Project X and its connection to neutrino physics: Part I

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NuFact08
Valencia
What does the Intensity Frontier Mean?

- New reach in oscillation physics
  - Seeing sub-dominant oscillations
  - Neutrino Mass Hierarchy
  - CP violation
  - The detectors to get us there

- Electroweak Physics:
  - NuSONG and/or HiResMν: Measuring sin^2θ_w with ν-e scattering

- Kaon Physics
  - Using rare decays to understand CP-violation

- Anti-Proton physics

- Muon Physics
  - Muon to Electron Conversion
  - g-2 of the muon

See N. Saoulidou’s Talk
What about J-PARC?

- J-PARC Main Ring commissioning now! (see T.Nakaya’s talk)
- 700kW proton source at 40-50 GeV
- First beam to T2K in April 2009
- Rich high intensity program there as well
  - Neutrinos
  - Kaons
  - Muons
- But the list of customers is long
  - So much physics, only so many protons to go around

http://j-parc.jp/NP08/
What is Project X? (simplified)

Replace Fermilab LINAC/Booster
With an 8GeV Superconducting LINAC

νOscillations
ν scattering
Electroweak Physics with ν’s

ν to e conversion,
Low energy ν experiments

ILC Style 8 GeV H⁻ Linac:
9mA x 1 msec x 5 Hz

Slide courtesy
H. Schellman, DIS08
μ to e Conversion

\[ \mu^- U_{\mu k} \nu_k U^*_{ek} e^- \]
Muon to Electron Conversion

\[ \mu^- N \rightarrow e^- N \]

\[ \frac{\Gamma(\mu^- + (A, Z) \rightarrow e^- + (A, Z))}{\Gamma(\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z - 1))} \]

Must occur in Standard Model but BR \( \sim 10^{-54} \)

Possible non-Standard Model Processes...just a few given here

Supersymmetry
Rate \( \sim 10^{-15} \)

Leptoquark
\[ M_{\text{LQ}} = 3000 (\lambda_{\mu d} \lambda_{ed})^{1/2} \text{TeV/c}^2 \]

Heavy Neutrinos
\[ |U_{\mu N} U_{eN}|^2 \sim 8 \times 10^{-13} \]

Second Higgs Doublet
\[ g(H_{\mu e}) \sim 10^{-4} g(H_{\mu \mu}) \]
Experimental Method

- 8 GeV protons strike target (23kW → 200kW)
- $\pi$’s captured, decay to muons
- Muons transported to detector, stop in foils
- Electrons spiral in the field, where they are tracked and momentum analyzed
- Highest Background: muon decay in orbit

Entire experiment is in a graded magnetic field

Slide courtesy R. Bernstein

@ NuFact08
Physics Reach of $\mu \rightarrow e$ Conversion

- 5 events signal, 0.5 events background for $R_{\mu e} = 10^{-16}$
- Mass reach to $10^4$ TeV
- This experiment will probe 10$^4$ times better than previous experiments, and possibly $10^6$ with Project X
- This is very tough: looking for a 10$^{-17}$ branching ratio!

http://mu2e.fnal.gov
From Liquid Argon Detector Development

Icarus, 2nd Half-Module transported
http://www.pv.infn.it/~icarus/T600/Second-module/images/

to

Cryostat full of 100ktons LNG
MicroBooNE

- Booster Neutrino Beamline: overlaps with T2K and K2K
- Excess of low energy events seen at MiniBooNE: what are the implications for T2K?
- Micro(Freda)BooNE: put scalable Liquid Argon detector technology in Booster \( \nu \) Beamline

100-200 tons
8 GeV protons

http://www-microboone.fnal.gov
Electroweak Physics through $\nu$-e scattering
NuSonG

- NuSonG is designed to measure $\sin^2\theta_W$ at 100GeV with $\nu$-electron scattering

- NuTeV beamline design (800GeV protons)

- CHARMII detector design

<table>
<thead>
<tr>
<th>Statistics</th>
<th>$\nu$/$\bar{\nu}$</th>
<th>Mode</th>
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<tbody>
<tr>
<td>600M / 33M</td>
<td></td>
<td>CC DIS</td>
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<tr>
<td>190M/12M</td>
<td></td>
<td>NC DIS</td>
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<td>75k/7k</td>
<td>$\nu$/$\bar{\nu}$ - e$^-$ NC scat.</td>
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<tr>
<td>700k/0k</td>
<td>$\nu$/$\bar{\nu}$ - e$^-$ CC QE</td>
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</tbody>
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Figures courtesy J. Conrad

4 modules of:
Glass target, (1/4 $\lambda_0$ seg.)
Proportional chambers,
Scintillator,
Muon Toroid
NuSOnG Schedule and Physics Reach

Autumn 2007: EOI submitted to Fermilab PAC
Autumn 2008: Letter of Intent to be submitted
Goal: Run in 2015, with new beamline fed by 800GeV p⁺

http://www-nusong.fnal.gov

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Figures courtesy J. Conrad
HiResMν

- NOMAD Detector surrounded by calorimetry
- Sit on axis in NuMI Beamline, parasitic to NOvA (6GeV ν energy)
- Physics goals
  - $\sin^2\theta_W$ with ν-electron scattering
  - Nuclear effects by putting in several targets
  - Neutrino event generator studies
- See R. Petti’s slides for more details on physics reach

Statistics: 3 year ν, 4 year anti-ν
  - 140M ν Charged Current events
  - 50M anti-ν Charged Current events
  - High statistics but energy below inverse muon decay threshold
Preparations at Fermilab for Project X

- Proton Source R&D: see next talk
- Water Cerenkov Costing Study
  - 150kton mass, to be submitted by end of year
- Staged Liquid Argon Development
  - MicroBooNE (100-200tons in Booster Neutrino Beamline) just received PAC approval, detector uses scalable technology
- Beamline Designs
  - $\nu$ Beam to DUSEL: able to take 2.3MW of proton power
  - $\mu$ to e conversion: 23kW-200kW of 8GeV protons, $10^{-9}$ extinction to reduce backgrounds
- Neutrino Cross Section Measurements
  - SciBooNE run successful: $\nu$, anti-$\nu$, 2007-2008
  - MINERvA Experiment to take data 2009-201x
Conclusions

• Everyone in this audience knows that the intensity frontier is important
• Intensity frontier begins with protons: see Andreas for how they will be supplied by Project X
• Getting to this new frontier means:
  – New reach in oscillation physics (see N. Saoulidou’s talk)
    • Much higher reach in sub-dominant oscillations
    • Matter effects at DUSEL
    • CP violation
  – Electroweak Physics: NuSonG and/or HiResMν: Measuring $\sin^2\theta_w$ with $\nu e \rightarrow \nu e$, with precision that NuTeV had with $\nu N \rightarrow \nu N$ scattering
  – Mu2E: taking a $10^4$ leap in new physics frontier