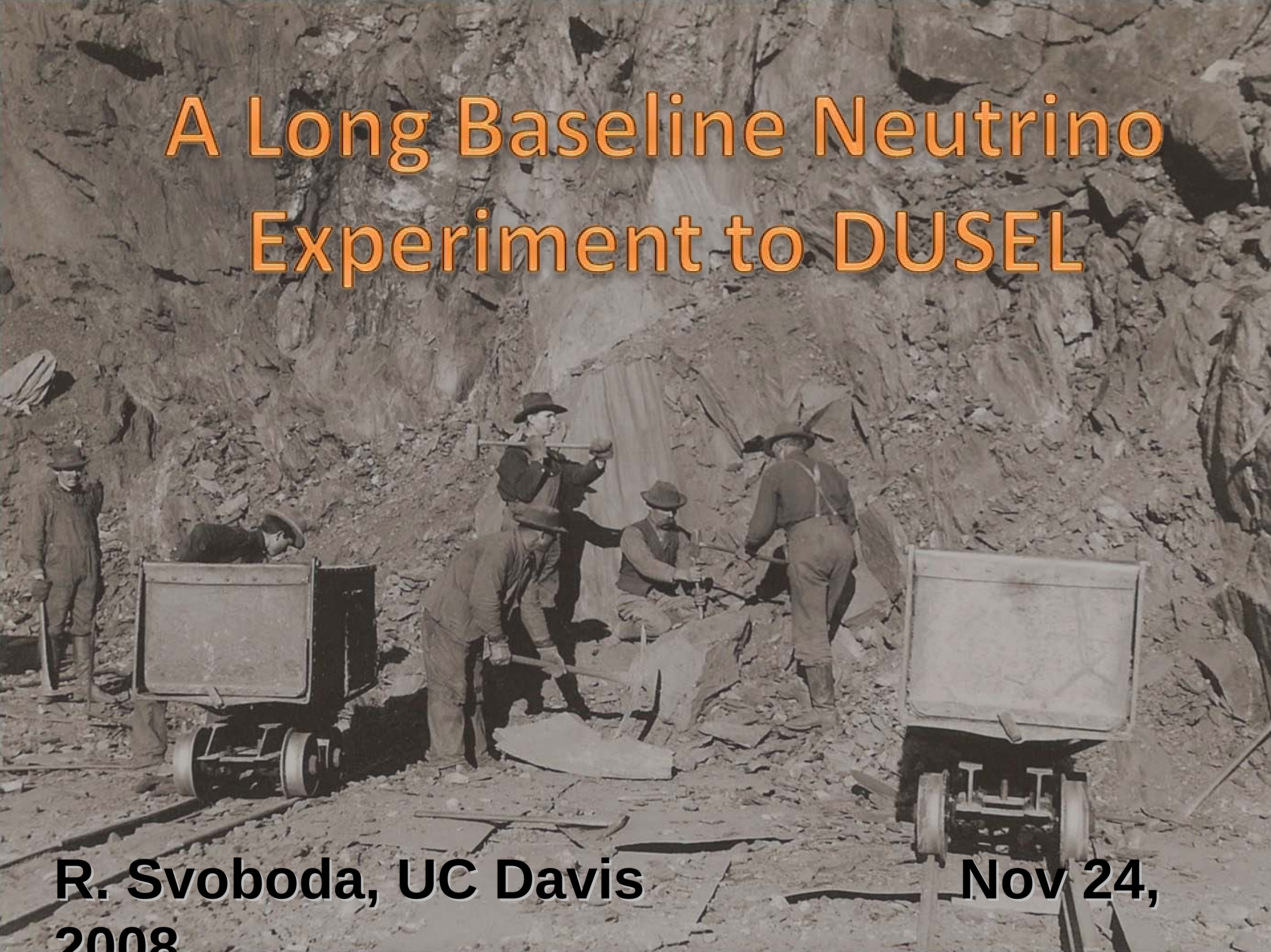
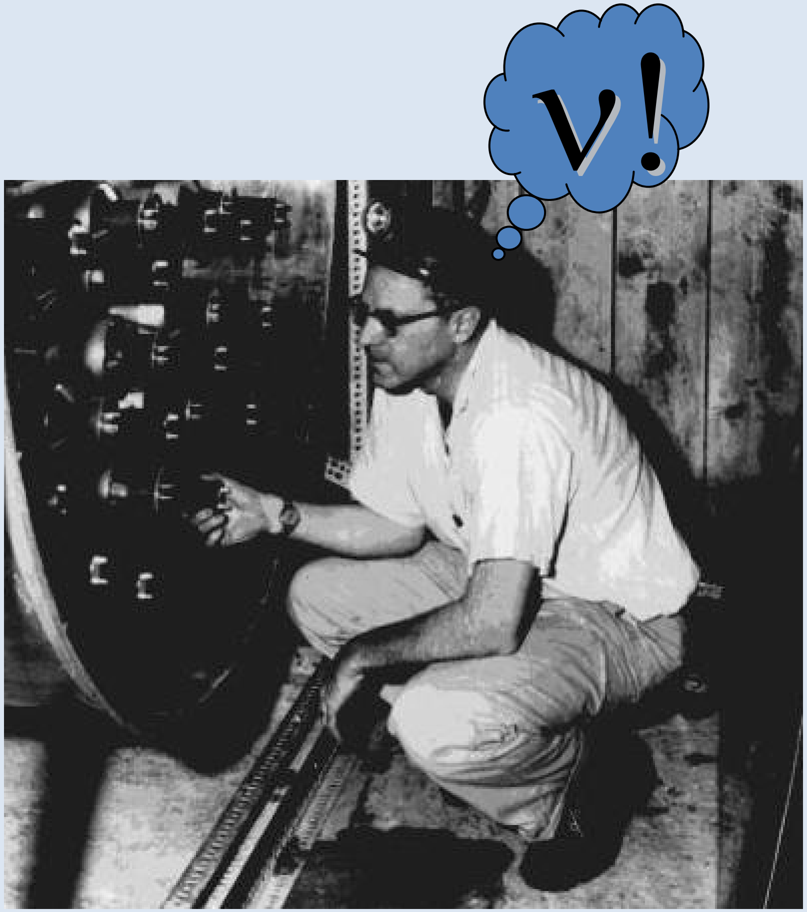
A Long Baseline Neutrino Experiment to DUSEL



R. Svoboda, UC Davis Nov 24, 2008

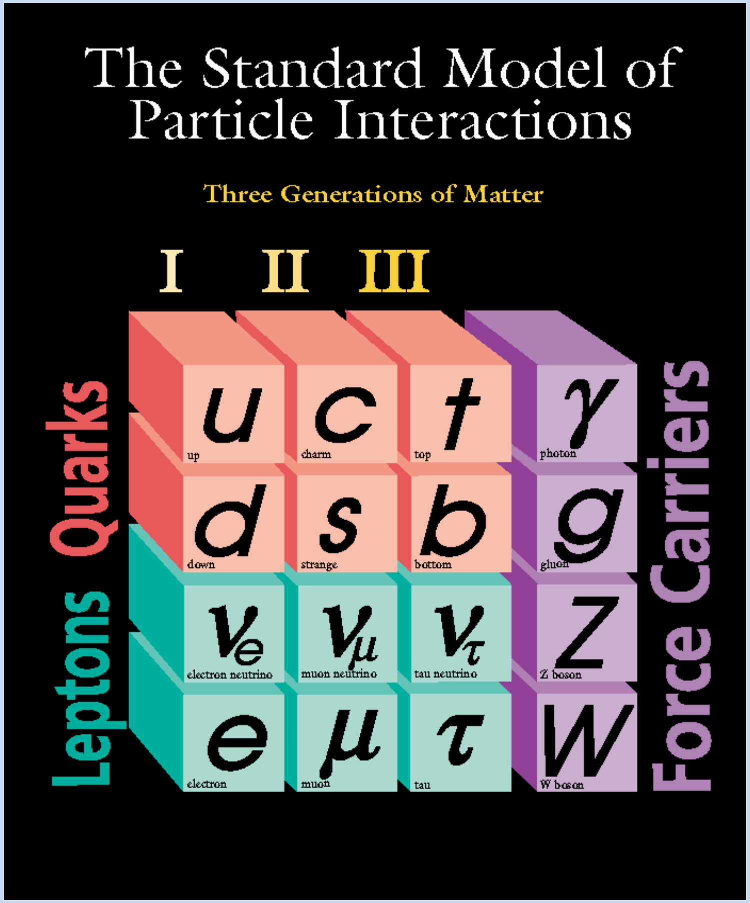

Neutrino Physics
Nucleon Decay
Supernovae

The Mysterious Neutrino

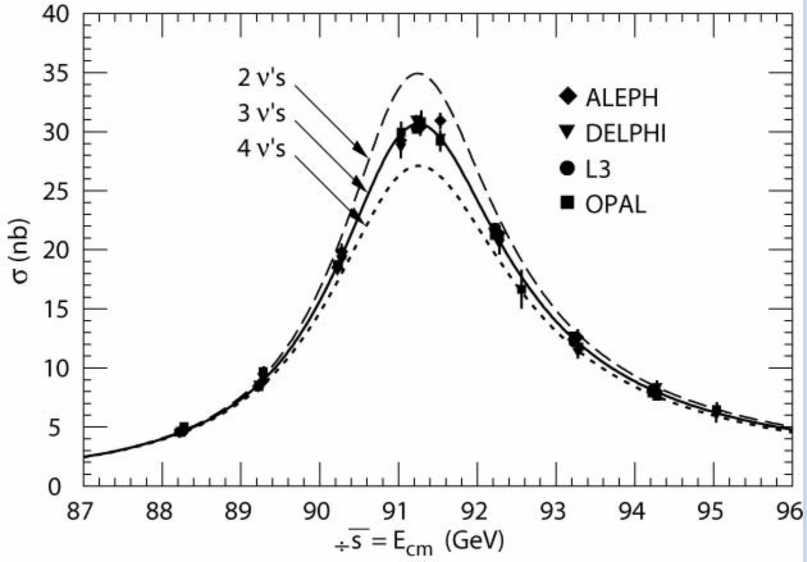


- 1956: Reines and Cowan detect neutrinos coming from the core of a nuclear reactor
- 1962: multiple types
- Nothing more until neutrino oscillations confirmed in 1990’s!

Like Gaul, Neutrinos divided into three types



…but the three types are *not* flavor eigenstates listed in the Particle Data Book



Neutrino Mixing

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

– U: 3 angles, 1 CP-phase + (2 Majorana phases)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric

solar

$s_{ij} = \sin\theta_{ij}$ $c_{ij} = \cos\theta_{ij}$

We now have numbers to put in!

$\theta_{12} \sim 30^o$

$\theta_{23} \sim 45^o$

$$\Rightarrow \begin{pmatrix} 0.9 & 0.5 & s_{13}e^{i\delta} \\ -0.35-0.6s_{13}e^{i\delta} & 0.6-0.35s_{13}e^{i\delta} & 0.7 \\ 0.35-0.6s_{13}e^{i\delta} & -0.6-0.35s_{13}e^{i\delta} & 0.7 \end{pmatrix}$$

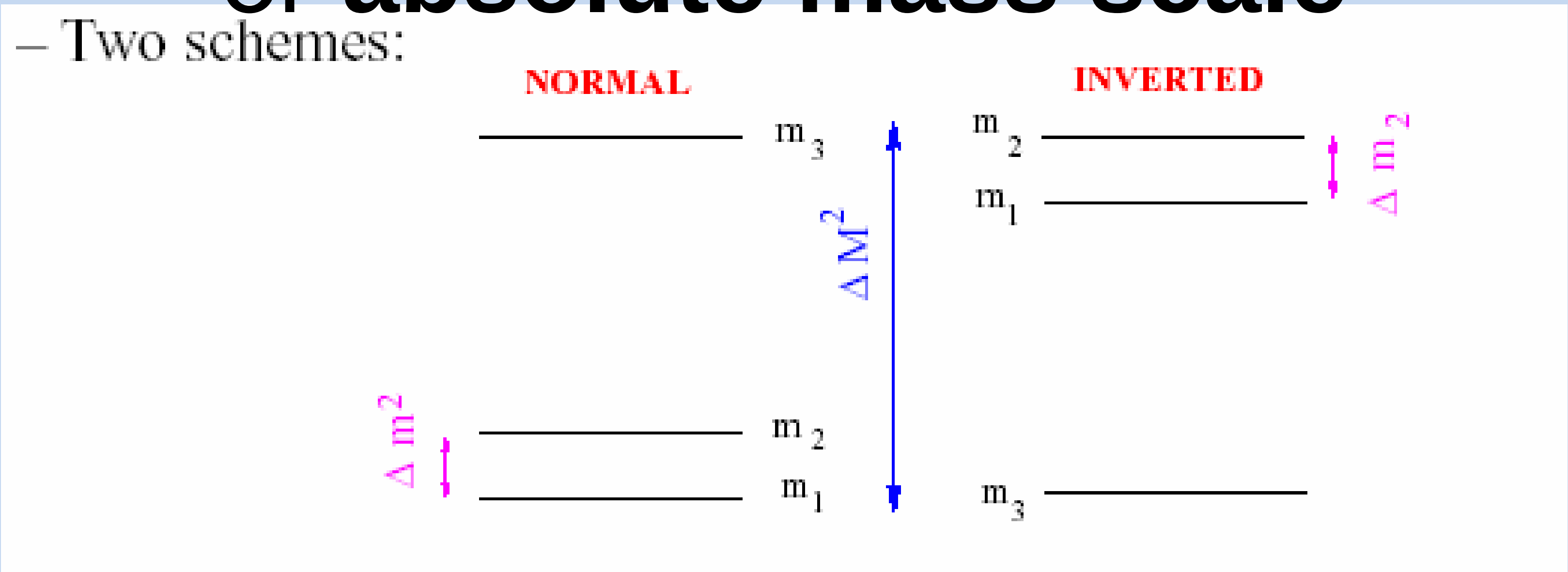
...but δ unknown

$\theta_{13} < 13^o$

$$\Rightarrow \begin{pmatrix} 0.9 & 0.5 & s_{13}e^{i\delta} \\ -0.35 & 0.6 & 0.7 \\ 0.35 & -0.6 & 0.7 \end{pmatrix}$$

U_{e3} is 100% sensitive to the mixing angle θ_{13}

but we don't know the **mass ordering**
or **absolute mass scale**



Do ν's violate CP?

Is θ_{13} non-zero?

Running/New Experiments

- θ_{13} Double Chooz, Daya Bay, Reno; T2K, NOVA
- Δm^2 MINOS, KamLAND, Super-Kamiokande,…
- m_ν KATRIN, MAJORANA, CUORE, …
- θ_{23} OPERA, MINOS, Super-Kamiokande, KamLAND,…
- **CP violation:**
- **Mass Hierarchy:**

Accelerator Experiments

- Signature is electron appearance
  - Requires massive detector with fine granularity (be able to distinguish e from P)
- Backgrounds
  - ν_e in the beam, (~1%, from μ, $K^{\pm}{}_{e3}$, $K^0{}_{e3}$)
  - Fake ν_e from ν_τ, $\tau \rightarrow e$, (at high energy)
  - Showers which look like e's, particularly $\nu N \rightarrow \nu N \pi^0$, $\pi^0 \rightarrow \gamma\gamma$
- Measurement has degeneracies due to CP-violation and matter effects

ν_e appearance in a ν_μ beam

$$P(\nu_\mu \to \nu_e) = (2c_{13}s_{13}s_{23})^2 \sin^2\Phi_{31}$$

$$+8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23})\cos\Phi_{32}\sin\Phi_{31}\sin\Phi_{21}$$

$$-8c_{13}^2 c_{12}^2 c_{23}s_{12}\, s_{13}s_{23}\sin\delta\, \sin\Phi_{32}\sin\Phi_{31}\, \sin\Phi_{21}$$

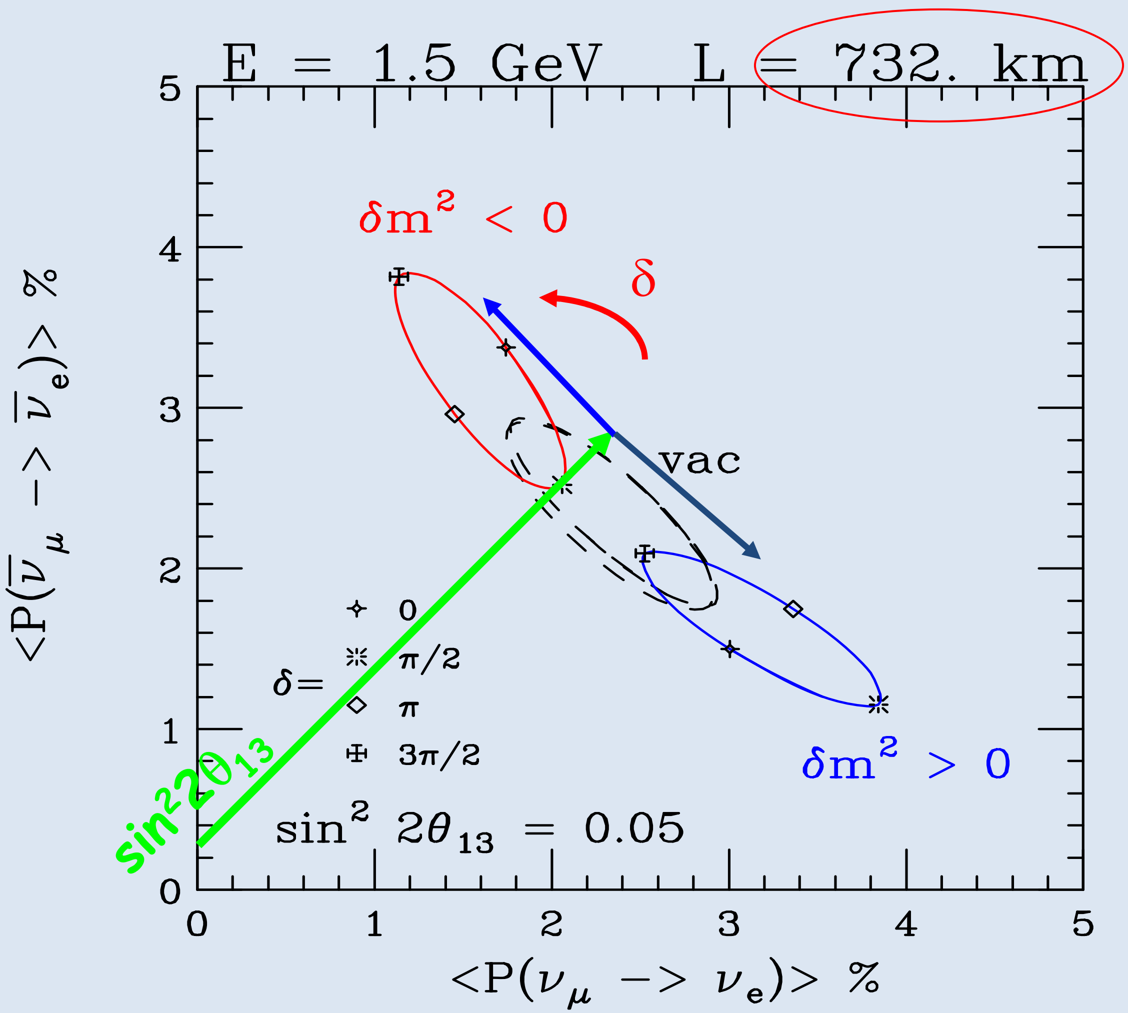
$$+4s_{12}^2 c_{13}(c_{12}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta)\sin^2\Phi_{21}$$

$$-8c_{13}^2 s_{13}^2 s_{23}^2(1-2s_{13}^2)(aL/4E)\cos\Phi_{32}\sin\Phi_{31}$$

a = constant X $n_e E$

CP: $a \to -a$, $\delta \to -\delta$

There are *Degeneracy Issues*



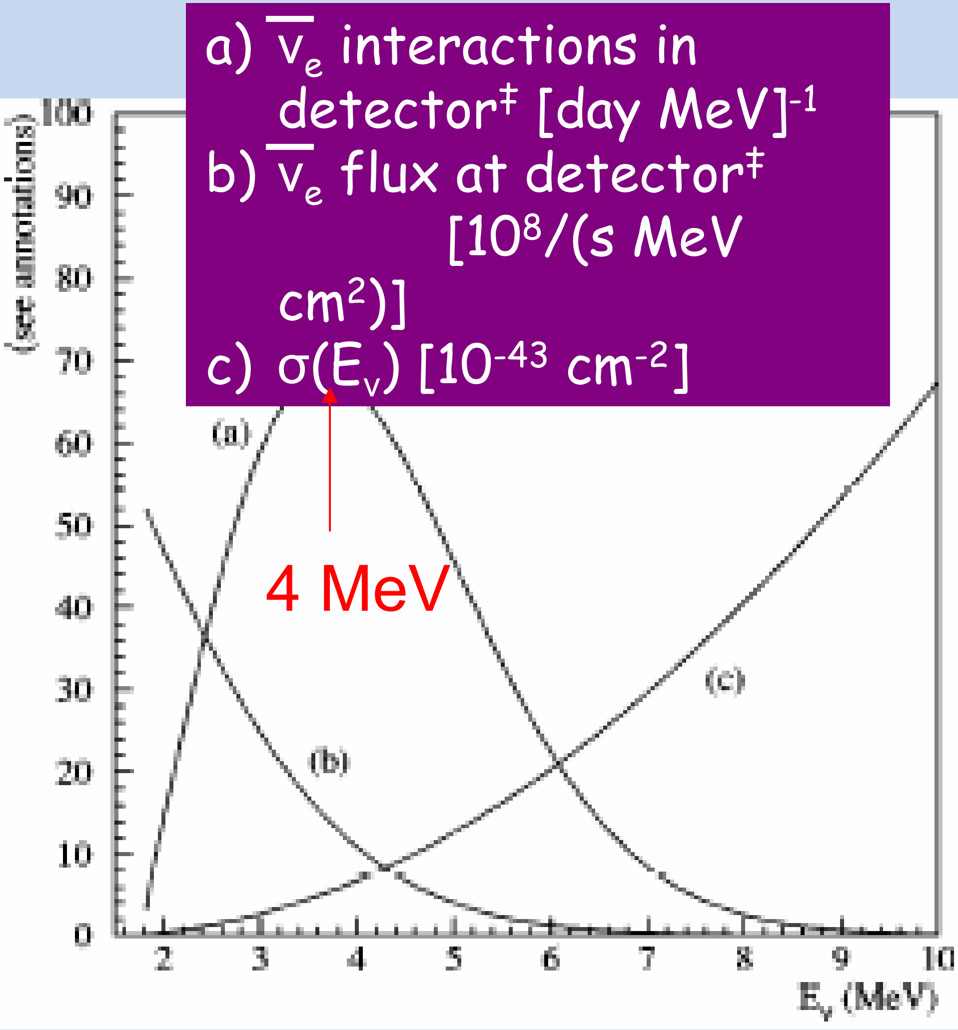
Minakata and Nunokawa, hep-ph/0108085

2 Observables:

- $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- $P(\nu_\mu \rightarrow \nu_e)$

Reactor Experiments

- reactors are an intense "free" source of ν_e
- low energy means distance need only be one or two km
- free of CP and matter effect uncertainties



‡ from Palo Verde

Oscillation Probability (with both Δm^2)

$P(\bar{\nu}_e \to \bar{\nu}_e) = 1$

$- \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2(\Delta m^2_{12} L/4E)$

$- \sin^2 2\theta_{13} \sin^2(\Delta m^2_{atm} L/4E)$

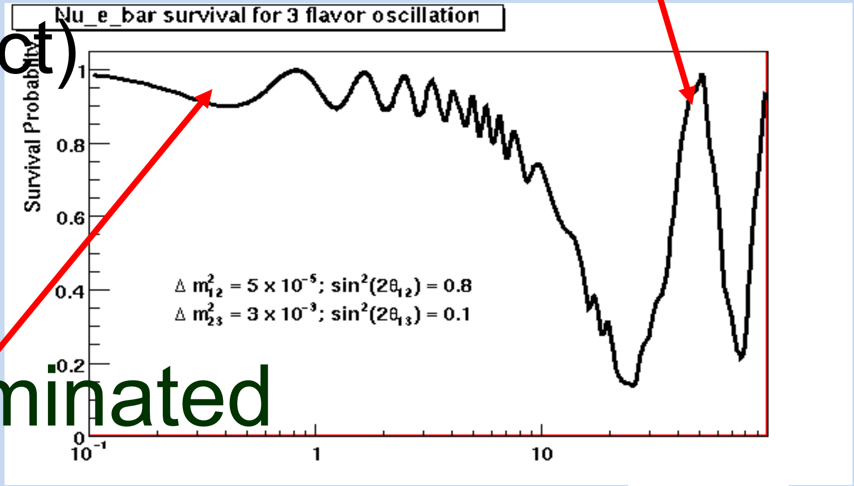
(Ignores tiny matter effect)

$L = pE/(2.54\ \Delta m^2)$

$\sim$ 1-2 km

Δm^2_{12} dominated

P



Δm^2_{23} dominated

L/E(km/MeV)

The Double Chooz Experiment

Univ. of Alabama, ANL,
Univ. of Chicago, Columbia,
U.C. Davis, Drexel Univ.,
Kansas State, Illinois Inst. Tech.,
LLNL, Notre Dame, SNL,
Univ. of Tennessee

CBPF, UNICAMP

Hiroshima Inst. Tech.,
Kobe Univ., Miyagi Univ.,
Niigata Univ., Tohoku Univ.,
Tohoku Gakuin Univ.,
Tokyo Metro. Univ.,
Tokyo Inst. Tech.

APC Univ. of Paris,
SUBATECH (Nantes)
DAPNIA CEA/Saclay

Aachen Univ., Hamburg Univ.,
MPIK Heidelberg, T.U. Munchen
E.K. Univ. Tubingen,

INR-RAS, IPC-RAS,
RRC Kurchatov

CIEMAT Madrid

Univ of Sussex

The experimental site

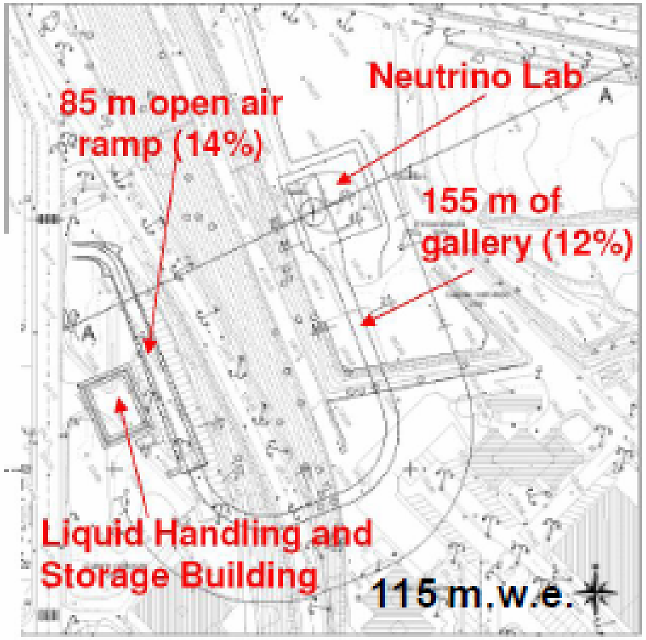
Far detector site status

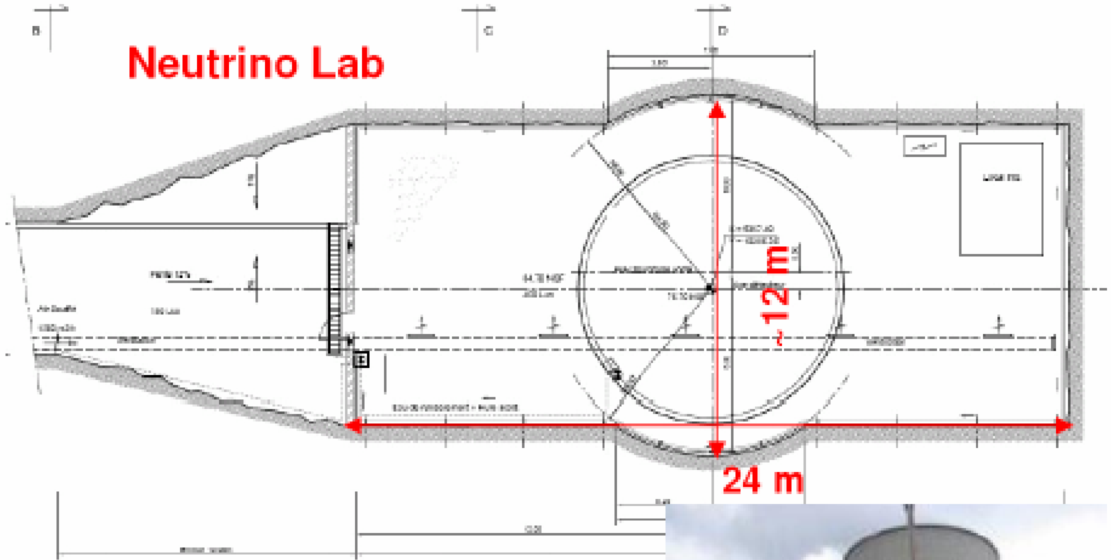
Installation in the Liquid Handling Building has started (6 large storage tanks from TUM)

Civil engineering work has been finished (detector pit refurbished, doors enlarged, new ventilation system, safety system).

Shielding steel bars have been mounted in the pit.

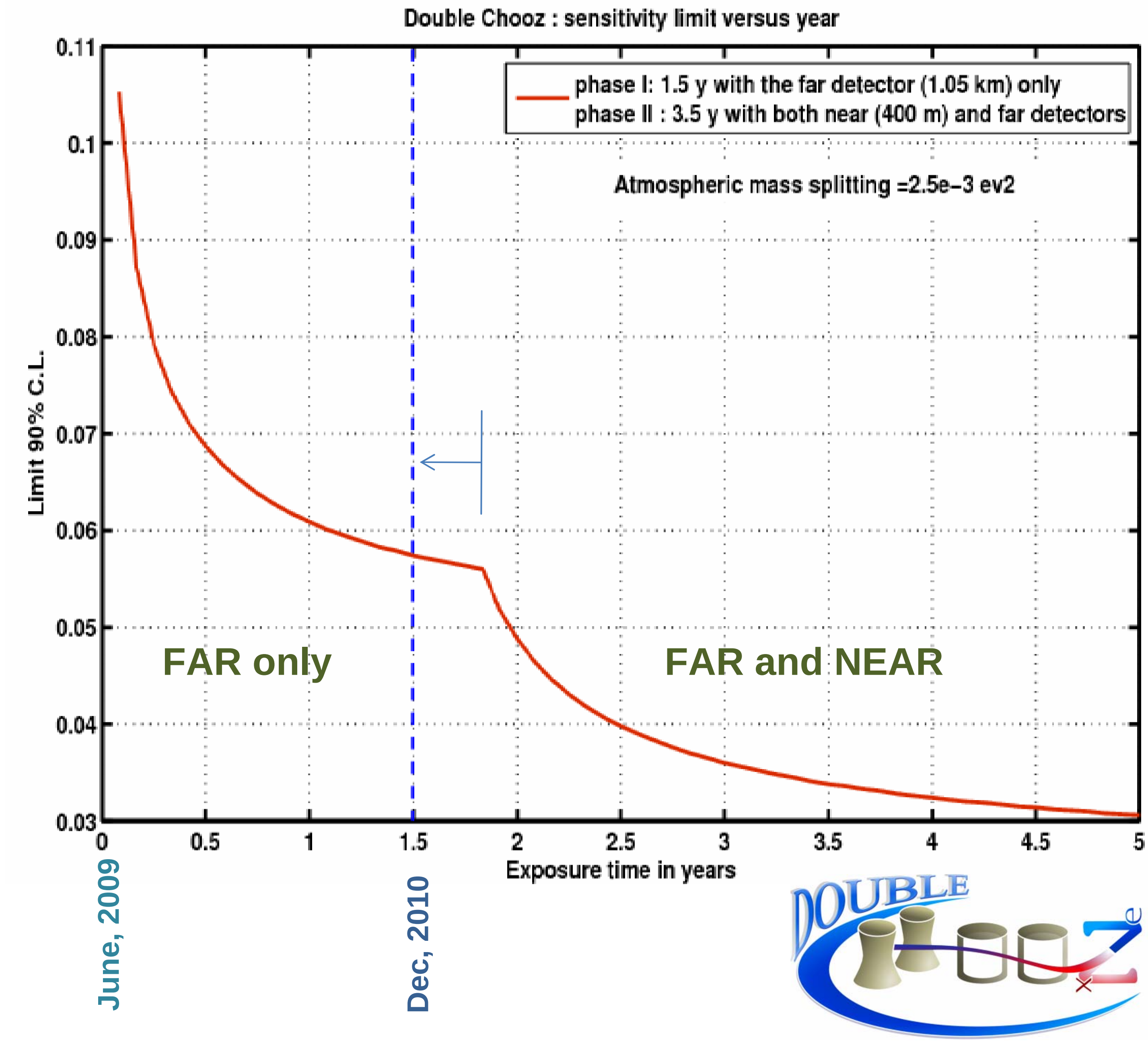
Near detector lab





Site has been chosen with >45m overburden, almost flat topology.

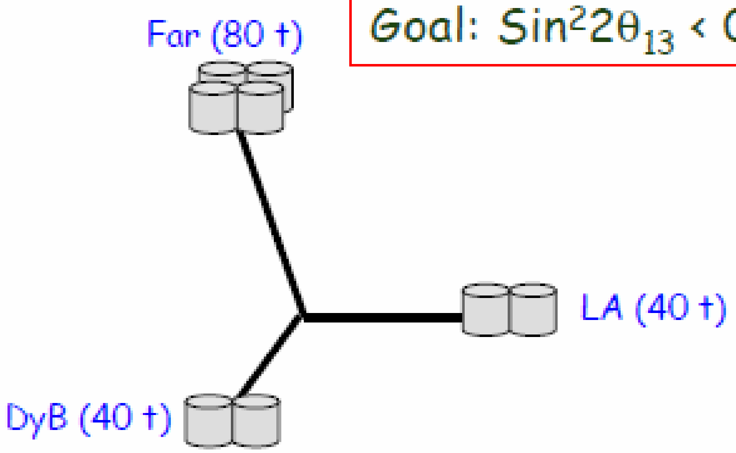
Geological site study completed.
Tender process for construction.
Schedule: lab available end of 2009.

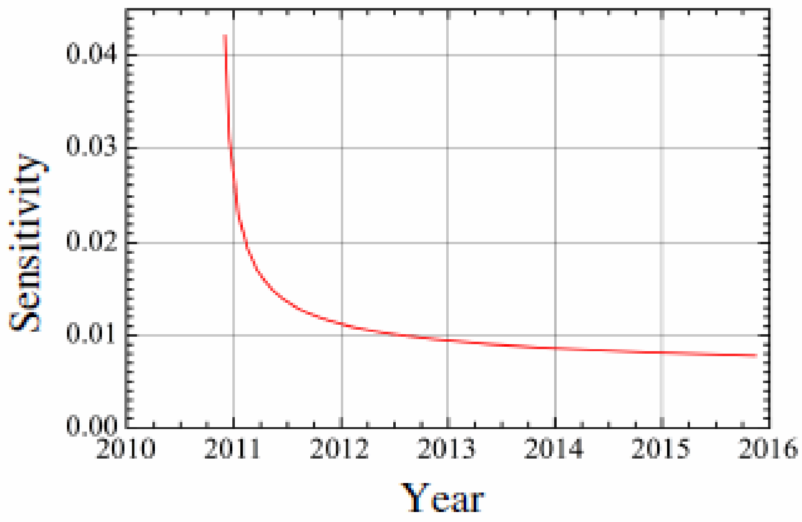

Double Chooz : sensitivity limit versus year
phase I: 1.5 y with the far detector (1.05 km) only
phase II : 3.5 y with both near (400 m) and far detectors
Atmospheric mass splitting =2.5e−3 ev2
Limit 90% C.L.
Exposure time in years
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
FAR only
FAR and NEAR
June, 2009
Dec, 2010

Sensitivity of Daya Bay

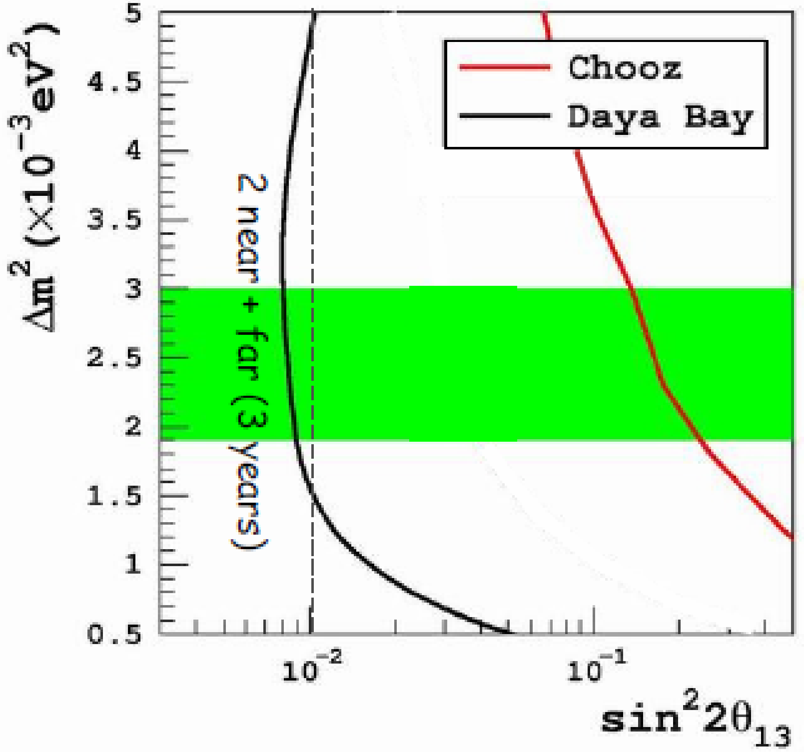
Goal: $\sin^2 2\theta_{13} < 0.01$

- Use rate and spectral shape
- input relative detector syst. error of 0.38%/detector





90% confidence level

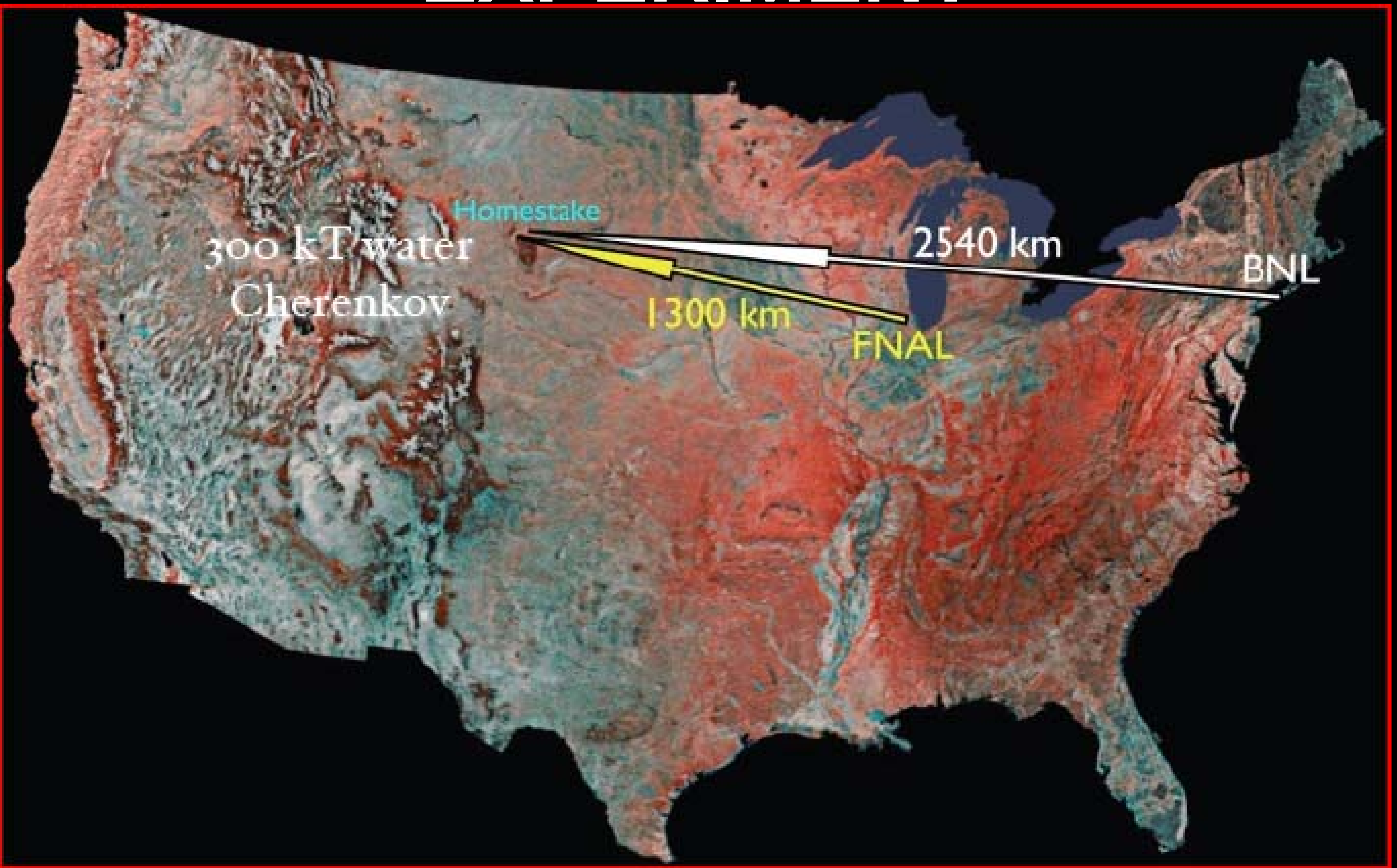



T2K:
The 1st Experiment
with
J-PARC Neutrino Beam
GOAL: θ_{13} to 0.01
295km
J-PARC
Mito
N37°
Fukushima
Honshu
Nagoya
Osaka
Kyoto
Kanazawa
E135°
T2K is aiming for the first results in 2010
with 100kw × 10^7sec integrated proton power on target
to unveil below CHOOZ limit with ν_e appearance

How to improve on CPV and mass hierarchy sensitivity?

- **Get more dirt**
- **get more neutrinos**
- **get a bigger detector**
- **use wide band beam**
- **all of the above**

DUSEL LONG BASELINE EXPERIMENT

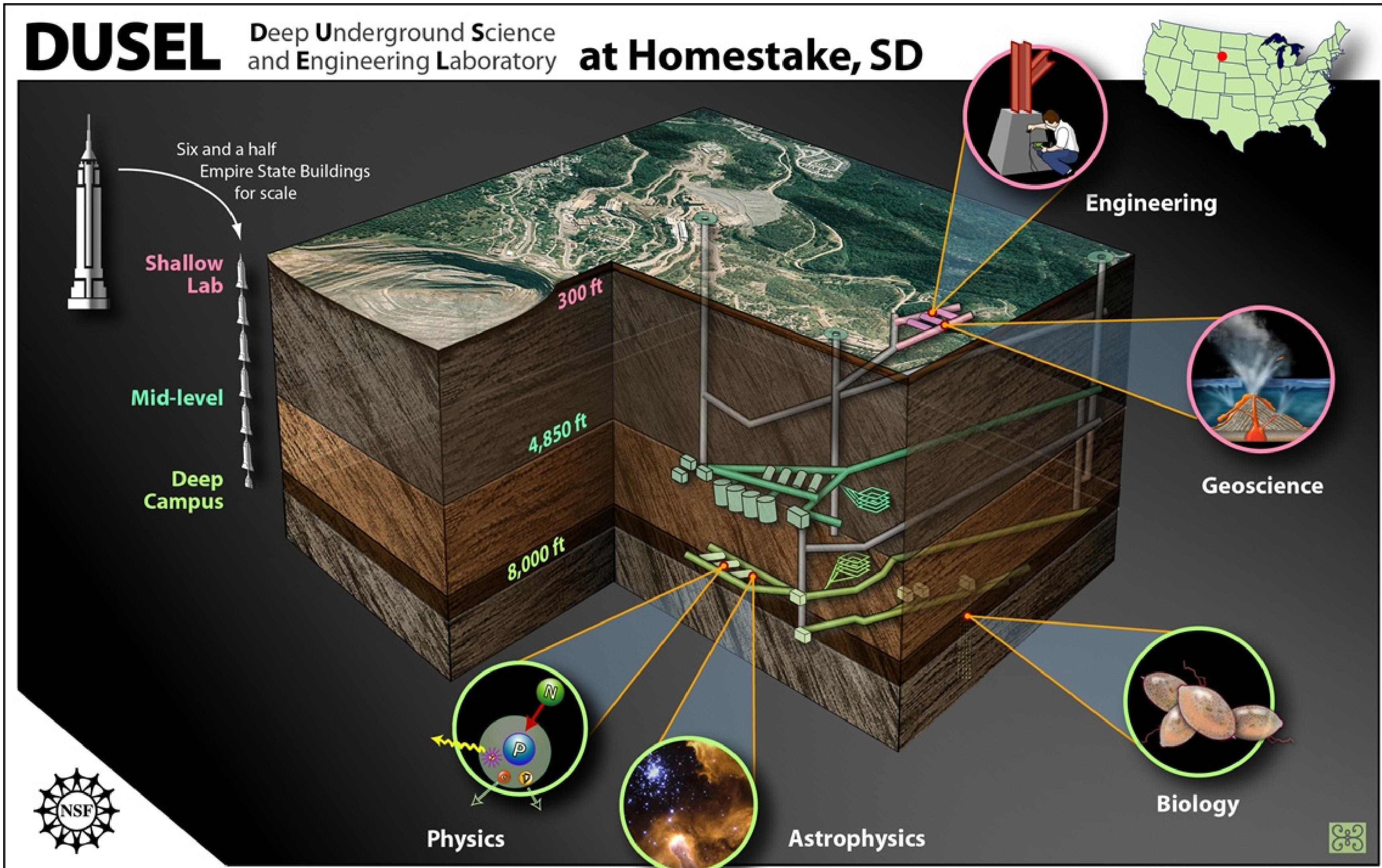


DUSEL Experiment Development and Coordination (DEDC)

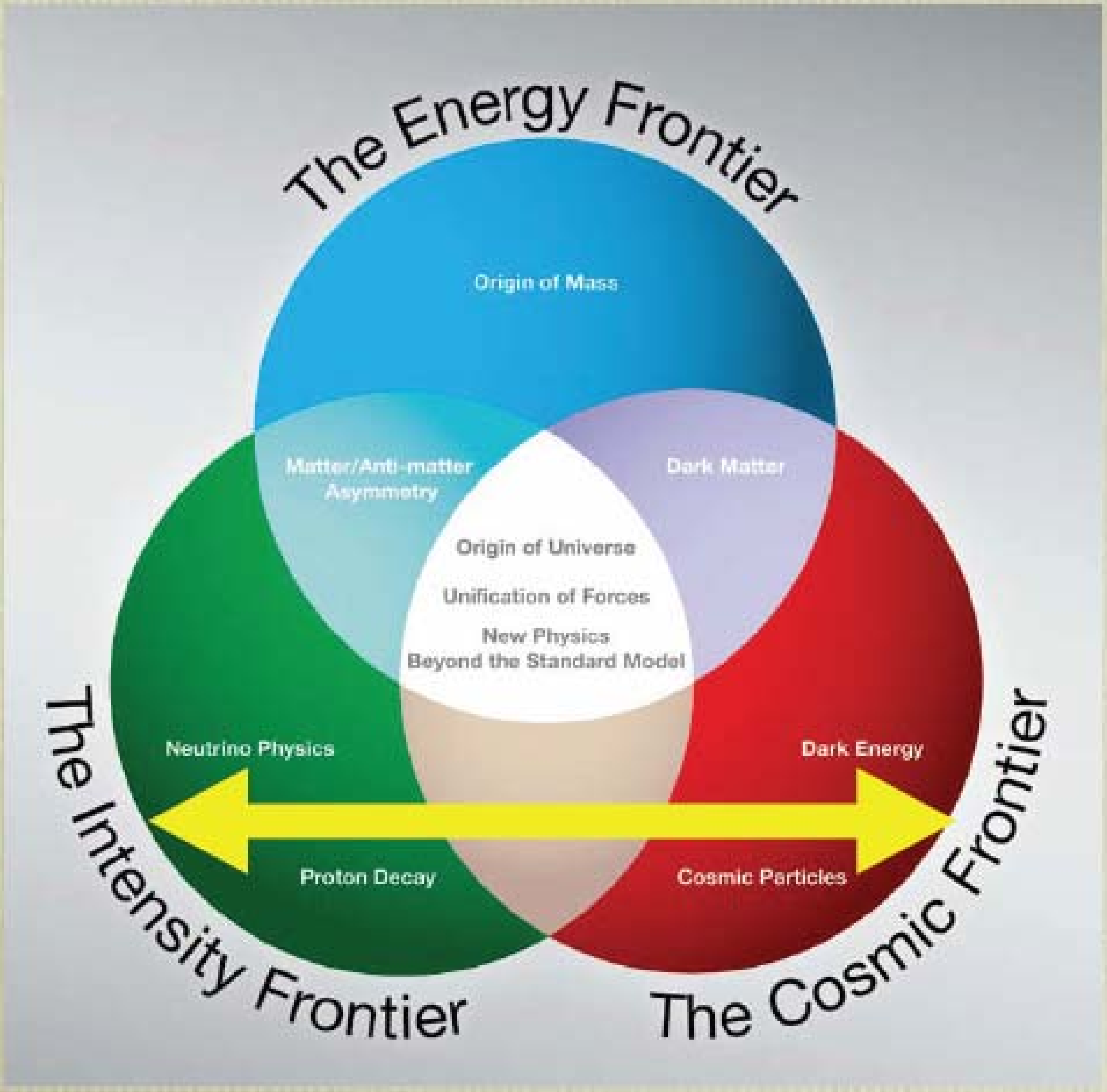
Internal Design Review

July 16-18, 2008

Steve Elliott, Derek Elsworth, Daniela Leitner, Larry Murdoch, Tullis C. Onstott and Hank Sobel



Science



From 2008 P5 report

Complementary to the physics of the energy frontier

Size, neutrino beam intensity, distance: the next step in neutrino physics.

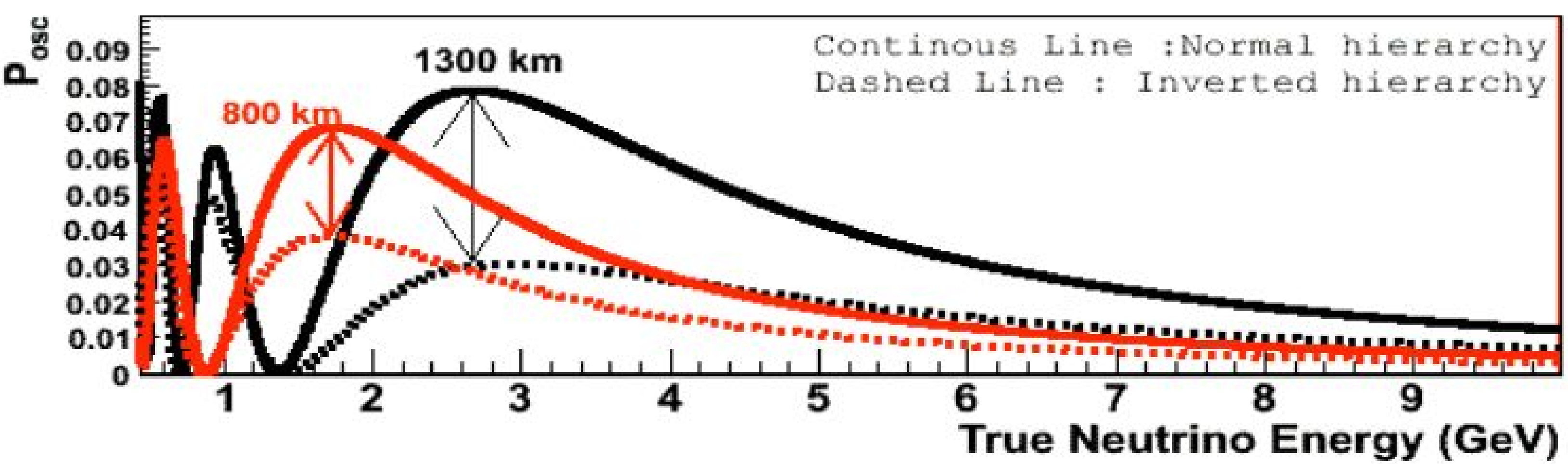
Size gives improved sensitivity to proton decay, our window to the unification of forces.

Depth and low background allows detection of neutrinos from present and past supernova at cosmological distances.

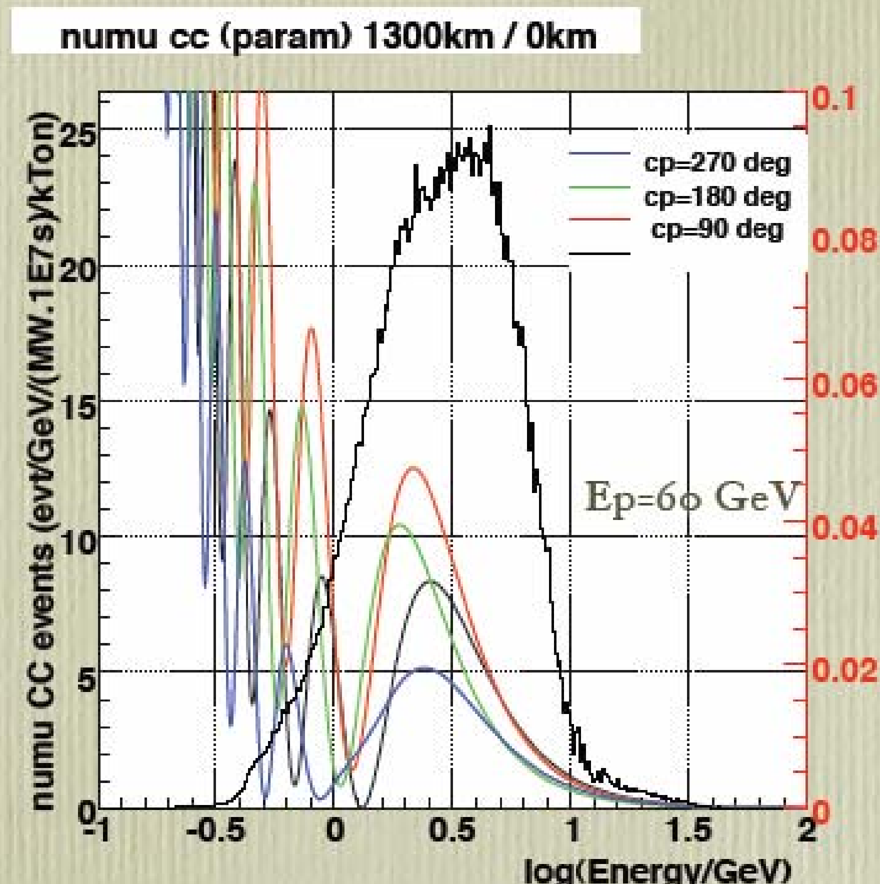
Very large increases to data from known natural neutrino sources: the Sun, and the atmosphere.

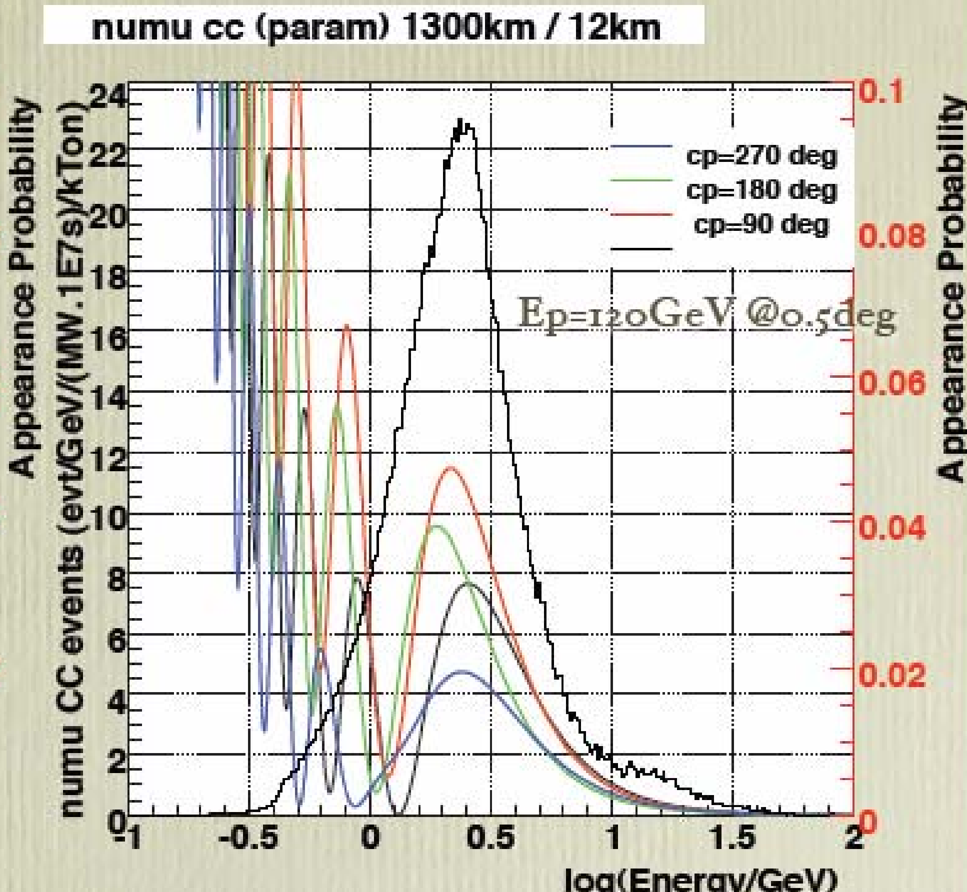
Why DUSEL?

- 1300 km distance is significant for determination of neutrino mass hierarchy
- Deep underground site allows rich physics program in addition to LB neutrinos



Spectra FNAL to DUSEL (WBLE:wide band low energy)





- 60 GeV at 0deg: CCrate: 14 per (kT*10^20 POT)
- 120 GeV at 0.5deg:CCrate: 17 per(kT*10^20POT)

Work of M. Bishai and B. Viren using NuMI simulation tools

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN
NATIONAL LABORATORY

Neutrino Beam Requirements*

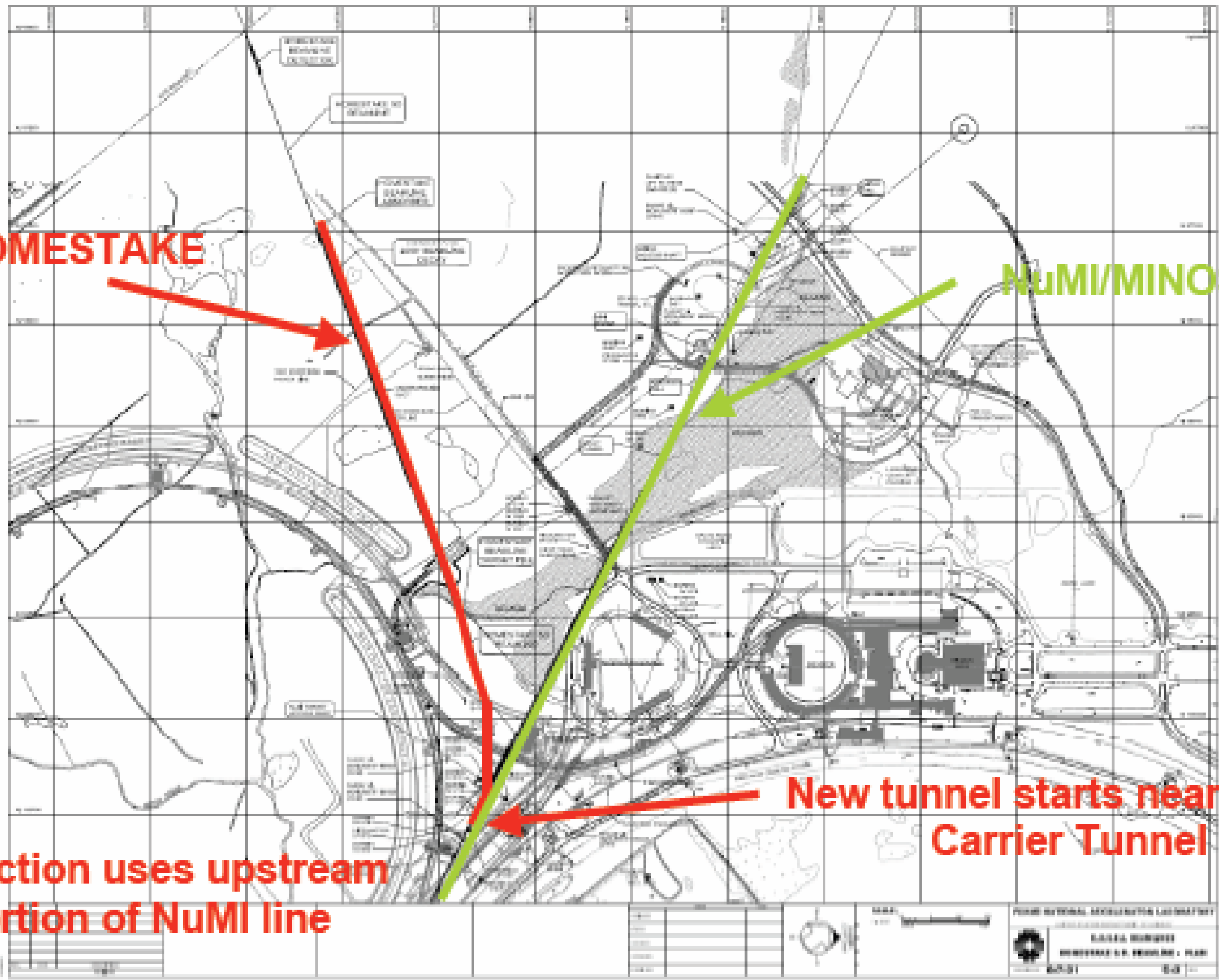
- The maximal possible neutrino fluxes to encompass at least the 1st and 2nd oscillation nodes, which occur at 2.4 and 0.8 GeV respectively
- Since neutrino cross-sections scale with energy, larger fluxes at lower energies are desirable to achieve the physics sensitivities using effects at the 2nd oscillation node
- To detect $\nu_\mu \rightarrow \nu_e$ at the far detector, it is critical to minimize the neutral-current contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV where there is little sensitivity to the oscillation parameters is highly desirable
- The irreducible background to $\nu_\mu \rightarrow \nu_e$ appearance signal comes from beam generated ν_e events, therefore, a high purity ν_μ beam with as low as possible ν_e contamination is required

**From "Simulation of a Wide-Band Low-Energy Neutrino Beam for Very Long Baseline Neutrino Oscillation Experiments", Bishai, Heim, Lewis, Marino, Viren, Yumiceva*

NuMI/Homestake DUSEL Beam

Location of the Homestake Beamline

Project X Workshop
Neutrinos
17 November 2007
Dixon Bogert

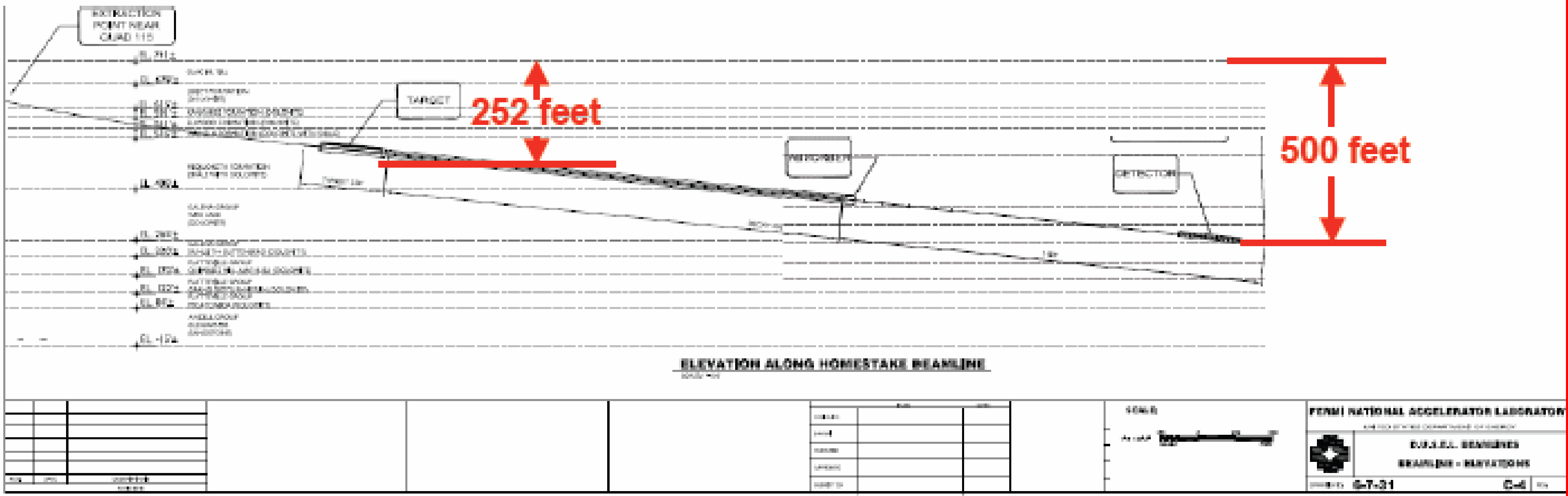


Homestake/DUSEL Neutrino Beam

NuMI/Homestake DUSEL Beam

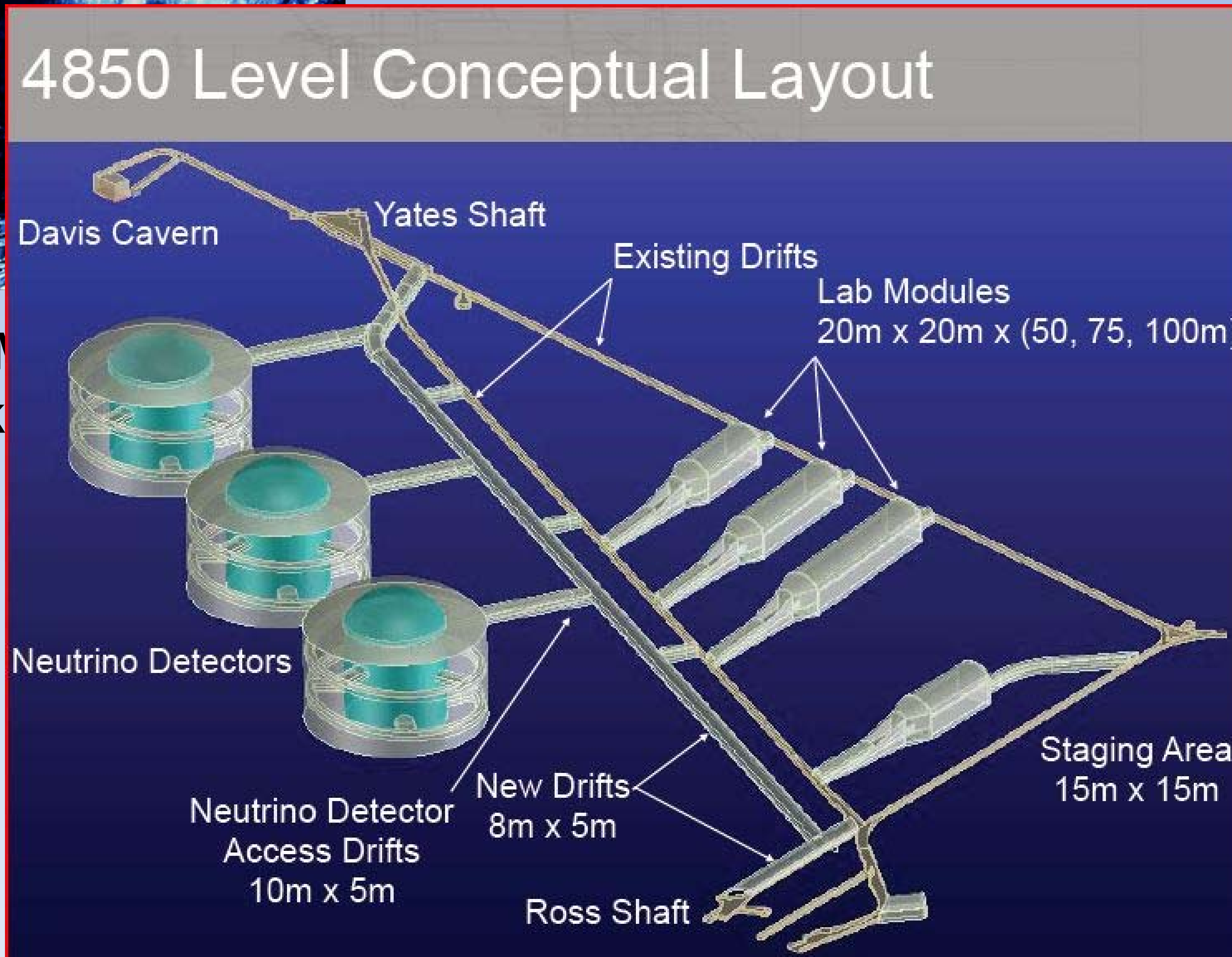
Second Elevation View of the Homestake Beamline

Project X Workshop
Neutrinos
17 November 2007
Dixon Bogert



This elevation view of the Homestake Beamline (-5.84^{o}) is drawn with the decay pipe limited to 400m. This shortens the beamline by 741 feet, and lifts The detector hall (and shaft) by about 75 feet (500 feet deep). Overall, this configuration will be cheaper to build and is probably adequate.

Water Cerenkov



IM

3 k

NuMI-Homestake Event Rates

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{12,23} = 0.86, 1.0$

Unoscillated ν_μ rates at 1300km:

120 GeV on-axis: 20,000 CC/MW.100kT.10^7, 9mrad off-axis: 9,000 CC/MW.100 kT.10^7s

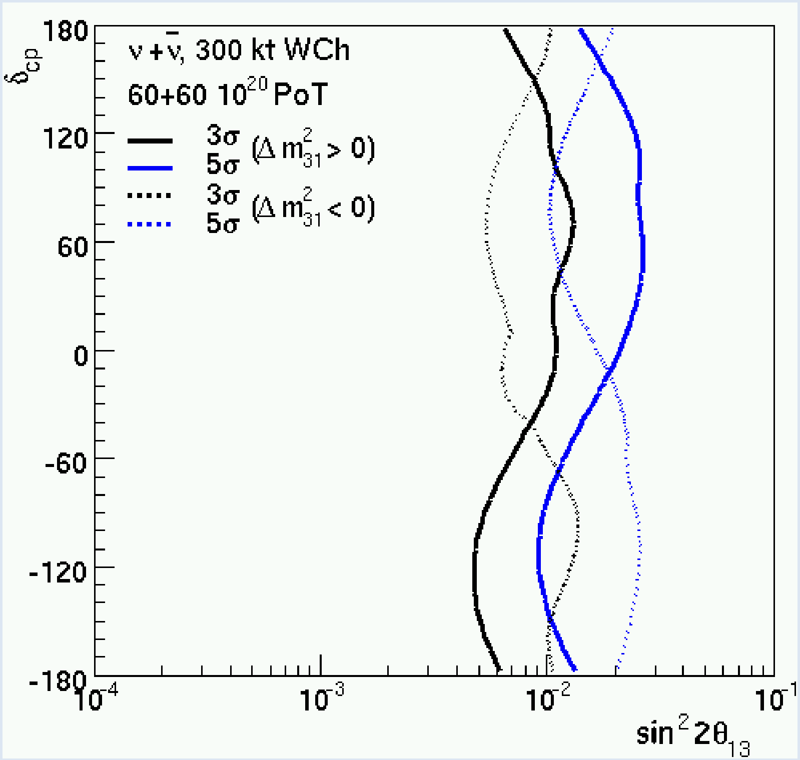
60 GeV on-axis: 15,000 CC/MW.100kT.10^7s

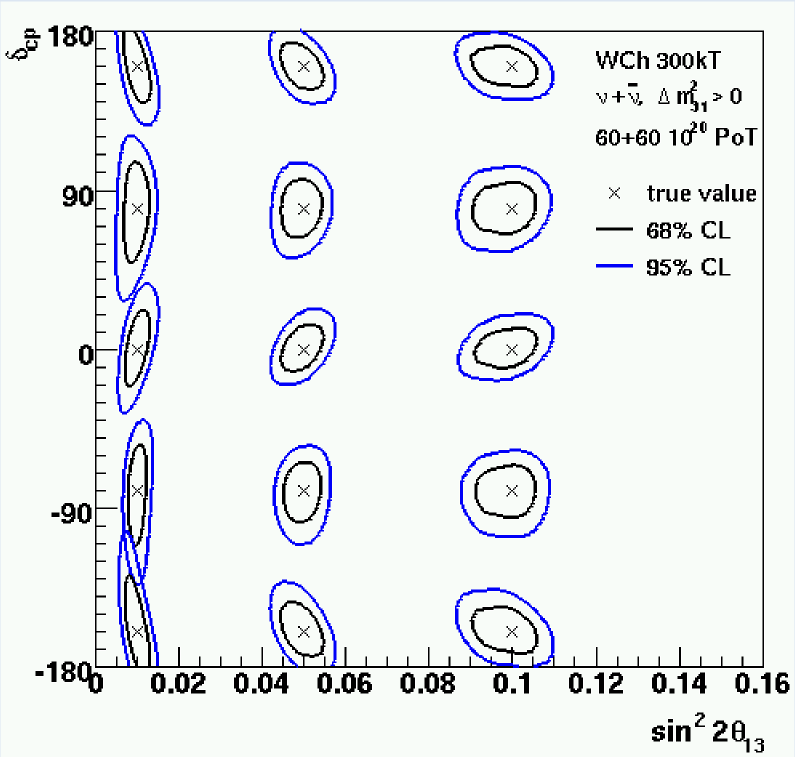
Oscillated rates at 1300km:

		$\nu_\mu \rightarrow \nu_e$ rate				$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ rates			
(sign of Δm^2_{31})	$\sin^2 2\theta_{13}$	δ_{CP} deg.							
		0°	-90°	180°	+90°	0°	-90°	180°	+90°
WBLE beams at 1300km, per 100kT. MW. 10^7s									
120 GeV, 9 mRad off-axis		Beam ν_e = 47**				Beam $\bar{\nu}_e$ = 17**			
(+/-)	0.0	14	N/A	N/A	N/A	5.0	N/A	N/A	N/A
(+)	0.02	87	134	95	48	20	7.2	15	27
(-)	0.02	39	72	51	19	38	19	33	52
60 GeV, on-axis		Beam ν_e = 61**				Beam $\bar{\nu}_e$ = 22**			
(+)	0.02	138	189	125	74	30	12	19	37
(-)	0.02	57	108	86	34	46	27	48	67

* = 0-3 GeV ** = 0-5 GeV, 1 MW. 10^7s = 5.2×10^{20} POT at 120 GeV, 1yr $= 2 \times 10^7 s$

300 kTon + 2.4 MW





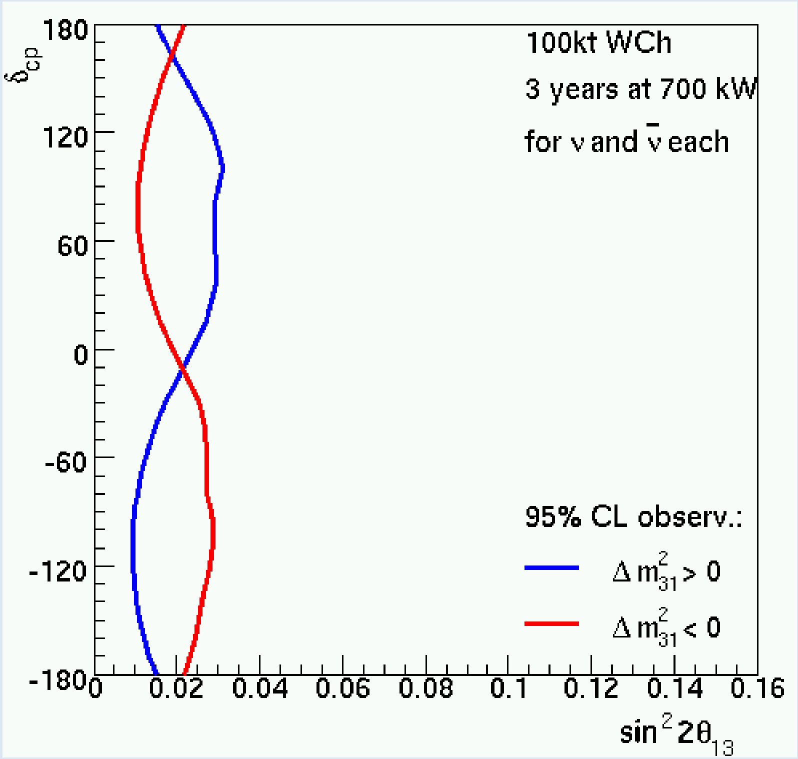
Mass Hierarchy

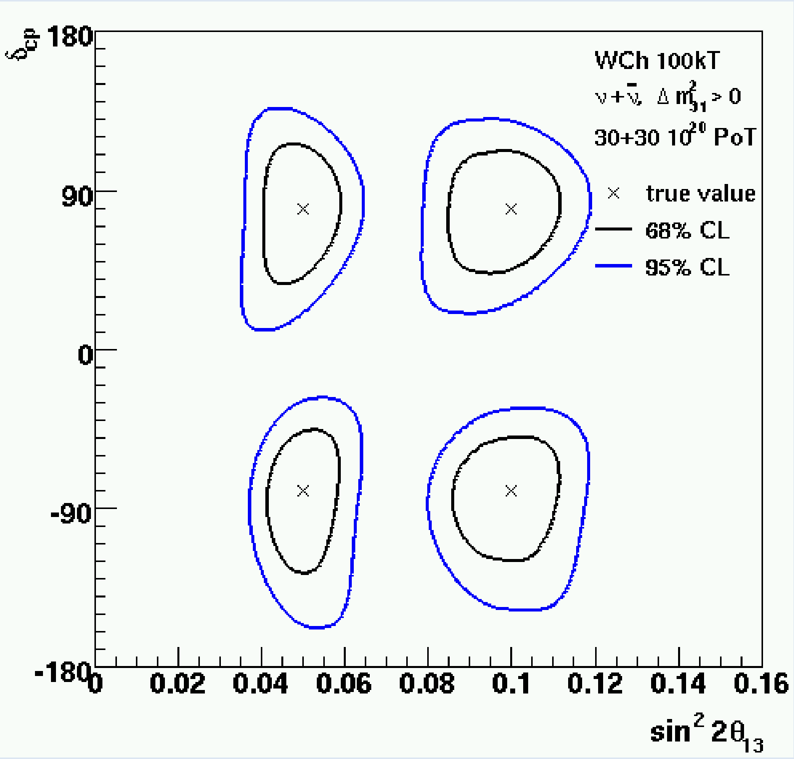
CP violation

M.Dierckxsens

5% background uncertainty
120 GeV 0.5 OA

100 kTon + 700 KW



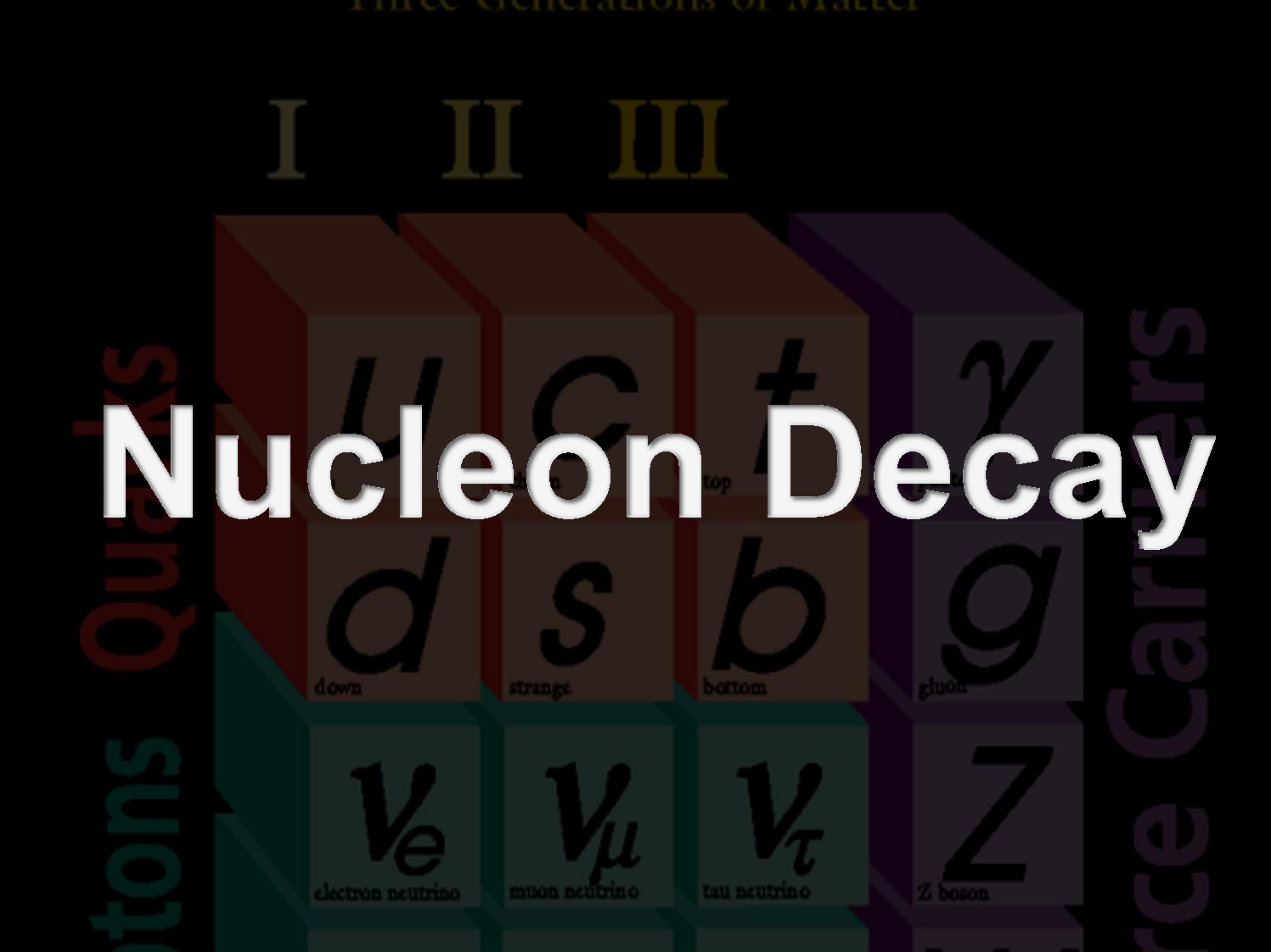


Hierarchy

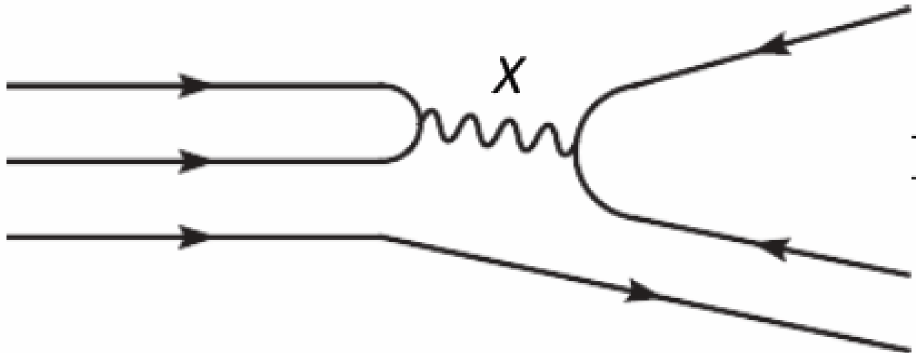
M.Dierckxsens

5% background uncertainty
120 GeV 0.5 OA

Nucleon Decay



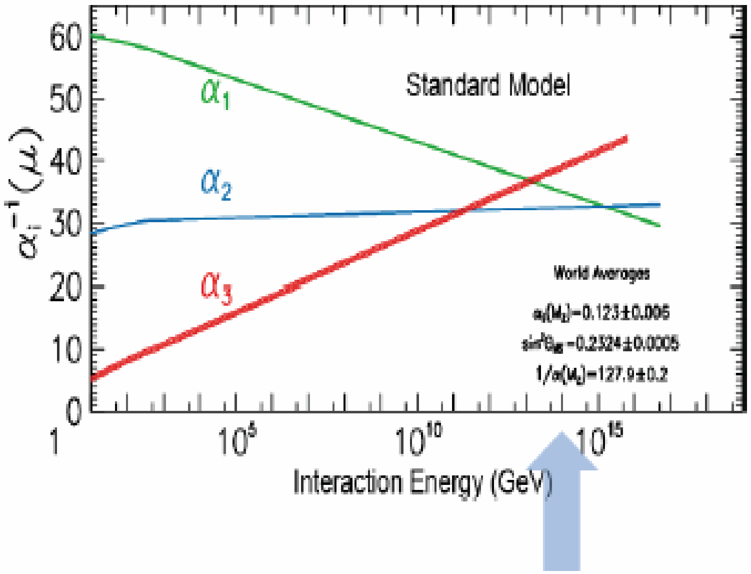
Nucleon Decay

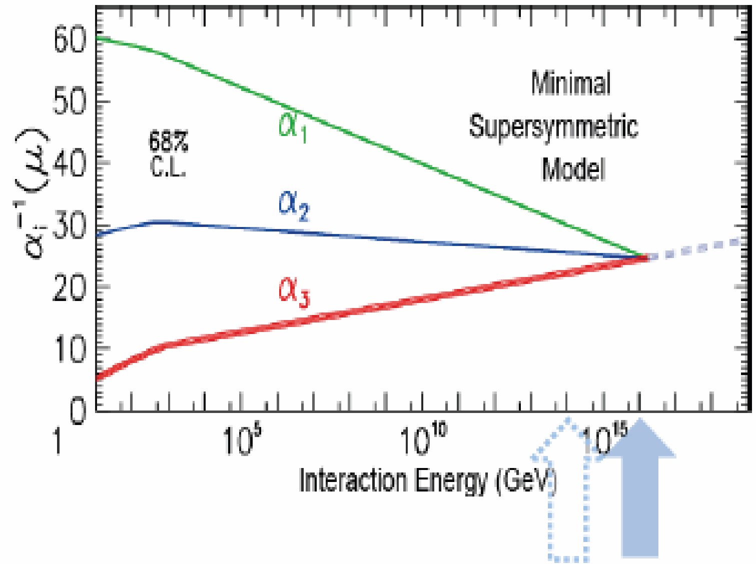


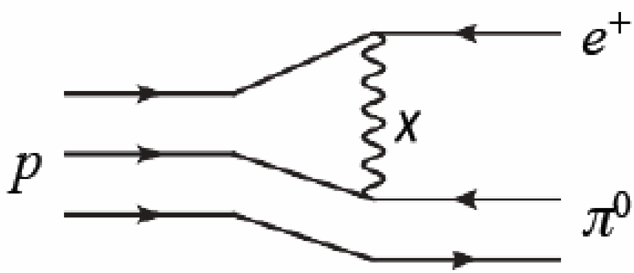
$$\Gamma \sim \frac{\alpha M_X^4}{m_p^5}$$

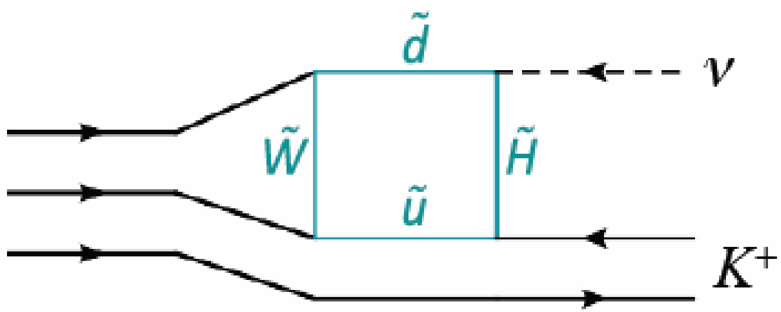
- ★ Highly prized physics motivation:
  Grand Unification of strong, weak, and electromagnetic forces!
  New force carrying particle!
- ★ Connections to neutrino mass, inflation, BAU ...
- ★ Test of basic symmetries: baryon number and lepton number.
- ★ Supersymmetric versions of GUTs are of great interest and value.
- ★ ~10^{15} GeV energy scale – inaccessible to accelerators.
- ★ Long lifetime (from SK) is already a difficult constraint
  which new models must work hard to evade.

Unification of Running Coupling Constants









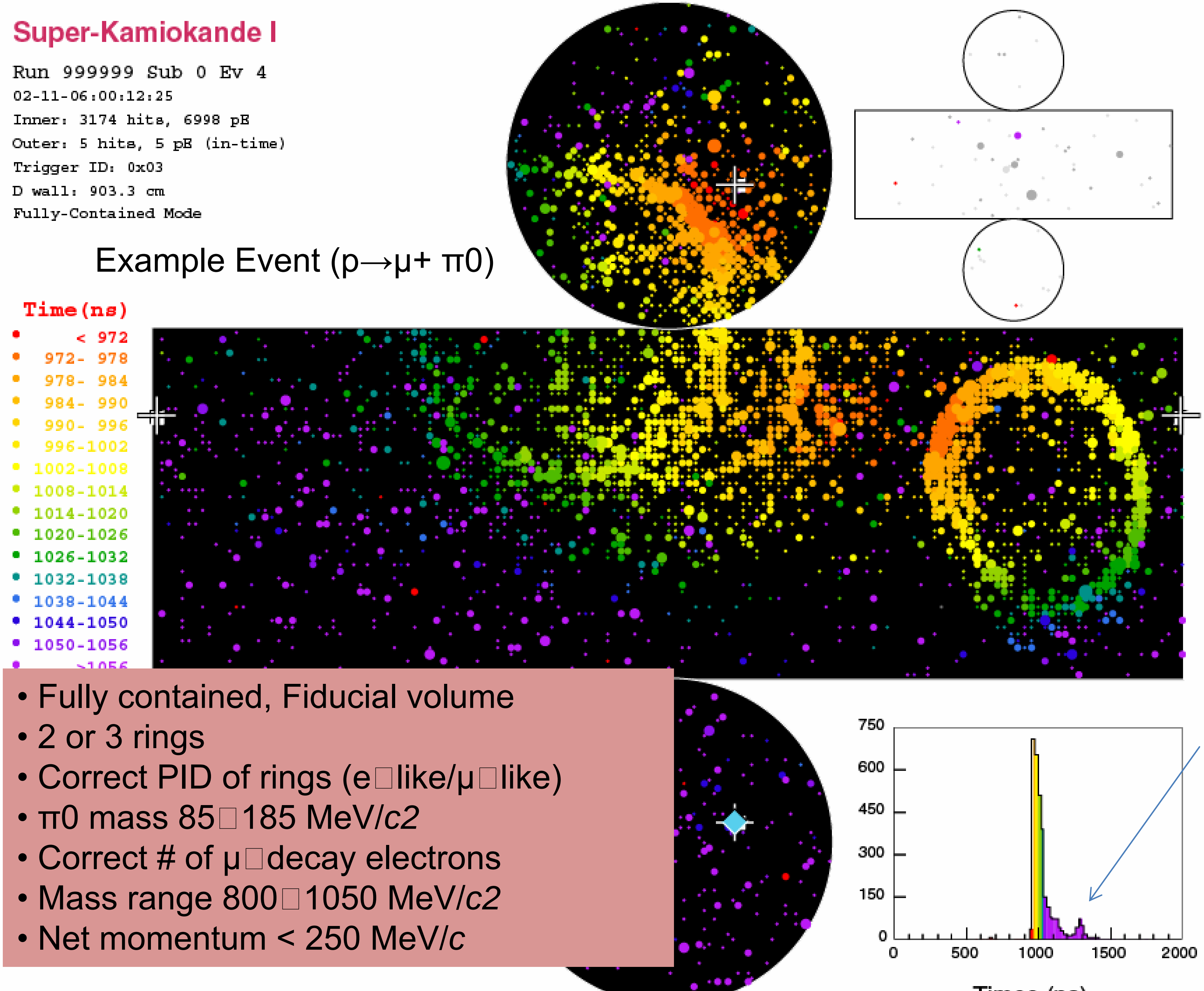
$$\tau/B = 4.5\times10^{29\pm1.7}\text{years}\quad \mathrm{SU}(5)$$
$$\tau/B > 8.4\times10^{33}\text{years}\quad \mathrm{SK\ I+II}$$

$$\tau/B = 10^{29-35}\text{years}\quad \mathrm{SUSY}$$
$$\tau/B > 2.3\times10^{32}\text{years}\quad \mathrm{SK\ I}$$

Model	Ref.	Modes	τ_N (years)
Minimal $SU(5)$	Georgi, Glashow [2]	$p \to e^+\pi^0$	$10^{30} - 10^{31}$
Minimal SUSY $SU(5)$	Dimopoulos, Georgi [11], Sakai [12] Lifetime Calculations: Hisano, Murayama, Yanagida [13]	$p \to \bar{\nu}K^+$ $n \to \bar{\nu}K^0$	$10^{28} - 10^{32}$
SUGRA $SU(5)$	Nath, Arnowitt [14, 15]	$p \to \bar{\nu}K^+$	$10^{32} - 10^{34}$
SUSY $SO(10)$ with anomalous flavor $U(1)$	Shafi, Tavartkiladze [16]	$p \to \bar{\nu}K^+$ $n \to \bar{\nu}K^0$ $p \to \mu^+K^0$	$10^{32} - 10^{35}$
SUSY $SO(10)$ MSSM (std. $d=5$)	Lucas, Raby [17], Pati [18]	$p \to \bar{\nu}K^+$ $n \to \bar{\nu}K^0$	$10^{33} - 10^{34}$ $10^{32} - 10^{33}$
SUSY $SO(10)$ ESSM (std. $d=5$)	Pati [18]	$p \to \bar{\nu}K^+$	$10^{33} - 10^{34}$ $\lesssim 10^{35}$
SUSY $SO(10)/G(224)$ MSSM or ESSM (new $d=5$)	Babu, Pati, Wilczek [19, 20, 21], Pati [18]	$p \to \bar{\nu}K^+$ $p \to \mu^+K^0$	$\lesssim 2 \cdot 10^{34}$ $B \sim (1-50)\%$
SUSY $SU(5)$ or $SO(10)$ MSSM ($d=6$)	Pati [18]	$p \to e^+\pi^0$	$\sim 10^{34.9\pm1}$
Flipped $SU(5)$ in CMSSM	Ellis, Nanopoulos and Wlaker[22]	$p \to e/\mu^+\pi^0$	$10^{35} - 10^{36}$
Split $SU(5)$ SUSY	Arkani-Hamed, *et. al.* [23]	$p \to e^+\pi^0$	$10^{35} - 10^{37}$
$SU(5)$ in 5 dimensions	Hebecker, March-Russell[24]	$p \to \mu^+K^0$ $p \to e^+\pi^0$	$10^{34} - 10^{35}$
$SU(5)$ in 5 dimensions option II	Alciati *et.al.*[25]	$p \to \bar{\nu}K^+$	$10^{36} - 10^{39}$
GUT-like models from Type IIA string with D6-branes	Klebanov, Witten[26]	$p \to e^+\pi^0$	$\sim 10^{36}$

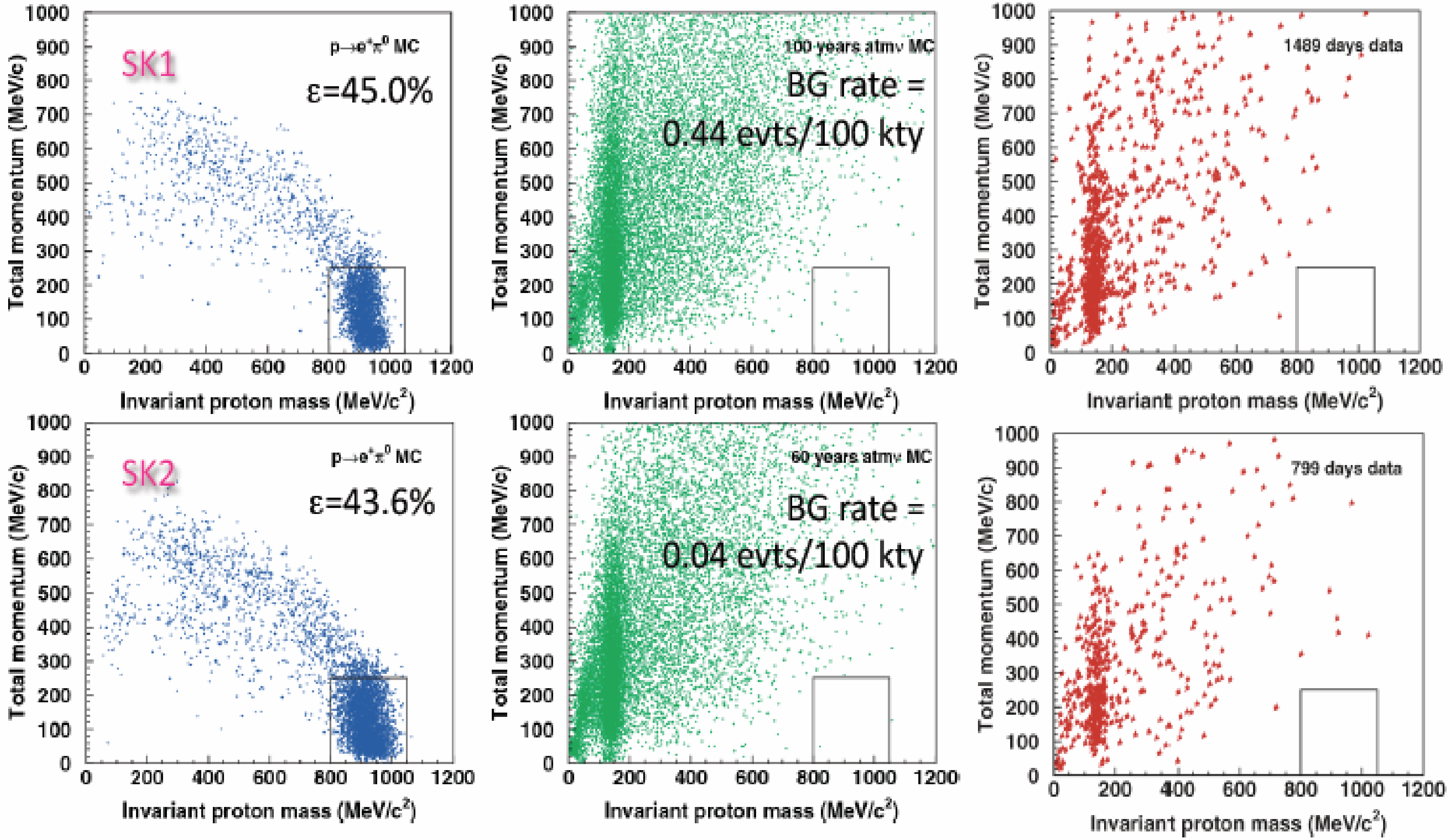
TABLE I: Summary of the expected nucleon lifetime in different theoretical models.

Example Event (p→μ+ π0)



- Fully contained, Fiducial volume
- 2 or 3 rings
- Correct PID of rings (e-like/μ-like)
- π0 mass 85–185 MeV/*c2*
- Correct # of μ-decay electrons
- Mass range 800–1050 MeV/*c2*
- Net momentum < 250 MeV/*c*

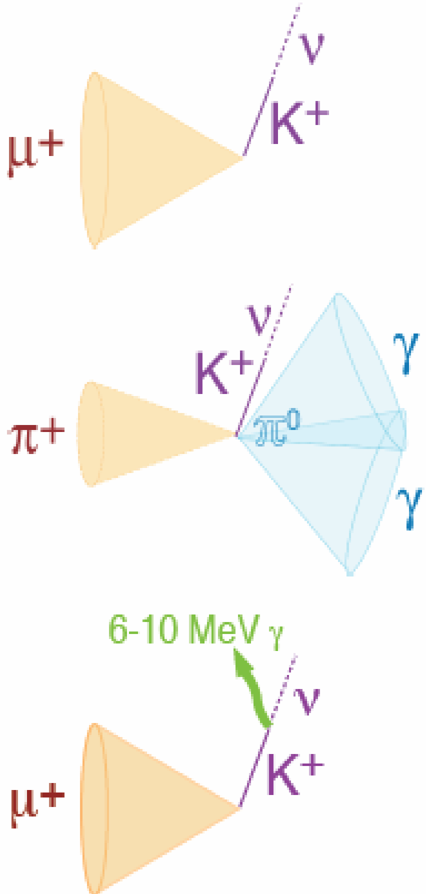
Super-Kamiokande Results ($p \rightarrow e^+ \pi^0$)



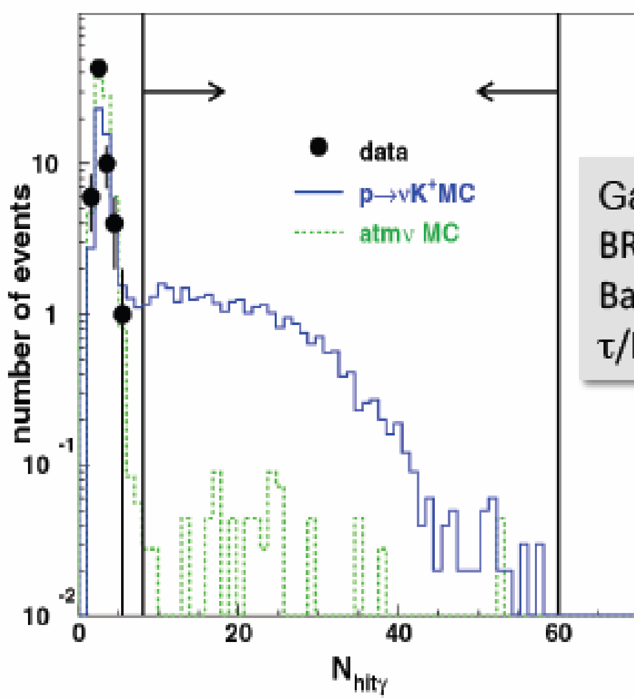
Indep. (Nuance MC) BG est. for SK1:
BG rate = 0.21 evts/100 kty

BG est. based on K2K 1KT:
BG rate = 0.16±0.07 evts/100 kty

Super-Kamiokande Search for ($p \rightarrow K^+ \nu$)



- ★ K^+ below Cherenkov threshold
- ★ Essentially a search for K^+ decay at rest
- ★ Three searches (eventually combined)
  - Monochromatic muon (65% BR, large background)
  - $K^+ \rightarrow \pi^+\pi^0$ (21% BR)
  - $K^+ \rightarrow \mu^+ \nu$ with early gamma tag from $^{16}O^*$



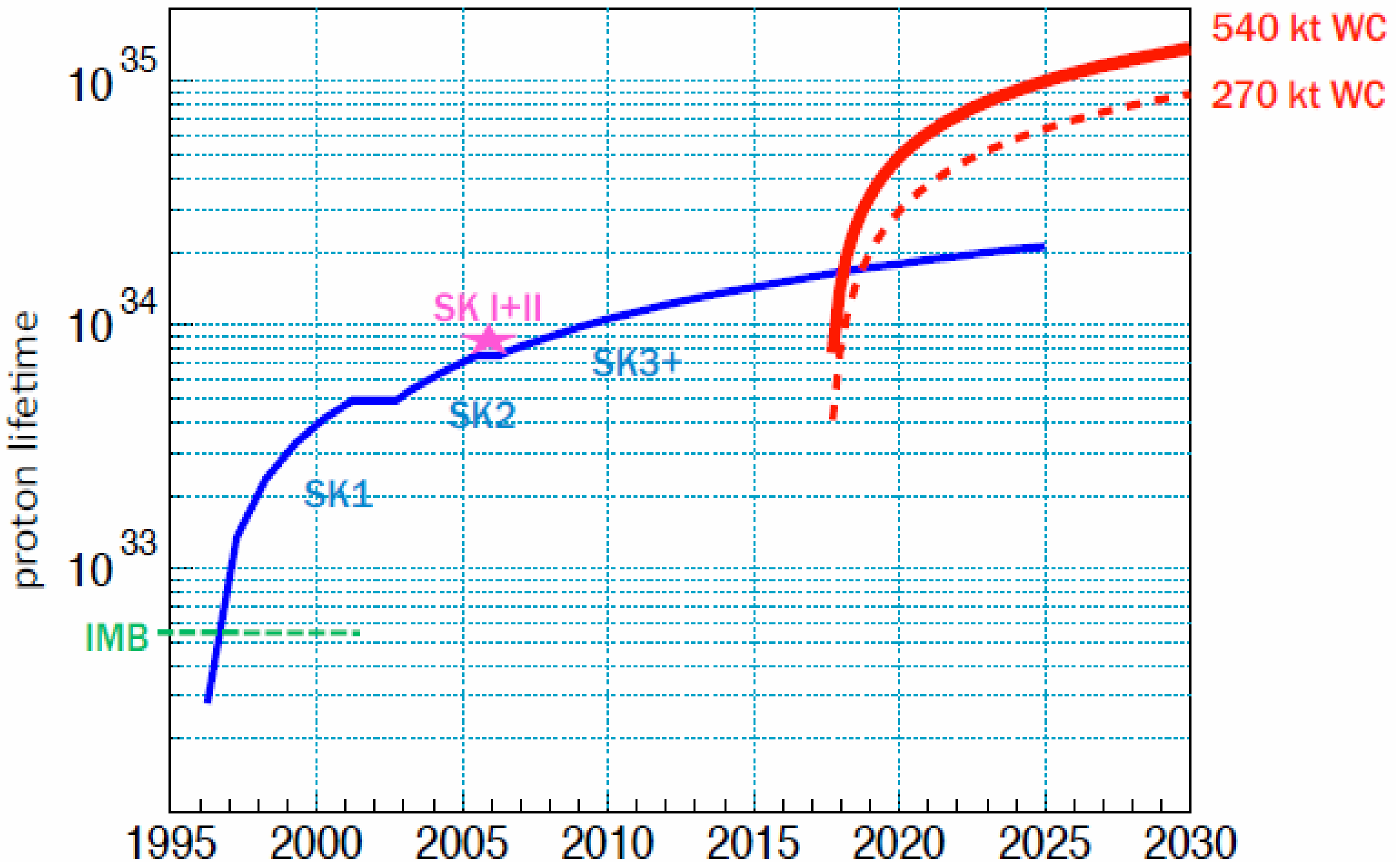
Gamma Tag Search:

$BR \times \varepsilon = 8.6 \pm 20_{sys}\%$

Background = 0.7 events (±59%)

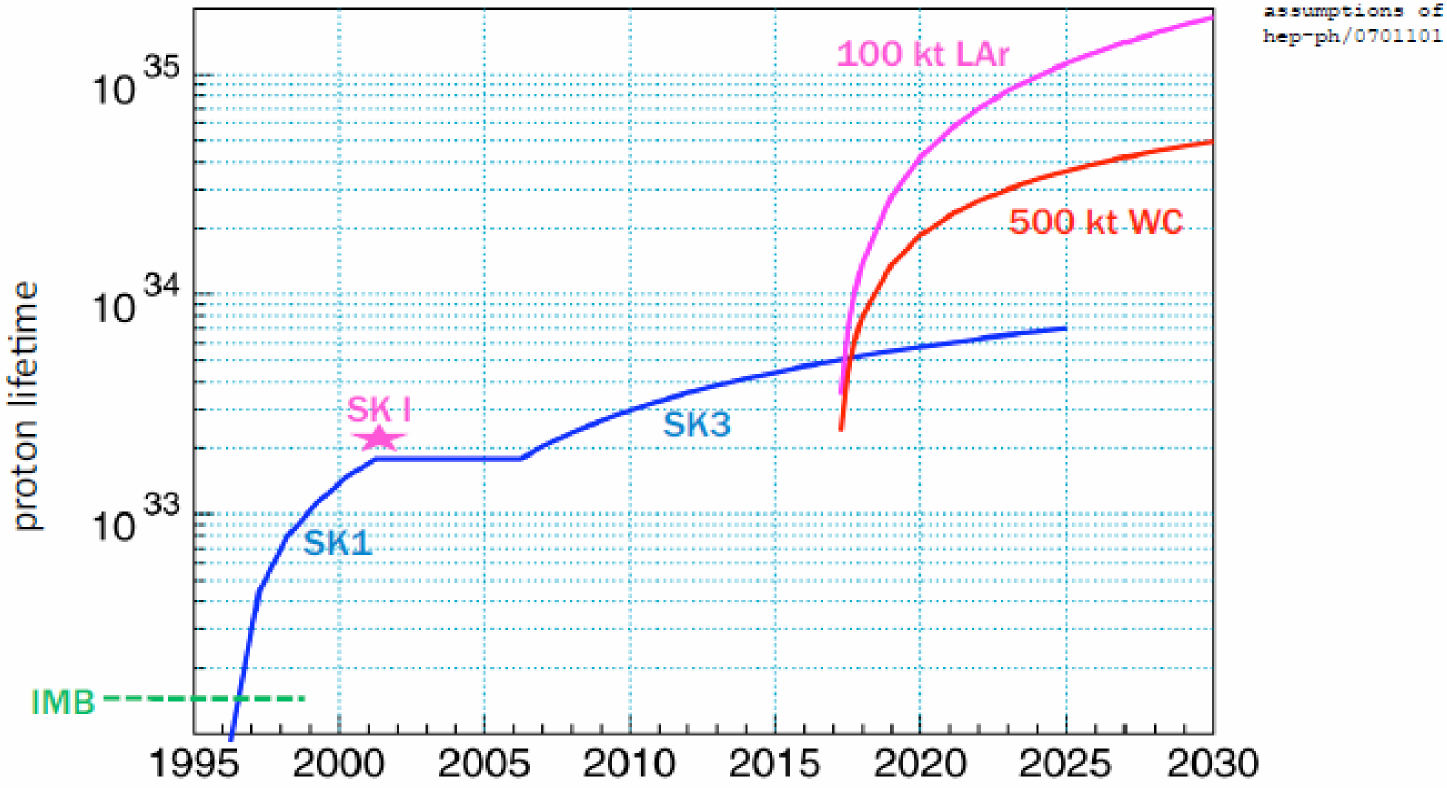
$\tau/B < 10 \times 10^{32}$ years

$$p \rightarrow e^{+}\pi^{0}$$



efficiency = 0.45
bg. rate = 0.2 evts/100 kty
$N_{obs} = N_{bg}$

$$p \to K^{+}\nu$$



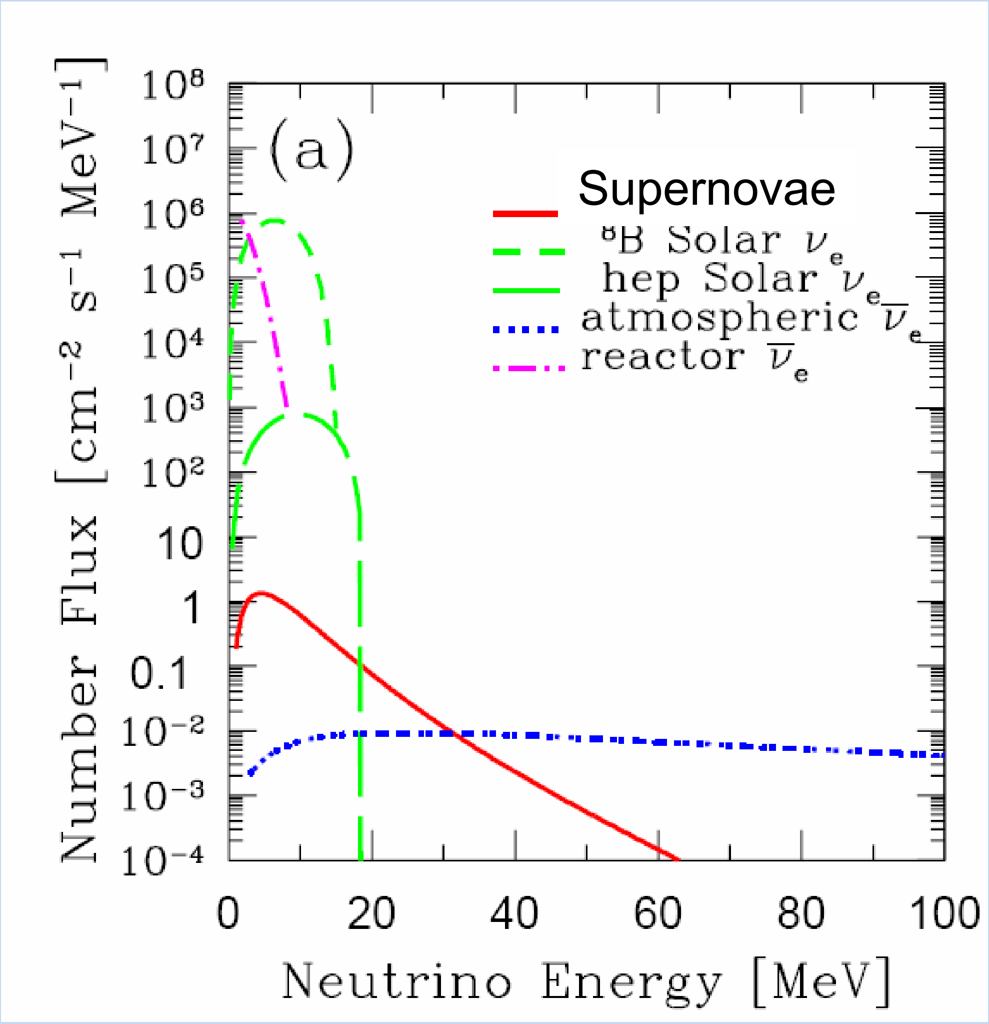
assumptions of
hep-ph/0701101
100 kt LAr
500 kt WC
SK-I
SK3
SK1
IMB
proton lifetime
10^{35}
10^{34}
10^{33}
1995
2000
2005
2010
2015
2020
2025
2030

Supernovae

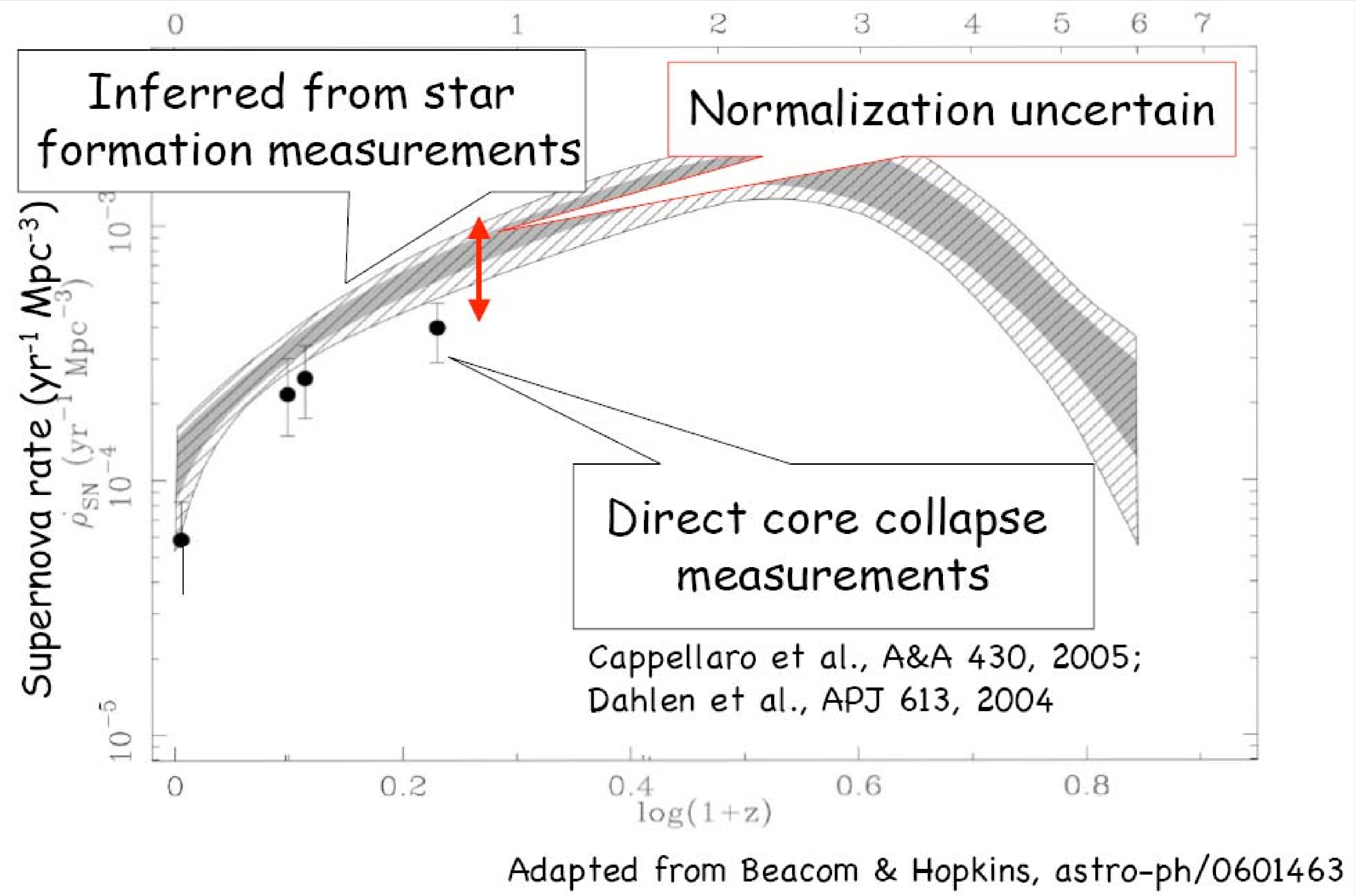
The feeble signal of all SNe

- Sum over the whole universe:

$$\sum_{\star} \Phi_{\nu}^{\star}$$



S. Ando and K. Sato, New J.Phys.6:170,2004.



Inferred from star formation measurements
Normalization uncertain
Direct core collapse measurements
Cappellaro et al., A&A 430, 2005;
Dahlen et al., APJ 613, 2004
Supernova rate (yr-1 Mpc-3)
log(1+z)
0
1
2
3
4
5
6
7
0.2
0.4
0.6
0.8
Adapted from Beacom & Hopkins, astro-ph/0601463

Spectrum fitting in SK-I

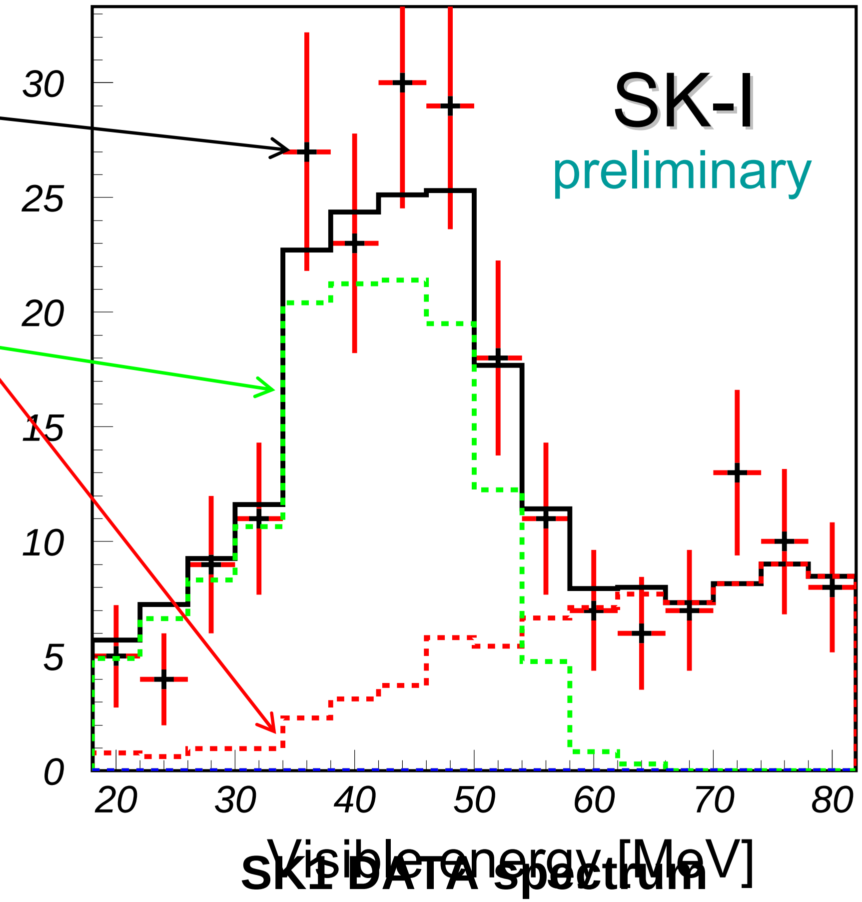
$$\chi^2 = \sum_i \frac{\left[N_{data}(i) - (\alpha \times N_{relic}(i) + \beta \times N_{\nu_e}(i) + \gamma \times N_{\nu_\mu}(i) \right]^2}{\sigma_{data}^2 + \sigma_{MC}^2 + \sigma_{systematic}^2}$$

$N_{data}(i)$: *real Data spectrum*

$N_{relic}(i)$: *SRN MC spectrum*

$N_{\nu_e}(i)$: *atmospheric ν_e spectrum*

$N_{\nu_\mu}(i)$: *atmospheric ν_μ spectrum*



free parameter

α = 0.0 : factor of SRN

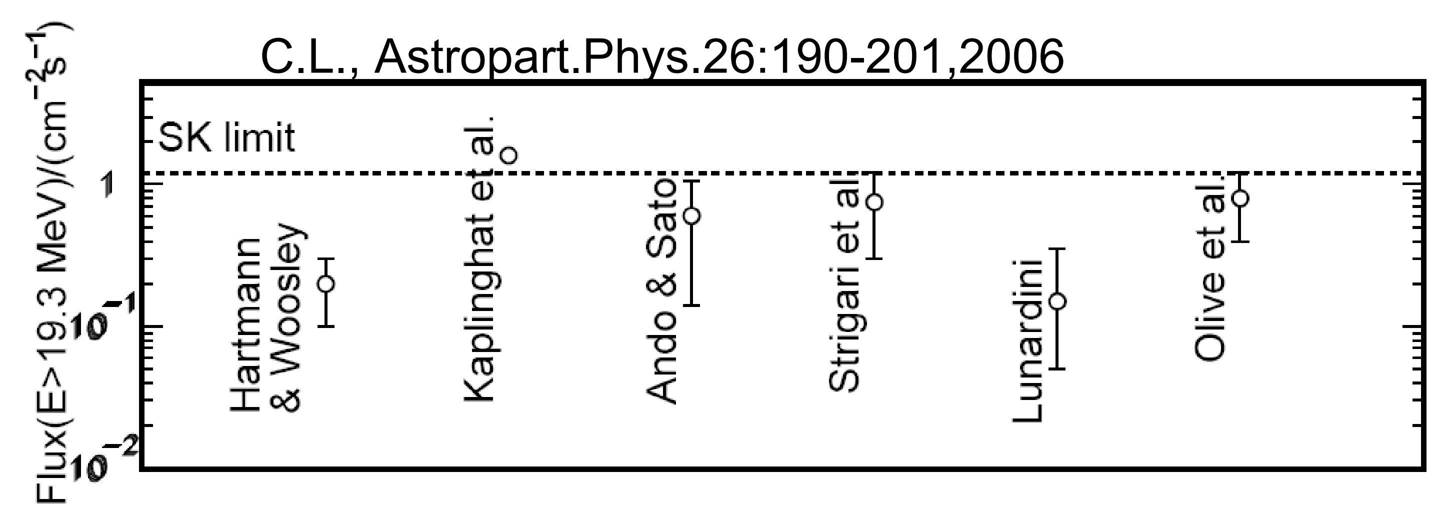
β = 1.30±0.2 : factor of ν_e

γ = 0.45±0.1 : factor of ν_μ

χ^2 = 7.2 / 13 d.o.f

Courtesy Iida, ICRR

Status of theory: anti-ν_e flux



- Differences due to different inputs/methods

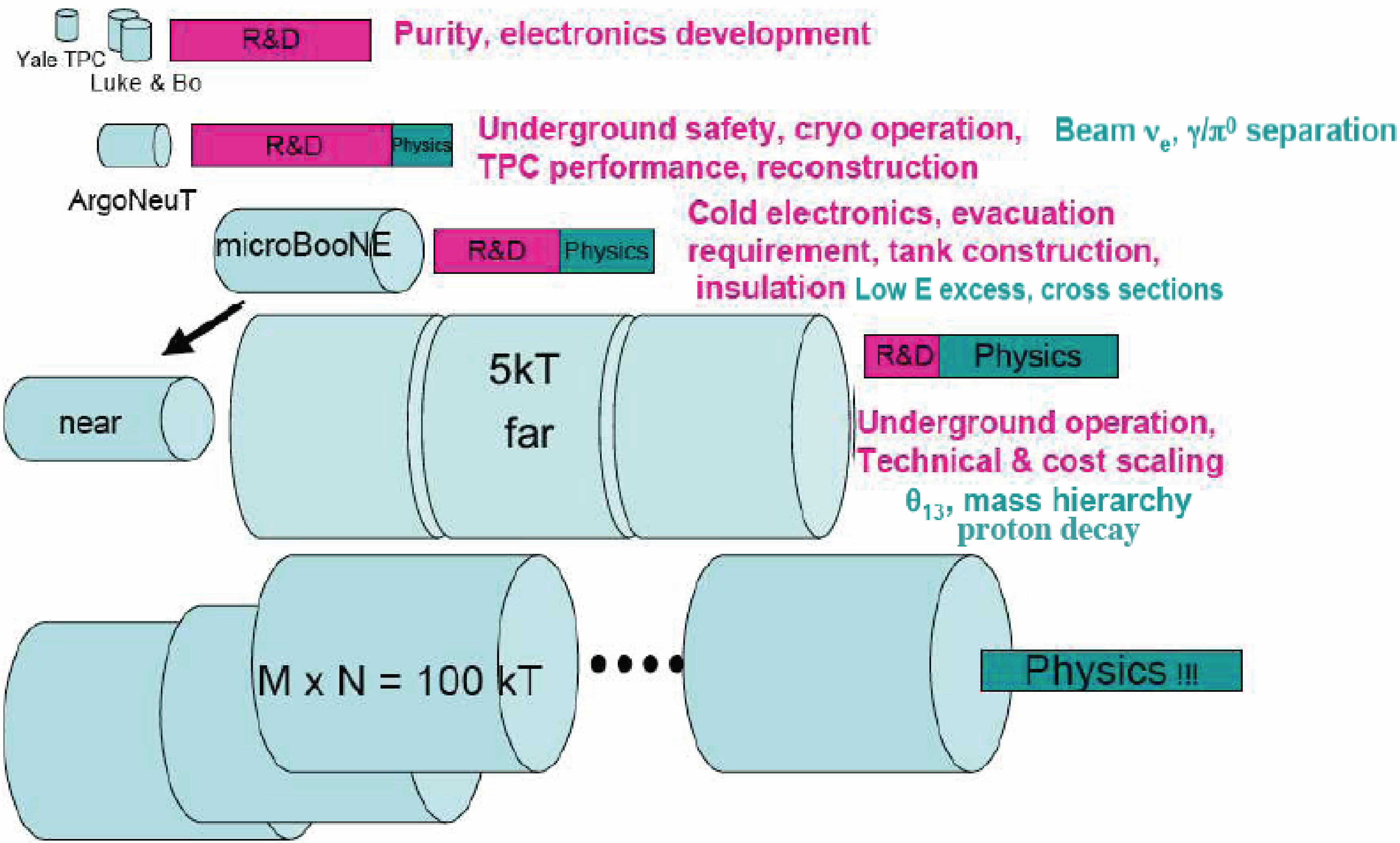
For a **<u>Gd-loaded</u>** 100 kton WC detector, estimates range from 2-20 events/year.

C.L., Astropart.Phys.26:190-201,2006, Fogli et al. JCAP 0504:002,2005, Volpe & Welzel, 2007, C.L. & O.L.G. Peres, to appear soon.

SK background of ~20/year significantly reduced by neutron tagging. (Beacom and Vagins)

Detectors

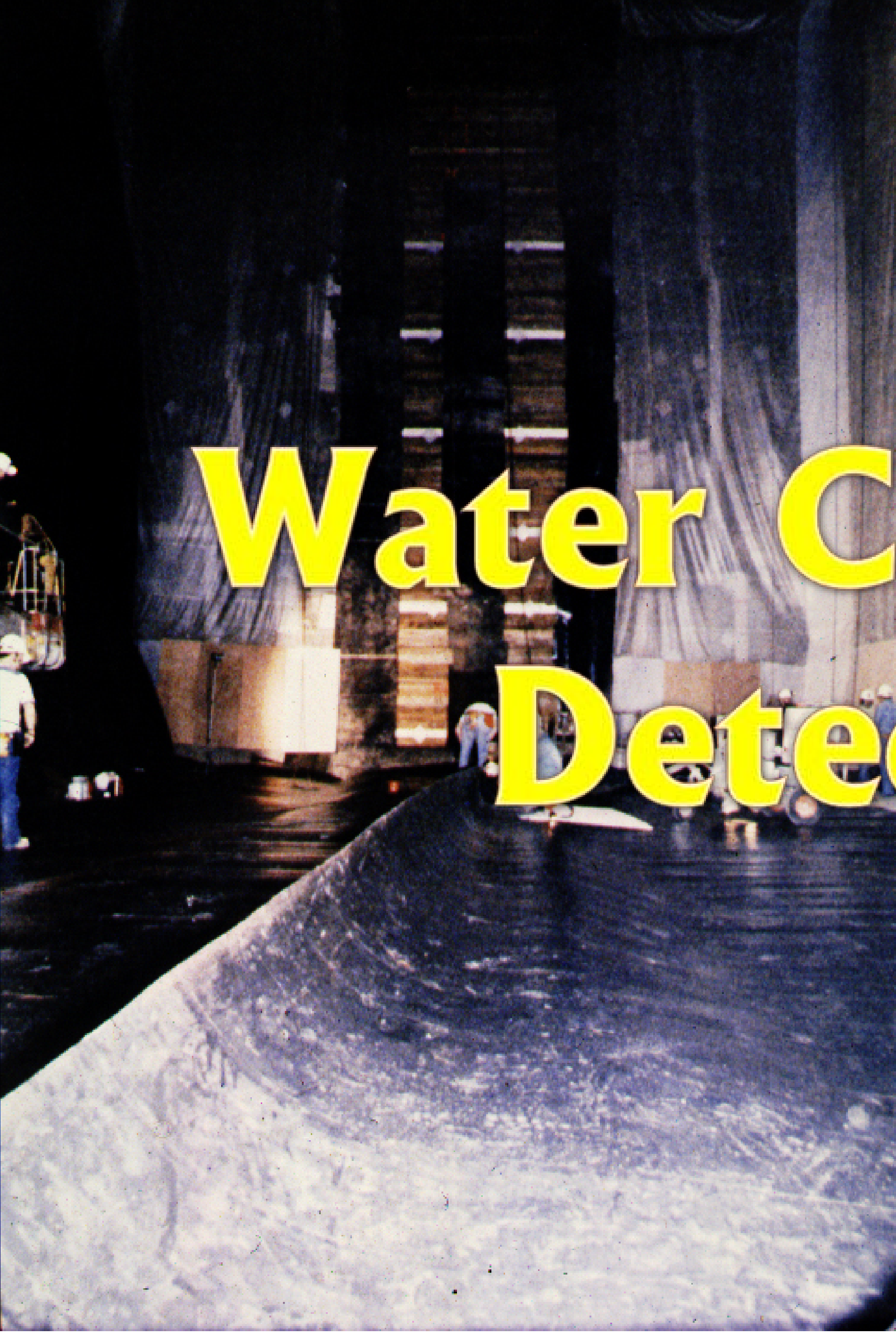
Evolution of the Liquid Argon Physics Program in the US

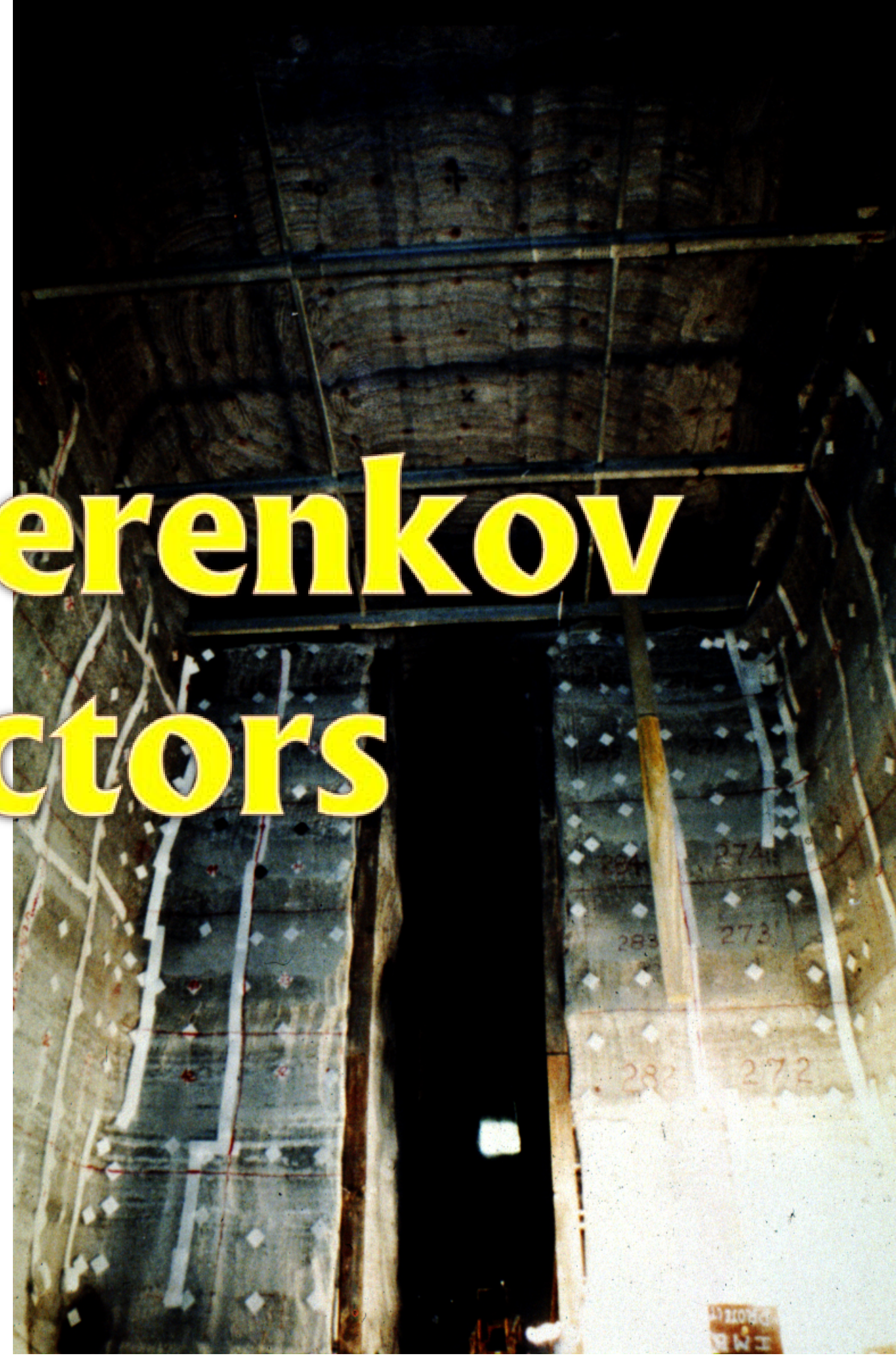


Liquid Argon R&D Issues

- Feasibility: insulation, purity, cold electronics, necessity for evacuation of vessel
- Underground safety – this is a major concern
- What is the cost? Initial predictions very high (>$1B)
- Also predictability of costs and minimization of risk are issues

Water Cerenkov Detectors





Mature Detector Technology

- IMB, Kamiokande, Super-K, SNO(D_2O), miniBooNE (oil)
- "Mature" = 3/5 did not have serious accident
- We know some of the major problems that can cause a disaster
- We know what to do to improve with little technical or schedule risk

Water Cerenkov R&D Issues

- What is the PMT coverage required for efficiency neutron capture detection?
- What is the PMT coverage required for detection of precursor gamma ray from $p \rightarrow \nu K$? (Note: 20% coverage in SK-II was too little).
- Can PMT's be installed without SK style "mufflers"? BNL is working on PMT implosion testing.

- How can Gd-loaded water be cleaned without removing the Gd? Is removal of Fe ions only enough– or do we have to worry about other things also?
- Can the walls of a large cavern be coated directly? Do we need to have concrete and/or a liner? How to mount PMTs cheaply?
- Do we need a veto region? SK had one, but DUSEL 4850 is much deeper. Note: IMB operated successfully without a veto region.
- Can efficiency for e/π^0 be improved?

How can we improve?

- Bring down cost
- improve sensitivity
- improve electronics
- improve PMT response
- ensure implosion hardness
- improved analysis and simulation
- new photosensors (more tentative)

Gadolinium Doping

- Sensitivity to neutron capture via 8 MeV gamma cascade (e.g. M.Vagins, NNN08)
- Inexpensive, low risk. Could be implemented after construction completed, no schedule risk.
- Technical challenges:

  - material compatibility (LLNL) Chose materials that do not contaminate the water.

  - water treatment (UC Irvine). Remove impurities but leave gadolinium in solution

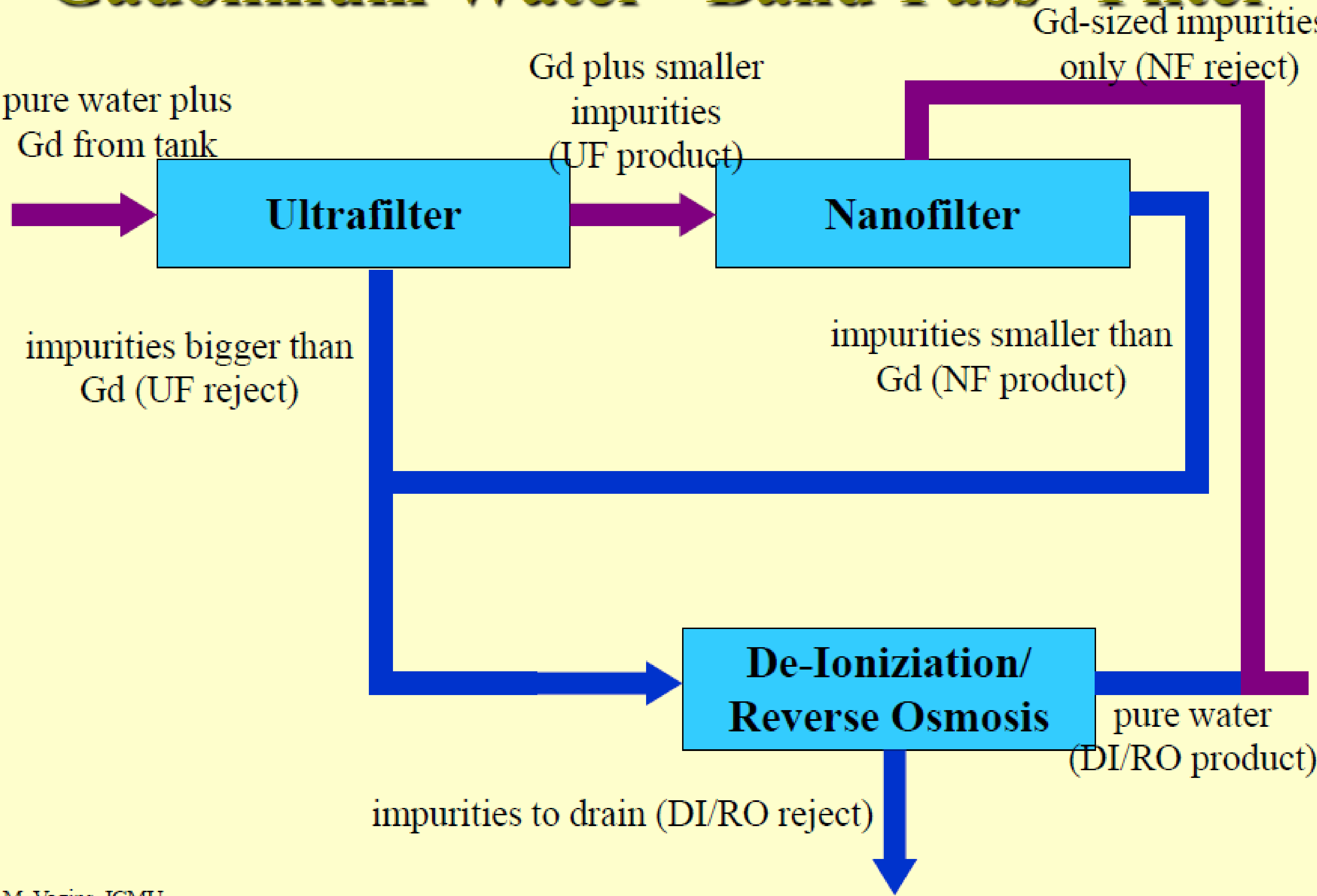
(10-20) x SK : event rate

- Exposure 1.6 Mton x year
  - e.g., 0.2 Mt for 8 years
  - Threshold 11.3 MeV, 100% efficiency

SN1987A-motivated (conservative)	Model-motivated (generic)	Max. allowed by SK limit
~22-128	~250	...

C.L., Astropart.Phys.26:190-201,2006, Fogli et al. JCAP 0504:002,2005, Volpe & Welzel, 2007, C.L. & O.L.G. Peres, to appear soon.

Gadolinium Water "Band-Pass" Filter



M. Vagins, ICMU

$Gd_2(SO_4)_3$ Filtering Progress

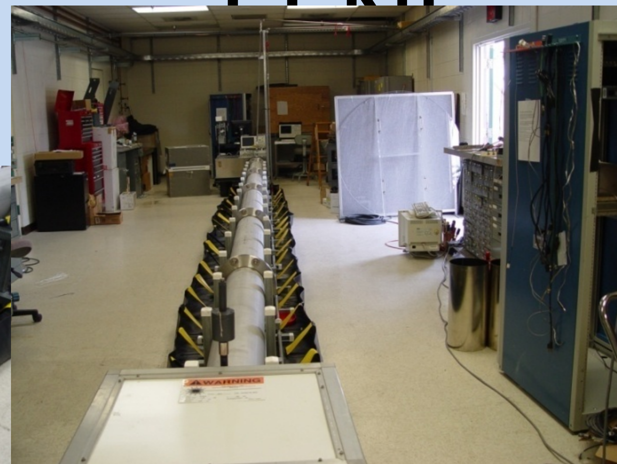
- took data with ultrafilter and two types of nanofilters
- basic principle is sound
- UF passed ~100% of $Gd_2(SO_4)_3$
- NF rejected >98% of $Gd_2(SO_4)_3$
- next: try multiple stages of NF; clean up product with RO units (before 2009)
- next: measure water transparency of $Gd_2(SO_4)_3$ (before 2009)

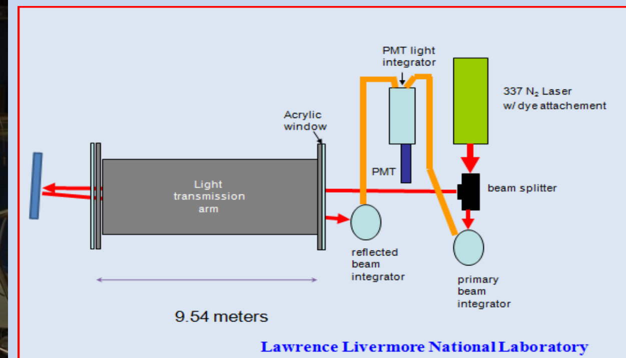
Currently Funded R&D LLNL: What makes good water go bad?

- Super-Kamiokande water must be continuously and cleaned – else transparency drops slowly
- Similar behavior seen in IMB (plastic walls) and SNO (acrylic walls – but much slower degradation)

REDUCING THE REQUIREMENT FOR RECIRC WILL LOWER COST OF MEGATON SCALE DETETOR, EVEN IF NO GD ADDED

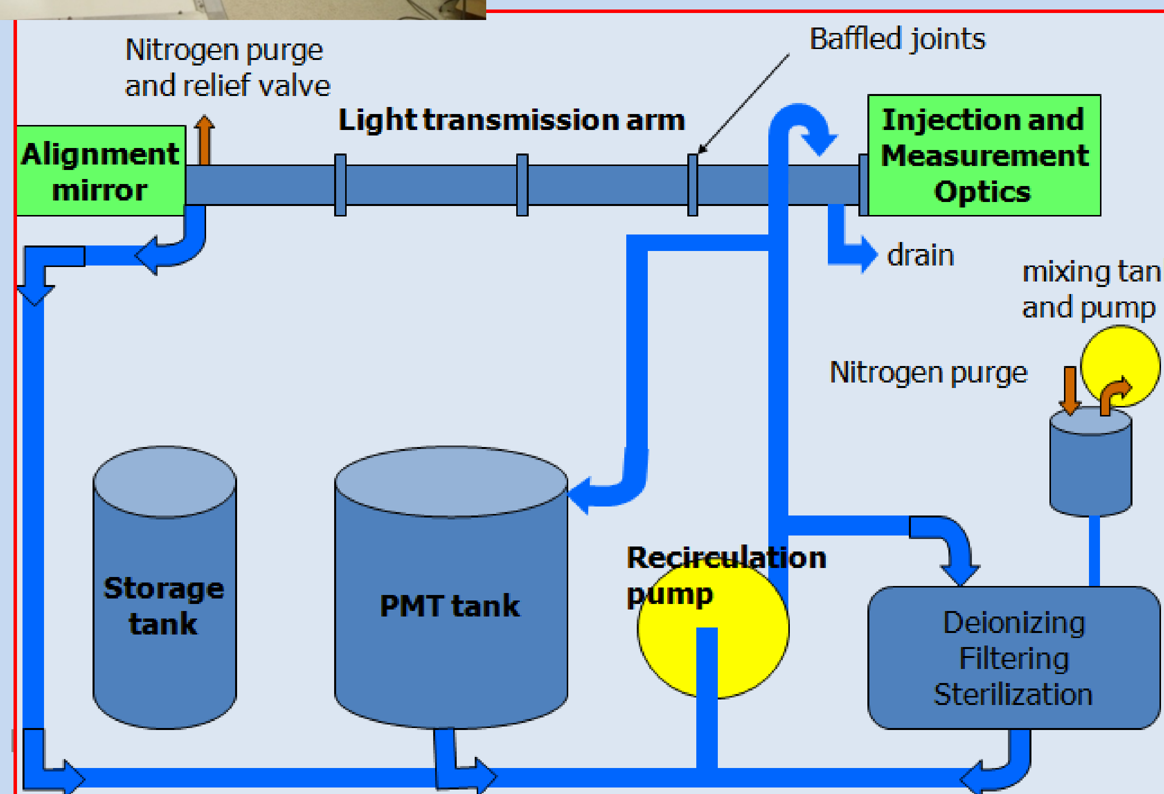
Testing of Material Compatibility at LLNL





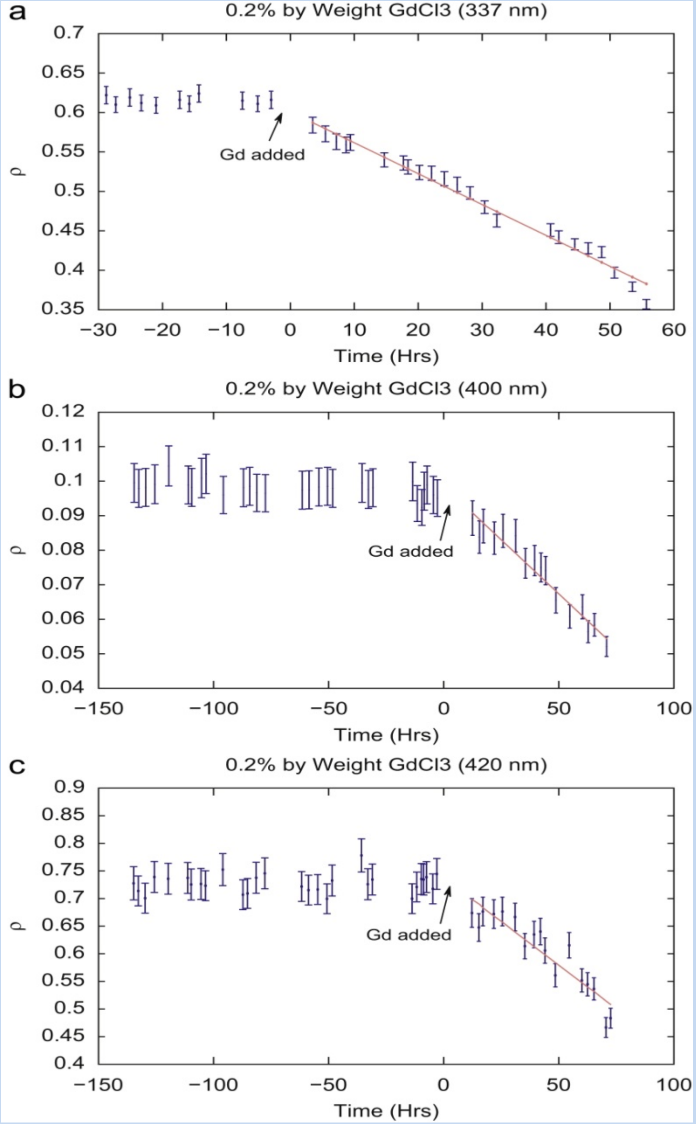
LLNL program to develop water-based neutron detectors

goal: determine cause of water "aging", identify "clean" materials



Water quality test (0.2% $GdCl_3$ in water): Results

- 1) $GdCl_3$ has no immediate effect on water quality
- 2) Subsequent deterioration is constant in time – suggesting exposure of $GdCl_3$ to surface of stainless pipe is the problem
  - Note: leaching of Fe from stainless steel was suspected (Fe is a strong UV and blue absorber)
- 3) Later additions to pipe from $GdCl_3$ water stored in polypro tank showed no sign of deterioration
- 4) Tests with $FeCl_3$ suggest that 14ppb Fe is enough to destroy water quality instantly
    - Again Suggests Fe leaching from SS



W. Coleman et al. / Nuclear Instruments and Methods, A 595 (2008) 339–345

Basic problem traced to stainless steel: Test with $FeCl_3$

- 10 ppm Fe^{+3} ion makes water look like ice tea. Clearly very low levels can affect transparency
- 7 ppb Fe^{+3} reduced transparency by ~30%
- Conclusion: Problem with Super-K is very likely due to reaction of Cl ions with the stainless steel tank to produce very low levels of Fe ions in water
- **Solution: Don't use steel components!**

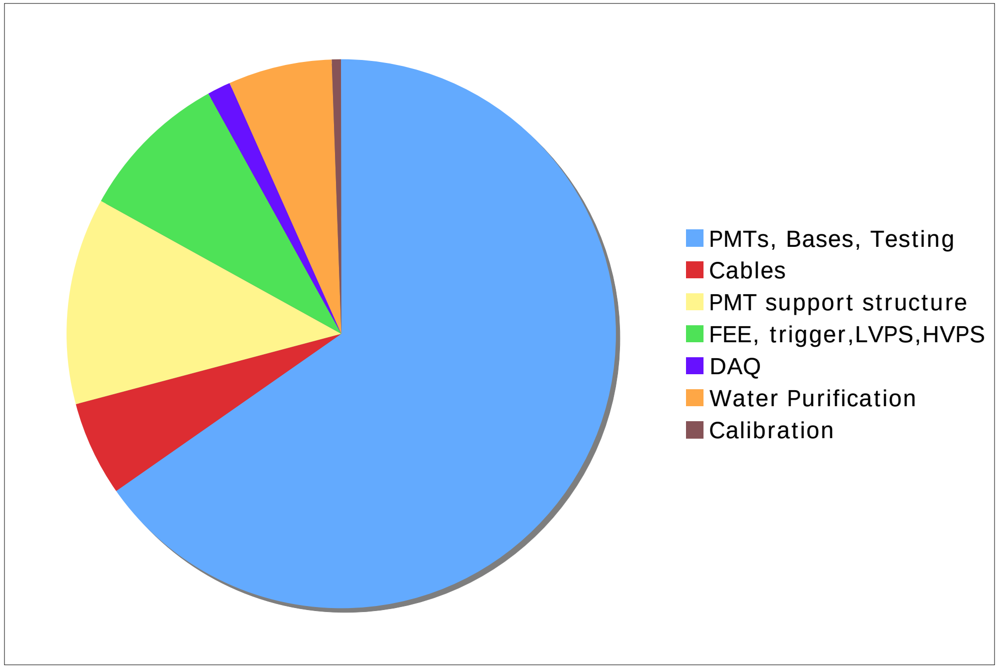
PMT considerations

	10 inch R7081	20 inch R3600
Number (25% cov)	~50000	~14000
QE	25%	20%
CE	~80%	~70%
rise time	4 ns	10 ns
Tube length	30 cm	68 cm
Weight	1150 gm	8000 gm
Vol.	~5 lt	~50 lt
pressure rating	0.7Mpa	0.6Mpa
∢ coverage/pmt	0.6 deg	1.1 deg
∢ granularity	1.0 deg	2.1 deg

Cost Drivers

- Study done for NuSAG: 30% cavern, 70% instrumentation
- Instrumentation costs driven my PMT's, mounts, electronics
- Cost analysis for CD-0 is in progress

Instrumentation only ~70% of total cost



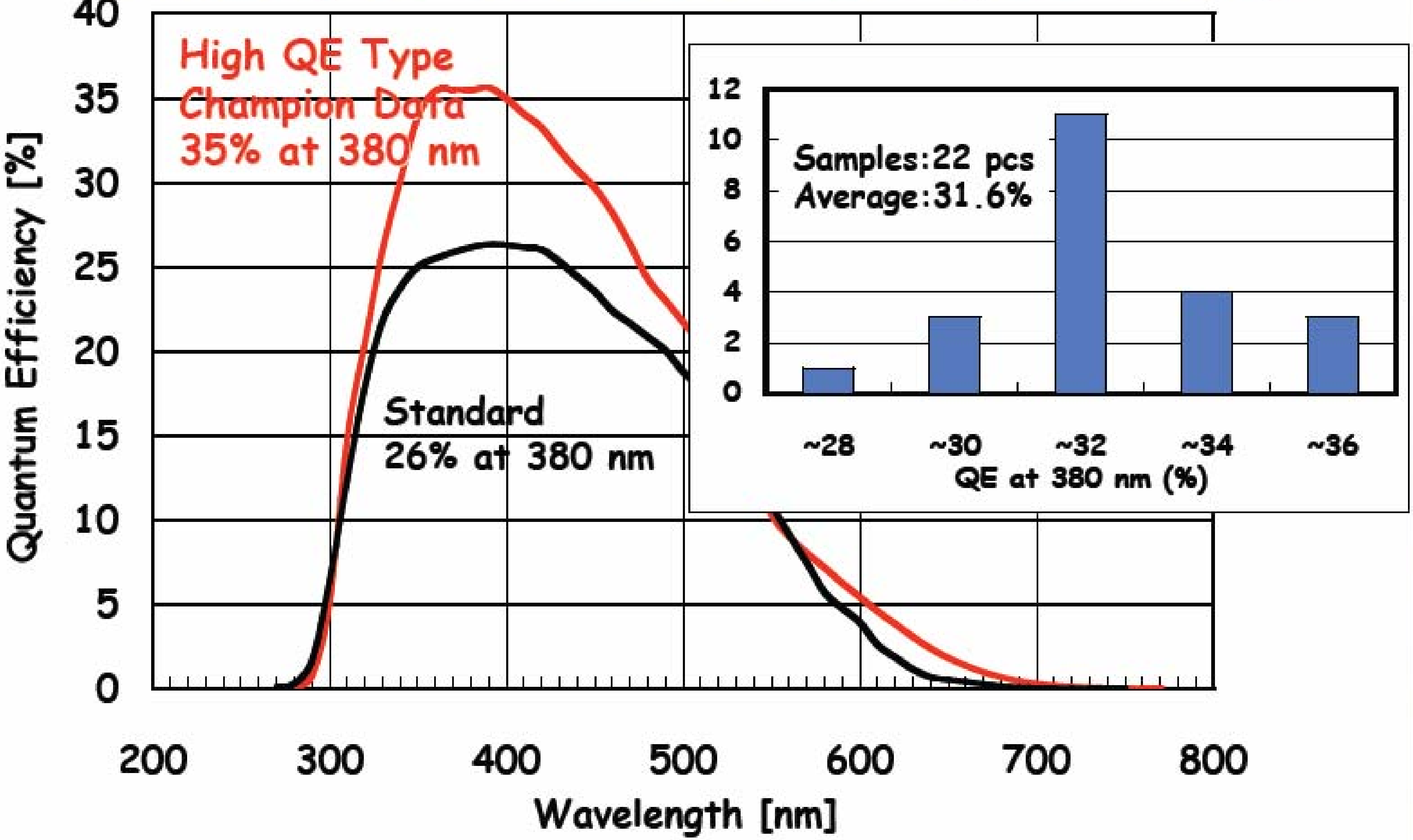
PMT: further choice

Items	Example 12-inch PMT	R7081 10-inch PMT	R5912 8-inch PMT
Diameter	300 mm	253 mm	202 mm
Effective Area	280 mm min.	220 mm min.	190 mm min.
Tube Length	330 mm	245 mm	220 mm
Dynodes	LF/10-stage	LF/10-stage	LF/10-stage
Applied Voltage	1500 V	1500 V	1500 V
GAIN	1.00E+07	1.00E+07	1.00E+07
T.T.S.(FWHM)	2.8 ns	2.9 ns	2.4 ns
P/V Ratio	2.5	2.5	2.5
Dark Counts	10,000 cps	7,000 cps	4,000 cps

NEW !

HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

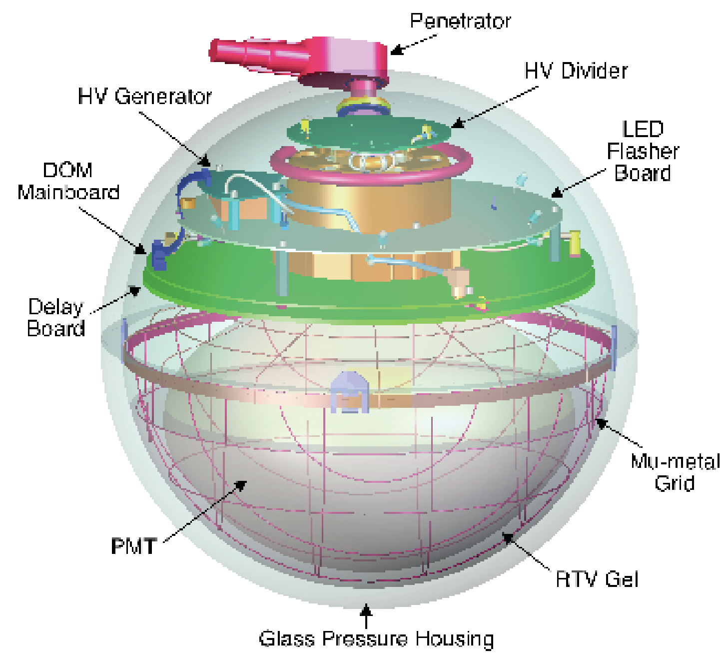
Example data R7081 (10 inch)



Goal of development is 43%

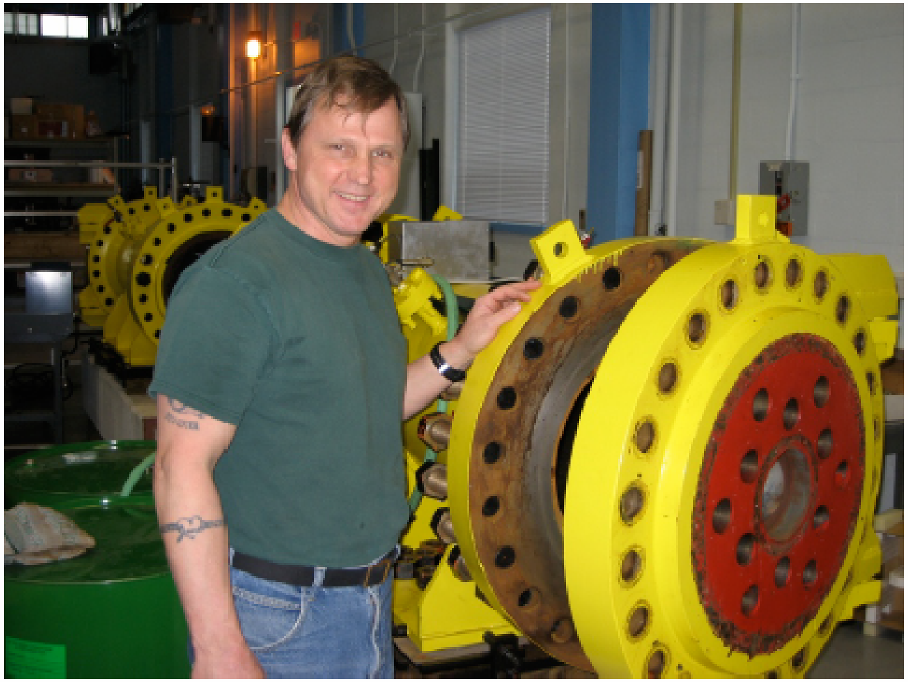
78 high quantum efficiency 10”PMT successfully tested for use in IceCube

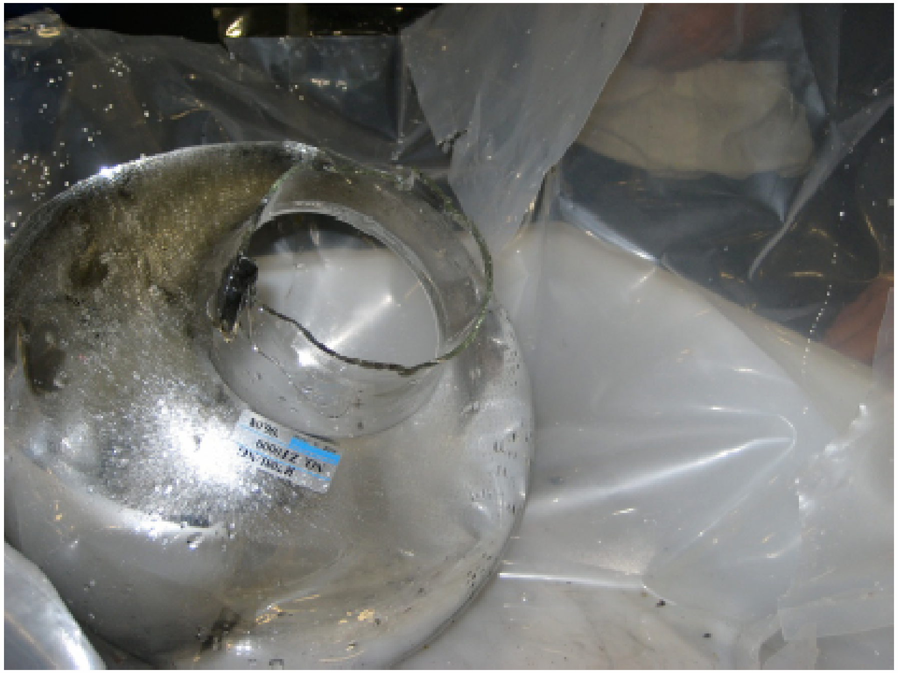
- More than 4000 sensors with standard 10” PMT (R7081-02) integrated and tested in IceCube
- 78 high quantum efficiency PMT (10”) tested with IceCube standard production test program.
- Result:
  - Quantum efficiency ~38% higher (405 nm, -40C)
  - No problems found
  - Low temperature (-40C) noise behavior scales with quantum efficiency as expected.
- Plan to use high QE PMT on 6 Deep Core strings for enhanced sensitivity at low energies (<100GeV, dark matter)
- Sensors already at the South Pole



A. Karle, UW-Madison

Pressure testing

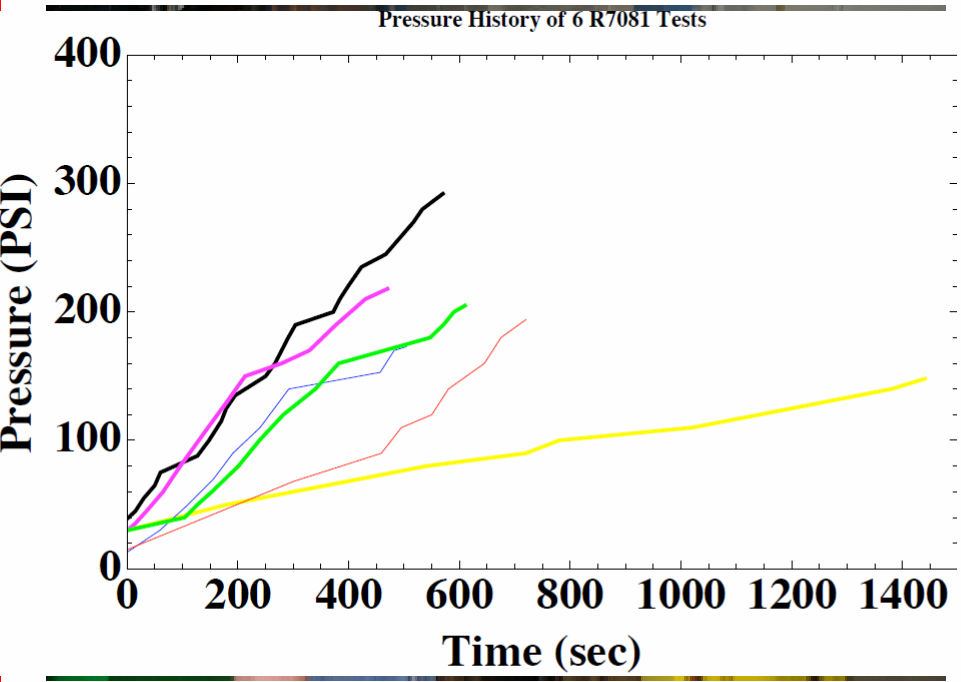


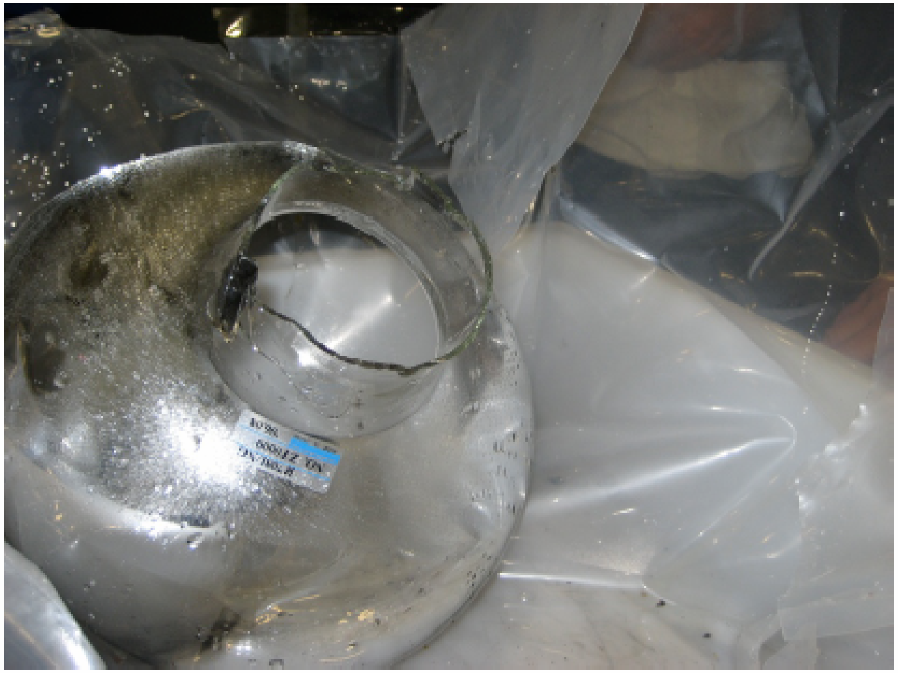


Have 32 phototubes from Hamamatsu. Pressure vessel from BNL. Evolving testing protocol.

Hamamatsu rating is ~7atm. Tested this tube until it broke at 148 psi (~10atm)

Pressure testing





Have 32 phototubes from Hamamatsu. Pressure vessel from BNL. Evolving testing protocol.

Hamamatsu rating is ~7atm. Tested this tube until it broke at 148 psi (~10atm)

Current/Future PMT R&D

- Working with Hamamatsu to improve PMT hardness
- improved QE will mean fewer PMTs needed for equivalent light collection
- Need to understand physics of implosion and improve PMT strength (new Wisconsin/RPI/BNL proposal to NSF)
- **Future: needed to devise and unambiguously test anti-chain reaction**

Electronics

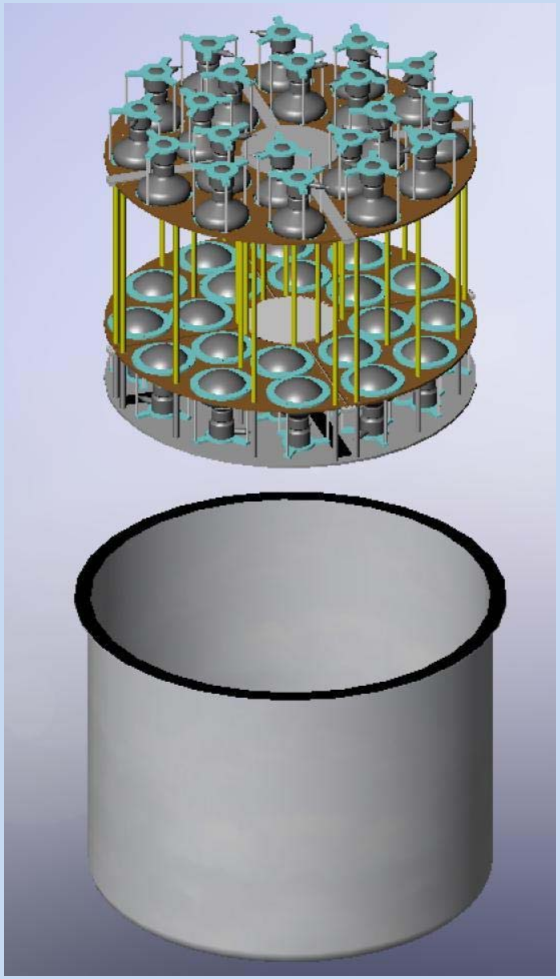
- If we have 50,000 PMT's and use same cabling scheme as used by SK, we need 13,000 km of cable!
- cross-talk, signal degradation, **high cost** associated with cable installation and storage
- how to improve this situation?

Wavelength Shifting Dyes

Use of water soluble dyes can increase Cerenkov light detection by up to a *factor of three* (SNO collaboration)
X.Dai, et al, NIM A 589 (2008) 290-295

carbostyril 124 (CS124) and Alexa Fluor 350 (AF350) are highly soluble, have strong absorption at 200-250 nm, and strong emission at 390-480 nm. Many other candidate dyes.

UC Davis test cell



LLNL WND test detector (under construction)

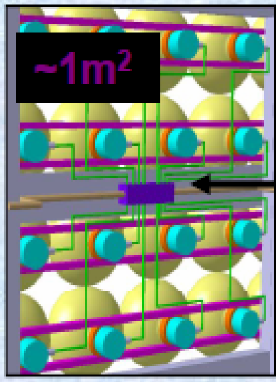
R&D : PMm2

contact: J.E.Campagne
campagne@lal.in2p3.fr

- 500k€/3yrs funded by French National Research Agency (ANR) for 2007-2010
- Participating: LAL-Orsay, IPN-Orsay, LAPP-Annecy, Photonis

PMm2 philosophy for large detectors:

Replace large PMTs (20”) by groups of smaller ones (eg.12”) originally proposed by Photonis Co. at NNN05



x16

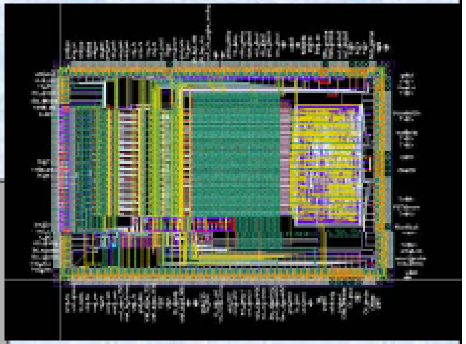
“Local”

FE-ASIC | Monitoring | HV

FPGA + µC

Network Controller

“No possible local coincidence”
(low energy event 10PMs/MeV over 81000 PMs)
⇓
TRIGGER LESS DAQ



Twisted pairs cables for
Clock sync.
- Digitized Data -
Power

“Outside”

Ethernet switches + server

DAQ

GPS receiver

*: MEMPHYS ~ 3 x 81,000 PMTs; LENA & GLACIER ~ 20,000 ÷ 30,000 PMTs

Institutional Board

- **ANL:** M. Goodman
- **Boston:** E. Kearns
- **BNL:** M.Diwan
- **Caltech:** R. McKeown
- **UC Davis:** R.Svoboda
- **UC Irvine:** H.Sobel
- **UCLA:** H.Wang
- **Chicago:** E.Blucher
- **Colorado State:** N.Buchanan
- **Columbia:** L.Camilieri
- **Drexel:** C.Lane
- **Duke:** K.Scholberg, C.Walter
- **FNAL:** R.Rameika
- **Indiana:** M.Messier
- **INFN(Catania):** R.Potenza
- **Kansas State:** T.Bolton
- **LLNL:** A.Bernstein
- **LBL:** R.Kadel
- **LSU:** T.Kutter
- **Maryland:** G.Sullivan
- **MIT:** J.Conrad
- **Minnesota:** M.Marshak, W.Miller
- **Minnesota(Duluth):** A.Habig
- **Penn:** K.Lande
- **Princeton:** K.McDonald
- **RPI:** J.Napolitano
- **S.Carolina:** C.Rosenfeld
- **U.Texas:** K.Lang
- **Tufts:** H.Gallagher
- **Wisconsin:** K.Heeger
- **Yale:** B.Fleming

Current Issues:
Depth Document
Election of Chair
Mission Statement
White Paper
Collaboration Governance

Conclusion

- Excitement over new facility at DUSEL
- “Intensity Frontier” large neutrino detector facility is being developed
- fast schedule: CD-0 now, CD-1 2009, CD-2 ~2011
- collaboration now being formed
- Thanks!

Beam	Det size (FIDUCIAL)	Exposure $\nu + \bar{\nu}$	syst. uncert on bkgd	$\sin^2 2\theta_{13}$	$\text{sign}(\Delta m^2_{31})$	CPV
NuMI/HStake	100kT	700kW 2.6+2.6yrs	5%	0.018	0.044	> 0.1
120 GeV	100kT	1MW 3+3yrs	5%	0.014	0.031	> 0.1
9mrad off-axis	300kT	1MW 3+3yrs	5%	0.008	0.017	0.025
	300kT	1MW 3+3yrs	10%	0.009	0.018	0.036
	300kT	2MW 3+3yrs	5%	0.005	0.012	0.012
	300kT	2MW 3+3yrs	10%	0.006	0.013	0.015
NuMI/HStake	100kT	1MW 3+3yrs	5%	0.012	0.037	>0.1
60GeV on-axis	300kT	1MW 3+3yrs	10%	0.008	0.021	0.037
	300kT	2MW 3+3yrs	5%	0.005	0.013	0.015

M.Bishai, ANL, P5 presentation

Some History

- NSF establishes DUSEL Experiment Development Committee (DEDC) late 2007
- DEDC asks M. Diwan and R. Svoboda to help organize a collaboration acting as Interim Project Coordinators (IPC's). First meeting at Homestake, April 2008
- FNAL meetings June and August. Formation of DUSEL LB Interest Group

- IPC’s appoint Interim Executive Board (IEB) in August
- This IEB is currently drafting a recommendation to the NSF for what depth would be appropriate to begin studying for location of a large detector
- In October, an Institutional Board (IB) was formed under a charter document drafted by the IEB. The IB consists of a representative from each institution.
- The IB met for the first time as a collaboration in October at BNL.

The Interim Executive Board

- E. Blucher, Chicago (Chair)
- A. Bernstein, LLNL
- B. Fleming, Yale
- E. Kearns, Boston
- J. Klein, Penn
- K. Lande, Penn
- D. Lissauer, BNL
- R. KcKeown, Caltech
- R. Rameika, FNAL
- K. Scholberg, Duke
- J. Siegrist, LBL
- H. Sobel, UC Irvine
- G. Sullivan, Maryland
- R. Svoboda, UC Davis and M. Diwan, BNL (ex-officio)

This Board has met 7 times since August 1, 2008.

This Interim Board will eventually be replaced by an Executive Board formed by the more representative Institutional Board

Controlling Costs

- **Cavern:** timely geotechnical investigation
- **Cavern:** reduce container cost, shape optimization
- **Cavern:** improve PMT mechanical strength
- **PMT's:** improve quantum efficiency
- **PMT's:** enhance industrial capability and competitiveness
- **PMT's:** Optimization for scope, possible phasing
- **Water System:** materials testing and selection
- **Electronics:** development of distributed, low-

R&D : MEMPHYNO

A small scale prototype of MEMPHYS

- ~10t of water (+Gd?)
- 2x2x2m^3 HDPE tank
- Matrix of 16 12" PMTs (from PMm2 R&D) and/or other photodetectors (e.g.: X-HPX)
- muon hodoscope
  2+2 planes of OPERA-like scintillator bars

APC-Paris
LAL-Orsay
LAPP-Annecy

PMT’s

- Roof spans are an important factor in cavern cost
- cavern depth is currently limited by ability of PMT’s to withstand implosion
- BNL program to investigate *how* PMT’s implode is underway in collaboration with Hamamatsu
- BNL, RPI, Wisconsin PSL proposal for improving PMT strength submitted to NSF PNA program

Reducing Cost of PMT’s

- New high Q.E. PMT’s from Hamamatsu would reduce number of PMT’s required. SK has 11,200 20” PMT’s with ~23% QE (40% coverage and 4 MeV threshold)
- New 10” PMT’s would require ~50,000 for 100 kton detector for “effective” 25% coverage
- We do not need a low threshold, but we do want to keep tracking resolution
- *What is the optimal number of PMT’s?*