First sensitivity limits of the ALPS TES detector

Jan Dreyling-Eschweiler

10th PATRAS Workshop on Axions, WIMPs and WISPs
9am, Friday, 4 July 2014, CERN

Overview

- Light-Shining-through-a-Wall (LSW) experiments
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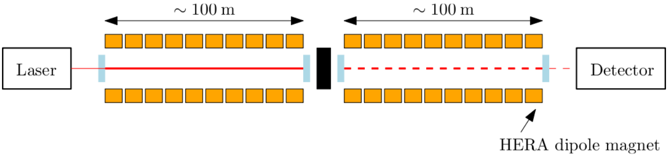

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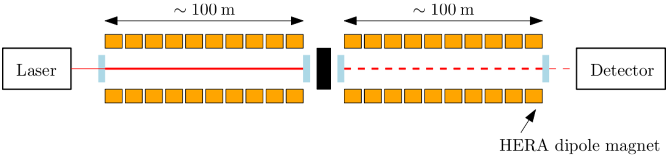
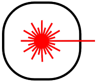


- **ALPS TES detector**
  - Working principle
  - Development and components
  - Results: First limit on sensitivity

ALPS and LSW for pedestrians



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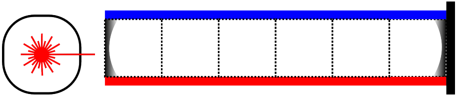

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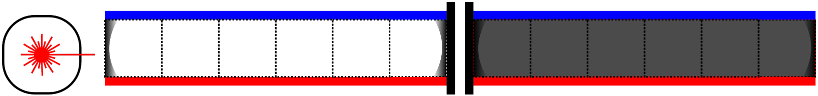

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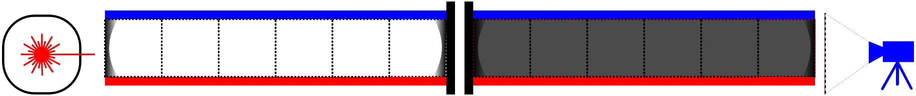

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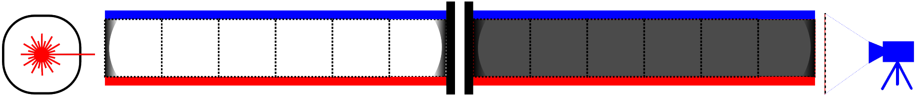

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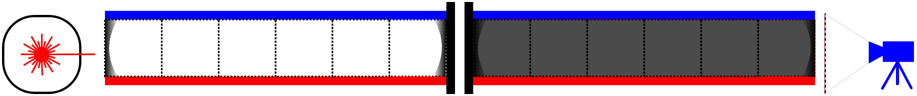
ALPS and LSW for pedestrians



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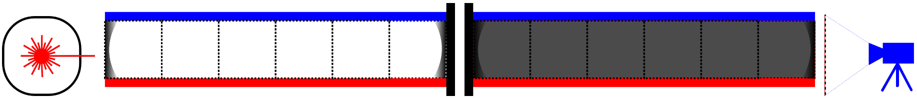

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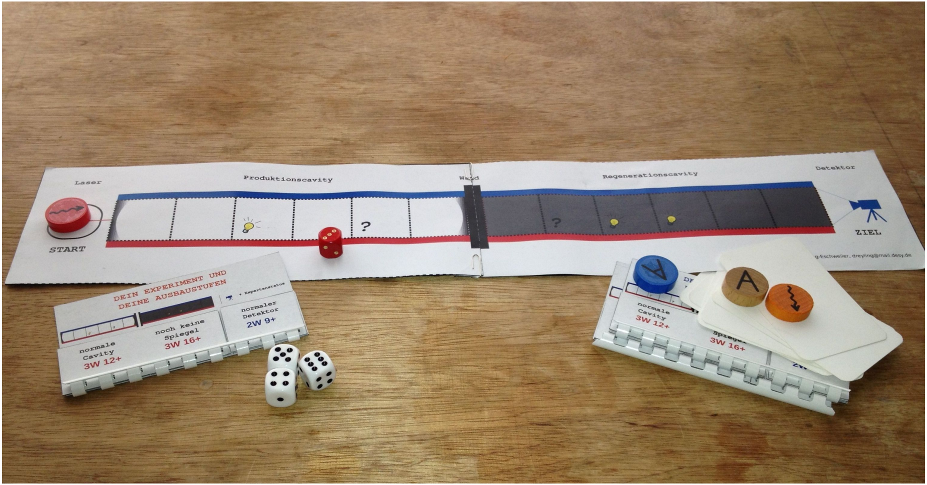
- time

“AXIONATOR” boardgame – simulation at home



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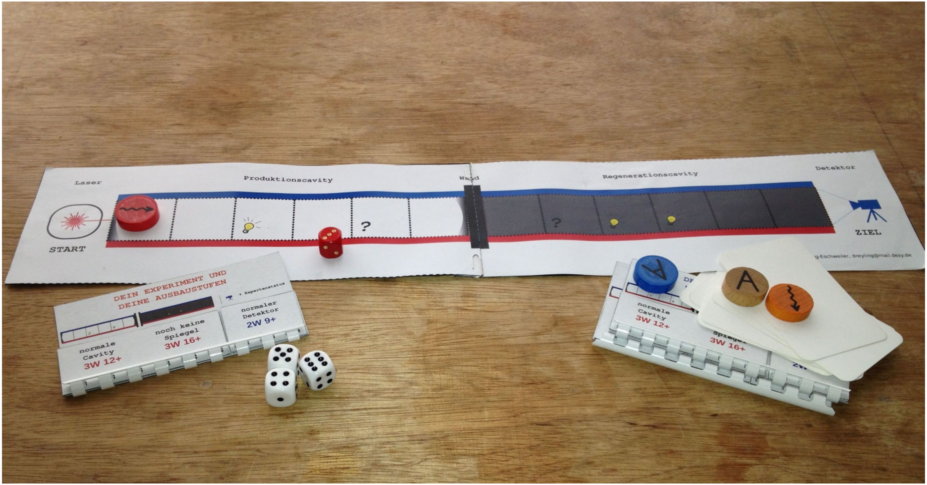

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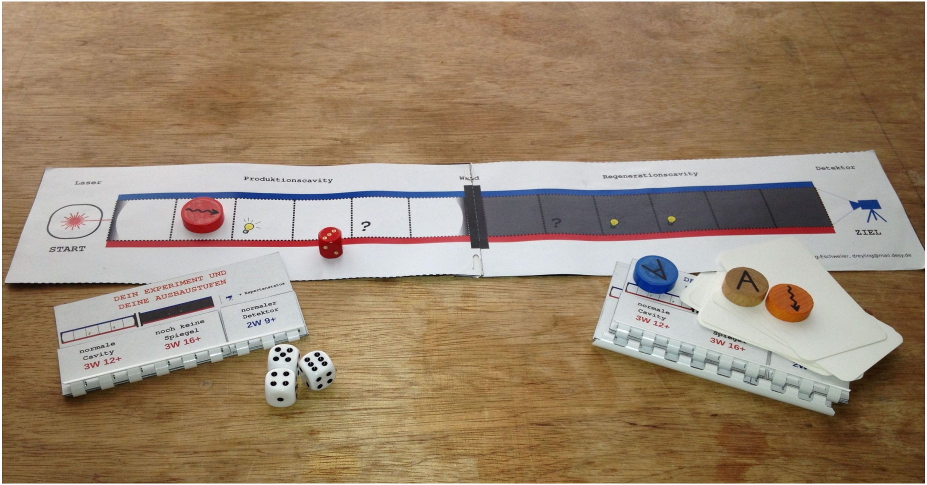

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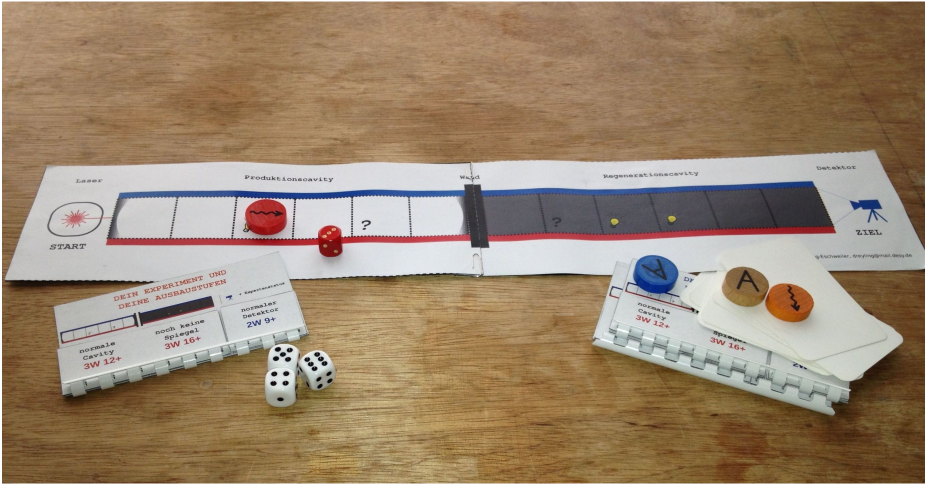

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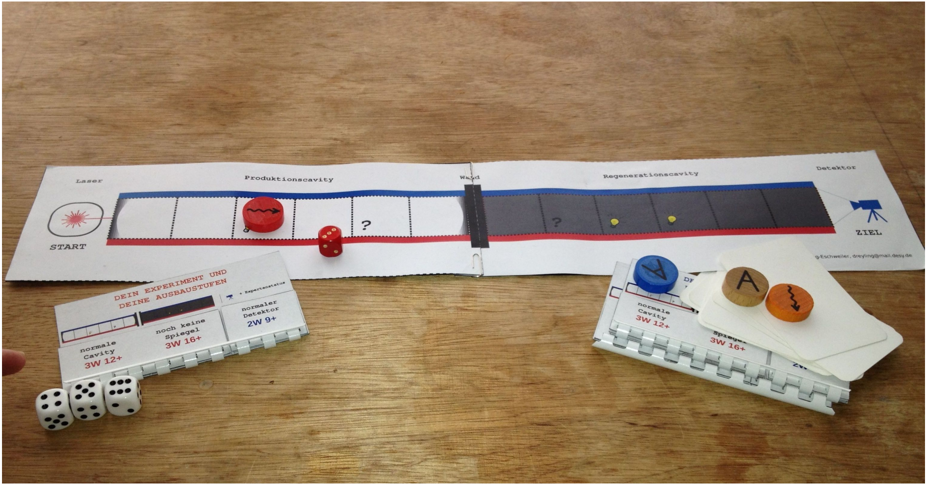

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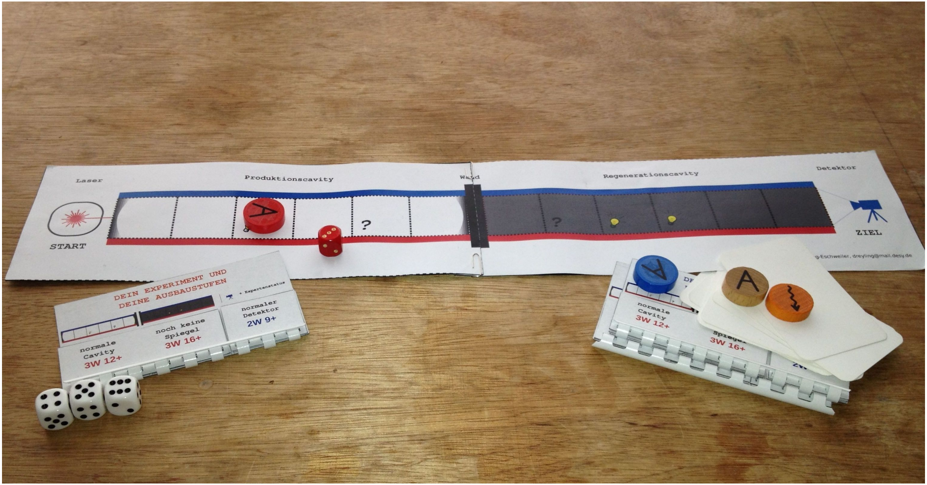

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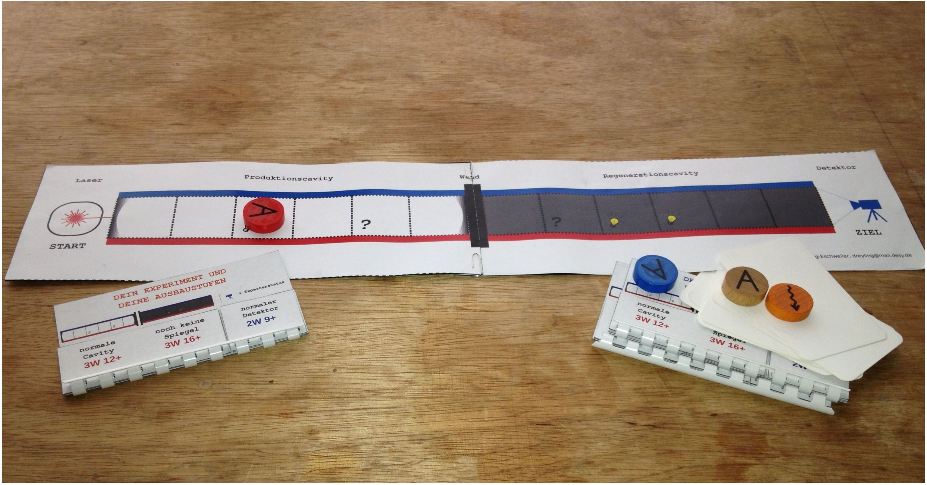

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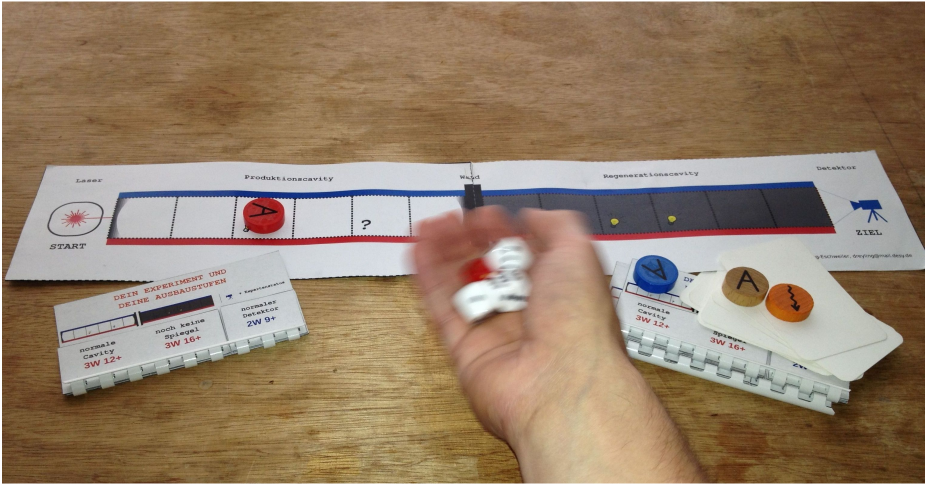

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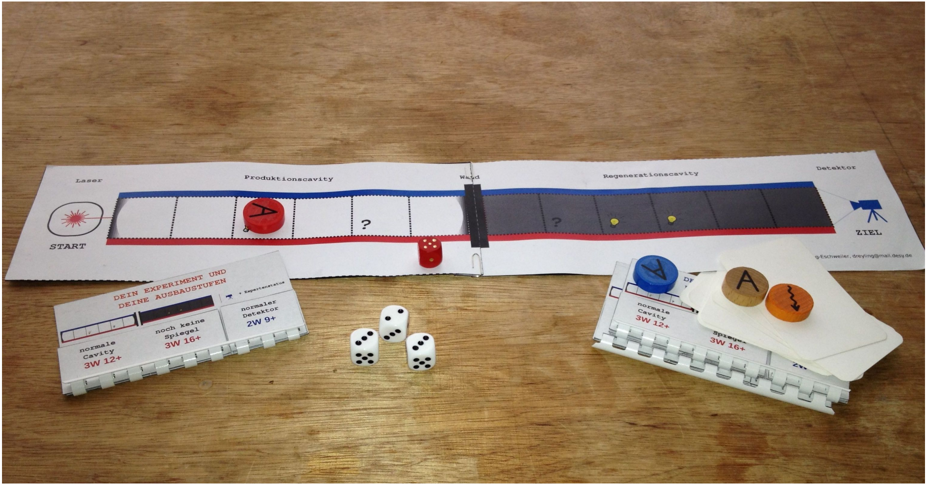

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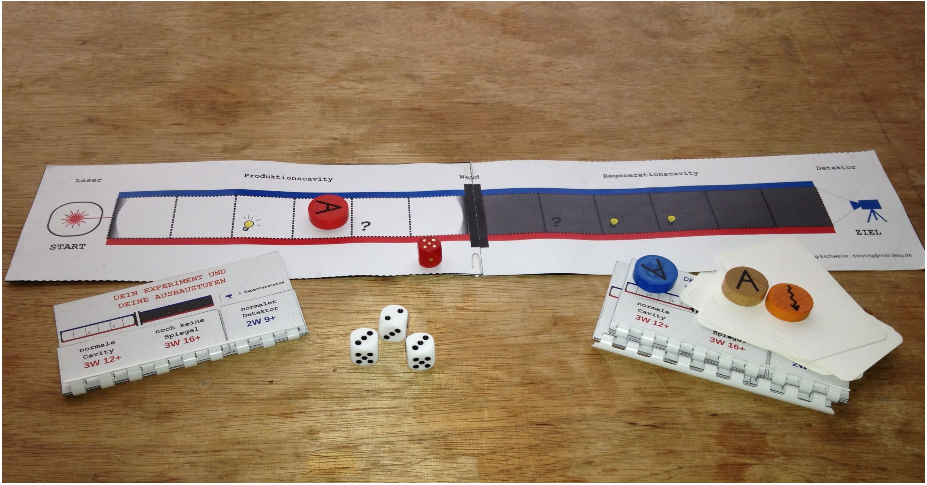

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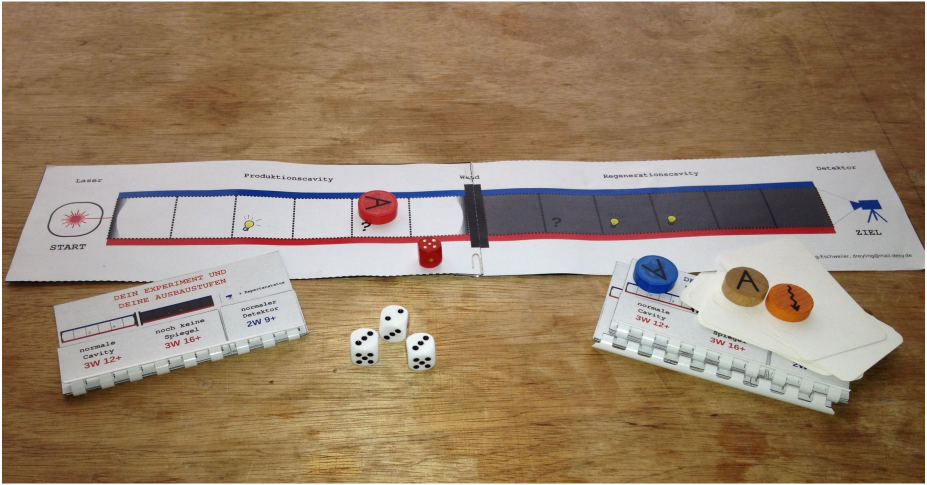

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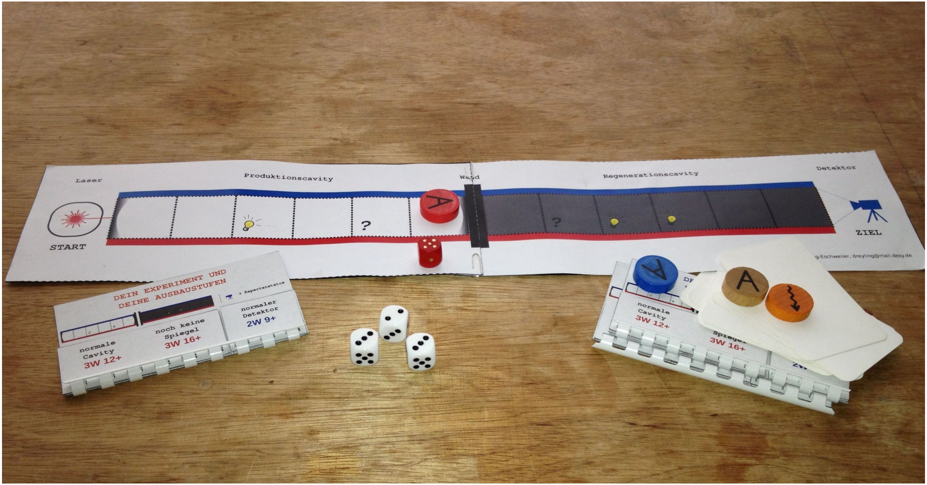

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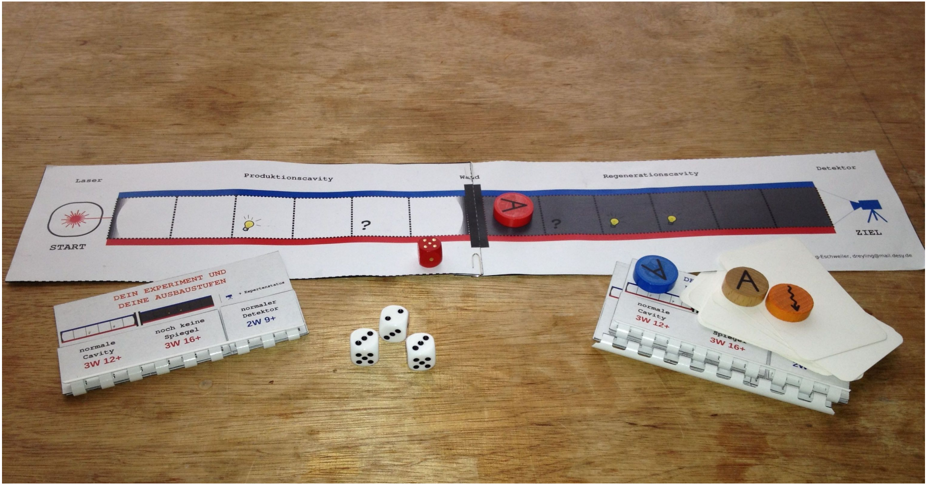

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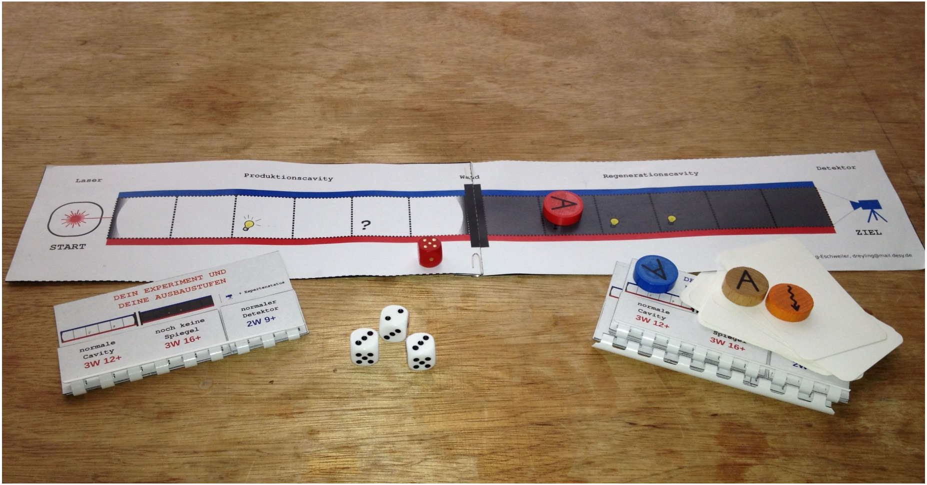

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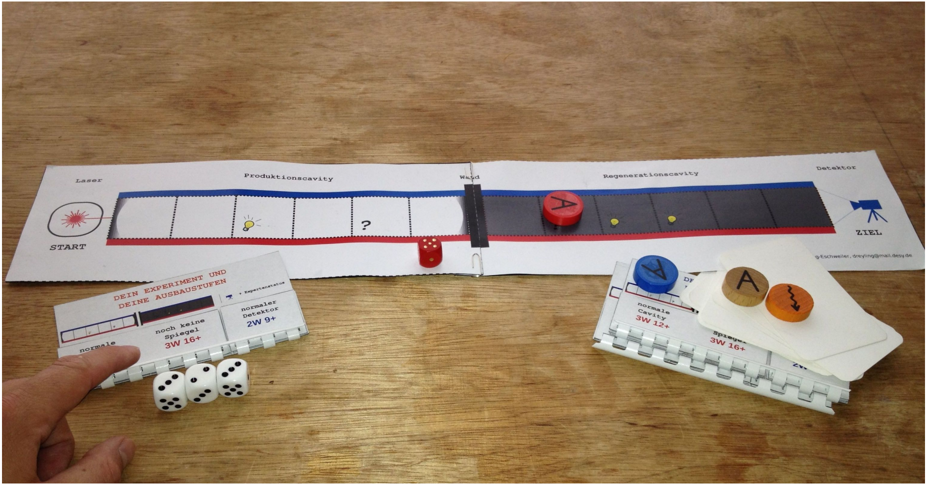

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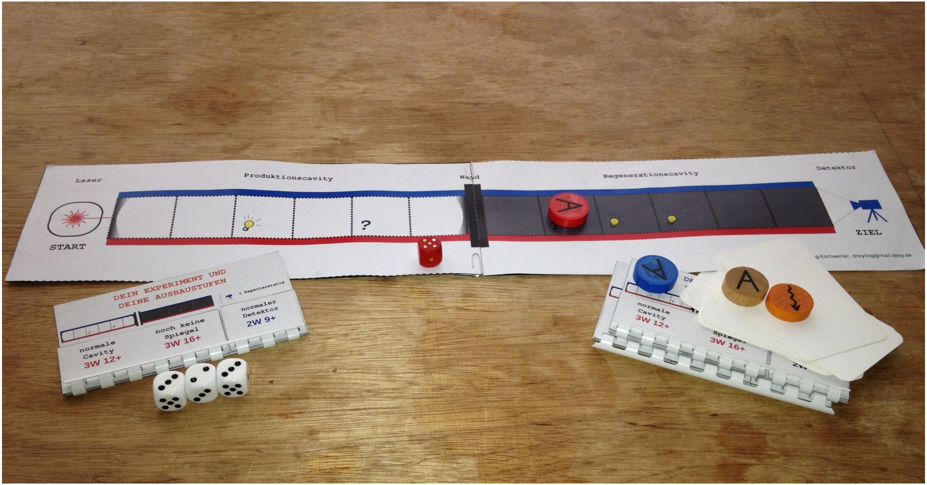

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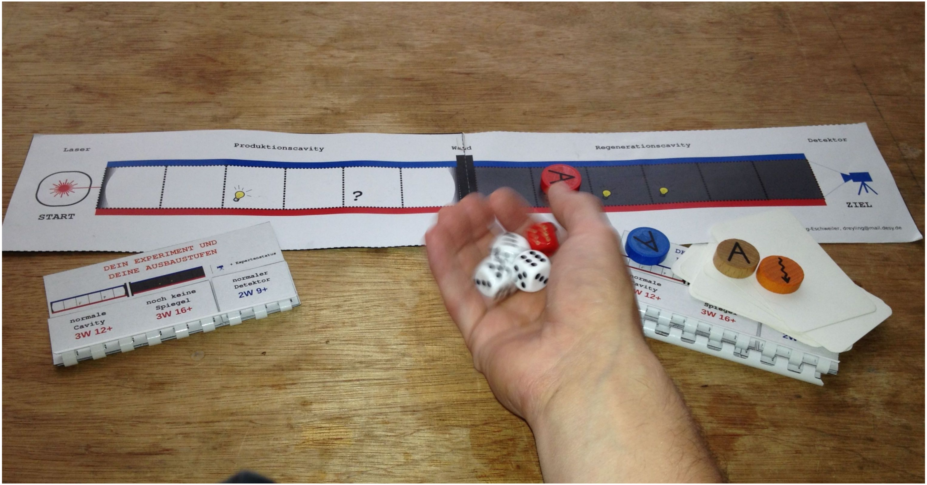

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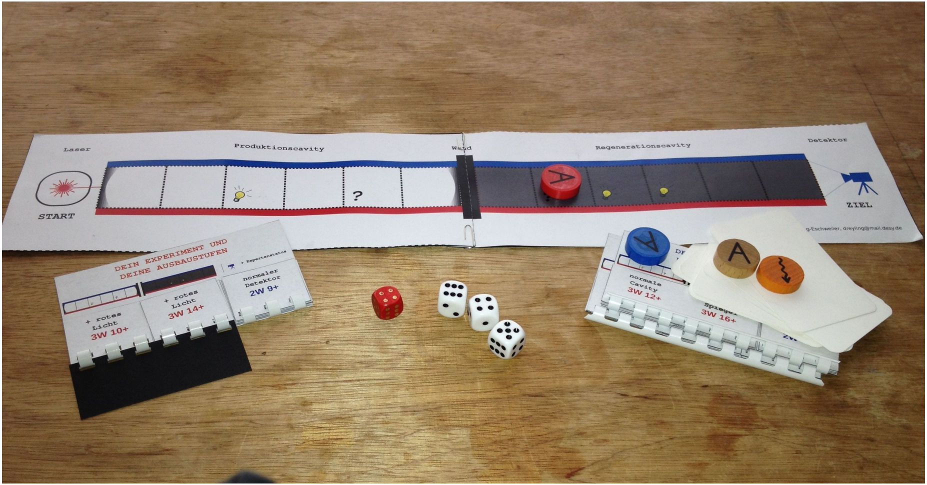

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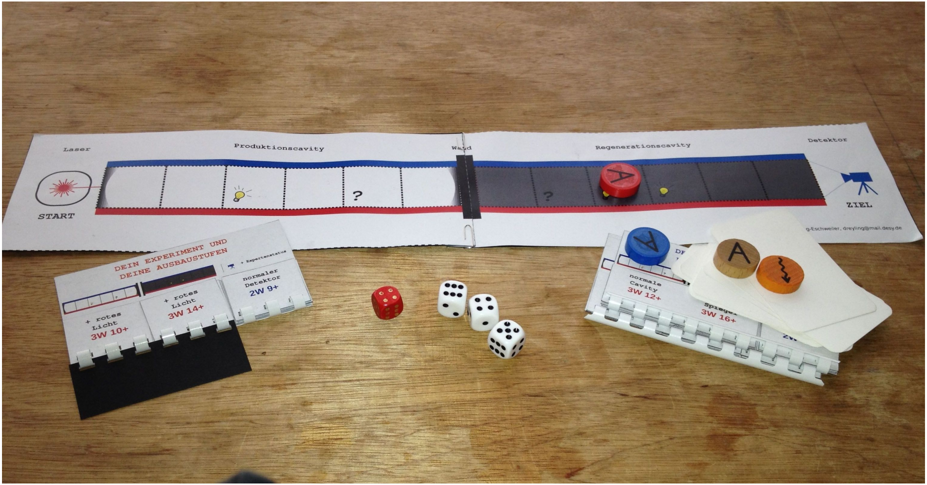

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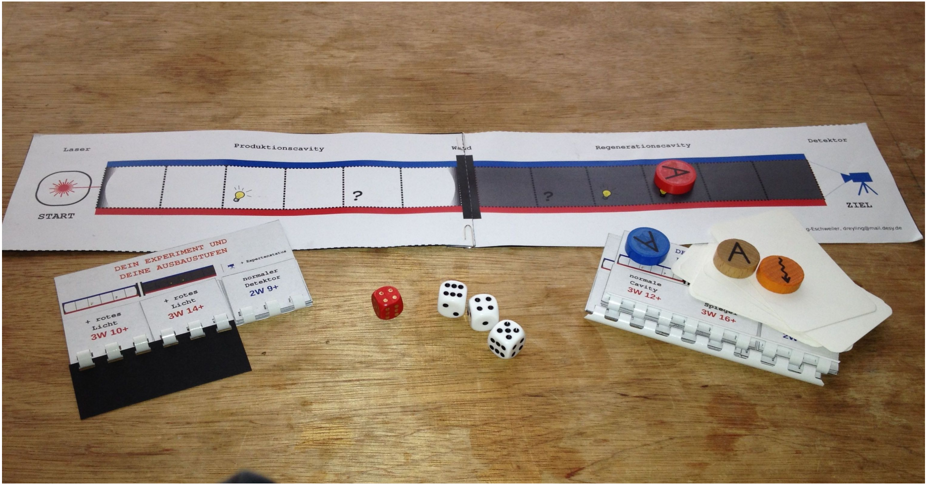

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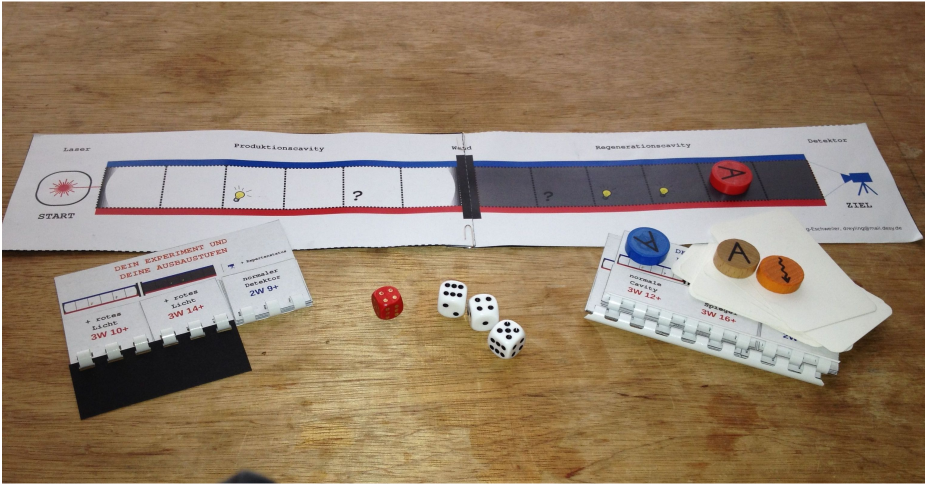

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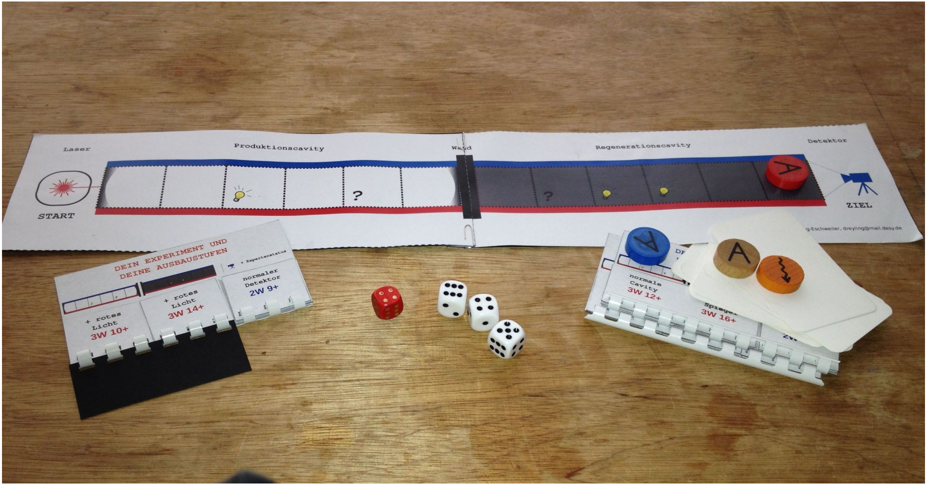

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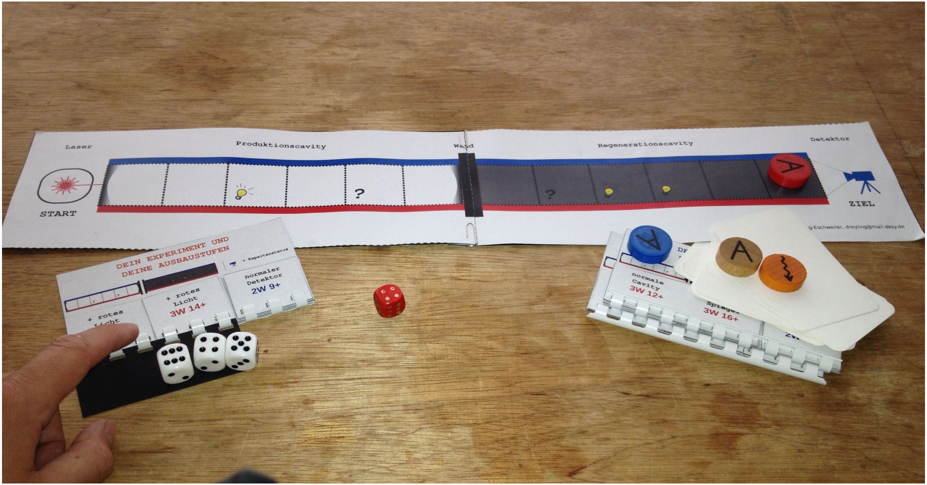

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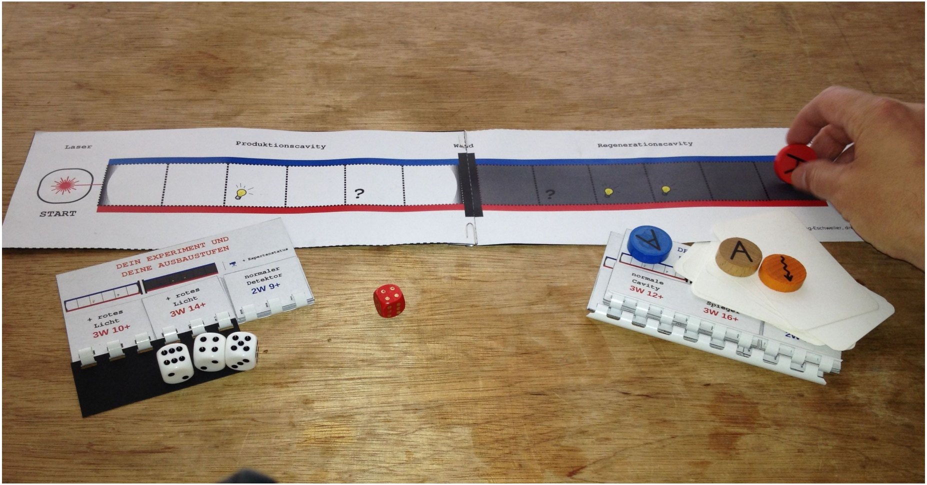

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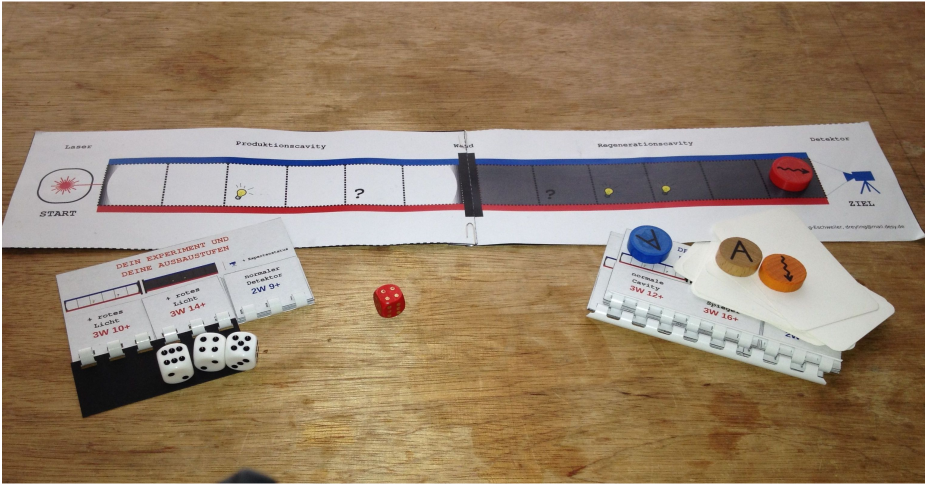

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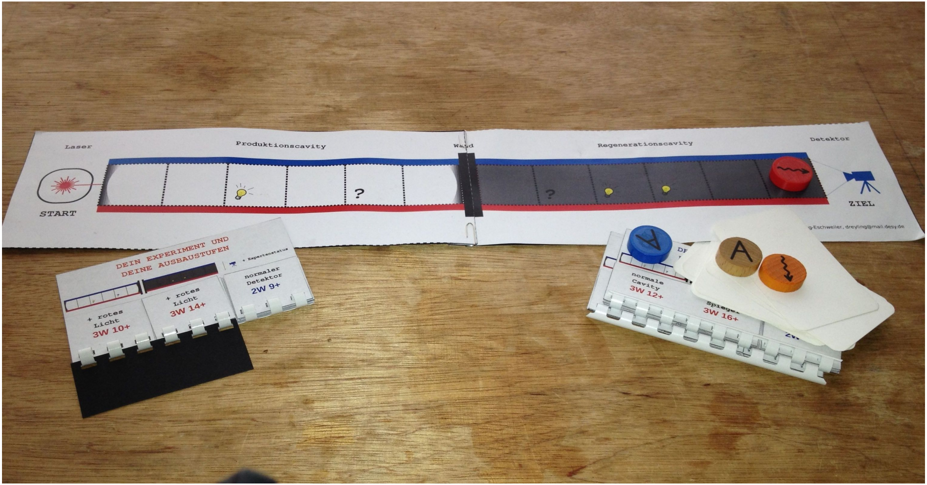

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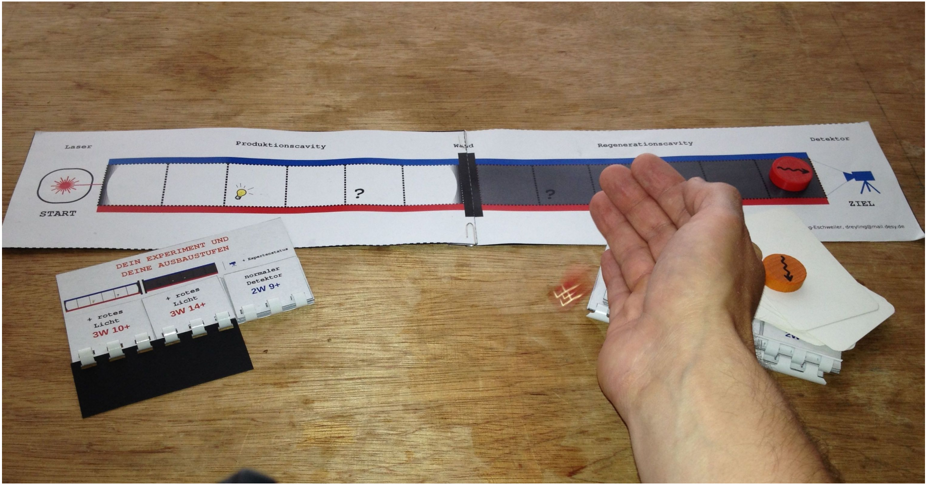

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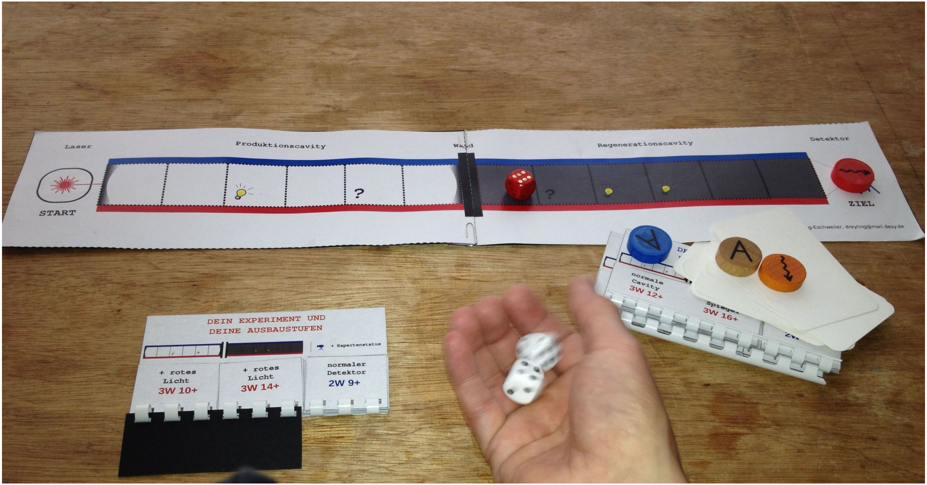

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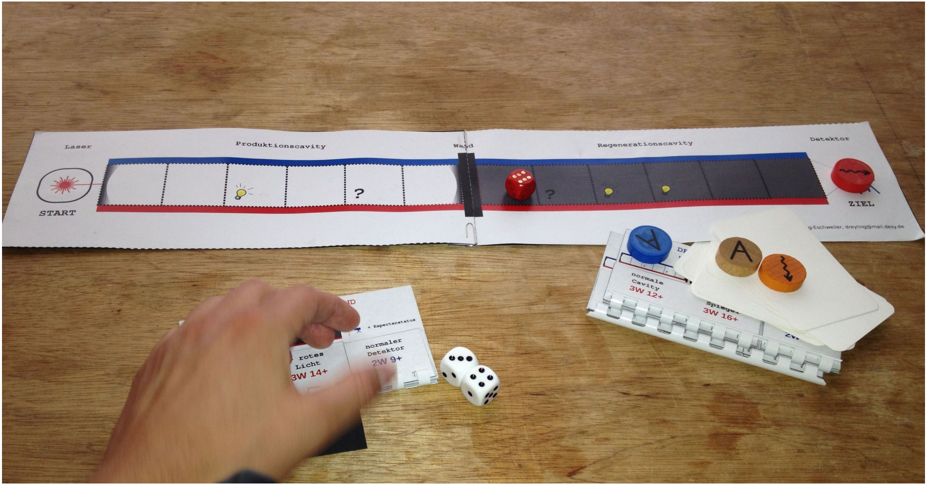

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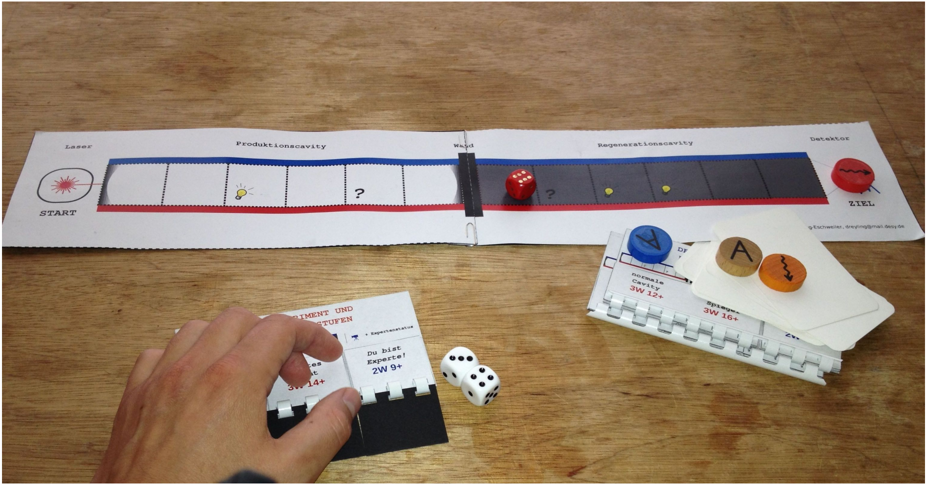

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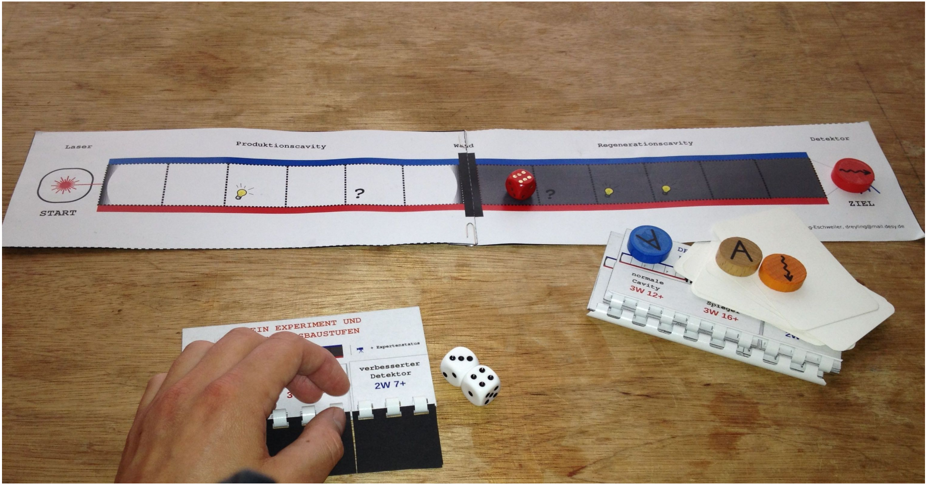

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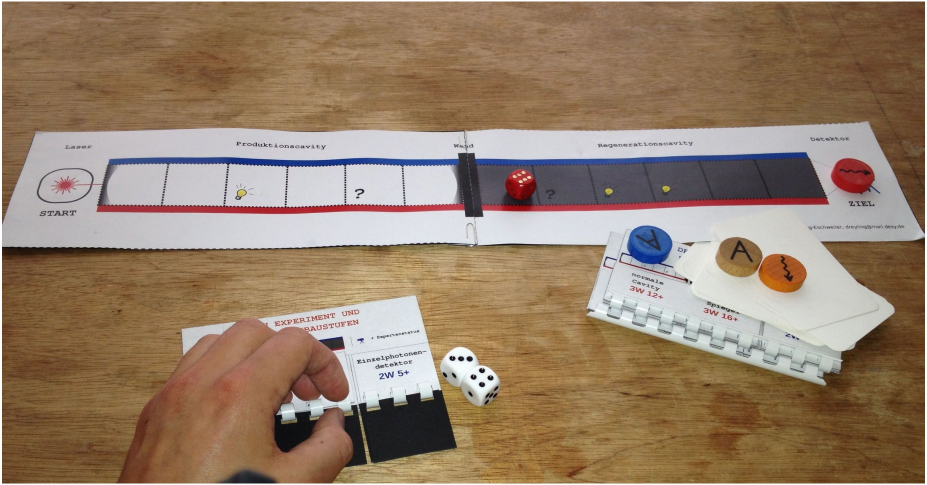

Detectors for ALPS

ALPS II asks for. . .

- detection of low rates (<1/h) of single photons (**1064 nm** $\sim$ 1 eV)
- detector with
  - high detection efficiency (DE) and
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(in terms of sensitivity $S_{\text{detector}} \equiv (\frac{\sqrt{DC}}{DE})^{1/4} \propto g_{a\gamma}$)

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commercial state-of-the-art silicon-based CCD (charged-coupled device)

ALPS I detector for ALPS II: CCD

+ $DC \sim 10^{-3}\ \mathrm{s}^{-1}$
- $DE \sim 1.2\ \%$ (**1064 nm**)

→ figure of merit: $S_{\text{CCD}} = 1.30$

A new detector for ALPS

Transition-edge sensors (TES)

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- broadband realizations: from X-ray to sub-mm waves or dark matter searches (e.g. CRESST)

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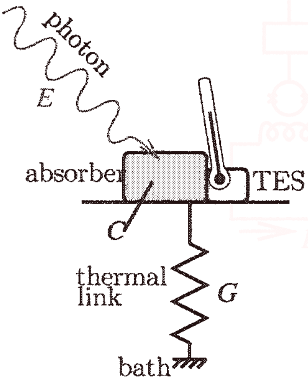
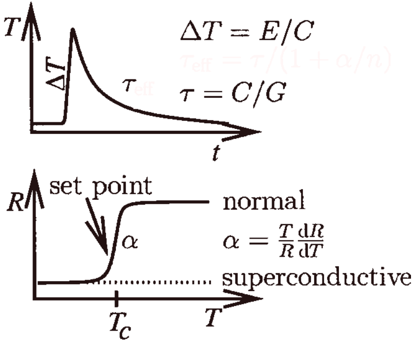
- broadband realizations: from X-ray to sub-mm waves or dark matter searches (e.g. CRESST)
- report in 2010: realization for infrared light $\rightarrow DE > 95\ \%$ (for 1310/1550 nm)

$\rightarrow$ How does a TES work?

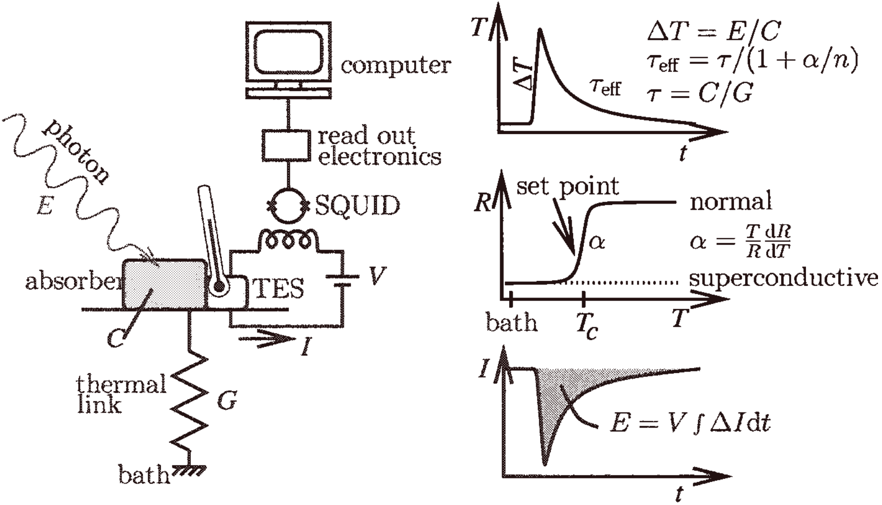
TES working principle: thermal circuit (simple calorimeter)





P.A.J. De Korte et. al., Proceedings of SPIE, pages 779-789, 2002

TES working principle: electrical circuit ($\rightarrow$ feedback)



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Setting up a TES detector

Starting from zero – very brief history

- 2011: gaining experience (PTB, INFN) and connecting to small TES-community
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Components of "ALPS TES detector" (2013)

- TES from NIST
- Read-out via SQUIDs from PTB
- Cryostat from Entropy GmbH

NIST

PTB

ENTROPY

Sensor module: TES with SQUID read-out

TES chips from NIST

- tungsten (W) 20 nm film
  - absorber = thermistor
  - $25 \times 25\ \mu\text{m}^2 \ \times\ 20\ \text{nm}$
  - single mode fiber coupled

→ superconducting transition: $T_\text{c} \sim 140\ \text{mK}$

→ optimized for 1064 nm: $DE \sim 97.5\ \%$ (NIST meas.)

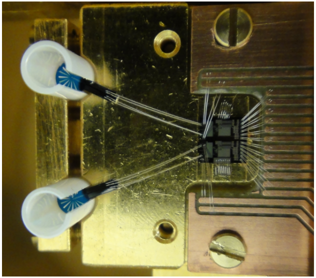
SQUID chip from PTB

- current read-out

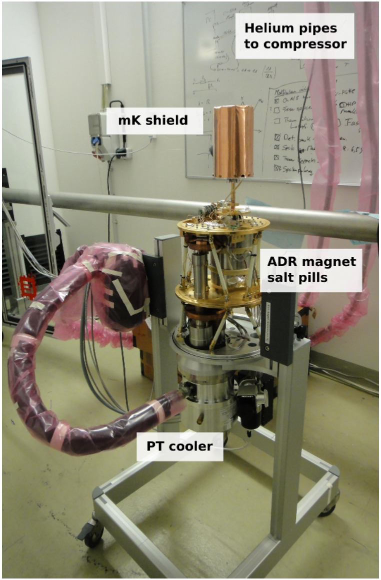
→ TES noise dominates SQUID noise

module with two channels

(scale ∼ 3cm × 3cm)



Milli-kelvin cryostat



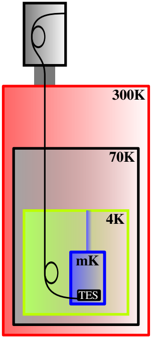
Cryostat from Entropy GmbH

- mK-cooling by adiabatic demagnetization cooling

→ continuous operation for ∼20 h at $80\ \mathrm{mK} \pm 25\ \mu\mathrm{K}$

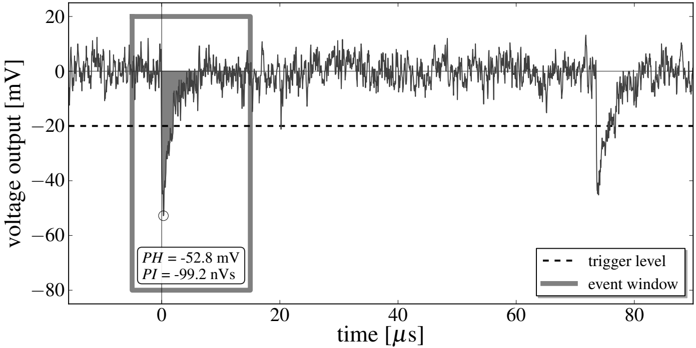
→ no problems? working point? measurements!

Applying single 1064 nm photons



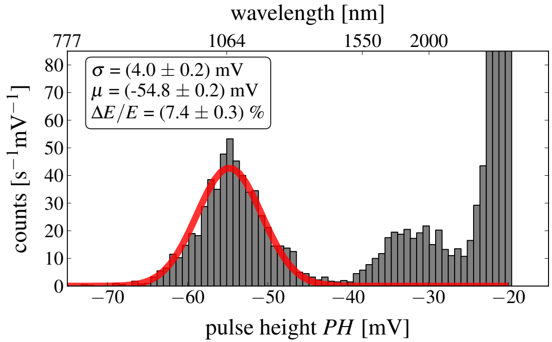
Standard fiber configuration with single photon source

exemplary timeline



→ extract pulse heights

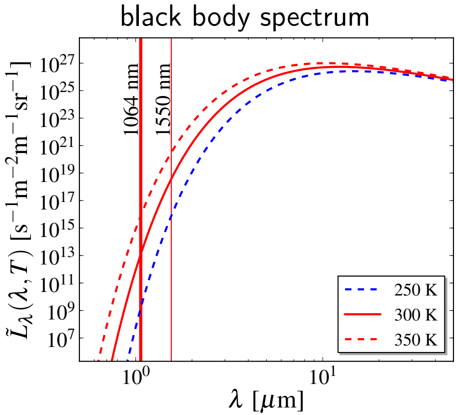
Pulse height distribution (PHD)



Events

- signal events → $\Delta E/E_{1064\ \mathrm{nm}} \approx 7 - 8\ \%$
- thermal events → black body spectrum
- noise events → system noise

Thermal photons from warm fiber end



Conservative estimate

- 300 K black body spectrum
- no optical losses
- $\Delta E/E = 10$ %

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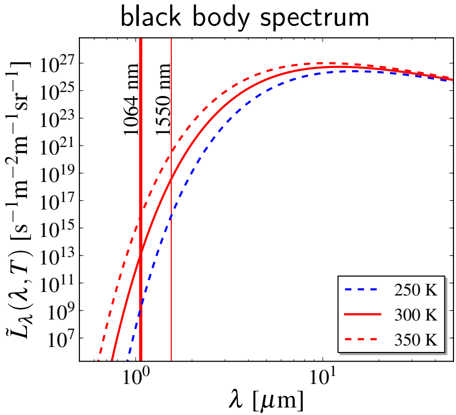

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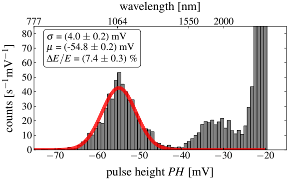
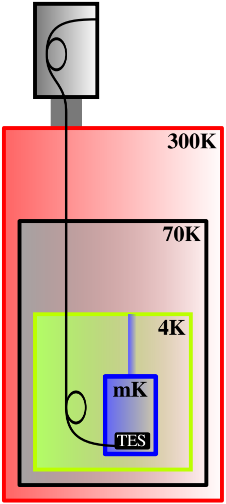
Expectation

1064 nm	band [nm]	$\tilde{N}$ [s^{-1}]
3σ-region	1520-818	$1.0 \cdot 10^{+1}$
half 3σ-region	1064-818	$\mathbf{3.4 \cdot 10^{-4}}$



Dark count rate (standard fiber)



Setup

- long-term measurements
- dark warm fiber end
- adjusted trigger level due to thermal photons

$\rightarrow$ high-energetic half 3σ-region

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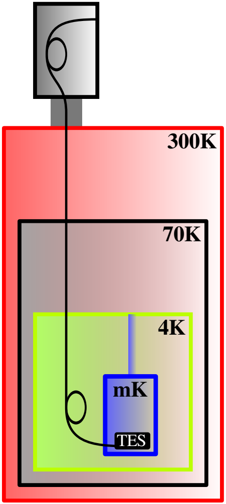

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Dark count rate (fiber-coupled)

- $DC_{\text{ALPS TES detector}} = (8.6 \pm 1.1) \cdot 10^{-3}\ \text{s}^{-1}$ (high-energetic half 3σ-region of 1064 nm signals)

Origin of 1064 nm dark counts

Comparing measurement to model (half 3σ region)

- measured: $DC_{\text{ALPS TES detector}} = (8.6 \pm 1.1) \cdot 10^{-3}\ \text{s}^{-1}$
- fiber end model of 300 K black body photons: $\tilde{N} = 3.4 \cdot 10^{-4}\ s^{-1}$

$\rightarrow$ measured rate is ~1.5 orders of magnitude higher!

Origin of 1064 nm dark counts

Comparing measurement to model (half 3σ region)

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- fiber end model of 300 K black body photons: $\tilde{N} = 3.4 \cdot 10^{-4}\ s^{-1}$

$\rightarrow$ measured rate is $\sim$1.5 orders of magnitude higher!

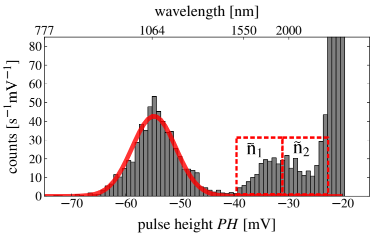
One possible solution

pile-up events due to time resolution:

$$\tilde{n}_{\text{eff}} = 2\,\tau\,\tilde{n}_1\,\tilde{n}_2$$

$(\tau_{\text{PSA}} \approx 0.5\ \mu\text{s}$ and $\tilde{n}_1 \approx \tilde{n}_2 \approx 10^2\ \text{s}^{-1})$

$$\longrightarrow \tilde{n}_{\text{eff}} \simeq 10^{-2}\ \text{s}^{-1}$$



Conclusion for ALPS

CCD and TES as ALPS-II detector (1064 nm)

	DE [%]	DC [s^{-1}]
CCD	1.2	$1.2 \cdot 10^{-3}$
TES	~ 18	$8.6 \cdot 10^{-3}$

$\longrightarrow$ gain of $S_{\mathrm{CCD}}/S_{\mathrm{TES}} = 1.55$
using the present ALPS TES detector

Remember: optimize $S_{\mathrm{detector}} \equiv \left(\frac{\sqrt{DC}}{DE}\right)^{1/4} \propto g_{a\gamma}$
concerning the ALPS detector

Summary and outlook

Take-away summary

- Transition-edge sensors are promising..
- .. but needs effort if starting from zero:
  $\rightarrow$ 3 years of development for
  the **ALPS TES detector**
- first characterization including extensive background measurements
- determination of dark count rate for 1064 nm signals

Brief outlook

- reduce thermal background
- ALPS II measurements in ∼2018 . . .

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  . . . via single photons

Two axion theorists meet the ALPS TES detector.