Standard Model Tests with Nuclei and Energy Applications

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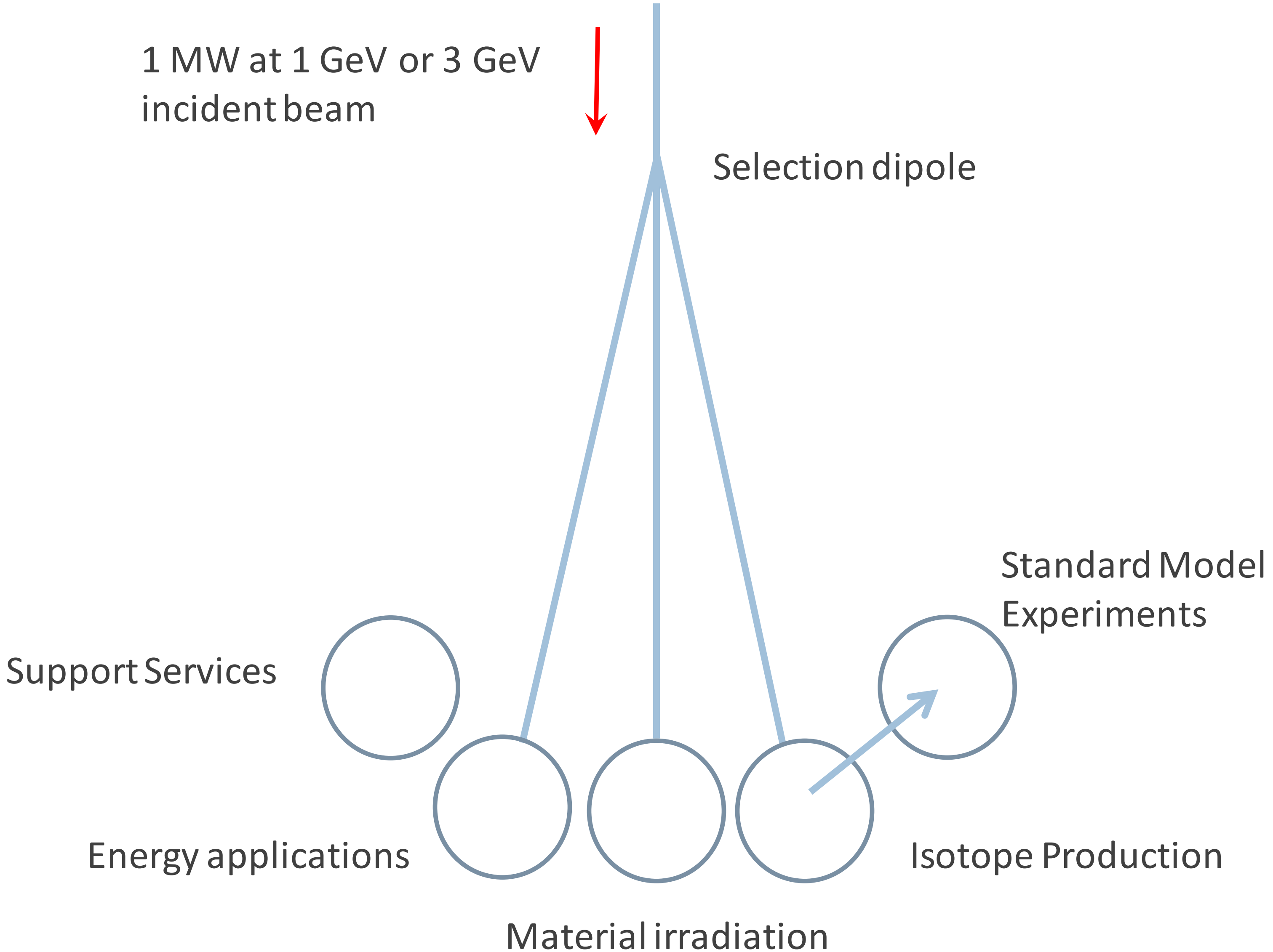
Joint Facility for Standard Model Tests with Nuclei and Energy Applications

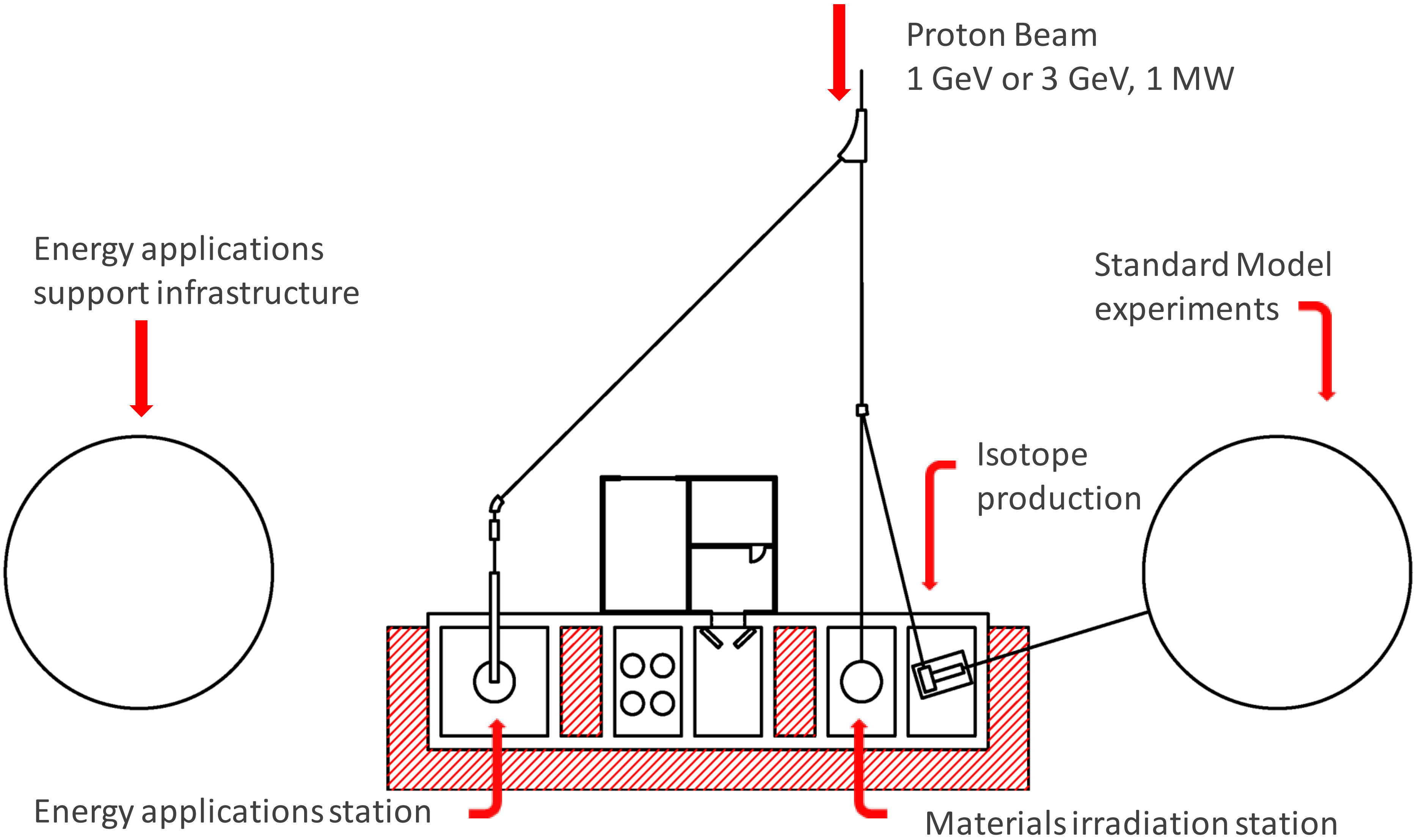
- MW-scale CW proton beams can serve a variety of functions beyond those of traditional high energy physics research, such as:
  - Copious production of special short-lived isotopes to support fundamental searches for physics beyond the Standard Model using stopped beams
  - Materials irradiations and target developments in support of future energy applications, especially for nuclear fission power, fusion power, and transmutation technologies

- Examples of flagship experiments enabled by such a joint facility are covered in this presentation

Functional Layout of the Joint Facility at Project X

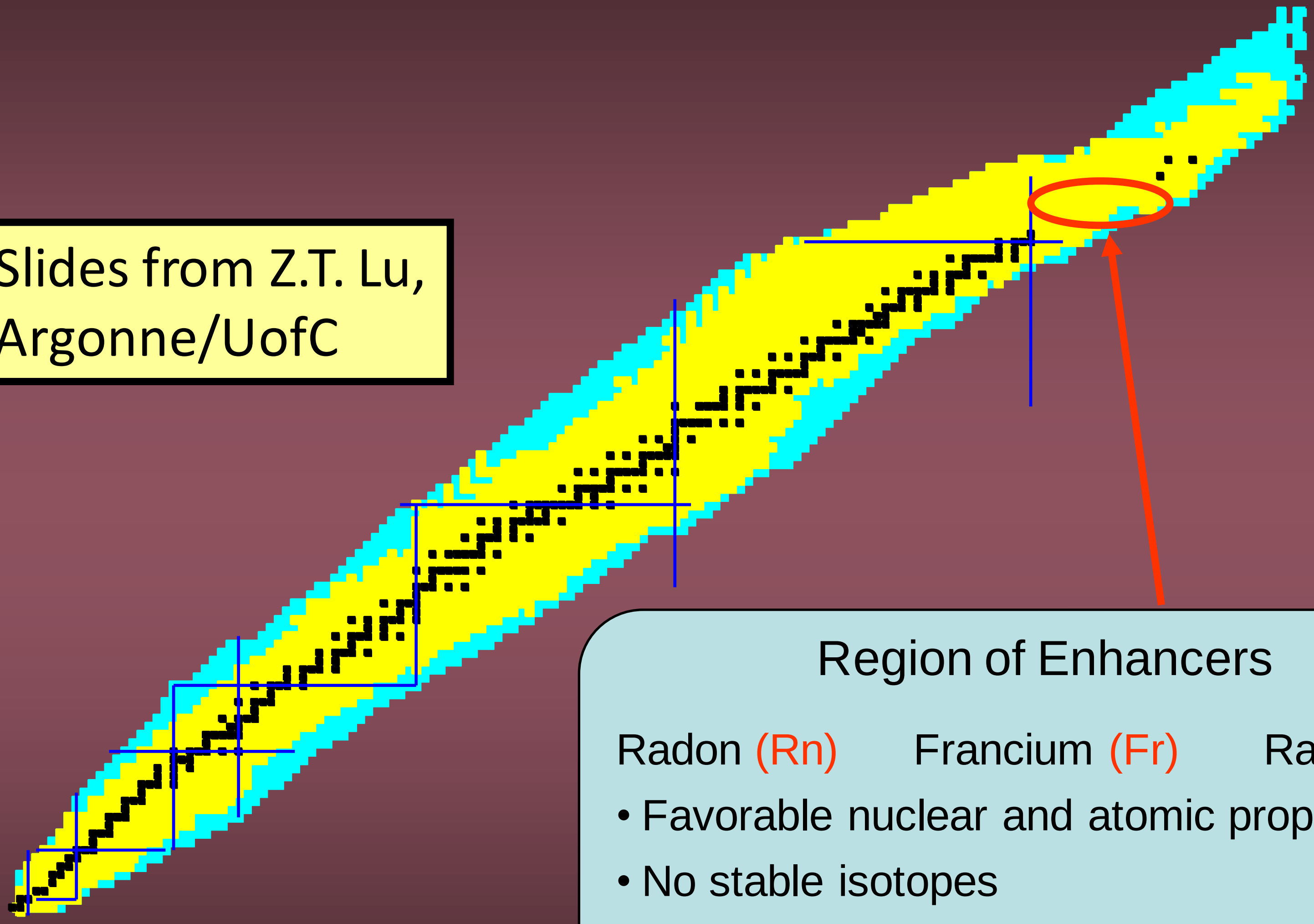


Schematic Layout of the Joint Facility at Project X



Project X: Source of Enhancer Isotopes

Slides from Z.T. Lu, Argonne/UofC



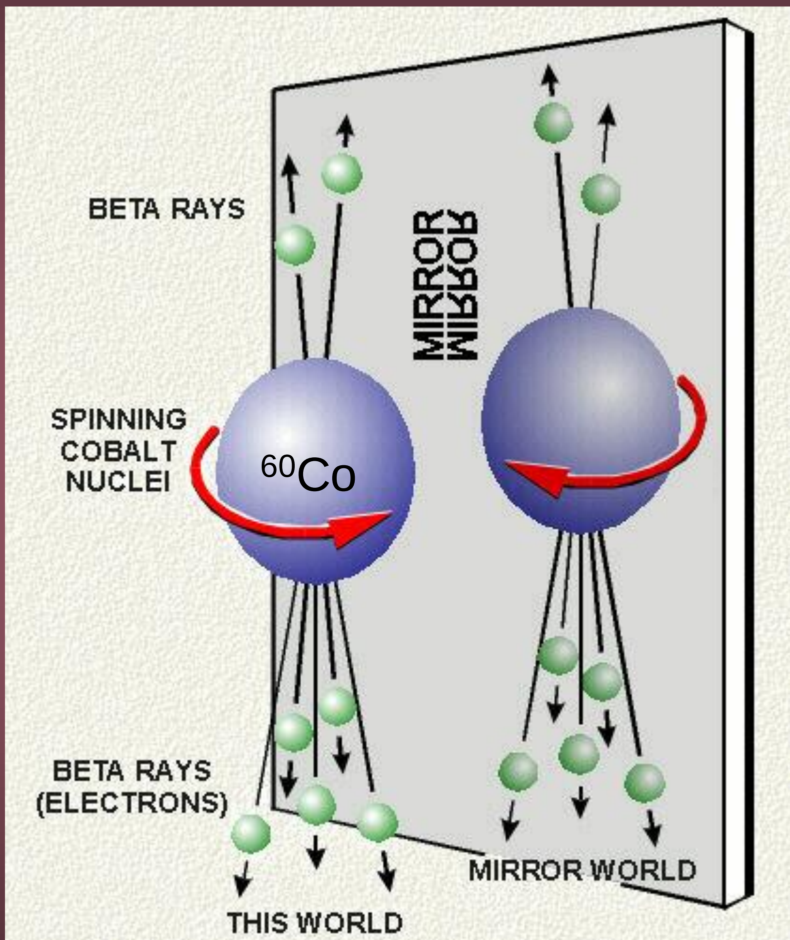
Region of Enhancers

Radon (Rn)   Francium (Fr)   Radium (Ra)

- Favorable nuclear and atomic properties
- No stable isotopes
- Project X will supply these isotopes in abundance

Discrete Fundamental Symmetries

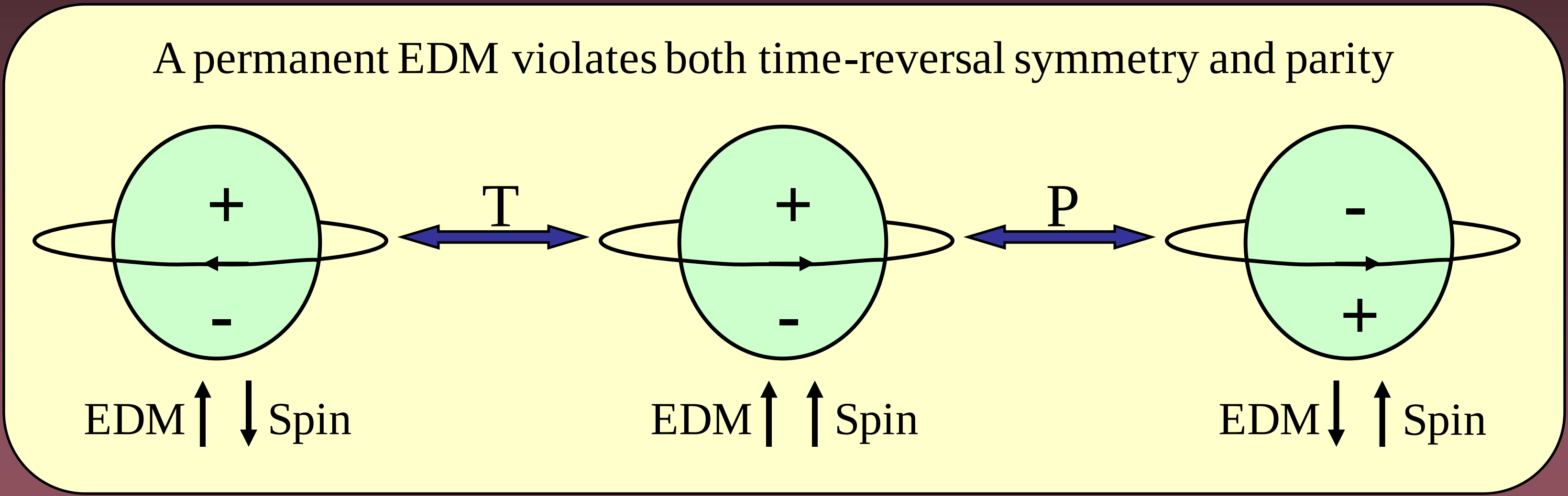
Parity violation – First observation



C. S. Wu *et al*. (1957)

- ~~P~~ Parity
- ~~C~~ Charge conjugation
- ~~CP~~ CP symmetry
- ~~T~~ Time reversal
- CPT – CPT – Exact symmetry in quantum field theory with Lorentz invariance

Electric Dipole Moment (EDM) Violates Both P and T



"The existence of an EDM can provide the "missing link" for explaining why the universe contains more matter than antimatter."

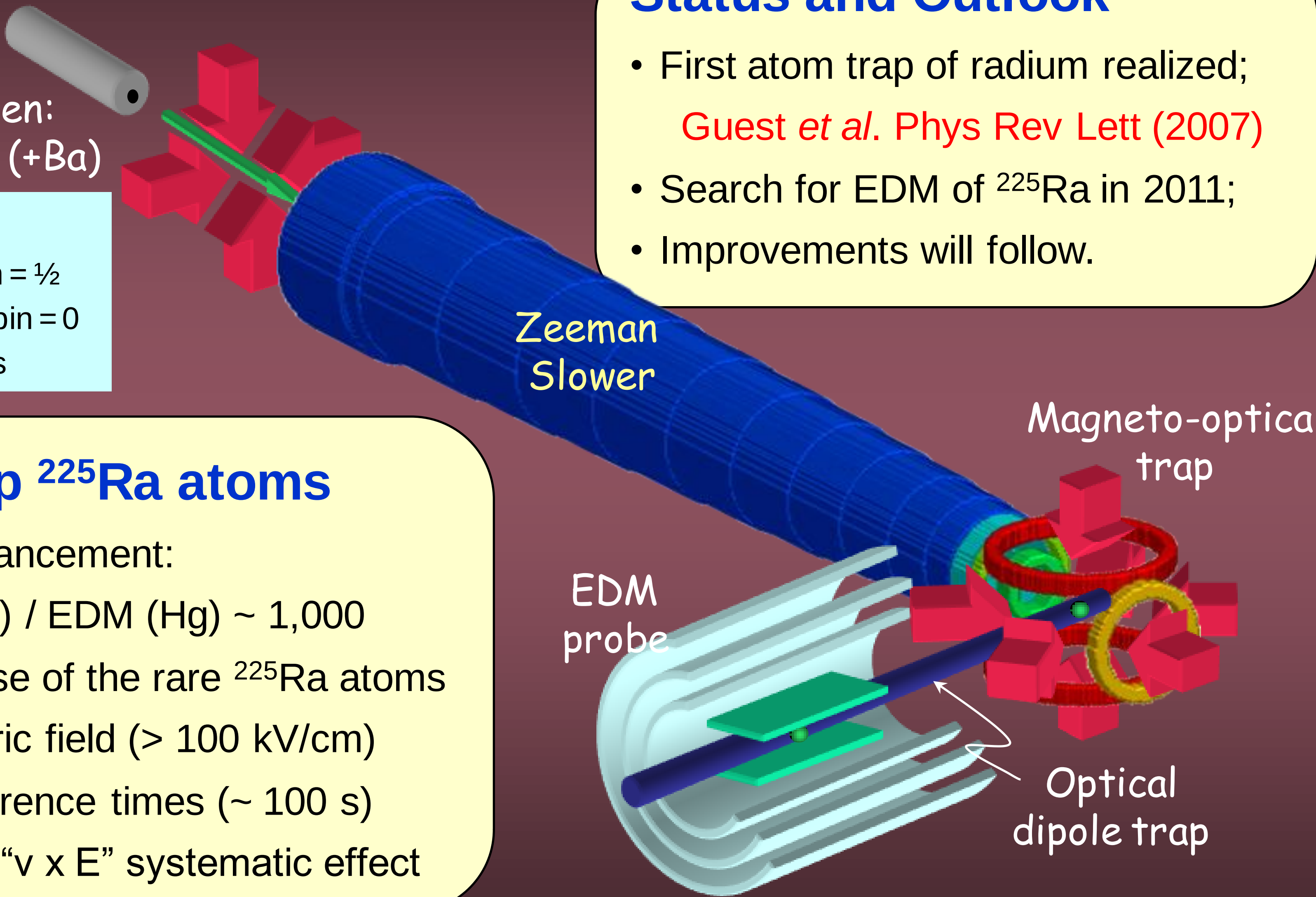
"The non-observation of EDMs to-date, thus provides tight restrictions to building theories beyond the Standard Model."

-- P5 report : The Particle Physics Roadmap (2006)

"A nonzero EDM would constitute a truly revolutionary discovery."

-- NSAC Long Range Plan (2007)

Search for EDM of ^{225}Ra at Argonne



^{225}Ra
Nuclear Spin = ½
Electronic Spin = 0
$t_{1/2}$ = 15 days

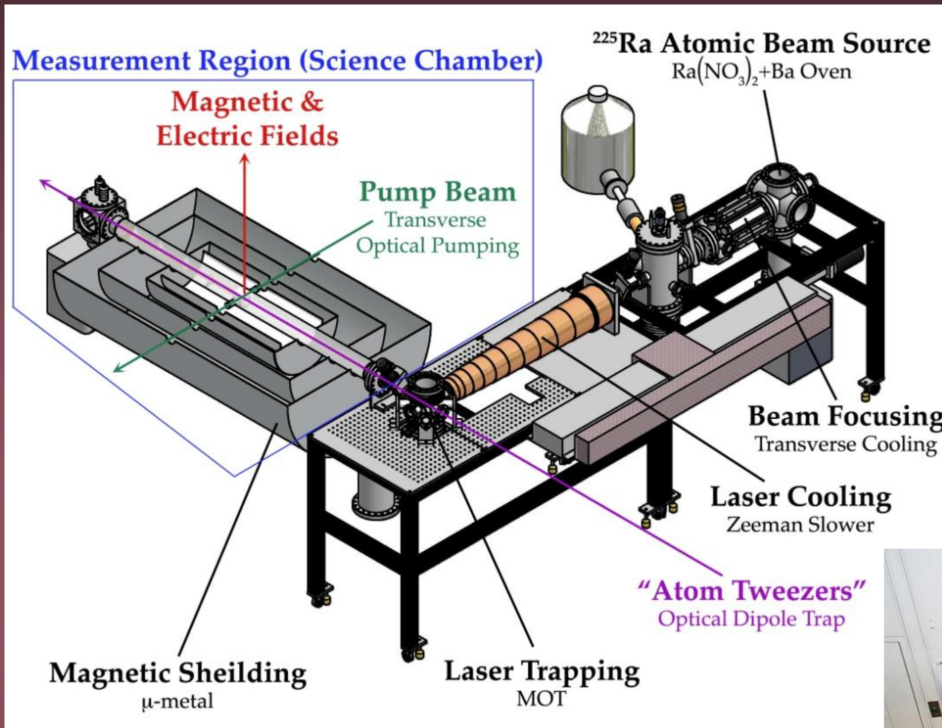
Status and Outlook

- First atom trap of radium realized;
  Guest *et al*. Phys Rev Lett (2007)
- Search for EDM of ^{225}Ra in 2011;
- Improvements will follow.

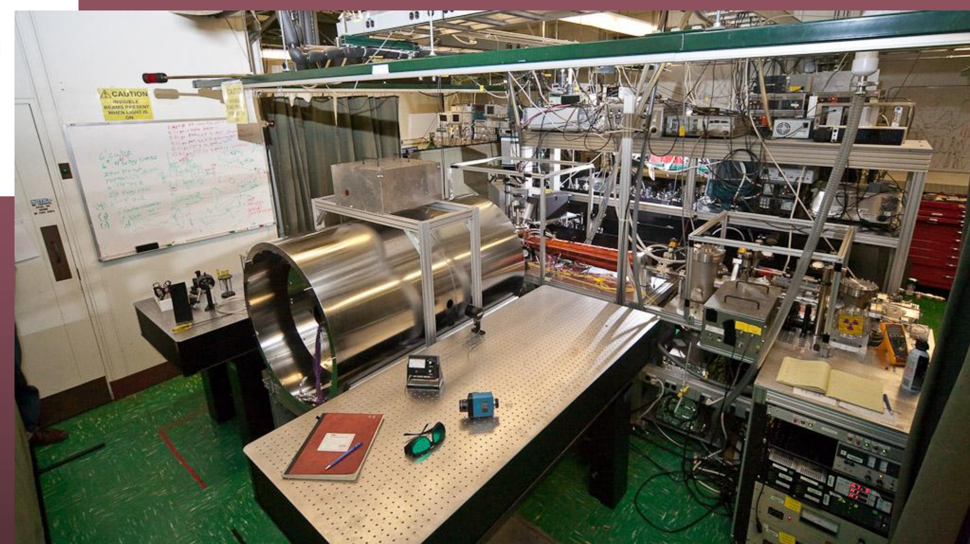
Why trap ^{225}Ra atoms

- Large enhancement:
  EDM (Ra) / EDM (Hg) ~ 1,000
- Efficient use of the rare ^{225}Ra atoms
- High electric field (> 100 kV/cm)
- Long coherence times (~ 100 s)
- Negligible "v x E" systematic effect

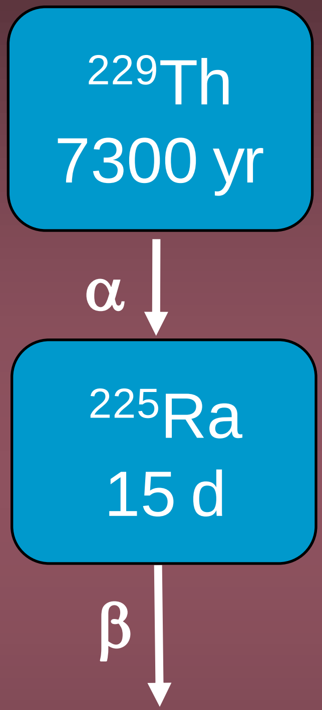
EDM search experiments are "portable"



^{225}Ra EDM search apparatus under construction at Argonne



Search for ^{225}Ra EDM at Project X



Present scheme

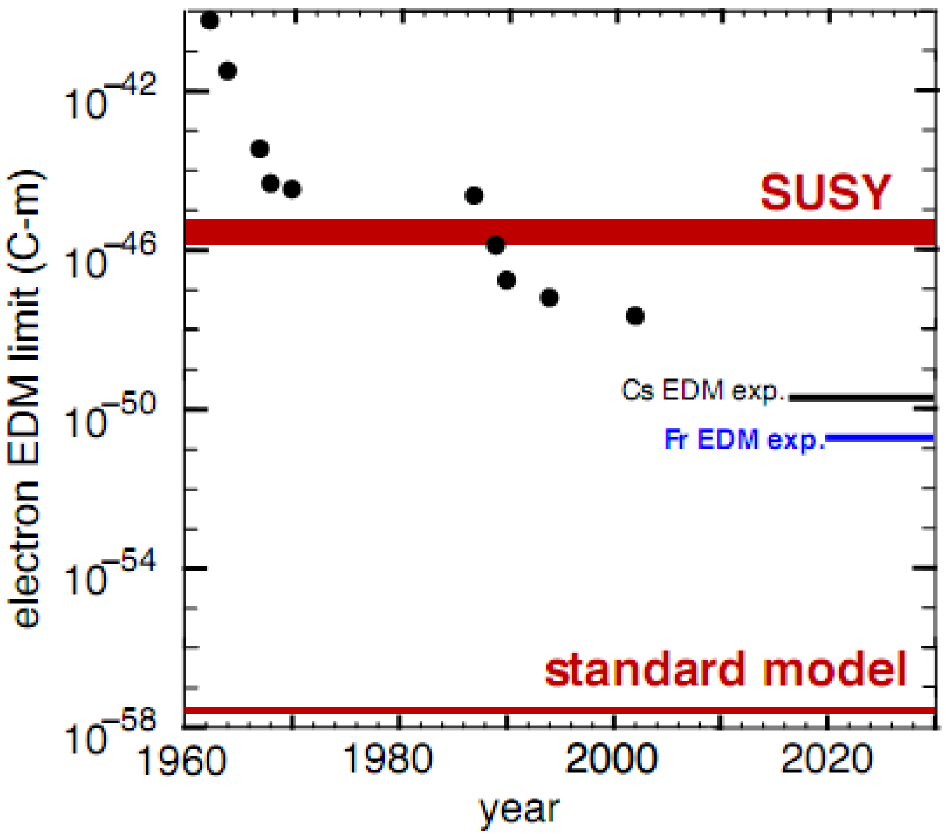
- 1 mCi ^{229}Th source → 4 x 10^{7} s^{-1} ^{225}Ra
- Upgrade path to 10 mCi
- Projected EDM sensitivity: 10^{-26} – 10^{-27} e-cm
- Equivalent to 10^{-28} – 10^{-30} e-cm for ^{199}Hg
- Current limit on ^{199}Hg: 2 x 10^{-28} e-cm

Search for ^{225}Ra EDM at Project X

- Project X yield: 1 x 10^{13} s^{-1} ^{225}Ra
- Projected EDM sensitivity: 10^{-28} e-cm
- Equivalent to 10^{-30} – 10^{-31} e-cm for ^{199}Hg
- Study systematics at 10^{-29} e-cm for ^{225}Ra

Supersymmetry (SUSY) and Electron EDM Bounds

EDM Experimental Bounds & Theory

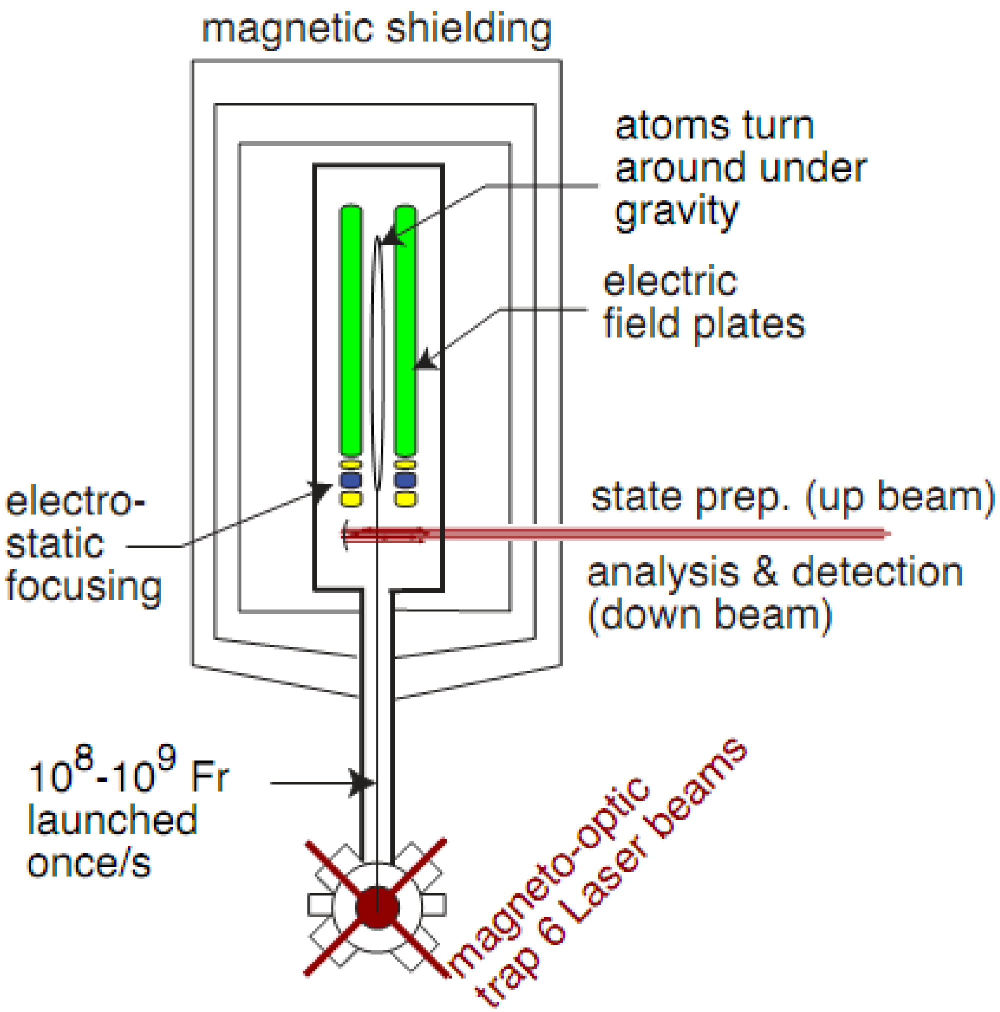


Generic SUSY, with CP-violating phases, of order 1 and superpartner masses of order 100 GeV predict EDMs that exceed experimental bounds by 10^2.

EDM search probes energy scales beyond the LHC

Francium Atomic Fountain EDM

Electron EDM greatly enhanced in Fr due to relativistic effects



Goal: Discover or Rule Out Electron EDM as Small as 2 X 10^{-51} C•m (factor of 10^3)

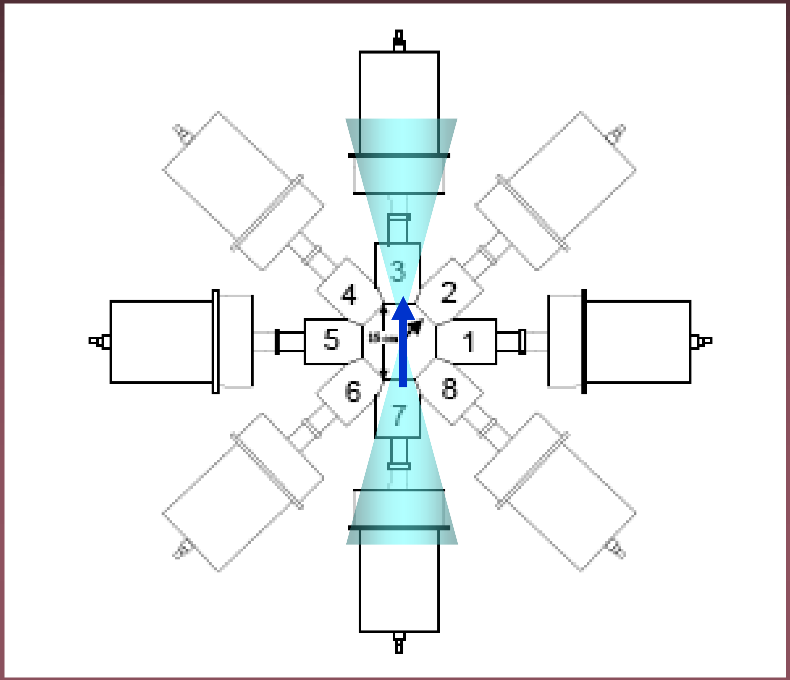
Experimenters

Benedict Feinberg (LBNL),
Harvey Gould (LBNL),
Juris Kalnins (LBNL),
David Kilcoyne (LBNL),
Charles Munger Jr., (SLAC)
Hiroshi Nishimura (LBNL),
Paul Vetter (LBNL)

Radon-EDM Experiment

TRIUMF E929 Spokesperson
T. Chupp (Univ of Michigan)
C. Svensson (Guelph)

Funding: NSF, DOE, NRC (TRIUMF), NSERC



- Produce rare ion radon beam
- Collect in cell with co-magnetometer
- Measure free precession

  (γ anisotropy or β asymmetry)

^{223}Rn (23 min) EDM projected sensitivity

Facility	^{223}Rn Yield	S_d (100 d)
ISAC	$10^7 – 10^8$ s^{-1}	10^{-26} - 10^{-27} e-cm
Project X	10^{11} s^{-1}	10^{-28} e-cm

~ 10^{-30} e-cm for ^{199}Hg

Project X: Target Spallation Production

Protons on thorium target: 1 mA x 1000 MeV = 1 MW

Predicted yields of some important isotopes:

Radon:	^{219}Rn >10^{14}	^{223}Rn ~10^{11} /s	
Francium:	^{211}Fr ~10^{13}	^{221}Fr >10^{14}	^{223}Fr >10^{12} /s
Radium:	^{223}Ra >10^{14}	^{225}Ra >10^{13} /s	
Actinium:	$^{225-229}$Ac >10^{14} /s		

Yields simulated by
I.C. Gomes using MCNPX,
Project X workshop,
October 2009

Project X will enable a new generation of symmetry-test experiments, and bring exciting opportunities for discovering physics beyond the Standard Model.

Technology of isotope production at 1 MW

- Existence proof at TRIUMF ISAC facility
  - ISAC has achieved stable operation at 500 MeV, 100 microamps, 100 microamps/cm^2 on carbide targets
  - Extrapolation to 10 cm^2 is feasible for thorium carbide

- Remote handling is essential but existing at other facilities
  - ISAC approach can be implemented with upgrade for actinides – currently being implemented for 500 kW photo-fission at TRIUMF
  - MW-scale facilities in operation at SNS and JPARC

- High efficiency extraction feasible due to long half-lives of important isotopes
  - $T_{1/2}$ ~days feasible by chemical separation
  - $T_{1/2}$ ~minutes feasible from hot carbides

Project X facility for Energy Applications

A Multi-Megawatt proton beam is

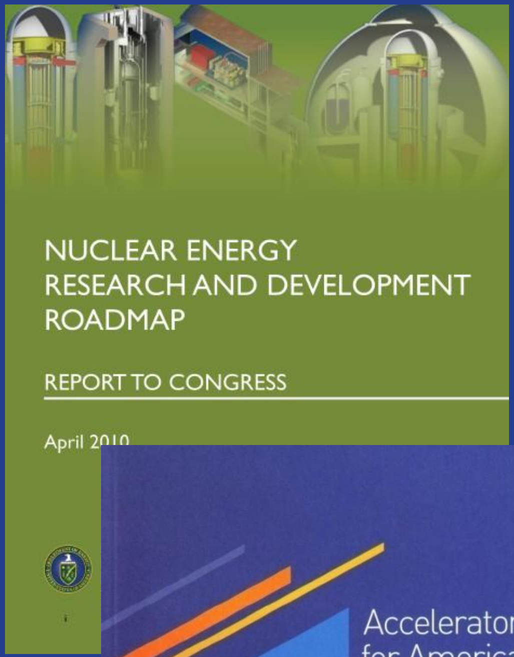
- a national resource,
- provides capabilities unparalleled in the world,
- with potential application far beyond high-energy physics

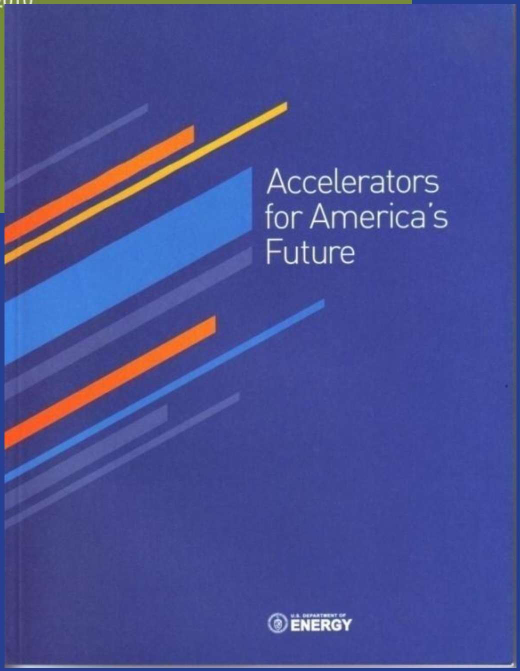
Project X can help to meet the national need in two research thrusts:

- A demonstration facility for Nuclear Energy:
  - Reliable acceleration operation
  - Transmutation of spent and processed nuclear fuel
  - Radiation capabilities that are required for the development of materials for advanced energy systems
- Development of advanced fuel cycles

National Needs in Advanced Energy Systems are Articulated in Numerous Recent Reports

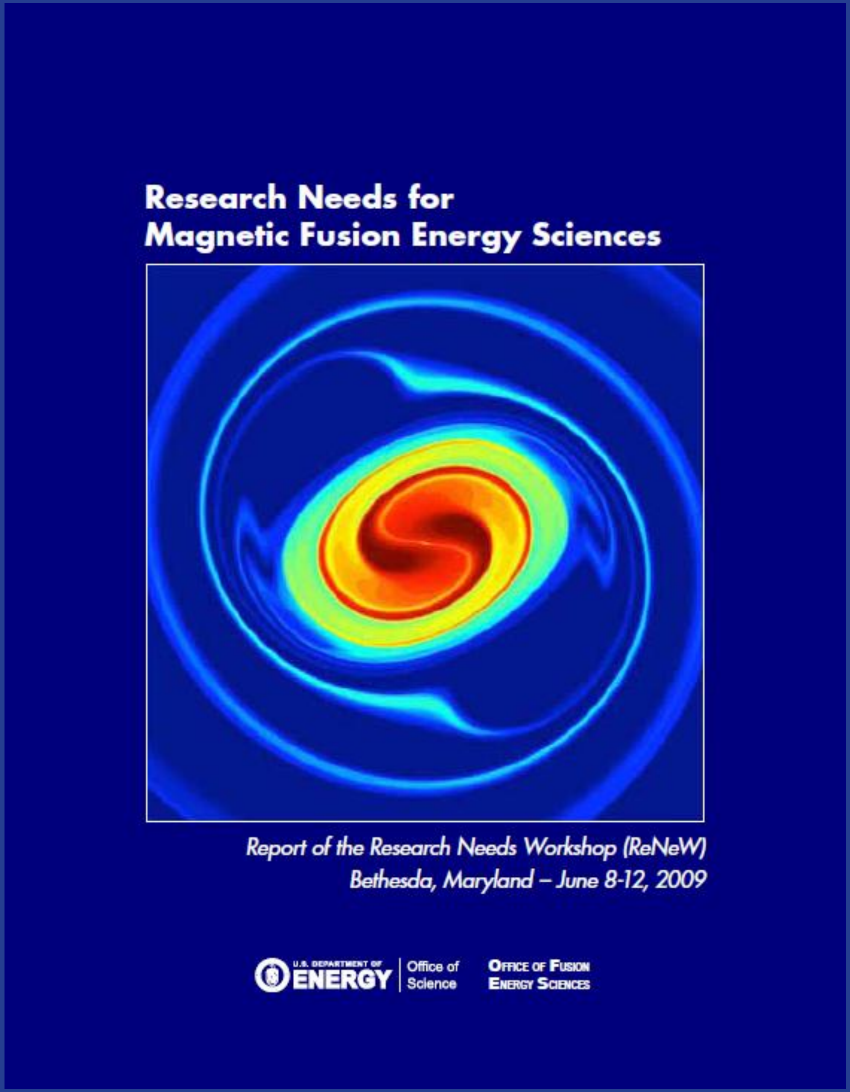
- DOE/NE Report: Nuclear Energy Research and Development Roadmap
  - R&D on Transmutation Systems for Sustainable Fuel Cycle Options
  - R&D to develop fast-spectrum reactor technology
- DOE/HEP Report: Accelerators for America's Future
  - R&D on Accelerator-Driven Systems technology focusing on high-reliability linear accelerator and liquid-metal target technology





National Needs in Advanced Energy Systems in support of fusion energy development

- DOE/FES Report: Research Needs for Magnetic Fusion Energy Sciences
  - Thrust: Develop the material science and technology needed to harness fusion power
  - *“Establish a fusion-relevant neutron source to enable accelerated evaluations of the effects of radiation-induced damage to materials”*



Basic Target Experiments

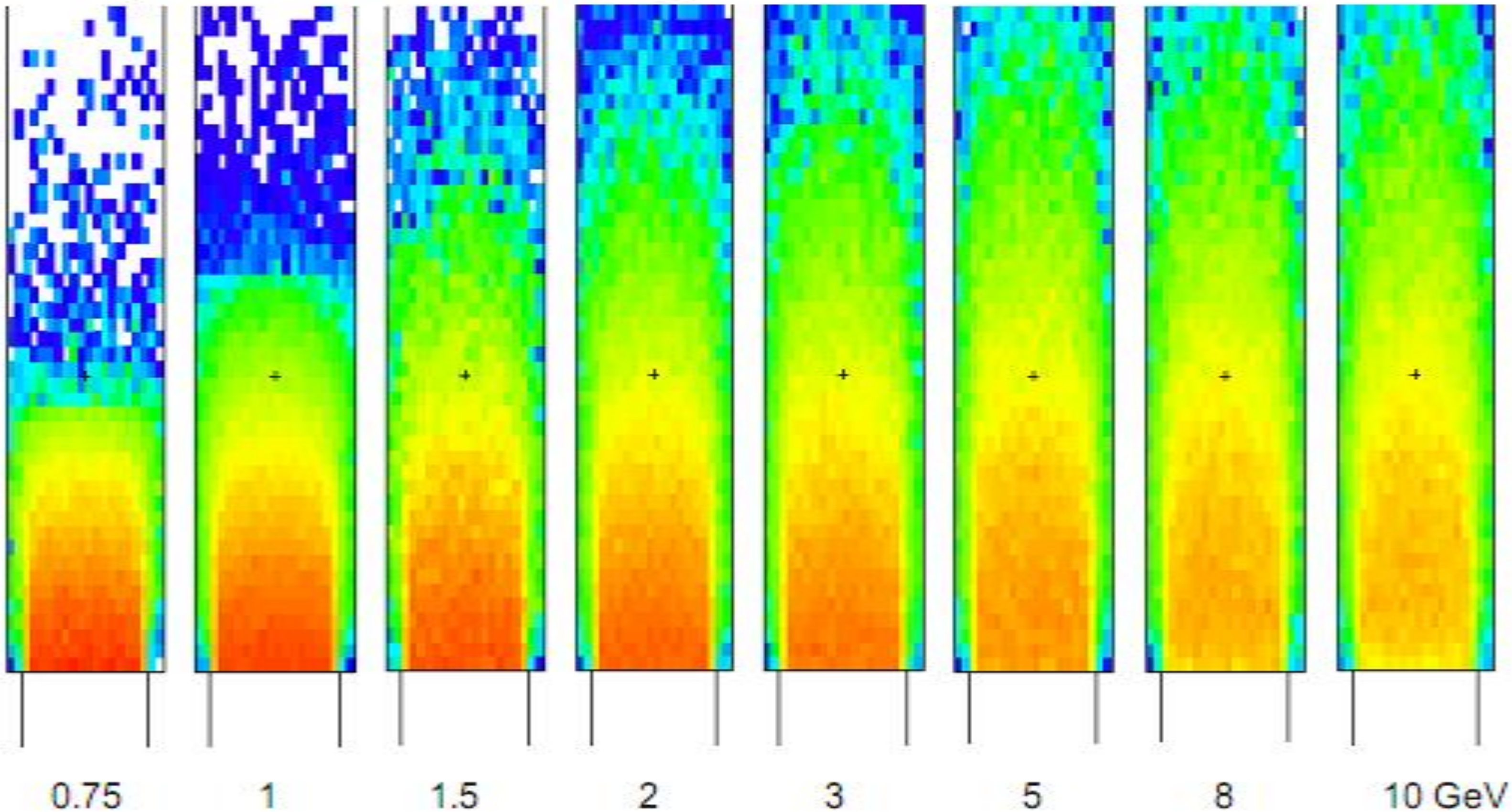
Demonstrate and verify the following aspects of the neutron spallation target systems:

- Neutron yield, spectra, and spatial distribution.
- Control and recovery of the spallation products.
- Chemistry control of the lead bismuth eutectic or the liquid lead to protect the structural material.
- Thermal hydraulics parameters of the target design including the velocity and the temperature distributions, and the pressure drop.
- Structural material performance including radiation damage and liquid metal effects.
- Target operation and replacement procedures
- The operation and the maintenance of auxiliary systems

Brad Micklich, ANL
Project X Workshop
October, 2009

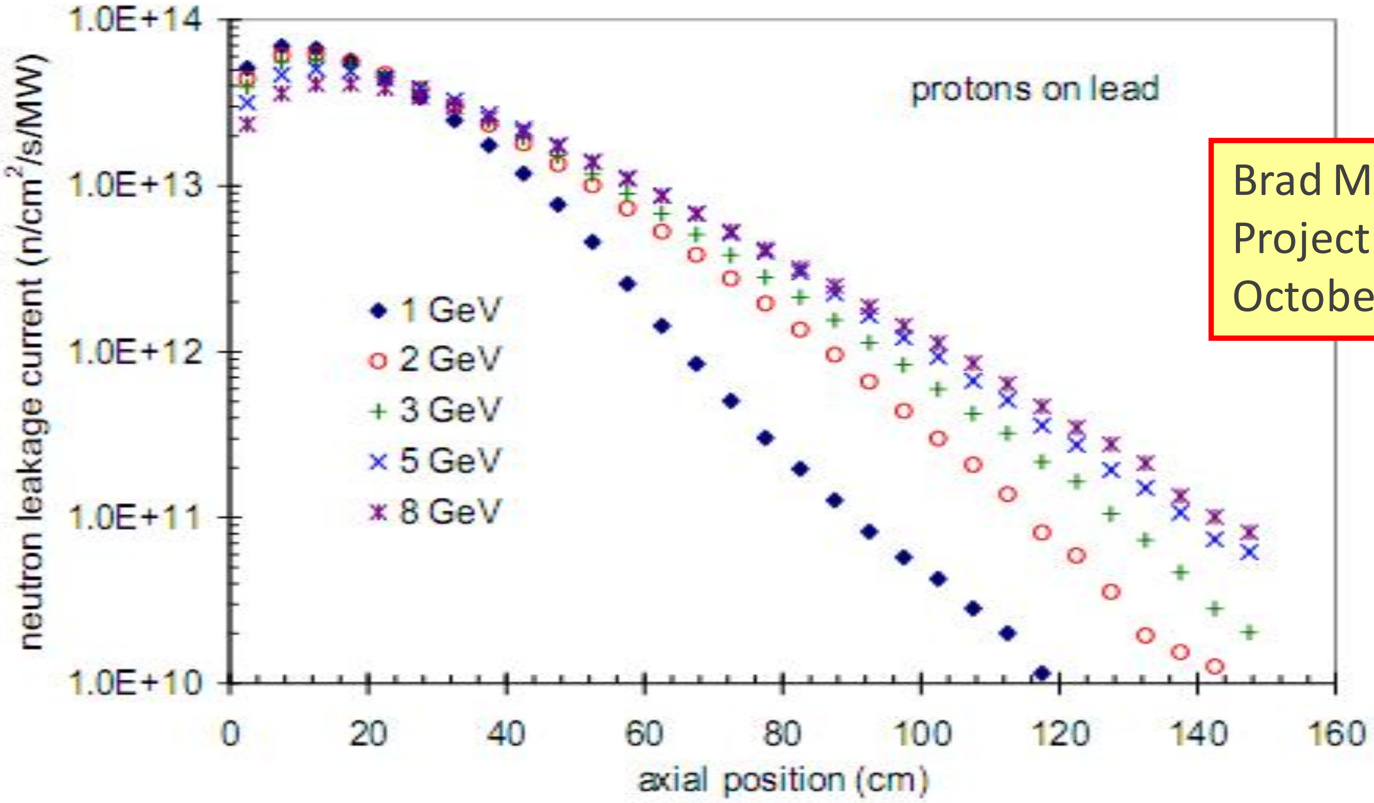
MCNPX Model – Target Neutron Production

- Proton energy varied from 0.75 to 10 GeV
- Target diameter 20 cm, length 200 cm; beam diameter 15 cm



Neutron Leakage Current vs. Incident Proton Energy

- At higher proton energies, peak neutron emission is lower, broader, and shifted downstream



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Summary

- Flagship experiments to search for physics beyond the Standard Model
  - Search for static electric dipole moments in atoms and electrons (EDM) [Experiments are small and portable]
  - Requires high yields of radioactive isotopes of Rn, Fr, and Ra
  - Project X extends isotope yields by factors of 10^2-10^4 over existing facilities
- Provides MW-scale proton beams for essential target and materials developments in support of high priority national programs for future energy sources
  - Tests of materials for fission reactors and transmutation technologies
  - Evaluation of materials for fusion energy applications