Low Energy Physics Potential of a Proton Driver

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http://home.fnal.gov/~kasper/talks/LRPC.ppt

Because it is Complementary!

- In an era where we will be producing events at 8 **TeV** CM Energy WHY would you ever want an 8 **GeV** program?
  - There is physics that you cannot do at ultra-high energy scale proton machines
    - e.g. Neutrino beams
  - Low energy experiments can help unravel high energy experimental mysteries
    - e.g. the high Q^2 HERA events could not have been leptoquarks -- the Atomic Parity Violation data ruled it out!
  - Stringent limits on "forbidden" low energy processes can probe energy scales not accessible to the colliders
    - e.g. neutron electric dipole moment

Topics Covered

- A physics program based on 8 GeV protons from the Booster or a Proton Driver (linear or circular) will likely fall into one or more of the following categories
  - Neutrino Physics
  - Fundamental Neutron Physics
  - Muon Physics
- In all cases, high intensities will be required in order to create a state of the art facility.
  - What might be achieved with the Booster?
  - What more could be done with a Proton driver?

What can we do with what we have?

- Enormous progress has been made recently on increasing the output from the Booster
- However the physics potential of NuMI and MiniBooNE make it worth the effort to push as high as we can.
- Even greater output is possible but we can only go so far
  - These experiments represent a great starting point for high intensity programs at both high and low energies
  - The Booster will hopefully be able to meet their needs in the short term
  - A Proton Driver not only allows the programs to advance but opens up other interesting possibilities

Proton Availability – Near Term

- Booster Now
  - ~5e16 p/hr (limited by tunnel activation)
  - ~5e12 p/cycle maximum sustainable intensity
  - 6.5 Hz maximum beam cycle rate @ 5e12 p/cycle = 1.2e17 p/hr
  - 1.8e17 p/hr (Shielding Assessment limit) = 5e12 @ 10 Hz
- Pbar Production + Full MiniBooNE (Booster limit → 1.2e17 p/hr)
  - 5e12 @ (0.5+5.0) Hz = 1.0e17 p/hr
  - 5e12 @ (1.0+5.0) Hz = 1.1e17 p/hr (with slip-stacking)
- Pbar Production + NuMI
  - 5e12 @ (1.0+2.5) Hz = 6.3e16 p/hr
  - 5e12 @ 3.0 Hz = 5.4e16 p/hr available to MiniBooNE
- NuMI will want to increase protons to the MI
- MiniBooNE will want to increase rep rate

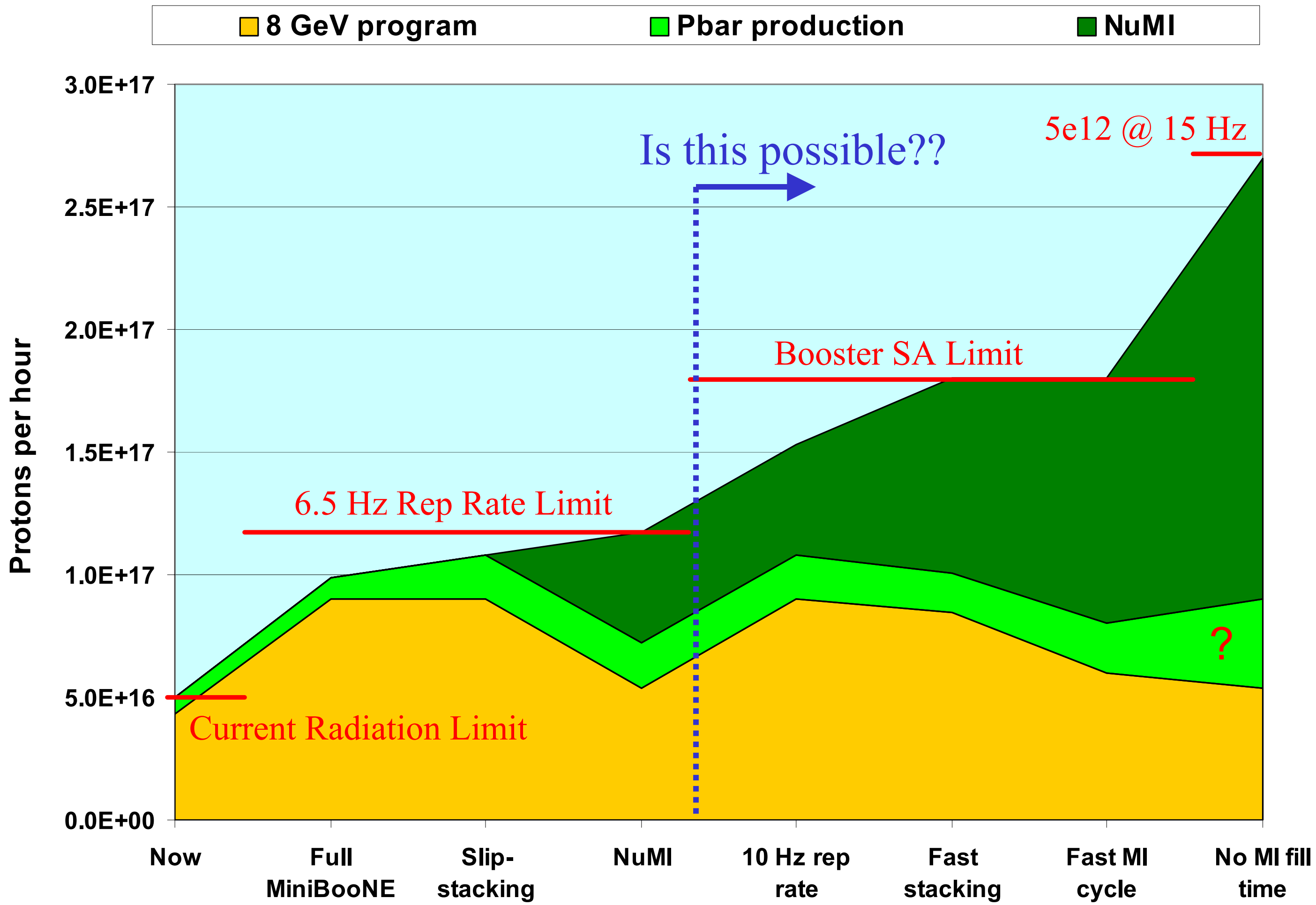
Proton Availability – Medium Term

- Increase rep rate to 10 Hz (Booster limit → 1.5e17 p/hr)
  - Full 9E16 p/hr rate for MiniBooNE/BooNE
- Introduce fast stacking in MI for NuMI and Pbar and raise Booster limit to SA value of 1.8e17 p/hr
  - MI must handle 6E13 p/cycle
  - Minimum MI Cycle time goes to 2.27 sec
  - MI gets 5e12 @ 5.3 Hz = 9.5e16 p/hr
  - 8 GeV users can get 8.5e16 p/hr (still OK for BooNE)
- Shorten MI acceleration cycle to 1 sec (few $10M's)
  - Minimum MI Cycle time goes to 1.8 sec
  - MI gets 5e12 @ 6.7 Hz = 1.2e17 p/hr
  - 8 GeV users can get 6.0e16 p/hr (probably adequate)

Proton Availability – Far Term

- Eliminate MI fill time??
  - Booster fills recycler while MI is accelerating
    - Assumes the recycler is not being used for P-bar’s
  - Recycler is used to do slip-stacking and to fill the MI
  - Minimum MI cycle time is reduced to 1 sec.
  - 12 x 5e12 Booster batches per second exceeds both the Booster SA limit and the assumed rep-rate limit
- Assume maximal Booster i.e. 5e12 @ 15 Hz = 2.7e17 p/hr
  - MI gets 5e12 @ 12 Hz = 2.2e17 p/hr
  - 8 GeV users can get 5.4e16 p/hr
  - Is this even possible?
- Additional gains will require a new proton source

Summary of Possible Booster Output



Recap

- The present facility can be made to meet the needs of MiniBooNE
- NuMI goals are challenging and may require significant MI and possibly Booster upgrades
- MiniBooNE and NuMI will be able to live together but as time goes on and demand goes up, there are significant issues that must be addressed.
- Upgrading to 10 Hz (if radiation can be controlled) will make a MiniBooNE successor possible.
- A fast slip-stacking scheme (if it can be done) will greatly benefit NuMI and leave sufficient protons for BooNE etc.
- Further increasing the MI's output will significantly reduce protons to any 8 GeV users.
- In the long term the only solution is a new proton driver

Proton Driver Machine Characteristics

	Energy (GeV)	Pulse (μs)	P/pulse	Rep Rate (Hz)	P/hr	Power (MW)
Booster (2005)	8	1.6	5.00E+12	6.5	1.17E+17	0.04
Booster (Max)	8	1.6	5.00E+12	15	2.70E+17	0.10
PD synchrotron	8	1.6	2.50E+13	15	1.35E+18	0.48
SC Linac	8	1,000	1.50E+14	10	5.40E+18	1.92

Protons available to 8 GeV programs running with the MI

	MI pulses (Hz)	8 GeV pulses (Hz)	P/hr	Power (MW)
Booster (2005)	3.5	3	5.40E+16	0.02
Booster (Max)	12	3	5.40E+16	0.02
PD synchrotron	6	9	8.10E+17	0.29
SC Linac	1	9	4.86E+18	1.73

15 - 90 times what we can get from the Booster!!

Physics Potential with Low Energy Protons

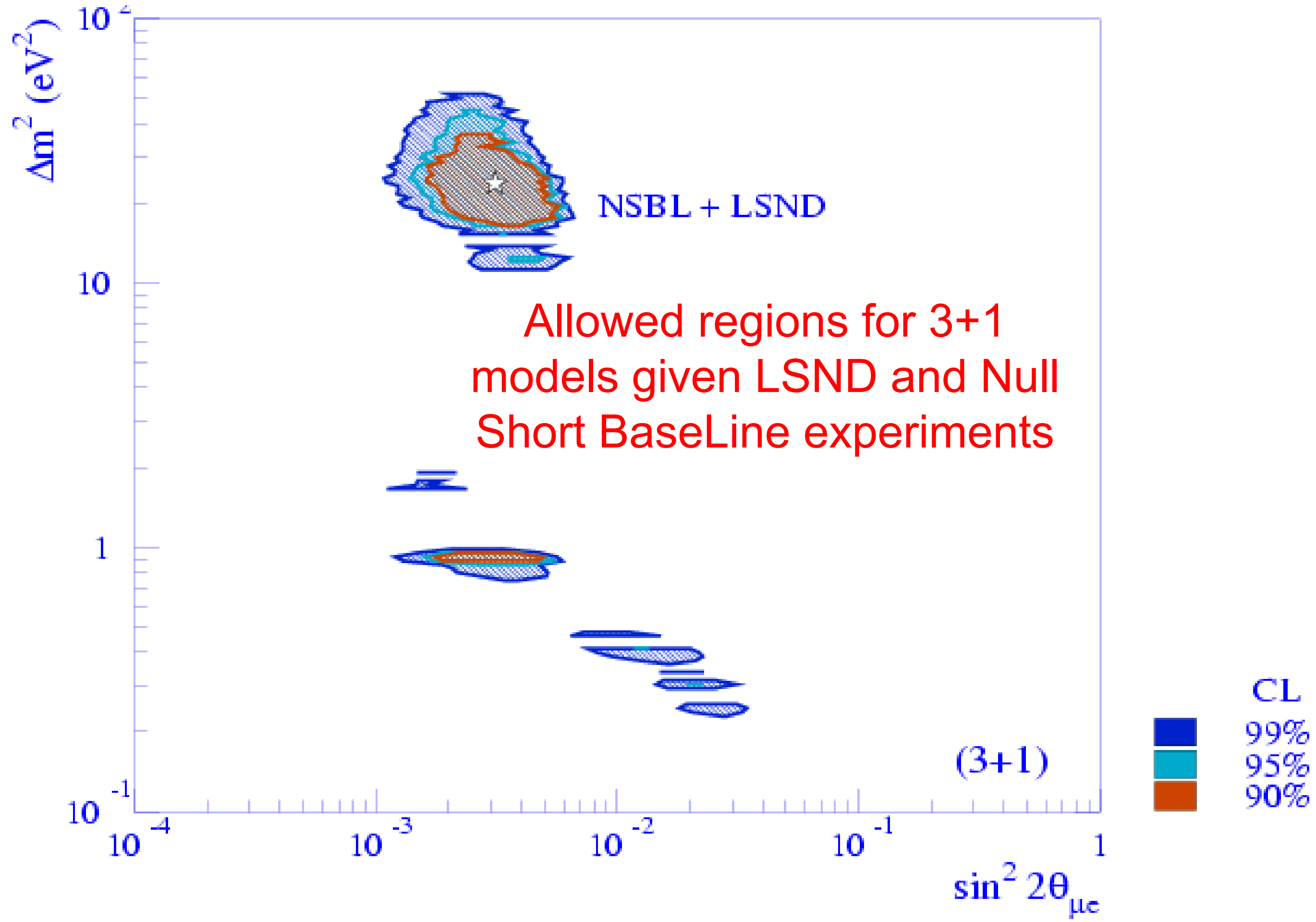
- ν Can comfortably support any MiniBooNE follow on experiments together with MI operations.
- n Provides sufficient additional beam power to produce a world class neutron source dedicated to experiments in particle physics
  - Address fundamental questions in our field
  - Are on the scale of small HEP experiments
- μ Provides sufficient additional beam power to produce high intensity low energy muon beams
  - Beyond the Standard Model searches
  - Muon collider R&D
- These are just the examples that we have thought of now
- Great physics at relatively low cost and low risk

Low Energy Neutrino Physics

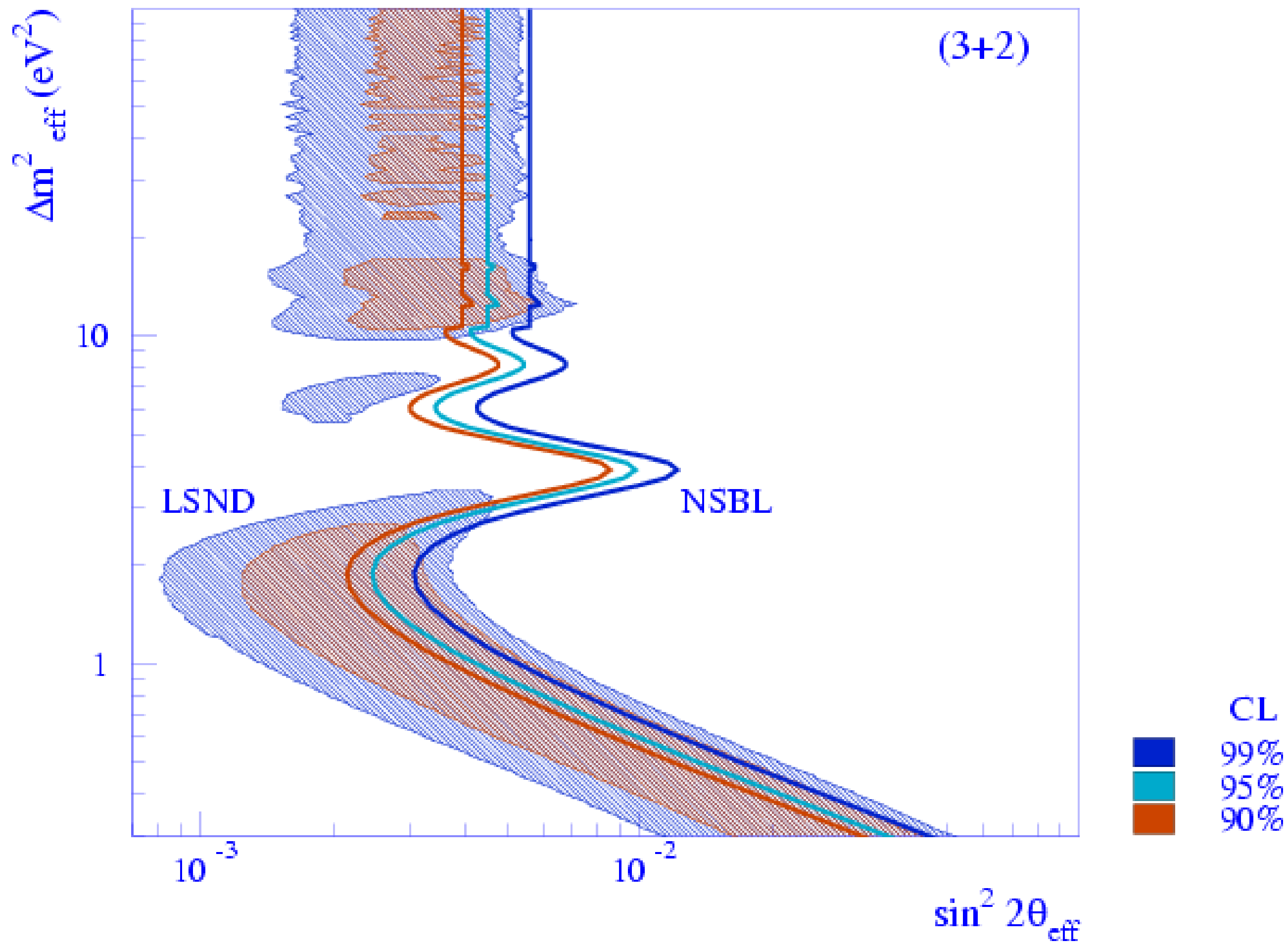
- MiniBooNE hopes to complete its neutrino running some time in 2005 (after NuMI start up).
- If MiniBooNE sees a signal then precise measurements will be required (BooNE)
  - An upgrade to two "MiniBooNE-type" detector sites
  - There may be more than one "MiniBooNE-type" detector at the new location (under discussion)
  - The needs will be for about the same rates as MiniBooNE receives now (no significant upgrades to the beam)
  - If the new proton driver "hooks in" at the same place as the present 8 GeV line, then the set-up is in place.

What if MiniBooNE sees a signal? .. Exciting!

- The present data cannot be fit with just 3 neutrinos
- The favored extensions to the Standard Model assume sterile neutrinos



- But multiple sterile neutrinos are likely to be involved
- It will require much study to understand this new situation. Fermilab should position itself to be able to follow up.

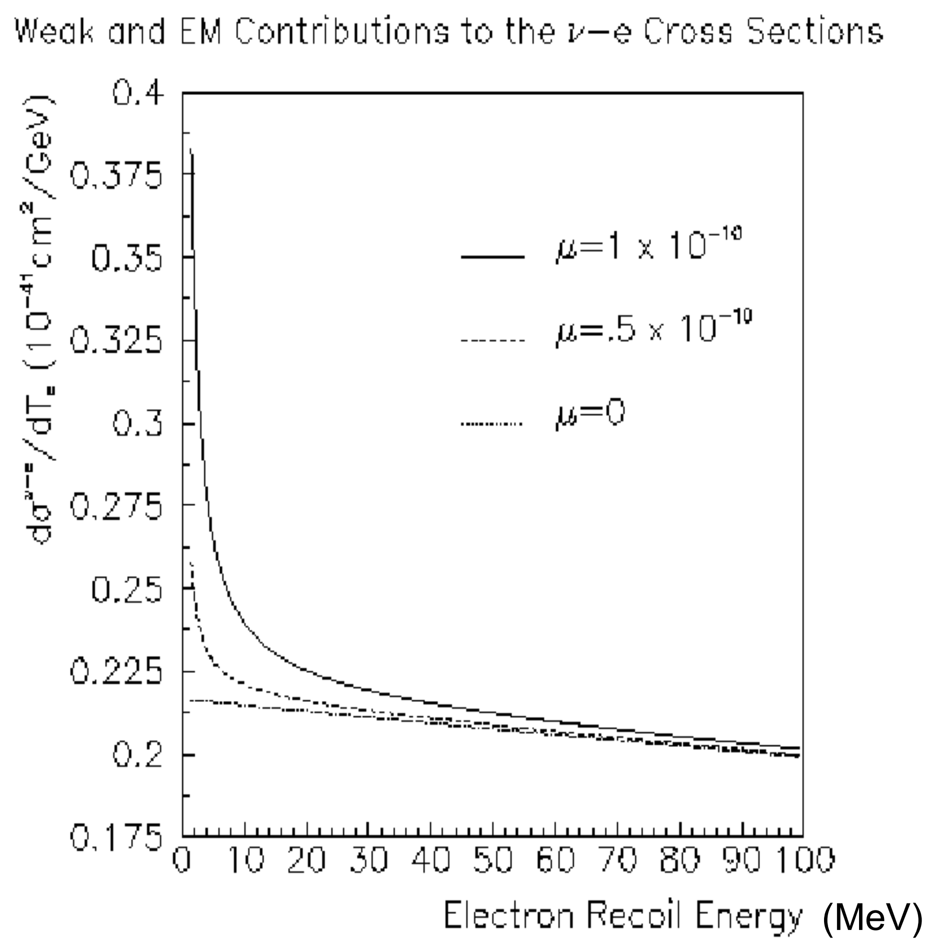


Other Interesting Neutrino Experiments

- FINeSE – Measuring the strange spin of the proton
  - Proposal in progress: An example of "Build it and they will come"
  - Cheap and simple 10 ton detector placed 100 m downstream of the BooNE decay pipe
  - Neutrino running parasitic on MiniBooNE with comparable intensity requirements.
  - Will help reduce MiniBooNE's flux errors
  - Provide useful information on NC x-section for NuMI
- Other proposals are likely assuming the low energy neutrino beam is still available late in the decade.

Neutrino Magnetic Moment

- Non-zero neutrino magnetic moment, μ, is indicative of physics beyond the standard model.
- Theories with extra dimensions predict large ($\mu \lesssim 10^{-11}\ \mu_B$) magnetic moments
- Can be detected through an extra contribution to the neutrino-electron scattering x-section coming from a photon exchange as well as the normal Z exchange.



Neutrino Magnetic Moment (cont.)

- Current best measurement by LSND $\mu < 6.8 \times 10^{-10}\ \mu_B$
- MiniBooNE hopes to make a modest improvement over the LSND result ($\mu \lesssim 4 \times 10^{-10}\ \mu_B$)
- To reach sensitivities of order $10^{-11}\ \mu_B$ will require
  - a detector sensitive to electron recoil energies ≥ 1 MeV
  - An order of magnitude more beam than is available with the current facility
- See thesis of Bonnie Fleming for details (http://home.fnal.gov/~bfleming/thesisprint.html)
- To take advantage of the extra intensity available with a PD the current 8 GeV target station and beamline will need to be upgraded

A Neutron Source for Particle Physics

- Can address many fundamental questions such time-symmetry violation, baryon number conservation, parity violation in strong interactions, right-handed weak currents, and quantum mechanics at the macroscopic scale. [Nucl. Inst. & Meth. **A440** (2000) 471]
- Optimize source design for specific particle physics experiments unlike existing facilities dedicated to neutron scattering experiments.
- Make a long (400 μs) pulsed source
  - Requires short, high intensity proton pulse
  - Complementary to existing short (40 μs) pulsed sources.
- Advantages:-
  - High peak intensities
  - Can use TOF techniques to measure neutron energies
  - Reduced backgrounds due to low duty factor

Existing and Proposed Neutron Sources

Source	Beam Type	Power (MW)	Parameters	Time-Avg. Flux (10^{14} n/cm^2-s)	Duty Factor
Existing					
HIFR (ORNL)	Steady	100	Be Reflector	13.0	1.0
ILL (Grenoble)	Steady	60	D2O Reflector	15.0	1.0
SINQ (PSI)	Steady	1.30	0.6GeV	1.0	1.0
LANCE (LANL)	Short-pulsed	0.10	0.8GeV, 20Hz	0.04	0.001
ISIS (Rutherford)	Short-pulsed	0.16	0.8GeV, 50Hz	0.06	0.002
SNS* (ORNL)	Short-pulsed	2.00	1.0GeV, 60Hz	0.7	0.0024
Proposed					
ESS (PSI)	Short-pulsed	6.50	1.3GeV, 50Hz	2.5	0.002
JHF (JAERI)	Short-pulsed	1.00	3.0GeV, 25Hz	0.3	0.12
FNAL					
Booster	Long-pulsed	0.04	8.0GeV, 15Hz	0.07	0.0026
PD synchrotron	Long-pulsed	0.48	8.0GeV, 15Hz	0.65	0.006

* Projected to turn on in 2006

Neutron Electric Dipole Moments

- CP violation in flavor-conserving channels would be clear indication of new physics
- Extensions to Standard Model such as extra Higgs, right-handed currents, or SUSY can give rise to EDM
  - $d_n \sim 10^{-25}$ - 10^{-27} e-cm
- Best measurement to date
  - P.G. Harris et al, Phys Rev Lett 82 (1999)
  - ISIS at RAL
  - $|d_n| < 6.3 \times 10^{-26}$
  - Probes energy scales beyond the reach of colliders
- Two methods used
  - EDM coupled to an external electric field
  - EDM coupled to atomic fields during Bragg scattering in crystals
- Magnetic resonance techniques used to detect precession of the EDM

EDMs with External Fields

- Current best result is based on 1st method
- Can Improve sensitivity of by using trapped ultracold neutrons to maximize time spent in the electric field
- Need pulsed source and TOF to reject higher energy background neutrons
- With even 100 MeV TOF resolution orders of magnitude improvements could be obtained in S/N ratio

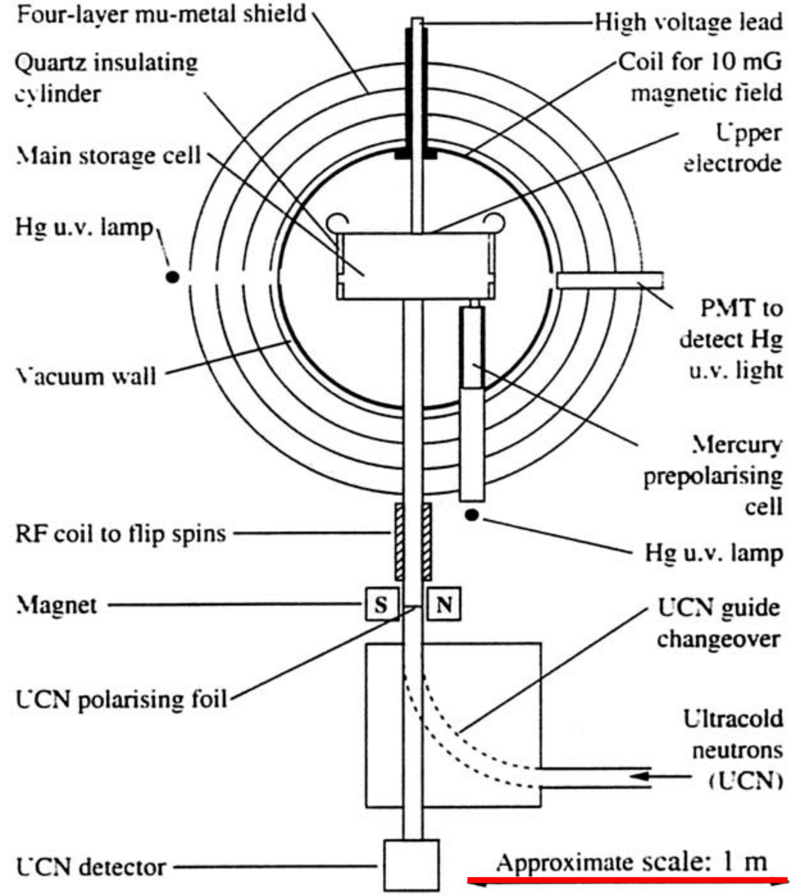


FIG. 1. The neutron EDM experimental apparatus.

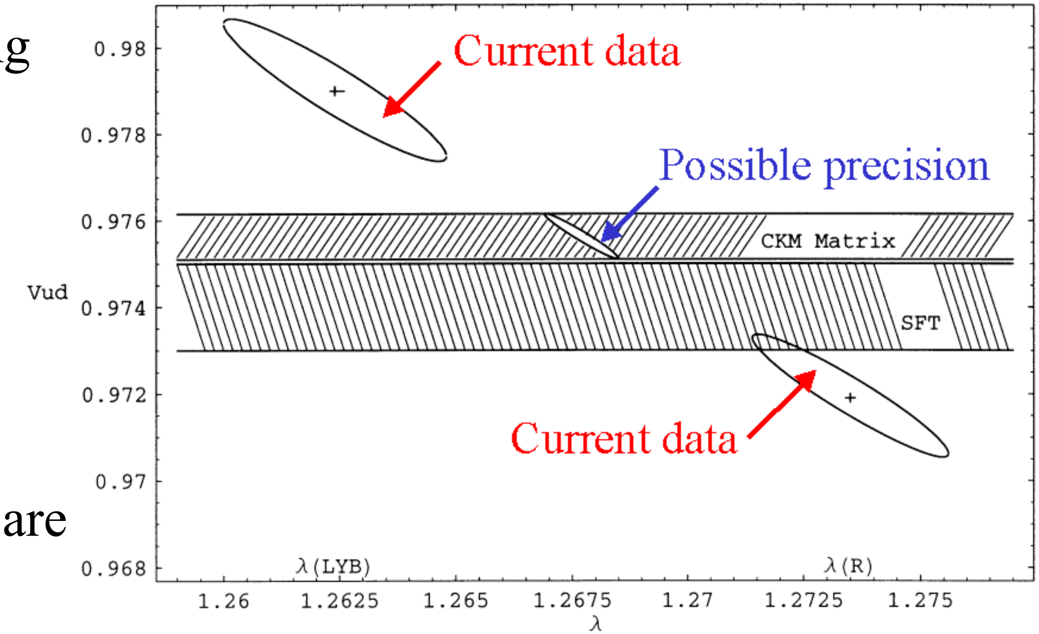
EDMs from Bragg Scattering

- Atomic E-fields are much greater than those generated in the lab
- Time spent in the field is much shorter
- Increasing the sensitivity of the method depends on the use of multiple Bragg scatters
- Made possible by using perfect silicon crystals
- To isolate EDM compare results from both 1.92 Å and 3.84 Å neutrons
  - Both scatter in Si but respond differently to an EDM precession
  - Use TOF to separate the two wavelengths

Neutron Beta Decay

- Provides a precision measurement of $|V_{ud}|$
  - Need to measure the neutron lifetime, τ, and the ratio of the vector and axial vector couplings $\lambda = g_A/g_V$
  - $1/\tau = 0.1897\,|V_{ud}|^2\,(1 + 3\lambda^2)\,(1 + 0.0739 \pm 0.0008)$
    - accurate at the 10^{-4} level

- λ is determined by measuring the beta asymmetry from polarized neutrons
- The current experimental situation is unclear with measurements forming two separated clusters.
- Both τ and λ measurements are well suited to a long pulse source

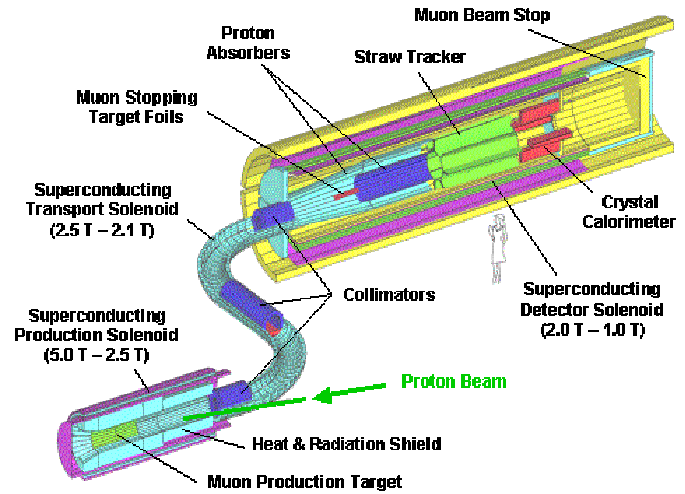


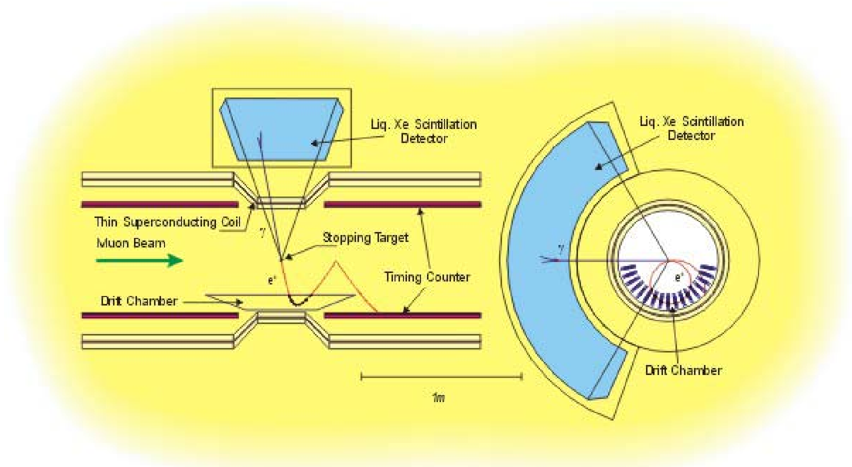
Physics with Low Energy Muon Beams

- Muon system is an excellent place to look for physics beyond the standard model
- There has been considerable interest in pushing the limits on LFV processes $\mu \rightarrow e\gamma$ decays and $\mu \rightarrow e$ conversion in nuclei
- Good examples of existing muon facilities are:-
  – The AGS (24GeV, 0.06MW) provides a pulsed muon source of $\sim 10^{11}$ stopped muons/sec
    - Suitable for $\mu \rightarrow e\gamma$ decay searches
  – The PSI cyclotron (590MeV, 1.0MW) produces a continuous beam of up to 10^{8} stopped muons/sec
    - Suitable for $\mu \rightarrow e$ conversion searches

Lepton Flavor Violation

- New experiments are currently under construction to address both processes
- MECO at AGS for m → e conversion
  - Current limit 10-12
  - expect a sensitivity of 10-16
  - SUSY predictions ~10-15
- MEG at PSI for m → eg decay
  - Current limit 10-11
  - expect a sensitivity of 10-14
  - SUSY predictions ~10-13
- Both experiments are expecting to take data in the latter half of the decade





Muon Source at FNAL?

- A Proton Driver of the types proposed would be capable of producing more intense beams than at existing facilities
- The physics case will depend strongly on what is learnt from MECO and MEG
  - Will a new generation of experiments be necessary? They could discover something!
  - If new generation experiments are called for … will the needed advances be in the muon source or in the detectors themselves
- Future progress could be coupled to the development of a front-end to a neutrino factory based on muon decays.

Concluding Remarks

- The Booster WILL max out
- A Proton Driver will provide a future for the lab's growing neutrino program
- It will provide the lab with the flexibility to respond to possible discoveries in the current program
- It also opens up possibilities for other new facilities attracting new user communities
- A surprising amount of work has been done to produce the present level of physics and machine studies
- **Further progress will depend on an indication from the lab that it is serious**