Qubit Radiation Simulations, Beam Experiments And Error Propagation

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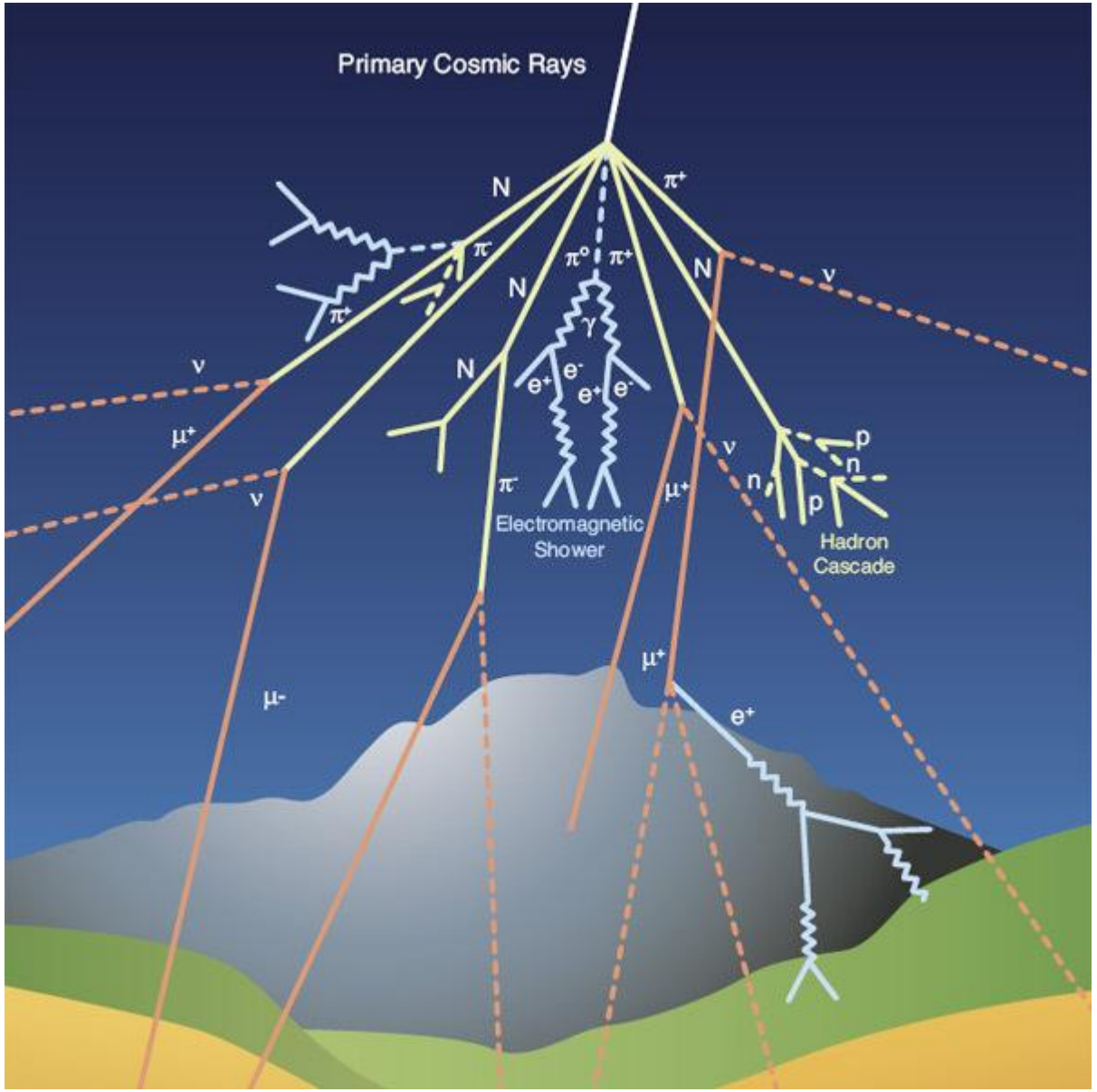
Radiation-Induced faults in Qubits

Energy deposition is known to influence the qubit state.
[Cardani, 2021; Cardani, 2023]

How does the corruption propagate in the quantum circuit?

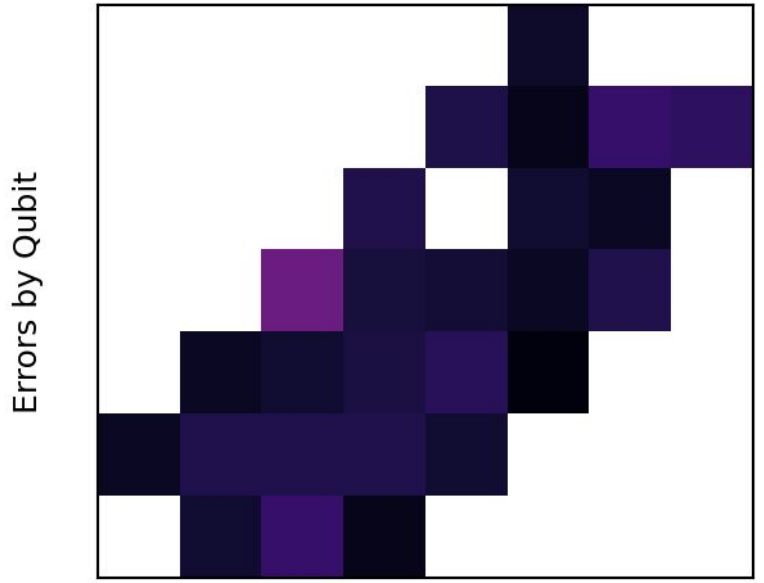
- Physically in time and space
- Logically

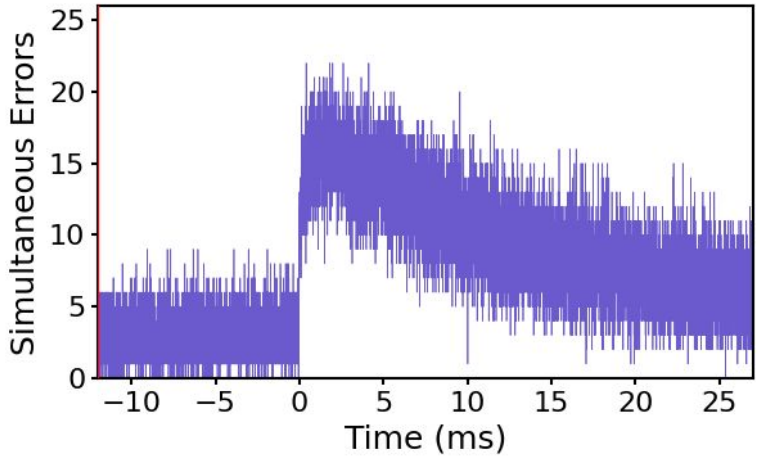


[CERN-DI-9905005, 1999]

Radiation impact on QC

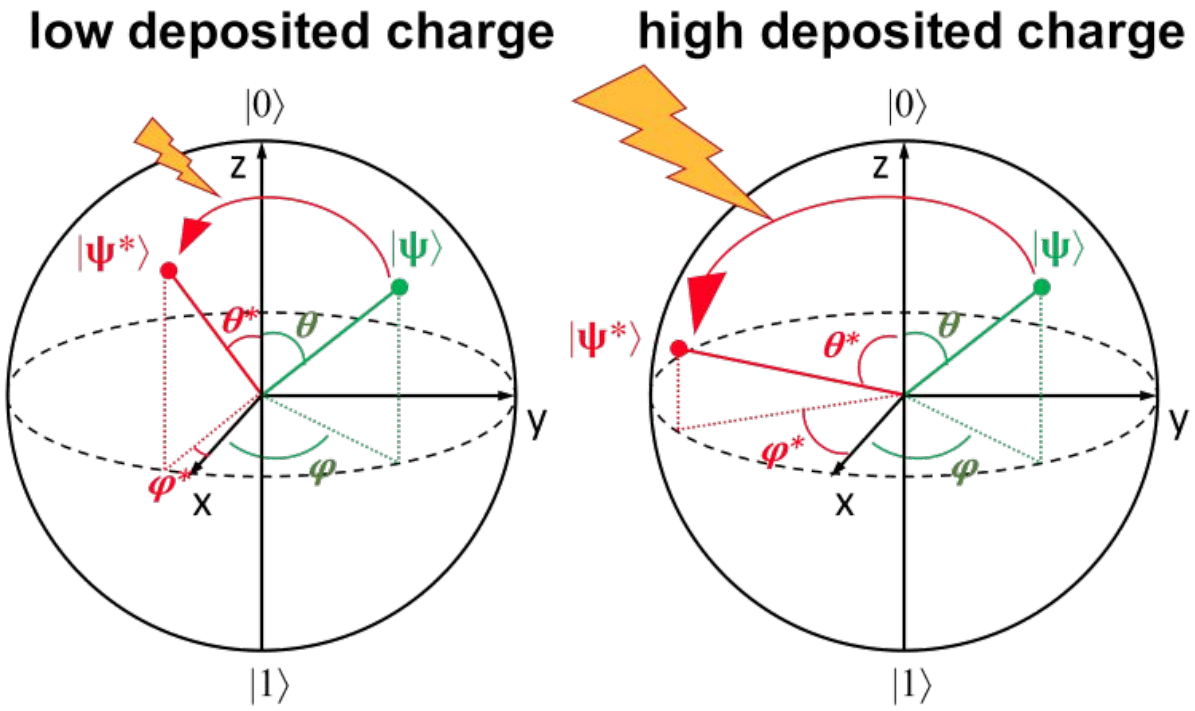
- Field test on Google *Sycamore*:
  10mm^2 chip with 25 qubits
- Fault transient **persistence**: 25ms
  Orders of magnitude **longer** than single circuit execution
- Fault frequency **~ once every 10s**



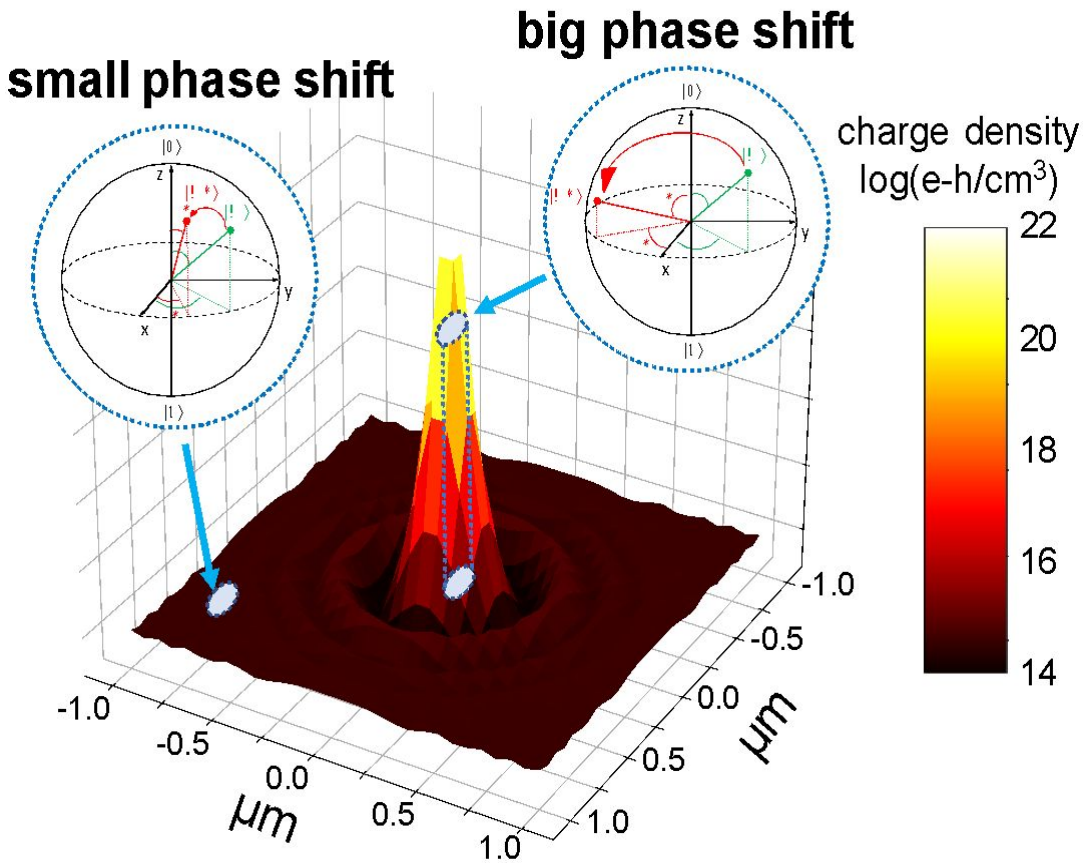


[McEwen et al, 2022]+[GoogleAI blog post]

Ionizing radiation in transmons devices

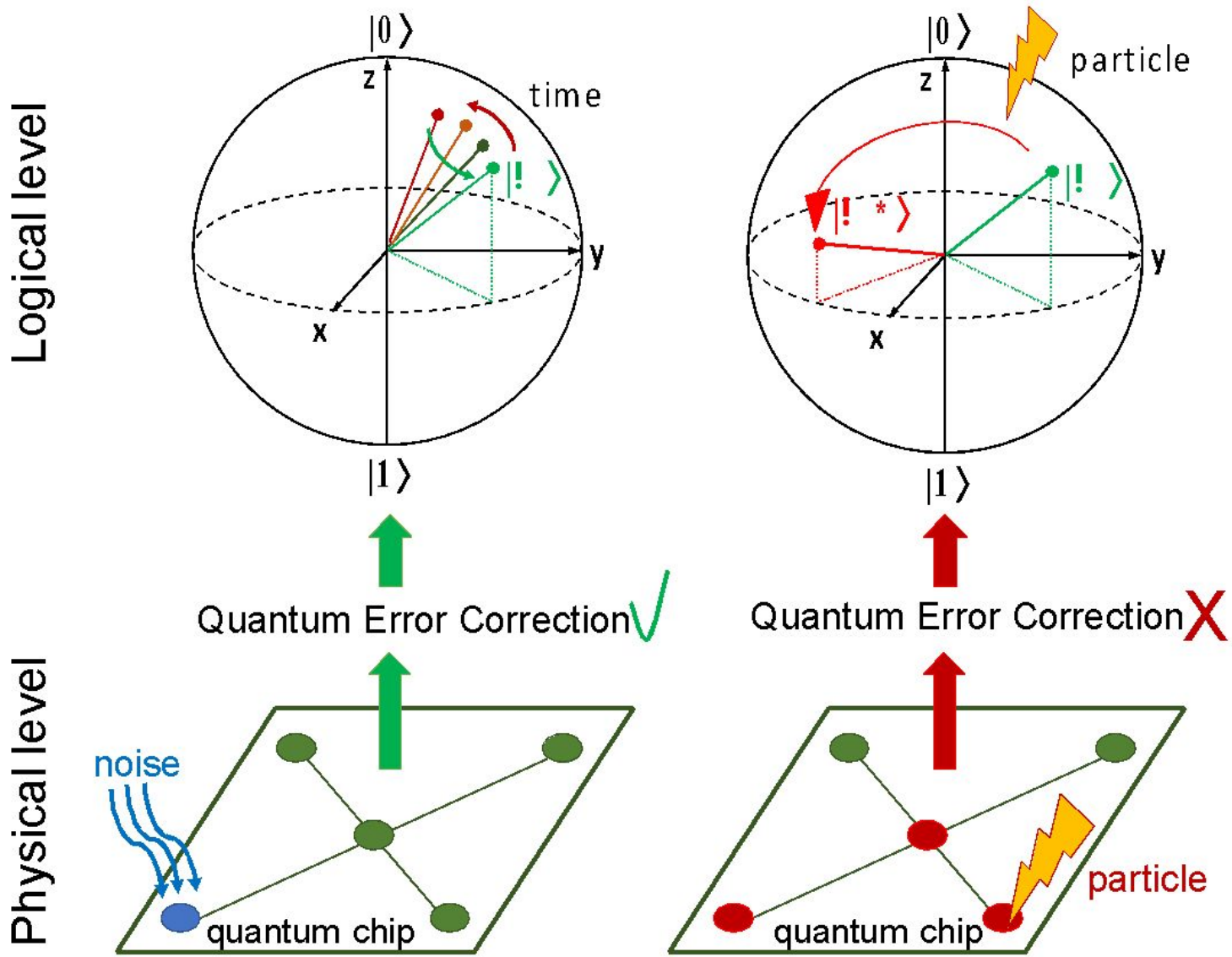


Adapted from: [Wilen et al, 2021]



Any particle of any energy can disturb a qubit. There is no longer a “critical charge”, since qubits state is not binary.

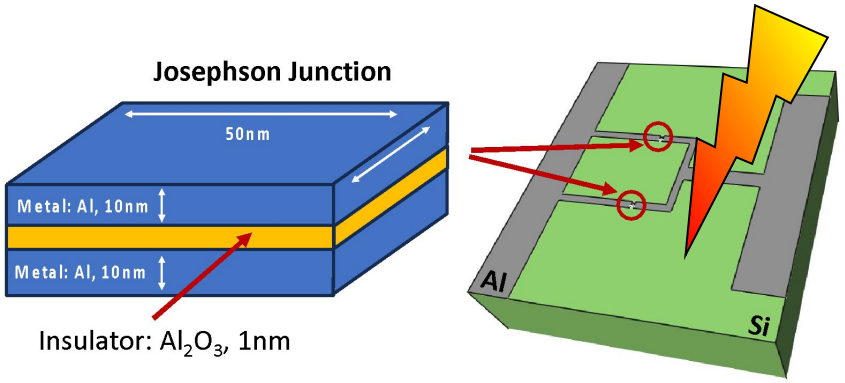
Ionizing radiation in transmons devices



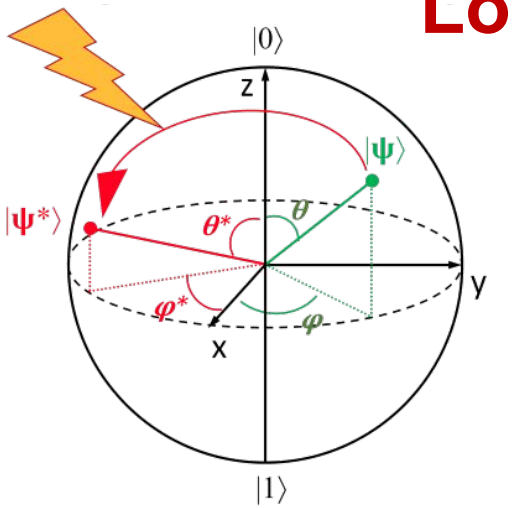
Research path

1 – modelling radiation effect in qubits

Physical level



Logic level



Research path

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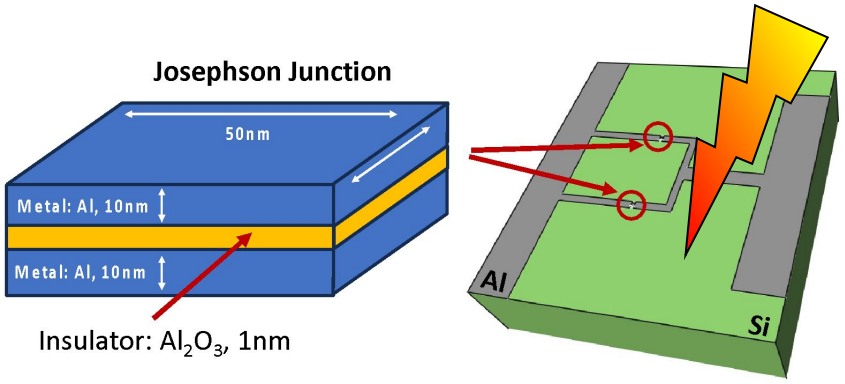
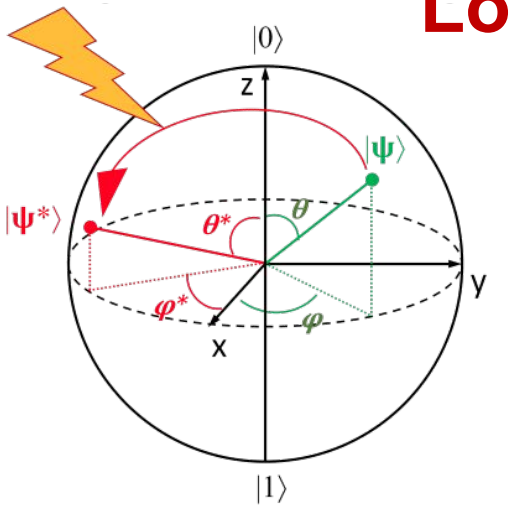
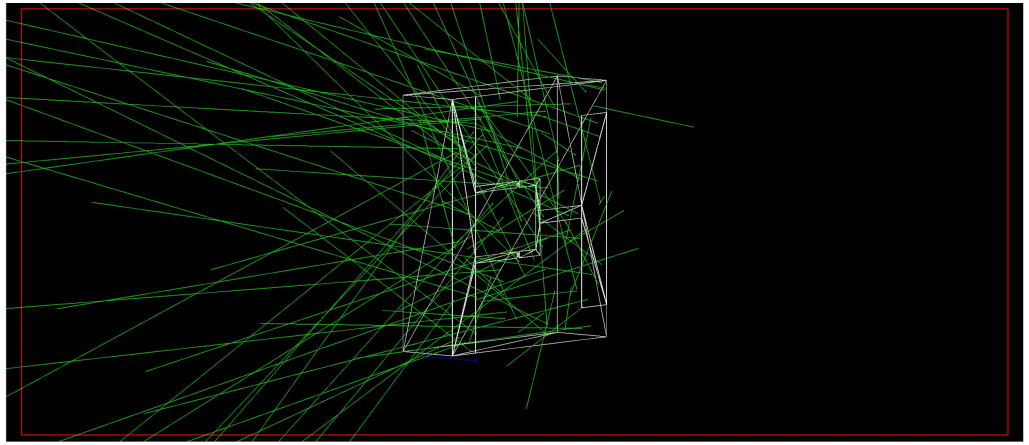
Physical level



Logic level



GEANT4 simulations*



*courtesy Gioele Casagranda

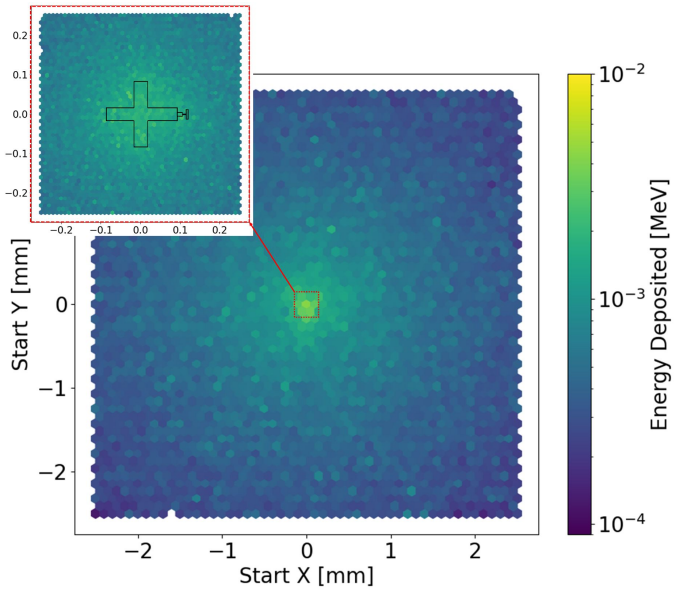
Beam experiments

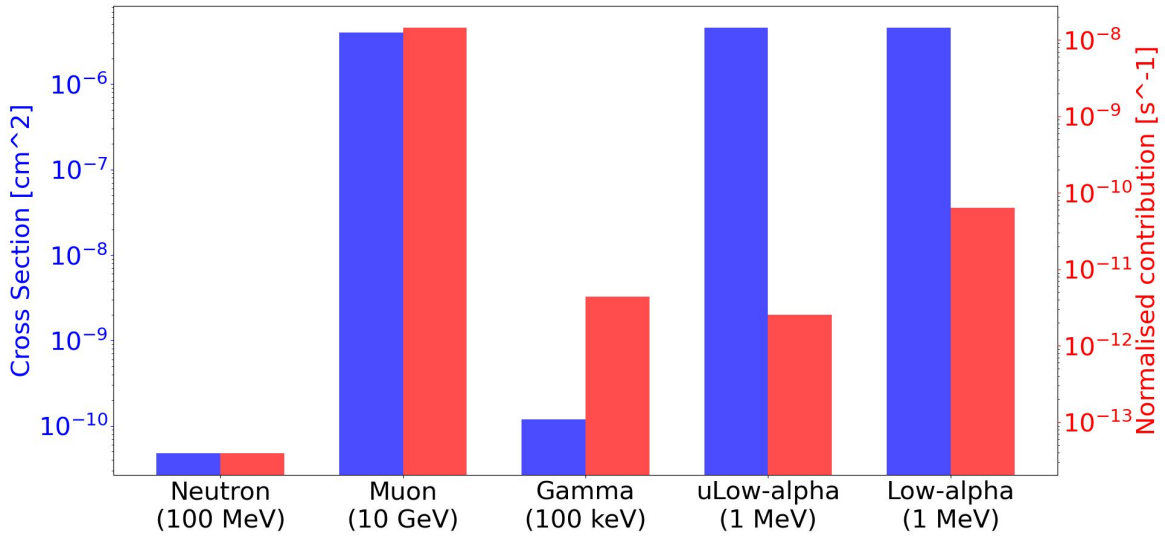
Research path

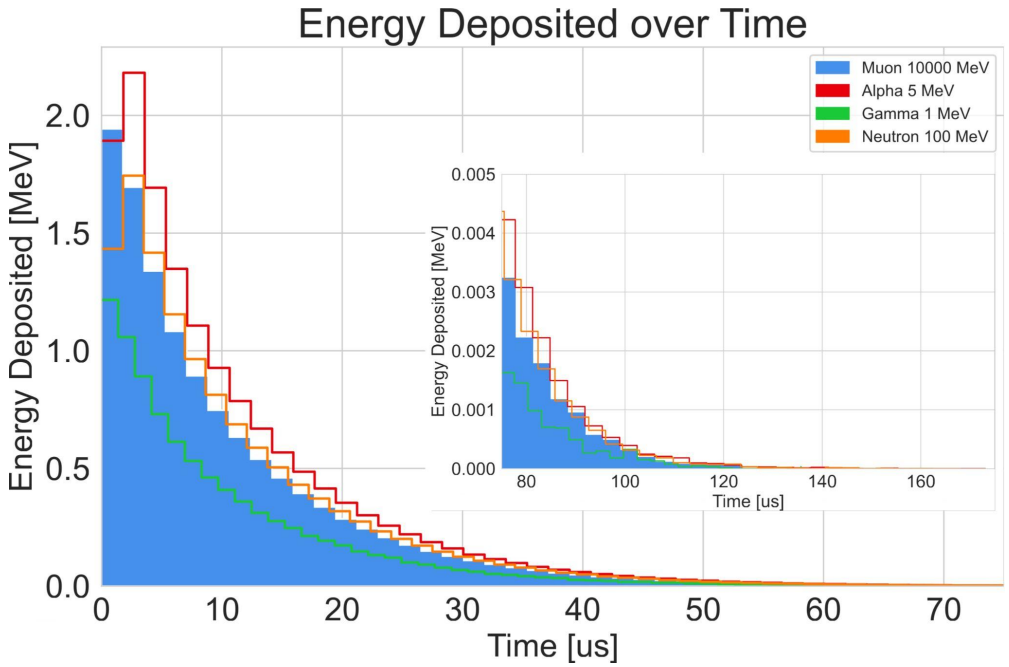
1 – modelling radiation effect in qubits

GEANT4 simulations

- Muons are the most harmful particles
- Energy persistency in the substrate is O(100 us)
- Energy spread in the substrate is (at least) O(mm)



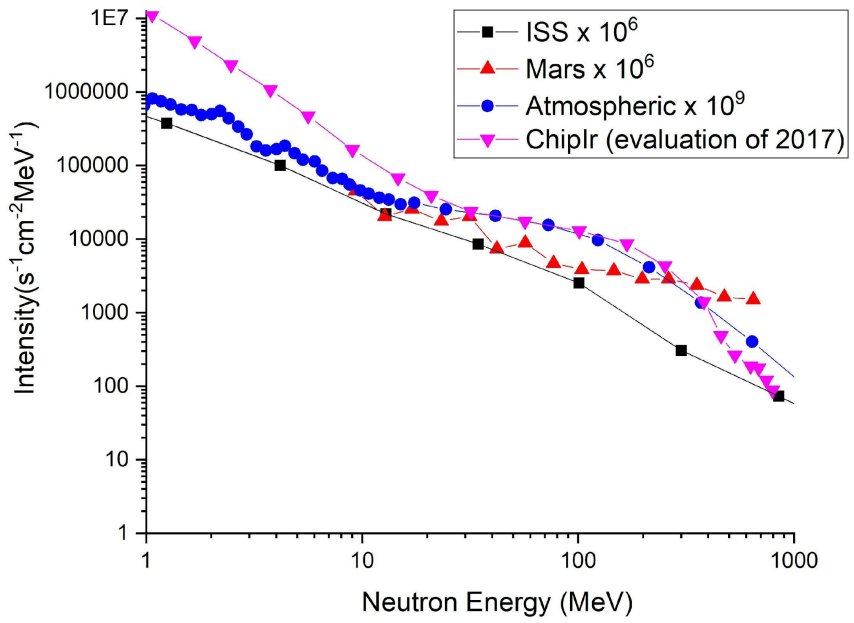




Research path

1 – modelling radiation effect in qubits

ChipIR (Neutrons)



Beam experiments

ISIS

Research path

1 – modelling radiation effect in qubits

ChipIR (Neutrons)

NILE (mono-energetic neutrons)

muons

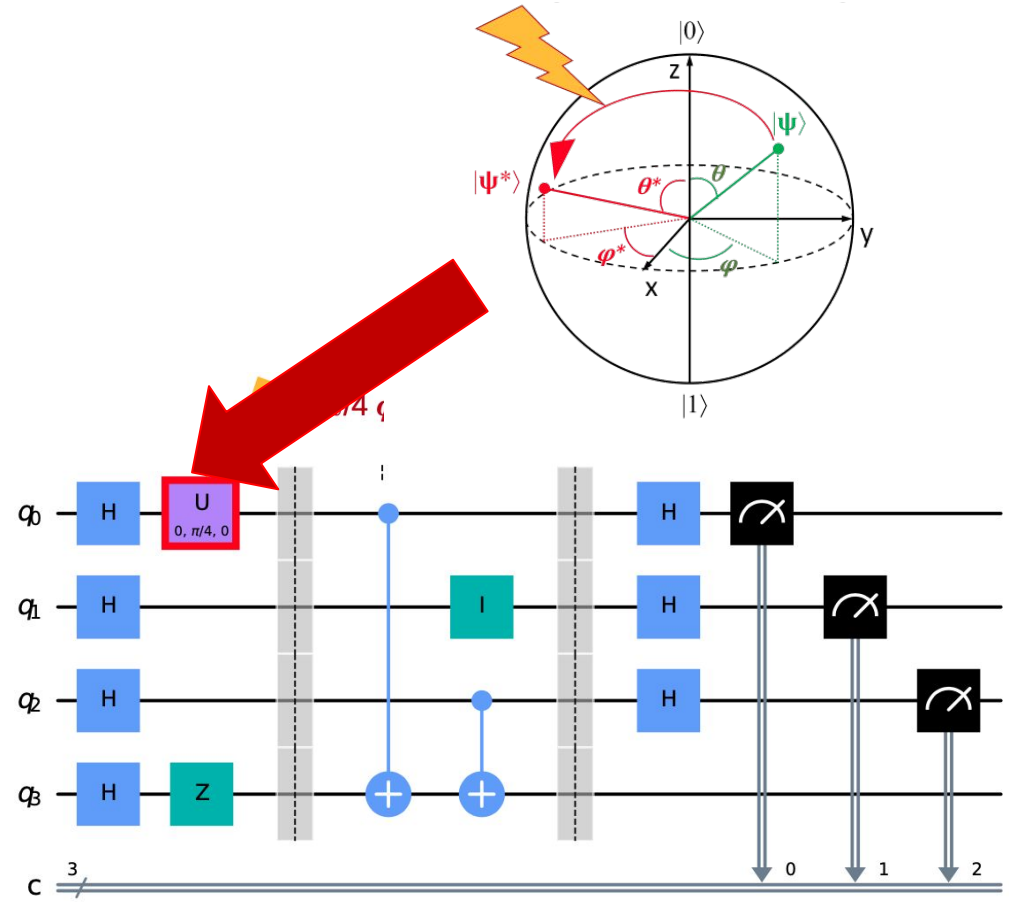
HiCrest

Beam experiments

ISIS

Research path

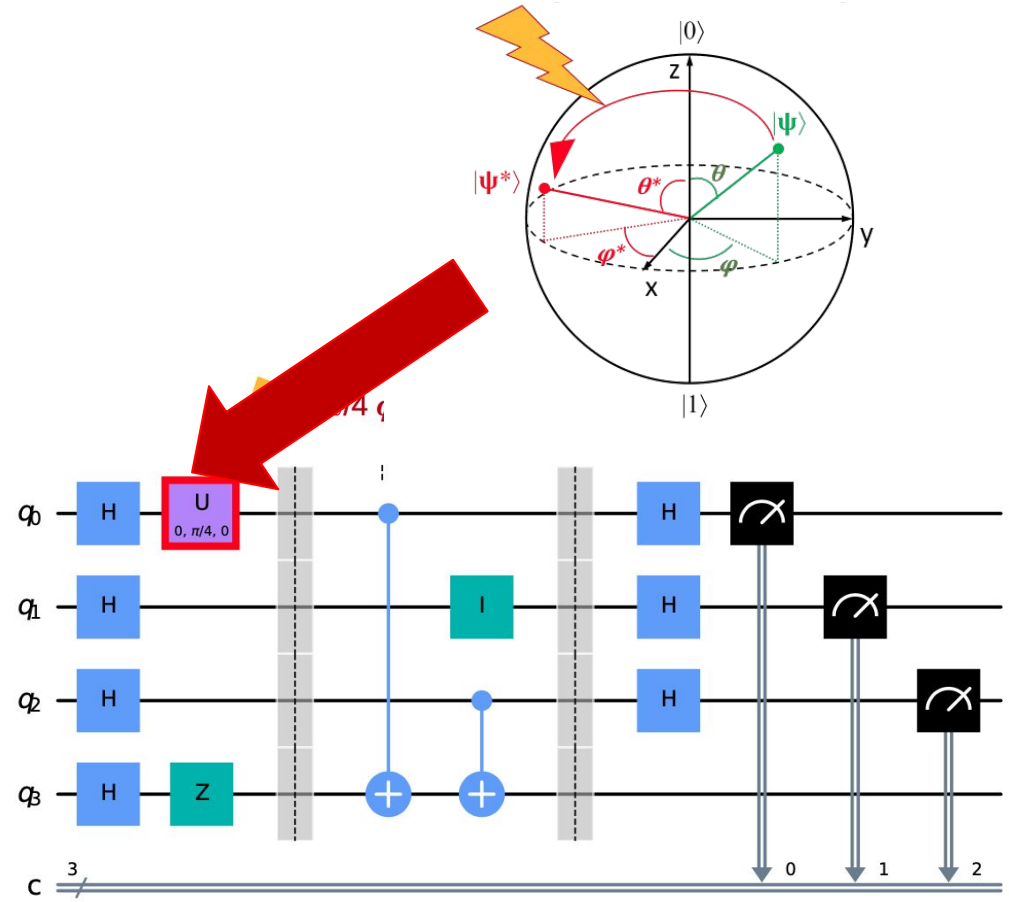
1 – modelling radiation effect in qubits
2 – track fault propagation in quantum circuits*



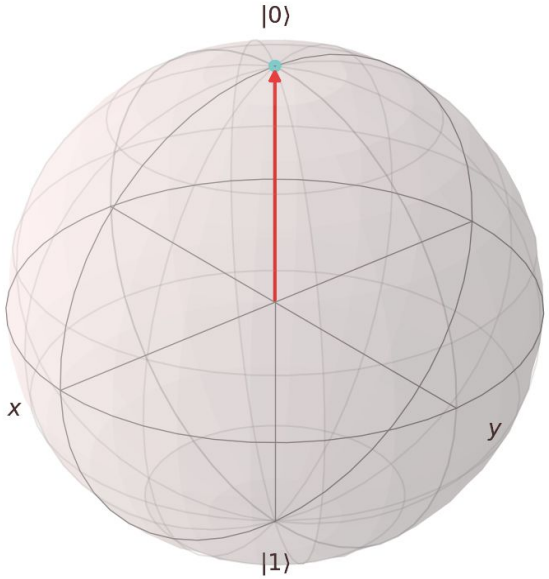
*courtesy Marzio Vallero

Research path

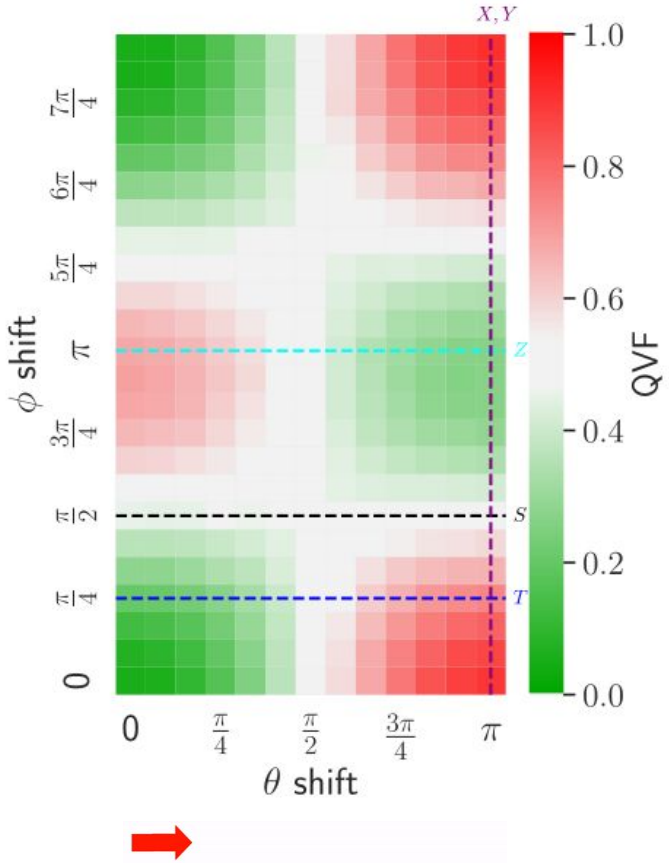
1 – modelling radiation effect in qubits
2 – track fault propagation in quantum circuits



logic fault



circuit output



Research path

1 – modelling radiation effect in qubits
2 – track fault propagation in quantum circuits

3 – understand the operative fault effect in quantum devices

4 – measure the fault probability

5 – reduce fault propagation (QEC?)

6 – design and test improved Qubit layouts

Thanks

CSN5 Technological research

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