

Fundamental Symmetries & Neutrinos: The Theoretical Effort

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AMHERST CENTER FOR FUNDAMENTAL INTERACTIONS

Physics at the interface: Energy, Intensity, and Cosmic frontiers

University of Massachusetts Amherst

<http://www.physics.umass.edu/acfi/>

DNP Town Meeting, Chicago
September 2014

In collaboration with V. Cirigliano,
G. Fuller, & W. Haxton

Goals for this talk

- *Articulate the vital role played by theory in advancing the fundamental symmetries & neutrinos program*
- *Describe the workforce context*
- *Identify needs & opportunities for the next decade*
- *Provide recommendations, scale of resources required, and anticipated outcomes*

Outline

- I. Nuclear theory for fundamental symmetries & neutrinos*
- II. The workforce context*
- III. Needs & opportunities*
- IV. Recommendations, resources, outcomes*

Four Components **

<p><i>EDM searches:</i> <i>BSM CPV, Origin of Matter</i></p>	<p><i>$0\nu\beta\beta$ decay searches:</i> <i>Nature of neutrino, Lepton number violation, Origin of Matter</i></p>
<p><i>Electron & muon prop's & interactions:</i> <i>SM Precision Tests, BSM "diagnostic" probes</i></p>	<p><i>Radioactive decays & other tests</i> <i>SM Precision Tests, BSM "diagnostic" probes</i></p>

Four Components

EDM searches:

BSM CPV, Origin of Matter

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton number violation, Origin of Matter

- *Reliably computing nuclear matrix elements*
- *Identifying benchmark sensitivities in BSM scenarios (heavy vs. light LNV)*
- *Analyzing associated pheno: oscillation studies, direct mass measurements, other LNV searches (LHC...), astro...*

radioactive decays & other

Precision Tests, BSM "diagnostic" probes

Four Components

EDM searches:

BSM CPV, Origin of Matter

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton number violation, Origin of

Electron & muon prop's interactions:

SM Precision Tests, BSM "diagnostic" probes

- *Computing EDMs in BSM scenarios & analyzing pheno (LHC, flavor,...)*
- *Developing refined baryon asymmetry calc's & relating to EDM parameters*
- *Identifying benchmark sensitivities*
- *Computing hadronic & nuclear matrix elements (d_n , $g_\pi^{(i)}$, Schiff moment...)*
- *Carrying out refined few-body calculations (future program)*

Four Components

EDM searches:

BSM CPV, Origin of Matter

- *Carrying out reliable SM predictions: HLBL in $g_{\mu}-2$, radiative corrections in PVES, HT/CSV,...*
- *Identifying benchmark sensitivities in BSM scenarios*
- *Analyzing associated pheno: LHC, neutrino m.m.,...*
- *Developing new experimental directions: PREX/CREX, LFV at EIC,...*

Electron & muon prop's & interactions:

SM Precision Tests, BSM "diagnostic" probes

Radioactive decays & other tests

SM Precision Tests, BSM "diagnostic" probes

ponents

- Carrying out reliable SM predictions: radiative corrections neutron & nuclear decay, nuclear corrections, hadronic form factors, recoil corrections, nuclear response in DM direct detection, ...
- Identifying benchmark sensitivities in BSM scenarios
- Developing tools for neutrino transport
- Analyzing associated pheno: LHC, pp chain, BBN, “dark forces”, ...
- Few-body and hadronic computations for hadronic PV
- Developing new experimental directions: neutron-antineutron oscillations, “dark boson” searches...

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton number violation, Origin of Matter

Radioactive decays & other tests

SM Precision Tests, BSM “diagnostic” probes

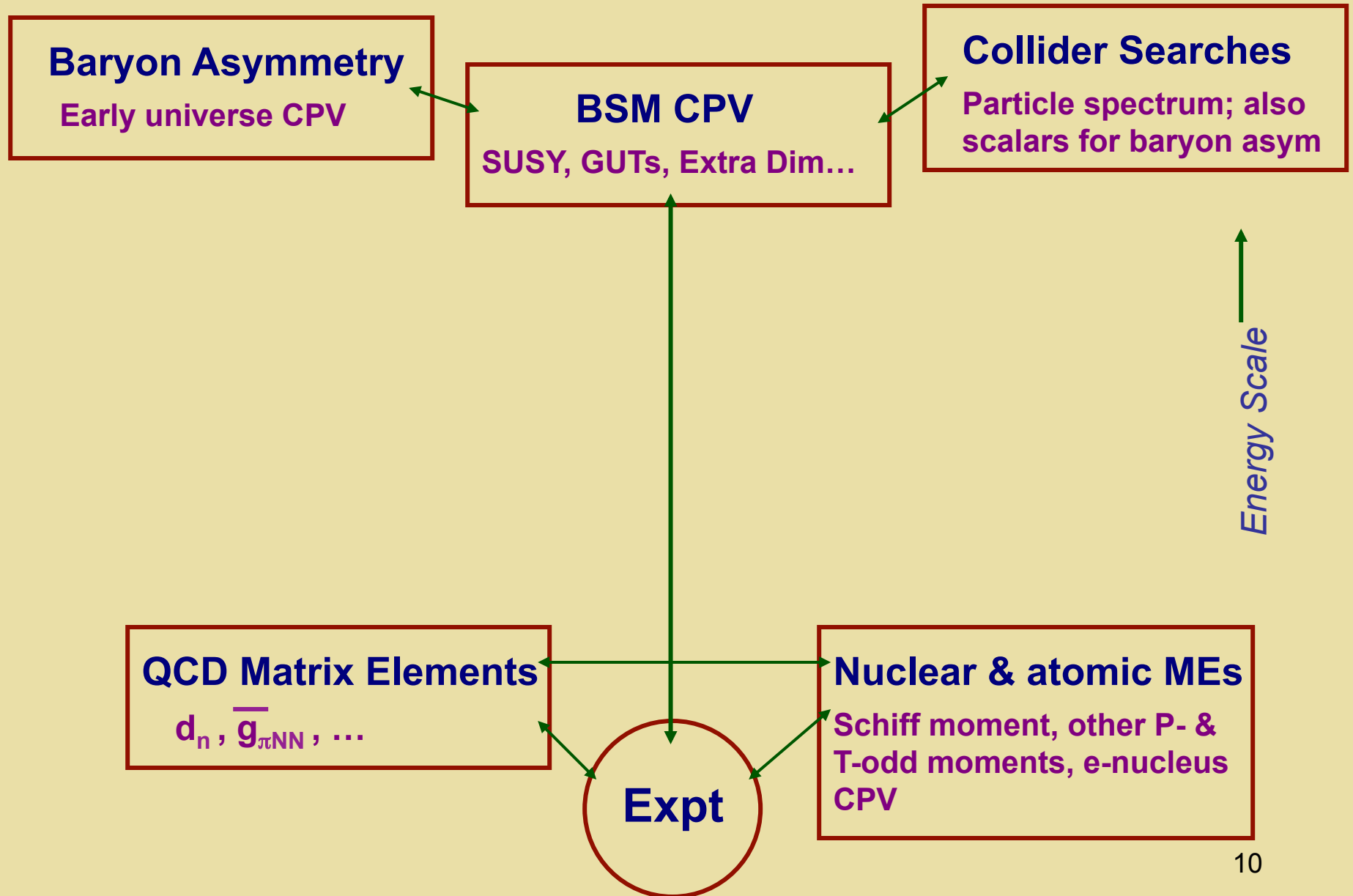
interactions:

SM Precision Tests, BSM “diagnostic” probes

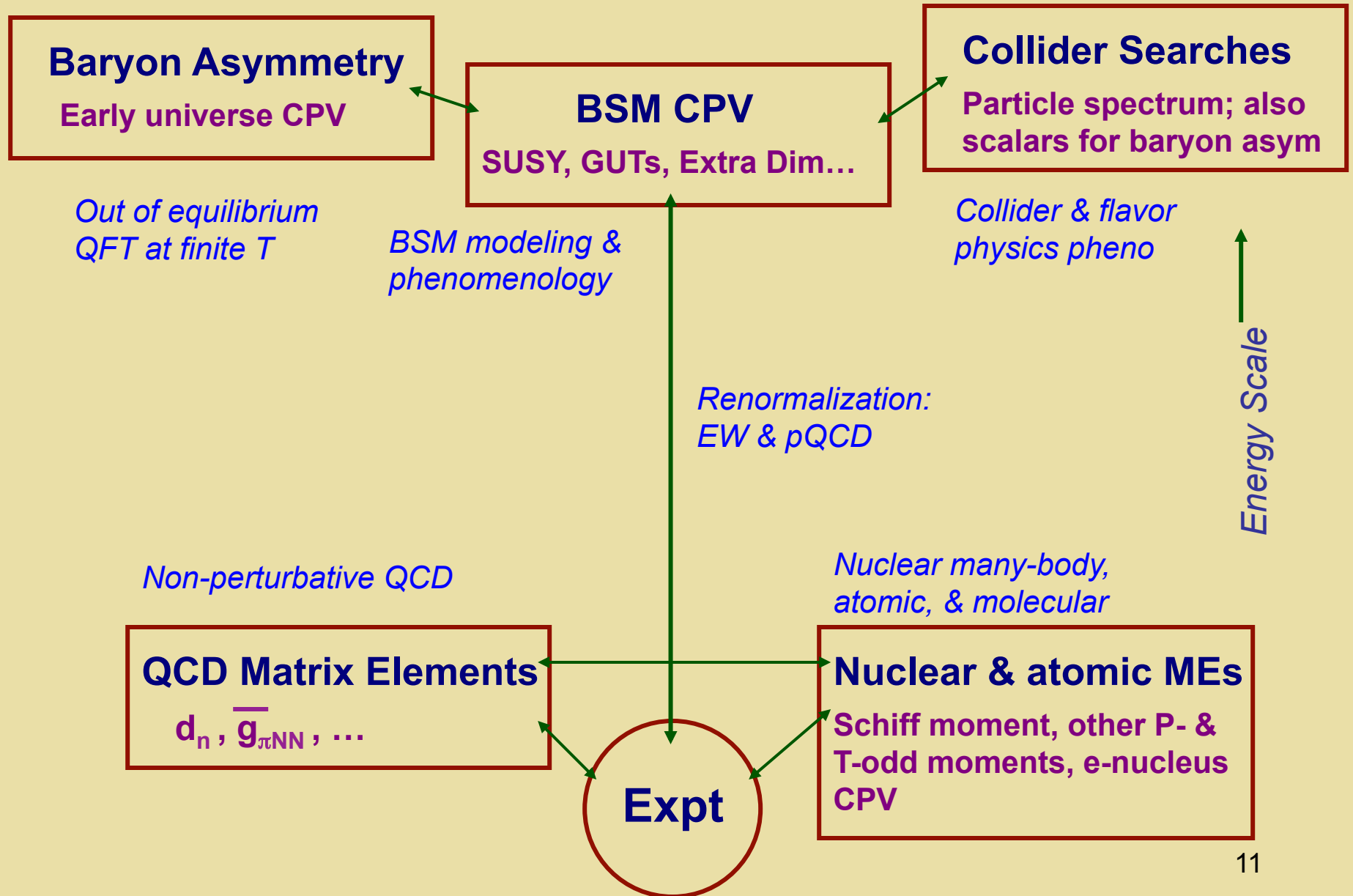
FS & N Expertise Needed

- ✧ *Illustrate: EDM problem*
- ✧ *Similar for other key problems*

EDM Interpretation & Multiple Scales



EDM Interpretation & Multiple Scales



Challenges



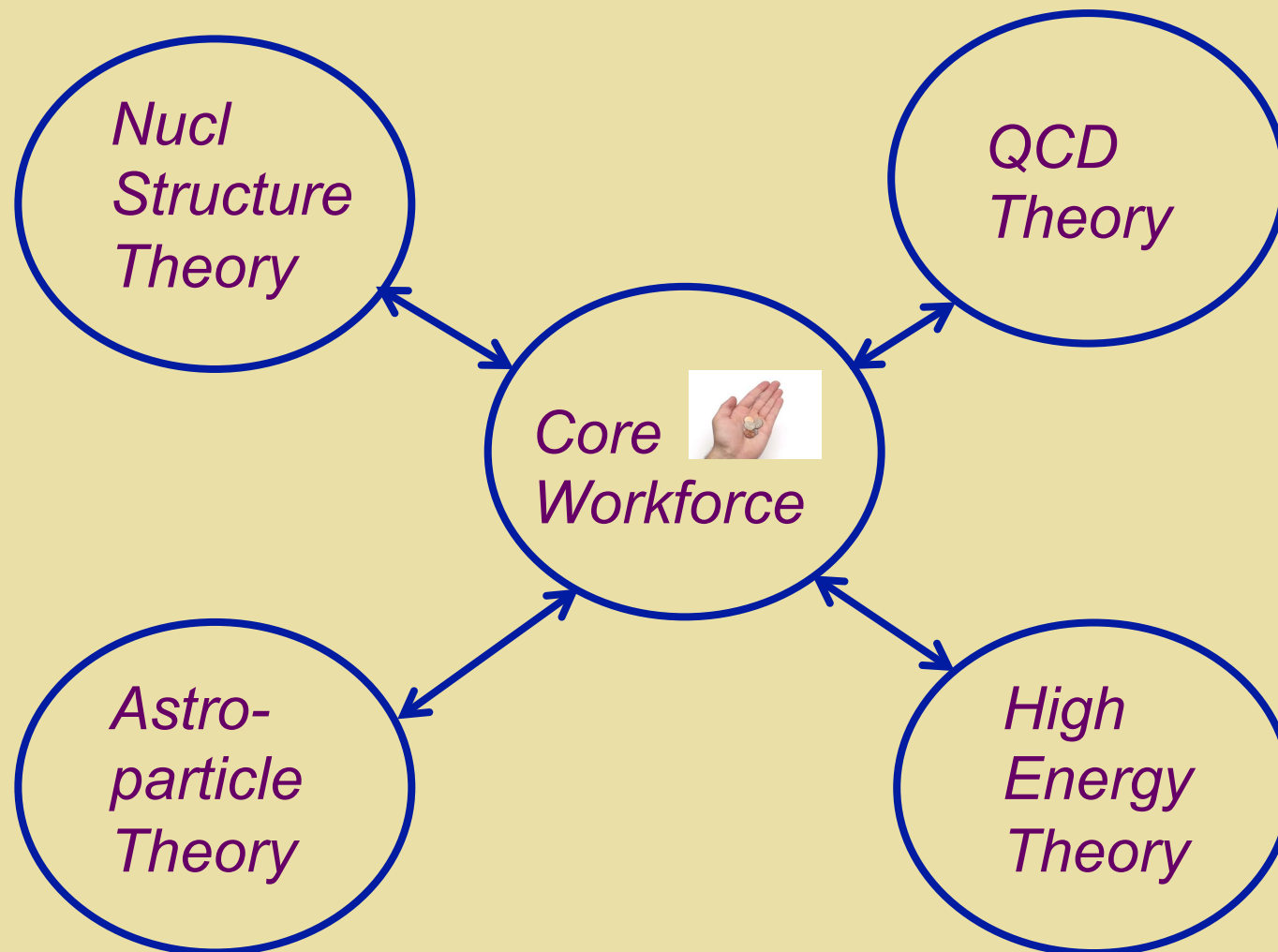
Challenges



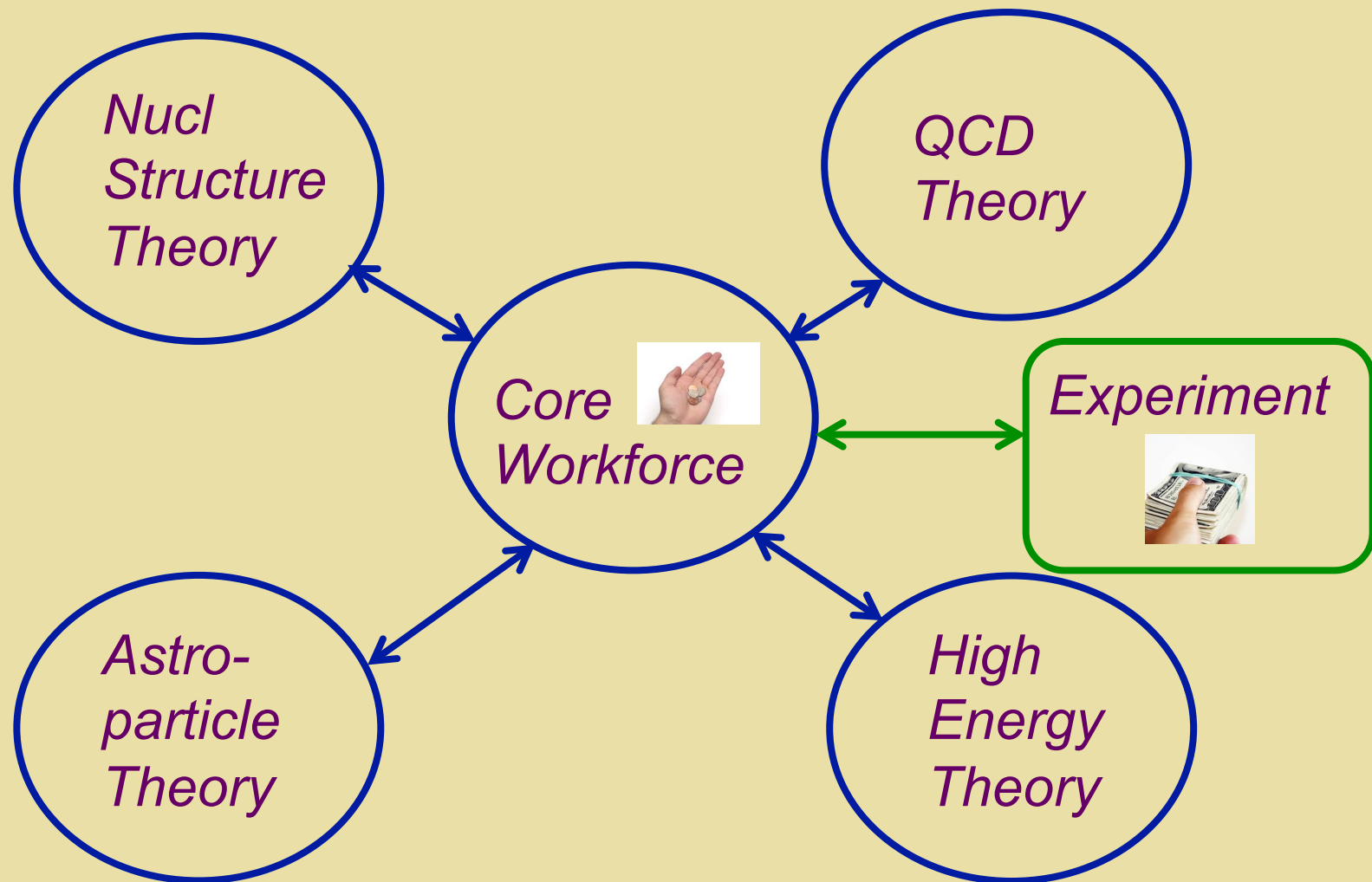
FS & N Theory Effort




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FS & N Theory Effort: DOE


Research Effort	Funding (\$M)	Faculty & Res Scientist FTE	Postdoc FTE	Grad Student FTE
Experimental Neutrino	14.1	28	22	21
Experimental Neutron	5.2	16	7	8
Experimental Other	2.7	10	7	11
TOTAL EXP	22.0	53	36	40
+ JLAB PV 				
TOTAL Theory	2.0	11.4	2.5	15

(Th'y) / (Exp) < 10% < 20% < 7 % < 40%

FS & N Exp + Thy: < 15% total DOE NP research budget
 FS Thy: < 7% total DOE nuclear theory budget

Thanks: V. Cianciolo

FS & N Theory Effort: DOE

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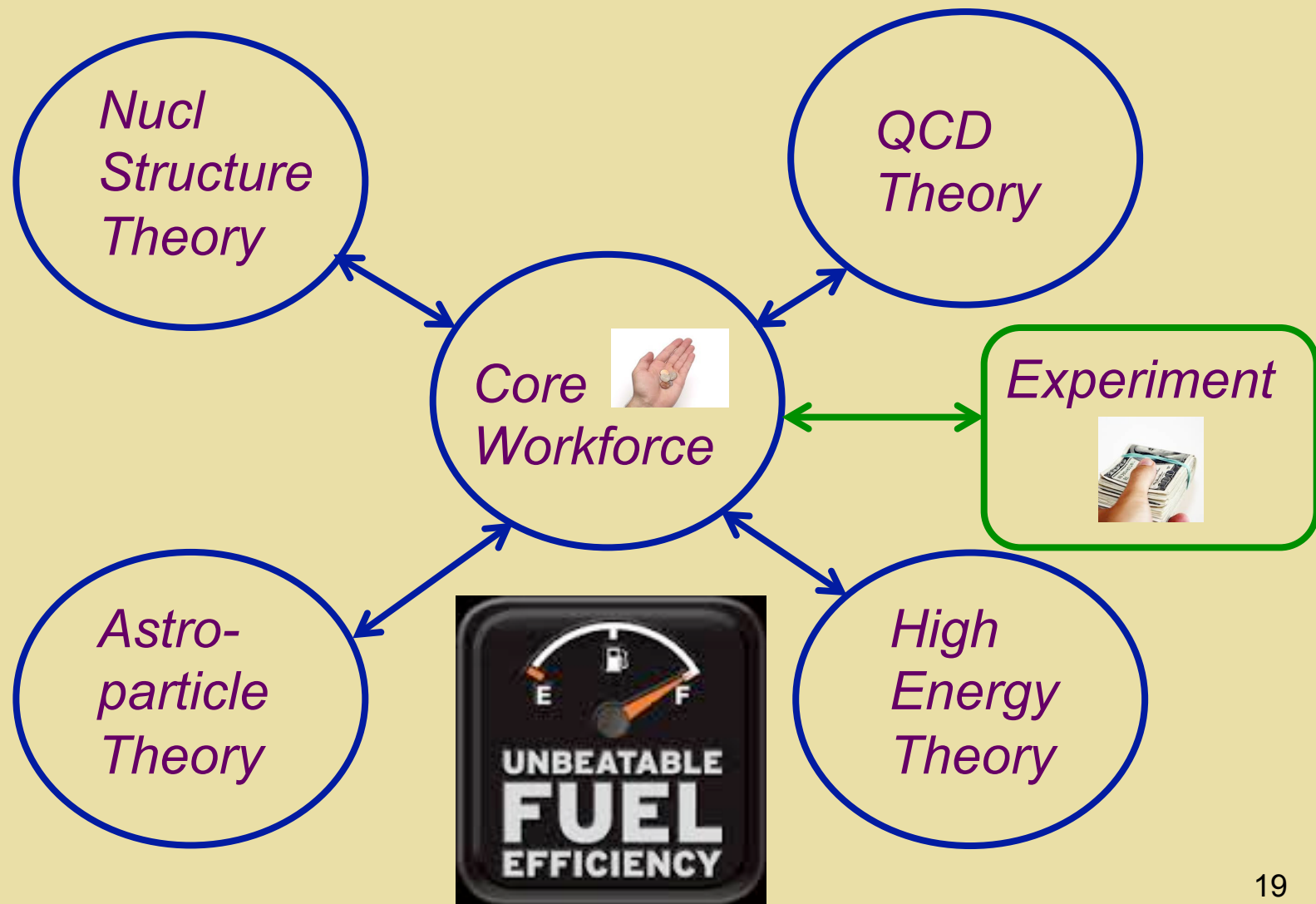
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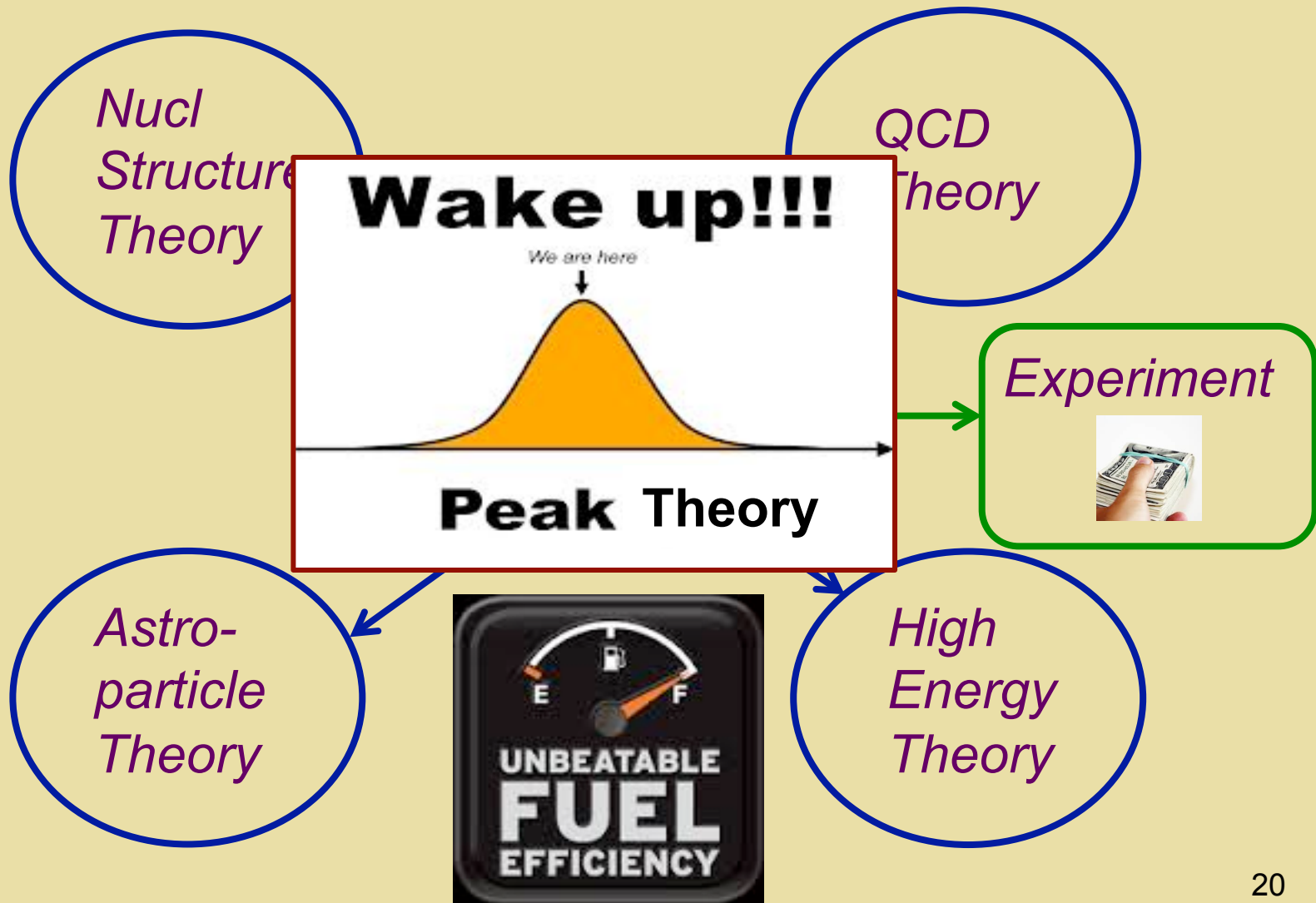
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Career op's ?!

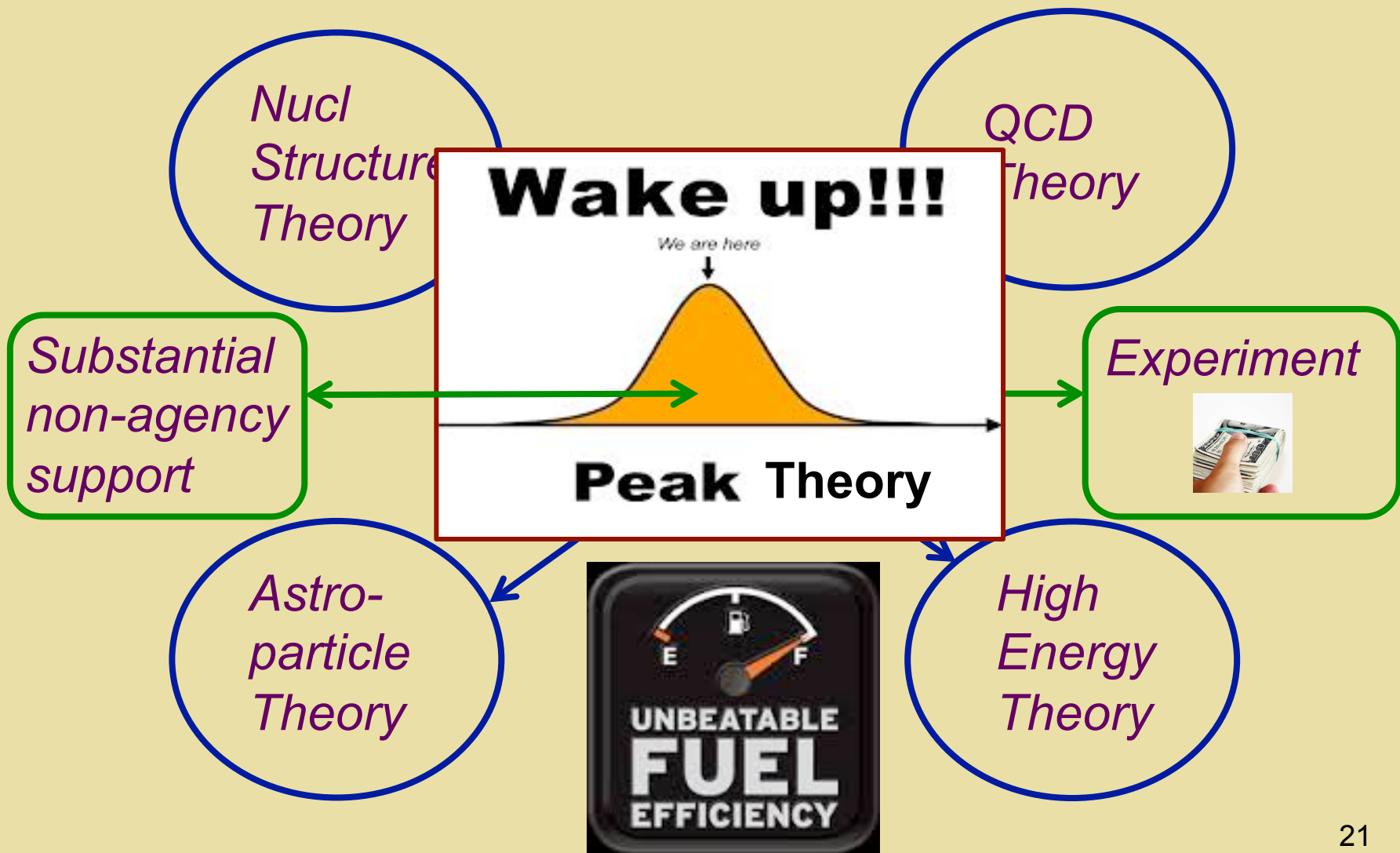
FS & N Theory Effort



FS & N Theory Effort



FS & N Theory Effort



FS & N Theory Effort: Needs

- ***Grow the core workforce to address key open problems***
- ***Enhanced resources to facilitate collaborations between core and related areas***
- ***Enhanced resources & “focal point” to facilitate theory-experiment collaboration in light of growing & ambitious experimental effort***

FS & N Theory Effort: Rec's

- ***Support for a five-year topical collaboration targeted to fundamental symmetries & neutrinos***
- ***Support for a national center to facilitate theoretical collaborations with related areas and theory-experiment interactions***
- ***Support for a realistic nuclear theory-wide computational physics initiative that addresses FS & N large scale computational needs***

FS & N Theory Effort: Resources

- ***Five-year topical collaboration: \$2.5 - \$3 m or \$500-\$600k/yr***
- ***National center: ~ \$300k/yr***
- ***Realistic nuclear theory-wide computational physics initiative: see D. Richards talk***

FS & N Theory Effort: Anticipated Outcomes

✧ *A sampling: additional community input welcome!*

Four Components

EDM searches:

BSM CPV, Origin of Matter

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton number violation, Origin of Matter

- *Robust nuclear matrix element computations (light ν_M & heavy LNV)*
- *Comprehensive phenomenology for disentangling mechanism*

radioactive decays & other tests

SM Precision Tests, BSM “diagnostic” probes

SM Precision Tests, BSM “diagnostic” probes

Four Components

EDM searches:

BSM CPV, Origin of Matter

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton number violation, Origin of

Electron & muon prop's interactions:

SM Precision Tests, BSM "diagnostic" probes

- *Robust hadronic matrix element computations*
- *Refined nuclear Schiff moment computations*
- *Robust solution to the quantum transport problem for baryogenesis*

SM Precision Tests, BSM "diagnostic" probes

Four Components

EDM searches:

BSM CPV, Origin of Matter

$0\nu\beta\beta$ decay searches:

Nature of neutrino, Lepton

- *Reduced uncertainty in HLBL for $g_{\mu-2}$ (lattice, dispersion relations...)*
- *Two-loop EW radiative corrections for PVES*

Electron & muon prop's & interactions:

SM Precision Tests, BSM "diagnostic" probes

Radioactive decays & other tests

SM Precision Tests, BSM "diagnostic" probes

Four Components

EDM searches:

- *Reduced hadronic uncertainty in EW corrections for β -decay*
- *Robust hadronic form factors for CKM unitarity tests & correlation studies*
- *Lattice & few-body calculations for hadronic PV*

$0\nu\beta\beta$ decay searches:

Structure of neutrino, Lepton number violation, Origin of matter

Electron & muon prop's & interactions:

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Radioactive decays & other tests

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FS & N Theory Effort: Rec's

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