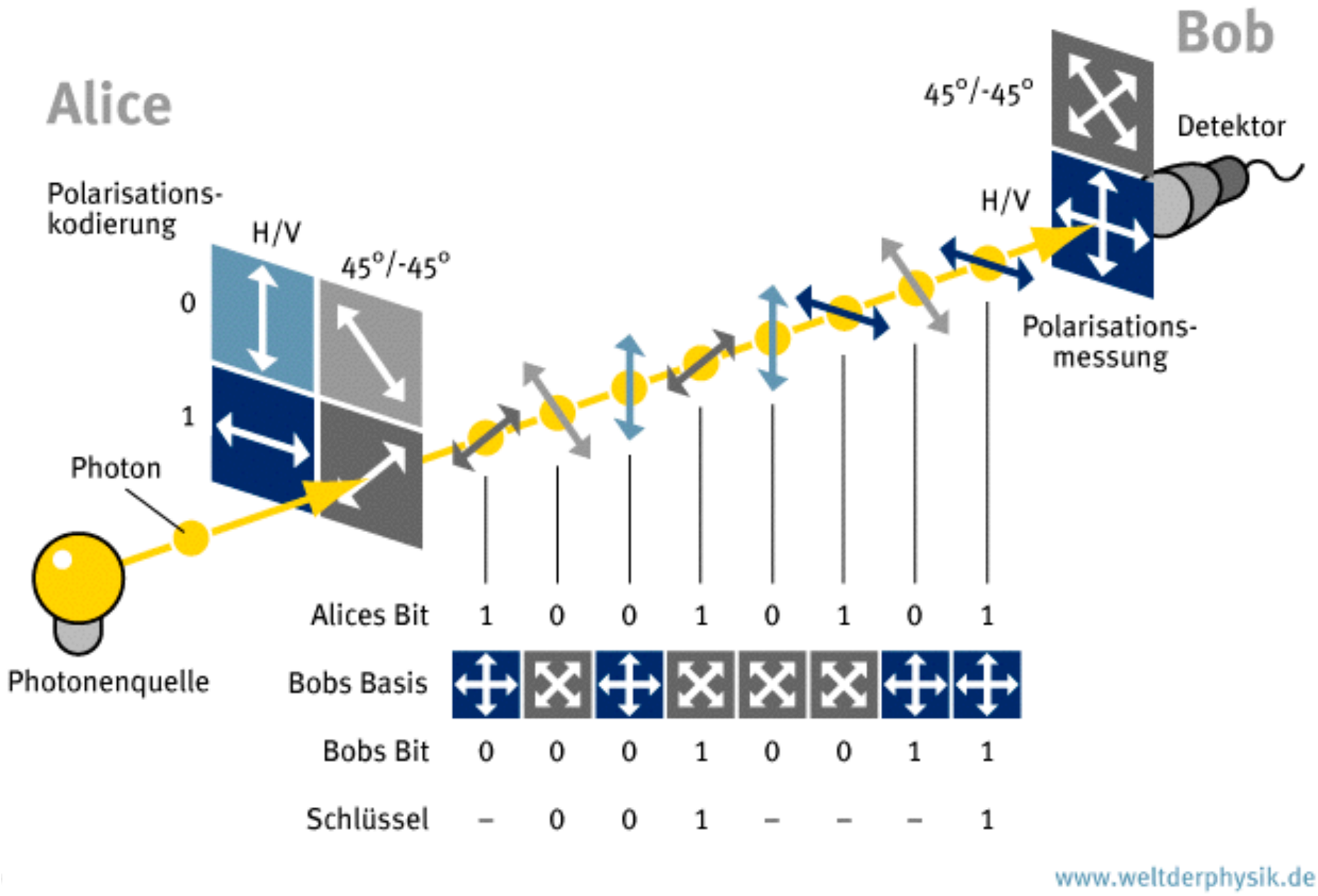
Introduction

- Cryptography is totally safe if one-time-pad is used to encrypt the message
- Problem: Safe distribution of key
- Solution: Quantum key distribution (QKD)

A basic QKD protocol: BB84

- Proposed in 1984 by Charles H. Bennett and Gilles Brassard
- Works by sending single photons from Alice to Bob
- Security check with simple photon statistics

A basic QKD protocol: BB84



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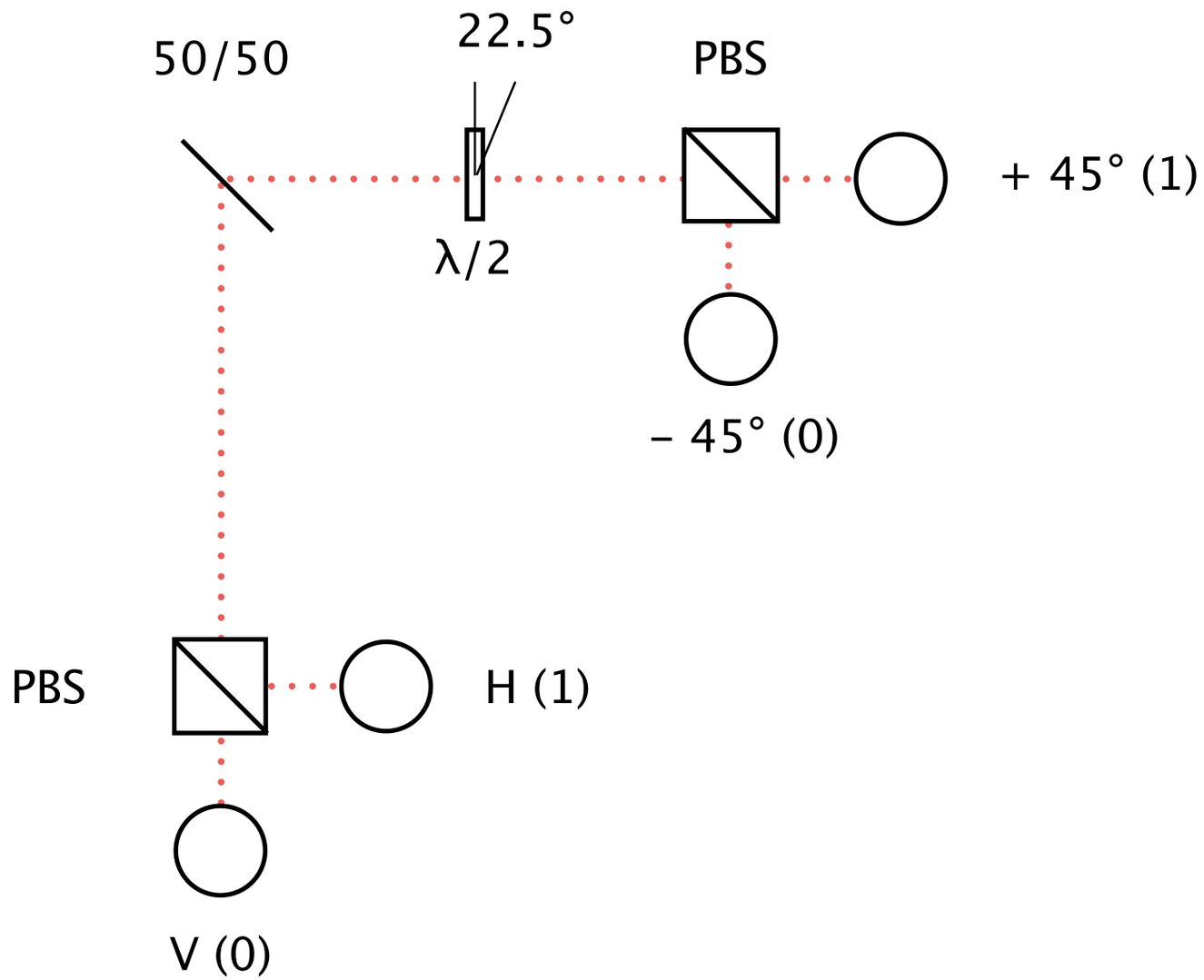
A basic QKD protocol: BB84

Bob´s perfectly random basis choice:



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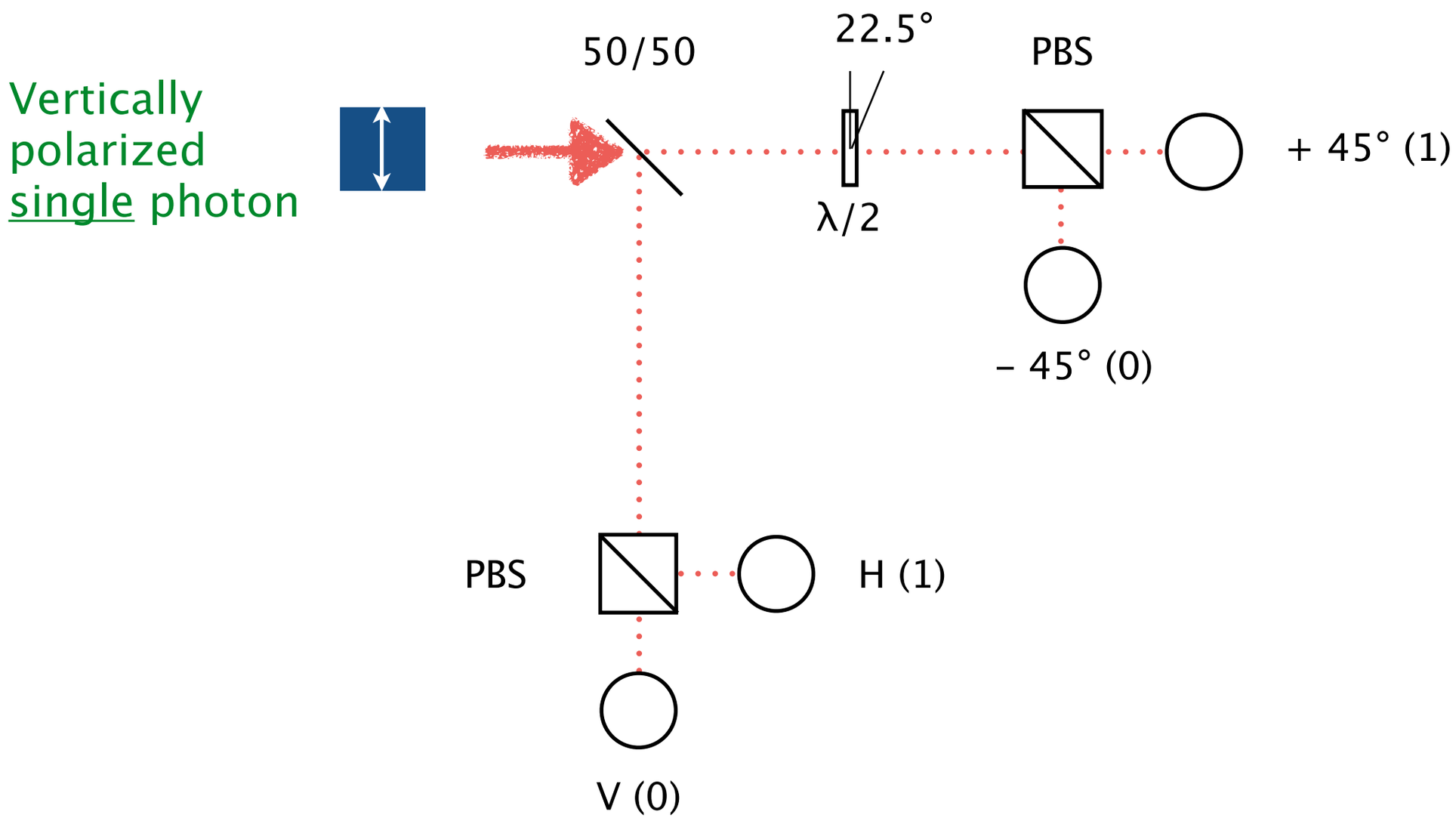
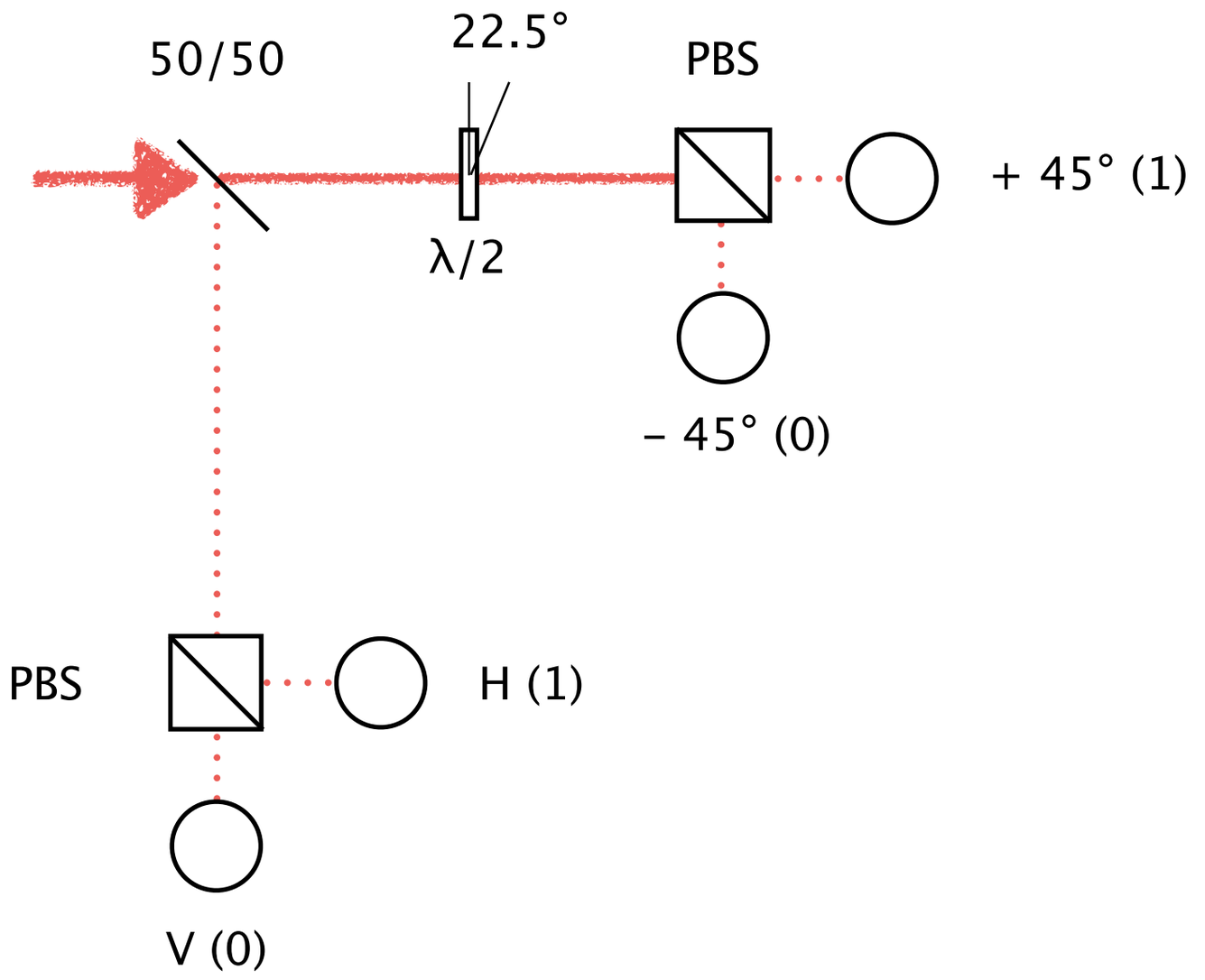


A basic QKD protocol: BB84

Bob´s perfectly random basis choice:

The basis of the photon is rotated into „+45°/–45°“ basis.

Vertically polarized single photon



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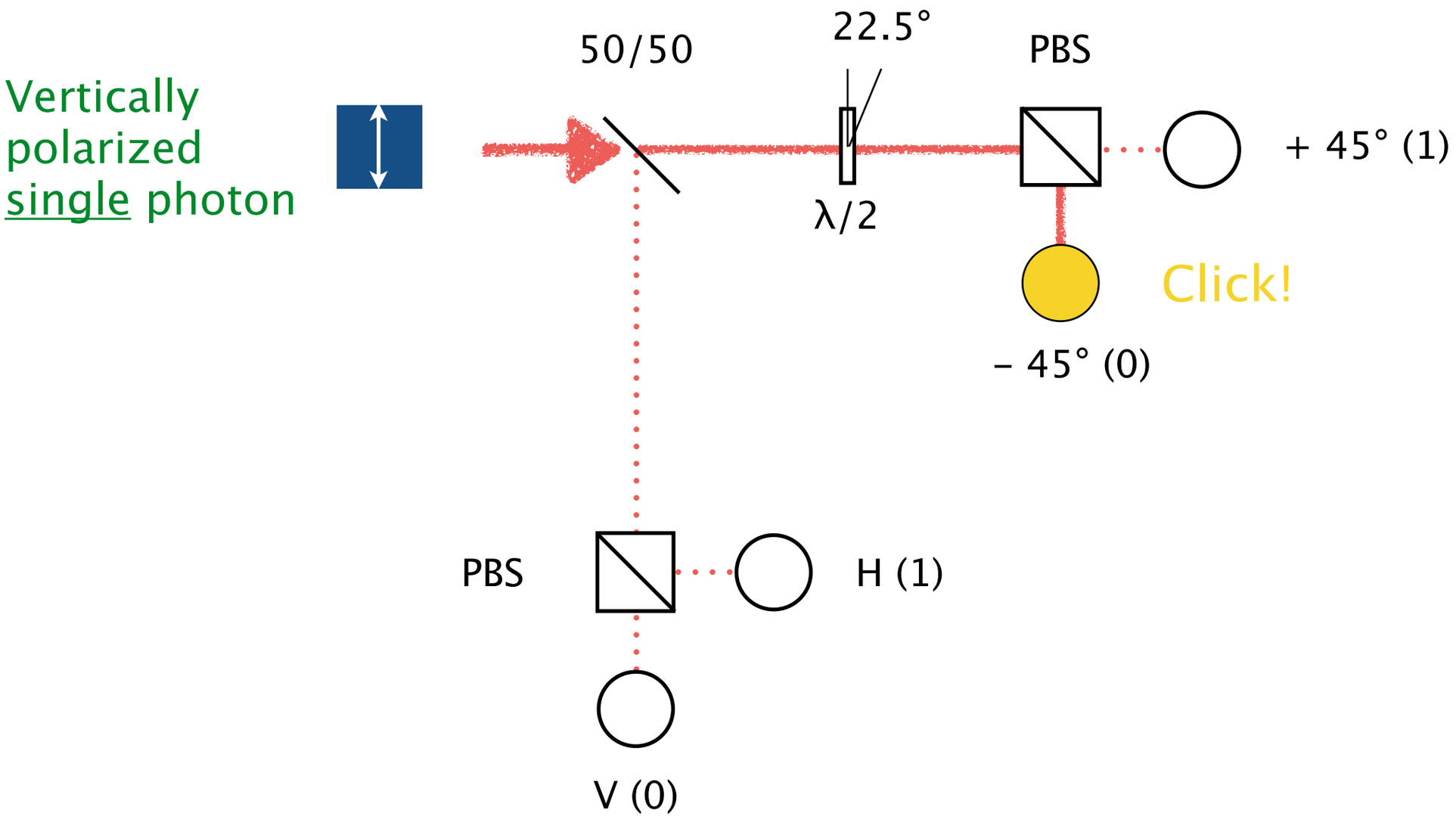

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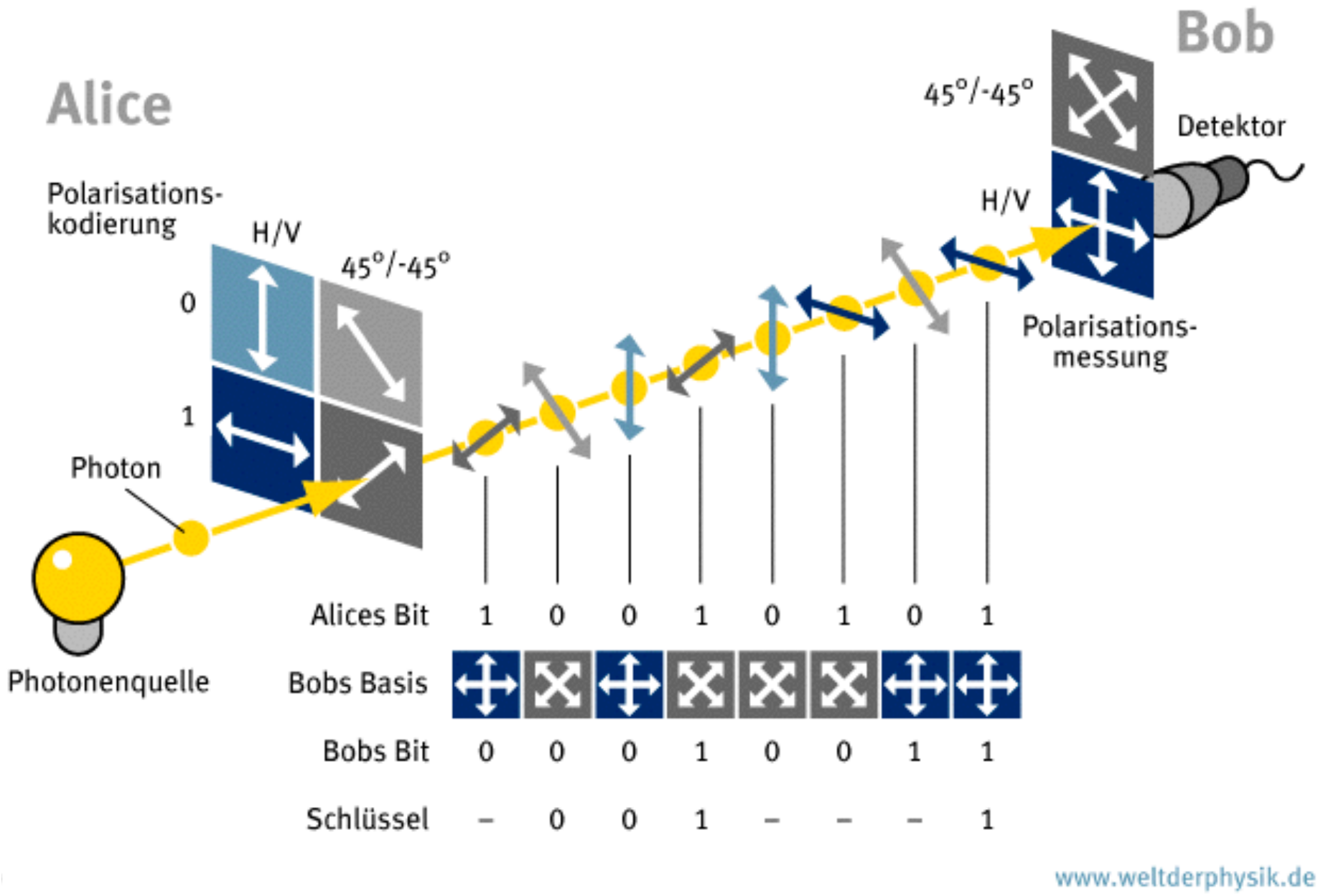

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A basic QKD protocol: BB84

<u>Secure under the following assumptions:</u>

- True random basis choice of Alice/Bob
- No one knows the basis choice of Alice/Bob
- Random choice of bits
- Use single photons

How can QKD be hacked?

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QKD can´t be hacked in theory…

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QKD can´t be hacked in theory…

…but in practice, if the security assumptions are violated!

How can QKD be hacked?

Exploit loopholes to violate assumptions!

How can QKD be hacked?

- Photon number splitting
  (violation: non-single photon sources are used)

- Trojan Horse attack
  (violation: Bob´s basis choice is known/dictated by Eve)

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<u>Basic idea of the attack:</u>

- Goal:
    - Eve interferes the communication and makes a measurement
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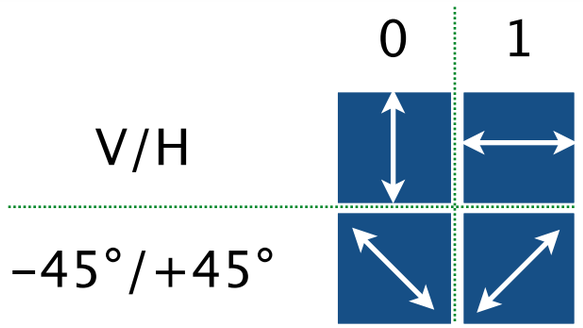
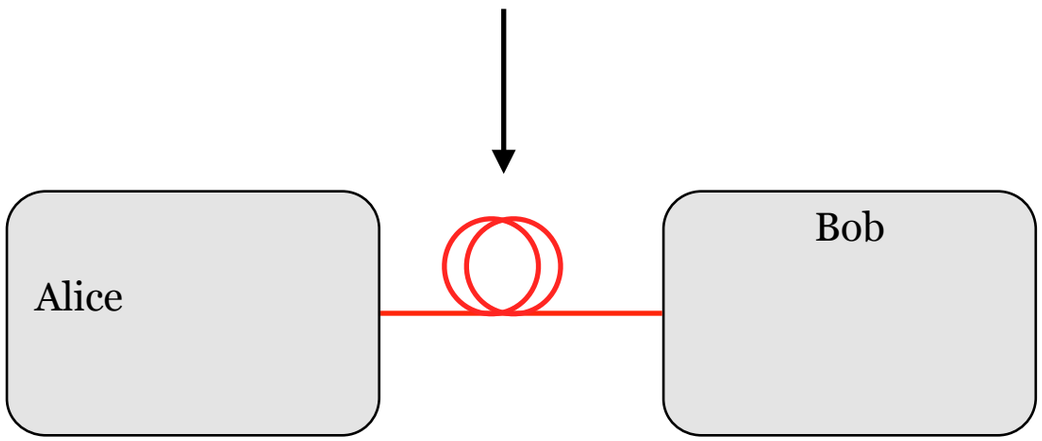
- Goal:
    - Eve interferes the communication and makes a measurement
    - Eve is able to dictate what Bob measures
- Approach:
    - Technical loophole: Bob´s photon detector (Avalanche photo diode, APD)

Example: The Trojan Horse attack

Basic scheme:



BB84



QM

http://arxiv.org/pdf/1008.4593v2.pdf

Example: The Trojan Horse attack

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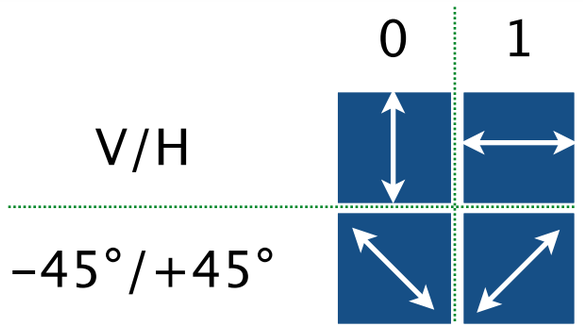

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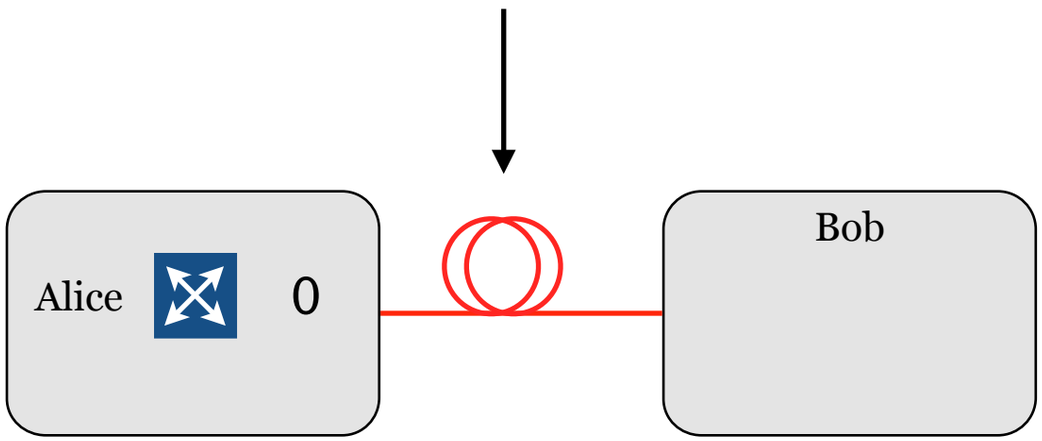

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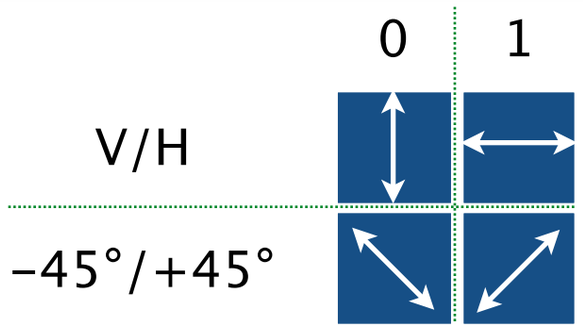

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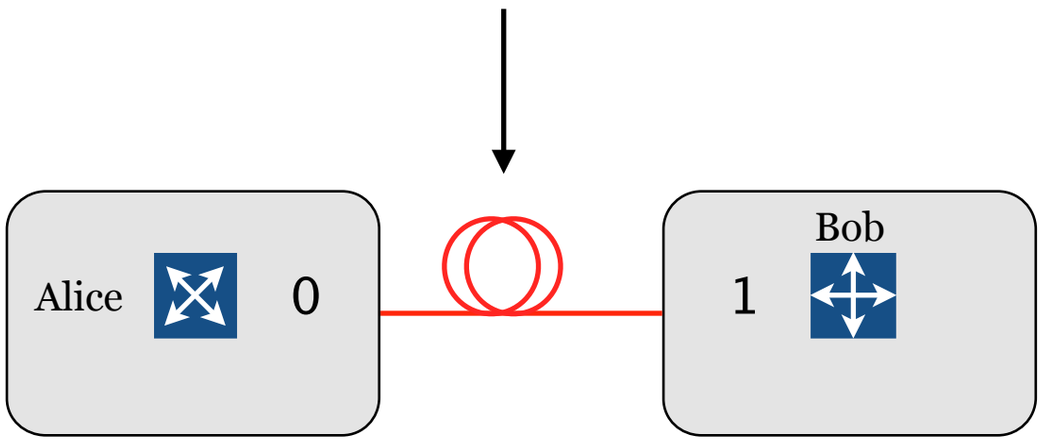

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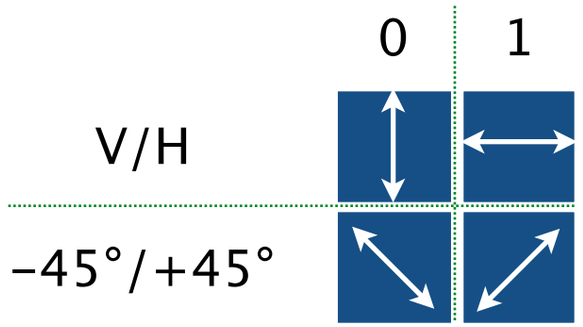

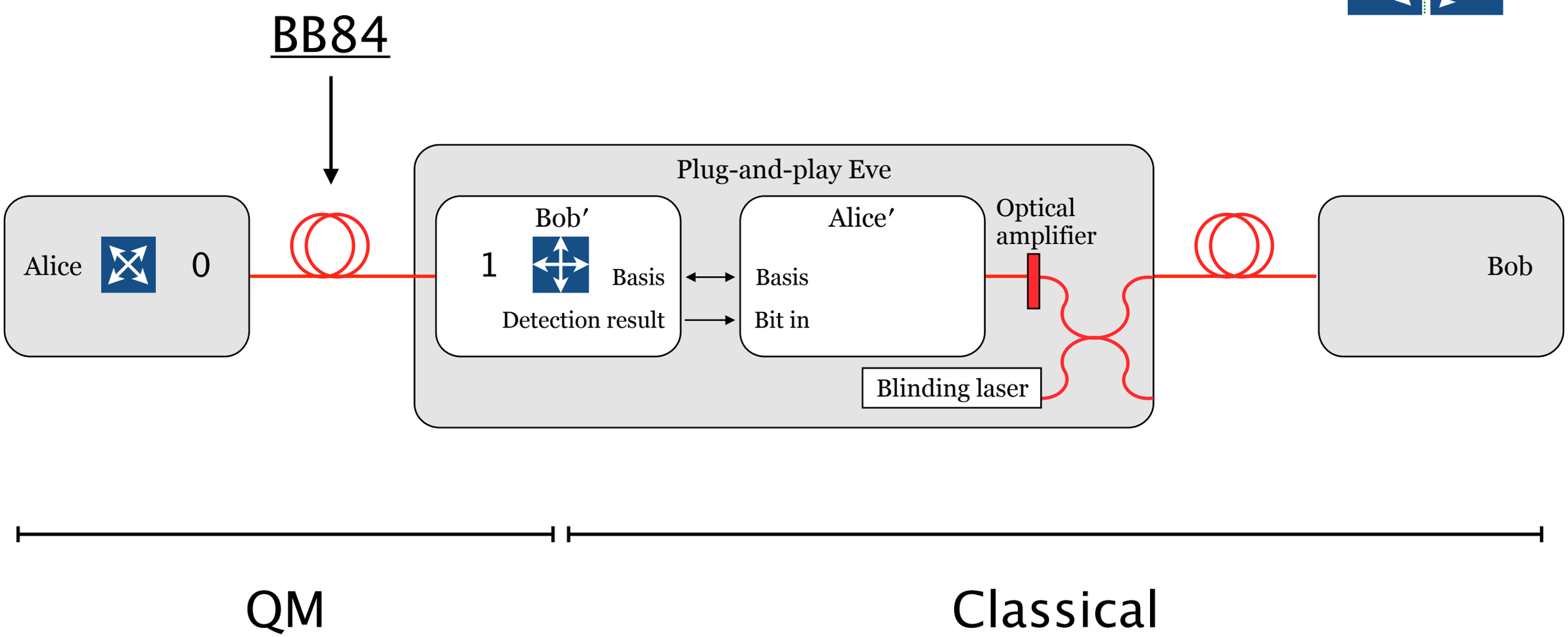

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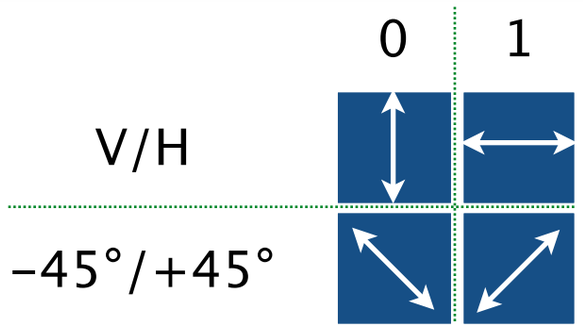

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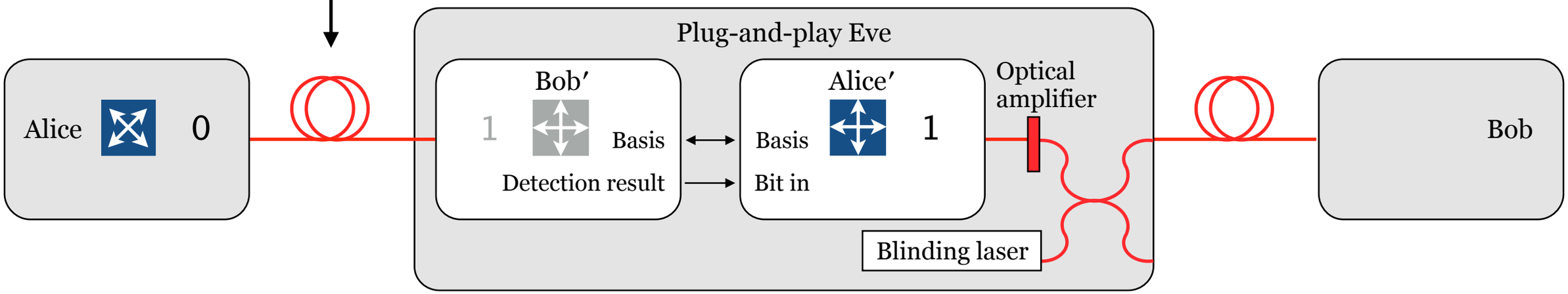

QM

Classical

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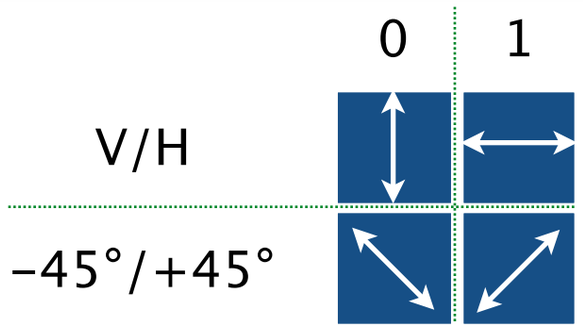

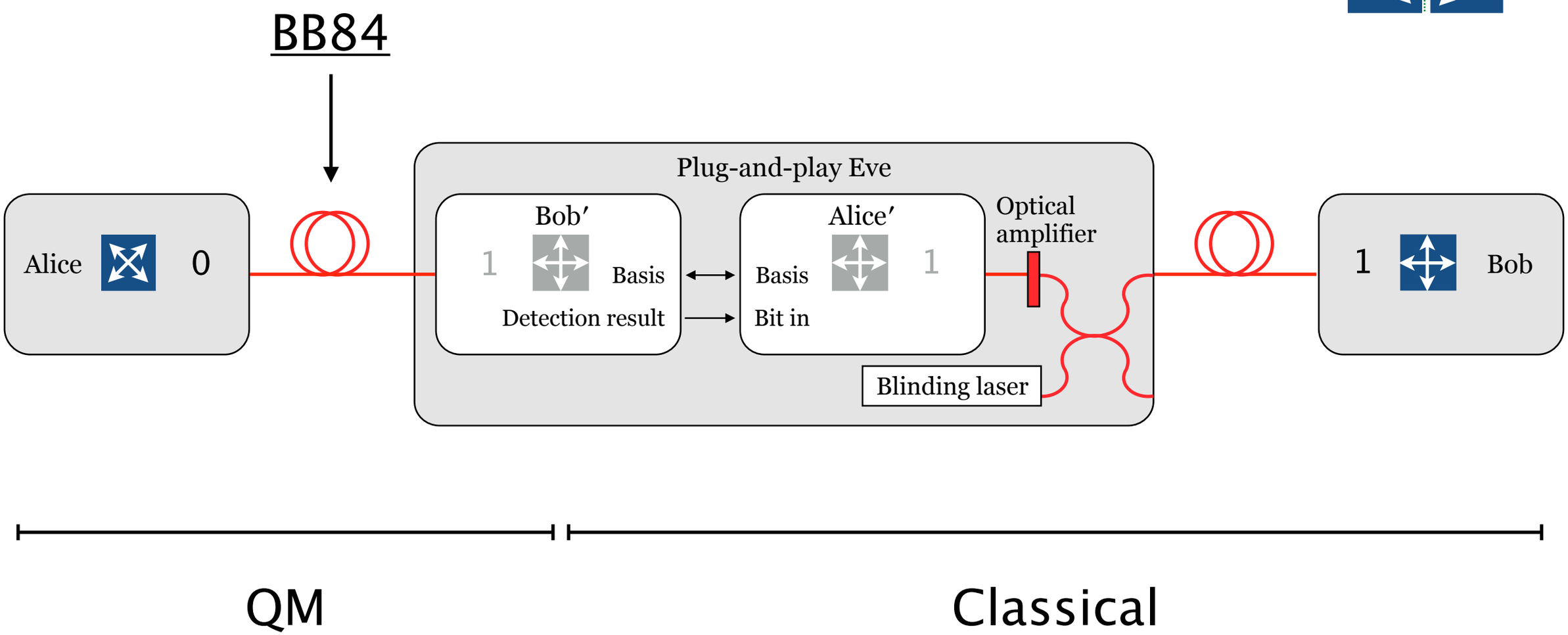

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Example: The Trojan Horse attack

The only question remaining:

How can Eve take control of Bob´s detectors?

Example: The Trojan Horse attack

Bob´s APDs (photon detectors) **have two operating modes:**

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1. **Linear mode** (gives signal linear to incoming intensity, **click** if incoming signal power is over a **threshold**; basically it **behaves like a normal photo diode**)

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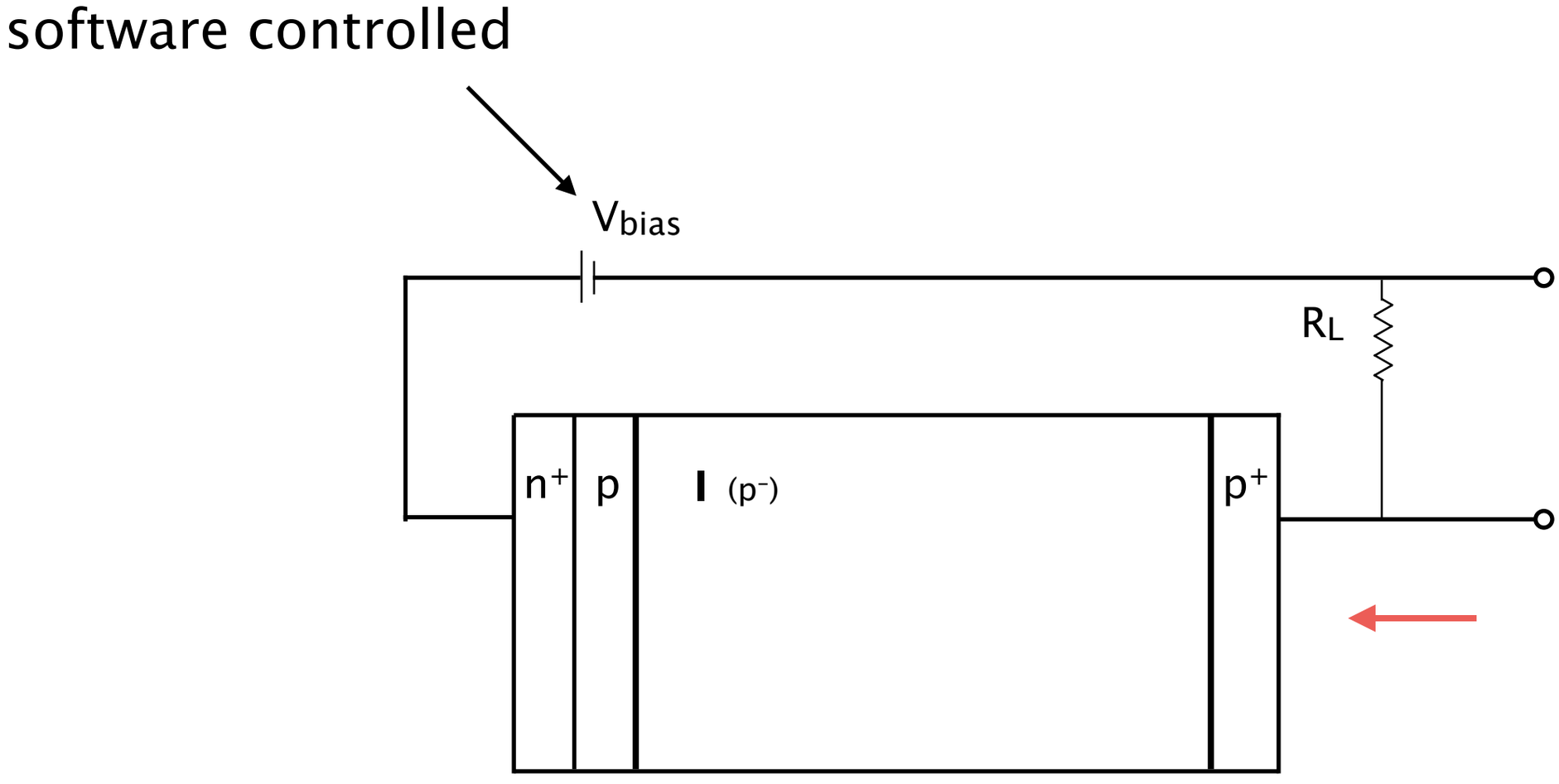
1. **Linear mode** (gives signal linear to incoming intensity, **click** if incoming signal power is over a **threshold**; basically it **behaves like a normal photo diode**)

2. **Geiger mode** (counting single photons, **click** if **single photon** comes in, efficiency <50%)

Example: The Trojan Horse attack

Linear mode: $V_{bias} < V_{br}$



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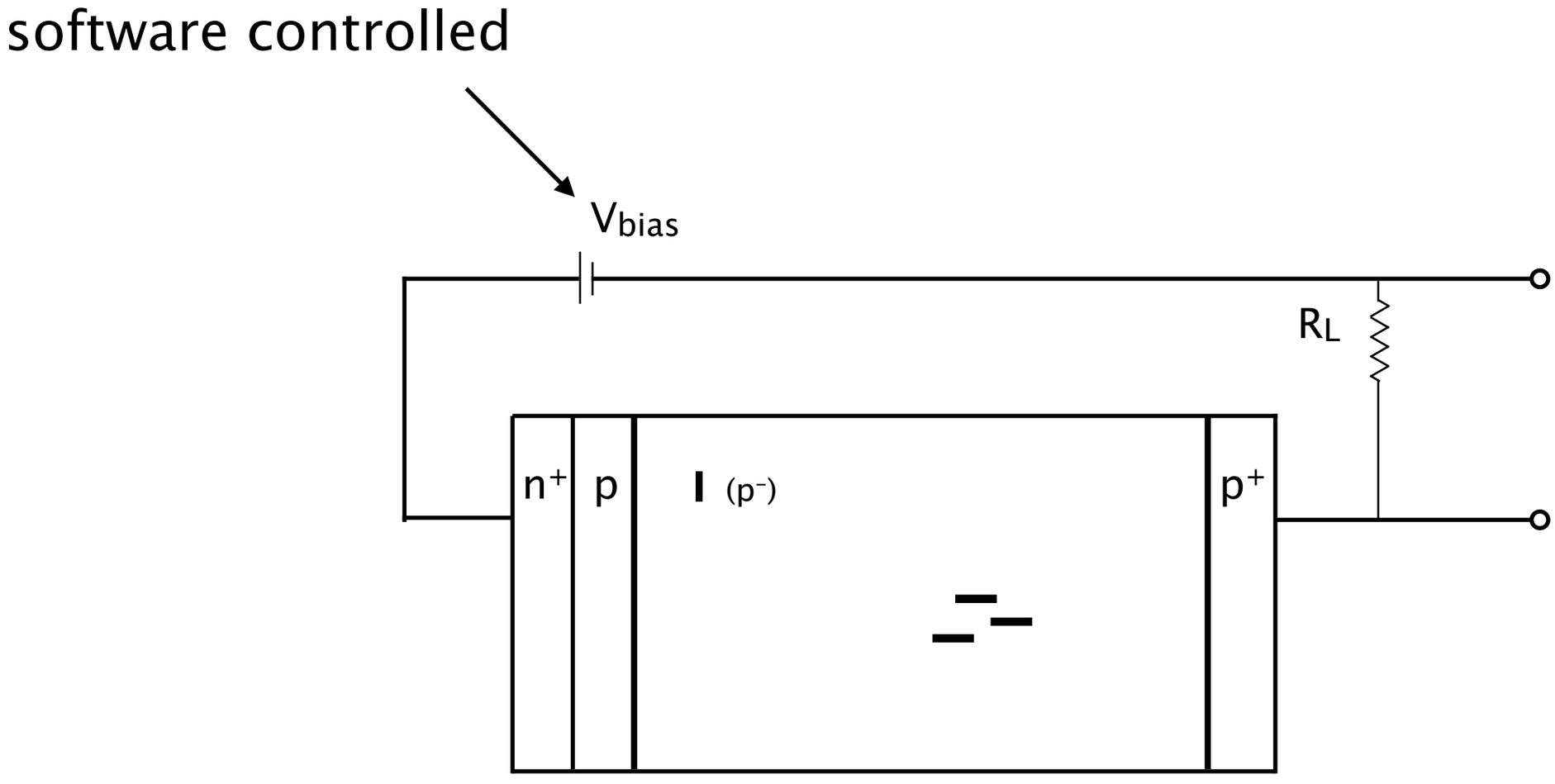

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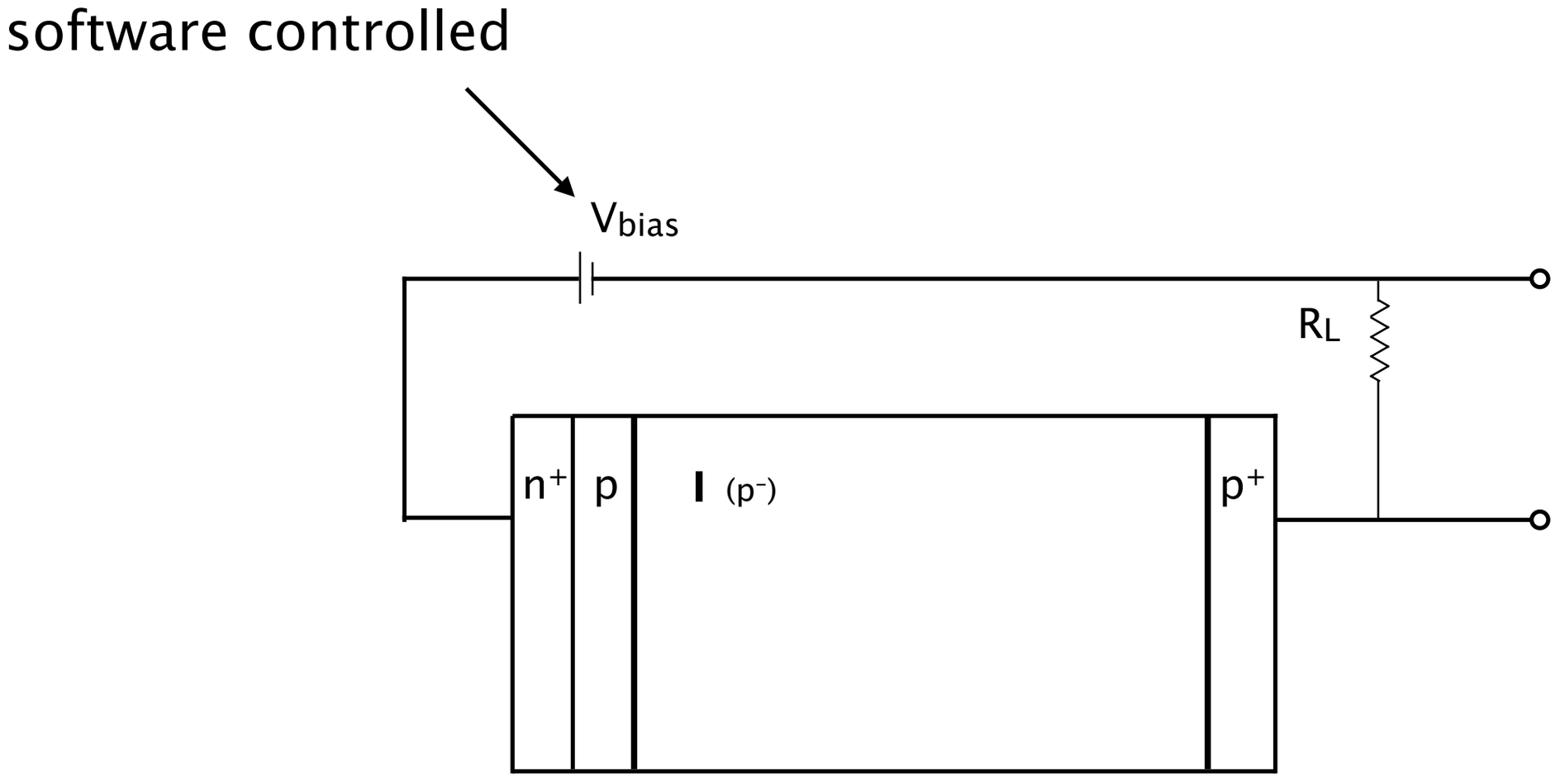

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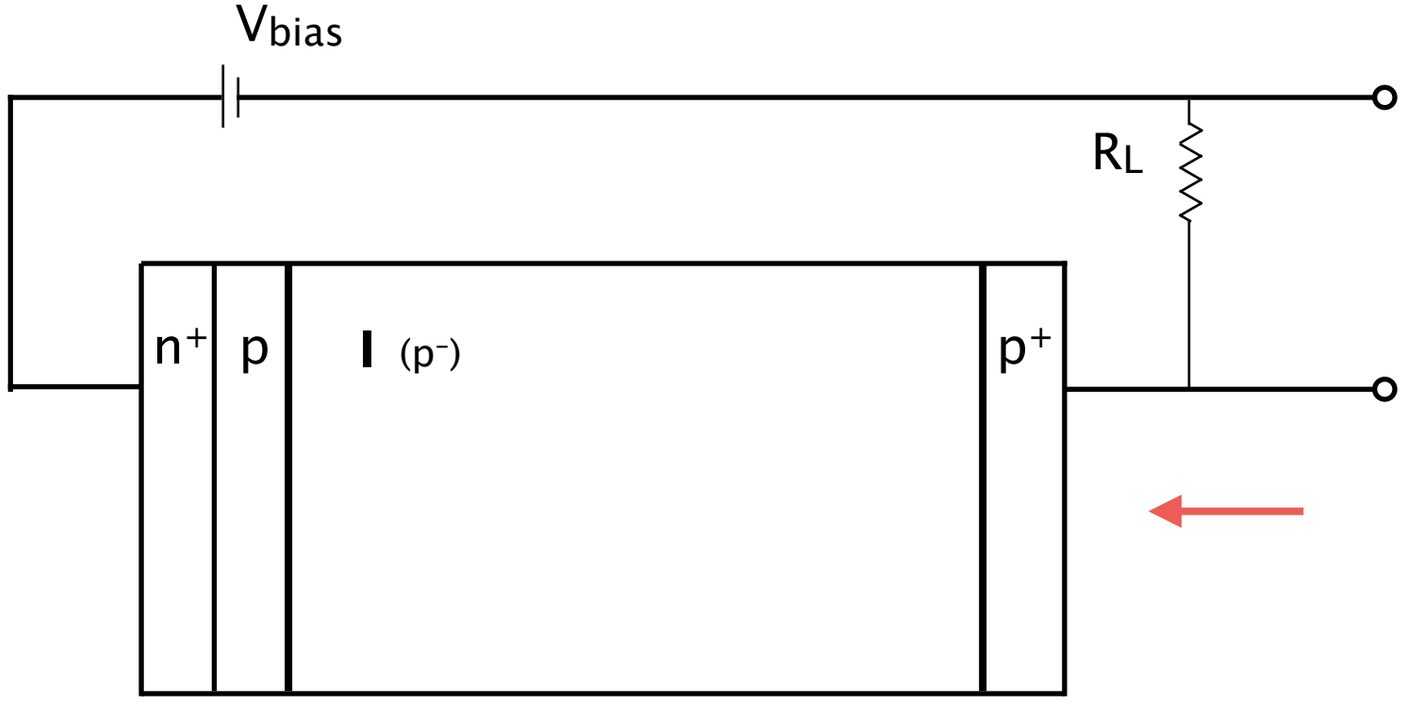

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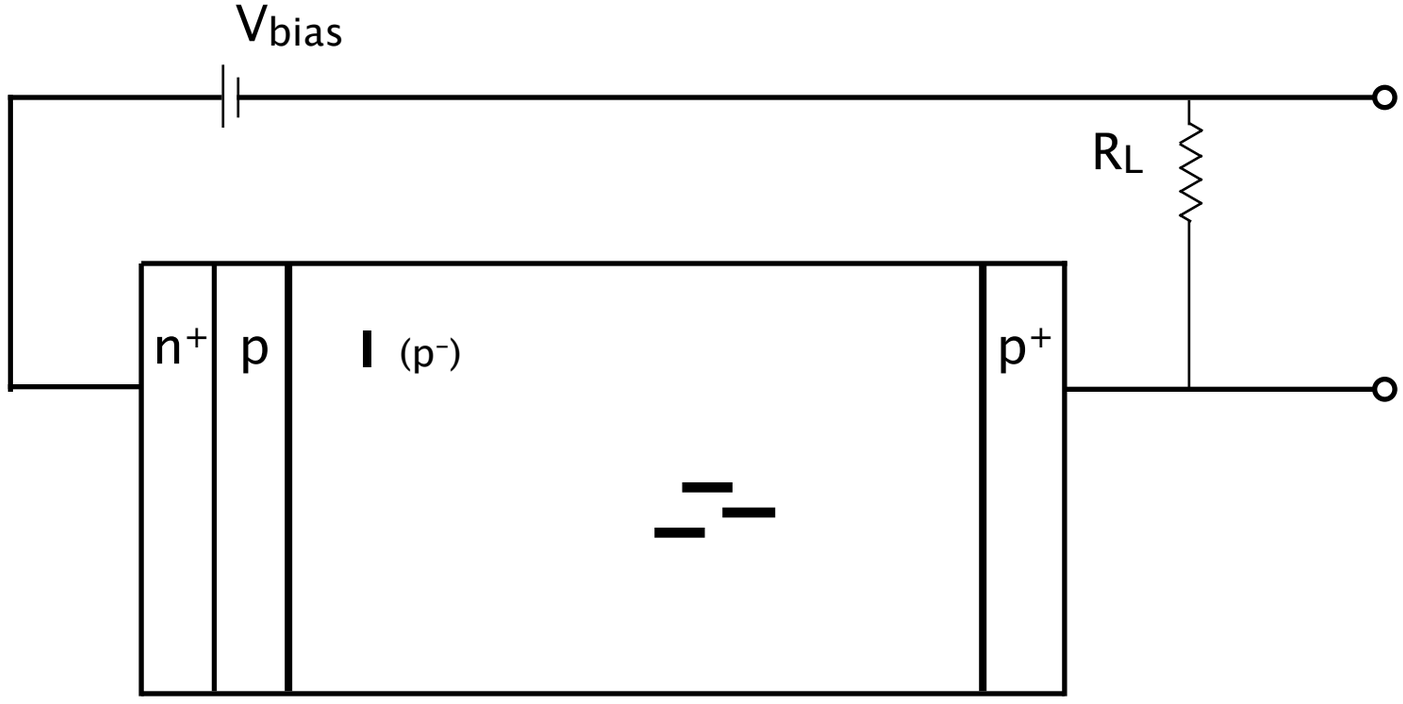

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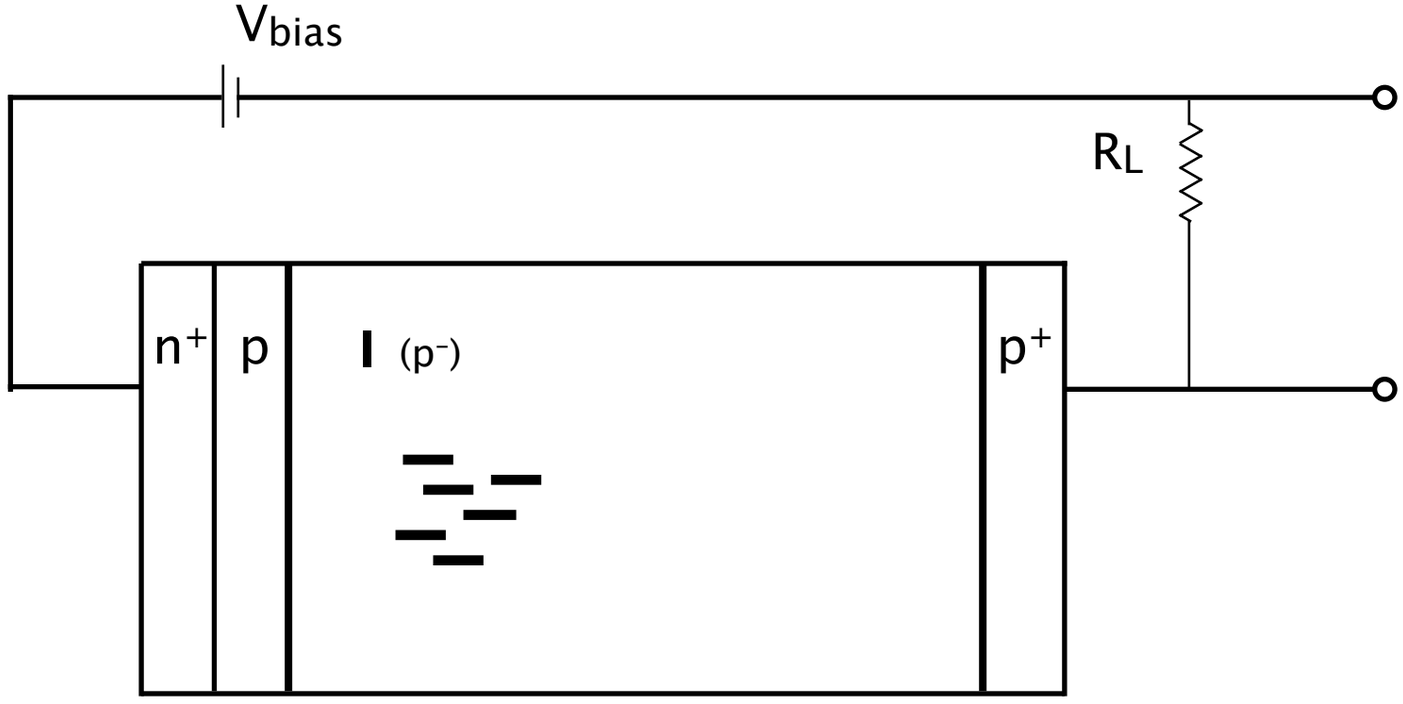

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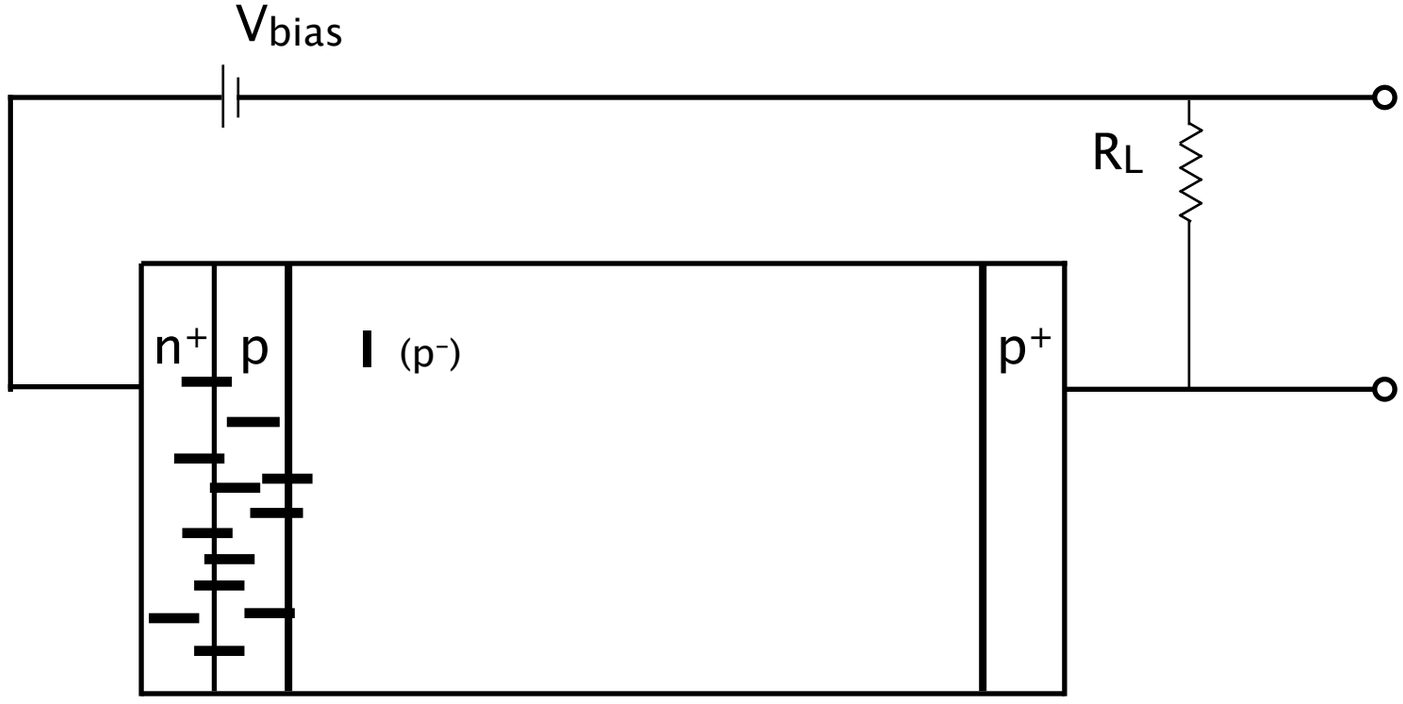

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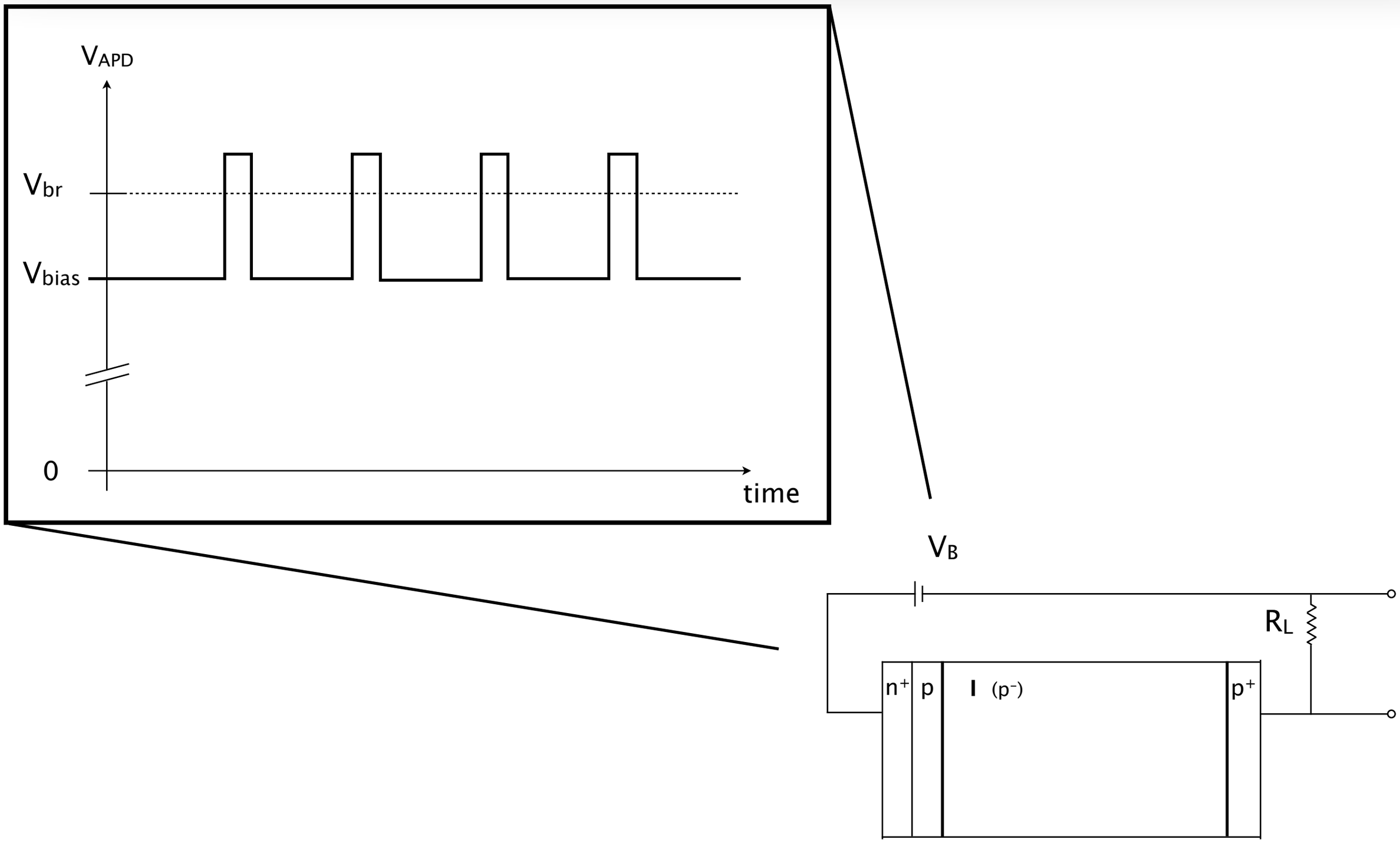

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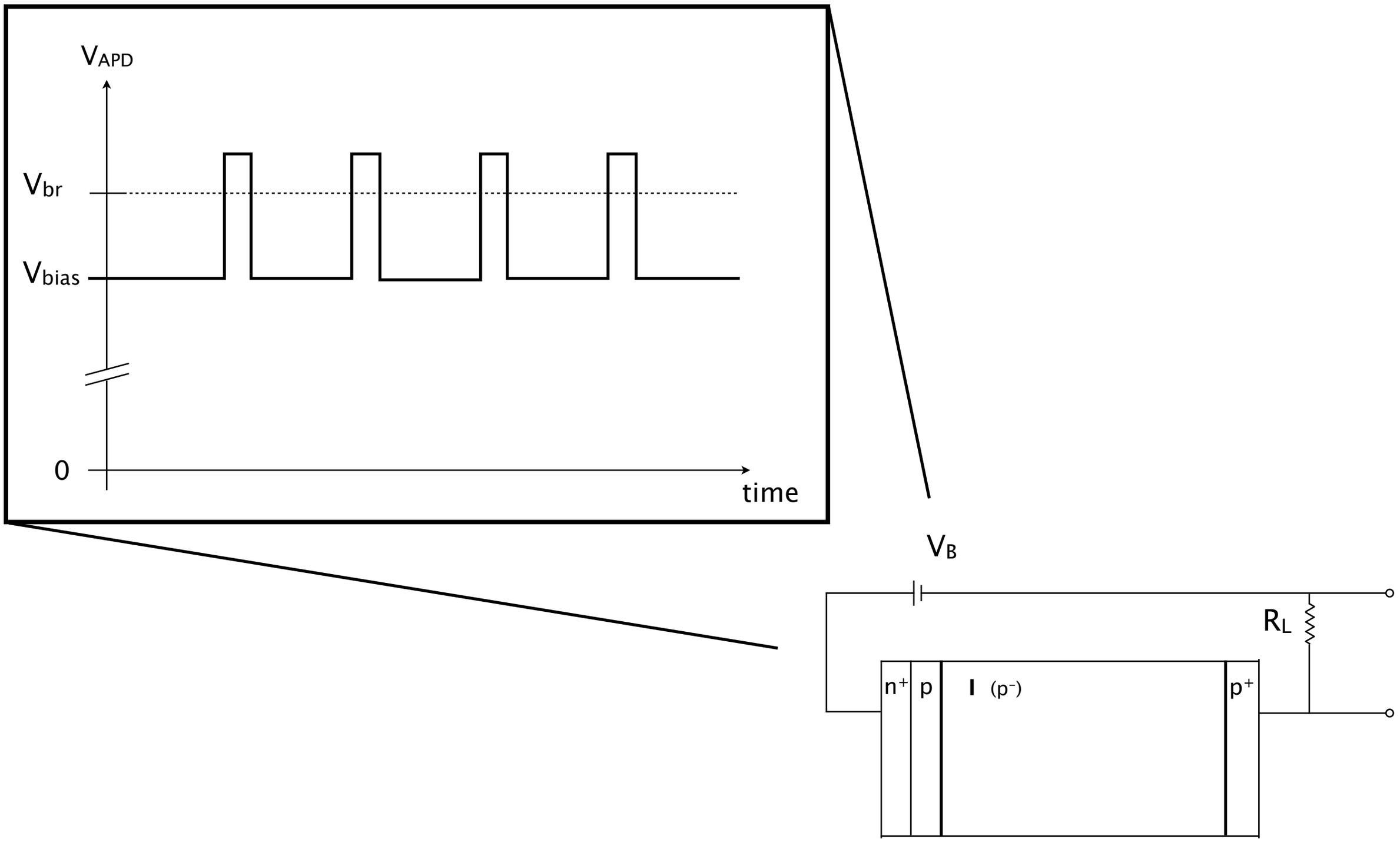
Example: The Trojan Horse attack

What Eve needs to do:

Get Bob´s APDs into linear mode

Example: The Trojan Horse attack



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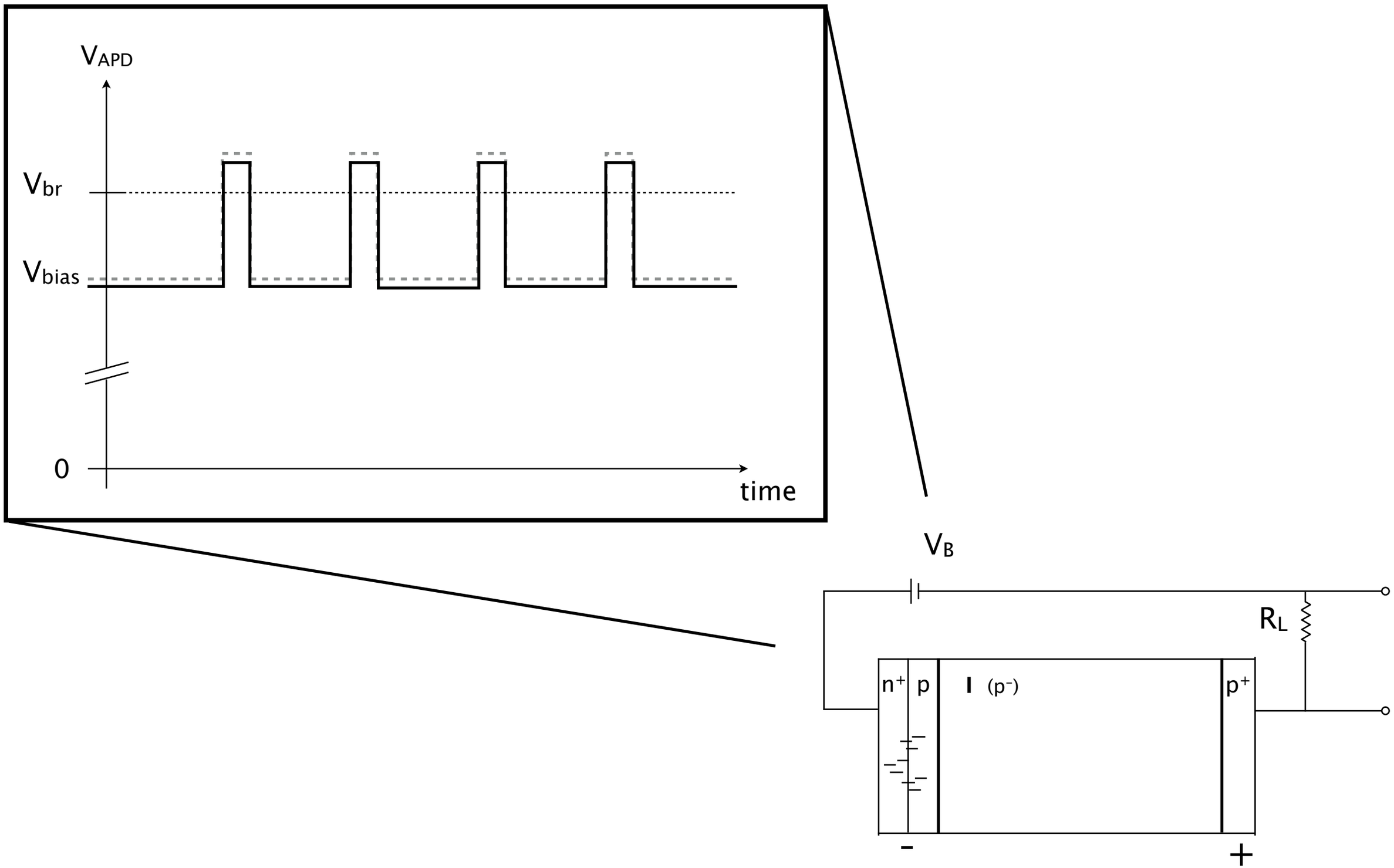

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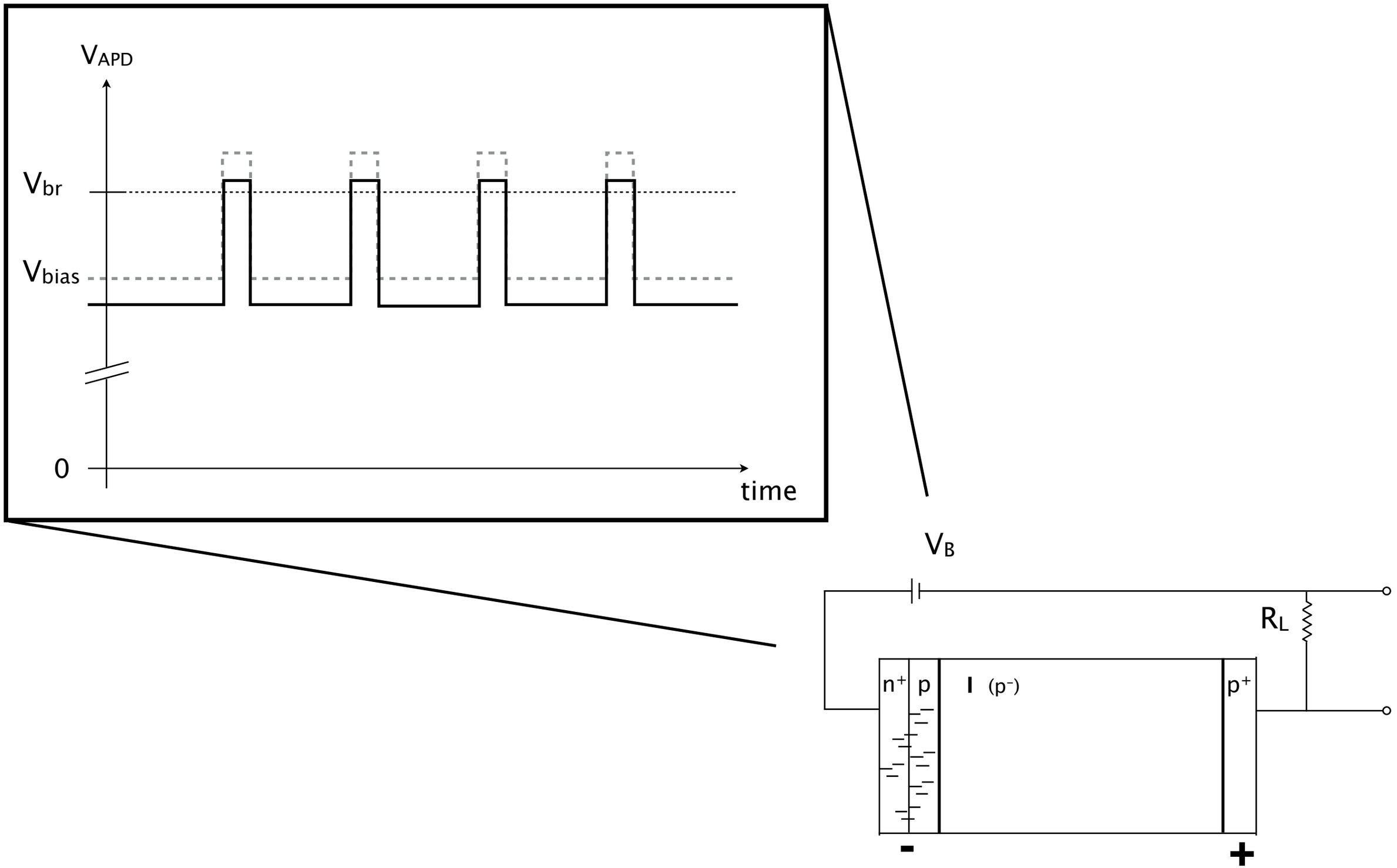

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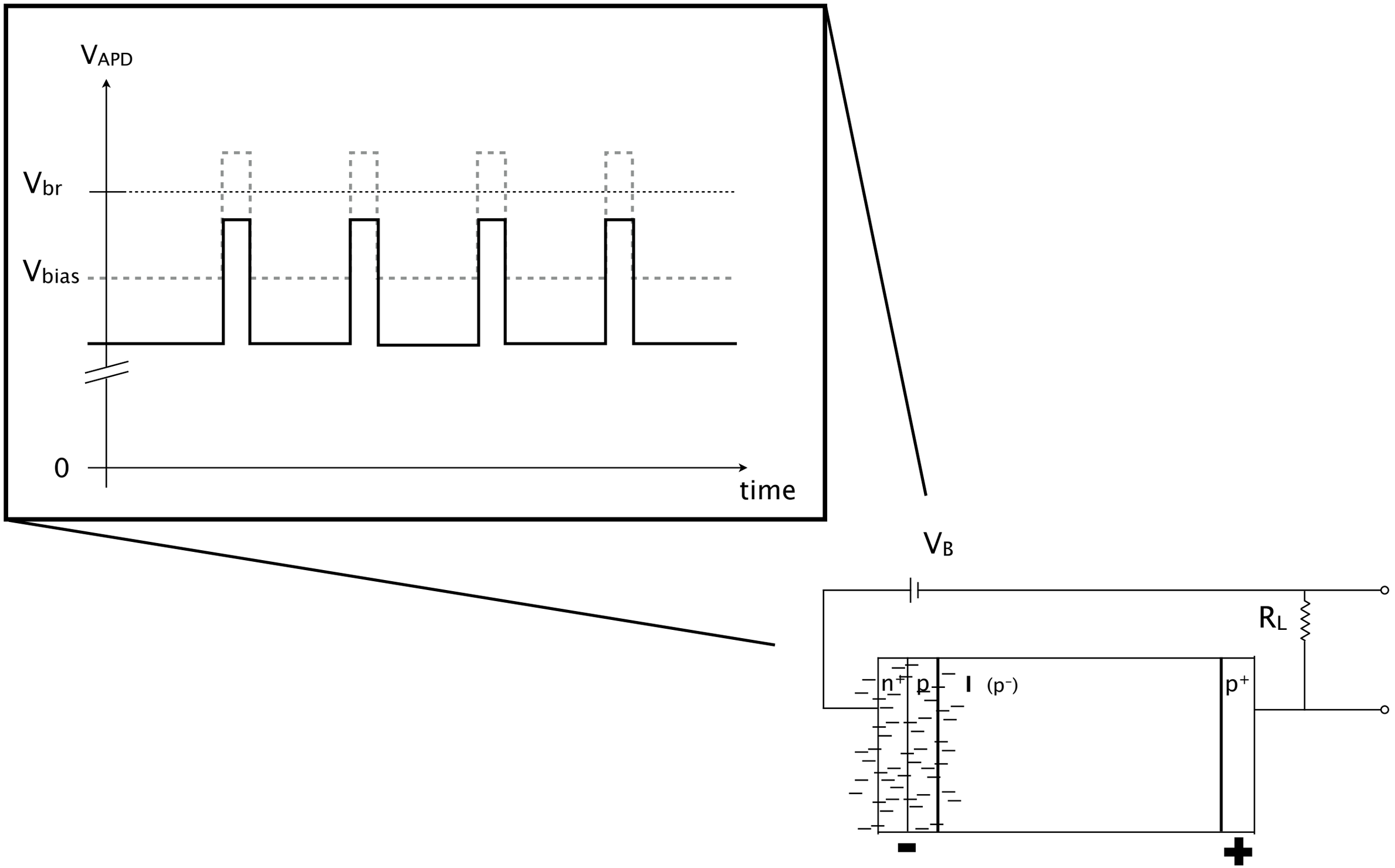

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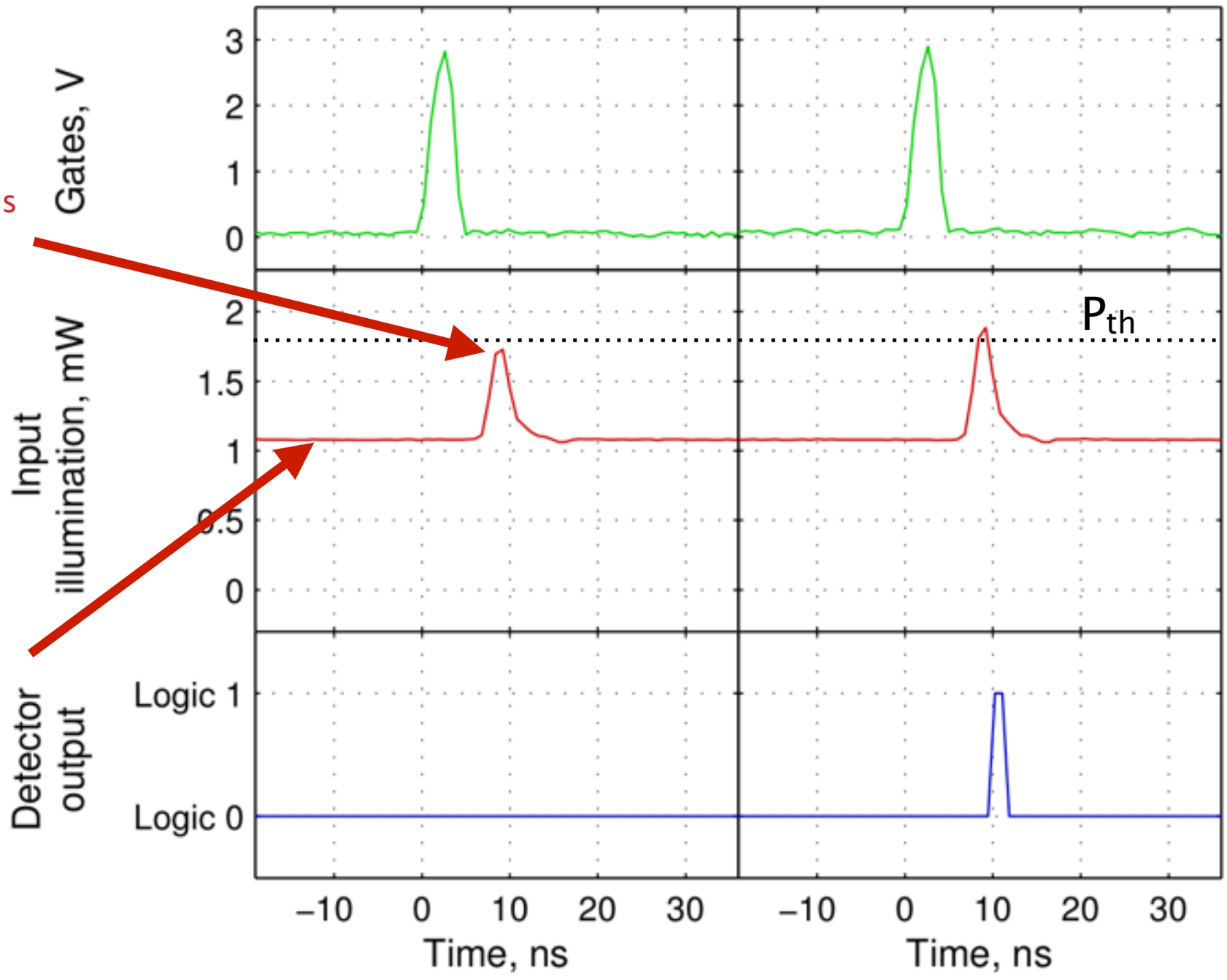
Example: The Trojan Horse attack

peek pulse, information is encoded in here



V_{bias}

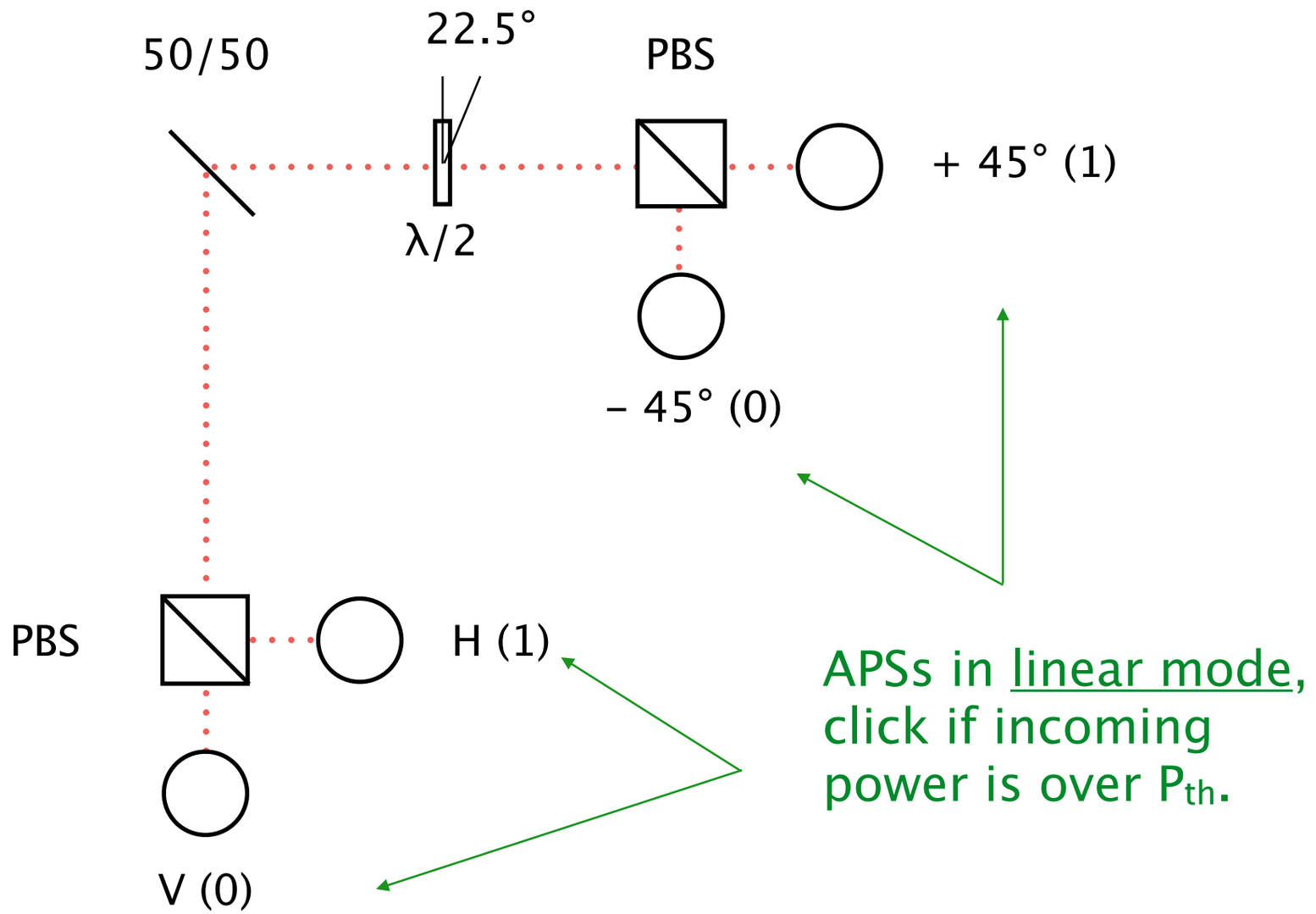
Eves input

Bobs output

constant illumination to keep APD in linear mode

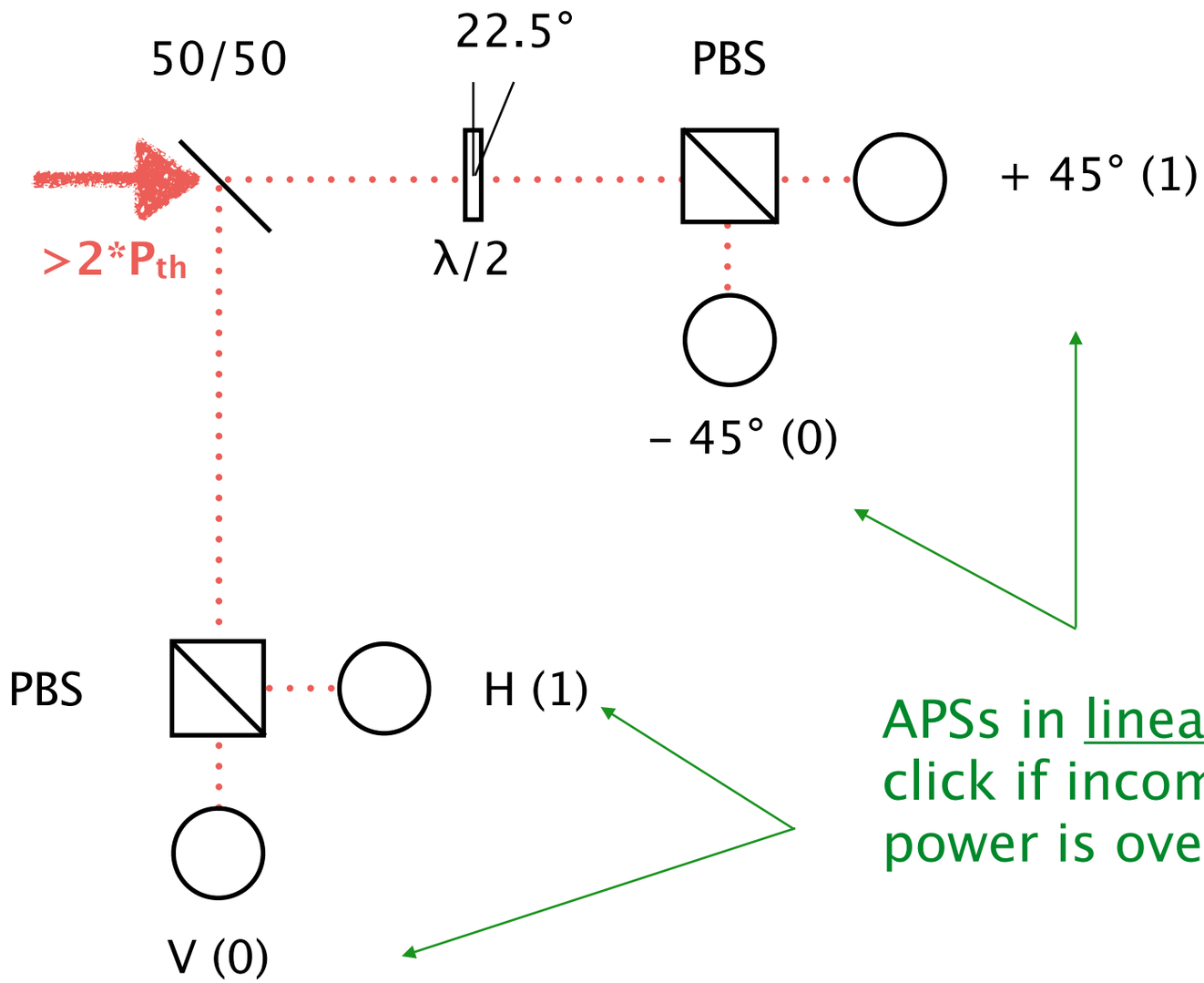
http://arxiv.org/pdf/1008.4593v2.pdf

Example: The Trojan Horse attack



Example: The Trojan Horse attack

Eve´s bright light pulse, e.g. „V“ in the basis „V/H“



APSs in linear mode, click if incoming power is over P_{th}.

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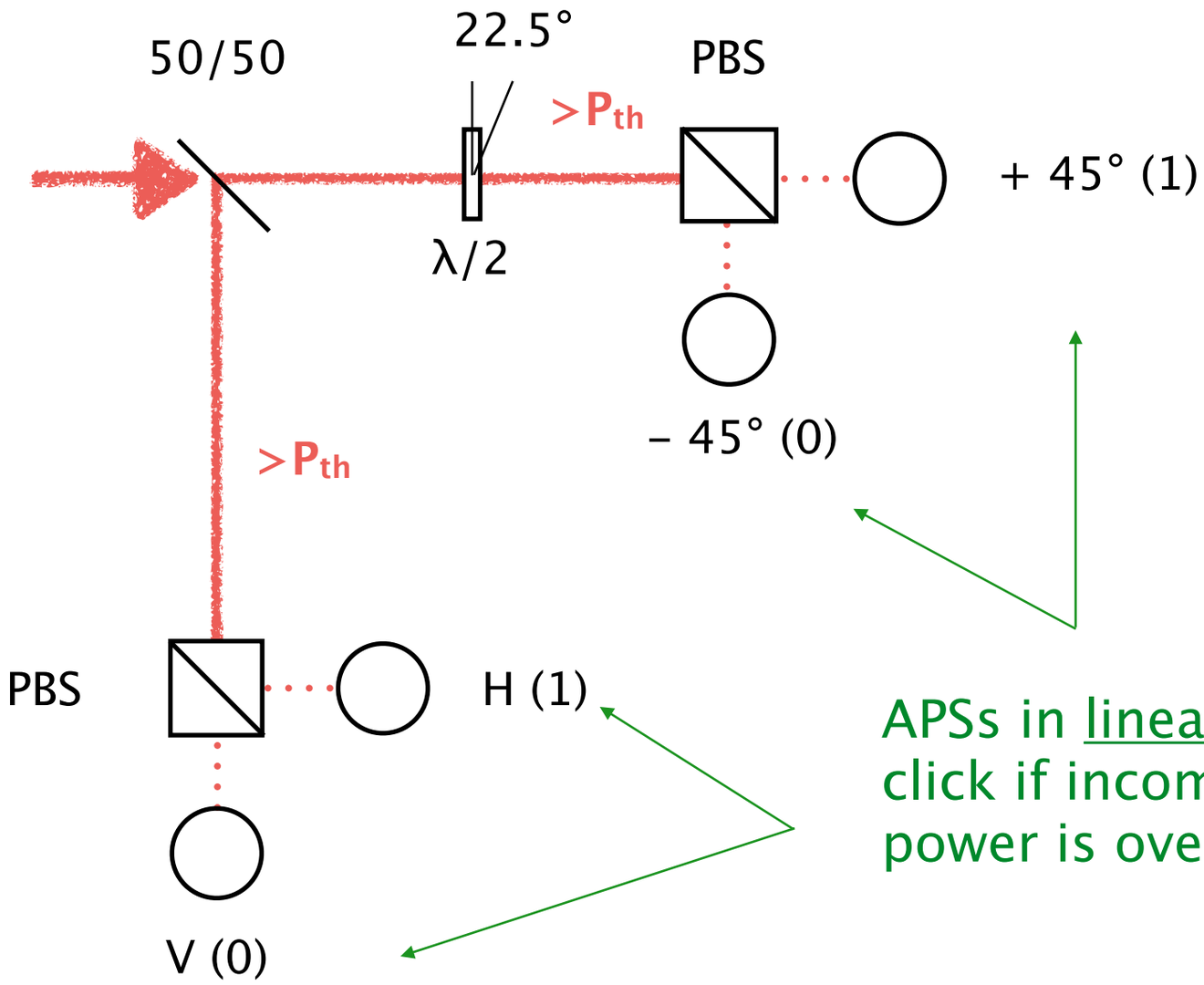

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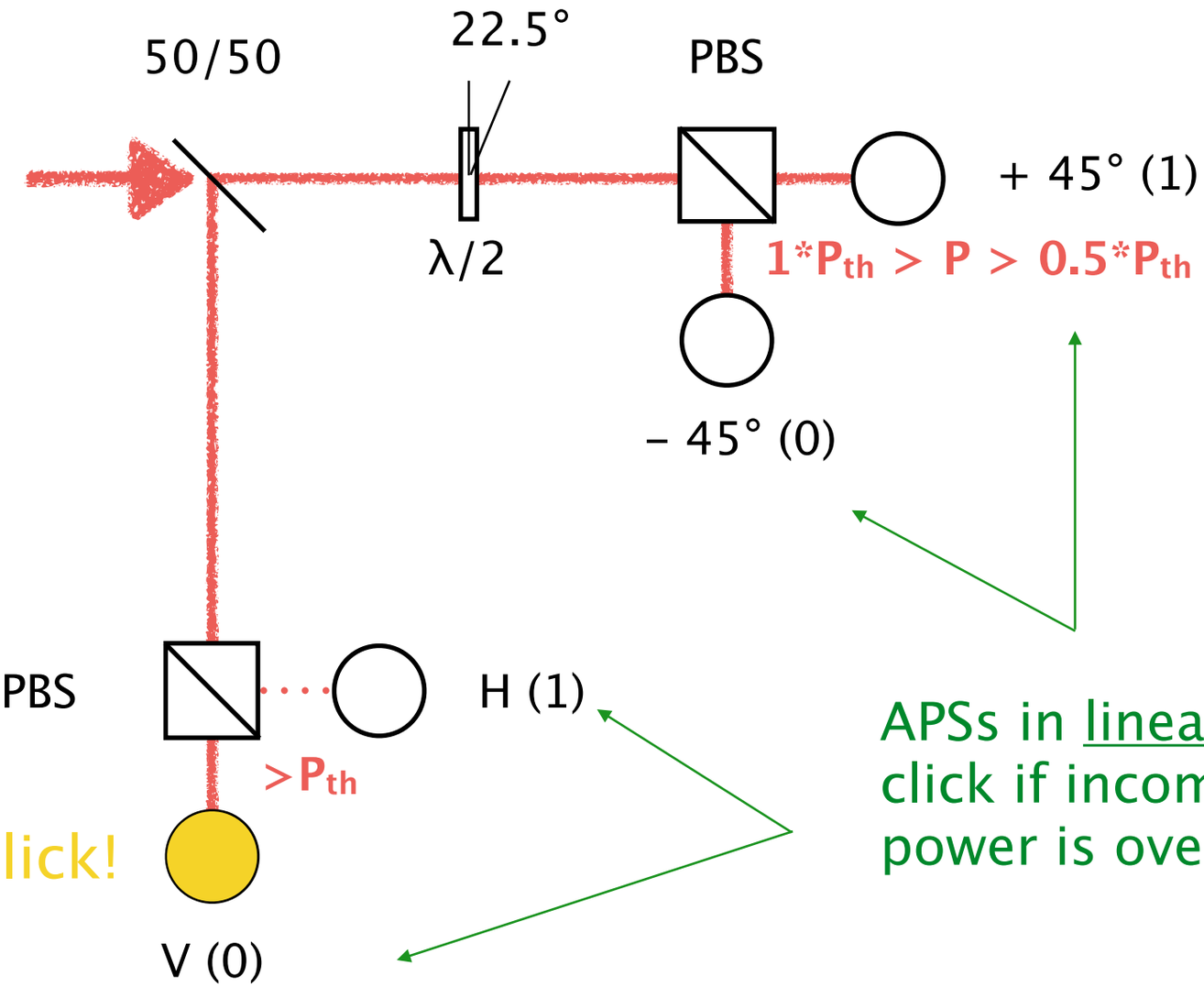

APSs in linear mode, click if incoming power is over P_{th}.

Conclusion

- QKD can be hacked in practice
- There is no prove, excluding any loophole
- The battle between encrypter and hacker still goes on

Questions?

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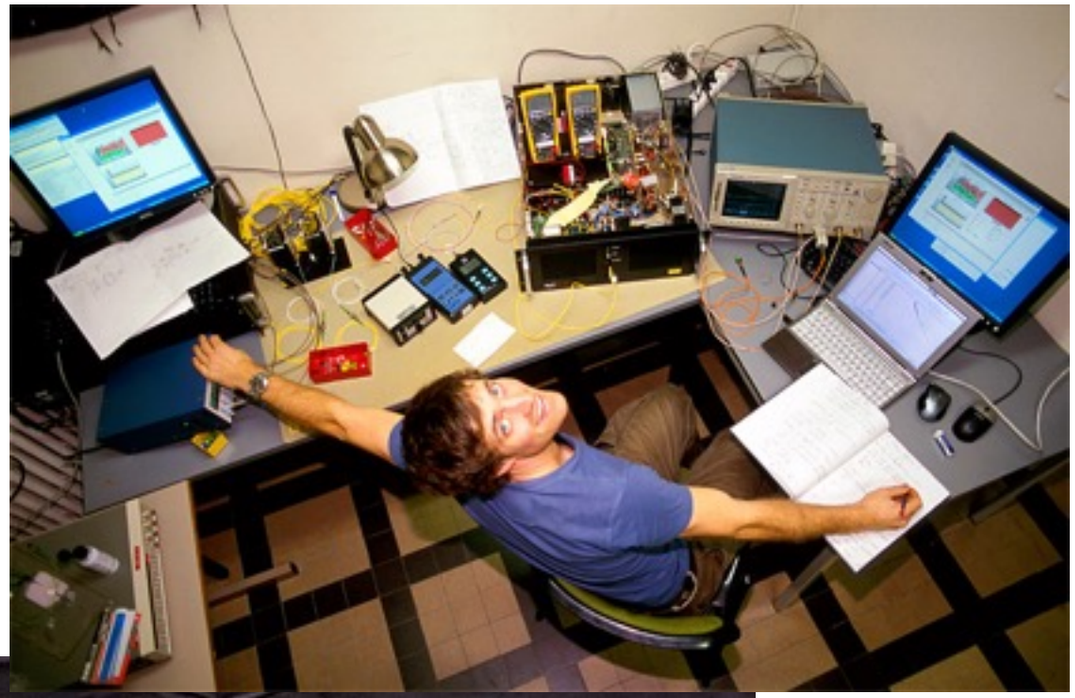

http://www.vad1.com/lab/hacking-commercial-quantum-cryptography-2010/