UNO
Underground Nucleon Decay & Neutrino Observatory

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Overview

• The Science in Brief – Neutrinos and Nucleon Decay
• The UNO Collaboration
• The Detector Concept
• Location Matters – Physics & Cost
• R&D Plans
• Summary
UNO Physics Goals

- Nucleon decay
- Supernova Neutrinos
- Supernova Relic Neutrinos
- Atmospheric Neutrinos
- Supernova Neutrino sources
- Super-beam (+Beta-beam)
- Solar Neutrinos

- Multi-purpose detector
- Comprehensive programs in astrophysics, nuclear and particle physics
- Synergy between accelerator and non-accelerator physics
UNO Proton Decay Sensitivity

IMB/Kamiokande
SuperK in 10 years
UNO in 10 years

$10^{30}$ $10^{31}$ $10^{32}$ $10^{33}$ $10^{34}$ $10^{35}$ $10^{36}$ $10^{37}$

Non-SUSY SU(5)
Two-step Non-SUSY SO(10)
Complete 5D SU(5)
String Theory 6D–Branes
Three Family Heterotic String Model

MSSM SU(5)
Flipped SU(5)
Split multiplets
MSSM SO(10)
Fermion mass correlated
MSSM SO(10)–generic
Extra dimension at GUT scale
UNO Proton Decay Sensitivity

- IMB/Kamiokande
- SuperK in 10 years
- UNO in 10 years

Lifetimes in years:
- $10^{30}$
- $10^{31}$
- $10^{32}$
- $10^{33}$
- $10^{34}$
- $10^{35}$
- $10^{36}$
- $10^{37}$

- $\bar{\nu} K^+$
- MSSM SO(10)
- Complete 5D SU(5)
- 5D SU(5) Strongly Coupled
- SUSY Without GUT
- Minimal SO(10) SUSY Model
- MSSM SO(10) Fermion mass correlated
- MSSM SO(10)–generic
Galactic Supernova $\nu$

- An example of unstable Eq. Of State
  Pons et al., PRL 86, 5223 (2001)

- $\sim$140,000 events in UNO, $\sim$1/30 years
  $\Rightarrow$ msec timing structure of the flux
  $\Rightarrow$ Determination of core collapse mechanism
  $\Rightarrow$ Possible Observation of Birth of a Black Hole!

Beacom, Boyd and Mezzacappa
PRL 85, 3568 (2000)

$m_{\nu_e} = 1.8$ eV
### Super K Supernova Relic $\nu$ Limits

<table>
<thead>
<tr>
<th>Theory Model</th>
<th>SK SRN Rate Limit (Efficiency Corrected)</th>
<th>SK SRN Flux Limit (18 MeV $&lt; E_{\nu} &lt; 82$ MeV)</th>
<th>SK SRN Flux Limit (Full Spectrum)</th>
<th>Predicted SRN Flux (Full Spectrum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxy evolution (Totani et al., 1996)</td>
<td>3.2 events/year 22.5 kton</td>
<td>$&lt; 1.2 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>$&lt; 130 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>44 $\frac{V_e}{cm^2 \text{ sec}}$</td>
</tr>
<tr>
<td>Heavy metal abundance (Kaplinghat et al., 2000)</td>
<td>3.0 events/year 22.5 kton</td>
<td>$&lt; 1.2 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>$&lt; 29 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>54 $\frac{V_e}{cm^2 \text{ sec}}$</td>
</tr>
<tr>
<td>Constant supernova rate (Totani et al., 1996)</td>
<td>3.4 events/year 22.5 kton</td>
<td>$&lt; 1.2 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>$&lt; 20 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>52 $\frac{V_e}{cm^2 \text{ sec}}$</td>
</tr>
<tr>
<td>LMA neutrino oscillation (Ando et al., 2002)</td>
<td>3.5 events/year 22.5 kton</td>
<td>$&lt; 1.2 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>$&lt; 31 \frac{V_e}{cm^2 \text{ sec}}$</td>
<td>11 $\frac{V_e}{cm^2 \text{ sec}}$</td>
</tr>
</tbody>
</table>


- UNO at 4000 mwe can discover SRN or rule out all these models within 3-5 years
UNO Physics Goals

• Primary goals highlighted in reports of several distinguished panels/advisory groups
• Most recently – National Academy of Sciences report: Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics
  – Action Item 5: The committee recommends that the properties of neutrinos be determined through a well-coordinated, staged program of experiments developed with international planning and cooperation.
    • Longer-term goals should include experiments to unravel possible charge-parity violation in the physics of neutrinos and renewed searches for proton decay. There may be a valuable synergy between these important objectives, as the neutrino charge-parity violation measurements may require a very large detector that, if placed deep underground, will also be the right instrument for detecting proton decay.

• S1 Report – “A large underground detector with an active mass greater than 100 kT could becomes a key shared physics research facility for the future US particle, nuclear, and astrophysics research programs.”
UNO Collaboration

99 collaborators, 43 institutions,

Argonne National Laboratory
M. Goodman, D. Reyna, R. Talaga, J. Thron
Universitat Autonoma de Barcelona/IFAE, Spain
E. Fernandez, F. Sanchez
Brookhaven National Laboratory
M. Diwan, M. Goldhaber, R. Hahn, B. Viren, Minfang Yeh
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R. Potenza
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J. Fanchi, M. Hitzman, M. Kuchta, J. McNeil
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INFN-Padova, Italy
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University of Kansas
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Kansas State University
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Kyungpook National University, South Korea
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Los Alamos National Laboratory
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University of Minnesota, Minneapolis
M. Marshak
University of Missouri, Lincoln
D. Claes
National High Magnetic Field Laboratory
J. Miller
University of New Mexico
S. Seidel
Northern Illinois University
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Purdue University
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J. Bouchez, L. Mosca, F. Pierre
Sejong University, South Korea
Y. Kim, J. Lee, J. Lee
Stony Brook University
INRIPhE, France
C. Racca, J. M. Brom
ICRR Kamioka Observatory, Univ. of Tokyo, Japan
M. Shiozawa
Tufts University
T. Kafka, W. A. Mann
University of Utah
K. Martens
Warsaw University, Poland
D. Kielczewska
University of Washington
H. Lubatti, C. Daly, J. Wilkes
College of William and Mary
J. Nelson
Advisory Committees

• UNO advisory committee
  - Jacques Bouchez (Saclay)
  - Maury Goodman (ANL)
  - Tom Kirk (BNL)
  - Takahaki Kajita (ICRR)
  - Tony Mann (Tufts)
  - Kenzo Nakamura (KEK)
  - Masayuki Nakahata (ICRR)
  - Yoichiro Suzuki (ICRR)
  - Jeff Wilkes (U. of Washington)
  - Bob Wilson (Colorado State U.)

• Theoretical advisory committee
  - {John Bahcall (IAS/Princeton)}
  - John Beacom (FNAL)
  - Adam Burrows (U. of Arizona)
  - Maria Concepcion Gonzales-Garcia (Stony Brook)
  - Jim Lattimer (Stony Brook)
  - Bill Marciano (BNL)
  - Hitoshi Murayama (Berkeley)
  - Jogesh Pati (U. of Maryland)
  - Robert Shrock (Stony Brook)
  - Frank Wilczek (MIT)
  - Edward Witten (IAS/Princeton)
UNO Detector
Conceptual Design
Design Considerations

• **Goal:** physics capability $\uparrow$ detector cost $\downarrow$
• Tried and true technology – water Cerenkov
• Topology and Size
  – Light attenuation length limit in pure water: $\sim$80 m at 400 nm
  – PMT pressure limit: $\sim$6 atm w/mods. (60 m of water)
  – Largest possible width of underground cavity: $\sim$60 m

$\Rightarrow$ **Single largest active module size:**
$\sim$ 60m x 60m x 60m

• PMT (photocathode) coverage
  – Need relatively high coverage ($\sim$ 40%) for low energy physics (solar and SRN), and 6 MeV $\gamma$ detection from $p \rightarrow K^+ \nu$, and 5-10 MeV $\gamma$ from neutral current excitation of oxygen
  – Need fine granularity for LBL $\nu_e$ appearance experiments to reject $\pi^0$ background
Design Considerations

- Number and size of the modules for a fixed fiducial volume?
  - Module size ↓ detector cost ↑
    - Larger surface area to fiducial volume ratio - requires more PMTs
    - Smaller fiducial to total volume ratio
    - Need more access drifts and auxiliary/service space - typically excavation costs for drifts are more expensive than for large volume excavation
  - Module size ↓ Energy Containment ↓
    - especially crucial in atm nu studies, such as L/E study
  - Module size ↓ Pattern Recognition Capability (with same photocathode coverage) ↓

⇒ Keep the module size as large as possible

⇒ By the time UNO (or any “Large Multi-Purpose Detector”) is built SuperK will have ~20 years of data
Vital statistics:
• Proposed by Chang Kee Jung (Stony Brook) ~1999
• 60 m x 60 m x 180 m (3 modules)
• 648,000 tons water - ~180 Olympic swimming pools
• Super-Kamiokande – super-sized (x13)
  – approx. 20 times fiducial volume
• World’s largest man-made excavation
  – 2-3 million tons of rock
• # of 20” PMTs: 56,000; # of 8” PMTs: 14,900
  – 40% photocathode in central module
  – 10% in the wings
  – driven by economics not physics
Detector Site Considerations

- **Depth**
  - cosmogenic background
  - rock instability
  - rock temperature
  - detector cost

- **Optimal Depth**
  - ~4000 mwe (~5000 ft)
    - driven by the SRN search and solar nu study - reduce spallation background
    - reduce the risk of possible unknown B.G. to PDK searches at shallow depths
    - minimize detector dead time
    - keep some rate of cosmic rays for calibration purposes (~1800/hr)
  - Henderson DUSEL Central Campus ~optimal (no surprise…)

- **Distances from Major Proton Accelerator Labs**
  - Different baselines present greatly different physics potential
Many benefits to co-locating UNO at an existing DUSEL

- In US: focus on Henderson and Homestake
- Both appear to have geology to support UNO scale cavern
- Europe and Asia have Large Multipurpose Detector/(V)LBL options
At LIGHT06 (01/06) claim that Hamamatsu can have possibility for 100,000 PMT production in 2-3 years

Two years of rigorous detector design needed
Very Preliminary Cost Estimate

- Estimates based on scaling SuperK actual costs ($1 = 100 yen)
- Excavation cost quite site dependent
  - if built at existing DUSEL site (see later) excavation/access may be reduced to ~$100M
- Existing surface facilities reduce cost

Assumes we are no cleverer ⇒ $$\downarrow$$
If not linear cost scaling ⇒ $$\uparrow$$

Better costing estimate will require more detailed detector design
  - collaboration has resisted the urge to update this coarse estimate until we have the resources to do a thorough job

<table>
<thead>
<tr>
<th>Item</th>
<th>(k$)</th>
<th>SuperK</th>
<th>UNO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity Excavation &amp; access [1]</td>
<td>27,640</td>
<td>168,000</td>
<td></td>
</tr>
<tr>
<td>Cavity Treatment/Water Tank</td>
<td>18,400</td>
<td>25,000</td>
<td></td>
</tr>
<tr>
<td>Water Piping and Pumps</td>
<td>630</td>
<td>4,082</td>
<td></td>
</tr>
<tr>
<td>Water Purification System</td>
<td>1,850</td>
<td>11,988</td>
<td></td>
</tr>
<tr>
<td>Crane</td>
<td>760</td>
<td>2,280</td>
<td></td>
</tr>
<tr>
<td>PMT Support Structure</td>
<td>4,580</td>
<td>23,019</td>
<td></td>
</tr>
<tr>
<td>Counting Room</td>
<td>330</td>
<td>990</td>
<td></td>
</tr>
<tr>
<td><strong>Instrumentation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20” PMT (including cables)</td>
<td>34,670</td>
<td>155,457</td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td>6,330</td>
<td>9,495</td>
<td></td>
</tr>
<tr>
<td>DAQ</td>
<td>1,090</td>
<td>1,635</td>
<td></td>
</tr>
<tr>
<td>Air Conditioning</td>
<td>210</td>
<td>315</td>
<td></td>
</tr>
<tr>
<td>Veto Instrumentation</td>
<td>3,000</td>
<td>9,000</td>
<td></td>
</tr>
<tr>
<td>8” PMT (including cables)</td>
<td>2,262</td>
<td>17,881</td>
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<td><strong>Surface Facilities [2]</strong></td>
<td></td>
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<tr>
<td>Computer Building</td>
<td>1,860</td>
<td>2,232</td>
<td></td>
</tr>
<tr>
<td>Main Building</td>
<td>3,000</td>
<td>3,600</td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>720</td>
<td>2,160</td>
<td></td>
</tr>
</tbody>
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Technical Feasibility/Cost

• Is it feasible to excavate an UNO size cavern?
  – Can it be stable for > 30 years?
  – Can it be done economically?
• Can the water containment be done using liners?
  – Can it be stable for > 30 years?
  – Can it be done economically?
• Can the PMT mounting system be built economically?
• Can the photo-detection be done more economically?
  – Cheaper PMTs?
  – New photo-detectors?
  – Different optimization of sizes

• If all of the above are solved, can this design do the physics?
  – Compromises needed to reduce cost, buildability etc.

⇒ R&D Proposal
UNO R&D Proposal

- Excavation R&D (CSM/CNA Engineers/Itaska)
- Cavity Liner R&D (CSM/CSU)
- PMT Mounting R&D (UW)
- Photodetector R&D
  - PMT Testing – photoelectronic & mechanical (SB/CSU)
  - Referenc Tube R&D, funded (UC-Davis) -DOE Advanced Detector R&D and DOE (~$600k)
  - Burle Large PMT R&D, funded through DOE SBIR
  - GPD R&D, funded (CSU) through SBIR to aPeak Inc. (U. of Tokyo HPD R&D, funded ($4M))
- UNO software R&D (BNL/CSU/SB)
- “μUNO” (CSU/SB/UW)
- Planning (SB)
- Request for $1.8M over two years

- Submitted to NSF in October ’05; DoE submission February ’06
- Renewed interest since NuSAG (DoE/NSF Neutrino Scientific Assessment Group), P5, Nat’l Acad. Sci. report

- **R&D activities appropriate for Henderson DUSEL Upper Campus**
Large Area PMT Testing

- Develop > 60-m water pressure test tank at CSU for stress testing Hamamatsu 20"

- “Spherical” PMT concepts
- “Smart PMT"
  - Revisited at LIGHT06
  - Replace the dynode structure with scintillator and SiPm
- Other photo-detector R&D

Courtesy of Jeff Wilkes
Test Cavities

- **Cavity Liner R&D (CSM/CSU)**
  - cavity is too large for Super-K style container
  - use cavity rock walls
  - must maintain adequate environmental isolation (optical and radiological contaminants) for decades
  - Similar to SNO outer wall scheme

- Accelerated testing of sealant samples in the lab

- *In situ* testing on fresh excavated granitic rock (at Henderson Mine)
  - liner adhesion
  - structural integrity
  - radon penetration
μUNO

- Use liner test cavity for small-scale water-Cherenkov detector (16 8” PMTs)
  - these now available to SB from Kamiokande
- Get experience installing and operating an experiment in the mine
- An outreach opportunity – extension of the SALTA program that had high school students taking cosmic ray measurements underground
VLBL Analysis + Detector Software

• Work with BNL team on VLBL studies
  – Milind & Brett Viren very helpful

• Develop s/w infrastructure
  – Building on SuperK but developing new reconstruction algorithms
  – Generate large sample (5 yrs) of sample events
Conclusion

• **Interest in UNO/megaton-detector is high**
  – Specifically addressed by P5
  – “Large Multipurpose Detector” highlighted in recent National Academy of Sciences report
  – UNO Collaboration has proposed a two-year R&D program; proposal submitted to NSF and DoE
  – For a long time US R&D coupled to approved experiments

• **Expect DoE to be primary sponsor of UNO + ν super-beam**
  – Cost > $800 million; much greater than NSF DUSEL investment
  – Big question 1: FermiLab vs. Brookhaven for high intensity neutrino beam
    – BNL has a proposal on the table; FNAL has begun to investigate
  – Big question 2: Effect of ILC (lack of) decision

• **President’s SotU address (ACI) and budget good news for big science prospects**

• **Henderson “favored” by collaboration, but …**
  – Making an effort to do site independent R&D where possible
  – We will be happy if we get UNO ANYWHERE

• **Go/no-go decision driven primarily by strength of science case**