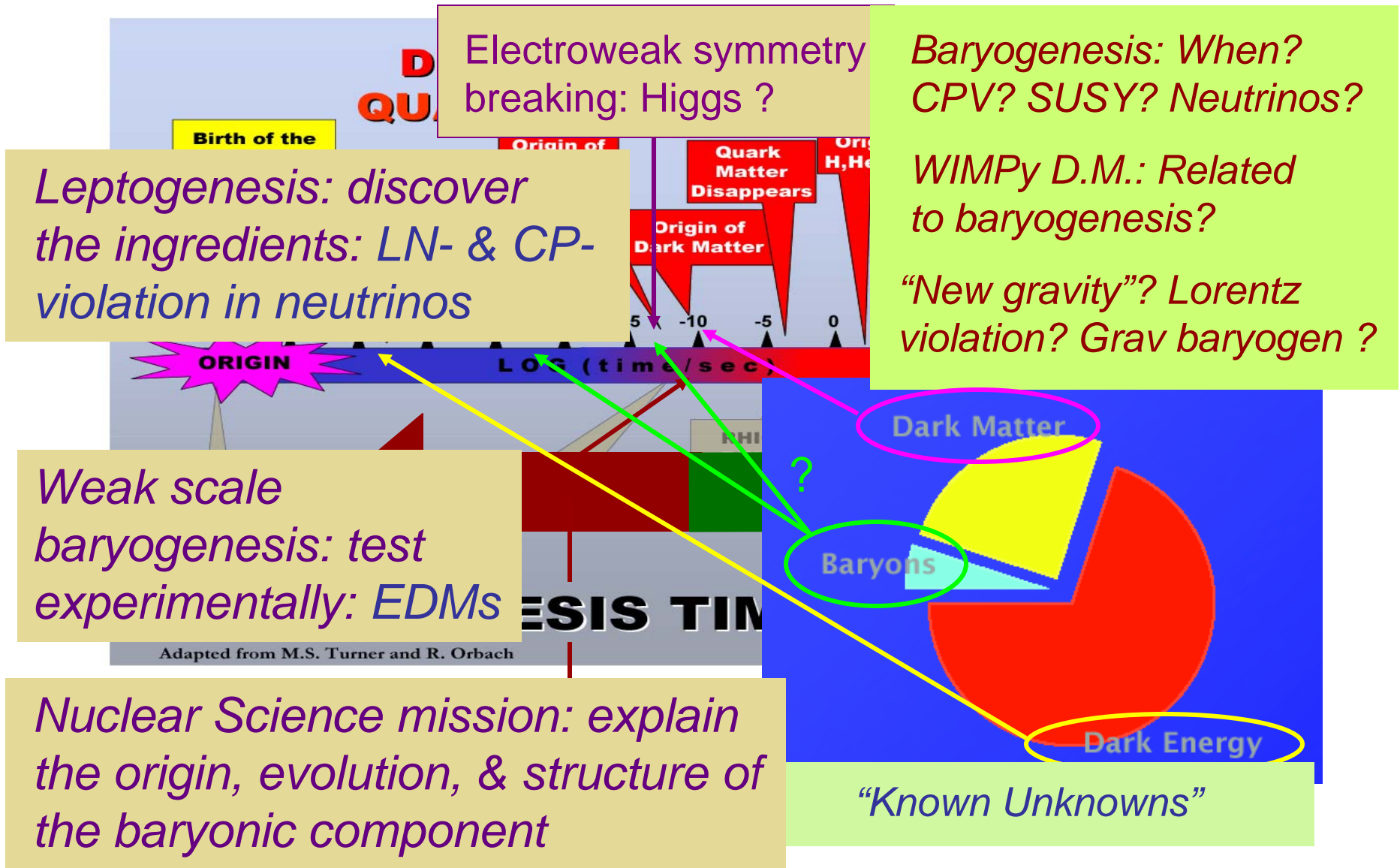


## *Scientific Opportunities*

- *Major Discovery Potential:* ←  
 *$0\nu\beta\beta$ -decay & EDM*
- *Precision measurements* ←  
*Neutrino mixing & hierarchy*  
*Weak decays, PVES,  $g_{\mu}^{-2}$*
- *Electroweak probes of QCD*  
*PVES, Hadronic PV,  $\nu N$  scatt...*

# The Origin of Matter & Energy



# $0\nu\beta\beta$ -Decay: LNV? Mass Term?

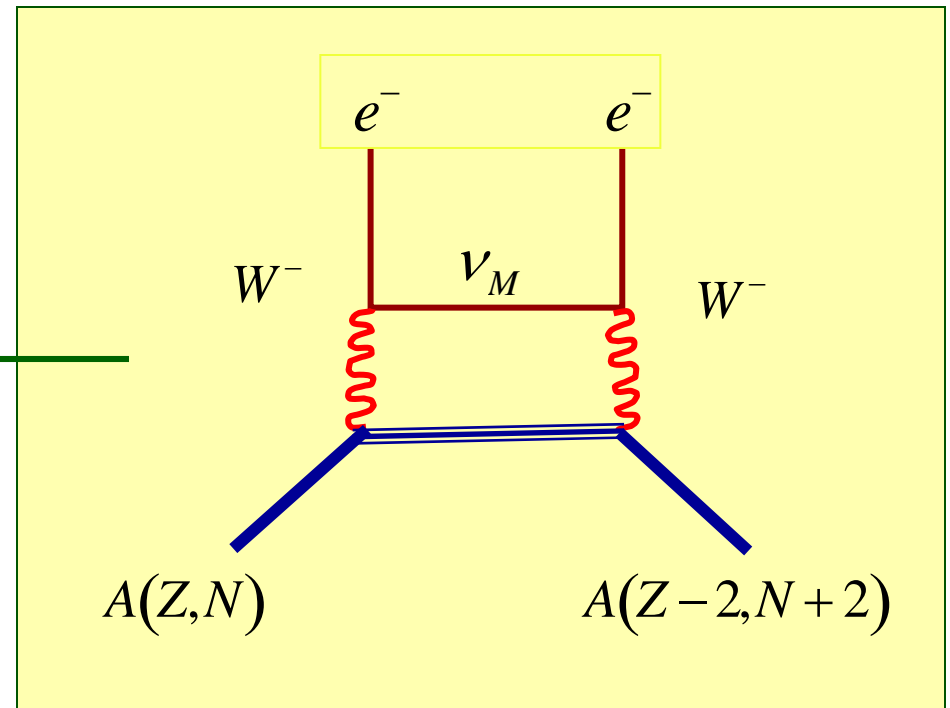
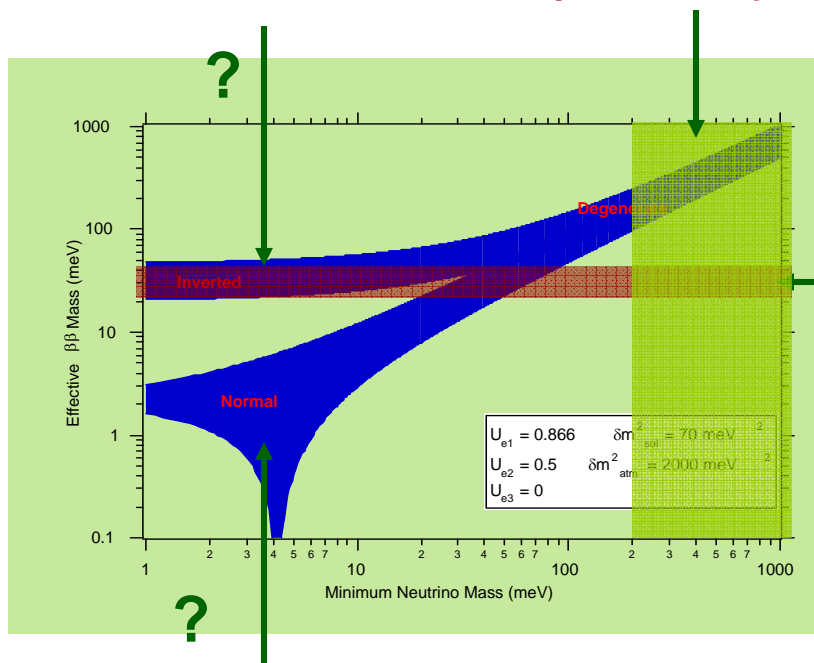
$$\mathcal{L}_{mass} = y\bar{L}\tilde{H}\nu_R + h.c.$$

*Dirac*

$$\mathcal{L}_{mass} = \frac{y}{\Lambda}\bar{L}^c\tilde{H}\tilde{H}^T L$$

*Majorana*

*Long baseline*       *$\beta$ -decay*



# EDM Probes of New CP Violation

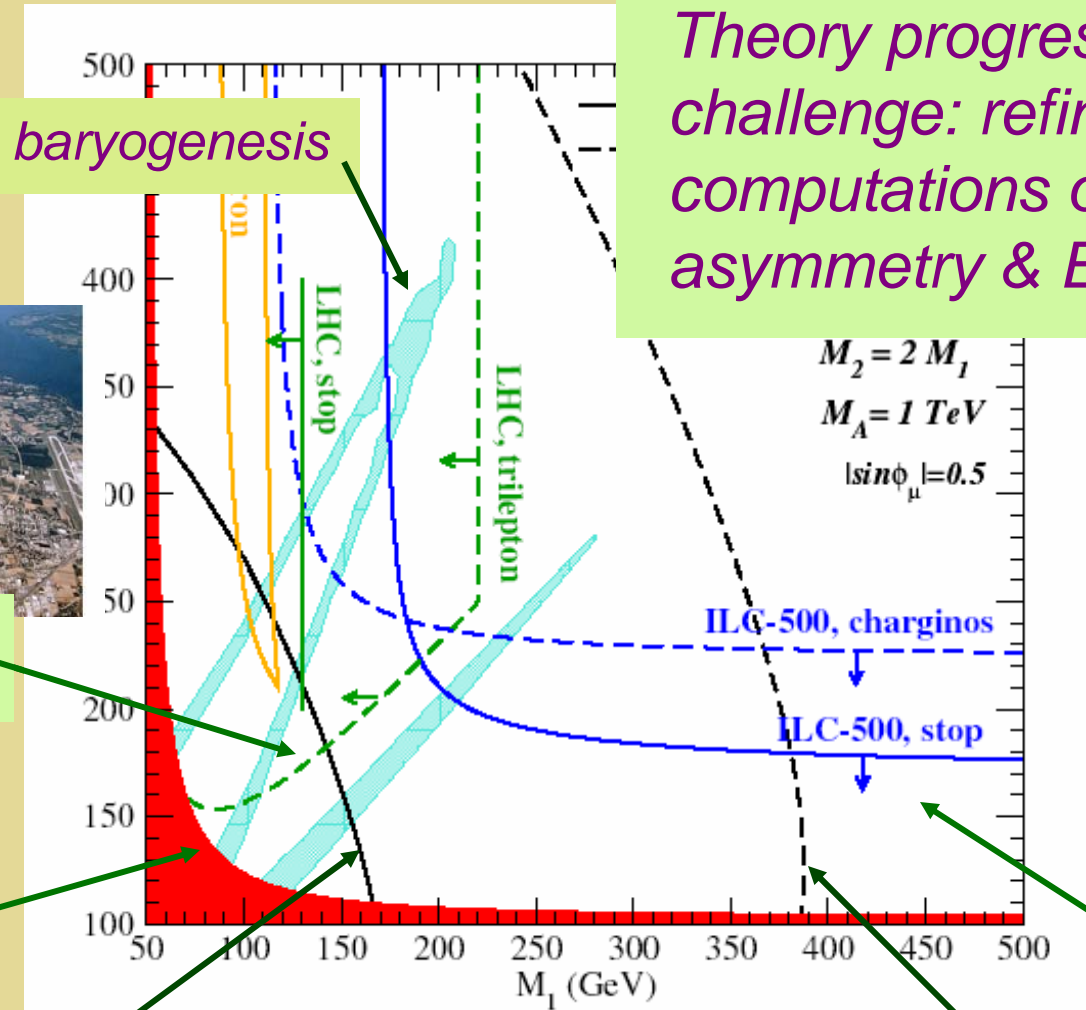
$f$	CKM	$d_{\text{CKM}}$	$d_{\text{new}}$	$d_{\text{future}}$
$e^-$	←	$\sim 10$	$\sim 1.0 \times 10^{-27}$	$\rightarrow 10^{-31}$
$n$	←	$\sim 10^{-33}$	$3.0 \times 10^{-26}$	$\rightarrow 10^{-29}$
$^{199}\text{Hg}$		$\sim 10^{-33}$	$\sim 1.0 \times 10^{-28}$	$\rightarrow 10^{-32}$
$\mu$				$\rightarrow 10^{-24}$

*Yale, Indiana, Amherst*  
*SNS, ILL, PSI*  
*ANL, Princeton, TRIUMF...*

Also  $^{225}\text{Ra}$ ,  $^{129}\text{Xe}$ ,  $d$  ← BNL

If new EWK CP violation is responsible for abundance of matter, will these experiments see an EDM?

# Baryogenesis: EDMs & Colliders



Theory progress & challenge: refined computations of baryon asymmetry & EDMs

LHC reach

LEP II excl

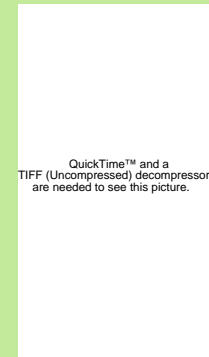
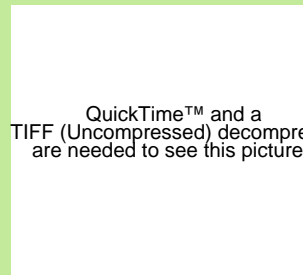
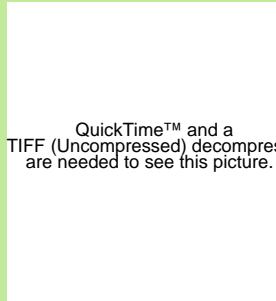
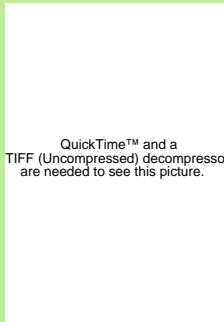
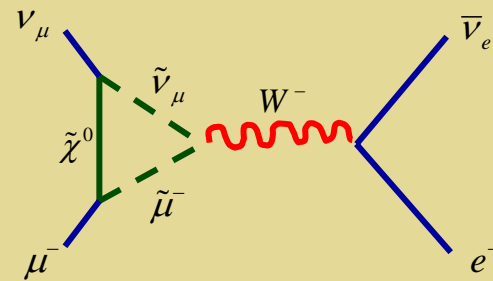
Present  $d_e$

$d_n$  similar

Prospective  $d_e$

ILC reach

# Precision Probes of New Symmetries

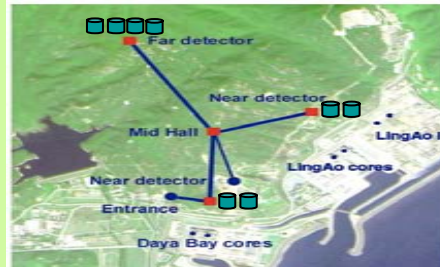


# Precision Neutrino Property Studies

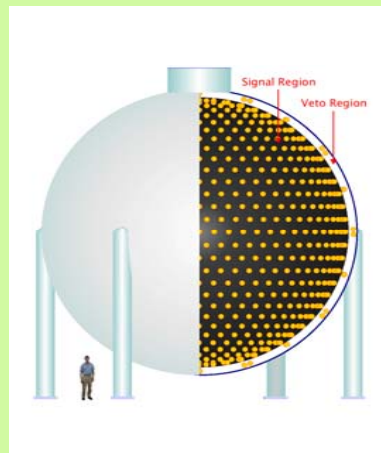
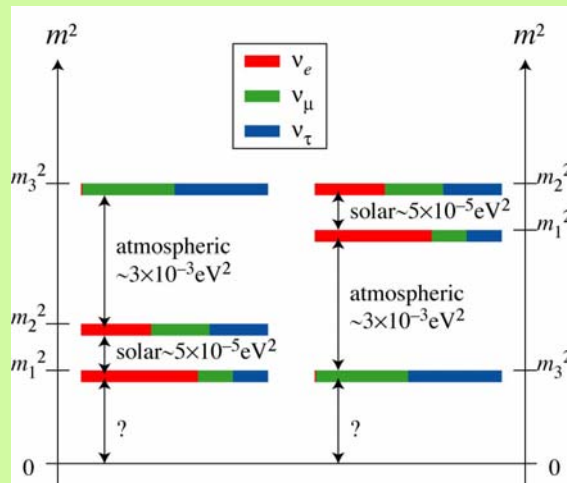
Mixing, hierarchy, & CPV

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}} \sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}} \sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}$$



Daya Bay



Mini Boone

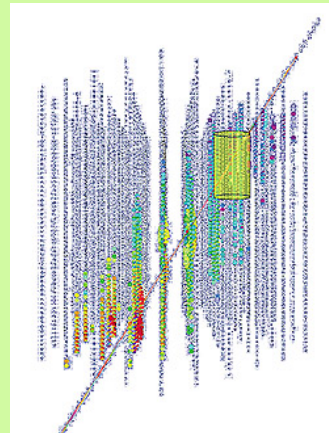
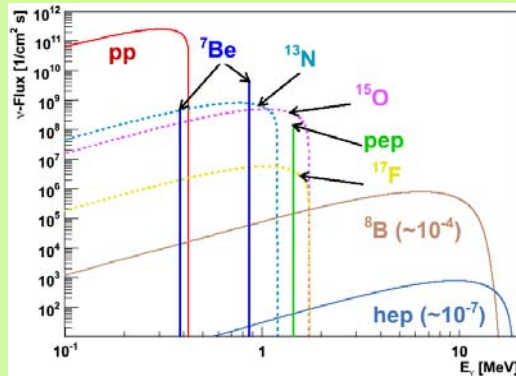
Long baseline oscillation studies:

CPV?

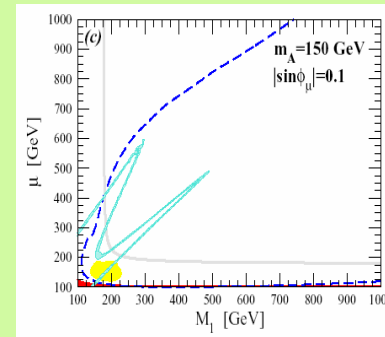
Normal or Inverted ?

# Precision Neutrino Property Studies

## Solar Neutrinos

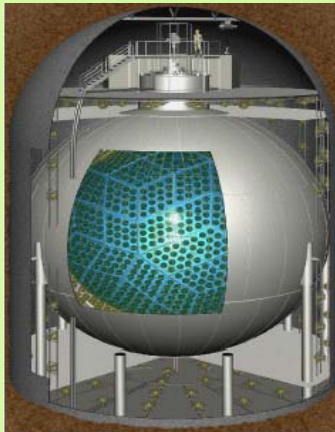


## High energy solar $\nu$ s $\chi^0 + \chi^0 \rightarrow Z^* \rightarrow \nu\bar{\nu}$



**DM +  
EWB**

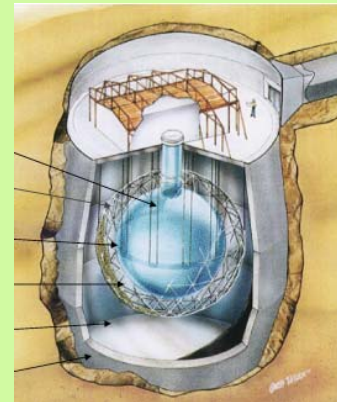
## Ice Cube



**KamLAND**



**Borexino**



**SNO+**



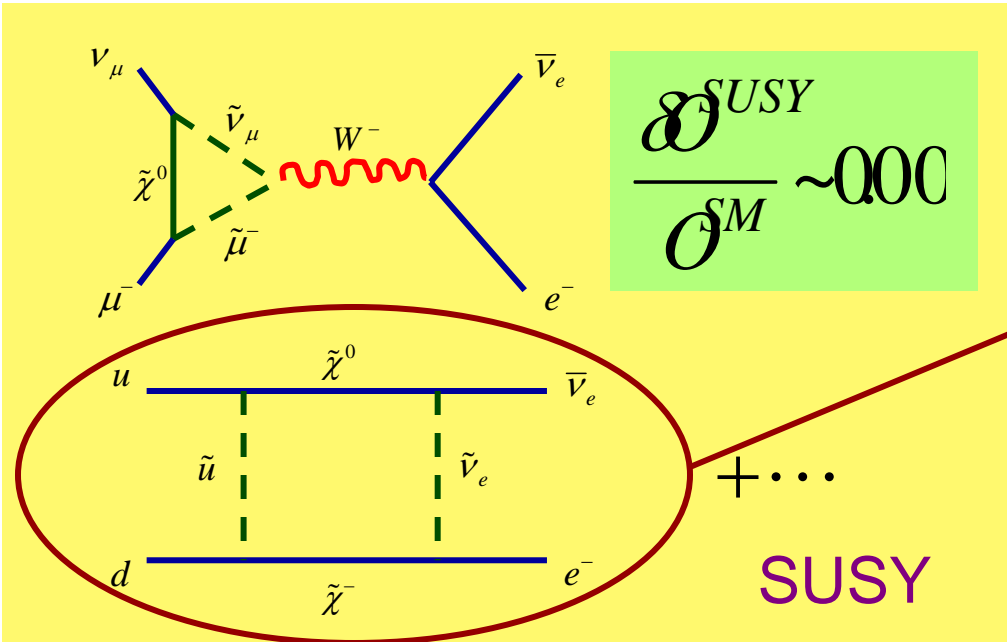
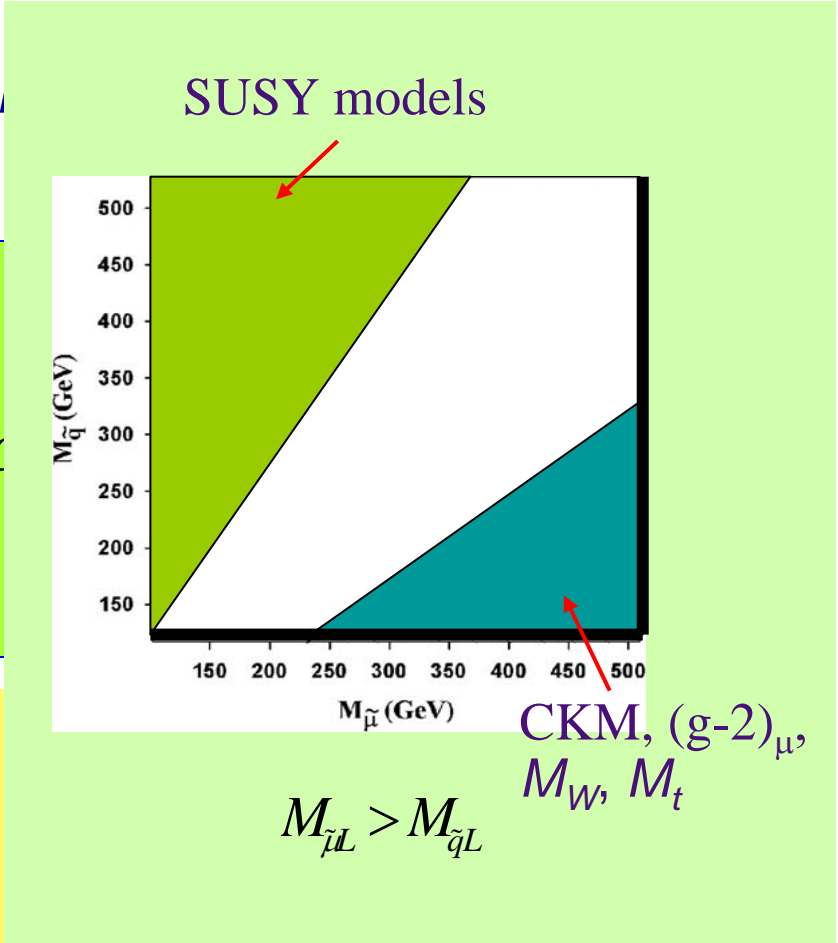
**LENS**



# Weak decays & new p

$$\begin{aligned}
 d &\rightarrow u e^- \bar{\nu}_e \\
 s &\rightarrow u e^- \bar{\nu}_e \\
 b &\rightarrow u e^- \bar{\nu}_e
 \end{aligned}$$

(u c

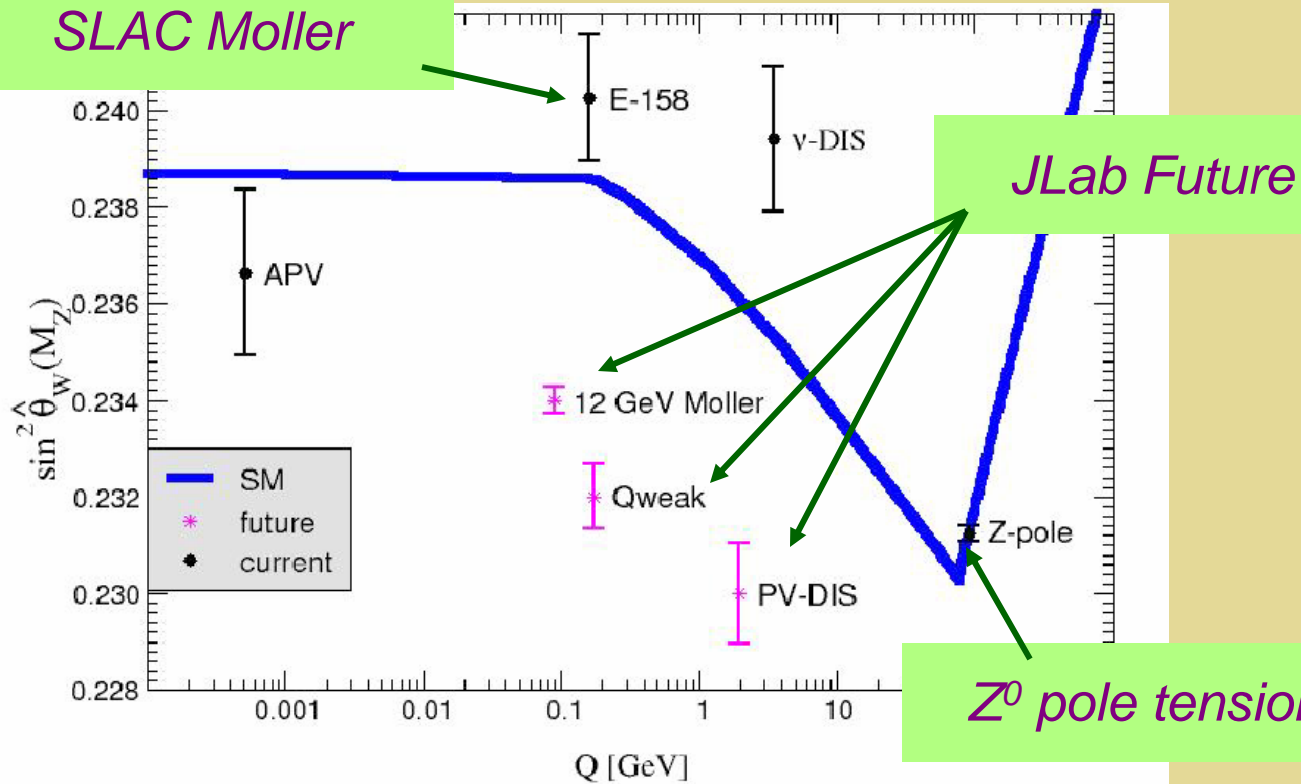


Similarly unique probes of  
 new physics in muon and  
 pion decay

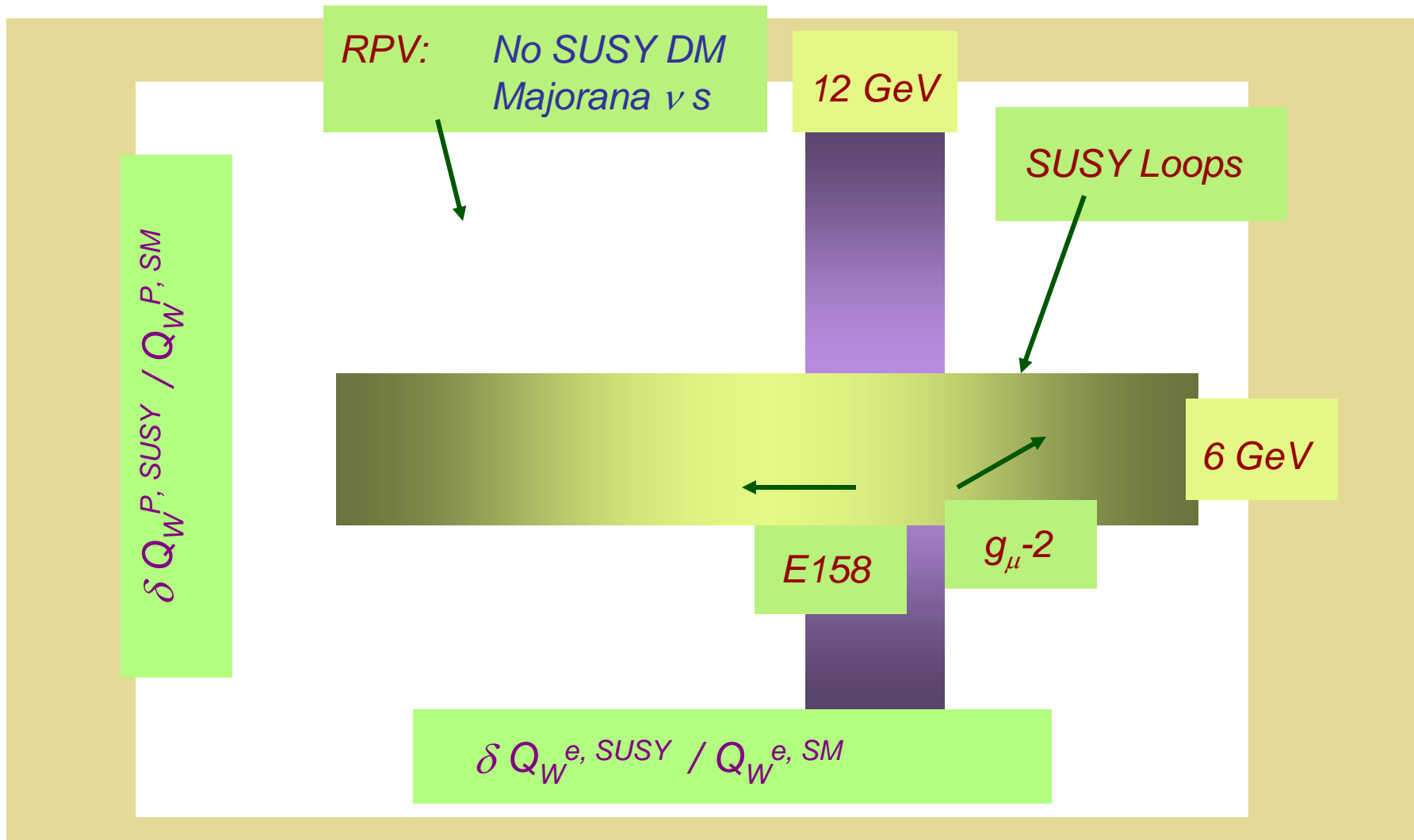
TRIUMF & PSI

# Weak Mixing in the Standard Model

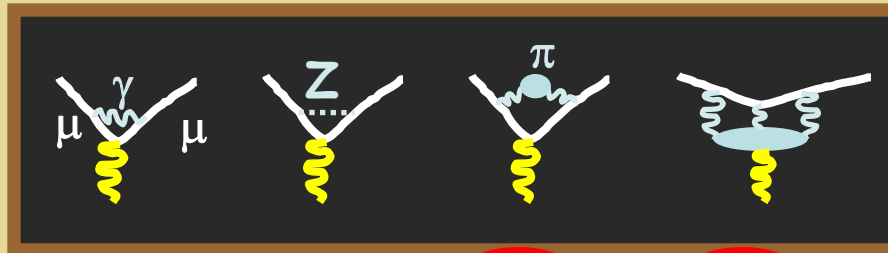
Parity-violating electron scattering



# Probing SUSY with PV Electron Scattering



# Muon Anomalous Magnetic Moment



QED

Weak

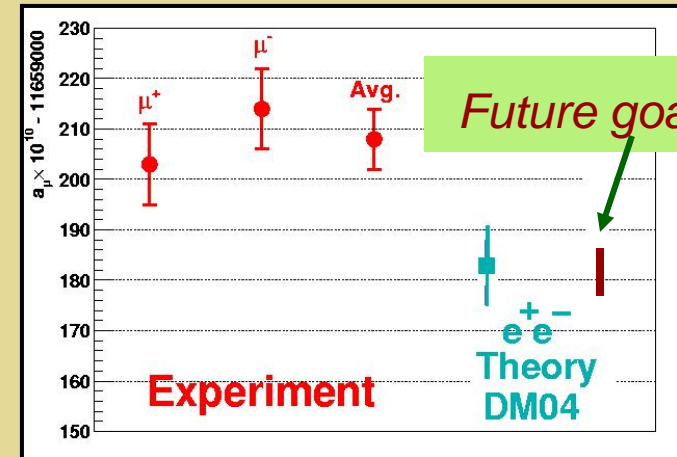
Had  
VP

Had  
LbL

*SM Loops*

QuickTime™ and a  
TIFF (LZW) decompressor  
are needed to see this picture.

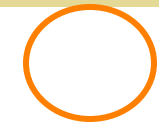
*SUSY Loops*



*Future goal*

**Experiment**

**Theory  
DM04**



QuickTime™ and a  
TIFF (LZW) decompressor  
are needed to see this picture.

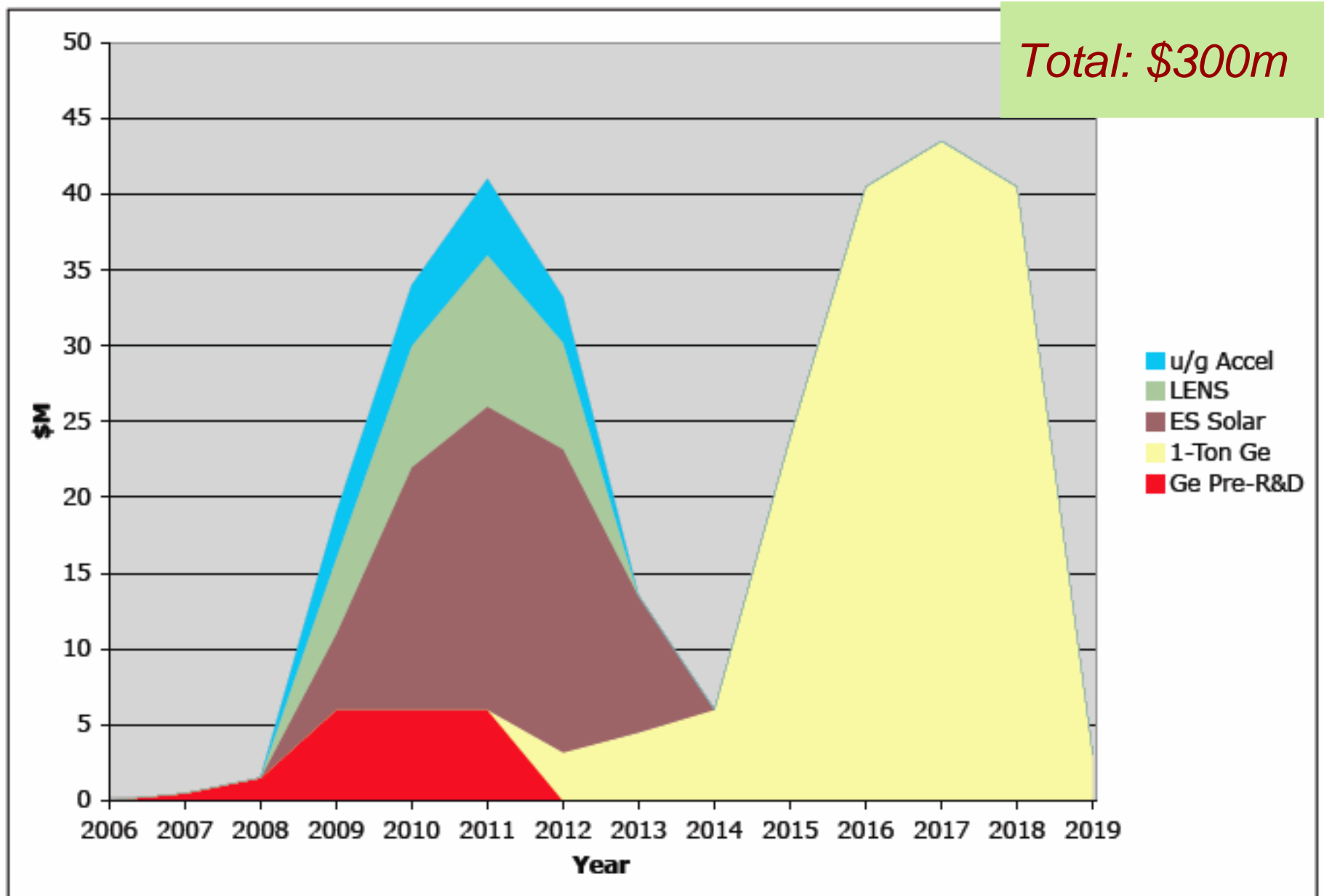
# *Recommendations*

- (1) The highest priority of this White Paper is the DUSEL including its complement of experiments. We strongly recommend beginning immediate support for a suite of  $0\nu\beta\beta$ -decay efforts in view of the importance of the physics and the time required to obtain the result.
- (2) We strongly recommend capital investment in, and support for, the nEDM experiment at the FNPF. We also recommend support for searches for rare-isotope EDMs and R&D toward a storage-ring based deuteron EDM measurement.
- (3) We strongly recommend a targeted program of precision electroweak studies at facilities such as FNPF, JLab, LANSCE, NIST, and BNL. Present and future opportunities having unique sensitivities to new physics include measurements of the muon anomaly, neutron decay parameters, and polarized electron scattering asymmetries.
- (4) We recommend a unified experimental and theoretical program in nuclear physics to construct a standard supernova neutrino model to understand how elements are produced in these explosions, and to develop a secure foundation from which to investigate other astrophysical cataclysmic events, such as gamma-ray bursts.
- (5) We recommend support for nuclear physicists involved in interdisciplinary efforts such as measurements of the neutrino mixing angle  $\theta_{13}$  through reactor and long-baseline experiments, direct and indirect searches for dark matter and sensitive tests of charged lepton flavor violation.
- (6) Substantially increased support for nuclear theory is critical to realizing the outstanding scientific opportunities in neutrinos and fundamental symmetries. The recommendations of the 2003 NSAC Report on Nuclear Theory should be implemented, with a particular focus on recruiting, nurturing and supporting young scientists in this field.

# *Resources*



# DUSEL Funding Candidates







# Resources

*Equivalent to a major new initiative:*

*“New Standard Model Initiative” (NSMI)*

- *~ \$750m over 10+ years*
- *One major new facility (DUSEL)*
- *Targeted program at other facilities*