Abstract

Long-baseline (LBL) accelerator neutrino oscillation experiments, such as NOvA and T2K in the current generation, and DUNE-LBL and HK-LBL in the coming years, will measure the remaining unknown oscillation parameters with excellent precision. These analyses assume external input on the solar parameters, θ_{12} and Δm^2_{21}, from solar experiments such as SNO, SK, and Borexino, as well as reactor experiments like KamLAND. Here we investigate their role in long-baseline experiments. We show that, without input on solar parameters, the sensitivity to detecting and quantifying CP violation is significantly, but not entirely, reduced. Thus long-baseline accelerator experiments can actually determine the solar parameters, and thus all six oscillation parameters, without input from *any* other oscillation experiment. In particular, Δm^2_{21} can be determined; thus DUNE-LBL and HK-LBL can measure both the solar and atmospheric mass splittings in their long-baseline analyses alone. While their sensitivities are not competitive with existing constraints, they are very orthogonal probes of solar parameters and provide a key consistency check of a less probed sector of the three-flavor oscillation picture. Furthermore, we also show that the true values of the solar parameters play an important role in the sensitivity of other oscillation parameters such as the CP violating phase δ.

Here Comes the Sun:
Solar Parameters in Long-Baseline Accelerator Neutrino Oscillations

Peter B. Denton

Pheno

May 8, 2023

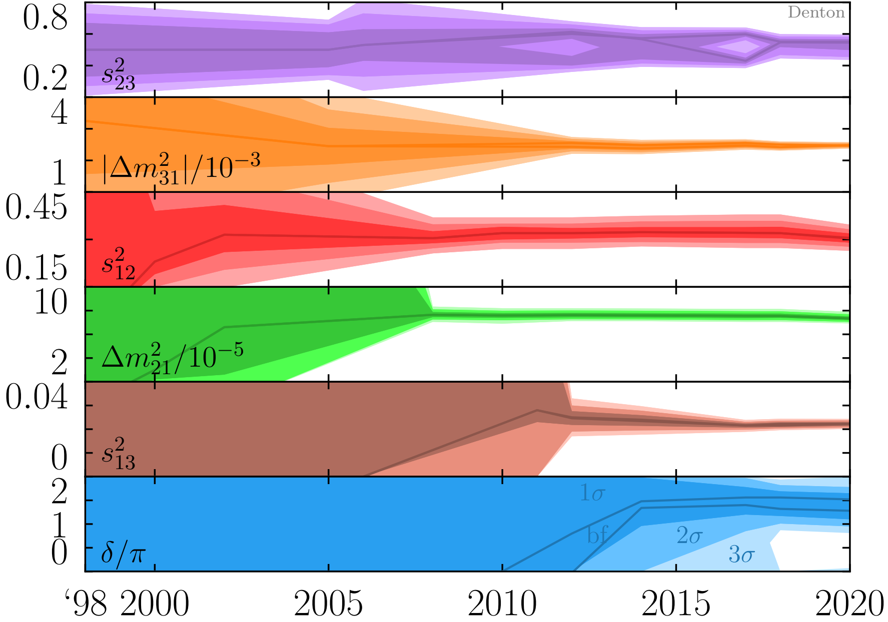
2302.08513

with Julia Gehrlein

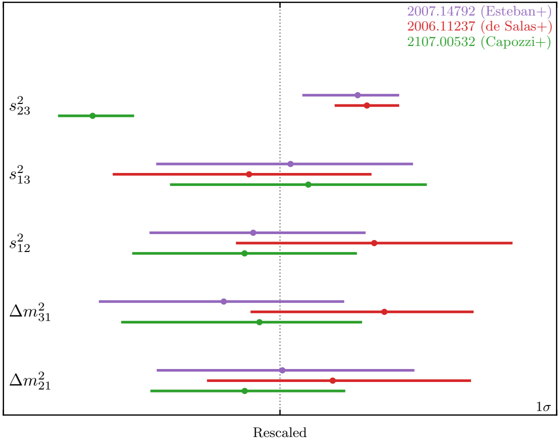
Brookhaven National Laboratory

Brookhaven NDI Neutrino Discovery Initiative

Speaking from Osage land

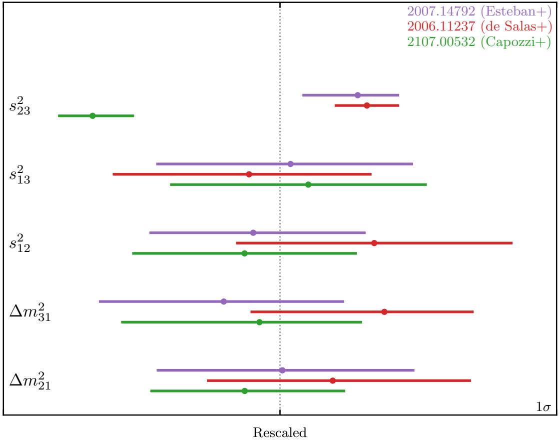

Denton
0.8
0.2
s^2_{23}
4
1
$|\Delta m^2_{31}|/10^{-3}$
0.45
0.15
s^2_{12}
10
2
$\Delta m^2_{21}/10^{-5}$
0.04
0
s^2_{13}
2
1
0
δ/π
1σ
bf
2σ
3σ
'98 2000
2005
2010
2015
2020

Global fit comparison



Esteban+ 2007.14792
de Salas+ 2006.11237
Capozzi+ 2107.00532

Global fit comparison



Esteban+ 2007.14792
de Salas+ 2006.11237
Capozzi+ 2107.00532

Global fit uncertainty $\Rightarrow \sim 1\sigma$ extra uncertainty

δ and CP violation

$$J_{CP} = s_{12}c_{12}s_{13}c_{13}^2 s_{23}c_{23}\sin\delta$$

C. Jarlskog PRL 55, 1039 (1985)

δ and CP violation

$$J_{CP} = s_{12}c_{12}s_{13}c_{13}^2s_{23}c_{23}\sin\delta$$

C. Jarlskog PRL 55, 1039 (1985)

1. Strong interaction: no observed EDM $\Rightarrow$ CP (nearly) **conserved**

$$\frac{\bar{\theta}}{2\pi} < 10^{-11}$$

J. Pendlebury, et al. 1509.04411

2. Quark mass matrix: non-zero but **small** CP violation

$$\frac{|J_{\rm CKM}|}{J_{\rm max}} = 3\times10^{-4}$$

CKMfitter 1501.05013

3. Lepton mass matrix: **?**

$$\frac{|J_{\rm PMNS}|}{J_{\rm max}} < 0.34$$

PBD, J. Gehrlein, R. Pestes 2008.01110

$J_{\rm max} = \frac{1}{6\sqrt{3}} \approx 0.096$

CP violation

- Need appearance to measure it
- Appearance has only been clearly seen in long-baseline accelerator neutrinos at NOvA and T2K

T2K 1502.01550

NOvA 1601.05022

But see also solar, atmospheric, and astrophysical

- Appearance probabilities depend on all six parameters

CP violation

- Need appearance to measure it
- Appearance has only been clearly seen in long-baseline accelerator neutrinos at NOvA and T2K

T2K 1502.01550

NOvA 1601.05022

But see also solar, atmospheric, and astrophysical

- Appearance probabilities depend on all six parameters

Can't determine CP violation
without knowing all five other parameters!

True in two ways

Which parameters are important?

DUNE-LBL and HK-LBL will have world-leading measurements of:

1. Δm^2_{31}
2. θ_{23}
3. δ
4. θ_{13} (ish)

External information on those parameters won't help much

Which parameters are important?

DUNE-LBL and HK-LBL will have world-leading measurements of:

1. Δm^2_{31}
2. θ_{23}
3. δ
4. θ_{13} (ish)

External information on those parameters won't help much

What about Δm^2_{21} and θ_{12}?

Solar parameter status

Data	Δm^2_{21} [10^{-5} eV^2]	$\sin^2\theta_{12}$	Ref.
SK+SNO	6.10	0.305	SK Neutrino 2022
KamLAND	$\pm$7.54	0.316	1303.4667 SK Neutrino 2022
SK+SNO+KamLAND	**7.49**	**0.305**	SK Neutrino 2022
Global fit	7.42	0.304	Esteban+ 2007.14792
	7.5	0.318	de Salas+ 2006.11237
	7.36	0.303	Capozzi+ 2107.00532

Solar parameter status

Data	Δm^2_{21} [10^{-5} eV^2]	$\sin^2\theta_{12}$	Ref.
SK+SNO	6.10	0.305	SK Neutrino 2022
KamLAND	$\pm$7.54	0.316	1303.4667 SK Neutrino 2022
SK+SNO+KamLAND	**7.49**	**0.305**	SK Neutrino 2022
Global fit	7.42	0.304	Esteban+ 2007.14792
	7.5	0.318	de Salas+ 2006.11237
	7.36	0.303	Capozzi+ 2107.00532

Generation	Data	$\delta x/x$ Δm^2_{21}	$\delta x/x$ $\sin^2\theta_{12}$	Ref.
Current	SK+SNO	15%	4.6%	SK Neutrino 2022
	KamLAND	2.5%	9.5%	1303.4667 SK Neutrino 2022
	SK+SNO+KamLAND	**2.4%**	**4.3%**	SK Neutrino 2022
	Global fit	2.8%	4.3%	Esteban+ 2007.14792
		2.9%	5.0%	de Salas+ 2006.11237
		2.2%	4.3%	Capozzi+ 2107.00532
Future	DUNE-solar	5.9%	3.0%	Capozzi+ 1808.08232
	JUNO	0.3%	0.5%	JUNO 2204.13249

Neutrino mass eigenstate definition: aside

The mass eigenstates can be numbered in a number of different ways

1. $|U_{e1}| > |U_{e2}| > |U_{e3}|$
2. $m_1 < m_2 < m_3$
3. $m_1 < m_2$ and $|U_{e3}| < |U_{e1}|$ and $|U_{e3}| < |U_{e2}|$
4. $\vdots$

PBD 2003.04319
PBD, R. Pestes 2006.09384
PBD, S. Parke 2106.12436

Neutrino mass eigenstate definition: aside

The mass eigenstates can be numbered in a number of different ways

1. $|U_{e1}| > |U_{e2}| > |U_{e3}|$
2. $m_1 < m_2 < m_3$
3. $m_1 < m_2$ and $|U_{e3}| < |U_{e1}|$ and $|U_{e3}| < |U_{e2}|$
4. $\vdots$

- #3 was commonly used in solar neutrinos
- We know that in the solar sector all three are equivalent
- We take #1 as our definition

PBD 2003.04319
PBD, R. Pestes 2006.09384
PBD, S. Parke 2106.12436

Neutrino mass eigenstate definition: aside

The mass eigenstates can be numbered in a number of different ways

1. $|U_{e1}| > |U_{e2}| > |U_{e3}|$
2. $m_1 < m_2 < m_3$
3. $m_1 < m_2$ and $|U_{e3}| < |U_{e1}|$ and $|U_{e3}| < |U_{e2}|$
4. $\vdots$

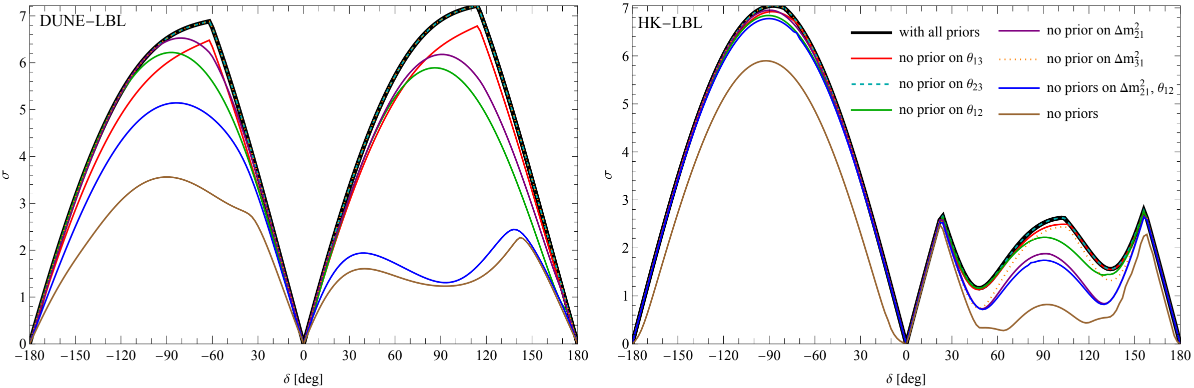
- #3 was commonly used in solar neutrinos
- We know that in the solar sector all three are equivalent
- We take #1 as our definition

Thus $\theta_{12} \in [0, 45°]$ by definition
Only solar data tells us that $\Delta m^2_{21} > 0$

PBD 2003.04319
PBD, R. Pestes 2006.09384
PBD, S. Parke 2106.12436

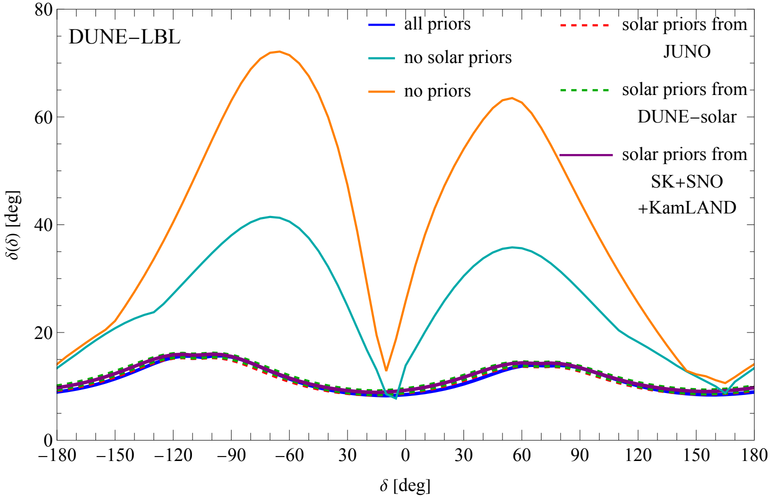
Impact of current priors

How much does removing one prior change the McDonald's plot?



(Bad degeneracy for HK-LBL for $\delta > 0$ and NO or $\delta < 0$ and IO, see backup)

Precision on δ

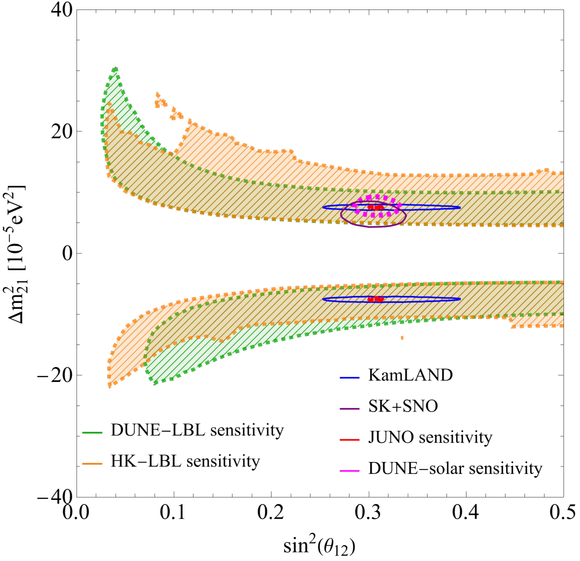


So external information on solar parameters is crucial

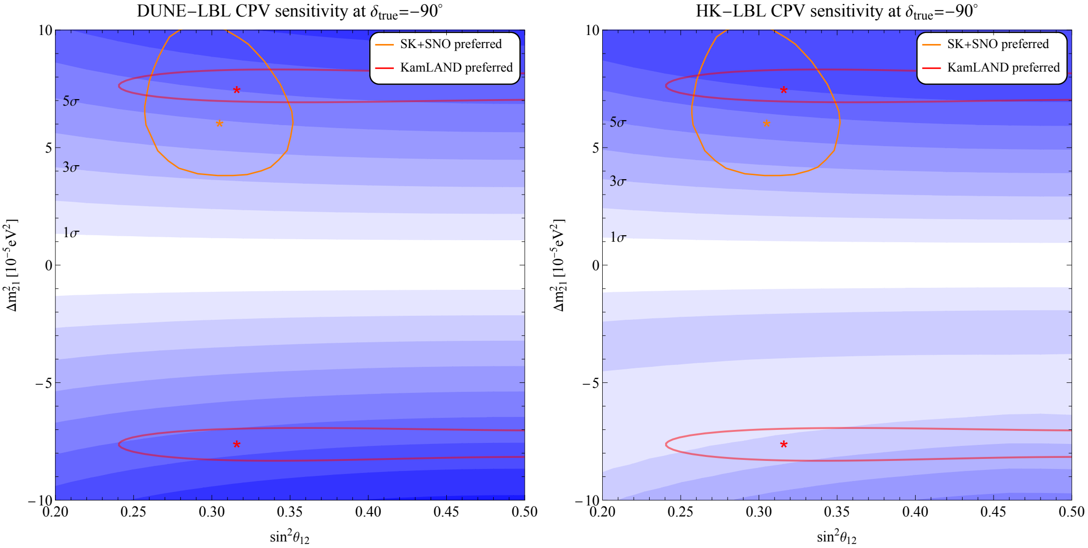
So external information on solar parameters is crucial

Some sensitivity to CP violation with no solar information?

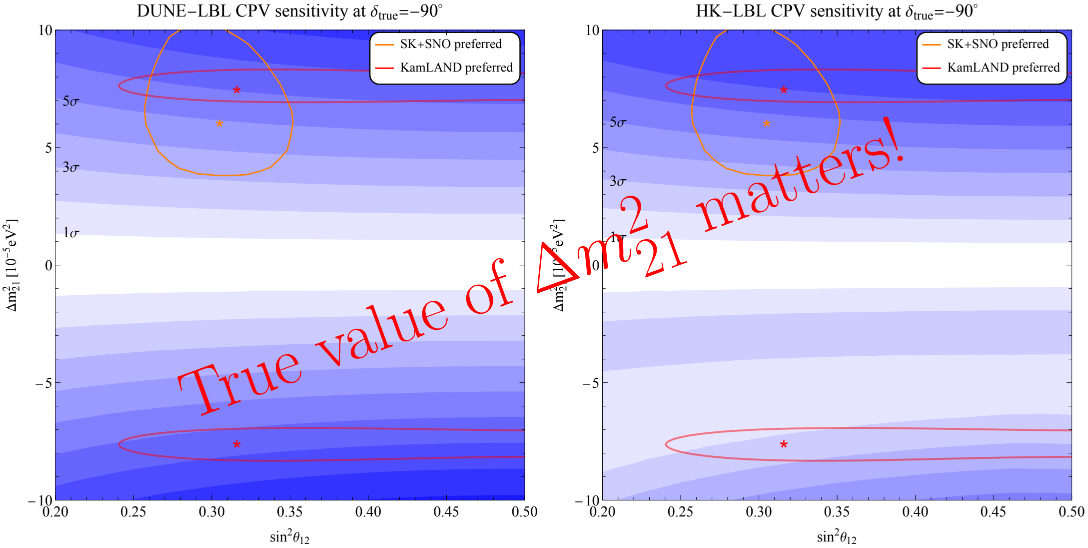
LBL can measure solar parameters!



True values matter



True values matter



Long-baseline solar parameter summary

- To reach δ goals, DUNE & HK *need* external input on Δm^2_{21} and θ_{12}
- DUNE & HK can provide a very orthogonal cross check of solar parameters
- Pay attention to the exact value of Δm^2_{21} that JUNO measures

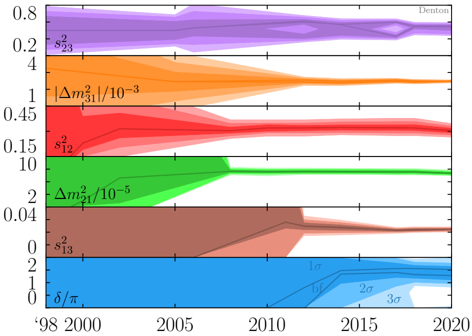
Long-baseline solar parameter summary

- To reach δ goals, DUNE & HK *need* external input on Δm^2_{21} and θ_{12}
- DUNE & HK can provide a very orthogonal cross check of solar parameters
- Pay attention to the exact value of Δm^2_{21} that JUNO measures

Thanks!

Backups

References



SK hep-ex/9807003

M. Gonzalez-Garcia, et al. hep-ph/0009350

M. Maltoni, et al. hep-ph/0207227

SK hep-ex/0501064

SK hep-ex/0604011

T. Schwetz, M. Tortola, J. Valle 0808.2016

M. Gonzalez-Garcia, M. Maltoni, J. Salvado 1001.4524

T2K 1106.2822

D. Forero, M. Tortola, J. Valle 1205.4018

D. Forero, M. Tortola, J. Valle 1405.7540

P. de Salas, et al. 1708.01186

F. Capozzi et al. 2003.08511

δ: what is it really?