DUSEL Working Group

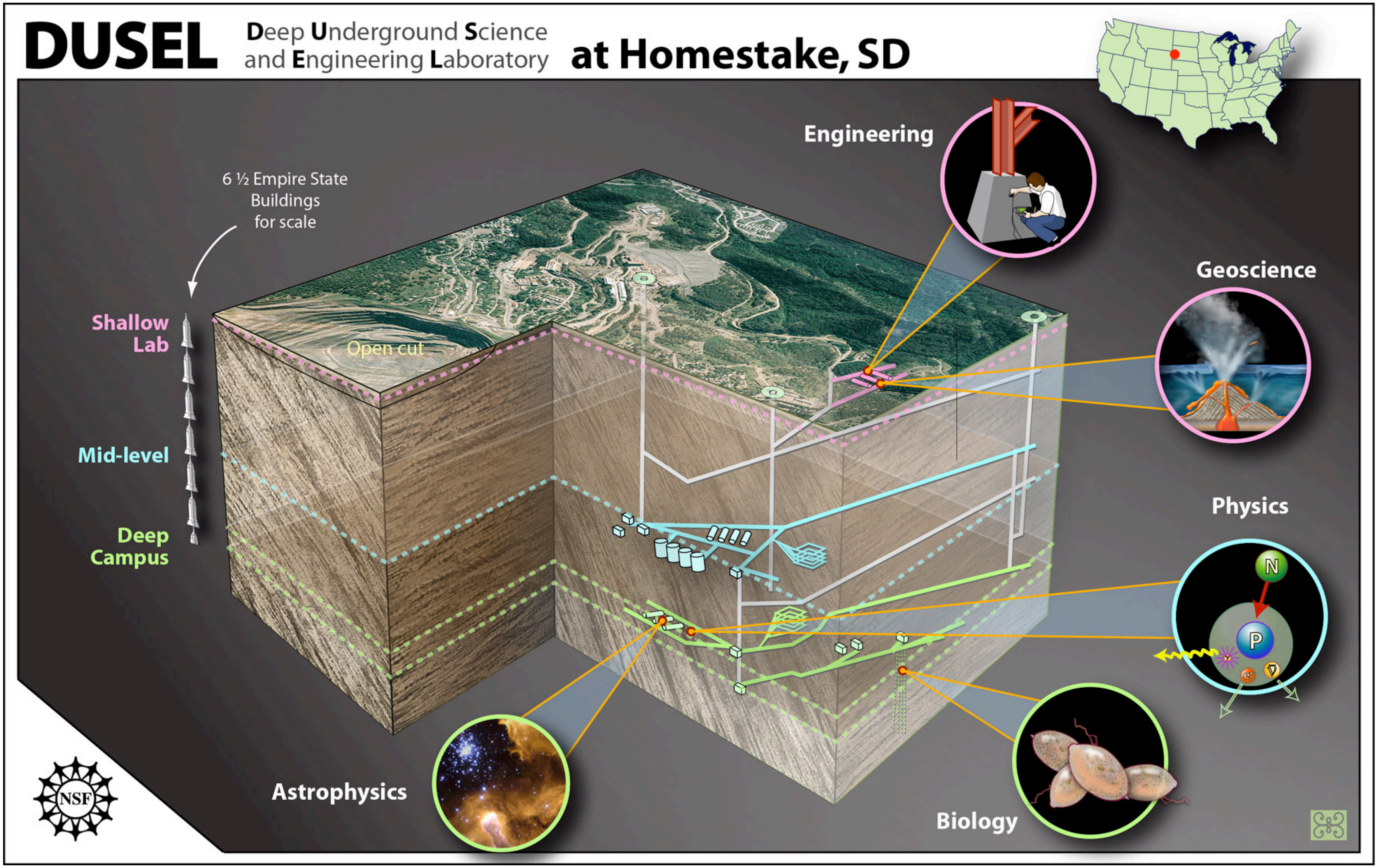
Zoltan Ligeti & Ernst Sichtermann

- Introduction
- Neutrino oscillations & proton decay
- Dark matter

- Nuclear astrophysics
- Neutrinoless double beta decay
- Recommendations

August 17, 2009

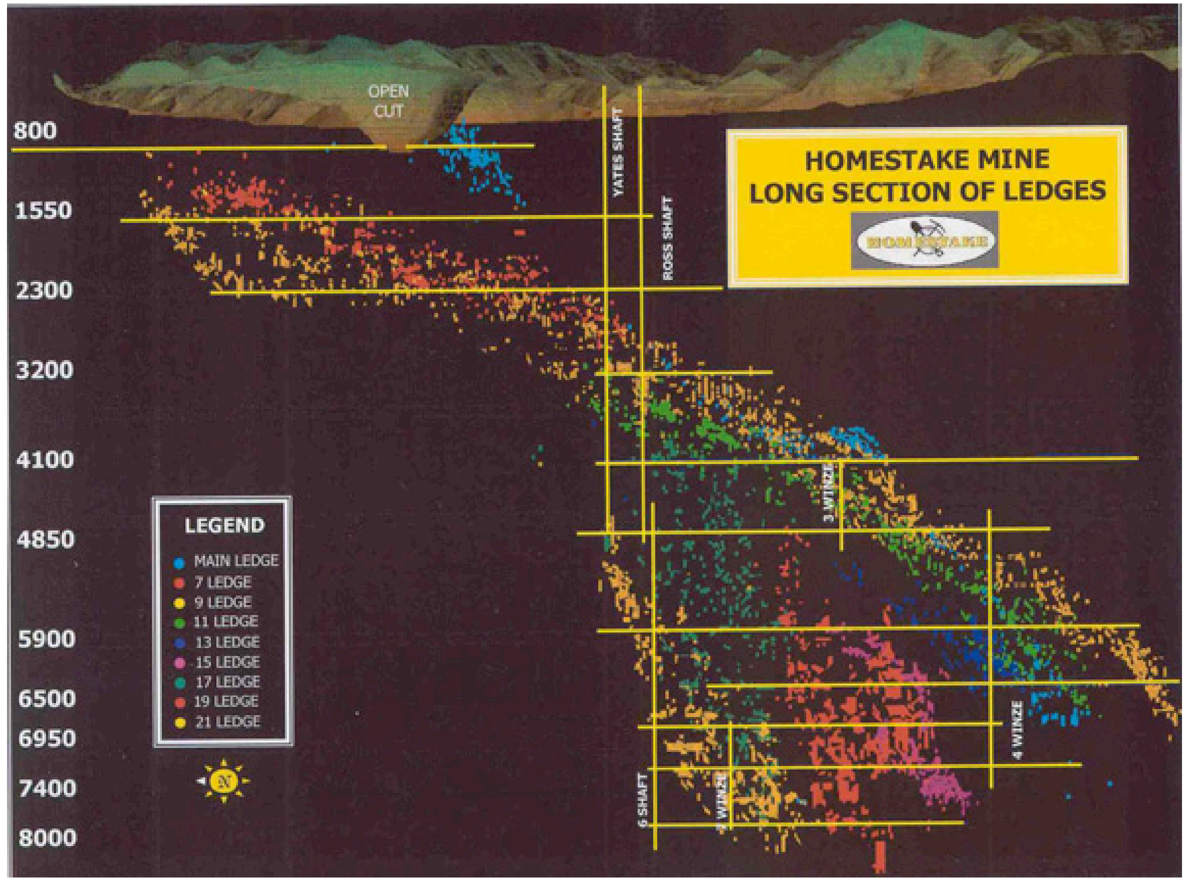
DUSEL facility



DUSEL facility

- NSF is developing DUSEL
- South Dakota investing $120M
- Expect MREFC $\sim \$500-600$M for initial suite of experiments
- 4850 ft level is dry since May
  Physics starting 2009–2010

  7400 ft level will be dry in 2011
  Physics starting 2012–2013, after NSB decides on MREFC



- DUSEL will be an active lab for the coming decades, and a major part of the US program, so we should plan what part of the science we want to be a part of

Committee formed (early 2009)

Physics	Nuclear Science	Engineering
Zoltan Ligeti (co-chair)	Ernst Sichtermann (co-chair)	
Christian Bauer	Jason Detwiler	Henrik von der Lippe
Murdock Gilchriese	Stuart Freedman	Steve Marks
Richard Kadel	Volker Koch	David Plate
Yury Kolomensky	Kevin Lesko	
Yasunori Nomura		
Natalie Roe		

Charge of the committee

"In the context of the scientific opportunities in high energy and nuclear physics presented by DUSEL, the Committee is asked to assess the present LBNL participation in its initial suite of experiments, and to propose a roadmap for our future participation in the facility. Proposals for experimental development have been submitted to the NSF (S4) in the following broad areas: Long Baseline Neutrinos, Proton Decay, Neutrinoless Double Beta Decay, Dark Matter Searches, Nuclear Astrophysics Experiments and Low Background Counting. For each topic, the committee should identify the scientific opportunity, and summarize the scale of current LBNL participation, the impact that LBNL is likely to have on experiments at the present level of effort, the value of additional manpower, and opportunities for synergistic Detector R&D activities.

Since both NP and HEP funding is anticipated for DUSEL experiments, the Committee should comment on the match of the proposed experiments to the HEP P5 report and NP long range plan.

DUSEL presents many opportunities, but the roadmap should be presented in the context of long-term commitments to other high priority programs such as JDEM, LHC, RHIC and existing neutrino efforts such as Daya Bay, KamLAND and CUORE."

Inventory of projects / proposals

- Concentrate on four science areas:

  Nuclear astrophysics: DIANA

  Neutrinoless double beta decay: Majorana, High pressure Xe R&D, EXO

  Long baseline neutrinos / proton decay: Water Cherenkov, Liquid Argon

  Dark Matter: GeoDM (cont. of CDMS); MAX, LZ20 (2-phase)
  DEAP/CLEAN (1-phase); DRIFT, DM-TPC (gas, directional)
  COUPP (single bubble in warm CF_3I, triggered by nuclear recoil, not min. ion.)

  Won't cover technical details in much depth here

- NSF S4 proposals: at least $15M for 3 yrs: "Development of Technical Designs for Potential Candidates for the DUSEL Suite of Experiments" (expect 10-15 awards)

Process: talks + discussions

Topic	Presenter	Date
Dark Matter: Current and Future	Y. Nomura	Feb 5
The DRIFT detector	D. Loomba	Feb 6
Discussion of the Charge	J. Siegrist & J. Symons	Feb 10
LUX, LZ20 and the race to detect WIMP dark matter	T. Shutt	Feb 10
Directional Dark Matter Search	G. Sciolla	Feb 12
Some Science Motivations for DUSEL	W. Haxton	Feb 24
Germanium Observatory for Dark Matter at DUSEL (GEODM)	B. Sadoulet	Feb 26
MAX: Multi-ton Argon and Xenon TPCs	C. Galbiati	Mar 3
Preparations for writing the report	Z. Ligeti & E. Sichtermann	Mar 13
The US LAr TPC Program Leading to DUSEL	B. Fleming	Mar 17
EXO Status and Perspectives	G. Gratta	Mar 20
DIANA	D. Leitner & P. Vetter	Mar 24
Development of a High Pressure Xenon Imager	A. Goldschmidt	Mar 25
Present Status of COUPP	J. Collar	Mar 26
Large Cavity Detectors at DUSEL	R. Kadel	Mar 31
The Majorana Project	S. Elliott	Apr 7
Analysis and discussions for the report	all	Apr 10, 17, 24 May 1, 5, 8, 15

Slides available at: http://www-theory.lbl.gov/~ligeti/dusel/

Berkeley involvement

- Survey of current + imminent efforts in the four areas
- Several check marks correspond to the same individuals
- Some are substantial, some are modest efforts

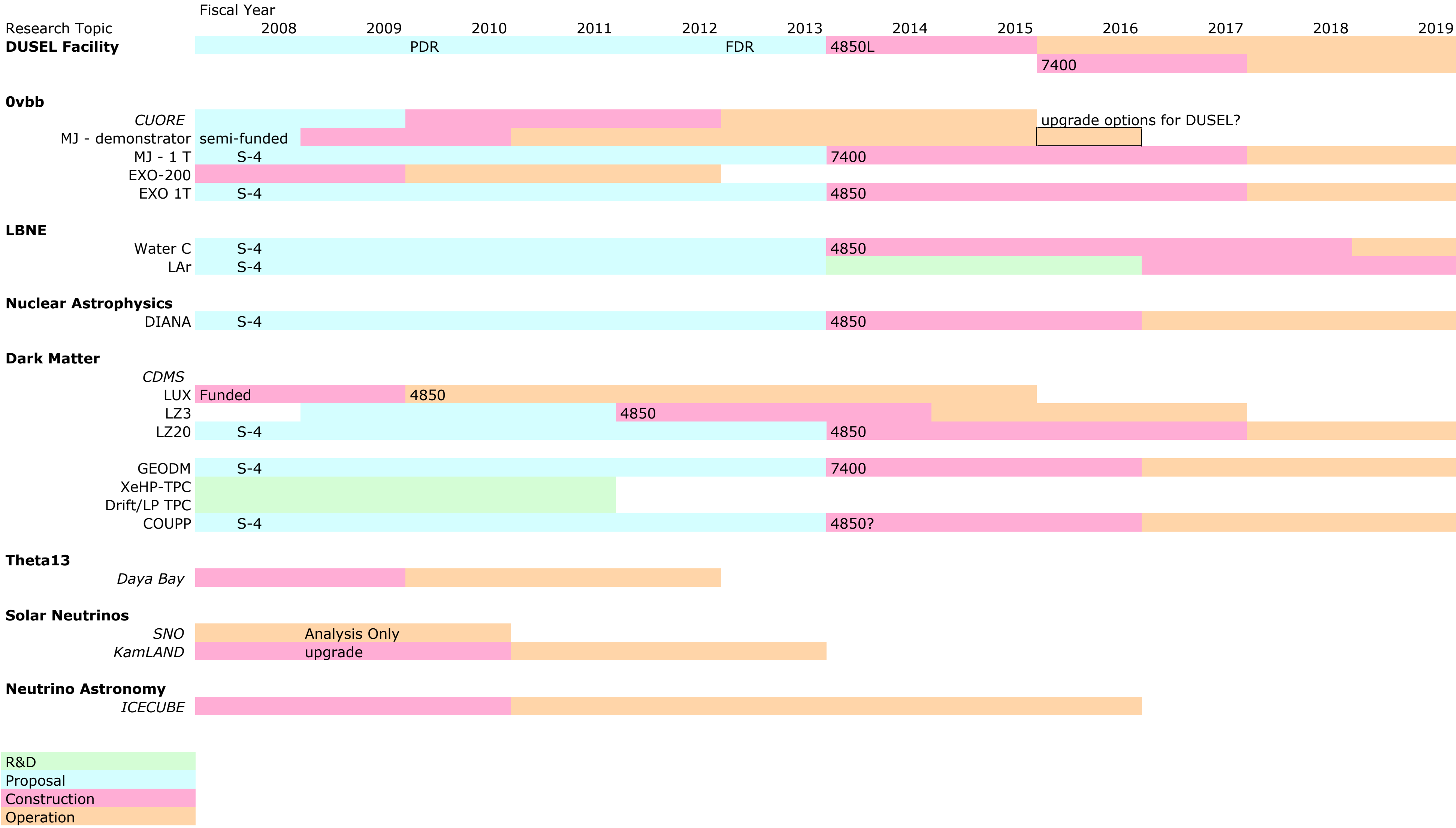
- Seems clear that dark matter and neutrinoless double beta decay are Nobel Prize experiments, in case signal is found

	UCB	NSD	PD	Eng	MSD	LBCF User	DUSEL Contact	DUSEL S4 Proposal
Nuclear Astrophysics								
DIANA	x	x		x			yes	yes
Neutrinoless Double Beta Decay Experiments								
DUSEL Experiments								
Ge 1 Ton	x	x		x		x	yes	yes
Other Experiments								
Cuoricino	x	x			x	x	n/a	n/a
CUORE	x	x	x		x	x	n/a	n/a
MJ demonstrator at Homestake	x	x		x		x	yes	no
R&D								
HighPressure Xe	x	x	x				no	no
Bolometric R&D	x	x	x				no	no
Long Baseline Neutrino Experiment and Proton Decay Searches								
Water Cherenkov			x				yes	yes
Dark Matter								
DUSEL Experiments								
LZ20	x	x	x	x		x	yes	yes
GEODM	x						yes	yes
Other experiments								
CDMS	x						n/a	n/a
SuperCDMS	x						n/a	n/a
LUX/LZ3 at Homestake	x	x	x	x		x	yes	n/a
Accelerator, Reactor, and Solar Neutrino Experiments								
SNO		x		x		x	n/a	n/a
KamLAND I	x	x	x			x	n/a	n/a
KamLAND II	x	x	x			x	n/a	n/a
ICECUBE	x	x	x	x			n/a	n/a
DayaBay	x		x	x			n/a	n/a

Experiment completed, analysis continuing

Experiment under construction

Timeline of considered projects



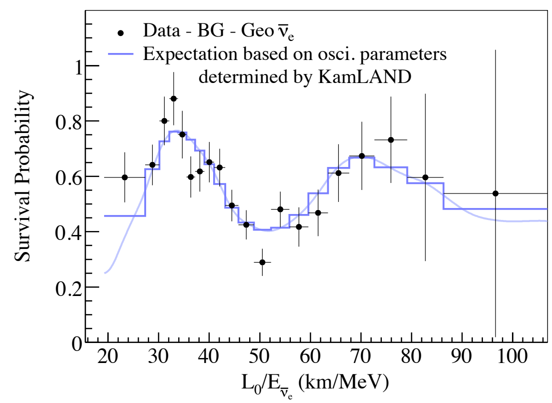
Neutrino oscillations and p decay

Neutrino oscillation measurements

- Two large mixing angles observed
- Oscillation between two flavors $(\delta m^2 = m_1^2 - m_2^2)$

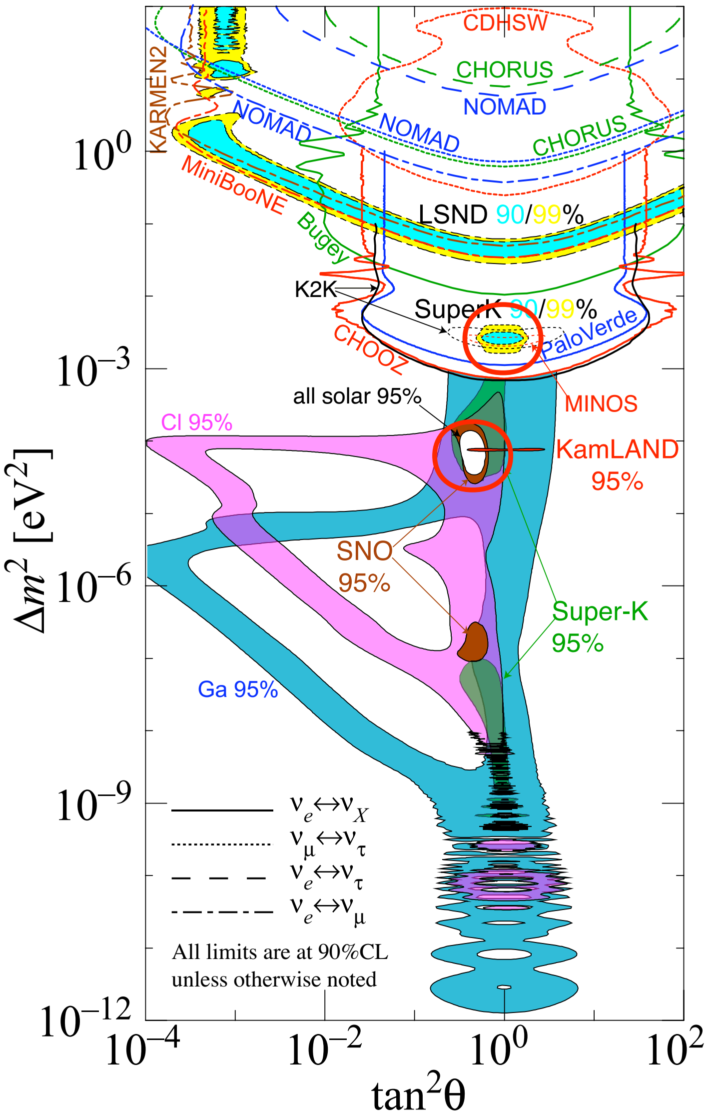
$$P_{\rm osc} = \sin^2(2\theta)\ \sin^2\left(1.27\,\frac{\delta m^2}{\rm eV^2}\,\frac{L}{\rm km}\,\frac{\rm GeV}{E}\right)$$

- Atmospheric: about half of upgoing ν_μ lost + KamLAND sees oscillation



- Solar ν-s: $\delta m^2 L/E \gg 1$
- Two mixing angles and two mass-squared differences are known, but not the absolute mass scale

From WMAP: $\sum m_i \lesssim 1\,\mathrm{eV}$

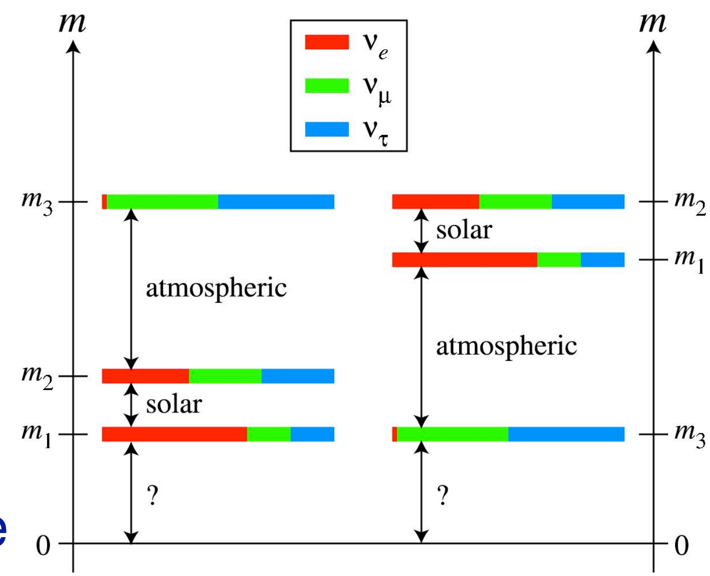


Neutrino mixing

$$U_{\ell i} = \underbrace{\begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix}}_{\theta_{23} \approx 45^\circ \text{ (atm)}} \underbrace{\begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix}}_{\theta_{13} \lesssim 10^\circ,\ \delta \text{ unknown}} \underbrace{\begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix}}_{\theta_{12} \approx 34^\circ \text{ (solar)}} \underbrace{\begin{pmatrix} e^{i\alpha_1/2} & & \\ & e^{i\alpha_2/2} & \\ & & 1 \end{pmatrix}}_{\text{Majorana phases}}$$

- Atmospheric: $\delta m^2_{23} = (1.9 - 3.0) \times 10^{-3}\,\text{eV}^2$
  $\sin^2(2\theta_{23}) > 0.92$

  Solar: $\delta m^2_{12} = (7.6 \pm 0.2) \times 10^{-5}\,\text{eV}^2$
  $\sin^2(2\theta_{12}) = 0.87^{+0.03}_{-0.04}$

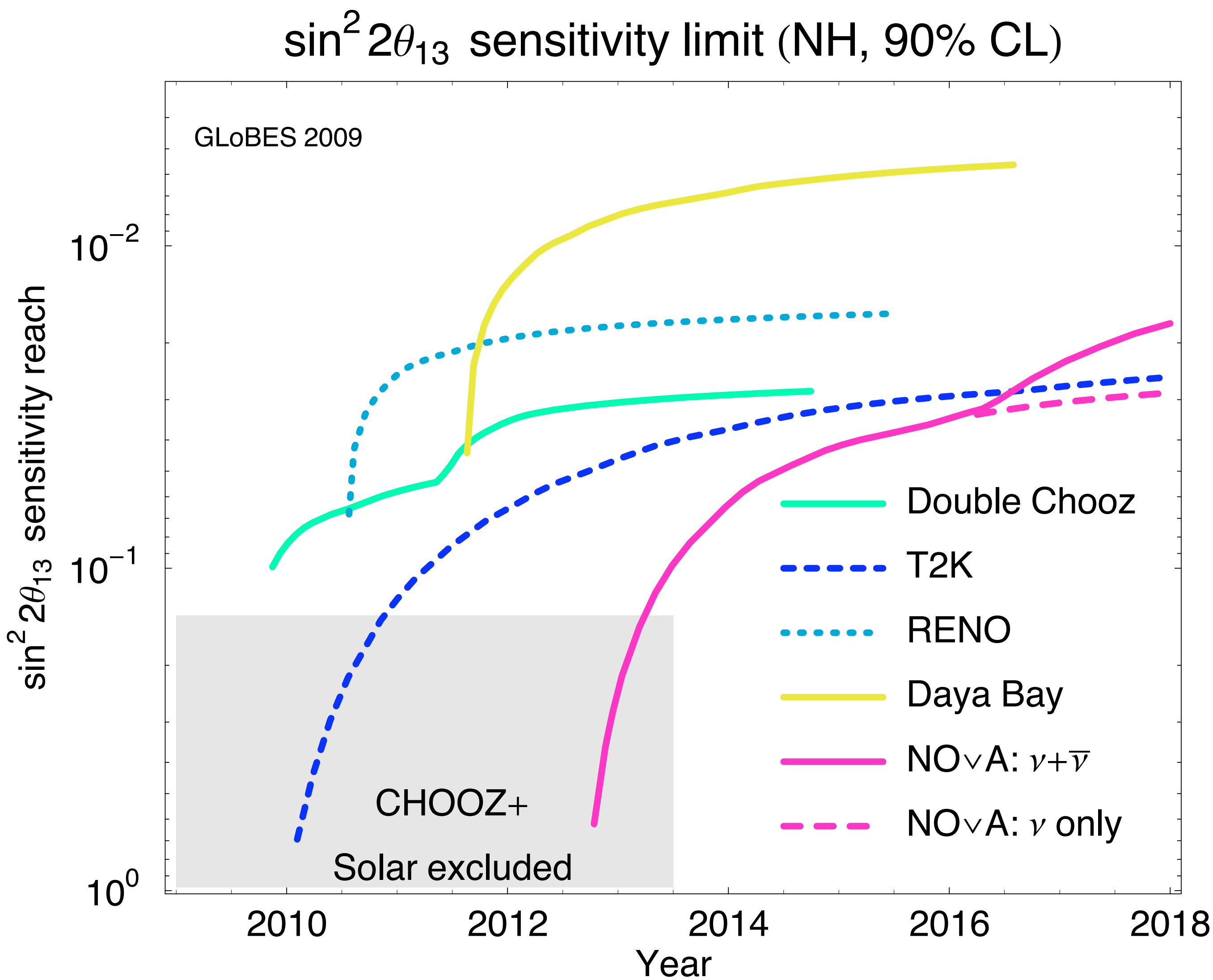


- Unknown: absolute mass scale, Majorana / Dirac

  smaller splitting between the lighter or the heavier states (normal / inverted hierarchy)

- If inverted hierarchy: $0\nu\beta\beta$ experiments may distinguish between Majorana / Dirac

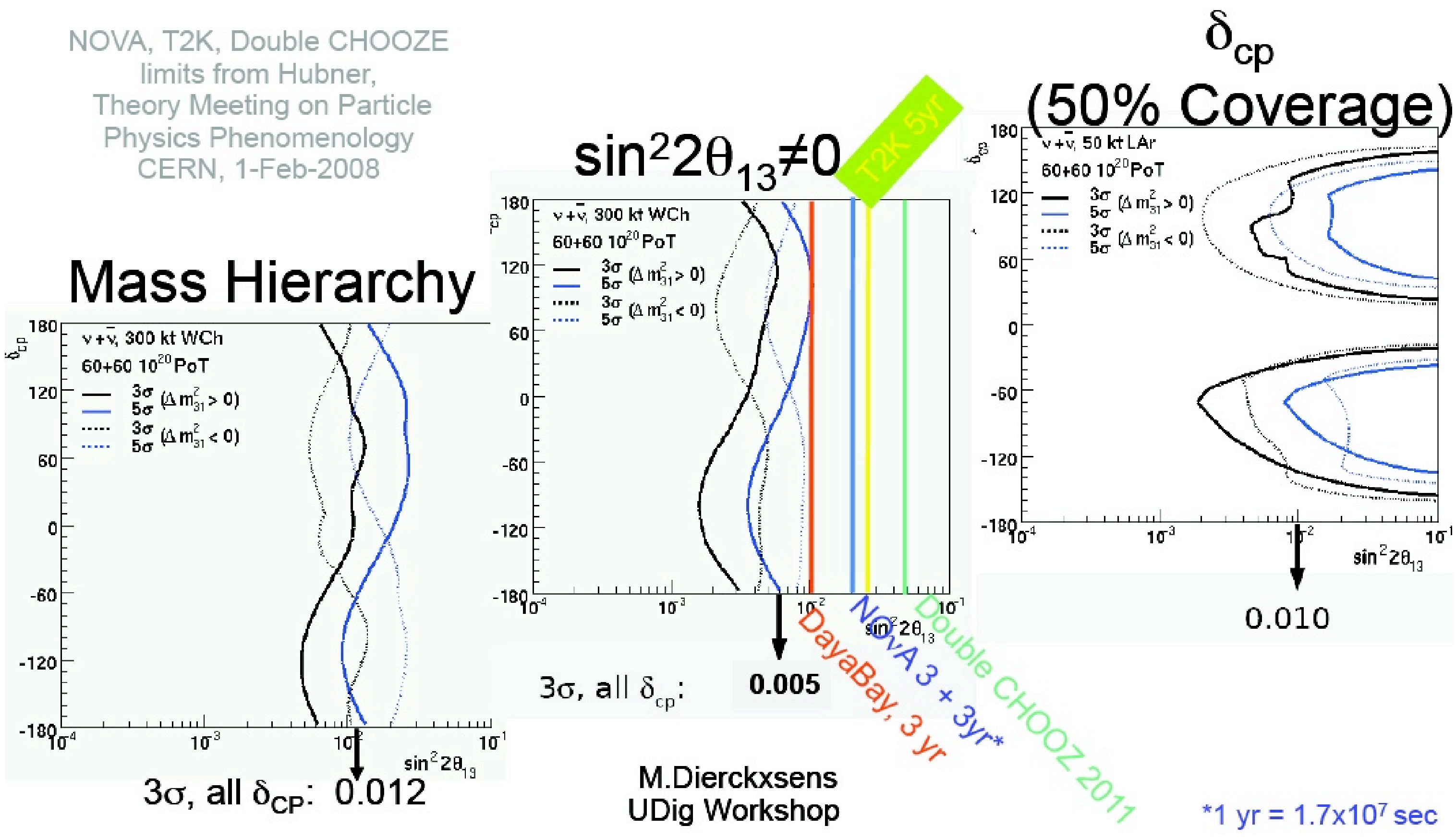
Future of θ_{13}



[arXiv:0907.1896]

LBNE measurements

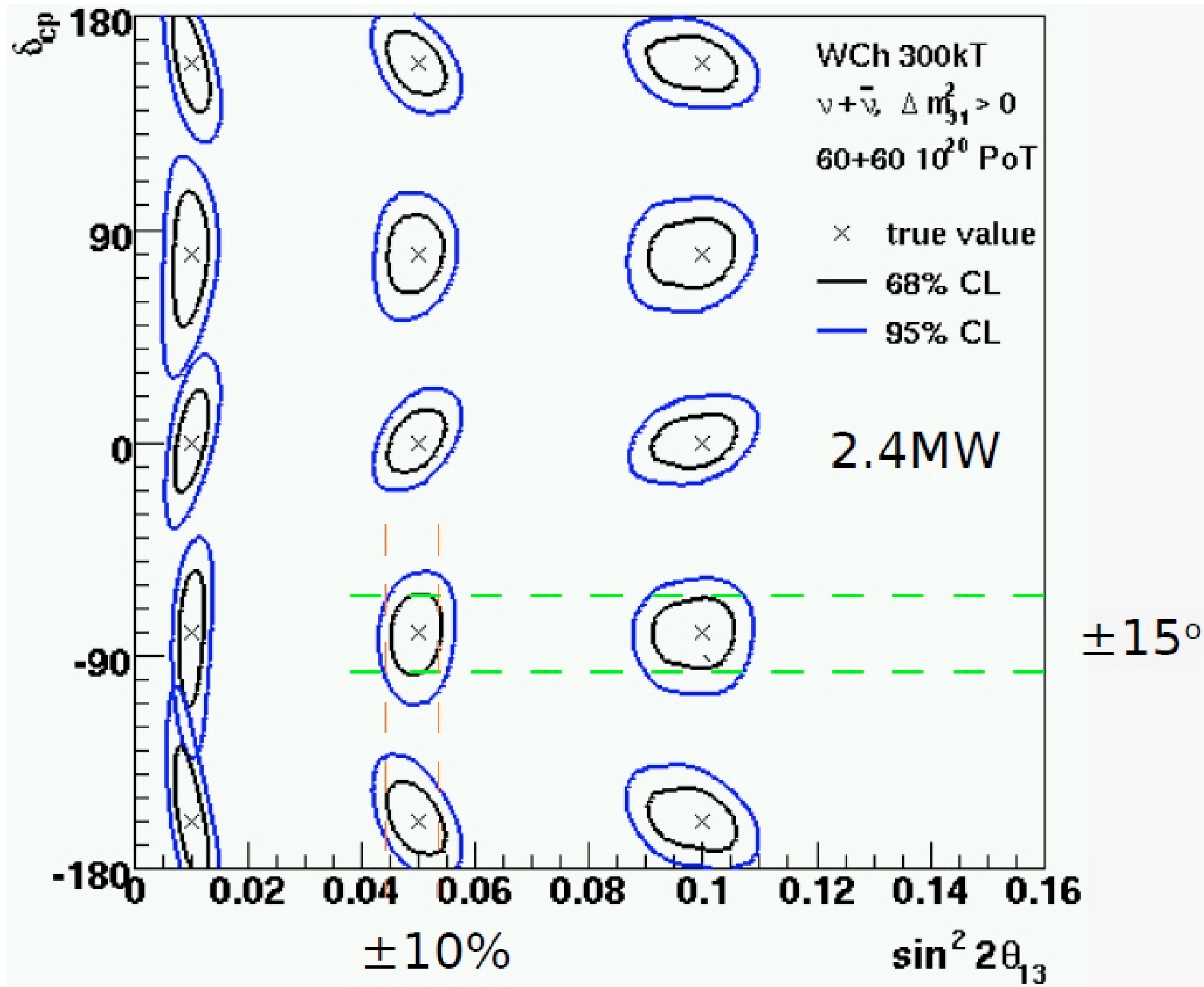
- Sensitivity of a 300 kT water Cherenkov detector — well tested techniques



- A water Cherenkov detector ≥ 300 kT is required to pursue CP violation and measure mass hierarchy and θ_{13} beyond reach of currently constructed experiments

$\sin^2(2\theta_{13})$ and CP violation

- Reconstructing $\sin^2(2\theta_{13})$ and δ_{CP} using a 300 kT water Cherenkov detector

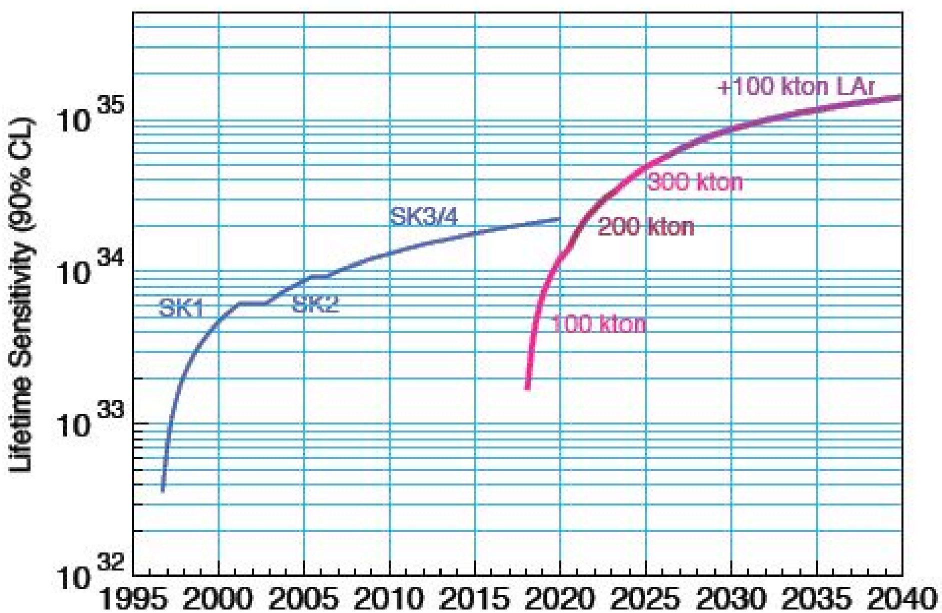


Berkeley Lab

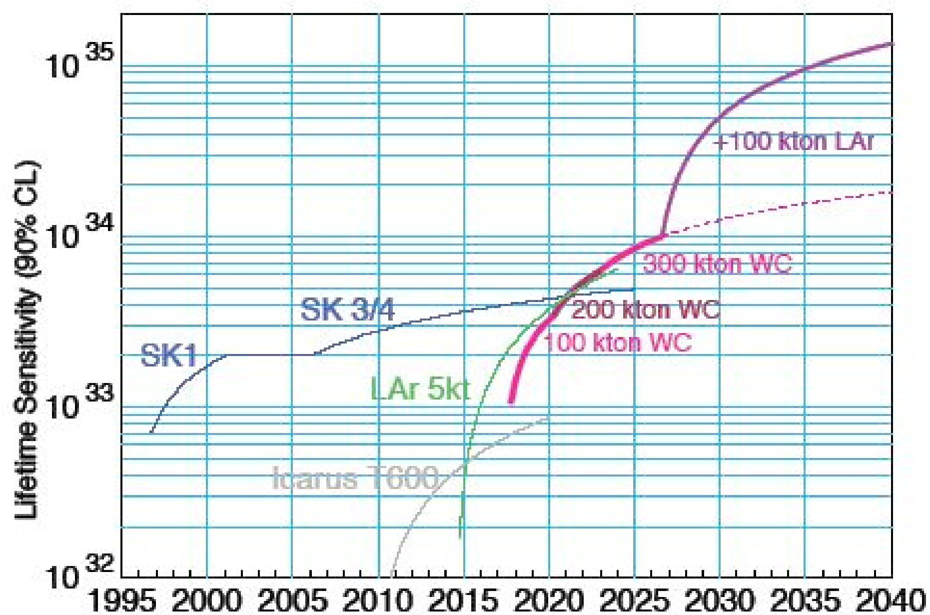
Proton lifetime limits

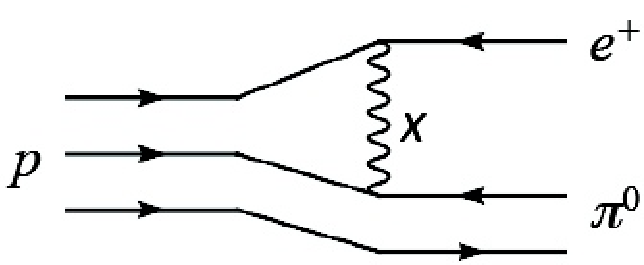
- Dictates depth requirement (also useful for supernova ν-s)

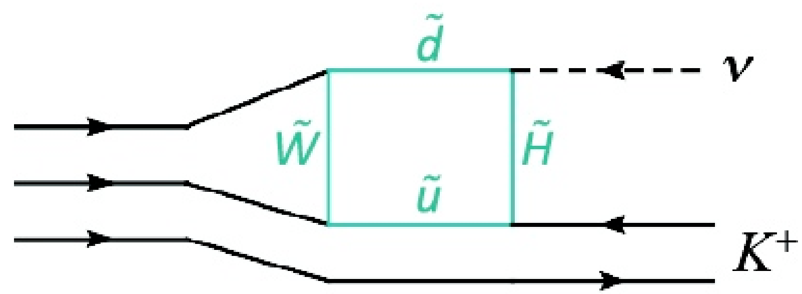
$p \to e^+\pi^0$



$p \to K^+\nu$







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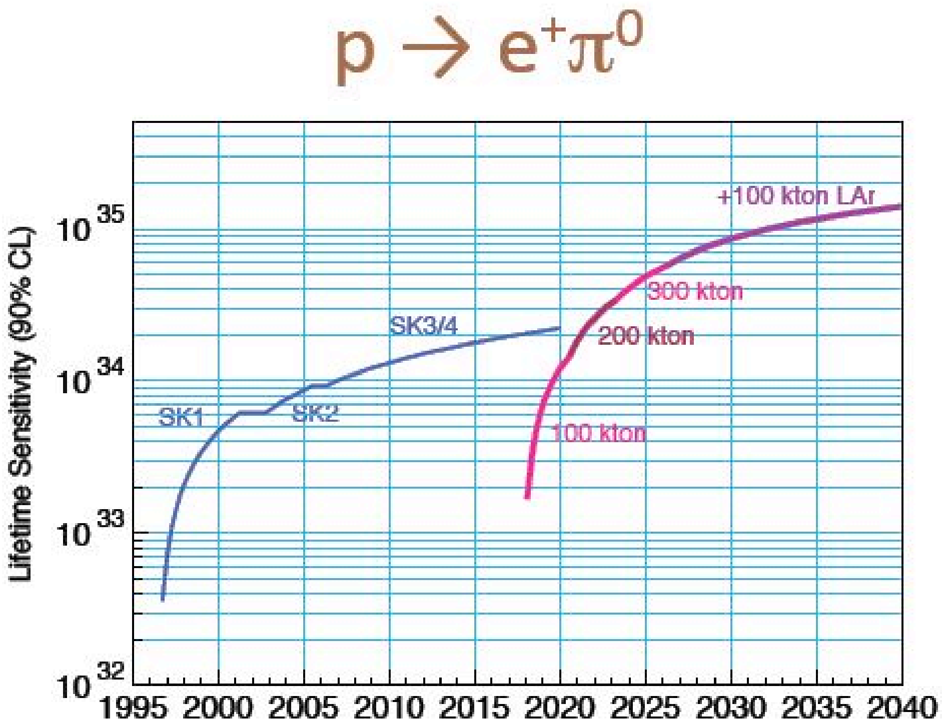
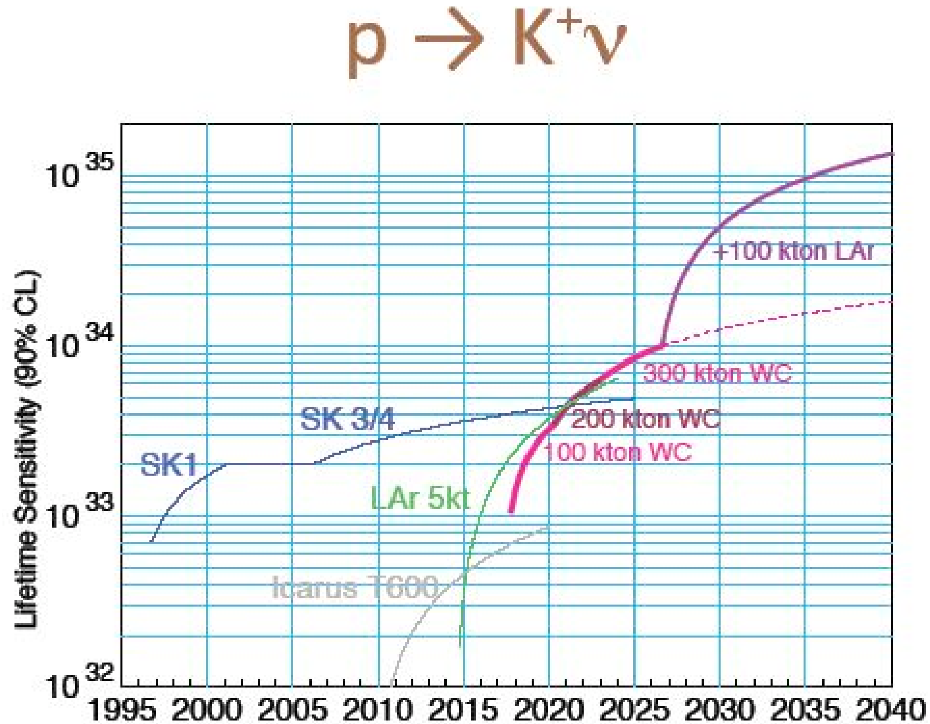




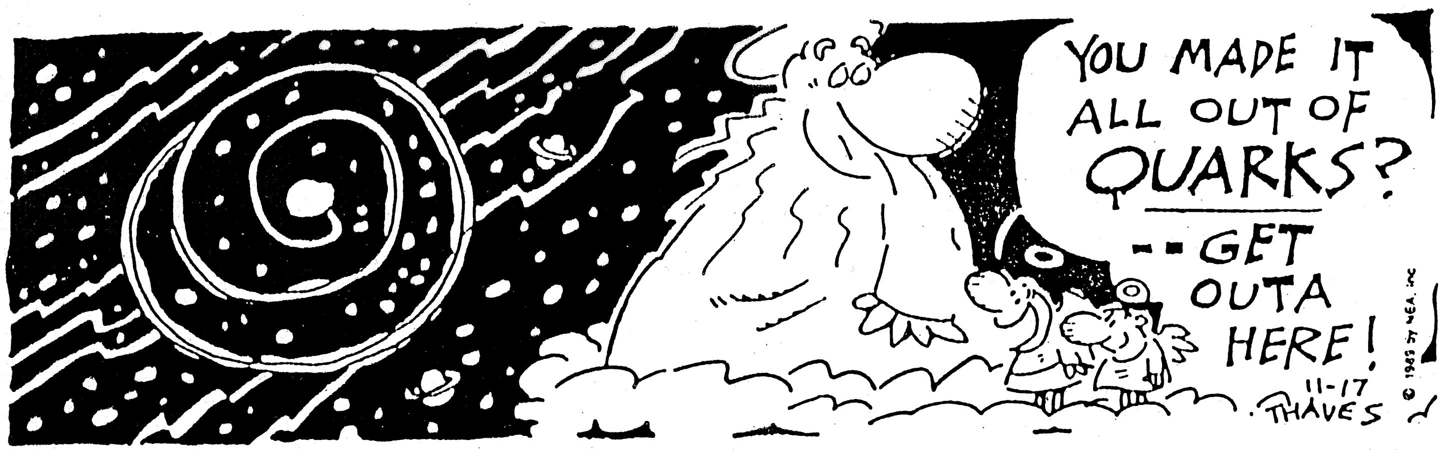
- To be competitive with SuperK (22 kT), requires a water Cherenkov detector of ~ 300 kT ($p \to e^+\pi^0$) or a LAr detector ~ 100 kT fiducial size ($p \to K^+\bar{\nu}$)
- Order of magnitude increase always interesting (no clear theory motivated target)

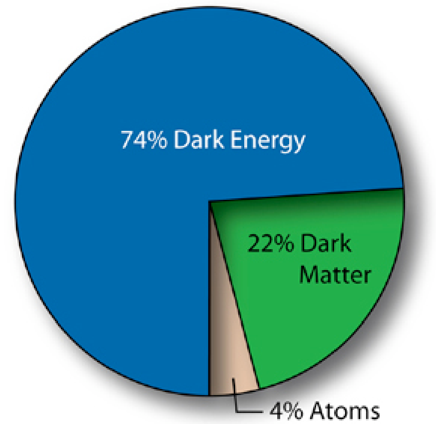
Recommendations — LBNE

- Modestly expand current involvement in a multi-100 kT water Cherenkov detector if funds can be attracted through DUSEL, the LBNE project, or other sources
  - Coordination between experiment and DUSEL facility
    cavity design, liner, drainage, maximizing fiducial volume
  - Help is sought by collaboration / FNAL / BNL
- Could provide a basis for increased future scientific involvement, which should be revisited when results of current experiments looking for θ_{13} are known

Dark matter

What is Dark Matter?





- Overwhelming evidence for DM: rotation curves, gravitational lensing, cosmology

  We know: non-baryonic (BBN), cold $=$ nonrelativistic at $z \sim 3000$ (structure formation), long lived, neutral (charge, color), abundance $\Rightarrow$ Cannot be a SM particle

  Don't know: interactions, mass, quantum numbers, one/many species

- Without theoretical prejudices, huge range of masses and cross sections allowed $(10^{-15} \lesssim m_X \lesssim 10^{18}\,\mathrm{GeV},\ 10^{-40} \lesssim \sigma_{\rm int} \lesssim 1\,\mathrm{pb})$

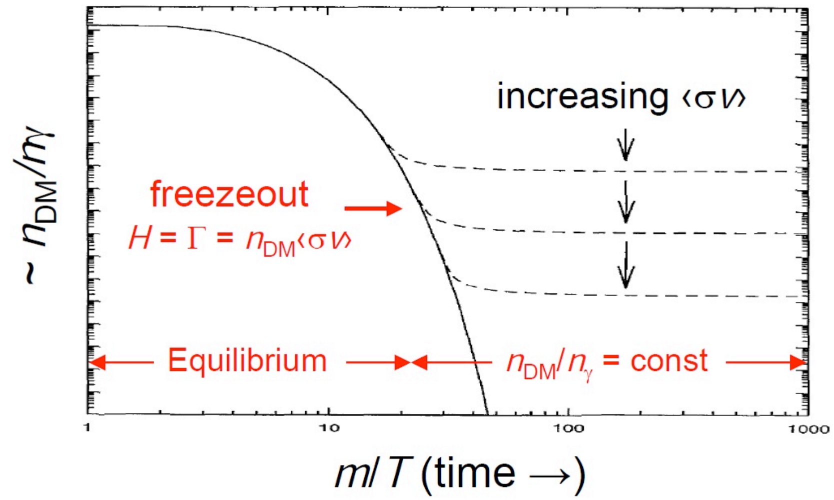
Weakly interacting massive particles

- DM as a thermal relic of the early universe?

  Annihilation cross section:

$$\Omega_{\rm DM} h^2 \sim \frac{3 \times 10^{-27} {\rm cm}^3/s}{\langle \sigma v \rangle} \quad \Rightarrow \quad \langle \sigma v \rangle \sim \frac{g^2}{8\pi} \frac{1}{\rm TeV^2}$$

  [Caveat: σ may be smaller/larger: non-thermal DM production? DM may have asymmetry?]



- Cosmology alone (w/o hierarchy problem) tells us to explore the TeV scale

  Hints already? DAMA/LIBRA (annual modulation), PAMELA (e^+/e^- “anomaly”)

  Led to lots of theoretical activity recently

- If DM $=$ WIMP, good chance for direct detection in the next 10–20 years

  Synergy with LHC: lightest of possible TeV-scale particles can easily be stable

WIMP detection experiments

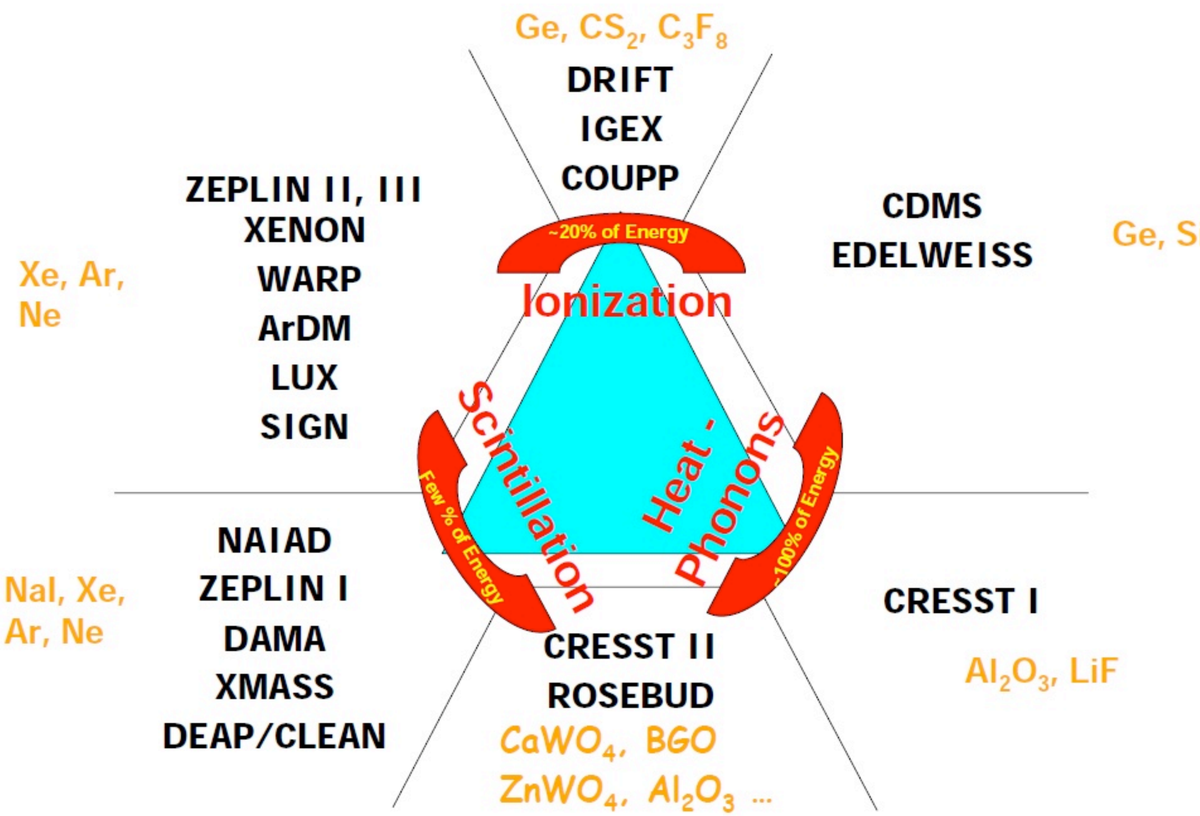
- Indirect detection: photons (galactic center, extra galactic)
  neutrinos (Earth, Sun, galactic center); antiparticles (halo)

- Direct detection

  Many experiments and broad spectrum of techniques

  New ideas and new collaborations appearing

  Two pieces of information can help recognize nuclear recoil, discriminate from background



- Winning technique not yet identified — which will scale best (mass, background)?

Status of direct WIMP detection

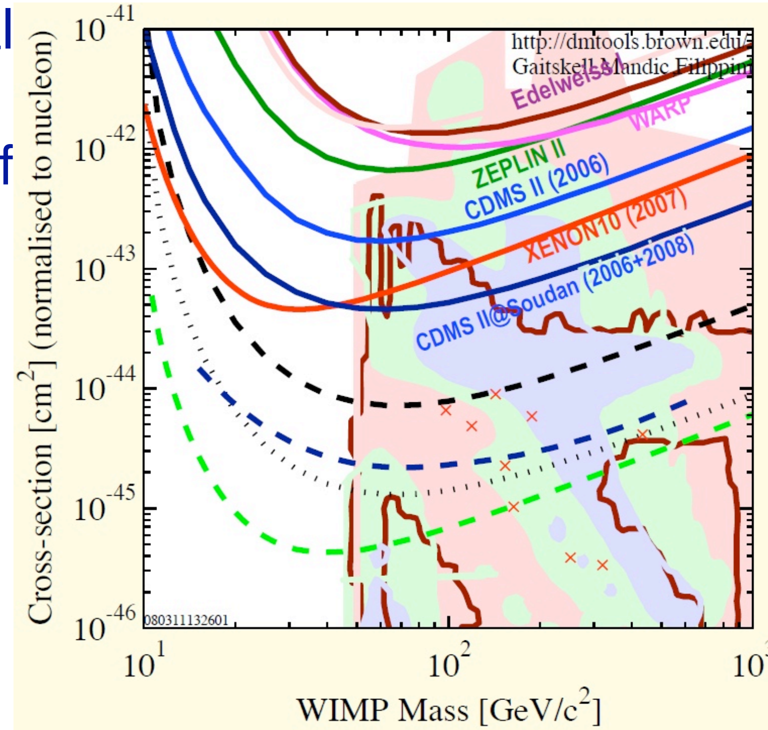
- Direct detection: $10-100$ keV nuclear recoil signal

  Spin independent: coherence $\Rightarrow$ enhancement of $\sigma \propto A^2$ — better limits

  Best current bounds are Xenon 10 and CDMS II

  Spin dependent: best current bound is from Ice^3

  Future: sensitivity to 10^{-45} cm^2 soon
  ultimately want to reach $< 10^{-47}$ cm^2



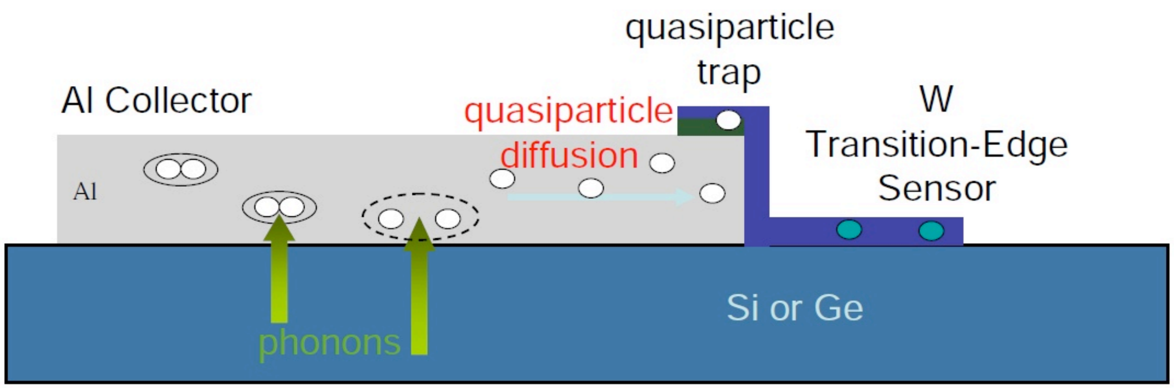
- Small rates $\Rightarrow$ large low-threshold detectors with good background discrimination

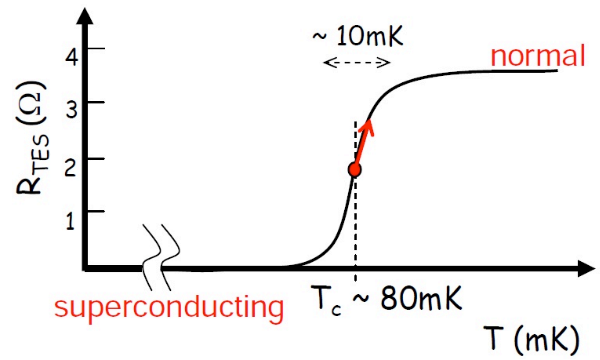
  $(\sigma = 10^{-42}\,\mathrm{cm}^2$ gives ~ 1 event/kg/day)

- To minimize internal contamination & incoming external radiation $\Rightarrow$ underground

CDMS / GEODM

- CDMS pioneered the use of low temperature phonon-mediated Ge or Si crystals





Recoiling nucleus generates phonons, propagate to surface, excite quasi-particle states which propagate to Tungsten and heat it, change in measured resistance

Only technique so far with zero background

- SuperCDMS: 15 kg at Soudan, 100 kg at SNOLAB; major Fermilab & SLAC roles
- GEODM: 1.5 ton Ge, at 7400 ft level, aims at $2 \times 10^{-47}\,\mathrm{cm}^2/\mathrm{nucleon}$ in 4 yrs (2021)
- Opportunities: Ge crystals $0.64 \rightarrow 5.1$ kg, technical overlaps with Majorana

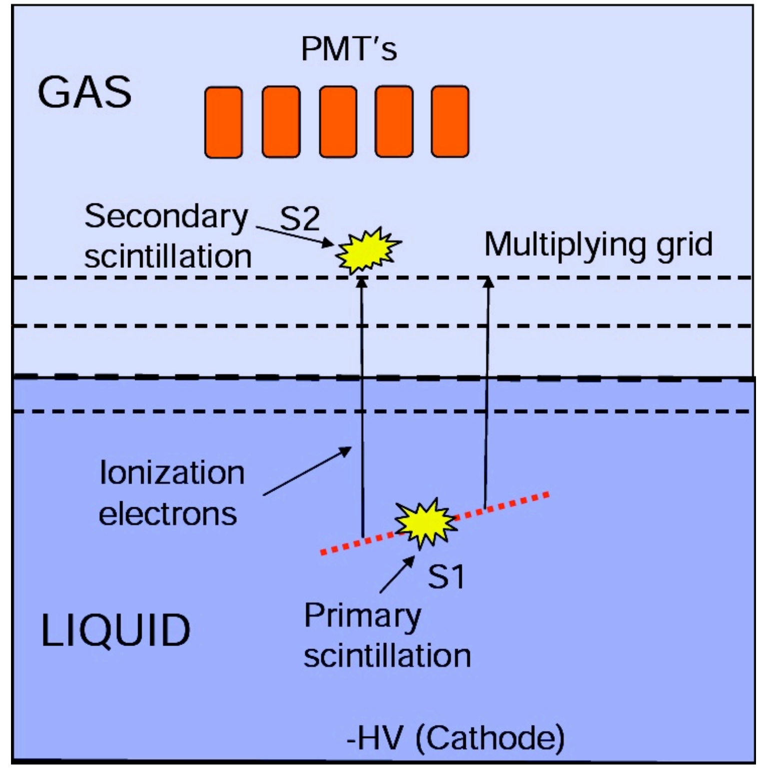
LUX / LZ3 / LZ20

- 2-phase Xe experiment (LUX + ZEPLIN)

  Scintillation from primary interaction in liquid; electrons drift to anode, increased field at interface $\Rightarrow$ multiplication and secondary scintillation

  Use pulse shape and (relative) scintillation intensities to discriminate

  Scalability issues might be less severe than for Ge — no lead lab identified yet



- LZ20: aims to cover practically all interesting WIMP region to $< 10^{-47}\,\mathrm{cm}^2/\mathrm{nucleon}$

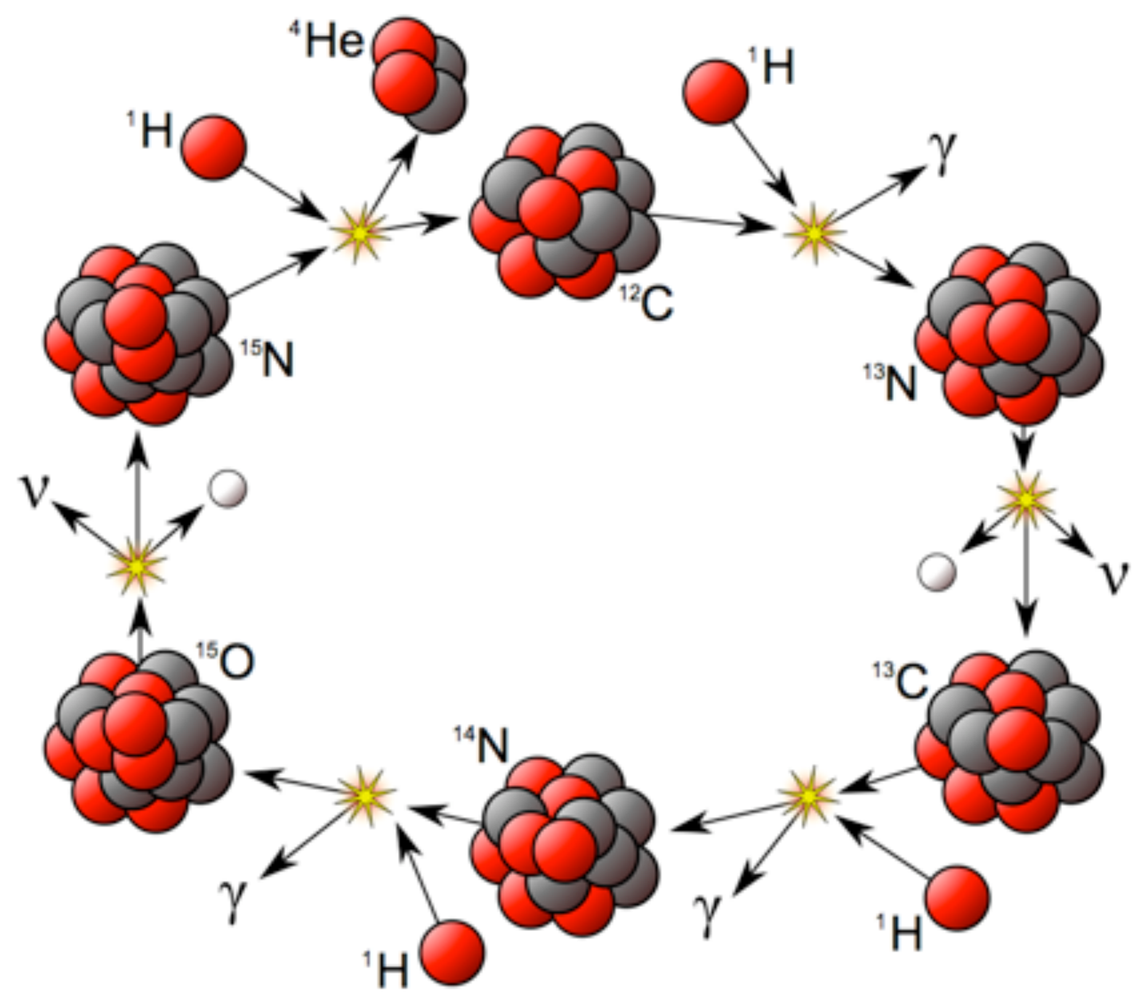
- Opportunities: Use SNO/KamLAND/Majorana expertise, engineering roles, possible synergy with Xe TPC R&D

Recommendations — Dark Matter

- Compelling science, excellent opportunities for LBNL; not having a significant scientific role in a DM experiment would be a missed opportunity
- We can have a significant scientific impact on at most one of these projects, credible scientific participation will likely require new resources
- Identify resources that would be needed for a credible scientific participation in either LZ20 or GEODM
- Participation in LZ20 or GEODM should be driven by the scientific leadership of the emerging LBNL effort

Nuclear Astrophysics

Nuclear Astrophysics



p.23

Origin of Elements in Stars and Stellar Explosions

low energy accelerators ⟷ nucleosynthesis processes in stars

radioactive beams ⟷ explosive nucleosynthesis

reactor and neutron spallation facilities ⟷ neutron-induced nucleosynthesis

neutrino-induced nucleosynthesis

Origin of Elements in Stars and Stellar Explosions

low energy accelerators	⟷	nucleosynthesis processes in stars
radioactive beams	⟷	explosive nucleosynthesis
reactor and neutron spallation facilities	⟷	neutron-induced nucleosynthesis
		neutrino-induced nucleosynthesis

"Realistically, only the low energy accelerator experiments are relevant for this report which discusses opportunities in underground science"

Pioneering measurement at LUNA, the Laboratory for Underground Nuclear Astrophysics

VOLUME 82, NUMBER 26 PHYSICAL REVIEW LETTERS 28 JUNE 1999

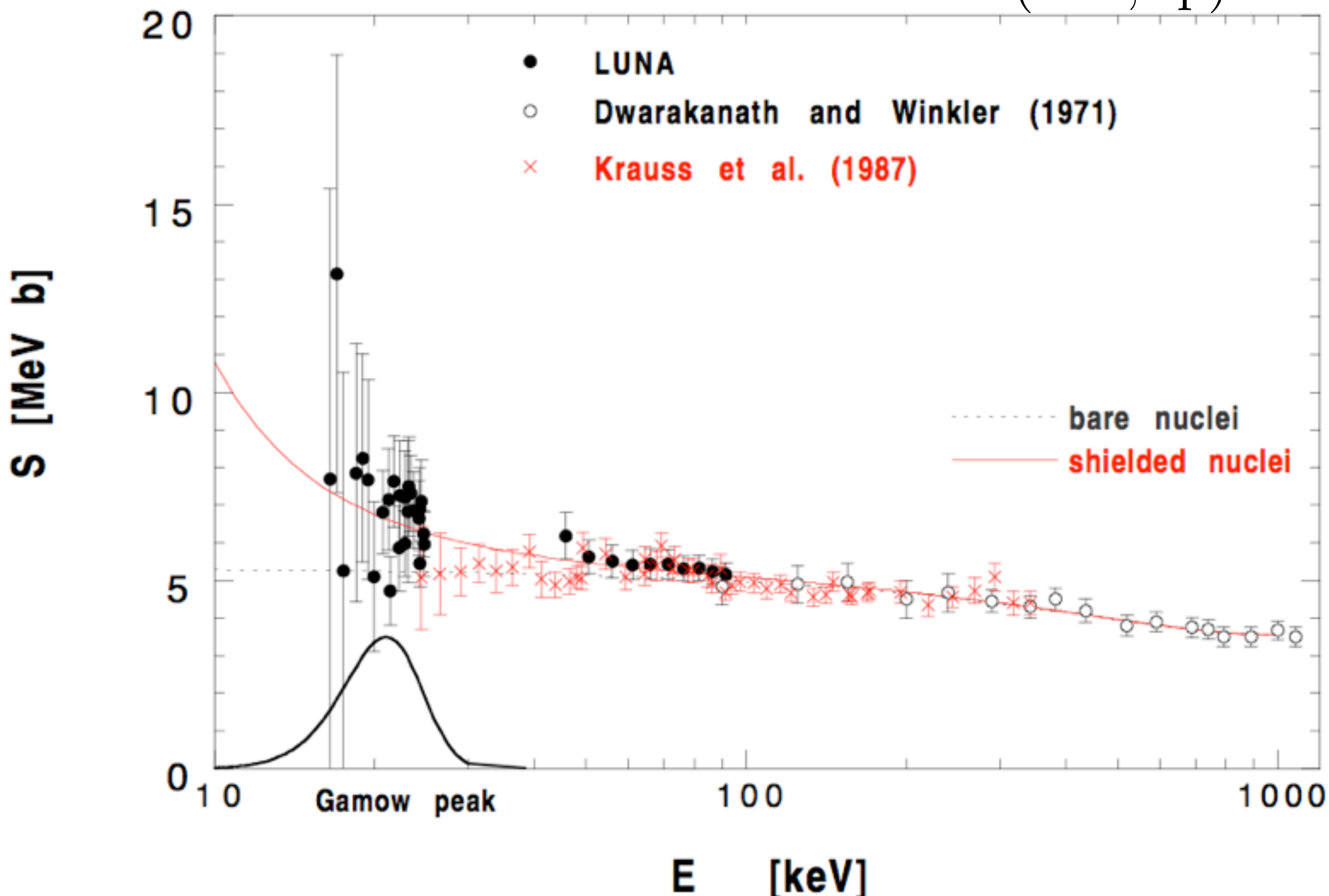
First Measurement of the ^{3}He(^{3}He, $2p$)^{4}He Cross Section down to the Lower Edge of the Solar Gamow Peak

R. Bonetti,[1] C. Broggini,[2,*] L. Campajola,[3] P. Corvisiero,[4] A. D'Alessandro,[5] M. Dessalvi,[4] A. D'Onofrio,[6] A. Fubini,[7] G. Gervino,[8] L. Gialanella,[9] U. Greife,[9] A. Guglielmetti,[1] C. Gustavino,[5] G. Imbriani,[3] M. Junker,[5] P. Prati,[4] V. Roca,[3] C. Rolfs,[9] M. Romano,[3] F. Schuemann,[9] F. Strieder,[9] F. Terrasi,[3] H.P. Trautvetter,[9] and S. Zavatarelli[4]
(LUNA Collaboration)
[1]*Dipartimento di Fisica and INFN, Università di Milano, Milano, Italy*
[2]*INFN, Padova, Italy*
[3]*Dipartimento di Scienze Fisiche and INFN, Università di Napoli "Federico II," Napoli, Italy*
[4]*Dipartimento di Fisica and INFN, Università di Genova, Genova, Italy*
[5]*Laboratori Nazionali del Gran Sasso, Assergi, Italy*
[6]*Dipartimento di Scienze Ambientali, Caserta and INFN, Seconda Università di Napoli, Napoli, Italy*
[7]*Frascati and INFN, ENEA, Torino, Italy*
[8]*Dipartimento di Fisica Sperimentale and INFN, Università di Torino, Torino, Italy*
[9]*Institut für Experimentalphysik III, Ruhr-Universität, Bochum, Germany*
(Received 4 February 1999)

We give the LUNA results on the $\sigma(E)$ cross section measurement of a key reaction of the proton-proton chain strongly affecting the calculated neutrino luminosity from the Sun: ^{3}He(^{3}He, $2p$)^{4}He. Because of the cosmic ray suppression provided by the Gran Sasso underground laboratory, it has been possible to measure $\sigma(E)$ throughout the energy range in which this reaction occurs in the Sun, i.e., down to 16.5 keV center of mass energy. The data clearly show the cross section increase due to the electron screening effect but they do not exhibit any evidence for a narrow resonance suggested to explain the ^{8}B and ^{7}Be solar neutrino flux reduction. [S0031-9007(99)09440-5]

Pioneering measurement at LUNA, the Laboratory for Underground Nuclear Astrophysics

$^3\mathrm{He}(^3\mathrm{He}, 2\mathrm{p})^4\mathrm{He}$

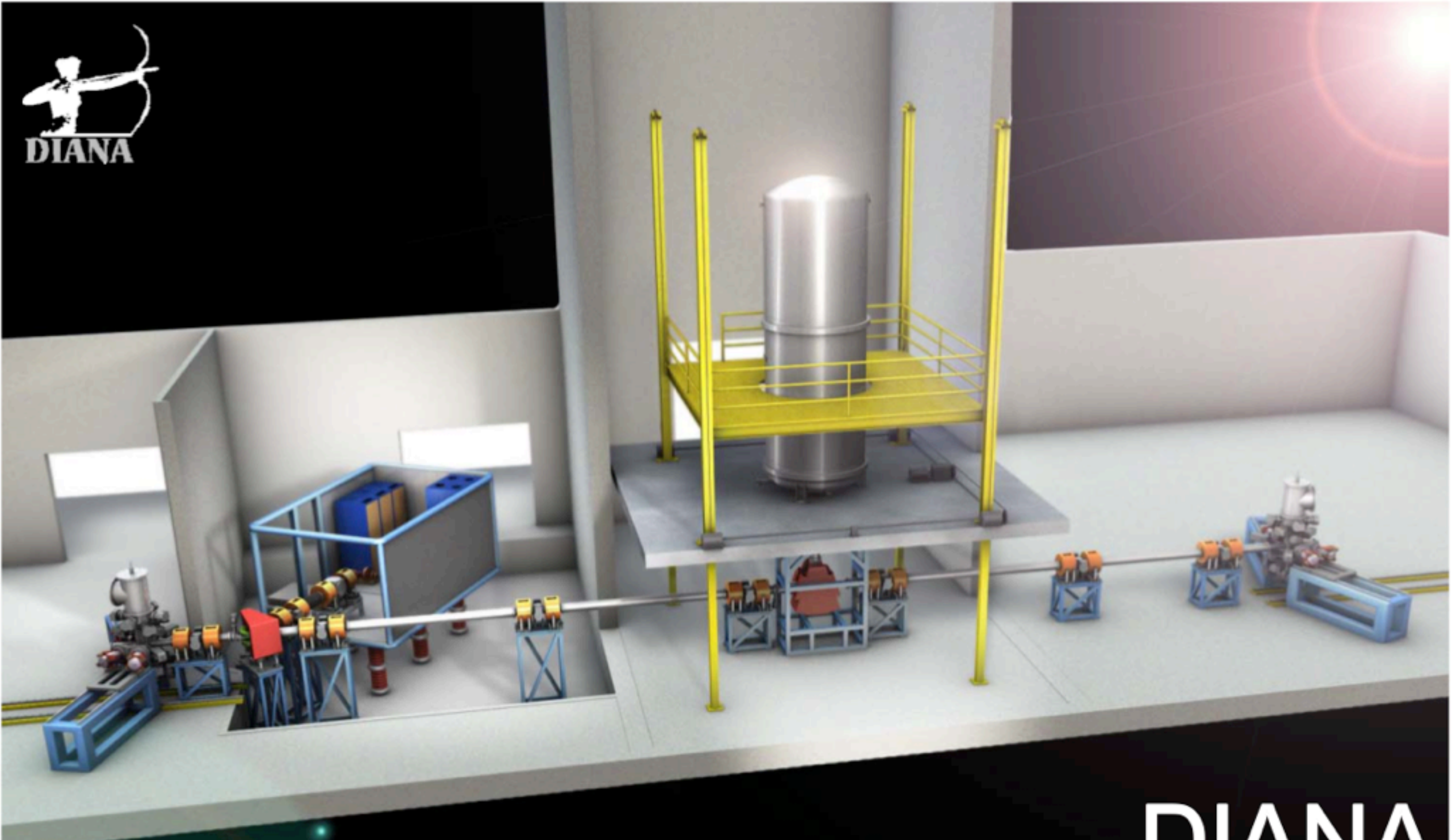


Subsequent LUNA measurements include e.g.

Nucl. Phys. A706 (2002) 203, $\mathrm{d}(\mathrm{p}, \gamma)^3\mathrm{He}$

Nucl. Phys. Rev. C 75 (2007) 065803, $^3\mathrm{He}(\alpha, \gamma)^7\mathrm{Be}$

See http://npgroup.pd.infn.it/luna/publications.html for a complete list.



DIANA

A NOVEL NUCLEAR ASTROPHYSICS UNDERGROUND ACCELERATOR FACILITY

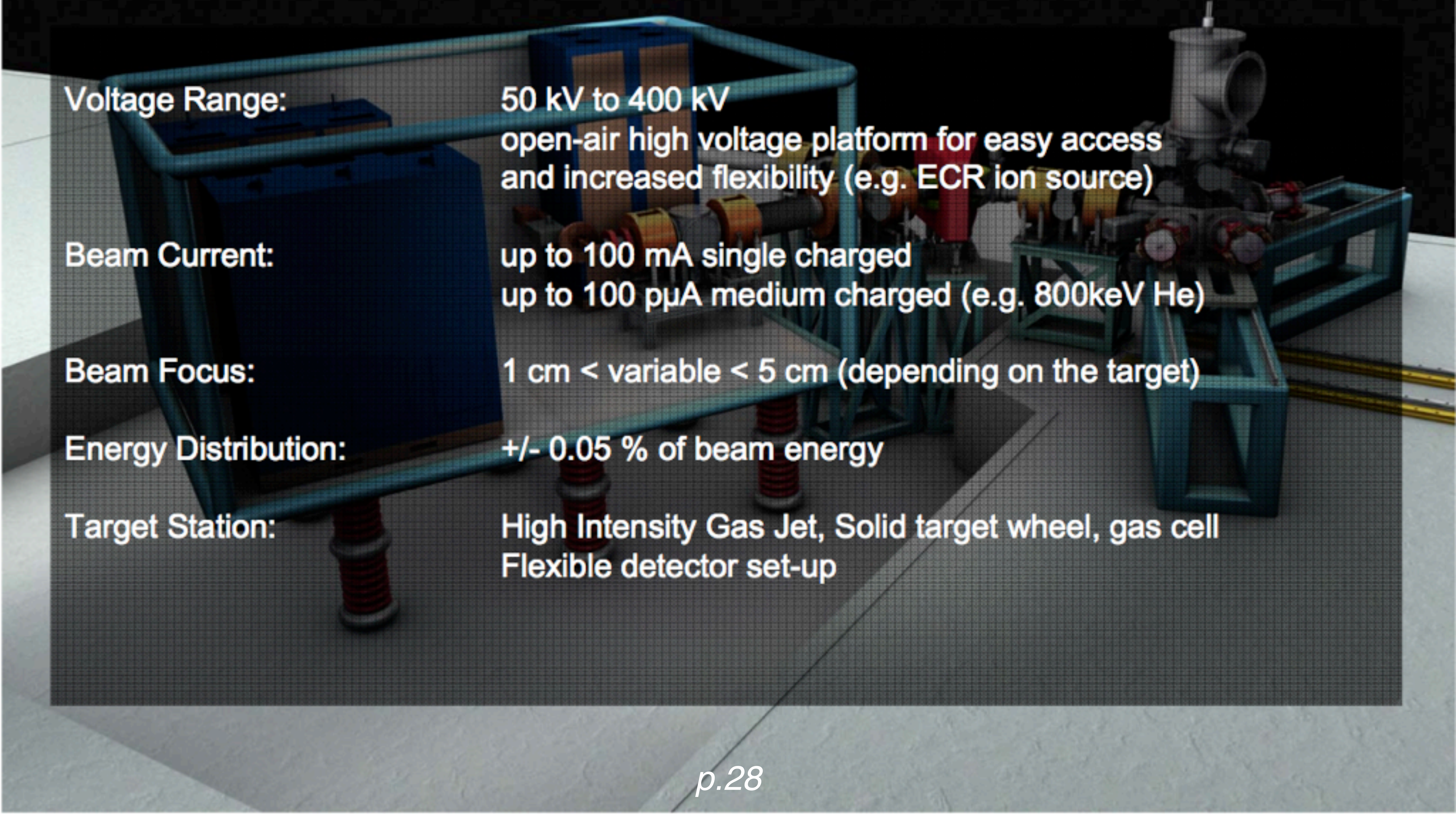
Daniela Leitner, Matthaeus Leitner, Paul Vetter
Lawrence Berkeley National Laboratory

RPM

March 23rd 2009

Unique Features of the DIANA Facility
Low Energy Accelerator and Target Station

One to two orders of magnitude higher ion beam intensity on target in order to address the low count rates close to the Gamow window energies.



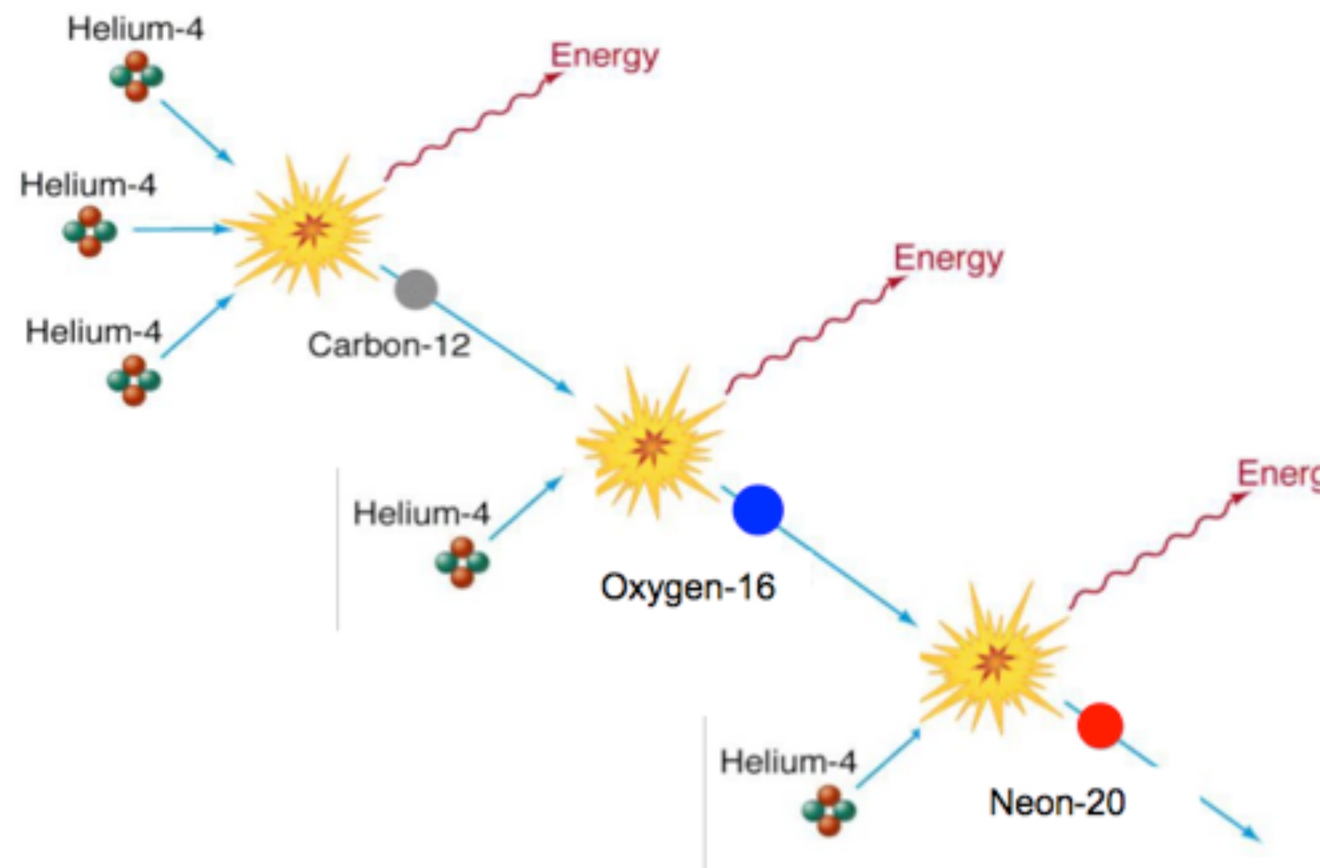
Voltage Range:	50 kV to 400 kV open-air high voltage platform for easy access and increased flexibility (e.g. ECR ion source)
Beam Current:	up to 100 mA single charged up to 100 pμA medium charged (e.g. 800keV He)
Beam Focus:	1 cm < variable < 5 cm (depending on the target)
Energy Distribution:	+/- 0.05 % of beam energy
Target Station:	High Intensity Gas Jet, Solid target wheel, gas cell Flexible detector set-up

DIANA Opportunities

Solar Neutrino Sources and the Metallicity of the Sun,

$$^{3}\mathrm{He}(\alpha,\gamma)^{7}\mathrm{Be}$$
$$^{7}\mathrm{Be}(\mathrm{p},\gamma)$$

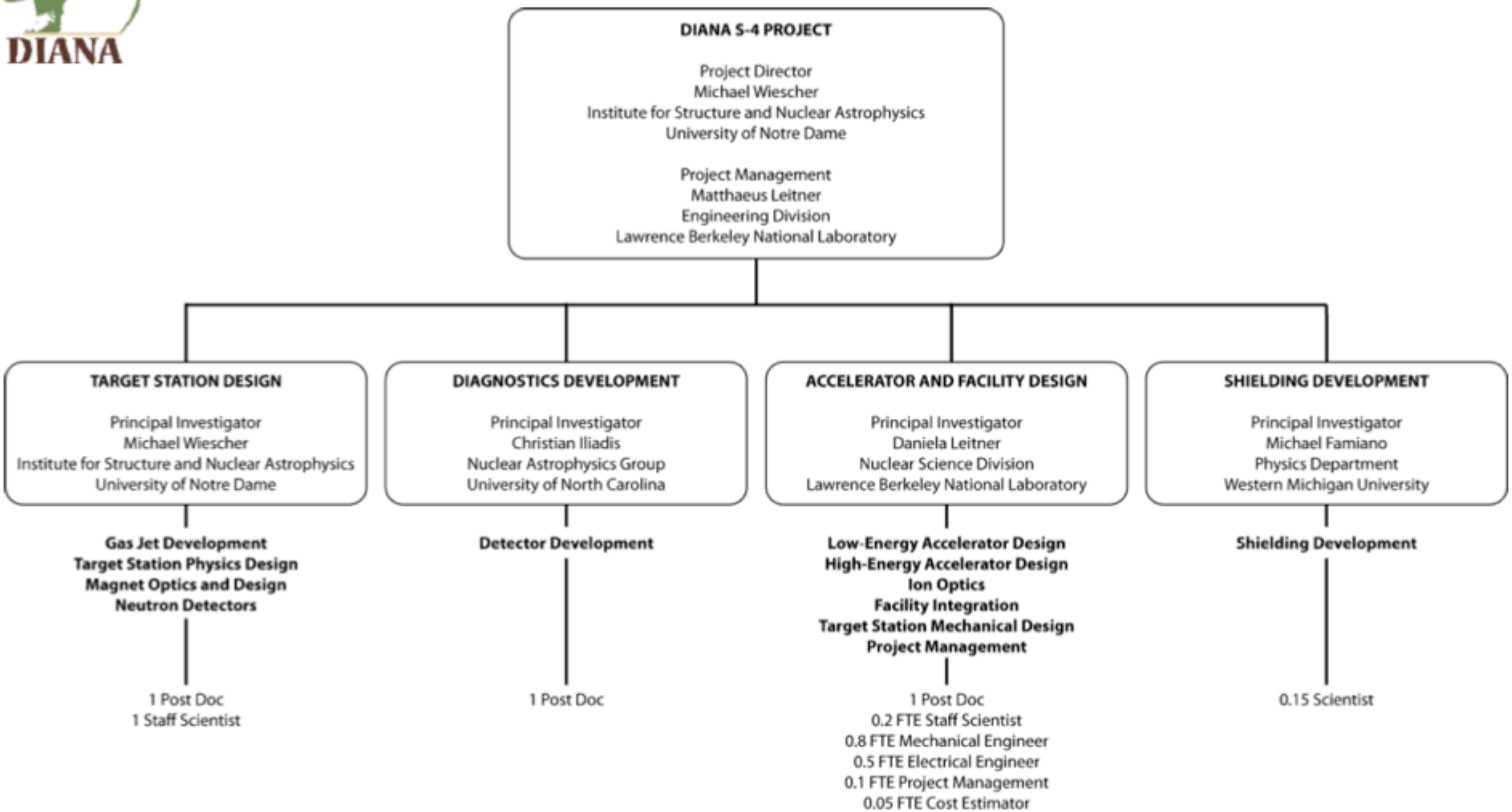
Carbon-based Nucleosynthesis,



$$^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$$
$$^{16}\mathrm{O}(\alpha,\gamma)^{20}\mathrm{Ne}$$

Neutron Sources for the Production of Trans-Fe Elements in Stars.

$$^{13}\mathrm{C}(\alpha,\mathrm{n})$$
$$^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$$



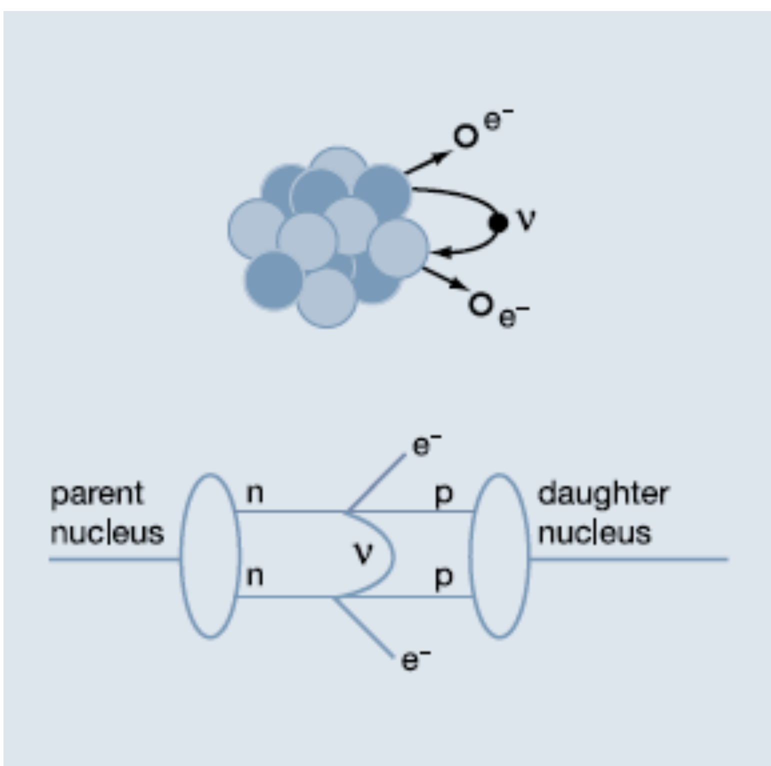
Dakota Ion Accelerators for Nuclear Astrophysics is a collaboration between the following institutions:

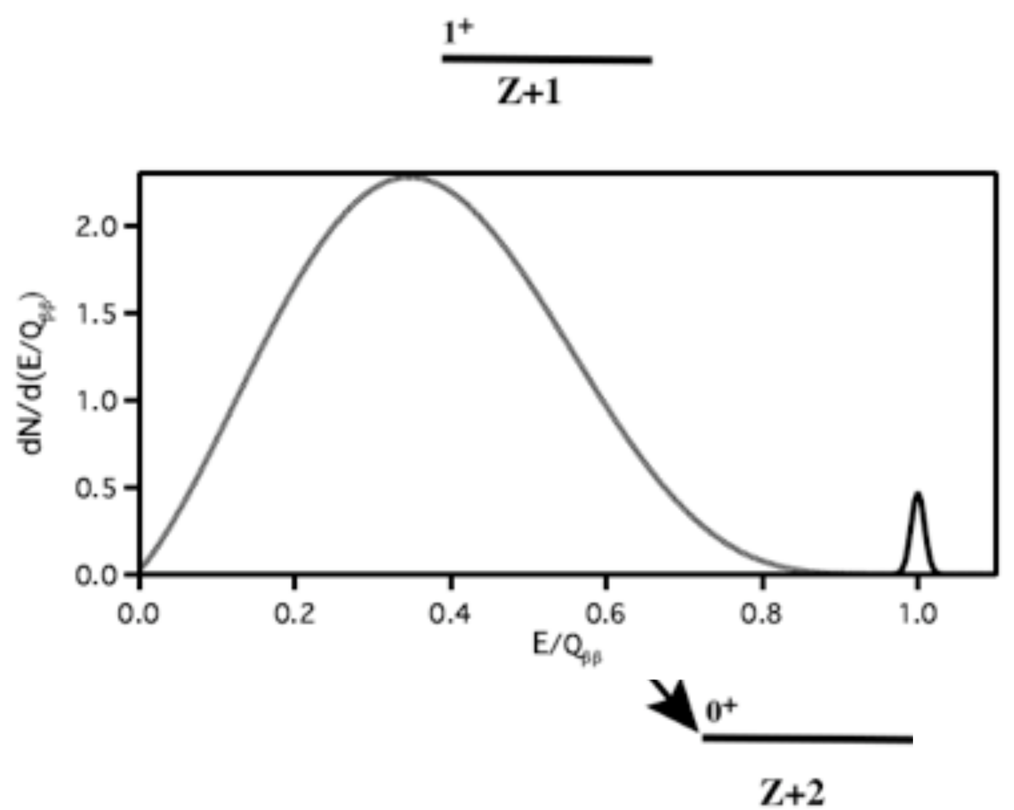
Recommendation - DIANA

LBNL holds the lead role in the accelerator development of the DIANA proposal. We recommend that, as DIANA progresses through review, the existing involvement in the accelerator becomes paired with commensurate scientific involvement if resources can be found. We recommend that, if additional resources cannot be found as DIANA progresses through review, the involvement in DIANA be revisited in the context of other commitments.

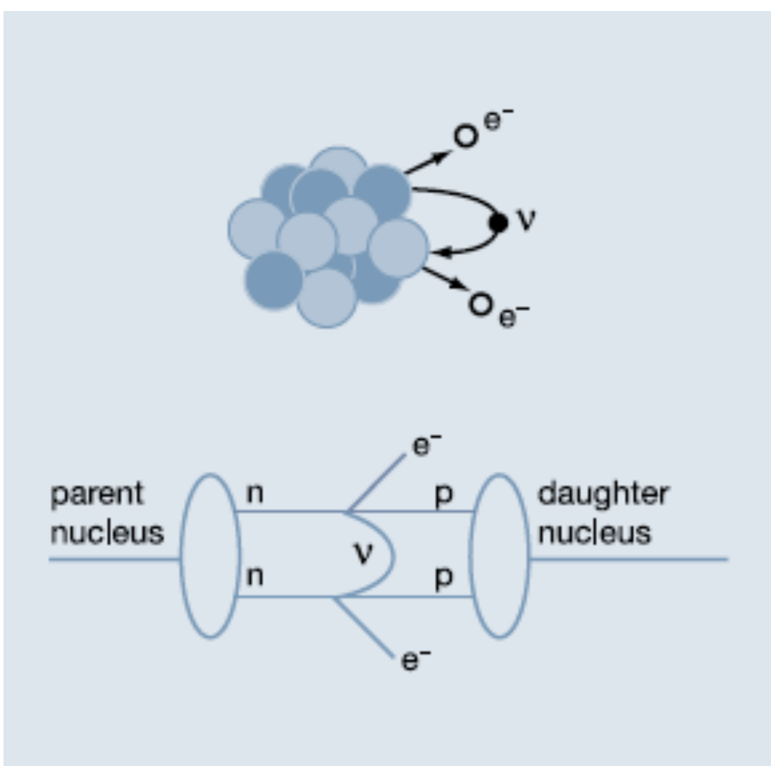
Neutrinoless Double Beta Decay

Neutrinoless Double Beta Decay





Neutrinoless Double Beta Decay



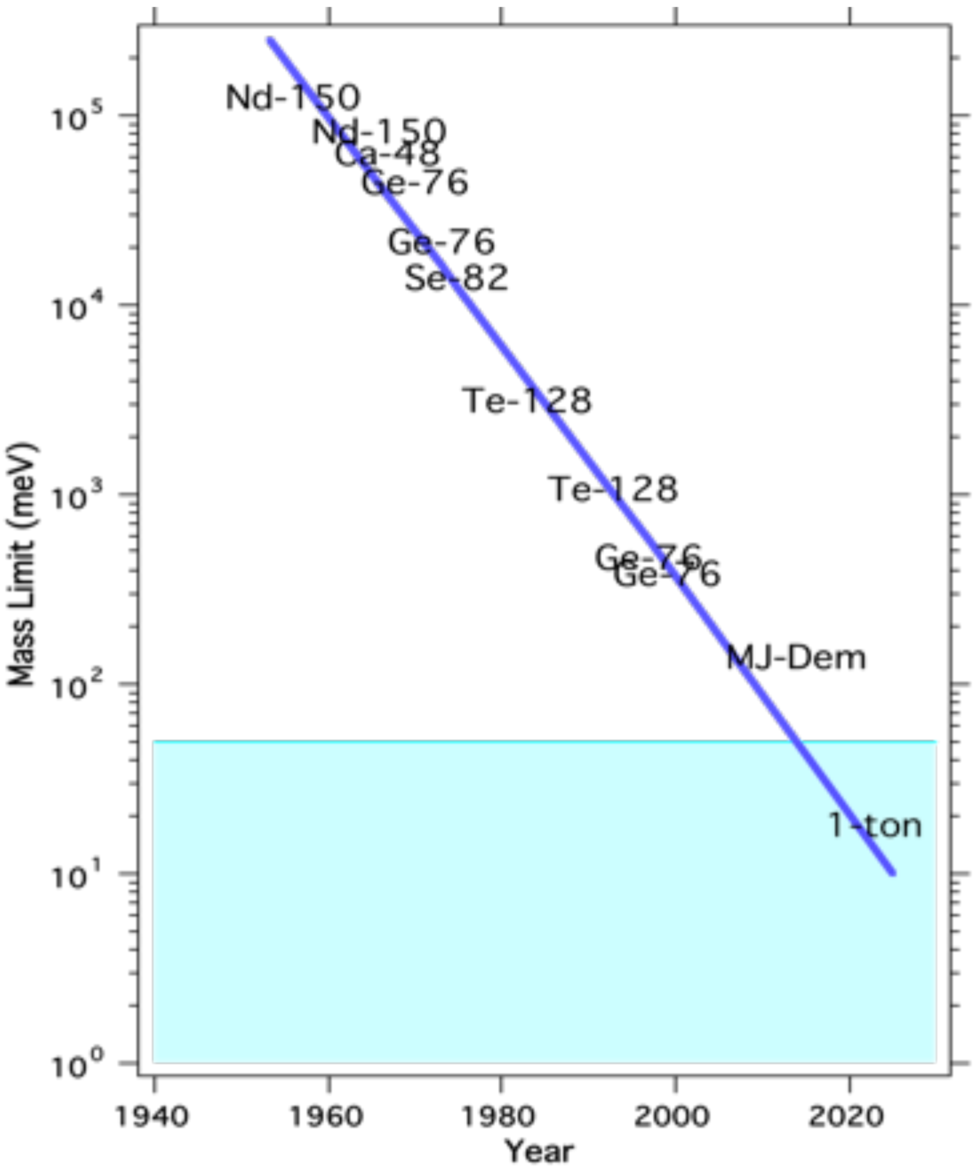
Decay can only occur if:
- lepton number conservation is broken,
- neutrinos are massive Majorana particles,

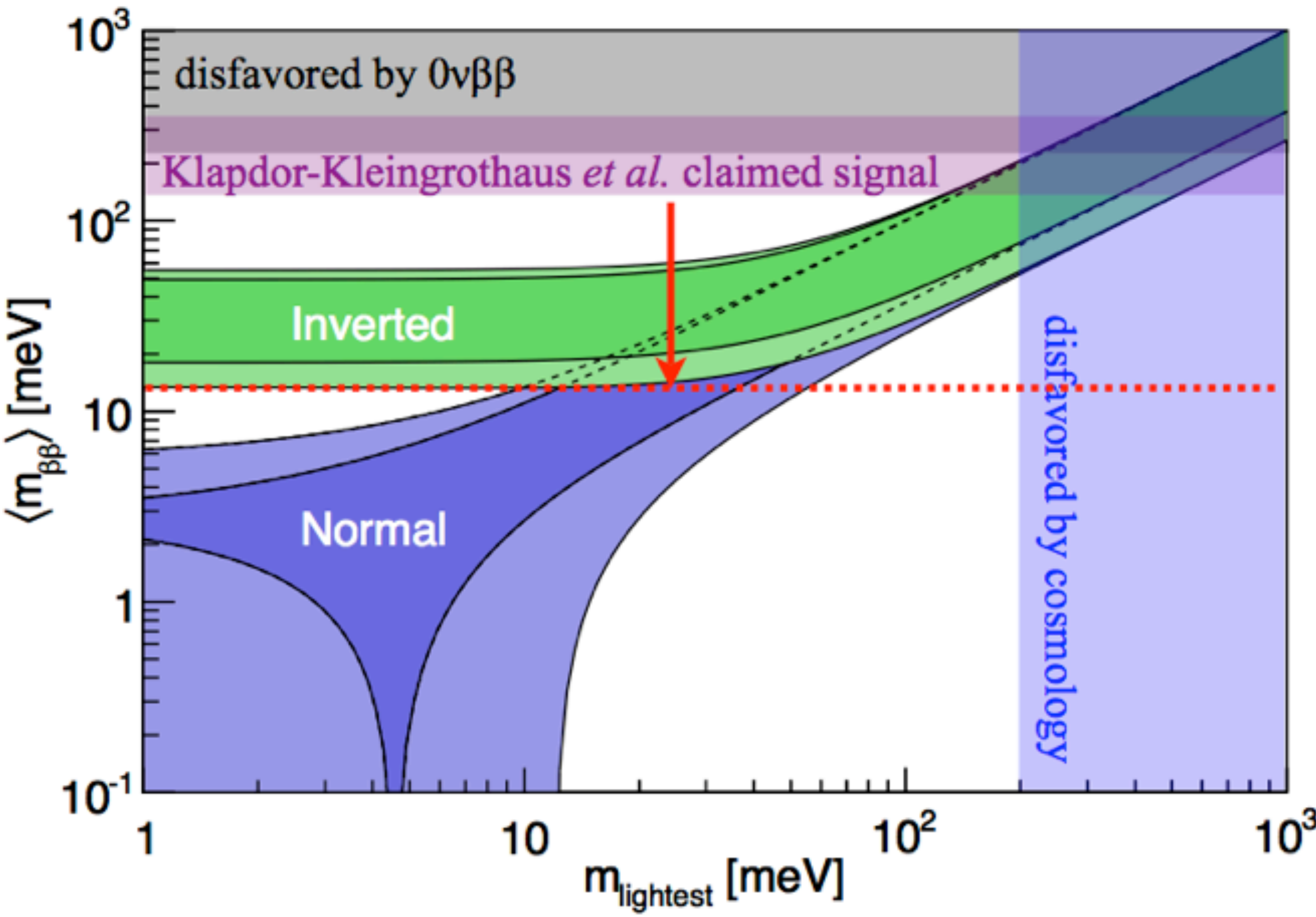
Decay rate proportional to neutrino mass,

Fundamental physics process,

ßß is the only practical experimental technique.

History and Goals





The MAJORANA Collaboration

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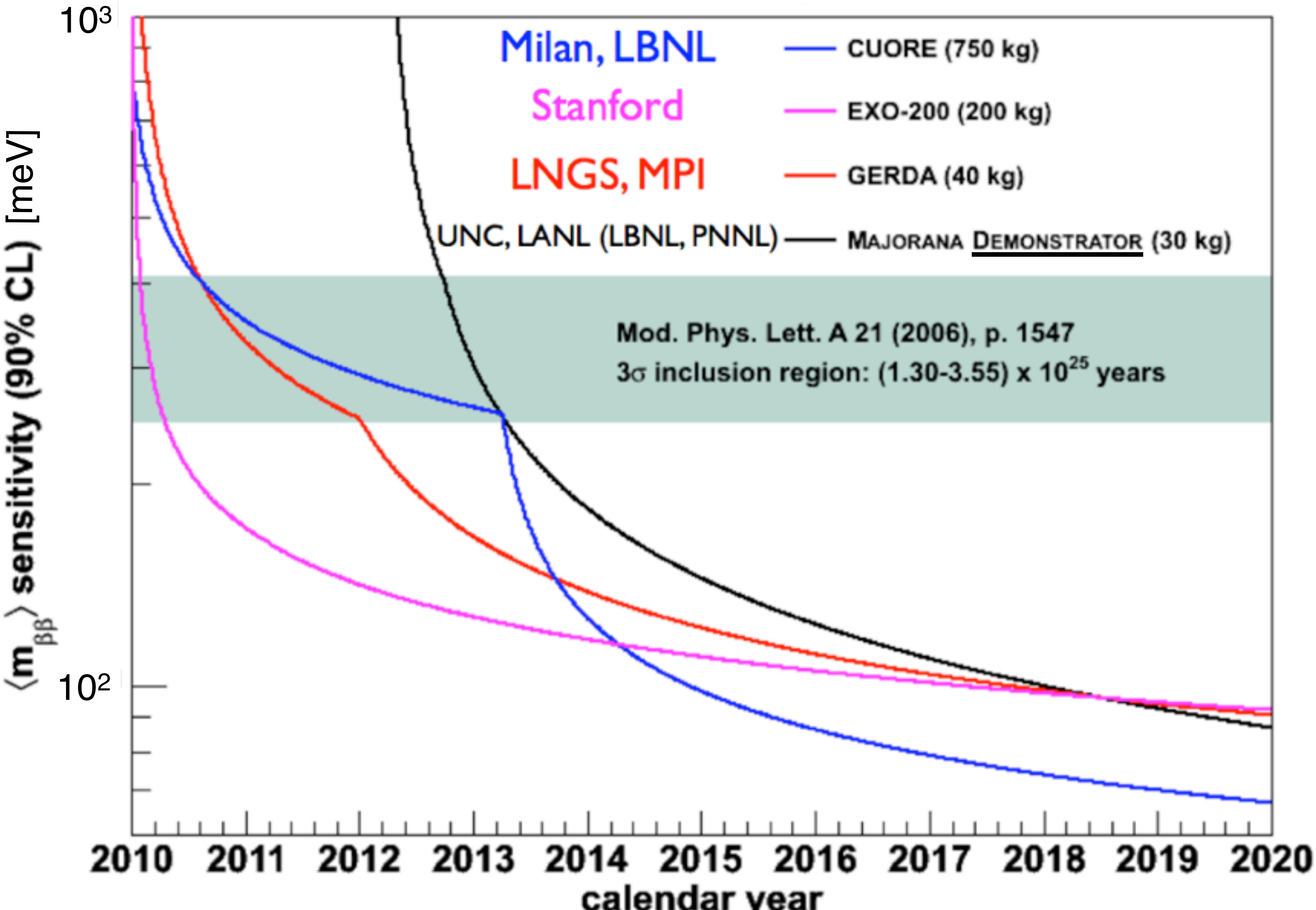

Complementary techniques:

- CUORE (Gran Sasso) - TeO_2 bolometer array,
- EXO-200 - liquid Xe
- Majorana - ^{76}Ge

Majorana Demonstrator is a key step towards Majorana:

- demonstrate background low enough to justify building a ton-scale experiment,

- examine detector technology options: p- and n-type, segmentation, point-contact,

- science sensitivity to test HDKK claim

Numerous LBNL strengths; detector R&D, materials and assay,
simulations, digitizer development,
LBCF, DUSEL facility, ...

Recommendation - $0\nu\beta\beta$

LBNL has a significant scientific investment and involvement in the Majorana Demonstrator and the Majorana experiment. A plan that leads to a sustainable leadership role for LBNL in Majorana on the timescale of the 1 ton experiment needs to be detailed. Re-establishing senior leadership to the LBNL effort is likely to be a necessary element of such a plan.

R&D

Recommendation - R&D

We strongly encourage R&D. In particular, there are ongoing R&D efforts in cryogenic bolometry (related to CUORE) and high pressure Xenon TPCs (related to neutrinoless double beta decay, and possibly dark matter experiments). If successful, these R&D efforts may provide the basis for one or more future generations of DUSEL experiments.

Recommendations

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Recommendations

Neutrinoless Double Beta Decay / Majorana:

LBNL has a significant scientific investment and involvement in the Majorana Demonstrator and the Majorana experiment. A plan that leads to a sustainable leadership role for LBNL in Majorana on the timescale of the 1 ton experiment needs to be detailed. Re-establishing senior leadership to the LBNL effort is likely to be a necessary element of such a plan.

Recommendations

Nuclear Astrophysics / DIANA:

LBNL holds the lead role in the accelerator development of the DIANA proposal. We recommend that, as DIANA progresses through review, the existing involvement in the accelerator becomes paired with commensurate scientific involvement if resources can be found. We recommend that, if additional resources cannot be found as DIANA progresses through review, the involvement in DIANA be revisited in the context of other commitments.

Recommendations

Neutrino Oscillations:

We recommend to modestly expand the current involvement in a multi-100 kT Water Cherenkov detector if funds can be attracted through DUSEL, the LBNE project, or other sources. This could provide a basis for increased future scientific involvement, which should be revisited when the results of current experiments determining θ_{13} *are known.*

Recommendations

Dark Matter:

Dark Matter experiments, in particular LUX/LZ20 and CDMS/GEODM, offer compelling science and excellent opportunities for LBNL leadership roles and technical contributions. The committee feels that not having a significant scientific role in a Dark Matter Experiment would be a missed opportunity. The committee also believes that LBNL can have a significant scientific impact on at most one of these projects, and that credible scientific participation will likely require new resources. We recommend to identify the resources that would be needed for a credible scientific participation in LZ20 or GEODM. A decision for either of these experiments should be driven by the scientific leadership of the LBNL effort.

Recommendations / Observations

Compelling science, fundamental to nuclear or particle physics, was presented in each of the four focus areas; nuclear astrophysics, neutrinoless double beta decay, neutrino oscillations and proton decay, dark matter searches,

Local interest and expertise has already led to significant involvements,

Cooperation and collaboration among the NS, P, and E Divisions, and UCB is a central feature of the current broad program,

The committee has identified no compelling reasons, at this time, to devote resources at Berkeley to potential future experiments (and related R&D) beyond those activities that already have significant Berkeley involvement,

The scientific involvement in some of the projects, however, should be strengthened.

Discussion