TRIUMF

New Initiatives for platforms for:
(1) Advanced AMO*, Precision, Quantum Measurement
(2) Detector Development

*AMO = Atomic, Molecular & Optical

Chloe Malbrunot

Stephan Malbrunot-Ettenauer

Makoto Fujiwara

For Precision/AMO/Quantum Task force

Akira Konaka

For Detector Development Task force

Discovery,
accelerated

AMO, Precision, Quantum Measurement Initiative

Task Force: Sarah Dunsiger, Makoto Fujiwara, Kenji Kojima, Jens Lassen, Chloe Malbrunot, Stephan Malbrunot-Ettenauer, Iain McKenzie, Ruediger Picker, Oliver Stelzer-Chilton, Andrea Teigelhoefer, with input from many people

Excerpts from TRIUMF 20 Year Vision

"Next-generation breakthroughs in fundamental physics will require new theoretical ideas and the application of ***novel technologies*** *such as new materials for future detectors or* ***precision quantum sensing with atoms and molecules****."*

"We will expand our cross-disciplinary expertise in ***precision measurements*** *with quantum objects (e.g., radioactive ions, atoms, molecules, neutrons, muons, antimatter) to drive the development of* ***new quantum measurement techniques*** *for discovery in fundamental physics and applied research."*

Why AMO, Precision, Quantum Measurements at TRIUMF?

- Unique infrastructure as a national lab
  - Accelerators & beams, particle detectors, vacuum, cryogenics, electronics, data acquisition, computing, magnets, project management etc
  - Enables AMO/quantum experiments of complexity that are beyond single university
  - Longstanding expertise on precision measurements on exotic species (mesons, radioactive nuclei etc)
- We have already a suit of AMO/Precision projects at TRIUMF
  - Diverse spectrum of projects of all scales
- Order $100M funded or proposed direct investments in this area
  - E.g. Francium Atomic Parity Violation*, Radioactive Molecules*, ALPHA/HAICU*, Ultracold Neutron EDM, TITAN, Laser Ion Sources/Polarizer, etc.

    [*Talks at TRIUMF x ICAP session on Wednesday – 40 registered from ICAP@Toronto]
  - Similar order of magnitude investment to other high priority projects like ARIEL, IAMI
- It would make sense to highlight this growing area as one of priority areas in FYP!

Centre for Precision Measurement & Quantum Sensing* [*name TBD]

- We propose creation of a new Centre for Precision Measurement & Quantum Sensing* at TRIUMF
  - One of the new initiatives in the TRIUMF Five Year Plan 2025 – 2030
  - A focal point for atomic, molecular, quantum sensing activities at TRIUMF, currently spread across departments and divisions
  - Primary interest in fundamental physics, but will also explore societal applications
  - Serves the TRIUMF and Canadian community
  - Connects to the international efforts
  - Synergies with other initiatives; Detector, CMMS, Computing, Theory, Training Centres
- National & International Context
  - Worldwide interest in applications of AMO/Quantum techniques for fundamental physics, e.g. at FNAL, CERN, KEK, UK QTFP
  - Lack of fundamental physics perspective in the current Canadian Quantum Strategy discussions — A gap in Canadian research ecosystem

Possible Implementation

2021-2024

Step 1

Closer interactions among APQ researchers at TRIUMF
and across Canada: Discussion forum, seminars, workshops etc.

We are here now!

2025

Step 2

Formal "Centre/Institute" with limited new resources:
A line item in FYP with new hires in Sci/Tech dept in cryo, mech engineers/techs,
-access to the existing resources, e.g. design office

2025-30

Step 3

Blue sky: Together with other initiatives (Detector, CMMS, Theory, Training etc.)
much needed new building for lab, office, technical human power

Detector Development Initiative

Vision of the Detector centre/platform

- Support operational excellence
  - Nurture and develop state-of-the-art detector technologies
    - The first TPC in an experiment (TRIUMF E104)
      - leads to new projects: Hermes TRD, E787 DC, Babar DC, T2K TPC, ALPHAg, TACTIC, …
    - The first SiPM in an experiment (T2K FGD)
      - leads to new projects: μSR, nEXO/ARGO, environmental monitoring…
  - Facilities for construction, calibration, and testing
    - Scintillator shop, ATLAS wire bonding facility, clean rooms, MHESA
    - M11, PIF/NIF, PTF, PHARR
- Training HQP opportunities
  - Coop/summer student program, TRISEP/GRID, Master class, Kirkness program
- Facilitate detector developments across the laboratory and Canada
  - TRIUMF to become a detector centre like CERN
  - Nuclear/Particle, CMMS, Accelerator (diagnostics),
  - Applications (TRIUMF innovations): Life Science, green technologies, space science
- Complementary to CFI funding projects

Detector centre/platform implementation

- Keep up with the state-of-the-art detector technologies
  - Expert personnel
  - Stable funding for sustained technology development
- Infrastructure for detector development
  - Maintaining the detector development facilities
  - Renew equipment (LADD2)
    - restore electronics pool
- Facilitate detector development
  - Laboratory-wide resource sharing
  - Technology transfer
  - Training program
- A new building to house the Detector Centre/Platform

Backup slides

Quantum sensors: definition

quantum sensors register a change of quantum state caused by the interaction with an external system:

- transition between superconducting and normal-conducting
- transition of an atom from one state to another
- change of resonant frequency of a system (quantized)

Then, ***a "quantum sensor" is a device, the measurement (sensing) capabilities of which are enabled by our ability to manipulate and read out its quantum states.***

and because the commensurate energies are very low, unsurprisingly, quantum sensors are ideally matched to low energy (particle) physics;

→ focus on CERN activities both in low energy and high energy particle physics

(I will not however be talking about entanglement and its potential applications)

5/32 EP seminar, 13.5.2022

Michael Doser, CERN Quantum Technology Initiative

I. Use of a quantum object to measure a physical quantity (classical or quantum). The quantum object is characterized by quantized energy levels. Specific examples include electronic, magnetic or vibrational states of superconducting or spin qubits, neutral atoms, or trapped ions.

II. Use of quantum coherence (*i.e.*, wave-like spatial or temporal superposition states) to measure a physical quantity.

III. Use of quantum entanglement to improve the sensitivity or precision of a measurement, beyond what is possible classically.

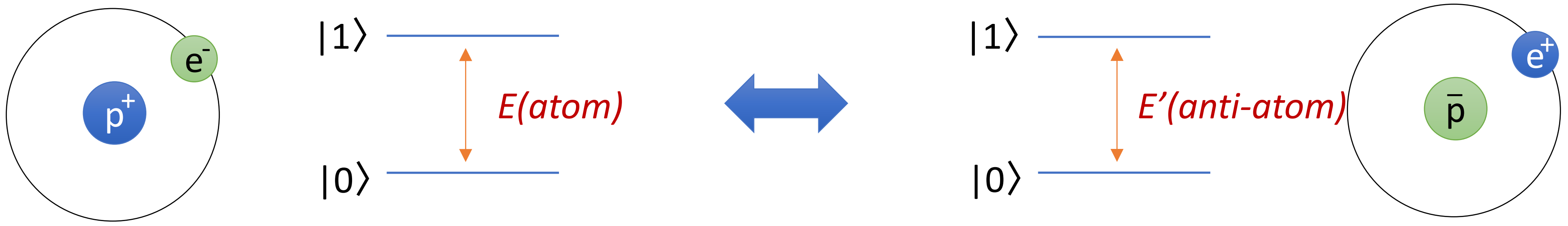
"Quantum sensing", Degen Reinhard, Cappellaro, Rev. Mod. Phys. 89, 035002 (2017)

(Anti)Atom as a Quantum Sensor

Atomic quantum sensor

Rev. Mod. Phys. 89, 035002 (2017)

Anti-atomic quantum sensor



$$E(atom) = E_0 + \Delta E_{ext} + \Delta E_{NP}\ (\equiv E_{QFT})$$

$E_0 \sim m_e\,\alpha^2 + \ldots$ fn{$Q_e, Q_p, m_e, m_p, r_p, \mu_e \ldots$ }

ΔE_{ext} : due to Ext field, e.g. E, B, Gravity

ΔE_{NP} : due to New Physics, e.g. DM, 5th force …

$$E'\ (anti\text{-}atom) = E_{QFT} + \Delta\ E_{CPTV}$$

E_{CPTV} : Shift due to CPT violation;

Beyond Quantum Field Theory!

CPT theorem requires $E = E'$ (i.e. $\Delta\ E_{CPTV} = 0$) in any local relativistic QFTs