The Quantum Bomb Tester
& Quantum Computing Basics

Maria Violaris, University of Oxford

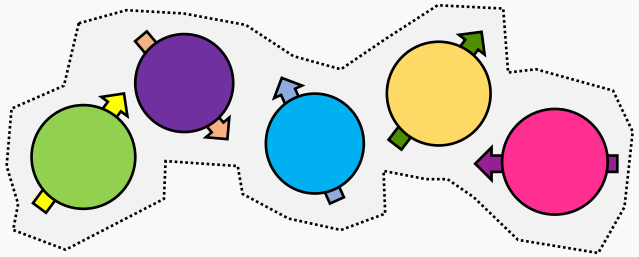
Indiana University Bloomington Quantum Summer School

10th July 2024

Hi!

maria@violaris.com
Maria Violaris
@maria__violaris
mariaviolaris.com
Maria Violaris
Maria Violaris

PhD



UNIVERSITY OF OXFORD

Industry

IBM Quantum Qiskit

river lane

Engagement

QUANTUM ON THE CLOCK

A physics lab inside your head:
Quantum thought experiments as an educational tool

OXFORD UNIVERSITY QUANTUM INFORMATION SOCIETY

Media

Host Quantum Foundations Podcast

physics world

Podcast interviews: Physics World, Quantum AI, Question Field, Constructor Theory

Quantum Paradox-Busting!

What's to come….

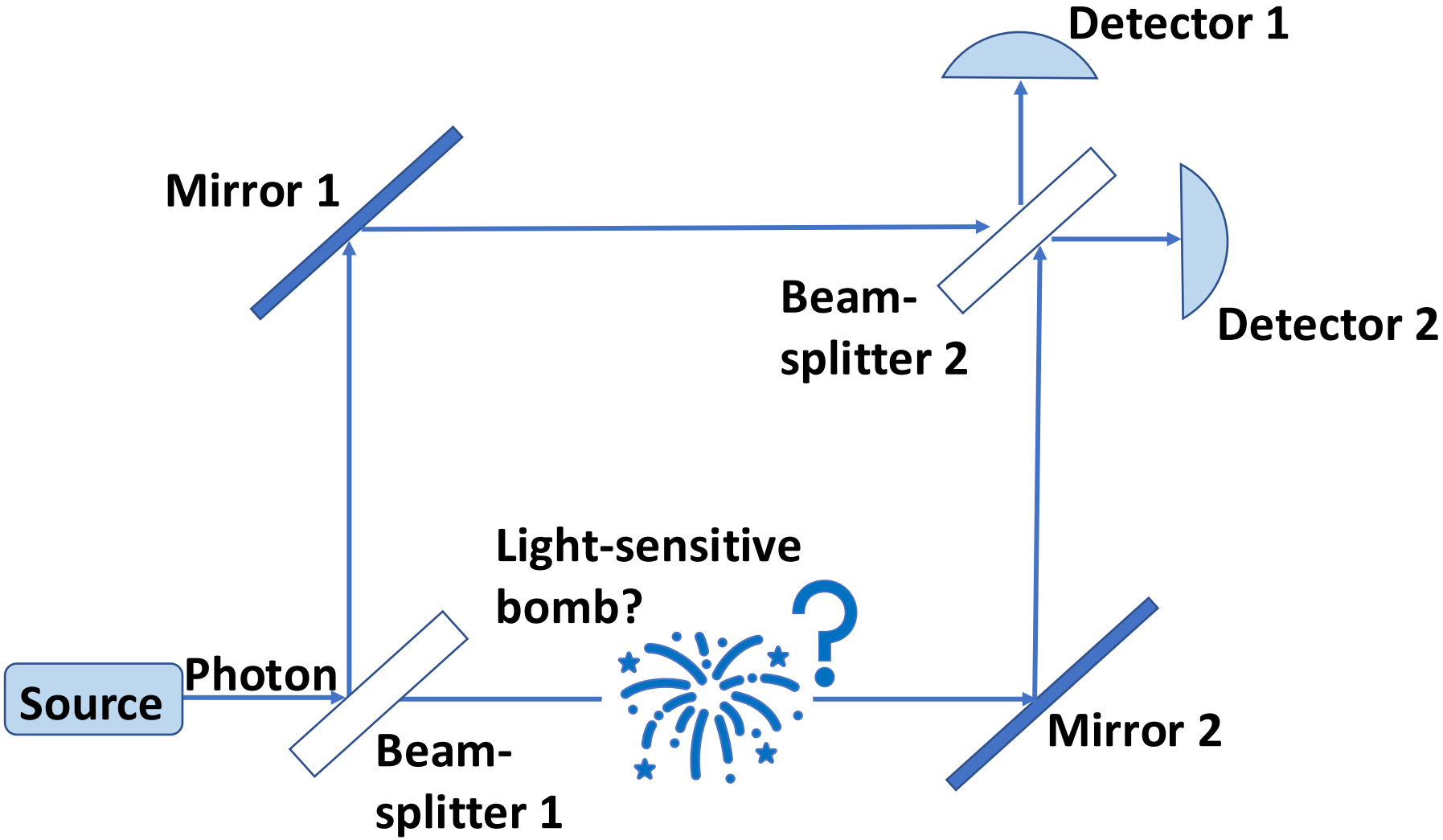
- Lecture 1, Wednesday 10th July
  - **The Quantum Bomb Tester and Quantum Computing Basics**
- Lecture 2, Wednesday 17th July
  - **Collapse vs Many-Worlds: Demystifying Schrödinger's Cat, the Double-Slit, and Quantum Observers**
- Lecture 3, Wednesday 24th July
  - **Entangling Disciplines: How Quantum Computing meets Relativity, Maxwell's Demon and Time-Travel**

Summary

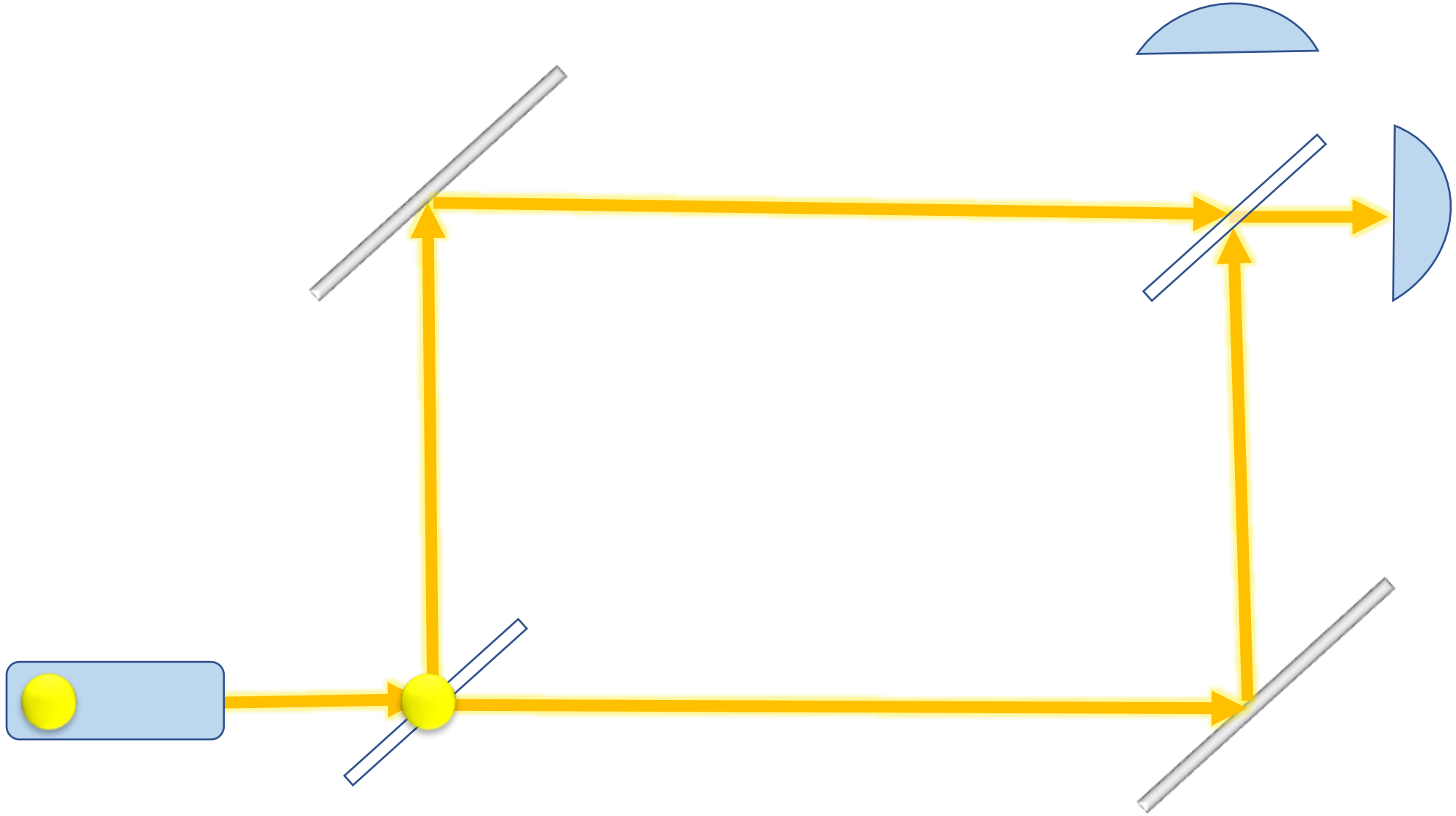
- The quantum bomb tester: see a bomb without looking!
- Up to 100% effective version with the “quantum Zeno effect”
- Mapping the bomb tester to a quantum circuit

Quantum bomb tester

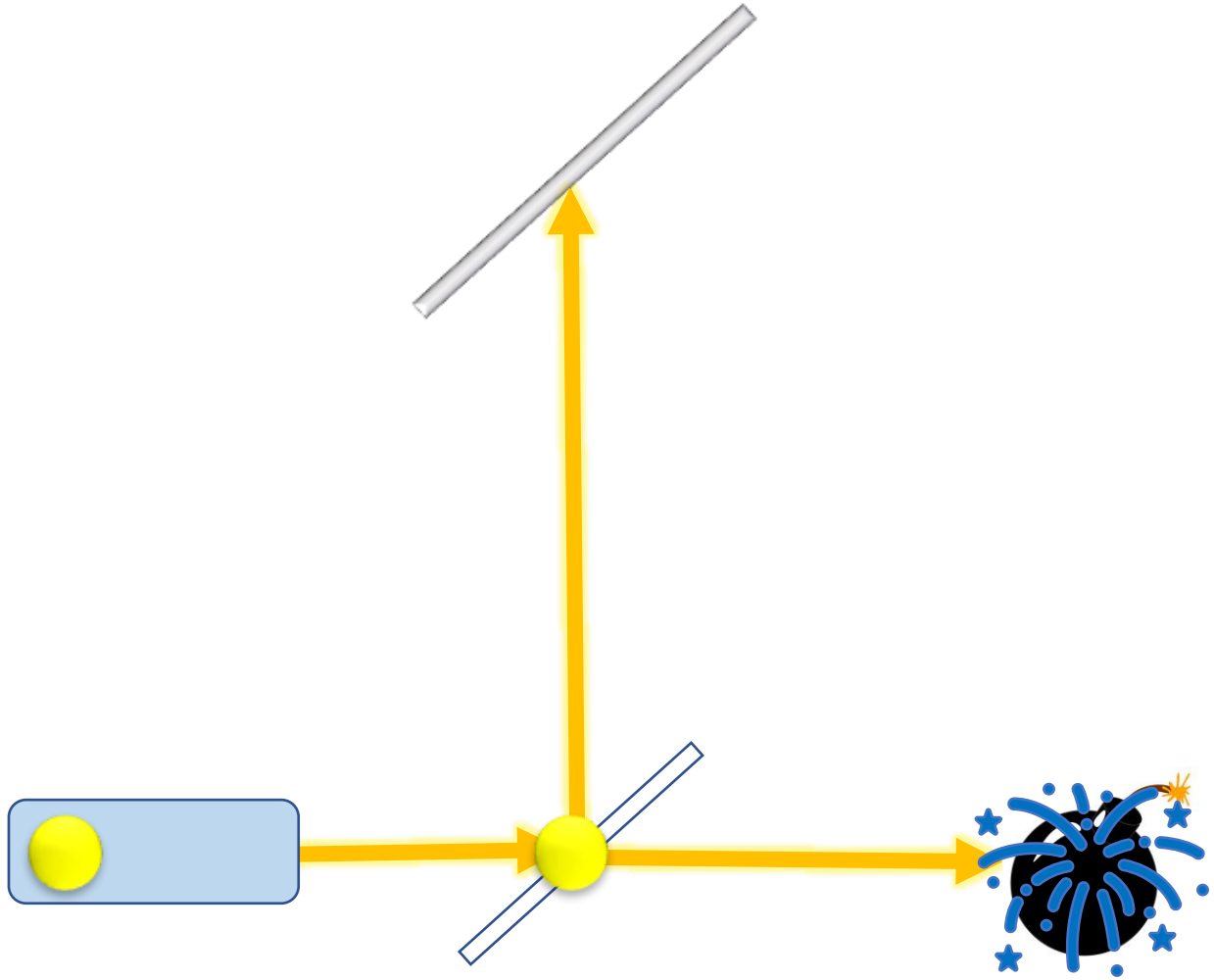
Quantum bomb tester

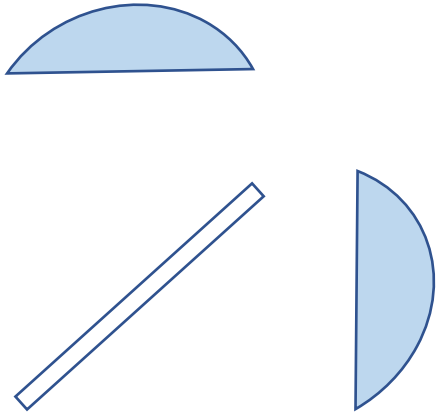


Animation of basic bomb tester with no bomb

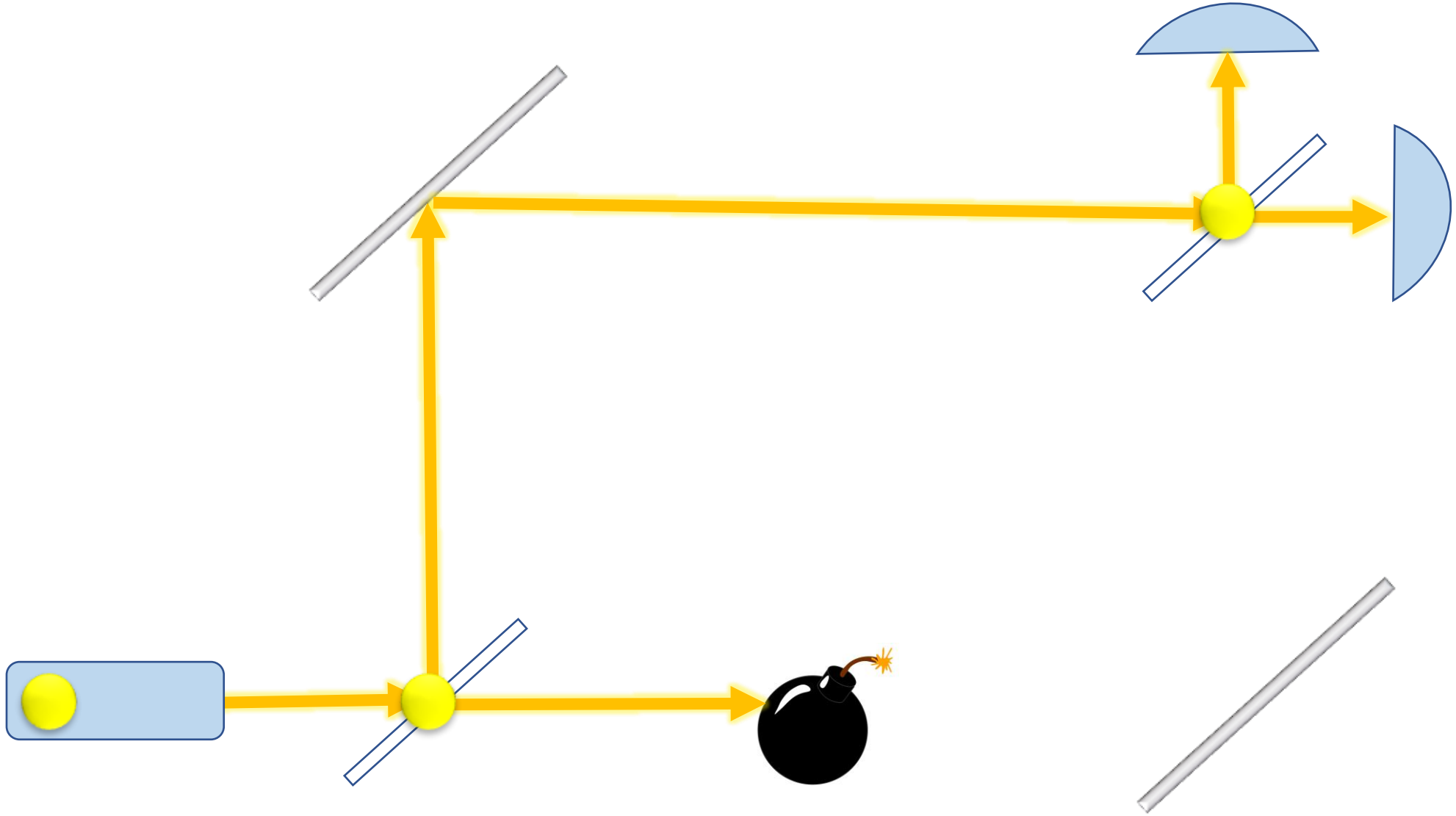


Animation of basic bomb tester with bomb, and bomb explodes

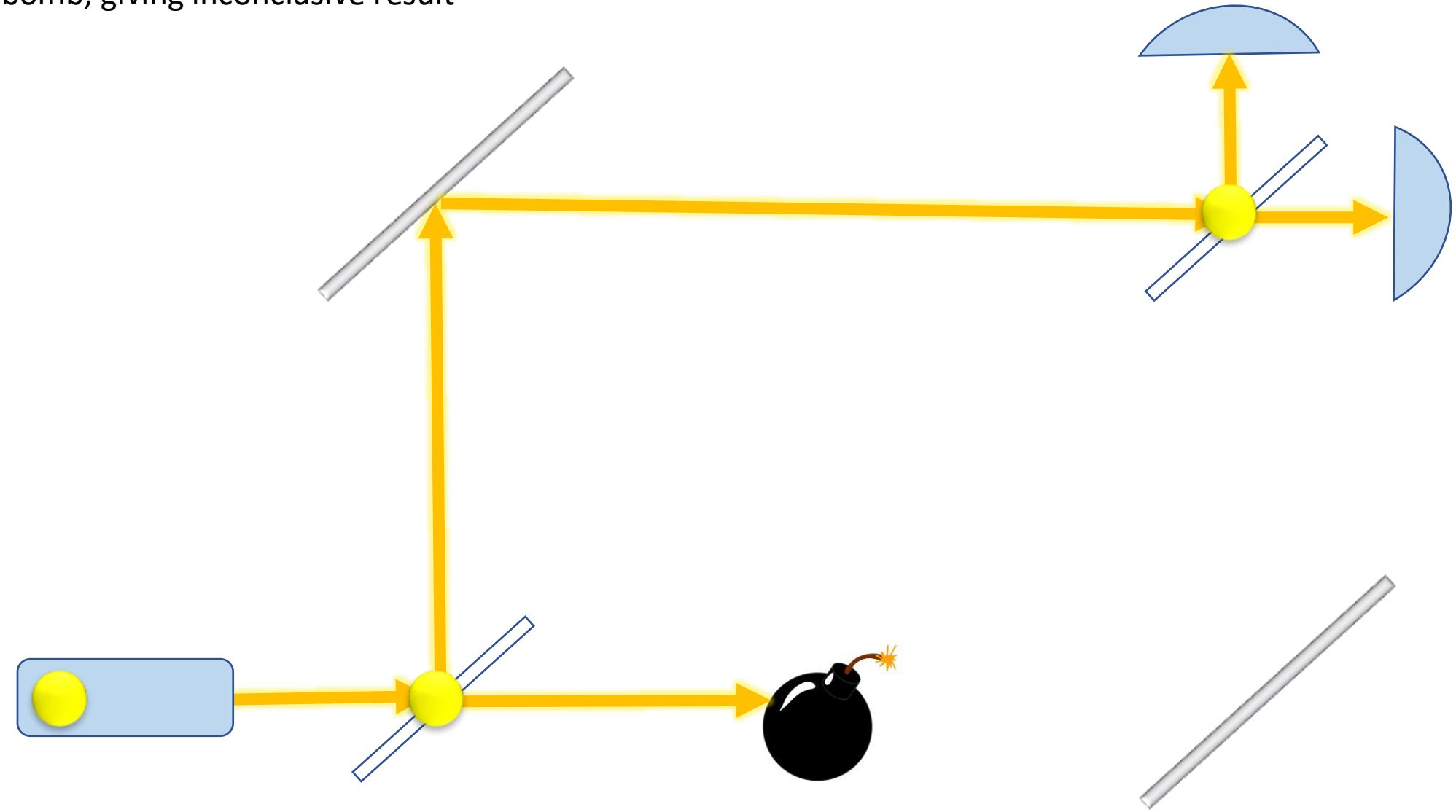




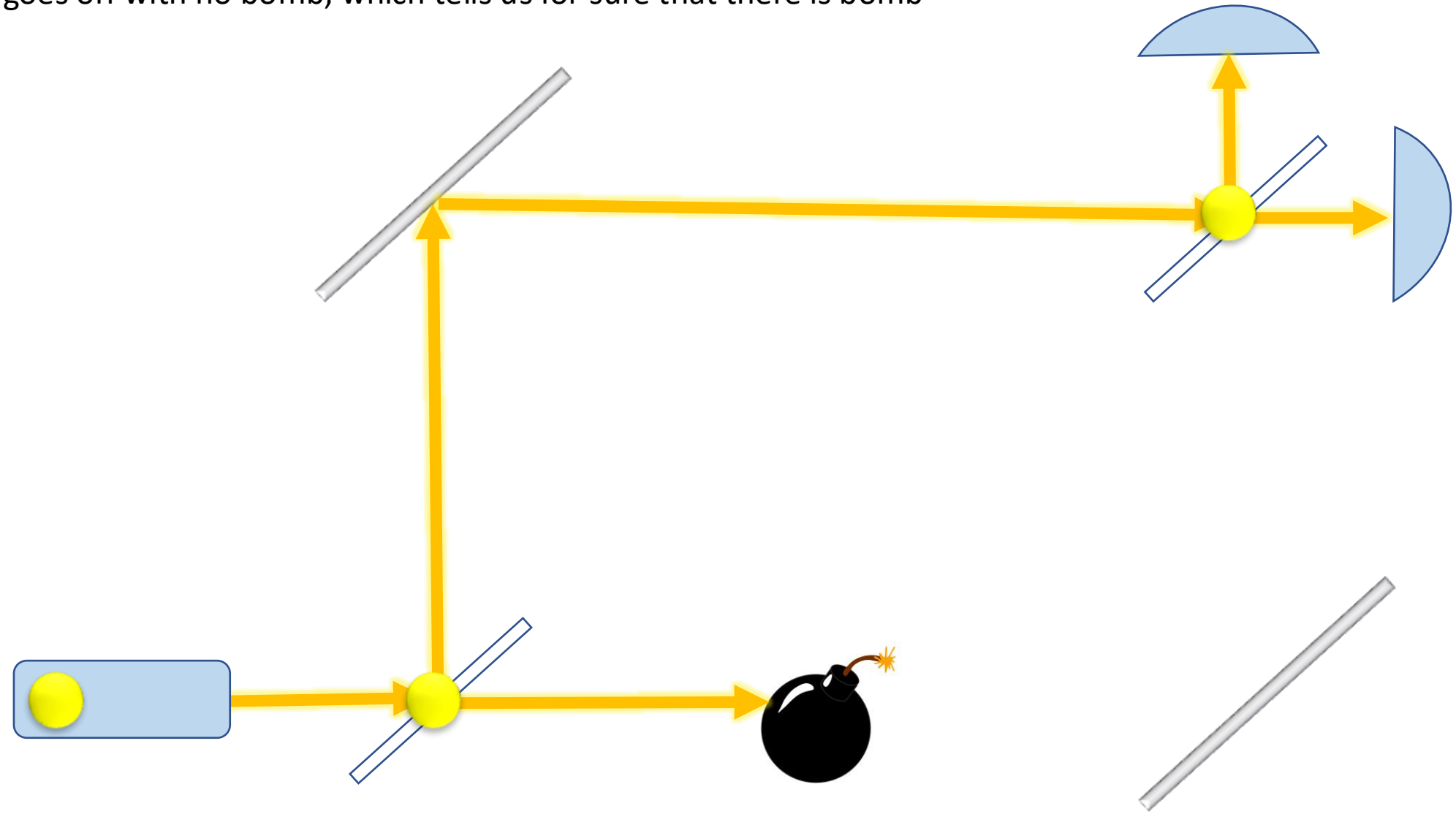
Animation of basic bomb tester with bomb, bomb doesn’t explode



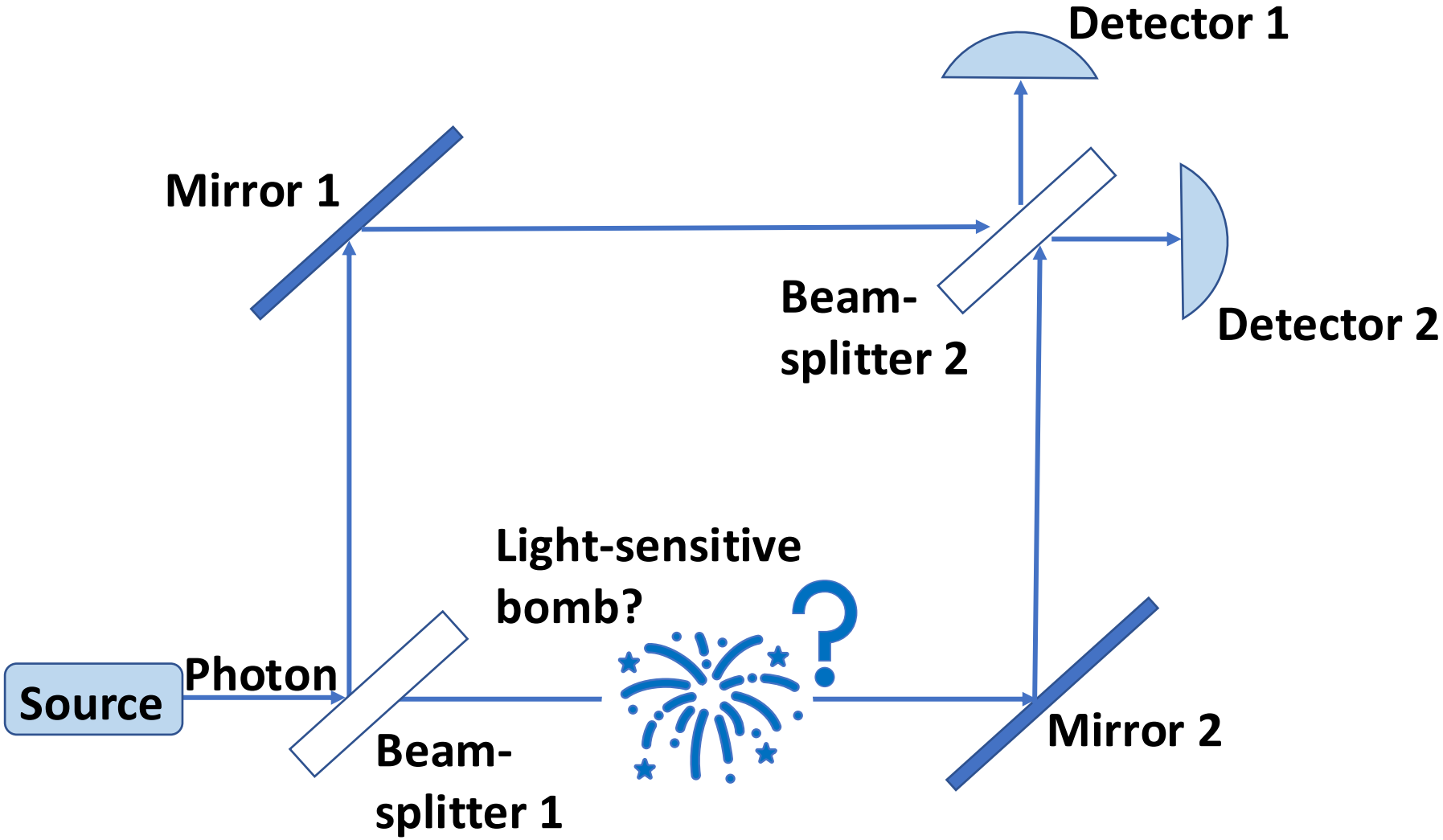
Animation of basic bomb tester with bomb, bomb doesn't explode, photon ends up at same detector as no bomb, giving inconclusive result



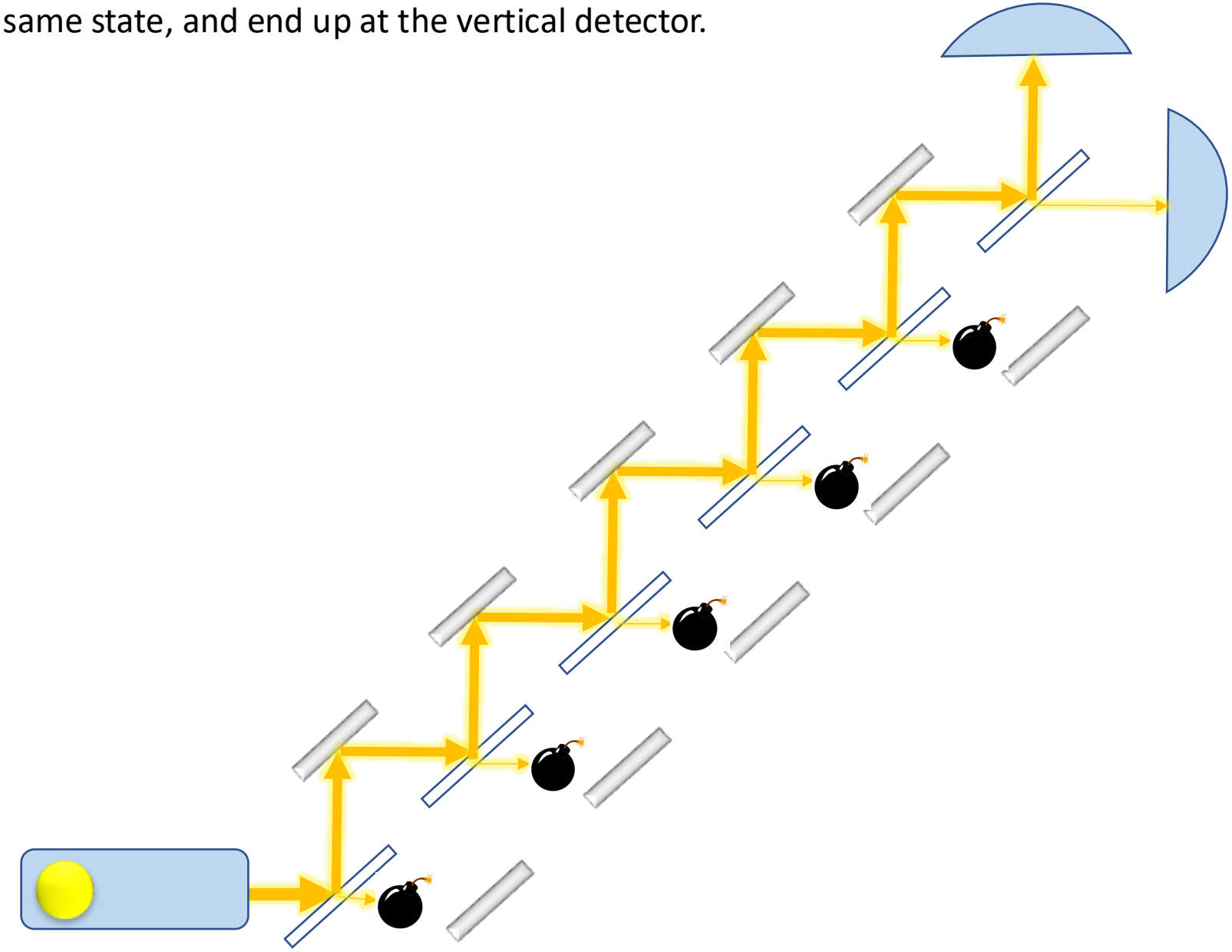
Animation of basic bomb tester with bomb, bomb doesn’t explode, photon ends up at detector that never goes off with no bomb, which tells us for sure that there is bomb



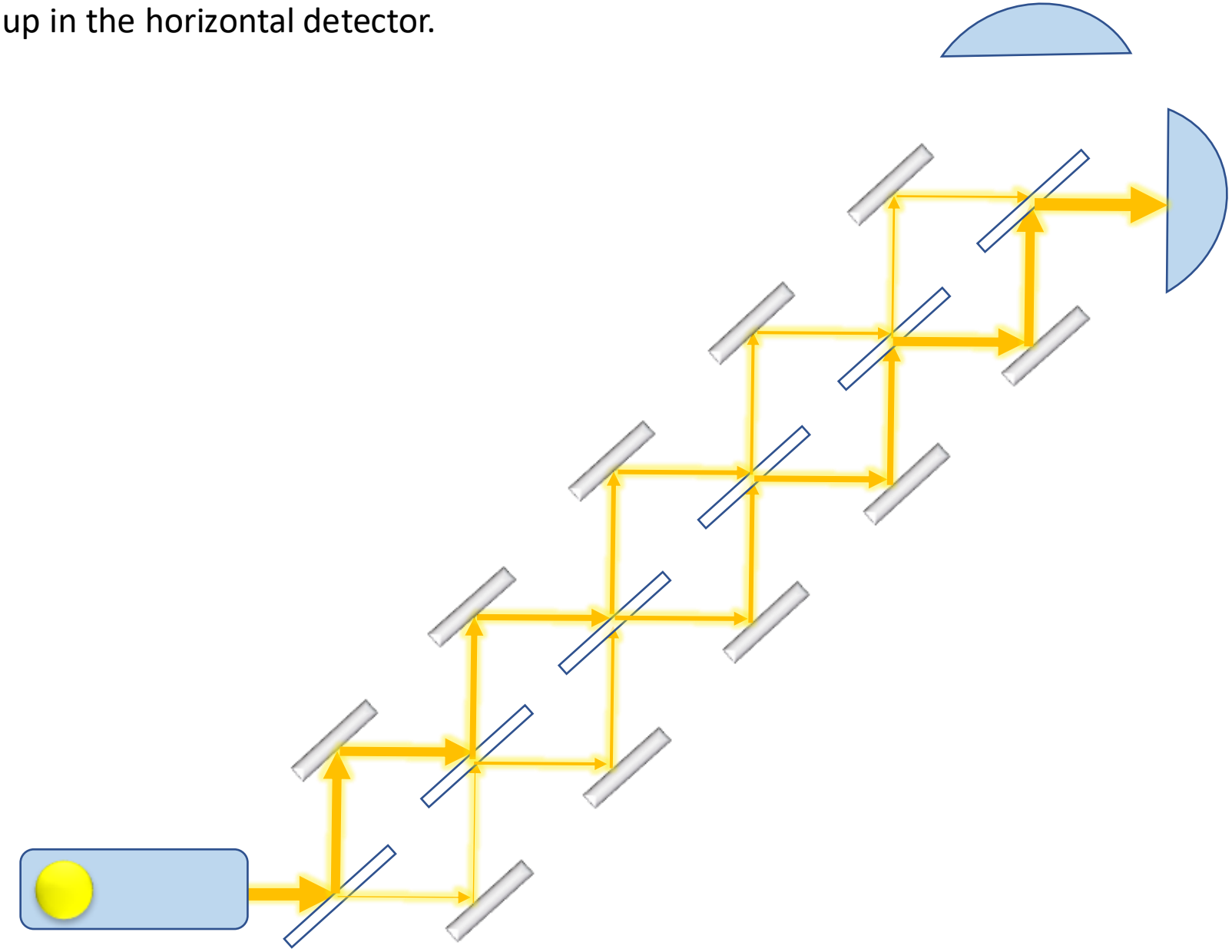
Quantum bomb tester



Improved bomb tester with 6 beamsplitters. When there is a bomb, the photon is likely to stay in the same state, and end up at the vertical detector.



Improved bomb tester with 6 beamsplitters. When there is no bomb, the photon changes state to end up in the horizontal detector.

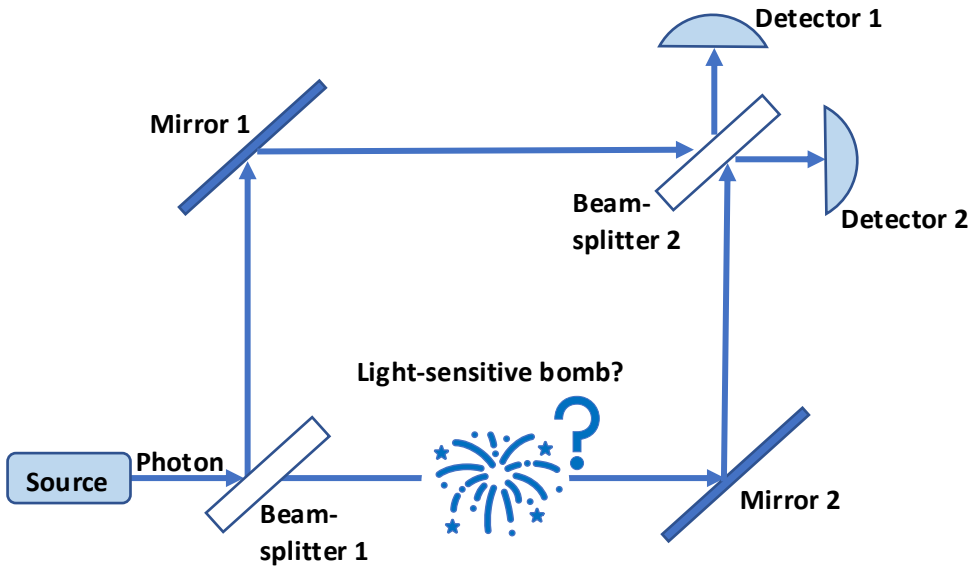


Weird implications & technology

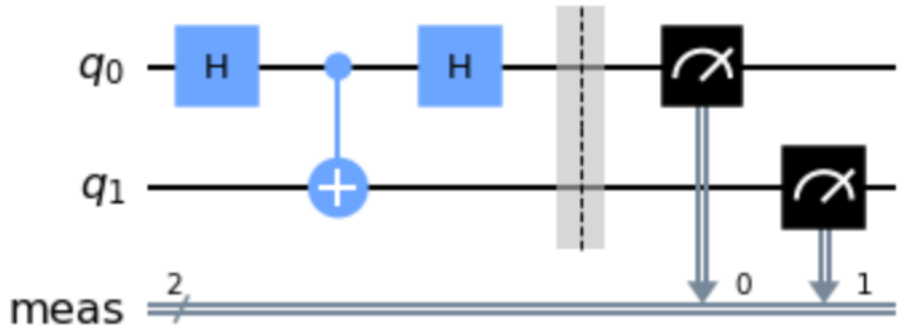
- Imaging delicate objects like cells using interaction-free measurement
- Counterfactual quantum communication (communicate without sending anything physically)
- Counterfactual quantum computing (compute without running the computation)

- ***Evidence for Many-Worlds theory of quantum mechanics?***

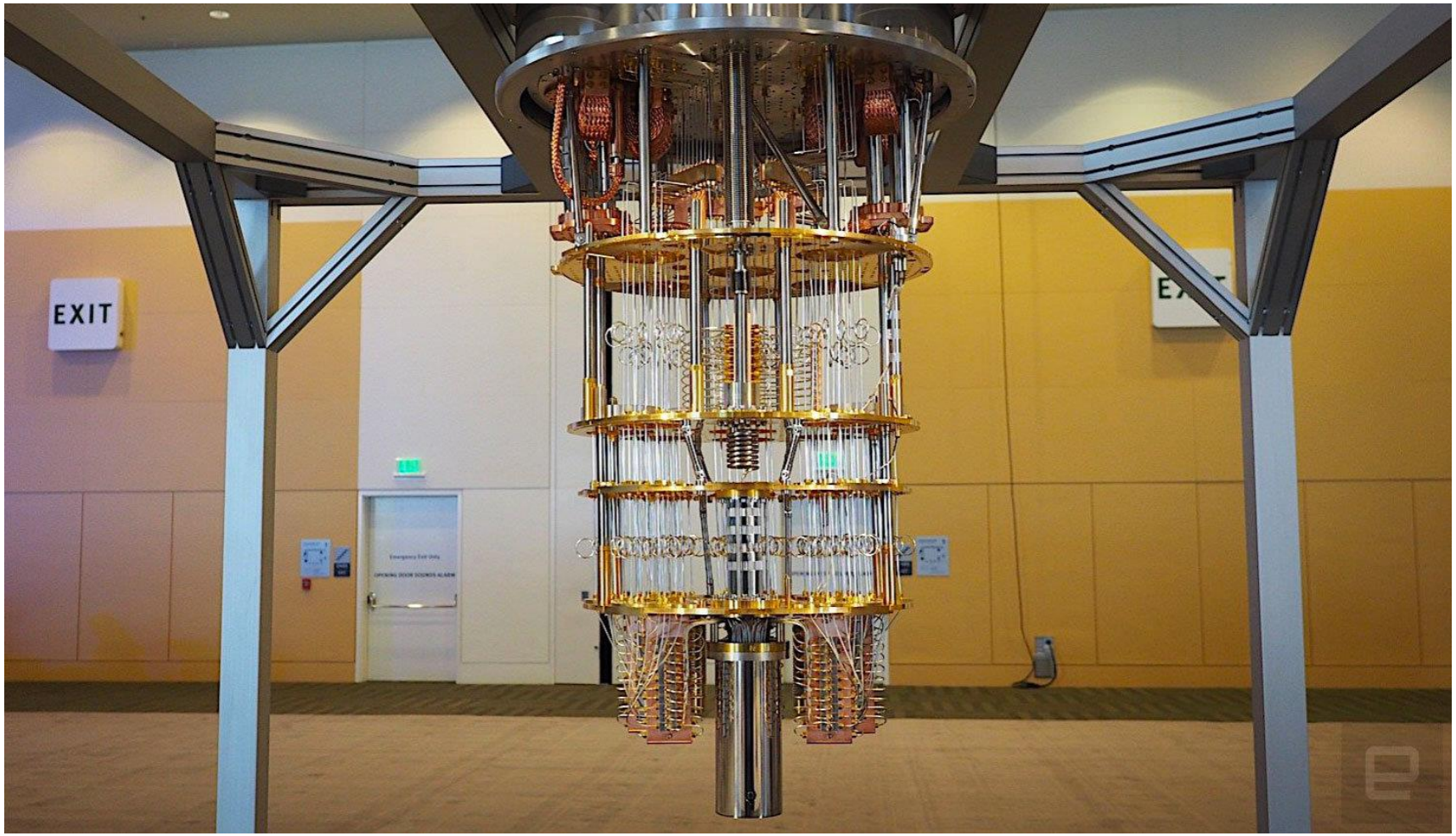
Photons → Quantum computers!



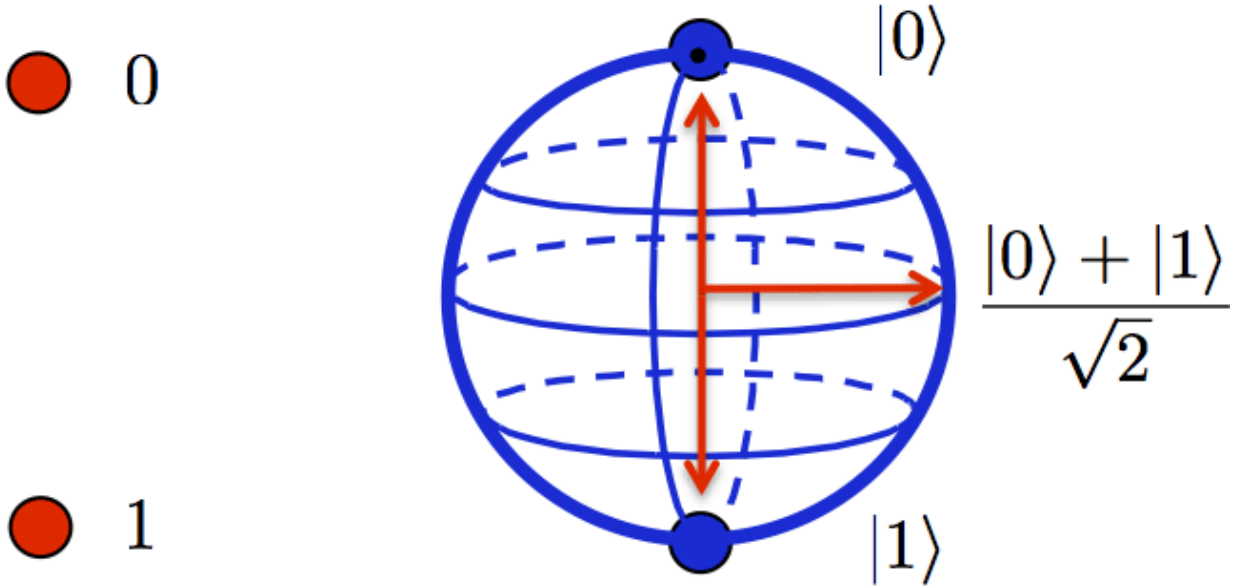

```
bomb_tester = QuantumCircuit(2)
bomb_tester.h(0)
bomb_tester.cx(0, 1)
bomb_tester.h(0)
bomb_tester.measure_all()
bomb_tester.draw(output='mpl')
```



Quantum computing

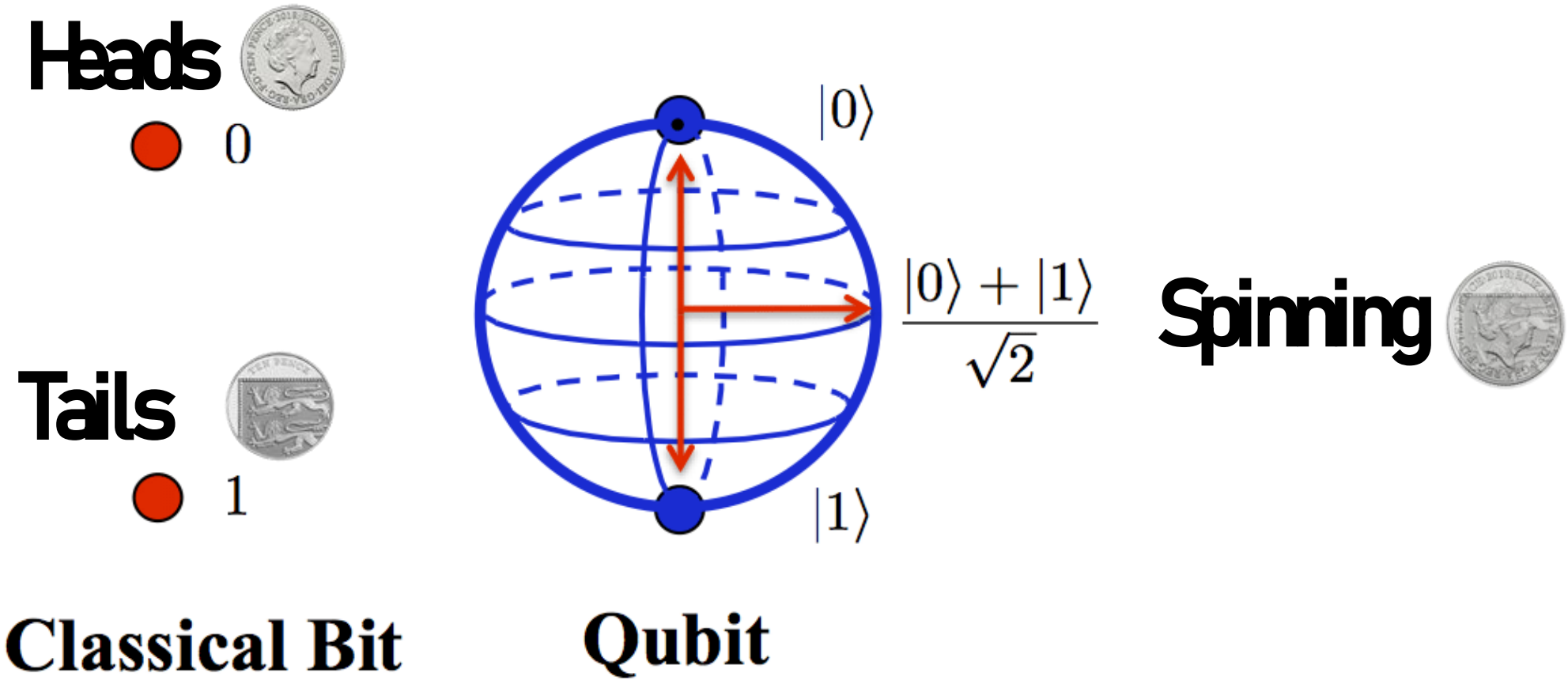


Qubits



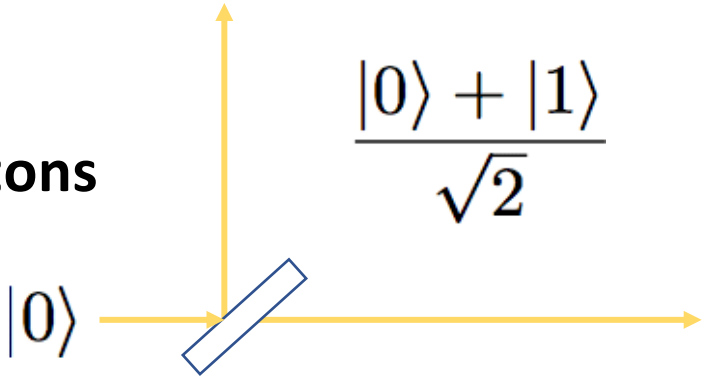
Classical Bit **Qubit**

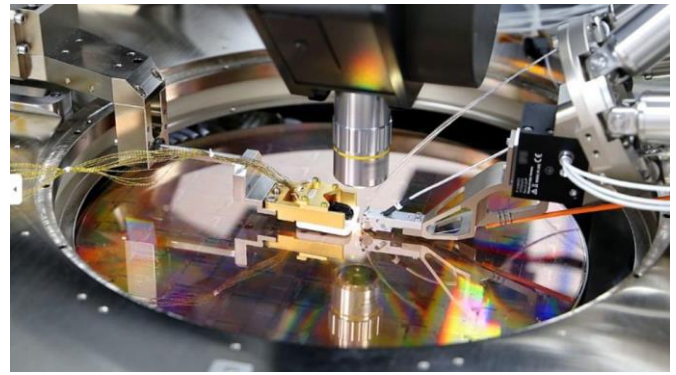
Qubits


Heads
0
Tails
1
Classical Bit
$|0\rangle$
$|1\rangle$
$\frac{|0\rangle + |1\rangle}{\sqrt{2}}$
Qubit
Spinning

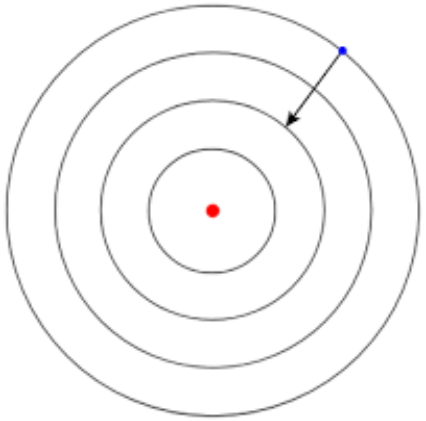
Qubits

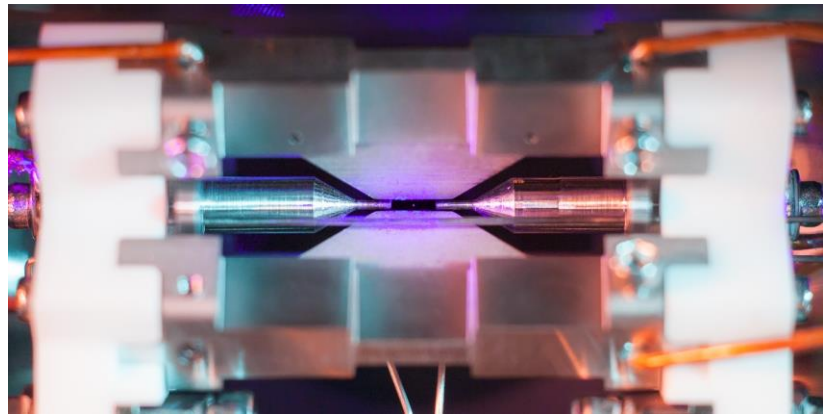
Photons



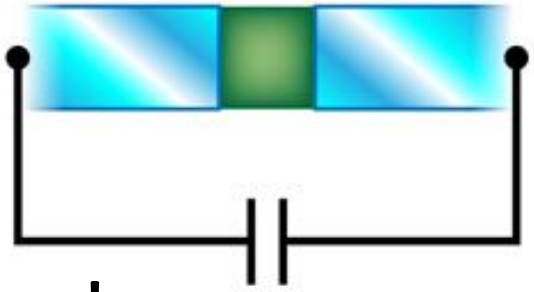


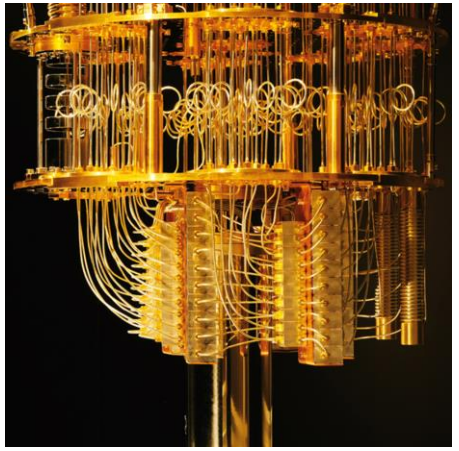
Atoms





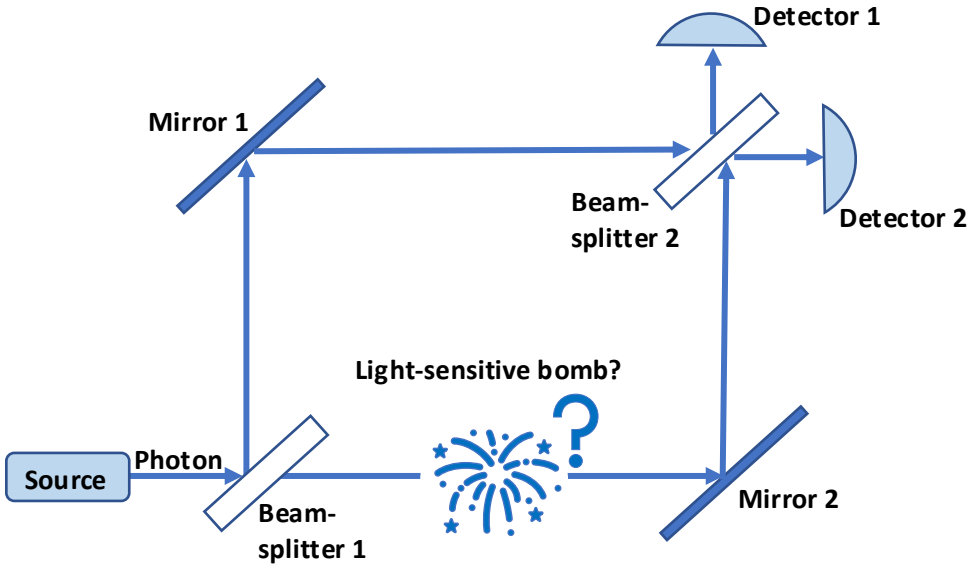
Superconductors



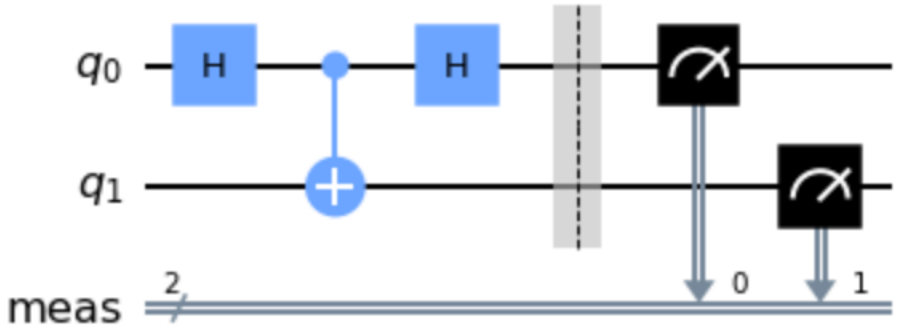


… and lots more!

Quantum circuits




```
bomb_tester = QuantumCircuit(2)
bomb_tester.h(0)
bomb_tester.cx(0, 1)
bomb_tester.h(0)
bomb_tester.measure_all()
bomb_tester.draw(output='mpl')
```



Qubits interact using **quantum gates**

Enter **superpositions** and become **entangled**

Constructively interfere to make the correct outcome have a high probability of being measured

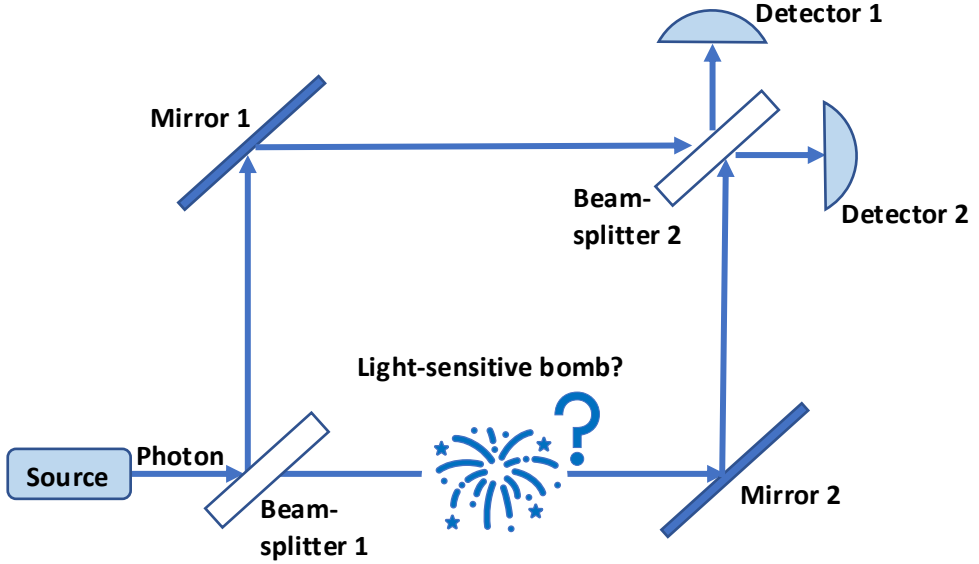
The Maths!

$$|00\rangle \xrightarrow{H_0} \frac{1}{\sqrt{2}}(|00\rangle + |10\rangle)$$

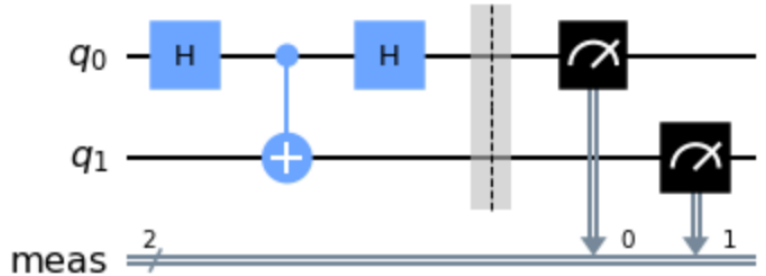
$$\frac{1}{\sqrt{2}}(|00\rangle + |10\rangle) \xrightarrow{\text{CNOT}_{0,1}} \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \xrightarrow{H_0} \frac{1}{2}(|00\rangle + |10\rangle + |01\rangle - |11\rangle)$$

$$\frac{1}{2}(|00\rangle + |10\rangle + |01\rangle - |11\rangle)$$




```
bomb_tester = QuantumCircuit(2)
bomb_tester.h(0)
bomb_tester.cx(0, 1)
bomb_tester.h(0)
bomb_tester.measure_all()
bomb_tester.draw(output='mpl')
```



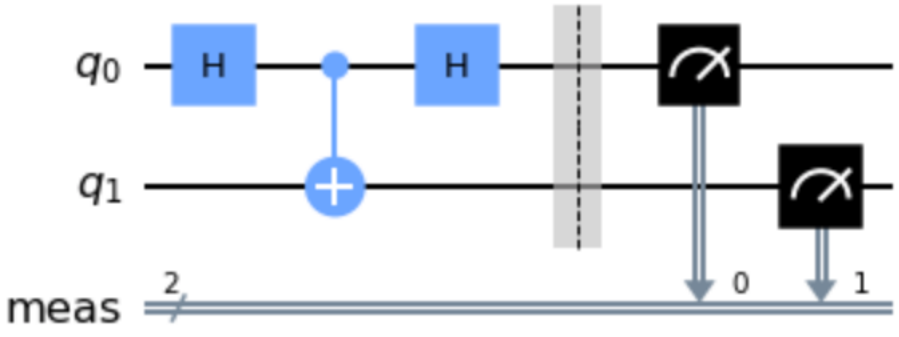
Take-home activities

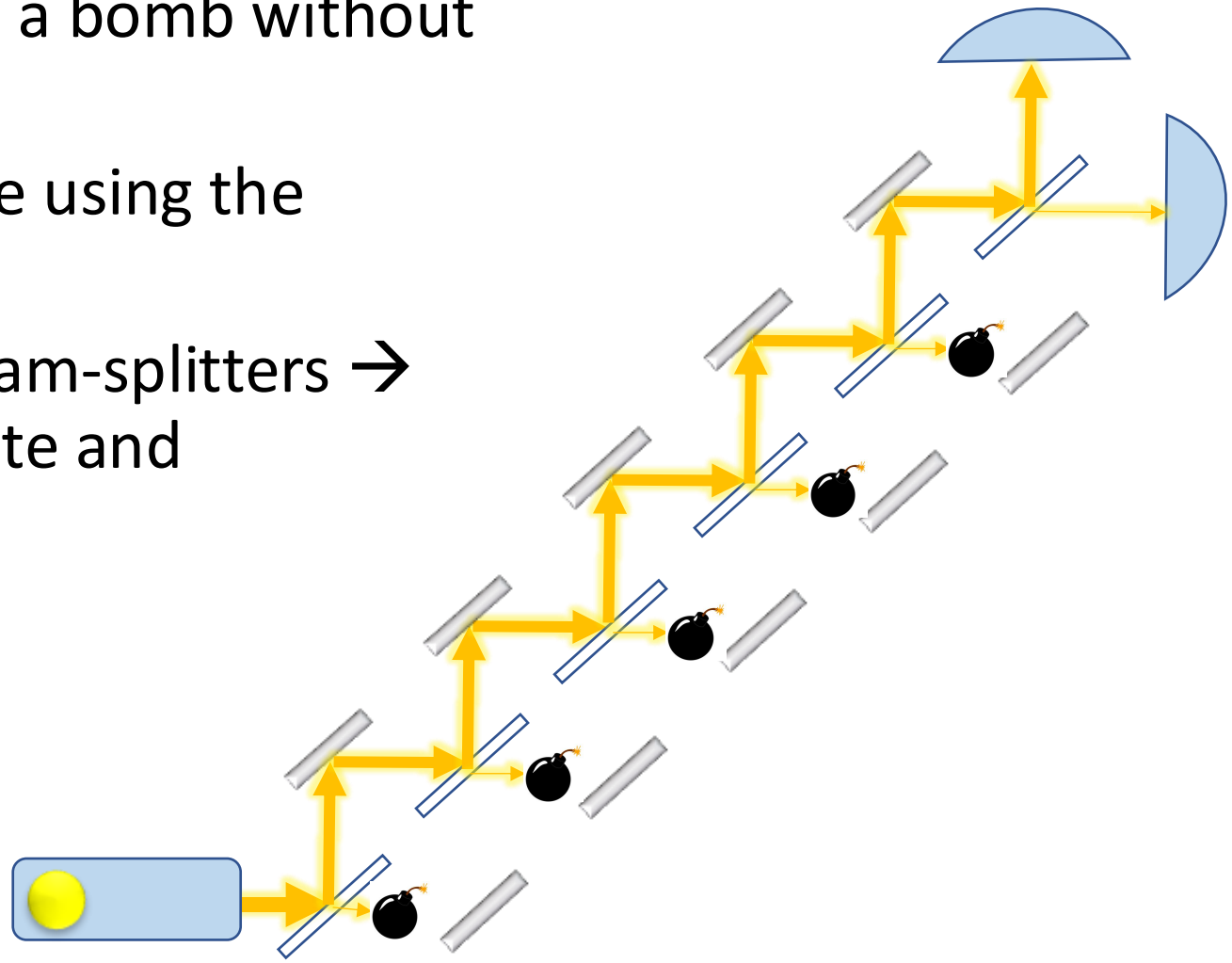
1. **Explain** the quantum bomb tester thought experiment to someone else. Can you draw out the interferometer diagram and explain the different possible outcomes?
2. **Play** with building the quantum bomb tester on the Quantum Flytrap Virtual Lab platform (Solution: https://lab.quantumflytrap.com/lab/elitzur-vaidman-bomb)
3. **Code** a quantum bomb tester simulation yourself using Qiskit in a Colab notebook. Identify the desired state where you've detected the bomb without exploding it! (Solution: https://github.com/maria-violaris/quantum-paradoxes/blob/main/quantum-minesweeper-code.ipynb)

Bonus: Play Quantum Minesweeper game & tell me your scores next week! (code is in my notebook tutorial).

Summary

- Quantum bomb tester lets us see a bomb without looking!
- Can be made up to 100% effective using the quantum Zeno effect
- Turn it into a quantum circuit: beam-splitters → Hadamard, detection → CNOT gate and entanglement.





Any Questions?

Quantum bomb tester content

Quantum Minesweeper Paradox: How to See a Bomb Without Looking

Qiskit • 16K views • 2 years ago

→Video https://www.youtube.com/watch?v=fus1nJ6JaTk

→Blog https://medium.com/qiskit/building-quantum-bomb-testers-and-other-thought-experiments-with-quantum-computers-c160060fdde4

→Code tutorial https://github.com/maria-violaris/quantum-paradoxes/blob/main/quantum-minesweeper-code.ipynb

Contact & Content

maria@violaris.com

Maria Violaris

@maria__violaris

mariaviolaris.com

Quantum Paradoxes series on Qiskit YouTube channel

Maria Violaris

Maria Violaris

A Physics Lab Inside Your Head: Quantum Thought Experiments as an Educational Tool (paper)

https://arxiv.org/pdf/2312.07840#:~:text=Now%2C%20quantum%20computers%20are%20putting,get%20creative%20with%20quantum%20computing

Resources: first steps

- Videos
  - Two-part documentary presented by Jim Al-Khalili: "The mind bending story of quantum physics", "Exploring the world of quantum physics"
  - Quantum Enigmas animated video series introducing quantum computing using puzzles.
  - Quantum bomb tester videos: Seeing without looking short movie, Up and Atom explainer, Sabine Hossenfelder explainer, my "Quantum Minesweeper" video about coding a bomb tester on a quantum computer (gets technical)
  - Quantum on the Clock competition winners – 21 three-minute videos about quantum science and tech made by High School students.
- Articles
  - Quantum City "Everyday Guide to Quantum Science"
  - Quantum articles on PLUS maths magazine: **"Who killed Schrodinger's cat?"**, **"A brief history of quantum field theory"**, **"What is quantum computing?"**
  - Physics World magazine
  - Quanta magazine
- Books
  - Quantum in Pictures, The Science of Can and Can't, Quantum Computing since Democritus (advanced), The Fabric of Reality, Decoding Reality

Resources: next steps

- Interactive online learning resources
  - Qiskit resources for learning quantum computing: online textbook, YouTube course and videos
  - UK Quantum Technologies Programme resources aimed at 16 - 18 year olds.
  - Quantum Computing for the Very Curious
- Online courses
  - "Qubit by Qubit" beginners quantum computing course for High School students and above, with scholarships for underrepresented participants.
  - Quantum Explorers for High School and above. Cohort-based, non-technical basics then builds up to applications. Updates on website soon, launches in July 2023.
- Opportunities
  - IOP QQQ group Quantum on the Clock schools video competition. Hoping to run again! Updates on webpage and QQQ group Twitter.
  - Quantum Ambassadors programme to engage people working in quantum with schools.
  - Qiskit Advocates Programme. High School students can become one by contributing to quantum computing community, and schools can request Advocates as speakers related to quantum computing.
  - Annual "Quantum Shorts" competition, switches between stories and videos each year.

Other compilations of resources!

- Quantum on the Clock compilation of resources
- Quantum A to Z from Quantum Shorts competition