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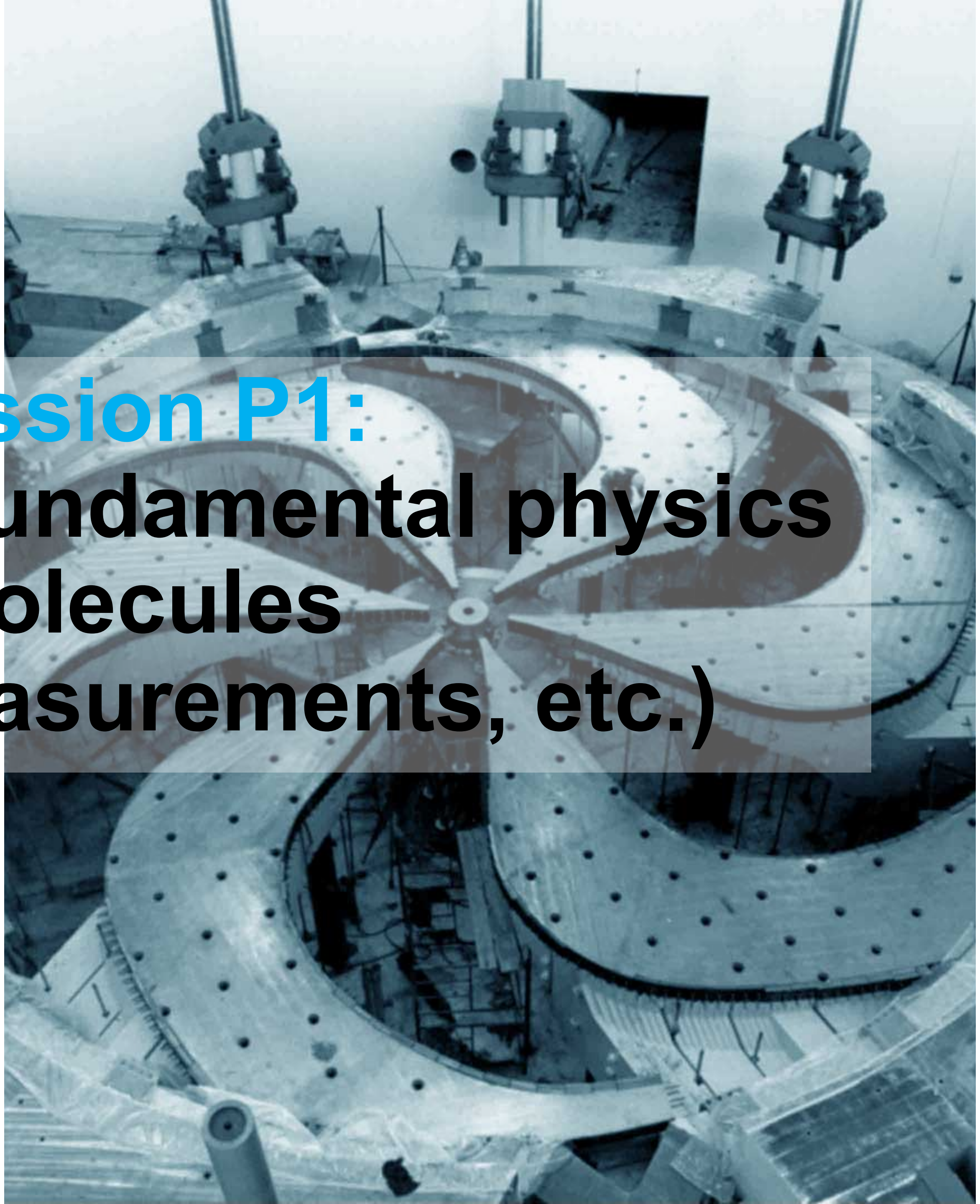


Summary parallel session P1:
New ideas to probe fundamental physics with nucleons and molecules (EDMs, precision measurements, etc.)

Beatrice Franke, Adam Ritz

DND2020 workshop

2020-11-06

Discovery, accelerated

Exploring AMO advances with molecules and molecular ions

- David DeMille (Chicago/Argonne)
- William Cairncross (Harvard)
- Kia Boon Ng (JILA)

- *Discussion moderator*
  – Gerald Gwinner (Manitoba)

Exploiting neutrons for precision measurements

- Albert Young (NC State)
- Chen-Yu Liu (Indiana)

- *Discussion moderator*
  – Jeff Martin (Winnipeg)

Broad range of fundamental physics questions:

- matter/antimatter asymmetry - leptonic/hadronic CP violation (EDMs)
- dark sectors - new ultralight dof (e.g. oscillating moments, exotic interactions)
- nucleon properties, ….

Slide from Tim Chupp's plenary talk

EDMs arise from many sources

Rev. Mod. Phys., Vol. 91, No. 1 (Jan 2019)

Fundamental theory

Wilson coefficients (13)

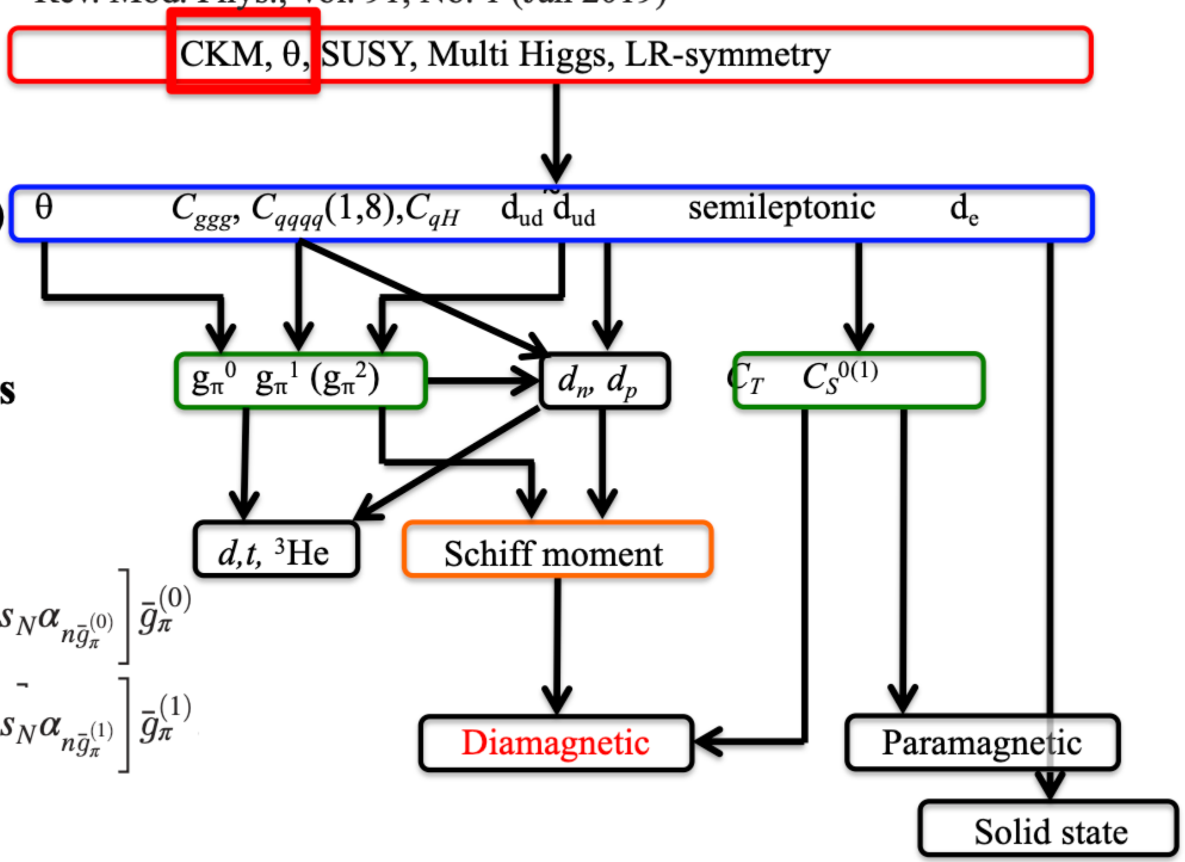
$$\mathcal{L}^{\mathrm{eff}}_{\mathrm{CPV}} = \sum_{k,d} \alpha_k^{(d)} \left(\frac{1}{\Lambda}\right)^{d-4} \mathcal{O}_k^{(d)}$$

Low energy parameters

$$\bar{g}^0_{CP} \approx 0.027\ \theta_{QCD}$$

Nucleus level

$$S = s_N \bar{d}_N^{sr} + \left[\frac{m_N g_A}{F_\pi} a_0 + s_N \alpha_{n\bar{g}_\pi^{(0)}}\right] \bar{g}_\pi^{(0)} + \left[\frac{m_N g_A}{F_\pi} a_1 + s_N \alpha_{n\bar{g}_\pi^{(1)}}\right] \bar{g}_\pi^{(1)}$$



Atom/molecule level

$$d_A = \eta_e d_e + \kappa_S S(\theta_{QCD}, g_\pi) + (k_T C_T + k_S C_S) + \textit{h.o.}$$

$\sim Z^3$ $\sim Z^3$

Rev. Mod. Phys. v. 91 015001 (2019)

‘Charge’ for the working group summaries

- What ideas could (or could not) be turned into actual experiments at TRIUMF/CENPA?
- What homework do we need to do to figure this out?
- Should we form a working group to answer such questions?
- Who are key people to target for this working group?

EDMs via Molecules & Molecular ions

- Targeting new sources of CP violation (from different sources)
- T-odd Observable - EDM, Schiff moment, magnetic quadrupole, level splitting…

- Advantage of Polar Molecules – high sensitivity via large internal electric fields
  - New technologies - sources, laser cooling, state prep, leading to increased precision/sensitivity. Further progress spurred by quantum computing etc.

- Experiments that have collected data on eEDM (and upgrades…):
  - YbF (Imperial College) & ACME & JILA
  - **Improvement by a factor of 100 over past decade in sensitivity to eEDM**

- Experiments in developments (partial list):
  - CENTREX (hadronic == pEDM & Schiff moment) ThF
  - PolyEDM (eEDM) laser cooled polyatomic molecules in a trap
  - And others…

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EDMs via Molecules & Molecular ions
Relevance for TRIUMF/CENPA?

- Rapidly developing field
  - if EDMs are on your radar, this technology should not be ignored…
- Potential competitive advantages:
  - Nuclei with octupole deformation (short-lived radioactive species), or that are difficult to obtain/handle eg. ^{229}Th (nuclear lab infrastructure available)
  - Projects are growing in scale, best suited to lab environment
- Challenges:
  - AMO technology may need beamline in a “quiet” environment (?)
  - Specialized infrastructure and knowledge is needed to deal with molecules in general (spectroscopy etc)
- New developments:
  - “Assembling” molecules from cold atoms (eg. tweezer technology): may allow for “ideal” systems like AgRa, or ^{223}Fr instead of Ra (Ag advantageous over Au and Cu)

EDMs via Molecules & Molecular ions
Next steps:

Historical investments have been made at both TRIUMF and CENPA in this research area (EDM searches)

Looking forward:

- Is there a competitive advantage for TRIUMF/CENPA in molecular techniques? (We think potentially YES using certain nuclei but the experiments are more difficult, so challenges need to be assessed)
- More generally, if EDMs are a target, can this technology be ignored at all?

We suggest assessing this opportunity in more detail with a working group of experts: Looking for volunteers…

Slide from Jeff Martin:

EDMs and other experiments with ultracold neutrons

- The "best" experiments:
  - Beta decay correlations
  - Neutron lifetime (CKM unitarity, new particles in loops, neutron lifetime problem, BBN/^{4}He abundance)
  - EDM (strong CP problem, SUSY CP problem, EW baryogenesis, …)
  - Gravitational levels (modification to gravity at ~um scale, chameleon fields)
- Others?
  - Invisible and not-so-invisible decays of neutrons (neutron lifetime problem).
  - Mirror neutrons (anomalous losses, neutron lifetime problem)
  - Axionlike particles (time-varying EDM's, precision clock comparisons)
  - n-nbar oscillation search (B-violation)

Which of those experiments can we or would we want to do at TRIUMF?

What is the competitive advantage? We will have a new intense UCN source!

- Commitment to nEDM
- Commitment to a second port == user facility -> EEC style process

Impact on current TUCAN nEDM R&D?

- It's good to have flexibility in mind – yet this should not overly impact the main priority to commission and operate spectrometer
- The field is highly competitive! We need to ensure competitiveness of both the source and the nEDM experiment.

Success in developing the source and nEDM experiment is key to facilitating further expansion and/or access to new physics

What other experiments are facilitated by a successful source and precise nEDM spectrometer?

nEDM (necessary ‘knobs’ to access new physics)

- Tunable magnetic field amplitude, different orientations
- Cell materials
- Cell dimensions
- Large scale multipurpose magnetically shielded room would enable us to support precession experiments with differing requirements

Neutron decay (lifetime & angular correlations)

- Dark sector searches
  Eg. HPGe detector near a UCN source, push threshold below the 511 keV noise limit
- Combine with CRES (C-Y L and AY thinking about this), both for lifetime, and decay correlations (access to Fierz term)
- Combine with ^{19}Ne beta+ decay, complementary or even SAME apparatus

What other experiments are facilitated by a successful source and precise nEDM spectrometer?
Next steps:

TRIUMF's efforts in the UCN community should not be considered established! From a planning perspective, this facility is still under construction and development – at the initial stage and needs to be supported and prioritized.

[There is a loose working group around UCN precession experiments potentially yielding slightly improved limits on exotic interactions, pointers to apparatus mod's. (A. Young, E. Dee, C. Swank, G. Pignol, S. Roccia, B. Franke, D. McKeen, et al)

Look for additional opportunities, with longer term outlook:
GE detectors close to UCN sources or lifetime experiments, embedding CRES technology into neutron decay and lifetime measurements (previous slide)
Large potential for working group!]

Summary

- Complementary approaches targeting similar physics:

  - EDM searches in molecules & neutrons

- Well motivated – however these technologies are difficult, so significant effort is needed!
- Precision measurements are long-term endeavors…

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Thank you
Merci

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