Changing the Questions

TRIUMF

May 18, 2010

Byron K. Jennings | TRIUMF
The Vision
  – Changing the questions.
    • Not just answering them.
    • Not just doing better than others.

Clarifying the Vision
  – Changing the science questions.
    • The last 15 years in nuclear physics.

Achieving the Vision
  – Changing the administrative questions.
    • Single-minded emphasis on increasing science impact.
• Define ourselves (TRIUMF) in terms of our science impact.
  – Not in terms of how we compare to others.

➤ Outrun the grizzly!
TRIUMF is Canada’s national laboratory for particle and nuclear physics. It is owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada with building capital funds provided by the Government of British Columbia. Its mission is:

- To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science;
- To act as Canada’s steward for the advancement of particle accelerators and detection technologies; and
- To transfer knowledge, train highly skilled personnel, and commercialize research for the economic, social, environmental, and health benefit of all Canadians.
Three Imperatives

- **Strong local science program.**
  - To strengthen the research community support.
- **Strong ties to the universities.**
  - To strengthen the university community support.
- **Strong benefits to society.**
  - To strengthen tax payer and government support.
• A strong science program underpins:
  – The mission statement
  – The three imperatives

• Science: The goose that lays the golden egg.
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The Vision

• To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science
  – The most compelling questions?
    • Platonic ideals?
  – Change the questions!
    • Not just in science but in running the division.

➢ To make discoveries that change the field!
  – Change our understanding of the universe.
  – Change the questions.
  – Change the paradigm (if you are a fan of Kuhn).
The nucleon-nucleon potential:
- The old model: Meson exchange.
- The new model: Effective field theory.

Theoretically Driven
- Renormalization group and related techniques
- Systematic suppression of virtual high-momentum states
- Relation to experimental program not immediately obvious.
- Bogner, Furnstahl, Schwenk, arXiv:0912.3688[nucl-th]

➢ Question changing.
A General Principle

• At low momentum the high momentum properties of a model are not probed.
  – Can replace “true” behavior with something simpler.
    • Must preserve low momentum properties.
  – Essential for progress in science
    • Do not need explicit string degrees of freedom.
    • Do not need explicit QCD degrees of freedom.

• Renormalization group
  – Peter Lapage
• **The problem:**
  – Start with an N-N potential that fits the two-body data and derive nuclear properties
    • Caveat: Role of many-body forces.
• **Other approaches to nuclear physics:**
  – Collective models
    • Use macroscopic degrees of freedom.
      ▪ For example: John Wood’s TRIUMF lectures, P. Garrett’s work on vibrational nuclei.
  – Direct calculation from QCD.
    • Constituent quark or quark-meson coupling model
    • Lattice QCD
The N-N Potential

• Relation to QCD.
  QCD \rightarrow N-N potential \rightarrow Nuclear Physics

• N-N potential decouples nuclear physics from QCD.
  – Nucleon degrees of freedom:
    • Not quarks and gluons,
    • Not collective degrees of freedom.
  – Potentials are not observables,
    • Hence N-N potential not unique
The N-N Potential

• Formally: Start with QCD
  – Integrate out quark and gluon degrees of freedom.
    • Nucleons are emergent.
  – Derive N-N potential.

• Practically: Start with symmetries of true model:
  – Write most general form.
  – Determine parameters phenomenologically
    • Compare with those calculated from QCD
  – Renormalization group simplifies short distance behavior.
Meson exchange (goes back to Yukawa)
- Very successful (Reid, Stony Brook, Paris, Bonn, Argonne).
- Dispersion relations: unitarity, crossing symmetry, analyticity.
- Meson couplings determined phenomenologically.
  - Phenomenological short range components (Argonne).
- Many-body forces not well controlled.
- Contains high momentum components.

Effective field theory
- Chiral symmetry.
- Low momentum expansion, expansion coefficients.
- Errors controlled.
- Only low momentum components.
  - Precursors: Volkov, Minnesota forces.
• **Strong repulsive core**
  – $\omega(782)$ boson exchange.
  – S-wave phase shift starts attractive and goes repulsive.
    • Repulsion present for any approximately local potential.
  – Makes nuclear many-body calculations difficult.
    • Disconnect between N-N potential and nuclear phenomenology.
  – Strong short range and tensor correlations
    • Reduced spectroscopic strength at low energies.
Meson-Exchange Compelling Questions

• What is the off-shell behavior of the N-N potential?
  – N-N bremsstrahlung (TRIUMF)

• What are the values of coupling constants?
  – Strong vs weak $\rho$ coupling
  – What is the nucleon form factor?

• How to evaluate many-body forces?
  – Tucson-Melbourne potential

• How do you treat a hard potential in a many-body system?
  – What are the values of spectroscopic factors?
Off-Shell Properties

• Nuclear calculations depend on them.
  – How to determine?

• Polarized proton-proton bremsstrahlung

• The Off-Shell Nucleon-Nucleon Amplitude: Why it is Unmeasurable in Nucleon-Nucleon Bremsstrahlung
Meson-Exchange
Compelling Questions

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Off-Shell Properties

Iterated two-body

Three-body
Effective Field Theory

Use to Calculate Nuclear Properties

Power Law Diagrams

Can evolve 3N forces consistently:
Jurgenson, Navratil, Furnstahl (2009)
The Three-Body Force

\[ E(\text{He}) \text{[MeV]} \]

\[ E(\text{H}) \text{[MeV]} \]

\[ \Lambda = 3.0 \text{ fm}^{-1} \]

\[ \Lambda = 1.9 \text{ fm}^{-1} \]

\[ \Lambda = 1.6 \text{ fm}^{-1} \]

\[ \Lambda = 1.3 \text{ fm}^{-1} \]

\[ \Lambda = 1.0 \text{ fm}^{-1} \]

"bare" AV18

"bare" CD-Bonn

\[ V_{\text{low k}} \text{AV18} \]

\[ V_{\text{low k}} \text{CD-Bonn} \]

Unitary Correlation Operator Method

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Effective Field Theory

• Choose degrees of freedom that are appropriate for the problem.
  – Nucleons for doing low-energy nuclear physics.

• Choose cutoffs that are appropriate for the problem.
  – The order of 2 inverse Fermi.

• Meson-exchange model not so much wrong but rather inconvenient.
  – Much of the problems and controversies in the past related to dealing with the high momentum components in an ad hoc manner (EELL effect in pion scattering, Dirac phenomenology).

➤ Nature abhors high momenta (not a vacuum).
Meson-Exchange
Compelling Questions

- What is the off-shell behavior of the N-N potential?
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  - What is the nucleon form factor?
- How to evaluate many-body forces?
  - Tucson-Melbourne potential
- How do you treat a hard potential in a many-body system?
  - What are the values of spectroscopic factors?
Spectroscopic Factors
The Definition

• Provides insight useful to a wide range of physics problems.
  – Atomic physics, nuclear physics

• Measures the change to the many-body wave-function when a particle is added or removed.
  – Spectroscopic amplitude (one-body overlap function).
    • \( \phi(r) = \langle \Psi_{A-1} | a(r) | \psi_A \rangle \).
  – Spectroscopic factor:
    • \( S = \int dr \ |\phi(r)|^2 \).
Spectroscopic Factors
Meson Exchange


\[ \sigma \propto |\langle \psi_n^A|\mathcal{F}|\psi_n^{n'}\rangle|^2 \]
\[ \mathcal{F} = \int dr \, dr' \, a^\dagger(r)a(r')F(r, r') \]
\[ \langle \psi_n^A|\mathcal{F}|\psi_n^{n'}\rangle = \int dr \, dr' \, F(r, r')\langle \psi_n^A|a^\dagger(r)a(r')|\psi_n^{n'}\rangle \]
\[ \langle \psi_n^A|a^\dagger(r)a(r')|\psi_n^{n'}\rangle = \sum_m \langle \psi_n^A|a^\dagger(r)|\Psi_m^{A-1}\rangle\langle \Psi_m^{A-1}|a(r')|\psi_n^{n'}\rangle \]
\[ = \sum_m \phi_m^*\phi_m^{n'}(r') \]
\[ \langle \psi_n^A|a^\dagger(r)a(r')|\psi_n^{n'}\rangle \implies \phi_m^*\phi_m^{n'}(r') \]

\[ \sigma \propto \int dr \, \phi_m^*\phi_m^{n'}(r) \exp(ik \cdot \vec{r})|\phi_m^{n'}(r)|^2 \]
\[ \sigma \propto S \int dr \, \phi_m^*\phi_m^{n'}(r) \exp(ik \cdot \vec{r})|\phi_m^{n'}(r)|^2 \]

\[ F(r, r') \implies \delta(r - r') \exp(ik \cdot \vec{r}) \]
\[ |\psi_n^{n'}\rangle \implies \text{the p } 7\text{Be scattering state.} \]
\[ \langle \psi_n^A| \implies 8\text{B final state.} \]
\[ \langle \Psi_m^{A-1}| \implies \text{complete set of } 7\text{Be states} \]

\[ \phi_0^{*n}(r) = \langle \Psi_{A-1}^0|a(r)|\psi_n^A\rangle \text{ spectroscopic amplitude for the } 8\text{B ground state.} \]
\[ S_0 = \int dr \, |\phi_0^n(r)|^2 \text{ spectroscopic factor} \]
\[ \phi_0^{n'}(r') = \langle \Psi_{A-1}^0|a(r')|\psi_n^{n'}\rangle \text{ optical-model wave function for p } 7\text{Be scattering state.} \]
• The spectroscopic factors are scale dependant.

• Shown to be unobservable 31 years ago.
    • Deuteron $d$-state probability is a specific case of a spectroscopic factor.

• Should look to asymptotic properties for observables:
  • Asymptotic $s$ to $d$ ratio for the deuteron,
  • Asymptotic normalization coefficient.
Meson-Exchange
Compelling Questions

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• How to evaluate many-body forces?
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• How do you treat a hard potential in a many-body system?
  – What are the values of spectroscopic factors?
What are the many-body forces and how do you characterize them?
What are the low energy expansion coefficients and how to calculate them in QCD?
How far can ab initio calculations go?
  – Few-body spectroscopy and reactions.
  – Intermediate-mass structure calculations.
  – Foundation for energy density functional.
  – Eventually derive collective Hamiltonian.

Ab initio calculations make contact with observables.
Challenge to the ISAC user community and the theorists:

– How can ISAC measurements:
  • Change the field?
  • Change our understanding?
  • Change the questions?

What must TRIUMF do to help the user community?
• Challenge to the TRIUMF community:
  – How can TRIUMF:
    • Change the field?
    • Change our understanding?
    • Change the questions?
• What must TRIUMF do to help the user community?
The Science Division

• **Science**
  – ISAC Program
  – Molecular and Materials Science
  – Particle Physics
  – Theory

• **Support**
  – Computing
  – Detector Facilities
The Three Imperatives

Reprise

- Strong local science program.
  - To strengthen research community support.
- Strong ties to the universities.
  - To strengthen the university community support.
- Strong benefit to society.
  - To strengthen tax payer and government support.
ISAC Program

• Contribution to imperatives:
  – Core of the onsite program
    • Essential for TRIUMF’s health.
  – Interaction with universities
    • 14 Canadian Universities
  – Strong Highly Qualified Personnel (HQP)

• Current compelling question:
  – How do we maximize the science impact?
    • Optimum use of facilities.
    • Optimum beam development strategy.
    • Optimum use of manpower.
• Previous questions:
  – How to build needed experimental facilities?
  – How to develop new beams?

• Current question: How to maximize science impact?
  – What is the optimum number of detector facilities?
  – What is the balance between developing new beams and exploiting current beams?
  – Evaluate programs not individual experiments?

➢ Hardnosed look at all aspects of the ISAC program to maximize science impact.
• Contribution to imperatives:
  – Onsite program
  – Strong university involvement
    • J. Brewer and the Brockhouse Metal.
    • 13 Canadian Universities
  – Practical applications
    • Battery research and green chemistry

• Current compelling questions:
  – How do we maximize the benefit from the increasing maturity of the field?
  – Can the MMS program carry more of the burden in justifying TRIUMF’s funding?
    • How to increase visibility?
• **Contribution to imperatives:**
  – Largely off-site.
  – Strong university connections.
    • Essential for TRIUMF’s health
      ▪ 10 Canadian Universities in ATLAS collaboration.
      ▪ 6 Canadian Universities in T2K collaboration.
      ▪ 14 Canadian Universities in off-site collaborations.
  – High visibility
    • Particularly ATLAS.
  – Other examples:
    • T2K, TWIST, PIENU, ALPHA,…

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• **Contribution to imperatives:**
  – Largely off-site.
  – Strong university connections.
    • Essential for TRIUMF’s health
  – High visibility

• **Current compelling questions:**
  – What is the next big project?
  – How to maintain and enhance detector development capability?
  – How important are the peripheral parts of the program?
• Contribution to imperatives:
  – On-site,
  – HQP (very successful RA program),
  – Collaborations with 6 universities

• Group is being renewed.
  – Has now made the transition to the new TRIUMF direction.
    • Two new hires, one more on the way.
• **Contribution to imperatives.**
  – Onsite, HQP, university collaborations

• **Group is being renewed.**
  – Has now made the transition to the new TRIUMF direction.
    • Two new hires, one more on the way.

• **Current compelling questions:**
  – How do we help the new members develop and take leadership roles?
  – How to increase the group’s visibility?
  – How to maintain or increase interaction with university community?
• **Contribution to imperatives:**
  – Major part of TRIUMF infrastructure.
    • Indirect contribution to all imperatives.
  – Recent major change made in how the group is run.
    – Following from a review last fall.
• **Current compelling question:**
  – How do we keep the current momentum going?
    • Outside consultants for Enterprise Resource Planning (ERP) software.
• **Contribution to imperatives:**
  – Strong university connection:
    • TRIUMF’s infrastructure role. (HERMES, BABAR, E787, ATLAS, Qweak, G0, SNO, T2K, DEAP, SNO+, EXO, Super B?).
    – Recent ISAC involvement.

• **TRIUMF mission statement:**
  – To act as Canada’s steward for the advancement of particle accelerators and detection technologies;

• **Current compelling question:**
  – How do we maintain a strong detector capability?
Management Style

• Compelling question: How do we increase the science impact?
  – Team Work
    • Team 1: Senior Management
    • Team 2: The Science Division
      ▪ Neither micromanagement nor abdication of responsibility.
    • Team 3: The user community
  – Resource allocation priorities set site wide
    • New project management procedures
      ▪ Coherent use of resources.
      ▪ Sharing of resources
      ▪ Matrix management structure.
Revolution in nuclear physics.
- High momentum components tamed.
- The questions changed.

Maximize the science impact.
- Change the field, our understanding and the questions:
  - That is the grizzly we are going to outrun.
- Hardnosed review of ISAC.
- Team work:
  - Across divisions, within the Science Division, and with the user community.
- Site wide resource sharing and allocation.
Thank you!
Merci!
Thank you!
Merci!