THE UNIVERSITY
of ADELAIDE

ARC Centre of Excellence in Precision Fundamental Physics

title not yet decided

Paul Jackson

March 5th, 2021

Centre name

ARC Centre of Excellence in Precision Fundamental Physics
ARC Centre of Excellence for Fundamental Discovery Physics
ARC Centre of Excellence for Discovery in Fundamental Physics
ARC Centre of Excellence for the next Discovery in Fundamental Physics
ARC Centre of Excellence for Discovery in Precision Fundamental Physics

Comment: Our research branch felt that “precision” gave the feeling of “just doing something that’s already been done a bit better” and that it wasn’t transformational.

Since the last meeting

- We agreed that I would take the role of Director for the CE23 bid

- Adelaide had a meeting with our DVCR, Director of Research Infrastructure, relevant Deputy deans and a full team from Research Services to "pitch" the bid.

- This was very well received, and we have been given the full backing of our DVCR's office to continue to the EOI stage (a little more on this later)
    - The DRI and DVCRs office have offered us support in whatever way we need
    - Discussed getting external reviewers to look at the bid document
    - Getting the CVs of candidates for the participation summary prepared so that we can discuss these with research branch

Key dates

ARC CENTRES OF EXCELLENCE (FOR FUNDING COMMENCING IN 2023) - IMPORTANT DATES

	ARC Dates	**Research Services Due Date**	**ARC Due Date**
***Recommended* draft Expression of Interest (EOI) -** based on the CE20 ITAs		10 May 2021	
Expression of Interest (EOI)	EOI period: 8 June 2021 to 28 July 2021	7 July 2021 *(3 weeks ahead of ARC EOI deadline)*	28 July 2021
Request not to Assess		7 July 2021 *(1 week ahead of ARC EOI deadline)*	14 July 2021
Rejoinder	Rejoinder period: 30 September to 14 October 2021	11 October 2021 *(3 days ahead of ARC EOI deadline)*	14 October 2021
ARC notifies shortlisted EOIs and invites full applications	TBA (Note - Full application period: 8 December 2021 to 23 March 2022)		

Today's meeting

- Chief Investigators
  - what are the rules (no constraints on number)
  - what drives the choices => money per CI and therefore postdocs per CI (if we stop thinking like this we may do well)
  - Number of nodes - shouldn't have small nodes - why? They only get some fraction of the funds but if they can leverage centre involvement as a multiplier at their university, is this bad? We've been informed that smaller nodes could be "clustered", think Sydney/UNSW
  - Gender balance and balance across the institutes
- Partner Investigators
  - We should cover a broad range both from the scientific perspective and to get global coverage
  - We must strive to get a good gender and diversity balance in the PIs
- Deputy Director Candidates
  - Who is interested? We should strike a balance across theory, experiment, age, gender.
- Who will be our seven highlighted participants?
  - Suggest we aim for a long-list of ~10, all complete the CV step, and select the best
  - By "best" we mean the 7 that maximize our chances of success at the EOI stage
- The Project
  - We only have 8 pages (less than a DP!) to write a concise and compelling project.
  - We should prepare a few people willing to draft a few paragraphs each on specific topics

Any Questions/Thoughts/Discussion before we move on?

CIs

Adelaide: Paul Jackson, Derek Leinweber, Martin White, James Zanotti, Ross Young

ANU: John Close, Joe Hope, Cedric Simenel

Melbourne: Matthew Dolan, Martin Sevior, Andrea Thamm, Ray Volkas,

Monash: Csaba Balazs, Ulrik Egede, Jordan Nash, Peter Skands, German Valencia

UNSW: Michael Schmidt

UQ: Jacinda Ginges, Pat Scott, Magdalena Zych

Sydney: Archil Kobakhidze, Kevin Varvell, Bruce Yabsley

Comments on composition:
Possible to be CIs on two EOIs in a Centre round.
Centre's in the CE20 round had between 14 and 27 CIs from up to 8 EOs.
EOI we know of: CoEPP2 (18 CIs, 13 PIs), DM (20 CIs, 9 PIs), CTP (16 CIs, 17 PIs)
We may wish to add others to help bolster the bid further – anyone who can be removed?
We can't expect every CI gets "their own" postdoc for the lifetime of a Centre

Gender/diversity: ***hiring of female staff at all/most nodes*** as a result of the Centre award.

PIs

Phiala Shanahan (MIT) – Leading Lattice Collaborator

Val Gibson (Cambridge) - LHCb

Tim Gershon (Warwick) – LHCb, Warwick/Monash alliance

Clara Matteuzzi (Milan) – LHCb

Stephanie Hansmann-Menzemer (Heidelberg) - LHCb

Toru Iijima (Nagoya) – Belle II Spokesperson

- Other Belle II and COMET suggestions???

Andreas Hoecker (CERN) – ATLAS Spokesperson

Frederic Deliot (Saclay) – Leader of Saclay group and ATLAS 4-top analysis team

Someone from Nvidia/Xilinx, another company? Leaders in HPC?

Others from theory, atomic and nuclear, quantum gravity (expt and theory)?

Expert input required here!

We need your suggestions here - otherwise the list will be stacked with collider particle physicists, which would be bad.

Node Leaders

Each node is free to decide who they consider a node leader. We can discuss this if you wish. I provide some suggestions below:

James Zanotti (Adelaide)

Kevin Varvell/Archil Kobakhidze (Sydney)

Cedric Simenel/Joe Hope (ANU) - depends on other Centre roles

Martin Sevior/Ray Volkas (Melbourne) - depends on other Centre roles

Peter Skands/Ulrik Egede/Jordan Nash (Monash) - depends on other Centre roles

Jacinda Ginges (UQ)

Michael Schmidt (UNSW)

Who takes these roles for a given node will depend on the leadership positions within the Centre and how each nodes sees this for themselves in terms of their own governance.

Theme Leaders – Leading roles

I provide some suggestions below:

Scientific Theme	Theory Leader - Volkas (Melbourne)	Experiment Leader - Egede (Monash)
Quantum Gravity	Joe Hope (ANU)/Archil Kobakhidze (Syd)	USyd New Hire
Atomic/Nuclear/EDM	Jacinda Ginges (UQ)/Cedric Simenel (ANU)	Adelaide experimental?
Lepton Collider	Michael Schmidt (UNSW)/German Valencia (Monash)	Kevin Varvell (Syd)
Hadron Collider	Matt Dolan (Melbourne)	Ulrik Egede (Monash)
Compute/Accelerators	Peter Skands (Monash)/James Zanotti (Adelaide)/Martin Sevior (Melbourne)	
Global Fits	Pat Scott (UQ)/Csaba Balazs (Monash)/Martin White (Adelaide)	

Deputy Director Candidates

- I feel the director, would be best served with two deputies
  - My preference would be for a “senior” figure to counter-balance any potential suggestion that I am too junior to manage the Centre and someone either at or around mid-career
- Deputy Director Candidates
  - We should strike a balance across the country/theory/experiment and also age/gender.
  - Shouldn’t be someone who becomes too oversubscribed by taking on the role (i.e. a node leader/theme leader AND deputy director)
- Jordan, Ray, Joe, Jacinda, Ulrik, Cedric are names that came to my mind.

Participant Summary Composition

Need 7 people that broadly cover the Centre activities.
Potentially:

Experiment Theory

Paul Jackson (Adelaide)	Director, Experimental
Jacinda Ginges (UQ)	CI, Node Leader, Low Energy Theory (potential DD)
Raymond Volkas (Melb)	CI, Theory program Leader (potential DD)
Joe Hope (ANU)	CI, Quantum Gravity Leader (potential DD)
Phiala Shanahan (MIT)	PI, Computational Theory
Kevin Varvell (Sydney)	CI, Node Leader, Experimental
Val Gibson (Cambridge)	PI, Experimental
Jordan Nash (Monash)	CI (potential DD), Experimental
Ulrik Egede (Monash)	CI (potential DD), Node Leader, Experimental

My preference would be that we make a long-list of ~10 and write out the two-page CVs for each then decide which 7 make the strongest case.

Governance and other roles

- Doesn't need to be completely fleshed out for the EOI stage but we should at least say a few words as to structure.

- Mention Chief Operating Officer, portfolio managers etc

Centre thoughts

PHYSICS

Atomic/Nuclear – EDM in atomic physics, CP- and P-violating studies in tabletop experiments

Flavour physics (Lepton Colliders) – Precision tests of Lepton flavour universality anomalies at Belle II, channels with missing energy, unique sensitivity in mu->e conversions

Flavour physics (Hadron Colliders) – Precision on FCNC and anomalies at LHCb and ATLAS in the 3rd generation

Quantum gravity and quantum atomic interferometry - measure inertial quantities with unprecedented stability, calibrated to universal properties of atoms

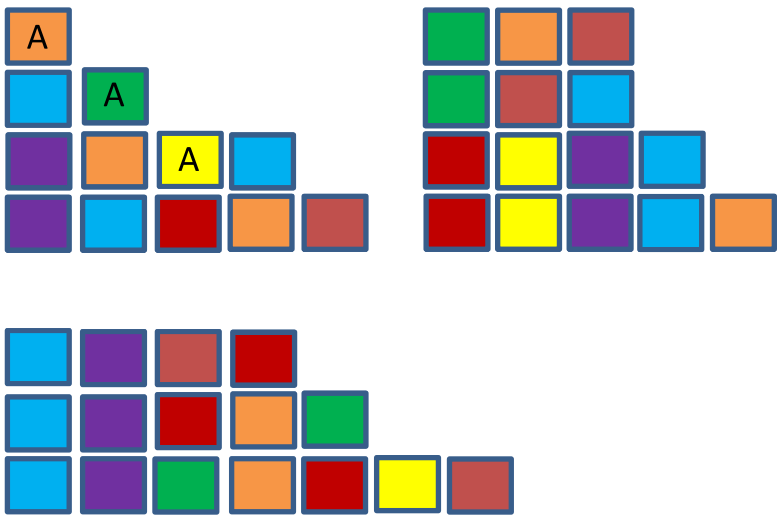
TECHNOLOGY/COMPUTE

High-Performance compute – Ultimate precision needs huge datasets and vast compute resources

Advanced Technologies - a paradigm shift in how we interact with experiments to best leverage the huge investment in the facilities. New readout methodologies

Precision frontier – quantum gravity and atomic experiments need new leaps in sensitivity, industry involvement

Synergies



	Experiment	Theory
Quantum gravity	🟧 A	🟩 🟧 🟫
Nuclear/Atomic Physics	🟦 🟩 A	🟩 🟫 🟦
Lepton Collider	🟪 🟧 🟨 A 🟦	🟥 🟨 🟪 🟦
Hadron Collider	🟪 🟦 🟥 🟧 🟫	🟥 🟨 🟪 🟦 🟧

Global Fitting	🟦 🟪 🟫 🟥
Technology	🟦 🟪 🟥 🟧 🟩
HPC	🟦 🟪 🟩 🟧 🟥 🟨 🟫

🟩 ANU
🟧 Sydney
🟥 Melbourne
🟪 Monash
🟫 Queensland
🟨 UNSW
🟦 Adelaide

A = Aspirational (will be seeded by the Centre)
There will be others….

Good feedback from the “Centre thoughts” email – much appreciated

The following is the text received from people regarding their Centre thoughts

Centre thoughts

1

We have many open questions within the SM which motivate the search for physics beyond the SM. Interest in light new physics, which can be tied to high energy solutions to these open questions, has gained traction in recent years. Light new particles can be probed extremely well in all kinds of precision experiments. This ranges from low-energy table-top precision experiments to low-energy accelerator experiments to Belle II and LHCb. Also, future colliders are very promising machines to measure e.g. exotic Z decays with astonishing precision. Also, electroweak precision observables will be measured with unprecedented precision which can lead to tight constraints on models including heavy new particles. I think a combination of exploring the intensity (and precision) frontier and the energy frontier will help us to construct a clearer picture of the BSM landscape.

Centre thoughts

2

Physics-wise, I think it is important to highlight the new measurements, particularly measurements of new observables, which were not possible previously, because this will be guaranteed results and not just exclusion curves. Myself I am currently particularly interested in b->s + invisible, where Belle 2 is sensitive to the SM prediction, and a more precise measurement of RD(*) and RK(*), which should either resolve or confirm the current anomalies. Obviously, a precise measurement will also help to constrain or discover new physics.

Centre thoughts

3

This Centre will bring together experimentalists and theorists across the broad spectrum of energy scales under the unifying theme of precision constraints of the Standard Model. From international colliders, such as BelleII and LHCb, to "table-top" experiments involving heavy atoms and molecules, from new theories of quantum gravity to lattice QCD, this Centre will be a truly national Centre involving many of the Go8 universities and an outstanding team of experts from atomic, molecular, nuclear and particle physics, and thereby creating the first team in the world that works across these sub-disciplines. This Centre is unique in its breath and will push the boundaries in detector R&D, HPC and data science in order to put Australia at the forefront of precision fundamental physics, an area that is anticipated to lead to the next Nobel-worthy discovery in physics.

Centre thoughts

4

There are three ways to discover new elementary particles and new fundamental interactions:
- Hit harder (energy frontier)
- Count more (intensity frontier)
- Look closer (detail frontier)

While the first approach has led to most discoveries up to now, culminating with the Higgs discovery at LHC, it has reached its limitation with current technologies. As a result, while evidences for BSM physics are overwhelming, no new particle has been found in the past 10 years.

The two other approaches follow a different strategy. At the intensity frontier, we search for rare events such as forbidden reactions and decays by increasing the number of collisions between particles.

At the detail frontier, we search for new ways for the particles to interact within atoms and molecules in tabletop experiments.

In both cases, deviations with predictions from the Standard Model of particle physics provide a new window into new physics.

Intensity and detail frontiers are two complementary aspects of "precision physics", and both frontiers need to be explored simultaneously with a concerted effort to maximise the potential for new discoveries in fundamental physics.

Centre thoughts

5

My suggestion for a name is:
"CoE for Precision Fundamental Science"

I'm optimistic that we can make a case that a centre will allow strong synergies to enable greater outcomes than the sum of the parts, as outlined by Peter and others at our virtual meeting. I think we can make a 1 minute pitch along the line of "unexpected precision measurements guide the way to discovering new physics paradigms". Maybe we could use the analogy of Michelson-Morley paving the way for the theory of relativity as a Segway into anomalous results (eg B-Physics) requiring new precision measurements, new precision theory and imaginative ideas for new physics. We need all people in all three specialities. The Centre enables this.

Centre thoughts

6

Fundamental discoveries in physics have often come about from precision measurement and precision theoretical calculation, often working together.

From the historically significant Michelson-Morley high-precision null result, through the discovery of the subtle CP violation in kaon decays and its verification in the B-meson system, to the constraints on new physics from precision electroweak tests, examples of this abound in all fields of physics. The discovery of gravitational waves is another, and the Higgs boson discovery channel used a rare decay mode that required precision measurement even in the context of an energy-frontier machine such as the LHC. Perhaps the exemplar of the confluence of high precision in both theory and experiment lies in the anomalous magnetic moments of the muon and electron where agreement is at the 9 or 10 significant figure level.

In particle physics, the energy frontier will not be pushed greatly forward for the foreseeable future, so the LHC is also now a precision tool looking for rare events or subtle disagreements between theory and experiment. The precision frontier is thus paramount to explore, and great strides are being made in that domain. One example is precision quark flavour physics through the on-going Belle II and LHCb B-factory experiments, and leptonic cousins such as the COMET mu to e conversion search.

Centre thoughts

6 continued

Another is in atomic physics, which is pushing the frontier through considerable advances in sensitivity to the CP-violating electric dipole moment of the electron. Even exotic cosmological scenarios such as the "chameleon" model have been probed in laboratory experiments.

Tests of fundamental quantum mechanics and how quantum systems behave in gravitational fields is yet another precision-frontier endeavour.

Tantalisingly, there are a number of anomalies revealed by current measurements that hold the clear prospect of confirmation through further precision tests over the next few years.

These include the long-standing discrepancy at >9 significant figures between the theoretical calculation of the muon anomalous magnetic moment and its experimental value, with a new experimental result anxiously awaited. In addition, certain decays of B-mesons are providing an unusually coherent indication of the possible violation of charged-lepton universality, the latter being a key feature of the standard model of particle physics. The great mystery of the cosmological asymmetry between matter and antimatter requires at least one new source of CP-violation as part of its explanation, an effect that can only be discovered through high-precision searches in multiple and multi-disciplinary domains, including long-baseline neutrino oscillation experiments, the aforementioned B-factories, and atomic electric dipole moment tests.

Centre thoughts

6 continued

An acceleration in our national capacity for precision fundamental physics would synergise different fields of physics in Australia in the quest for discoveries of Nobel-prize importance.

Centre thoughts

7

Fundamental physics has seen enormous strides over the last century. Several of the largest discoveries of this century have come after multinational efforts of unprecedented scale over decades. Examples such as the LHC show what can be achieved with a long-term vision. But there is an alternative to building bigger, better experiments to learn more about our universe. Sometimes the secrets are written in the details.

This Centre will use tabletop precision experiments to address the biggest mysteries in physics. Quantum-atom optics experiments have achieved tabletop precision that is as far beyond our everyday experience as the energy scales achieved in high-energy experiments. By careful design and analysis, we can show how different fundamental models can be distinguished in those tiny details.

Example 1: [EDM experiment links all the elements of particle, nuclear and atomic physics to find Standard Model deviations in tabletop spectroscopy]

Centre thoughts

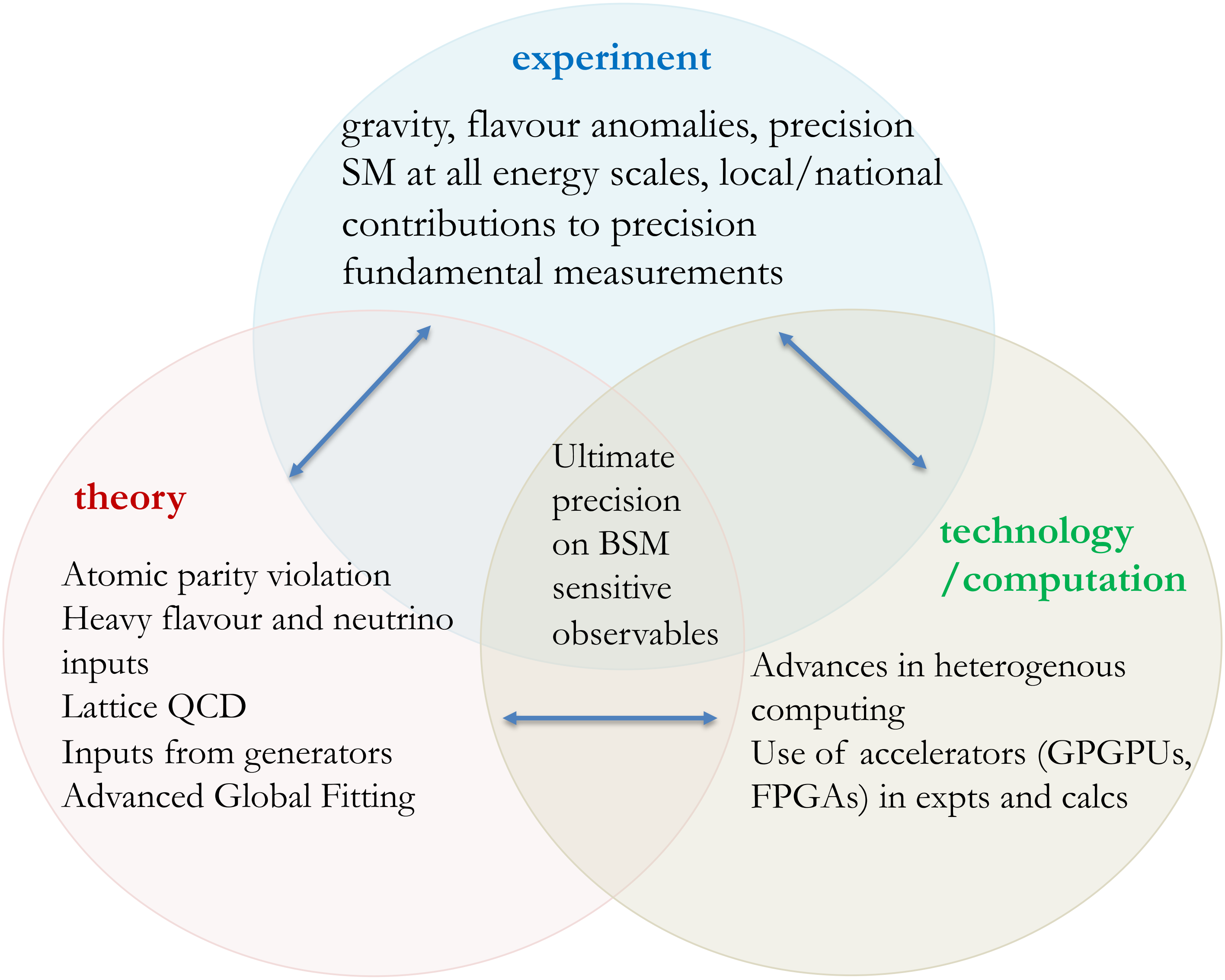
7 continued

Example 2 (Joe Hope and Simon Haine, ANU):
Another precision tabletop experiment that may lead to important discoveries is the atom interferometer. These measure inertial quantities with unprecedented stability, calibrated to universal properties of atoms. This project within the Centre would use machine design to optimise sensors using approaches well beyond current paradigms. It will be based on long experience with more conventional designs for sensing beyond the standard quantum limit. New precision limits for atom interferometers will improve their current technological applications, and also open up possibilities for investigating fundamental physics that is entirely inaccessible by other techniques.

Fundamental physics:
Quantum gravity is one of the big challenges in physics. With a natural particle energy scale of the Planck energy, evidence of quantum gravity will have to be either cosmological or based on precision experiments at lower energy. At the simplest level, it has not yet been shown that gravity is indeed quantised. This would require evidence that a coherent superposition of sources of gravity would induce a superposition of gravitational fields. The requisite interference experiment would have to be spectacularly sensitive, due to the weakness of gravity compared to other forces. Our program would develop a roadmap for experimentally achieving such a measurement.

Additional Material

Synergies



experiment

gravity, flavour anomalies, precision SM at all energy scales, local/national contributions to precision fundamental measurements

theory

Atomic parity violation
Heavy flavour and neutrino inputs
Lattice QCD
Inputs from generators
Advanced Global Fitting

technology /computation

Advances in heterogenous computing
Use of accelerators (GPGPUs, FPGAs) in expts and calcs

Ultimate precision on BSM sensitive observables

Topics spanning broad/focused range

- Precision flavour physics: LHCb, Belle II, COMET, ATLAS
  - Rare Penguin/Box diagrams and leptonic processes (B→Xll, b → sγ, B → lnu, B → D$\tau\nu$, $\mu \to e$ conversion, t → bW, maybe Higgs, plus others)
  - Precise determination of CKM matrix elements
- Quantum precision
  - Quantum limited and sub-quantum limited measurements of the gravitational field for beyond standard model physics and to test GR
- Precision in Nuclear/Atomic experimentation
- Lattice inputs for precise SM measurements and better predictions
  - Form factors and matrix elements
- Global fitting of inputs to improve SM precision and constrain BSM theories
- Theory Calculations for all rare processes
  - Precision flavour, impact on neutrinos and the lepton sector more broadly
- Atomic parity-violation, P- or T-violating electric dipole moments
- g-2 muon calculation
- Generator improvements to create more precise tools and simulations
- Technological advancements in triggering and data acquisition
- Use of accelerators (i.e. GPUs) in nuclear/particle → vast speed increases in calculations