

Optically probing the detection mechanism in amorphous MoSi SNSPDs

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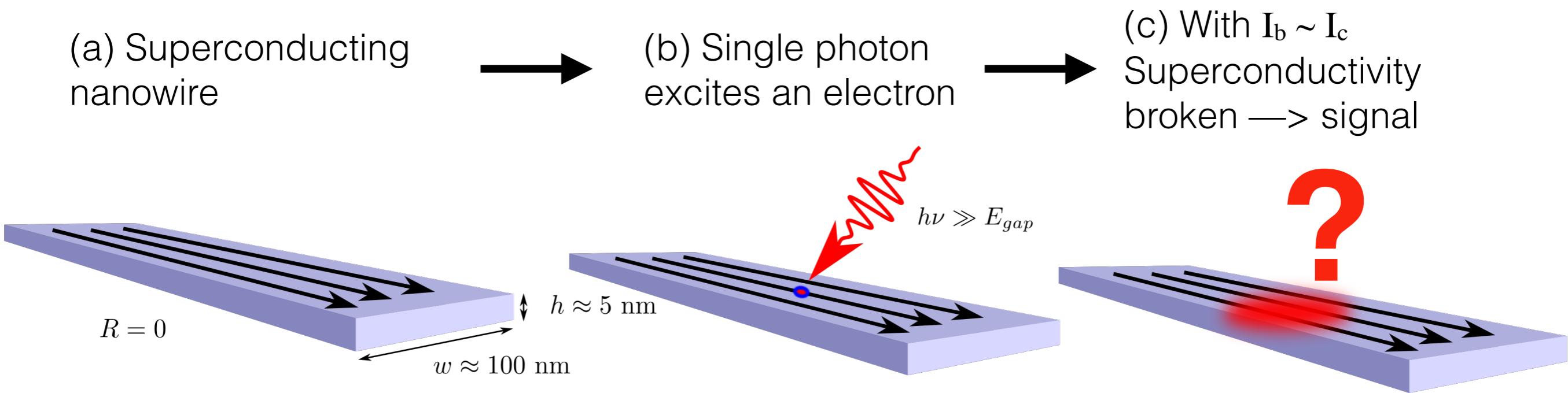
UNIVERSITÉ
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Collaboration



Introduction



Performances:

- High efficiency: ~93% at 1550 nm
- High repetition rate: >20 MHz
- Low jitter: < 20 ps
- Low DCR: < 10 Hz
- No after pulsing effect

still a challenge to combine all of them!

Motivation:

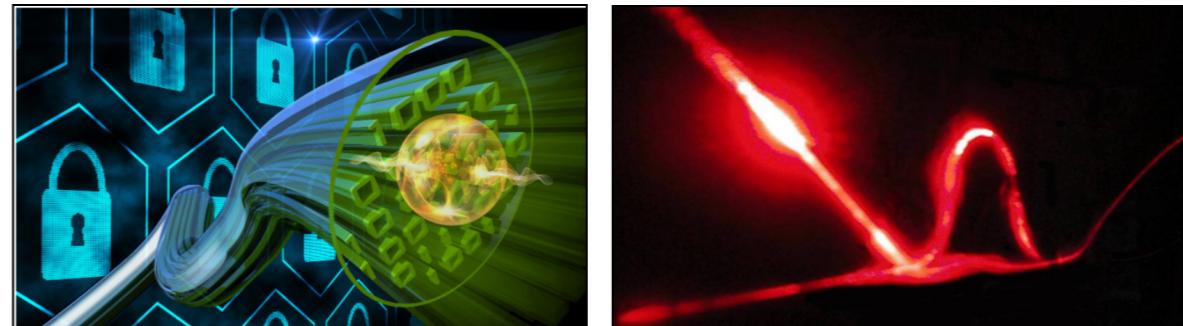
- Detection mechanism is still not completely understood
- Understand **fundamental limits**
- Reach **better performances**
- No extensive studies on amorphous **MoSi**

G. N. Gol'tsman et. al. *APL* **79**, 705 (2001)

SNSPDs in Geneva

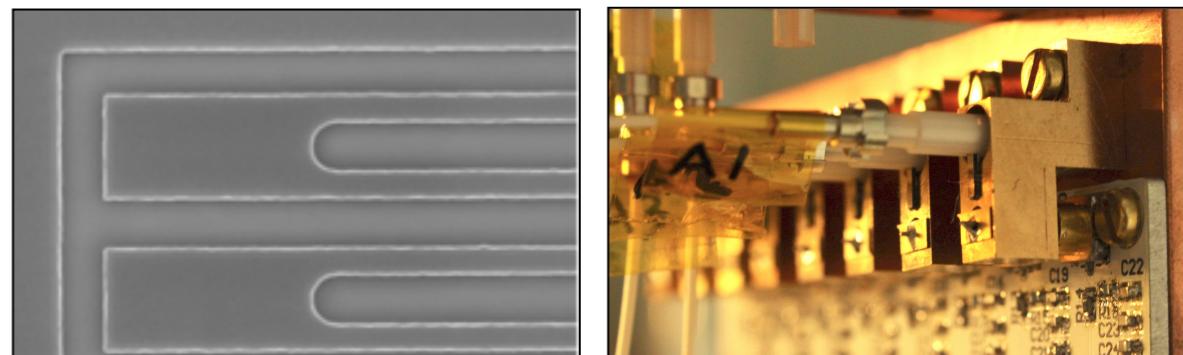
Some research themes in the group

- High-speed, long-distance **QKD** experiments
- Long-distance **quantum communication** in optical fibres
- High-performance **single-photon detection**
 - **direct integration** in the group experiments



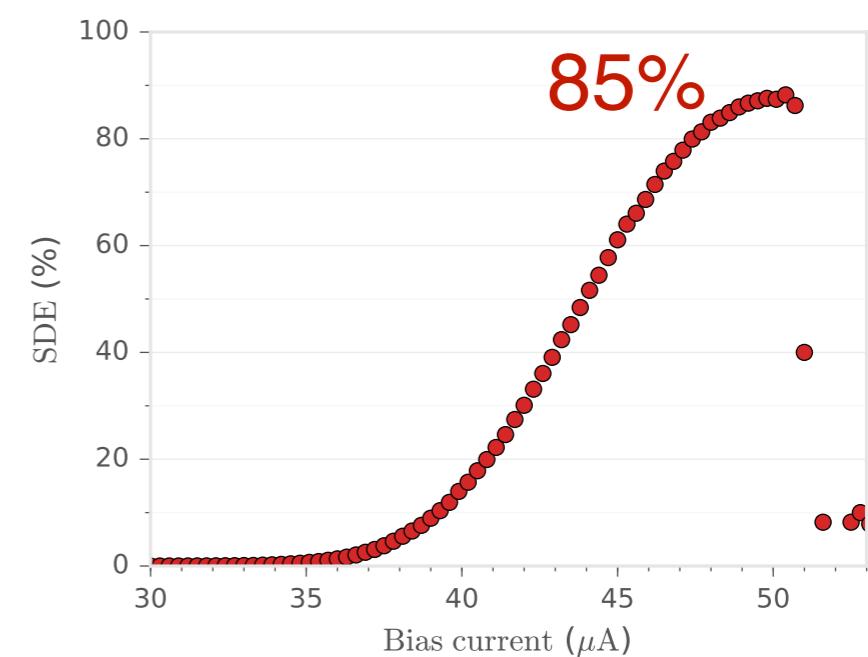
SNSPD development in 3 years

- Developed a **high-yield** fabrication process based on amorphous **MoSi**
- **Complete system:**
 - electronics
 - packaging
 - cryostat



We now achieve

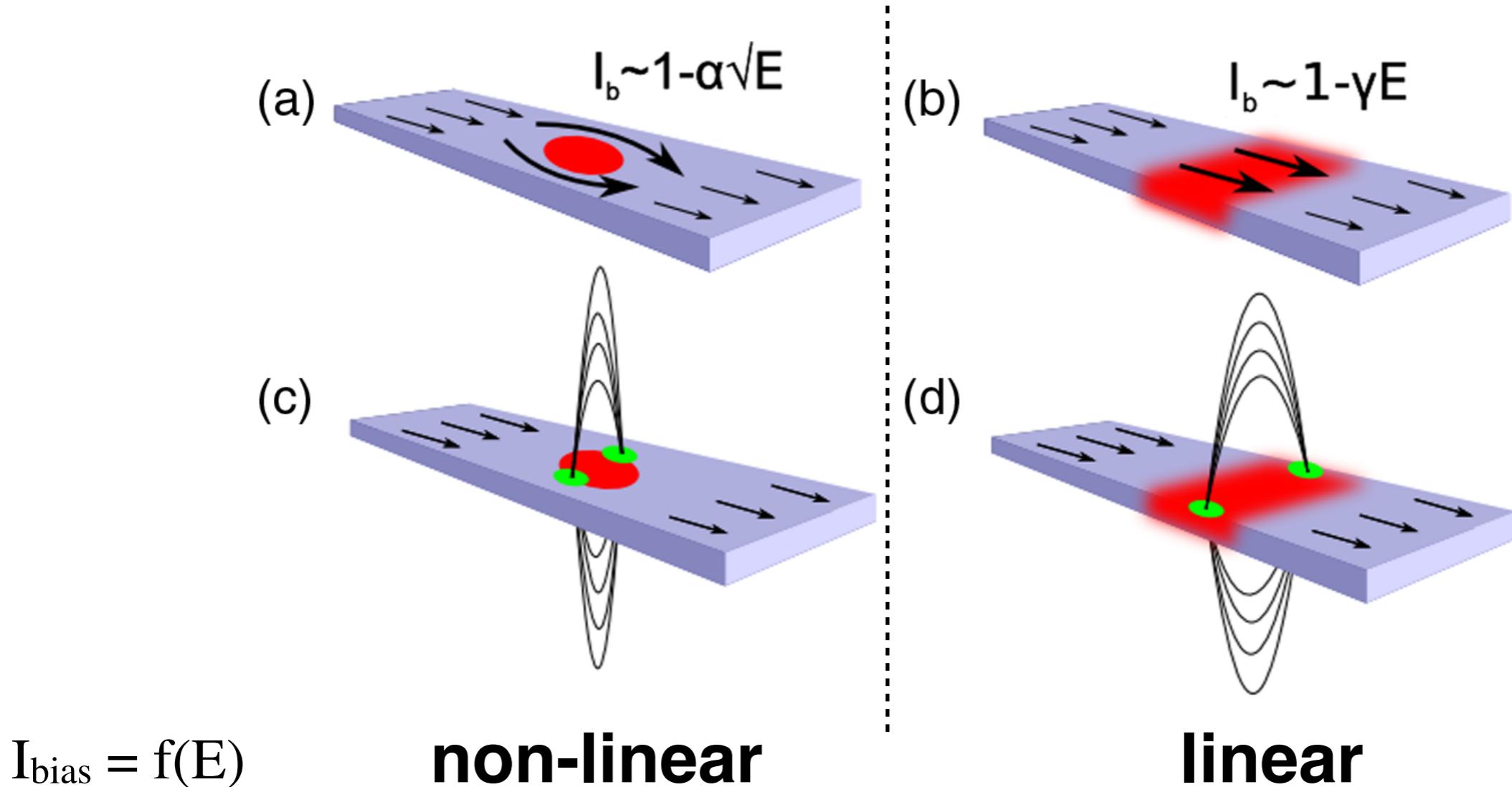
- System detection efficiency: **> 80%**
- **Jitter < 30 ps**
- Counting rate **> 10 MHz**
- DCR **< 10 Hz**



Detection models

How to probe the detection mechanism:

- **Energy-current relation**, $I_{\text{bias}} = f(E)$
- **Vortex** assisted mechanism



J. Renema et. al. *PRL* **112**, 117604 (2014)

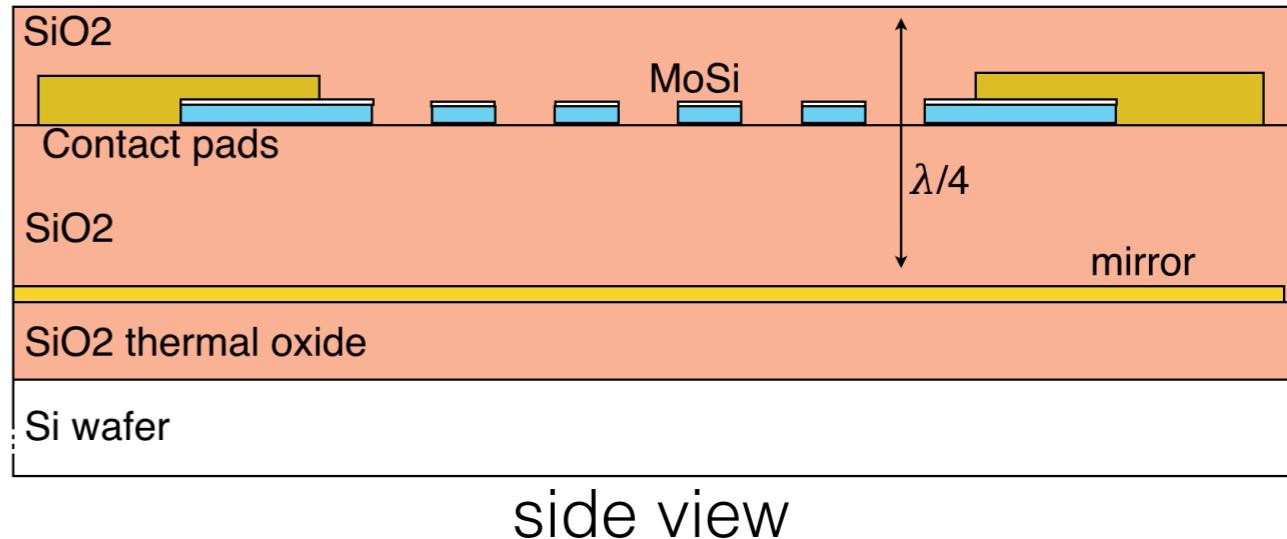
D. Vodolazov, *Phys. Rev. Applied* **7**, 034014 (2017)

A.G. Kozorezov et. al. *PRB* **96**, 054507 (2017)

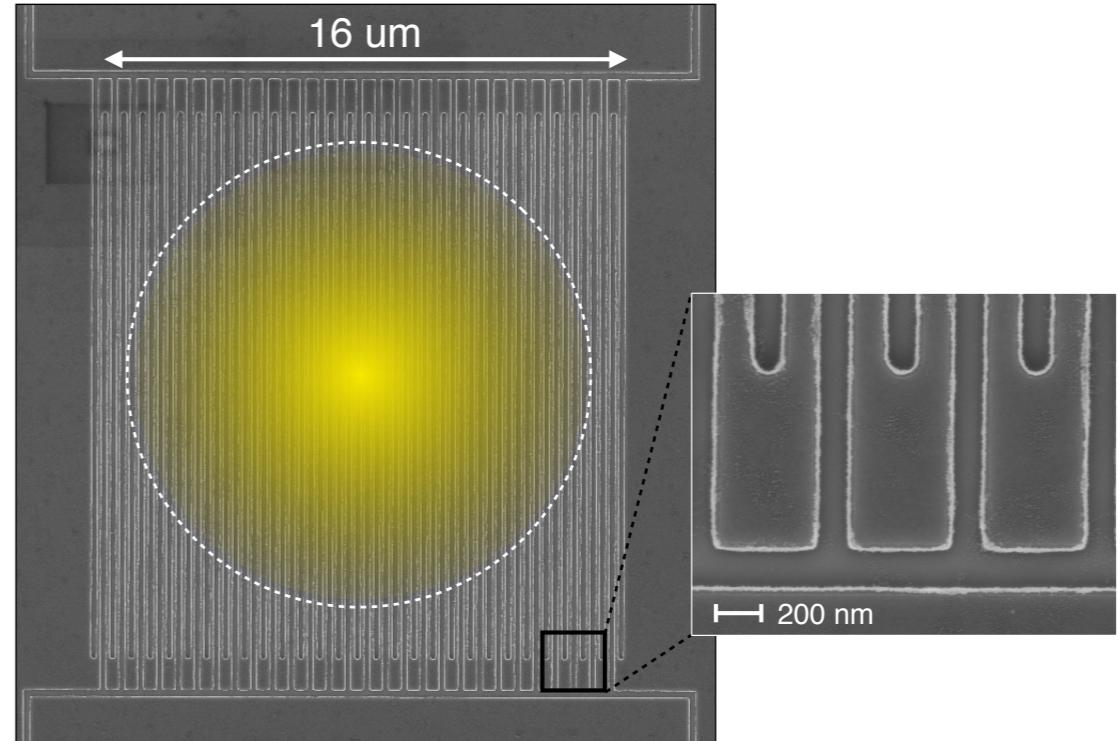
Nanofabrication

Molybdenum silicide:

- $\text{Mo}_{0.8}\text{Si}_{0.2}$: **5-7 nm** thick film by co-sputtering deposition
- **Different design:**
 - nanowire widths
 - fill factor
 - SNAP, spiral, etc...
- **Single layer** optical cavity (no TiO_2)
- $16 \times 16 \mu\text{m}^2$ area
- Self aligned package technique

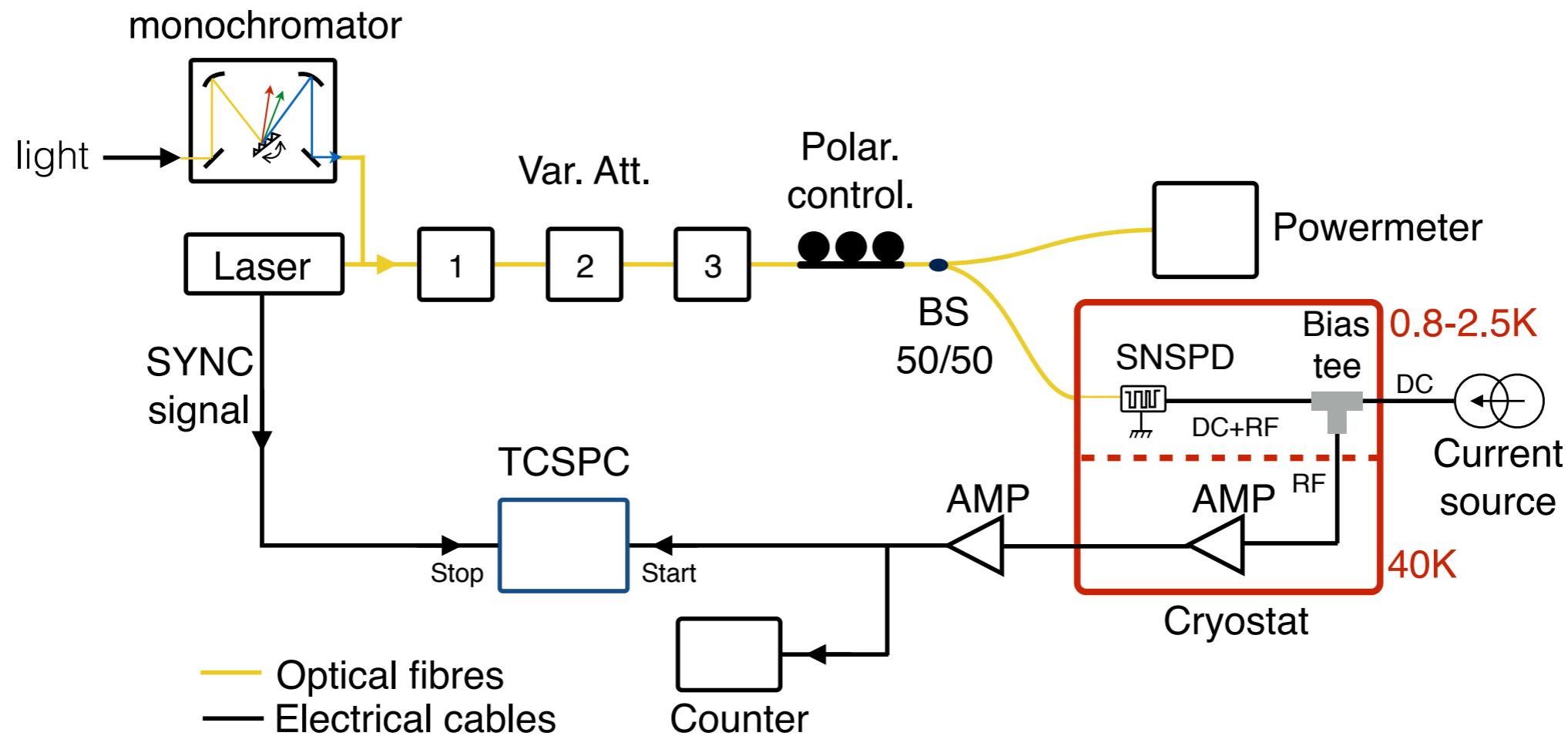


side view



top view

Probing the detection mechanism



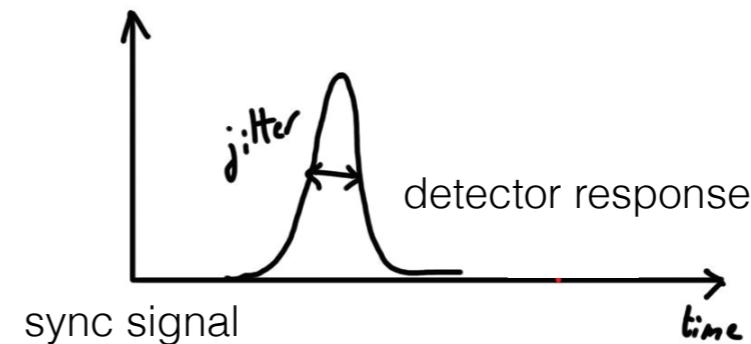
Photon count rate

- Unpolarized CW light from halogen lamp
- Calibrated monochromator:
 $\lambda : 550 \rightarrow 2050 \text{ nm}$

$$f(I_{\text{bias}}) = \text{PCR} - \text{DCR}$$

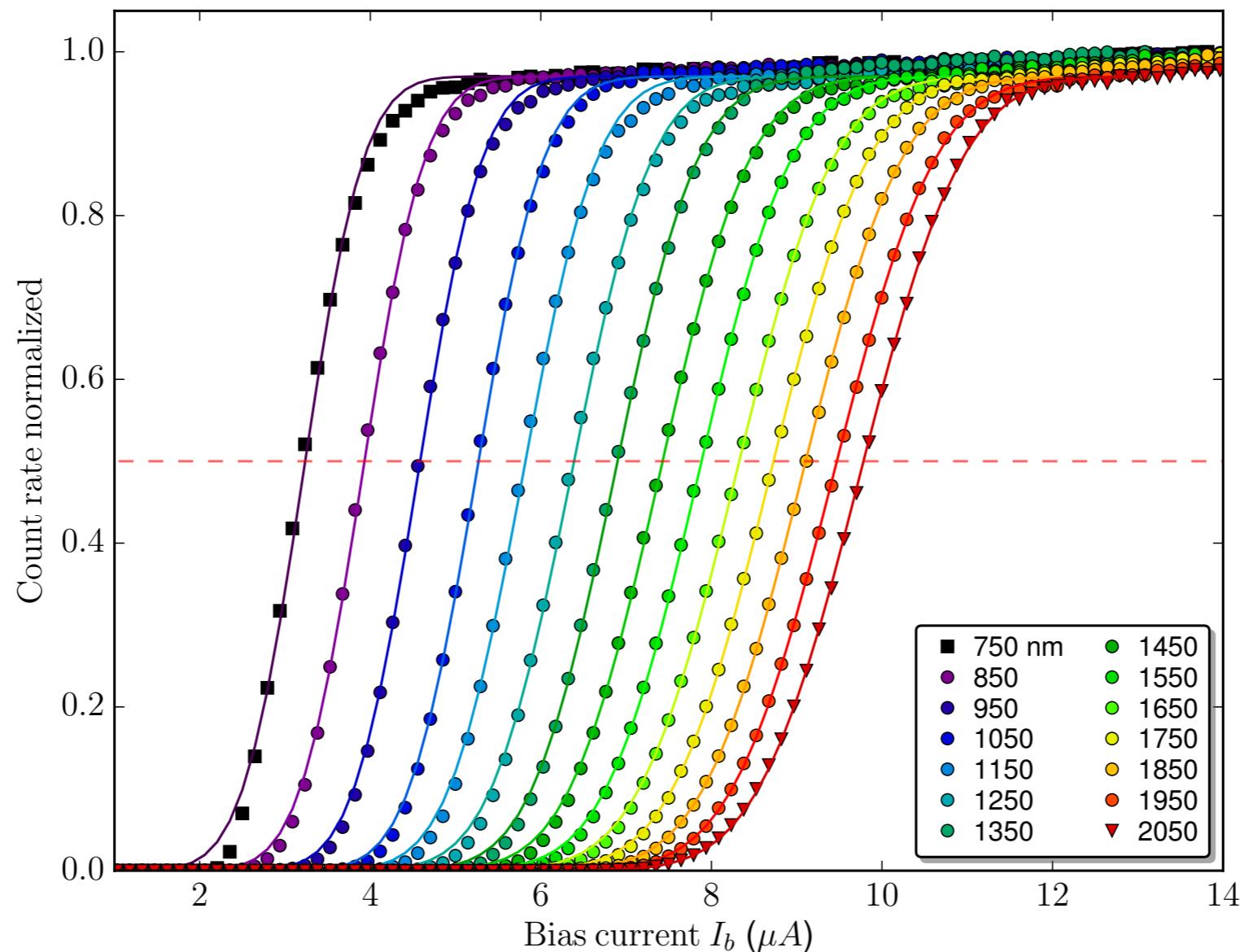
Jitter

- Constant fraction discriminator (CFD)
- 6 ps laser pulses, 1550 nm



Photon count rate

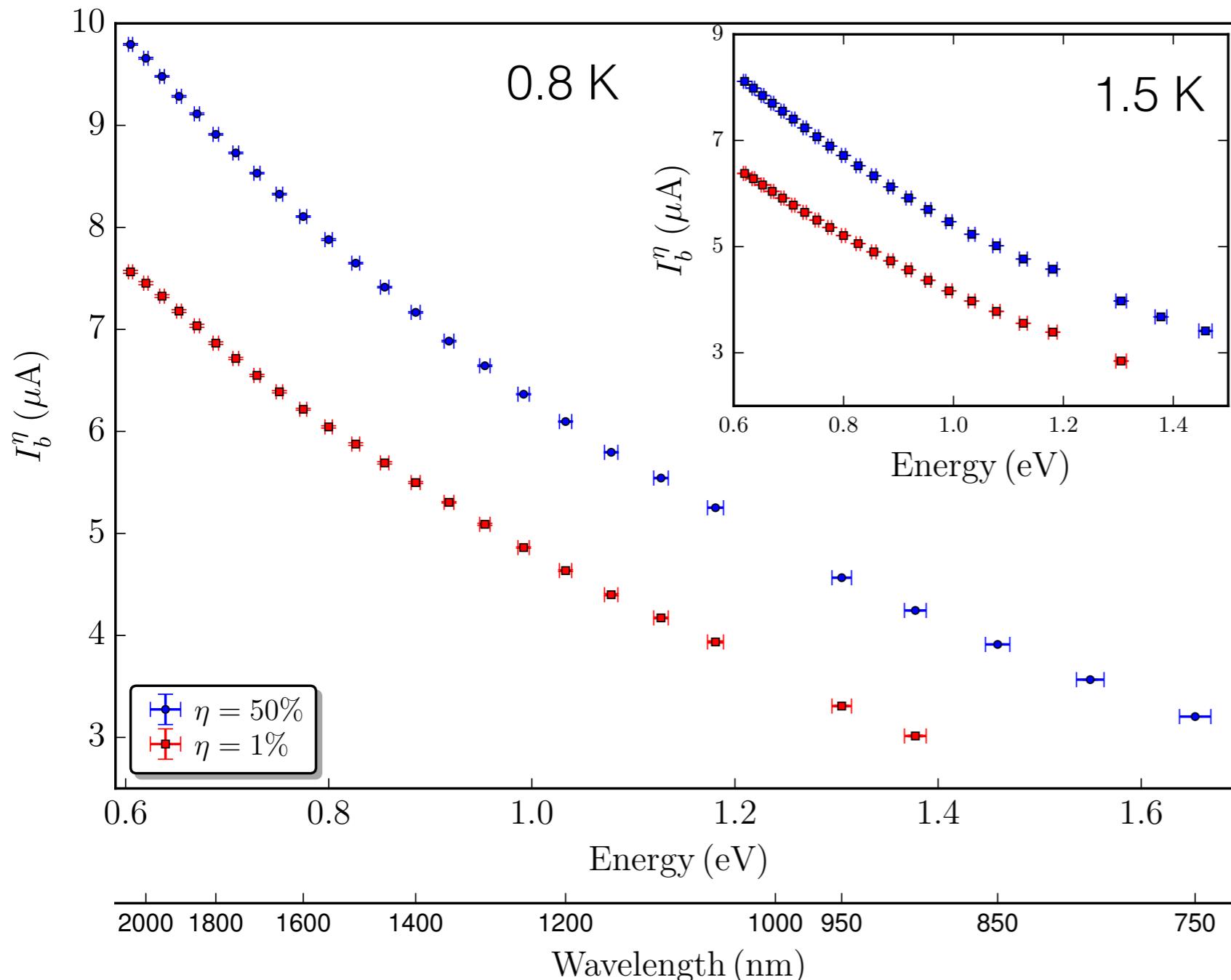
- **First study** with a **plateau** over the full range of energies (unique to MoSi and WSi)
- **All information** on the detector behavior
- If the photon deposits more energy when absorbed —> less bias current needed
- Discriminator settings limits to 750 nm



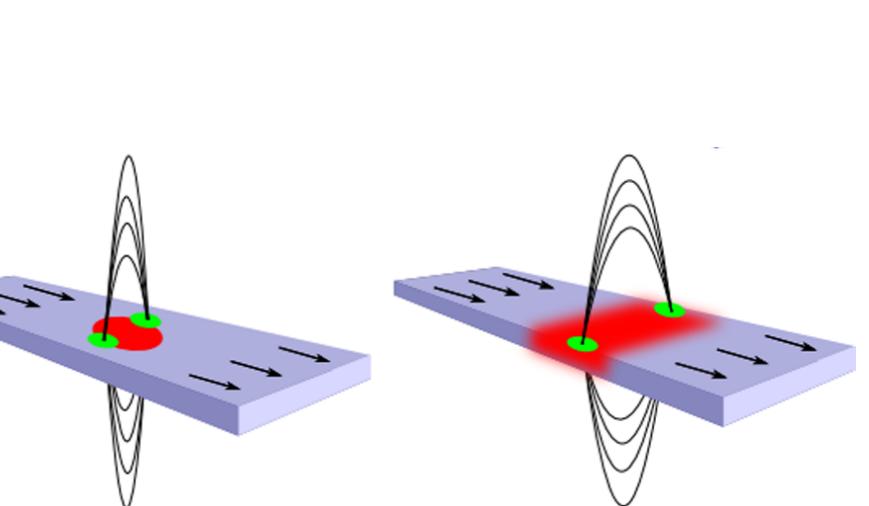
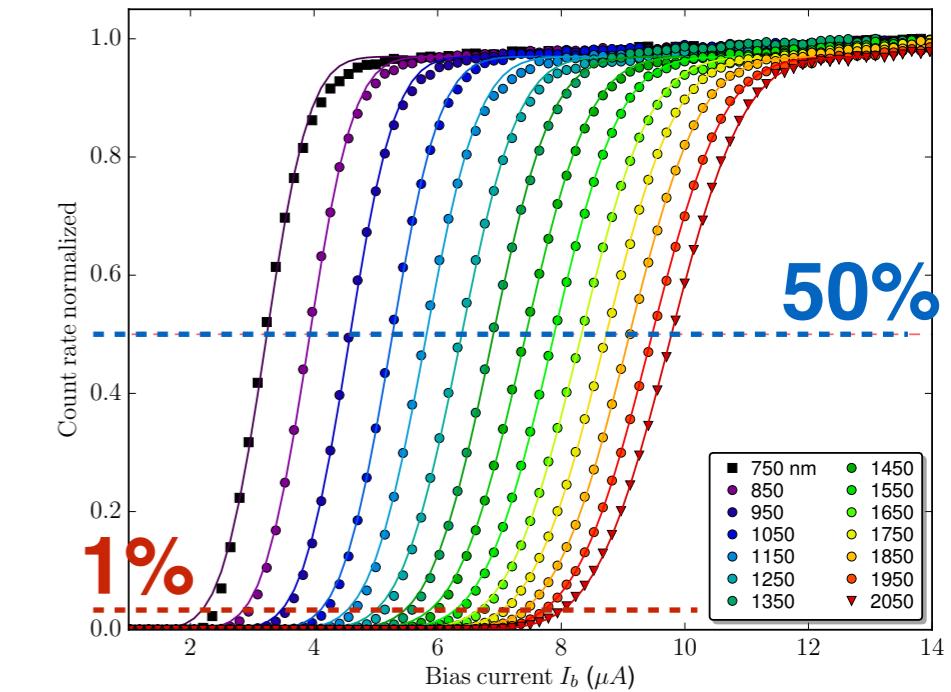
M. Caloz et al. *APL* **110**, 083106 (2017)

Photon count rate

- **Non-linear** over the full energy range
- Other temperature measurement



M. Caloz et al. *APL* **110**, 083106 (2017)



→ **Diffusion alone is not sufficient !**

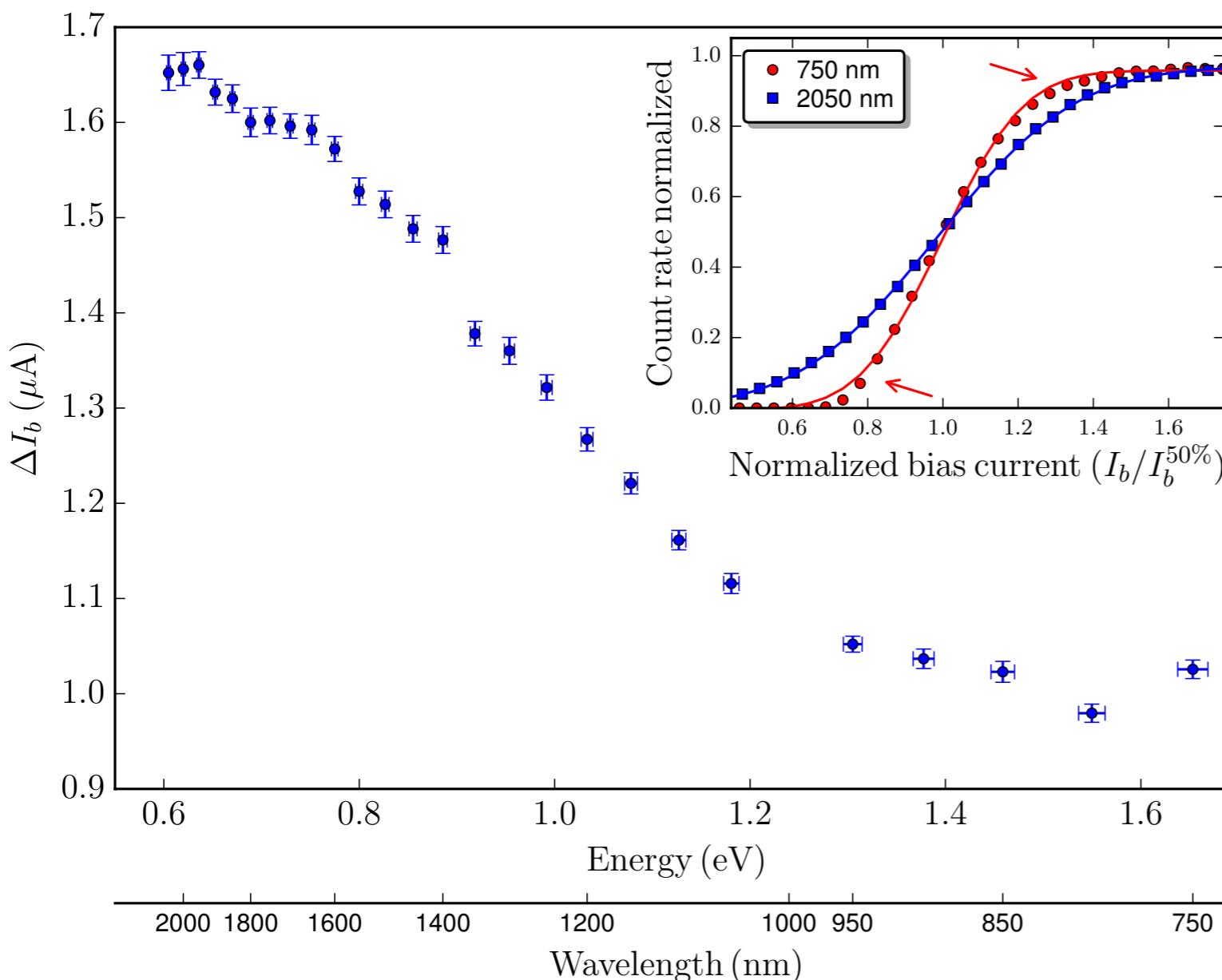
A.G. Kozorezov et. al.
PRB **96**, 054507 (2017)

Photon count rate

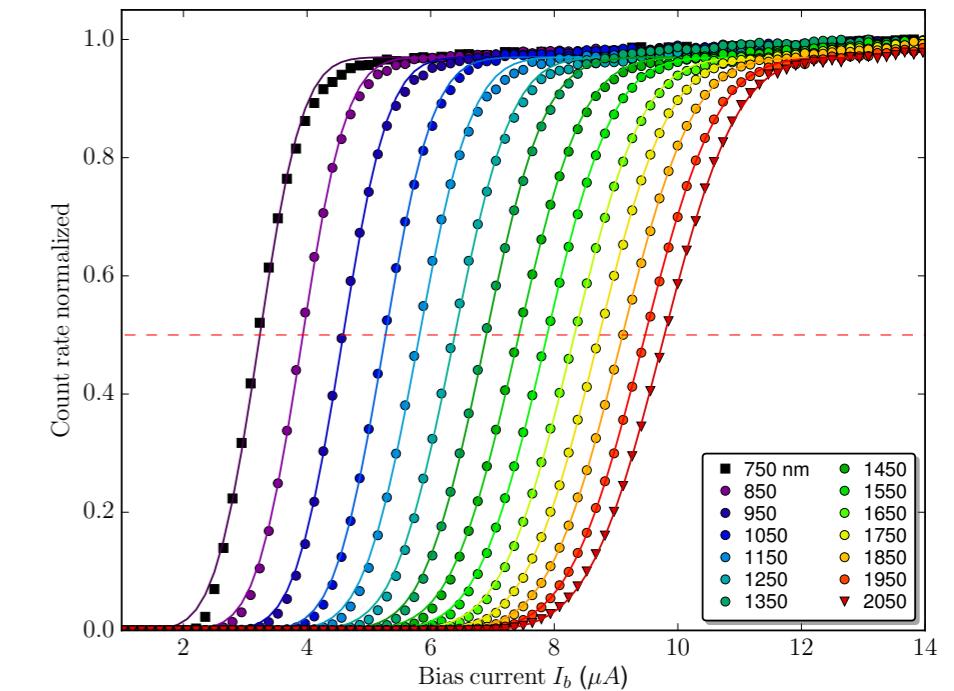
Transition width

$$\Delta I_b = I_b^{80\%} - I_b^{20\%}$$

- possible thanks to the **large plateau** region



M. Caloz et al. *APL* **110**, 083106 (2017)



- **50% reference value**
- Error function fits
- ▶ Fano fluctuations: number of quasiparticle fluctuates
- ▶ position dependent effect ?
- **New intrinsic** parameter to give input to the theory

A.G. Kozorezov et. al.
PRB **96**, 054507 (2017)

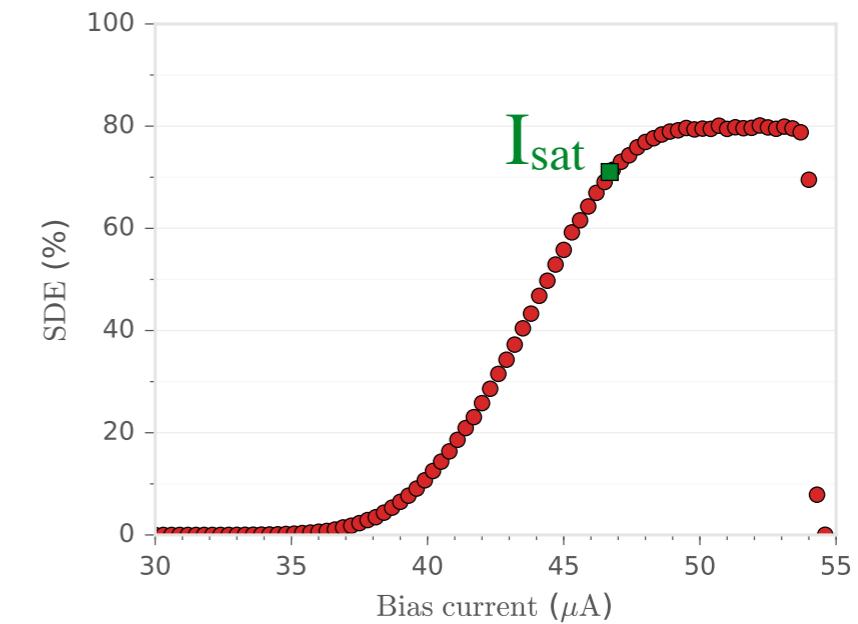
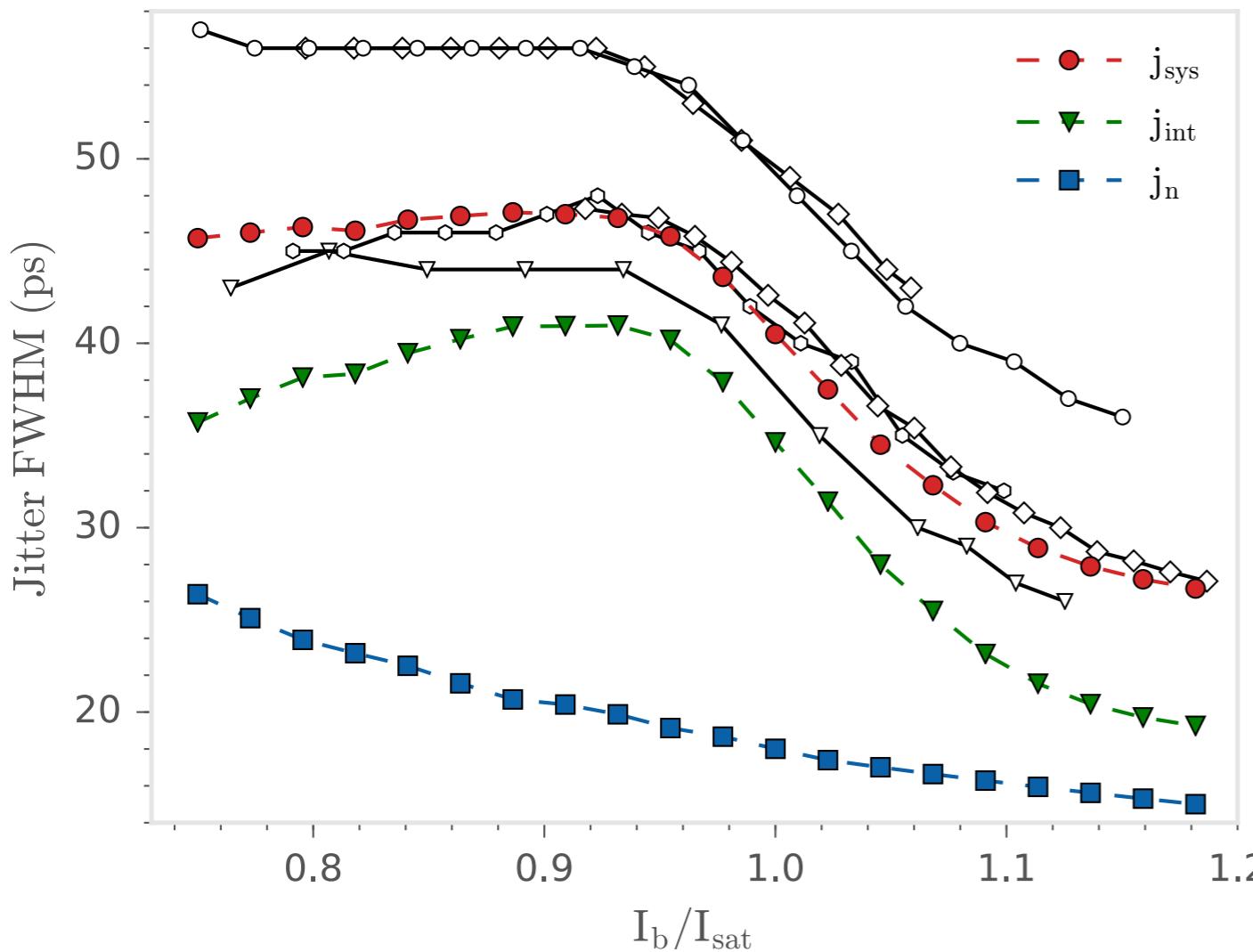
Jitter

Probing the detection mechanism with jitter measurement

- Intrinsic jitter is directly related to the hotspot dynamics

$$j_{\text{system}} = \sqrt{j_{\text{noise}}^2 + j_{\text{setup}}^2 + j_{\text{intr}}^2} \quad j_{\text{intr}} = \sqrt{j_{\text{hotspot}}^2 + j_{\text{geometric}}^2}$$

- possible thanks to 7 nm thick MoSi
 - high bias current operation → better SNR → jitter is not dominated by the noise

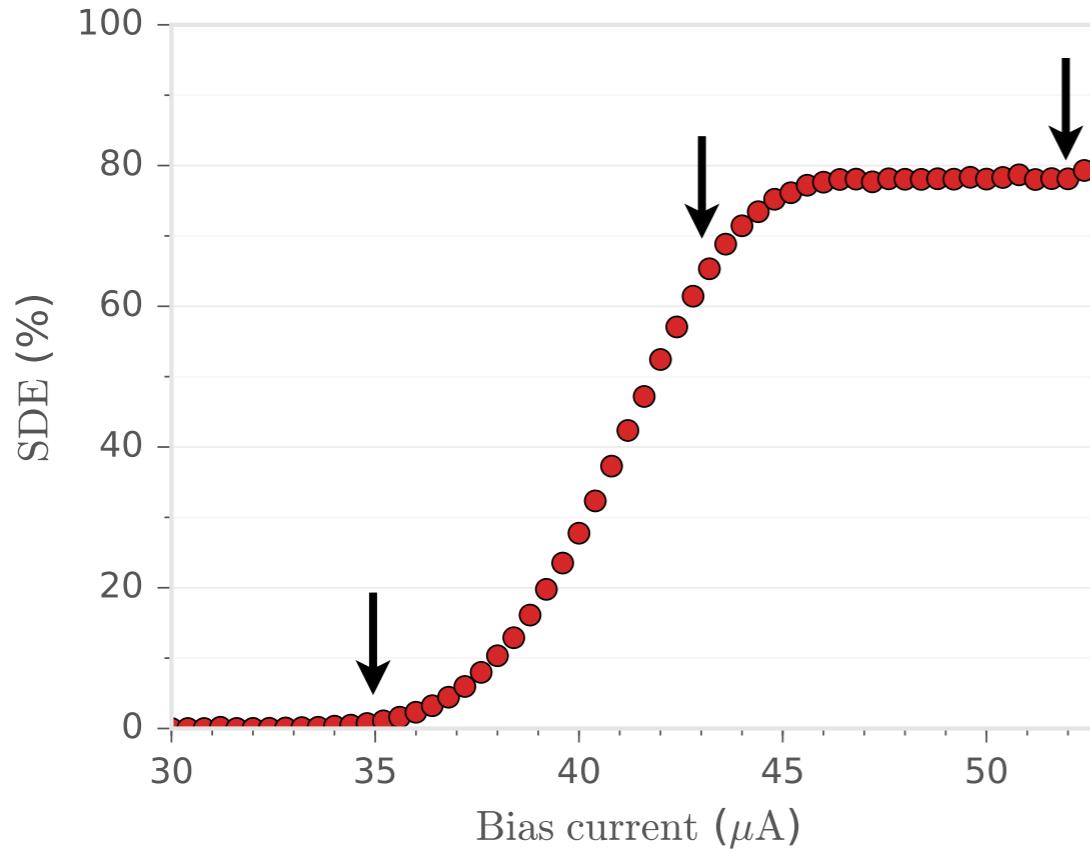


- MoSi meandered devices can have **very low jitter: 26 ps !**
- Same behavior for different designs
- This evolution is due to the **intrinsic jitter**

Jitter

Non-gaussian tail

- current dependent

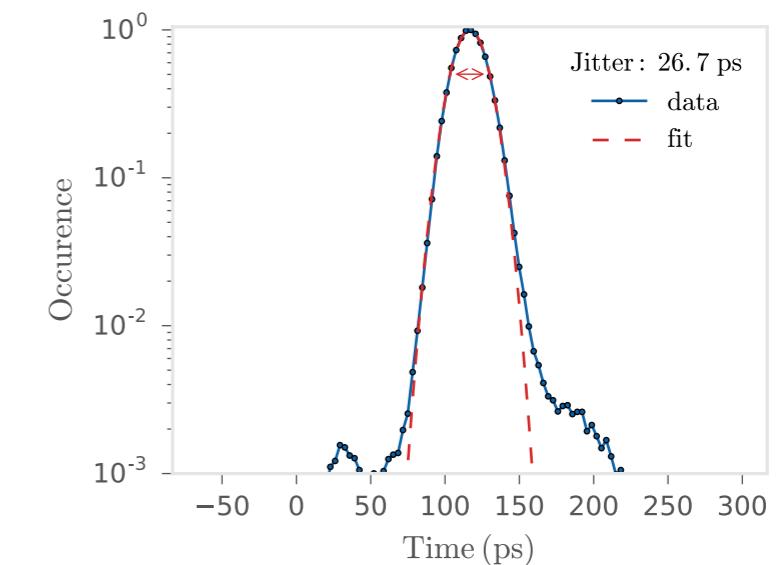
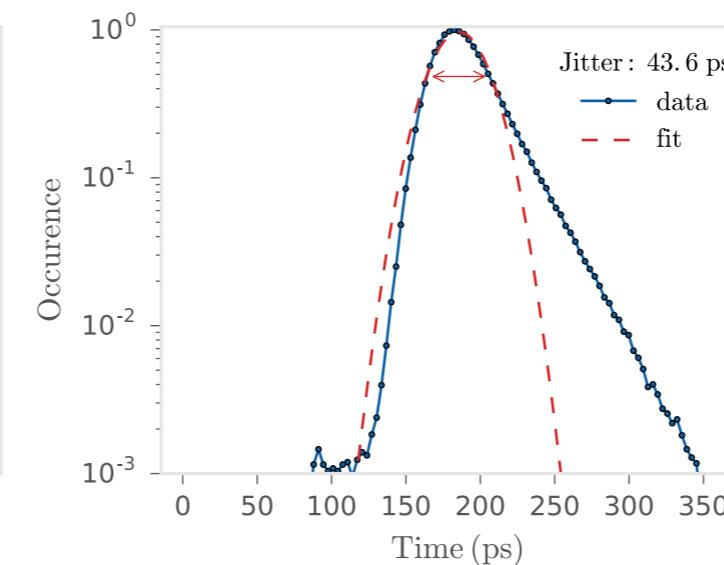
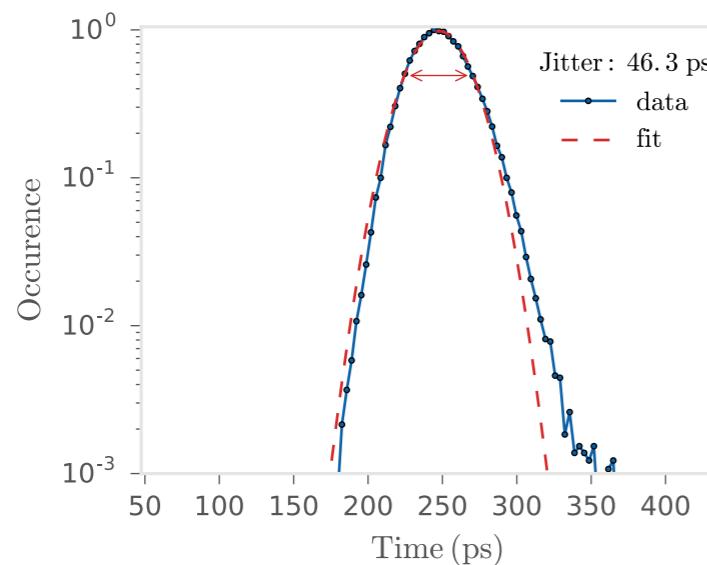


$$j_{\text{system}} = \sqrt{j_{\text{noise}}^2 + j_{\text{setup}}^2 + j_{\text{intr}}^2}$$

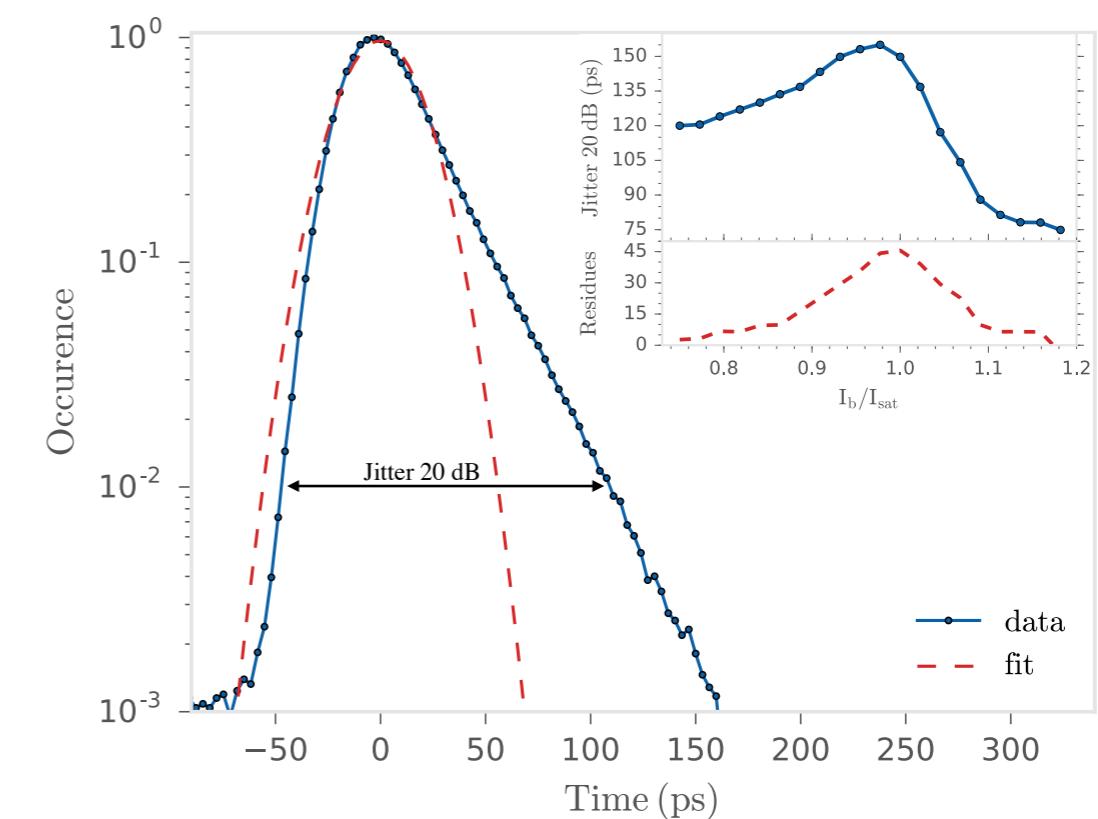
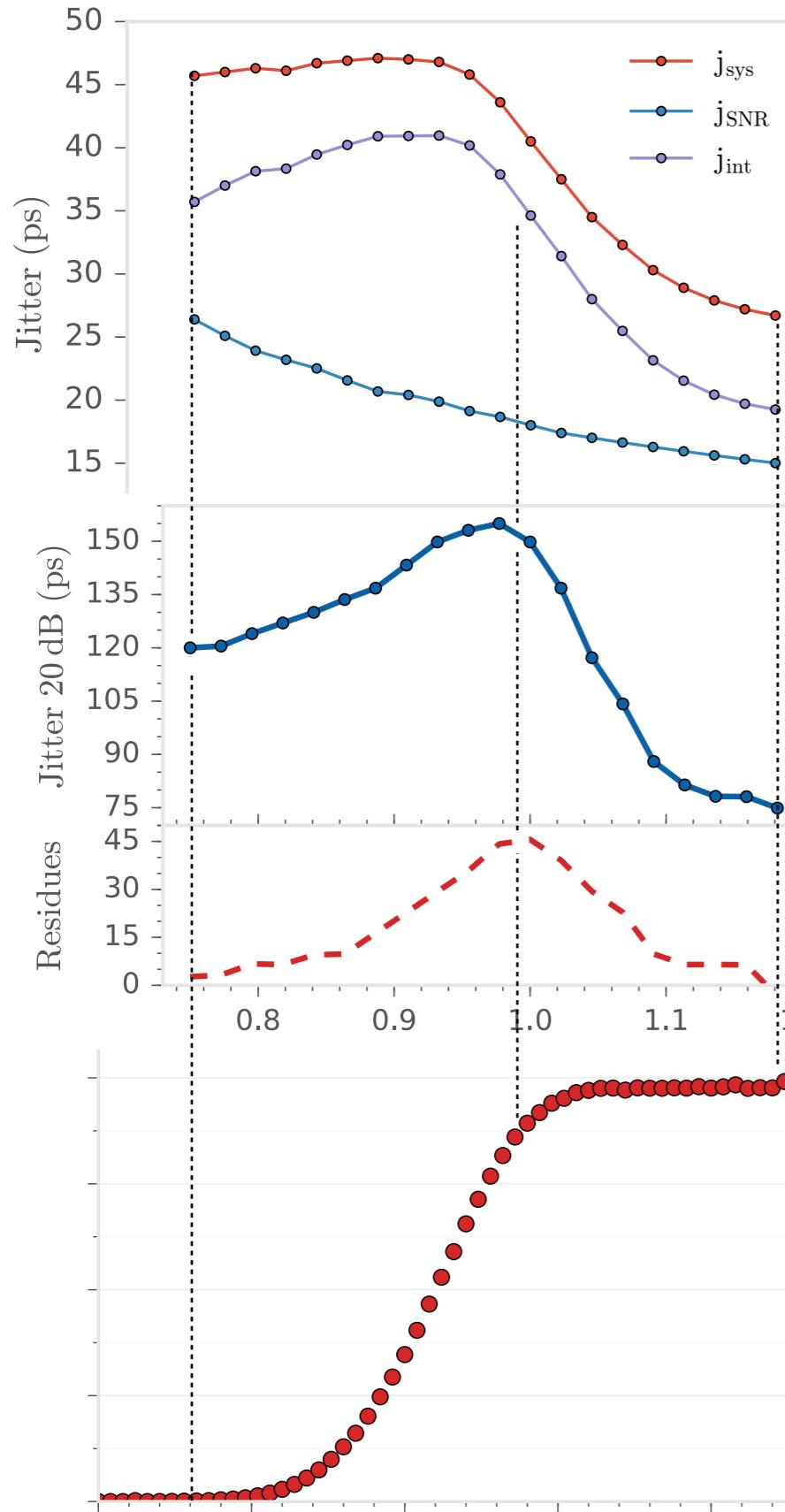
gaussian

The equation shows the total jitter j_{system} as the square root of the sum of the squares of three components: j_{noise} , j_{setup} , and j_{intr} . A horizontal line represents a Gaussian distribution, with two blue arrows pointing to it from the left and right, labeled "gaussian".

- All other contributions are gaussian
→ non gaussian tail due to **intrinsic behavior**



Jitter



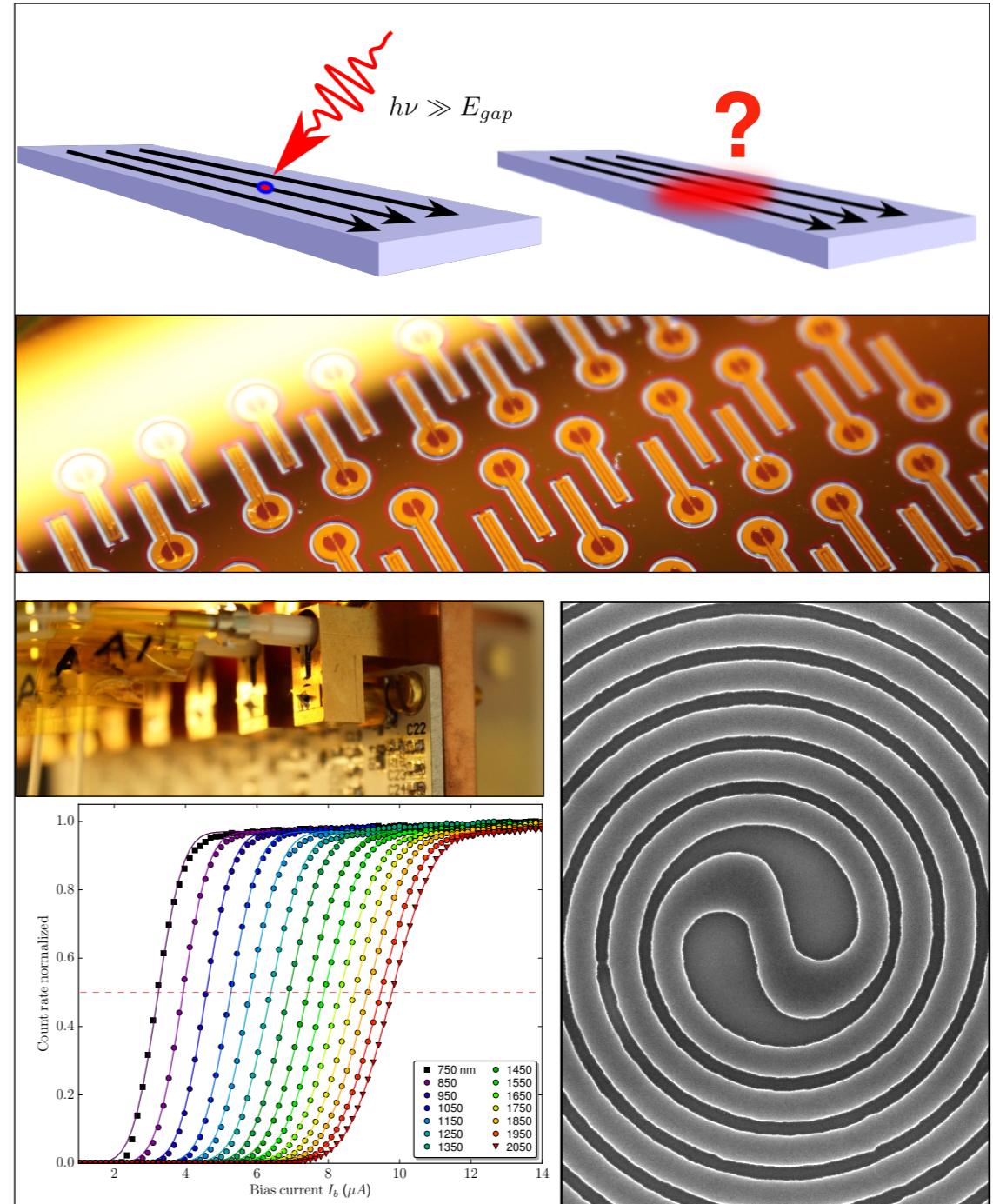
- Residues maximum $\sim I_{\text{sat}}$
- Even in the deterministic region (plateau), the jitter (3 and 20 dB) **decrease a lot**
- **intrinsic limitations ?**
- Measurement at lower wavelengths would be very interesting: probing far in the plateau
- Nice measurement to study the **detection mechanism**

M. Caloz et al. *to be submitted*

Conclusion

Main points:

- PCR with a **large plateau**
 - **All detector information**
 - **Non-linear** energy-current relation
 - QP diffusion only is not sufficient to explain our data
 - opportunity to reveal new intrinsic parameter
- Jitter measurement
 - **great improvement** for amorphous material
 - studying the intrinsic jitter behavior
- Experimental data with MoSi
 - **give inputs to theorists**



The team



Hugo Zbinden



Félix Bussières



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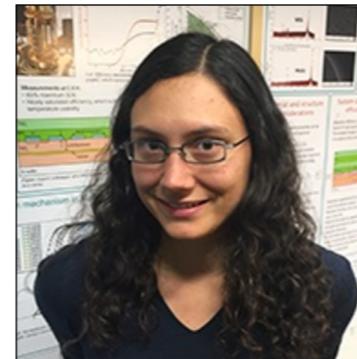
now at JPL



Misael Caloz



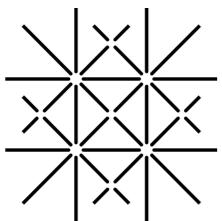
Matthieu Perrenoud



Claire Autebert



Boris Korzh



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Jelmer Renema