# Quantum non-Gaussian light:
# a compass for experimental Fock states

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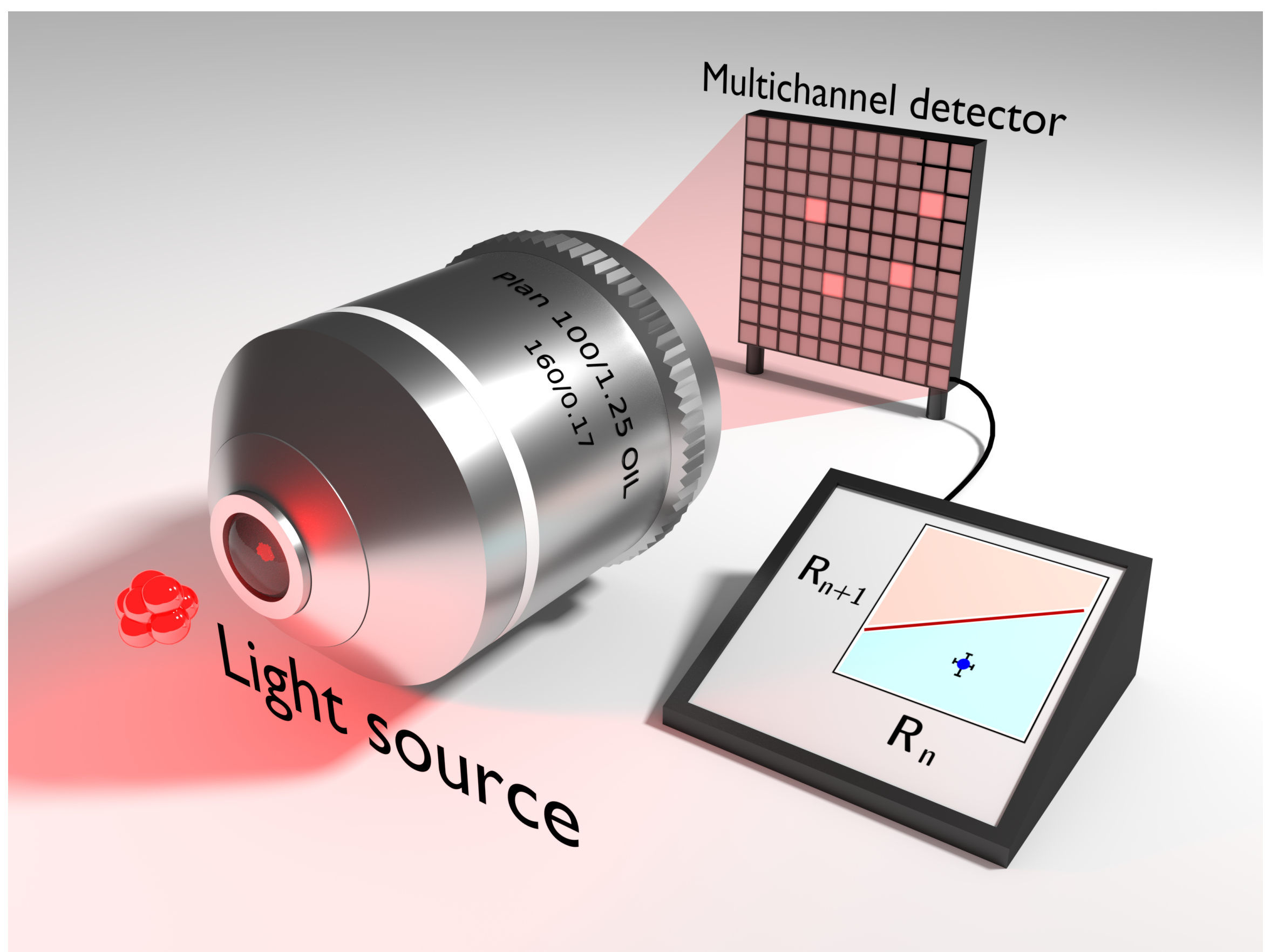
## Abstract

To recognize the quantum nature of Fock states, we use nonclassicality witnesses such as $g^2$ or negativity of the Wigner function. Unfortunately, experimental Fock states suffer from imperfections such as loss and noise.

Despite imperfections, nonclassicality is easy to achieve for high multiphoton states. Wigner function negativity, on the other hand, has been demonstrated only up to $|3\rangle$. Quantum non-Gaussianity (QNG) is a novel witness that stands in between [1-4].

We introduce a hierarchy of experimental QNG witnesses that use common multichannel detectors. We demonstrate QNG for up to 9 heralded photons and quantify their resilience to optical loss. We show a strong dependence on the number of single photons, opening new possibilities of counting single-photon emitters [5].

## Witnessing QNG light



By definition, quantum non-Gaussian light goes beyond any probabilistic mixture of Gaussian states [1]. All Fock states, even when subjected to loss, contain at most $n$ photons. We recognize this indivisibility by using a balanced $(n+1)$-channel detector. We measure coincidence probabilities $R_n$ and $R_{n+1}$. For QNG light, there is a sufficient condition for each $R_{n+1}$, represented by a minimal value of $R_n$ [5]. For small mean number of photons, this criterion can be approximated analytically [5, 6].

$$R_n^{n+2} > H_n^4(x)\left[\frac{R_{n+1}}{2(n+1)^3}\right]^n$$

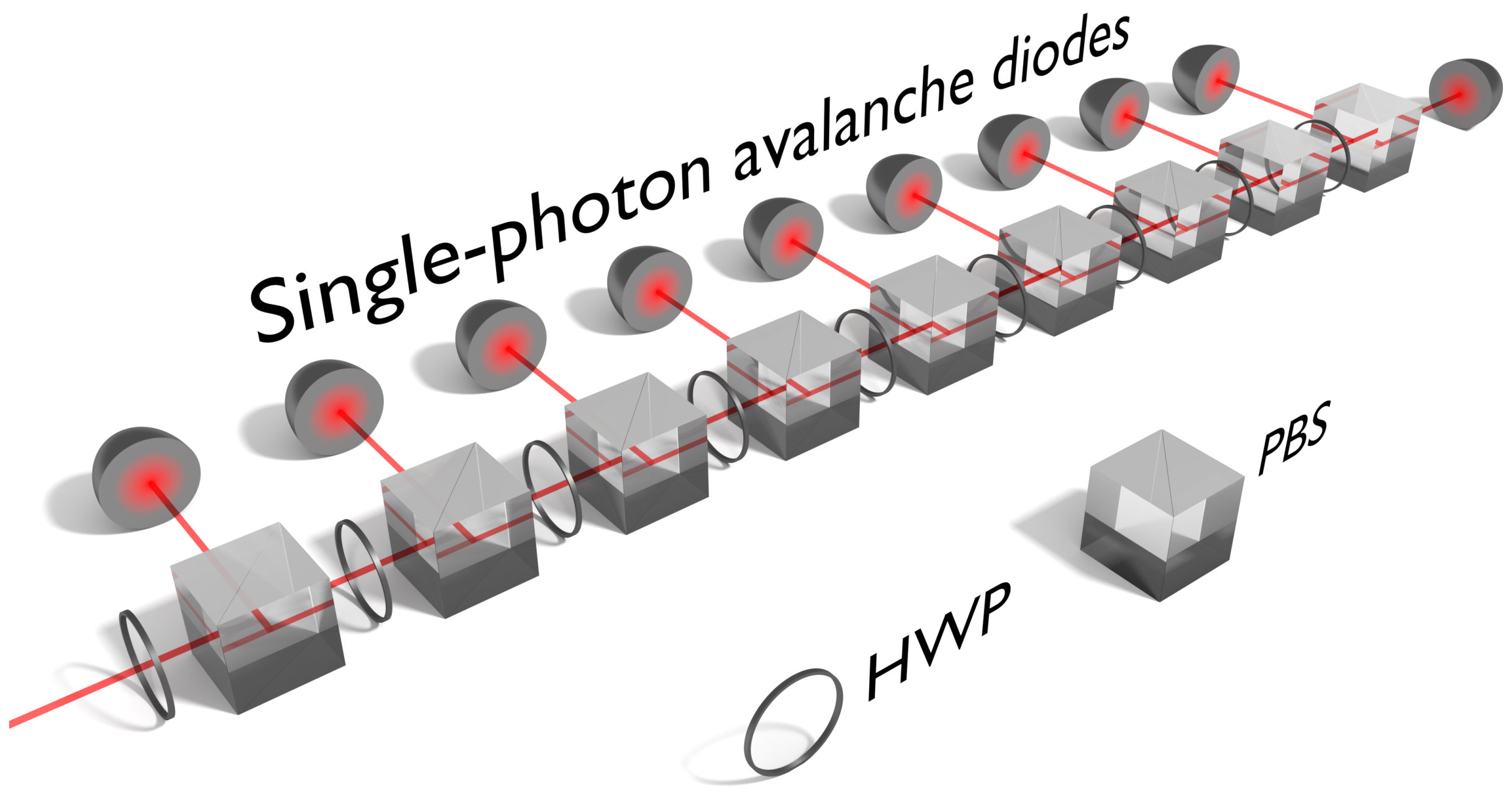
$$H_n(x) = \max_{x':H_{n+1}(x')=0} H_n(x')$$

## Qauntum non-Gaussianity

- Necessary milestone for Fock states
- Bridges the gap between nonclassicality and Wigner function negativity
- No tomography needed, criteria hold for directly measured coincidences.
- QNG depth directly quantifies tolerable loss
- Distinguishes the number of single-photon emitters

## Results

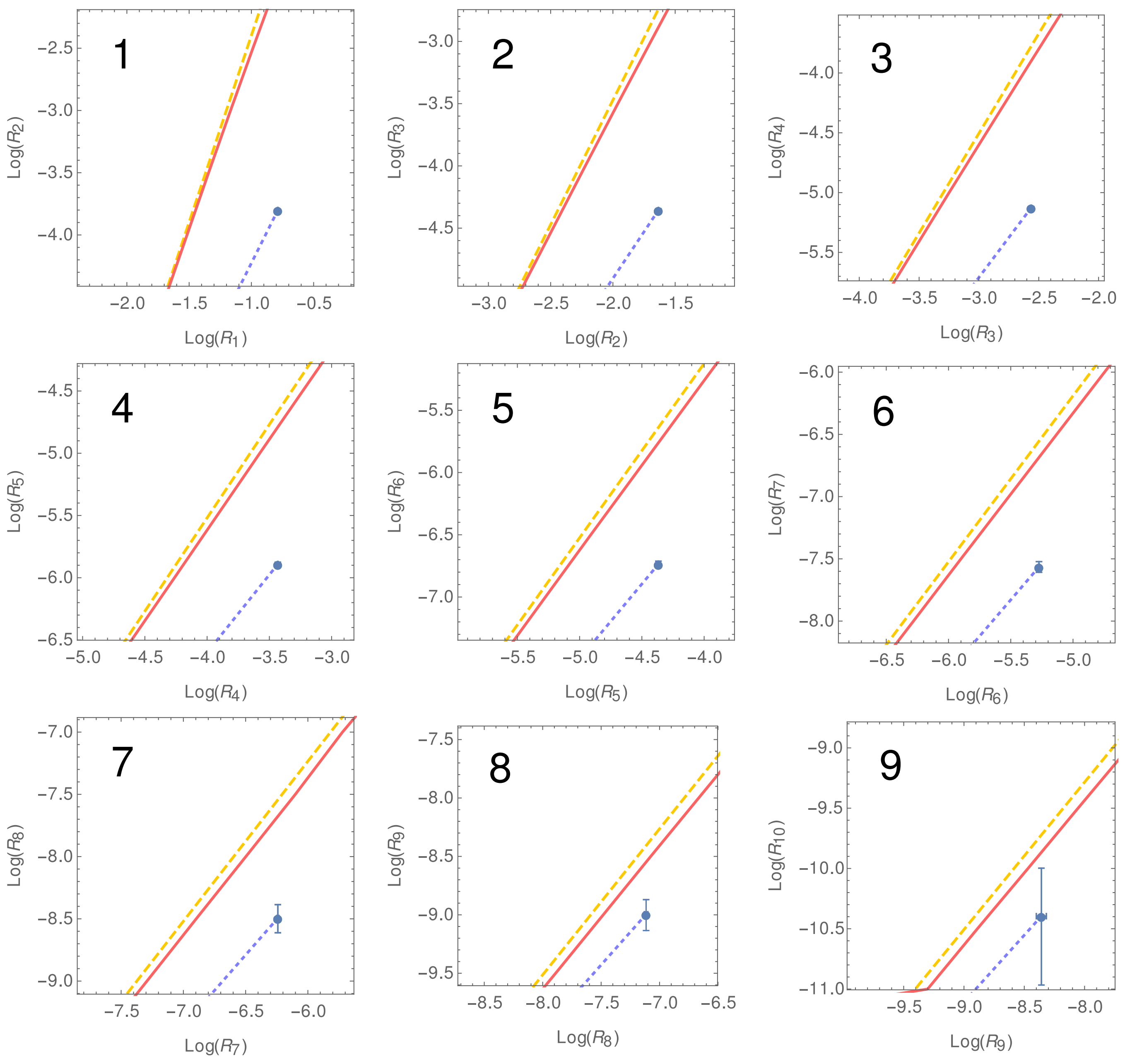
In order to produce QNG multiphoton states, we used temporal merging of $n$ subsequent heralded single-photon states emitted from a SPDC source [5]. This multimode approach also simulates incoherent mixing of signals from a cluster of $n$ identical single-photon emitters in separate modes.



We used a network of half-wave plates and polarizing beamsplitters to facilitate a balanced multichannel detector.

On the right, results are shown for $n$=1-9 heralded photons [5]. On horizontal axes, the $n$-fold coincidences $R_n$ are shown, while the vertical axes show the undesirable coincidences $R_{n+1}$. Solid lines represent QNG criteria, while dashed lines plot the approximative formula above. Dotted blue lines show the development under further optical loss.

$R_k$ = coincidence probability of a subset of $k$ channels chosen beforehand

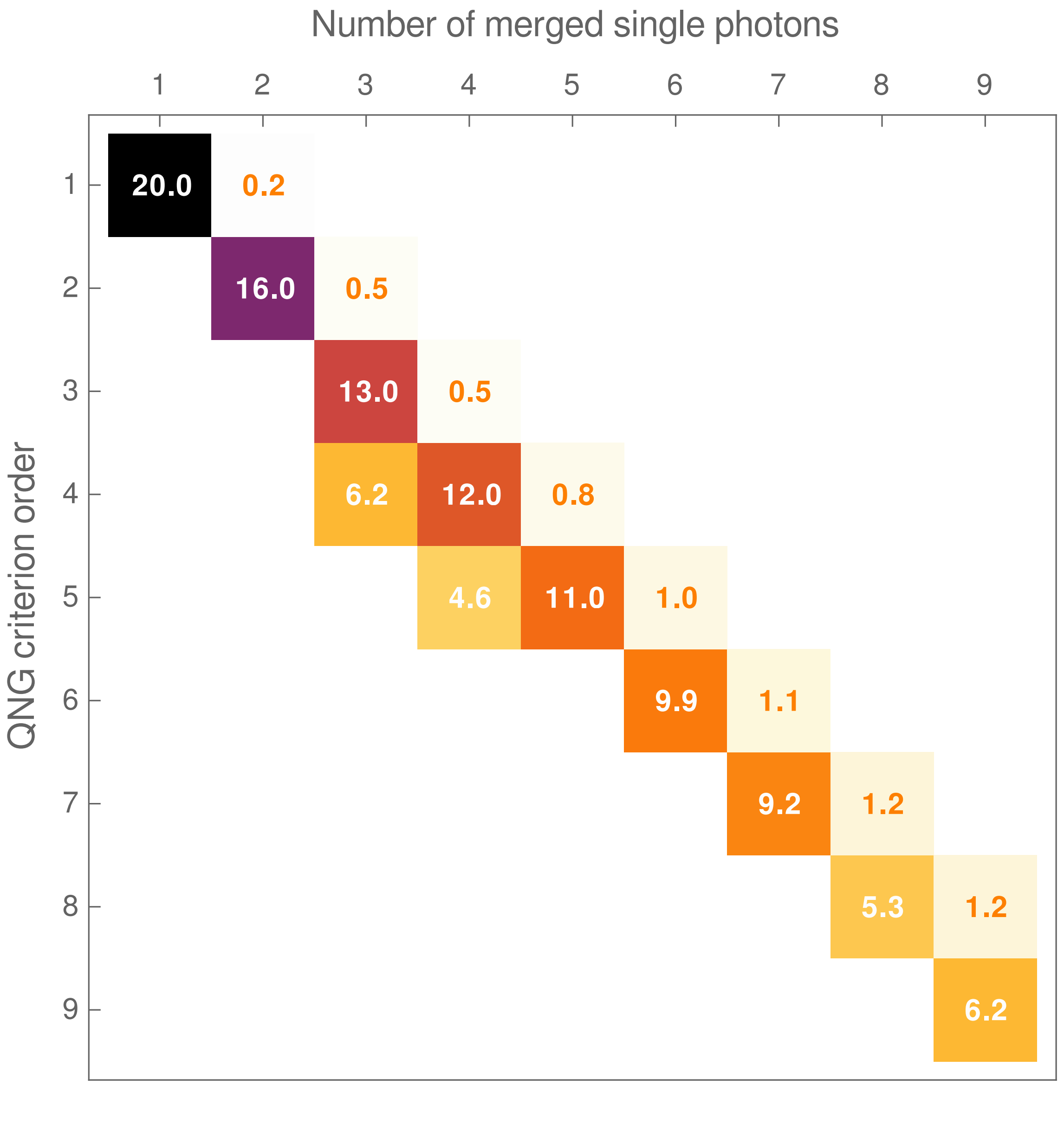


## QNG depth

We quantify the maximum amount of additional loss, after which a quantum state can still be recognized as QNG. This QNG depth measured for our data is shown on the right [5].

Each tile represents QNG depth in dB for various combinations of multiphoton states and QNG criteria. On the horizontal axis, the number of successive heralded single photons is shown. On the vertical axis, the order of the QNG witness $n$ is specified, where the number of detection channels is then $n+1$. The cases on the diagonal are presented in Results above.

For each quantum state, there is an optimal criterion that gives the highest QNG depth. This complies well with our initial motivation to test the indivisibility of $n$ photons using a criterion with $n+1$ detectors. Practically, if we consider the measured quantum states as a simulated collective emission from $n$ identical single-photon emitters, these optima offer a way to count the emitters based only on their emission.


Number of merged single photons

QNG criterion order

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.0 | 0.2 | | | | | | | |
| 2 | | 16.0 | 0.5 | | | | | | |
| 3 | | | 13.0 | 0.5 | | | | | |
| 4 | | | 6.2 | 12.0 | 0.8 | | | | |
| 5 | | | | 4.6 | 11.0 | 1.0 | | | |
| 6 | | | | | | 9.9 | 1.1 | | |
| 7 | | | | | | | 9.2 | 1.2 | |
| 8 | | | | | | | | 5.3 | 1.2 |
| 9 | | | | | | | | | 6.2 |

## References

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[5] I. Straka et al., arXiv:1611.02504 (2016).

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This work was supported by the Czech Science Foundation (17-26143S).

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