Concluding remarks

A. Yu. Smirnov

Max-Planck Institute fuer Kernphysik, Heidelberg, Germany

Workshop on recent developments in Neutrino physics and astrophysics, Gran Sasso, September 7, 2017

Content

Solar neutrinos

Atmospheric neutrinos

Sterile neutrinos

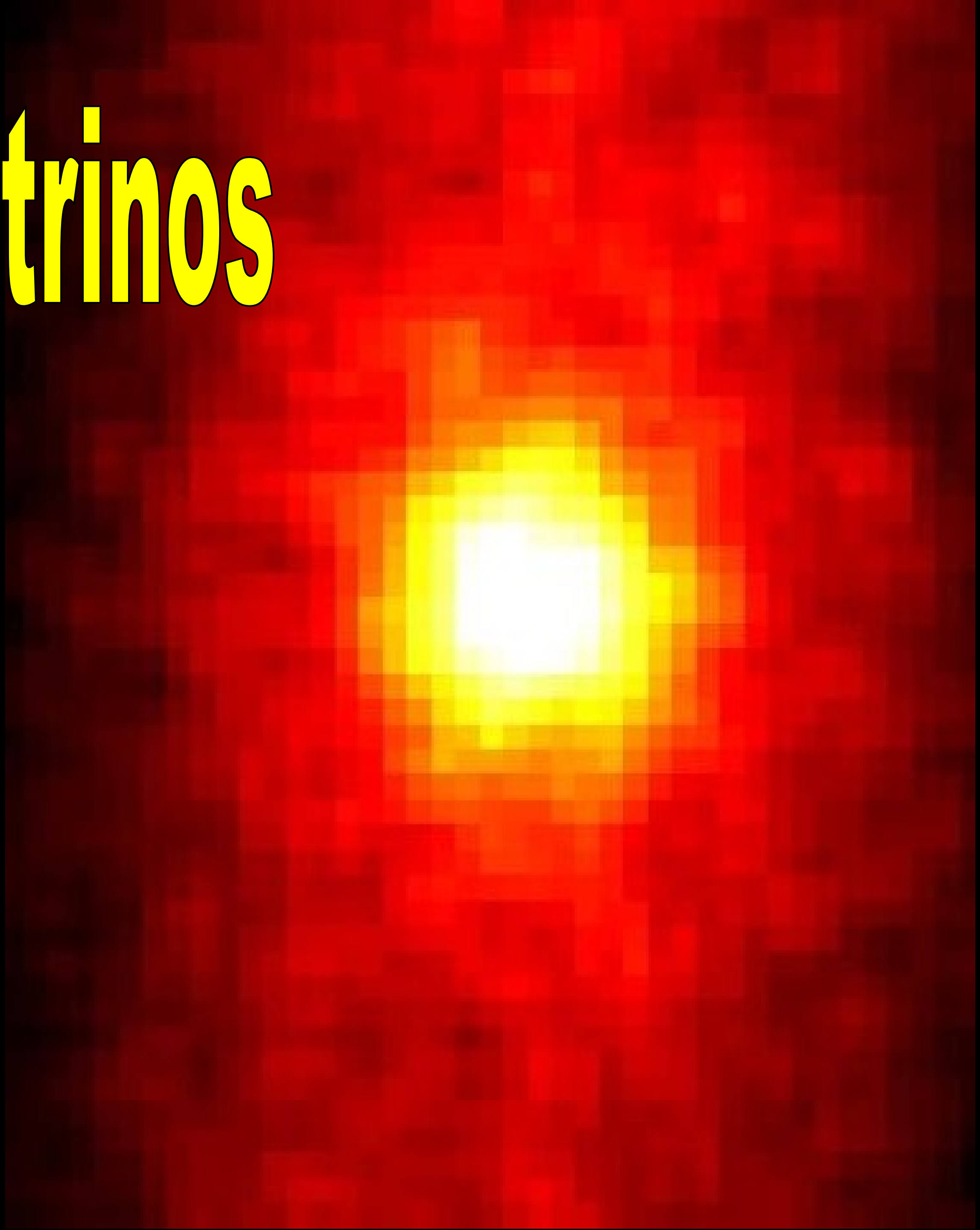
Neutrinos and DM

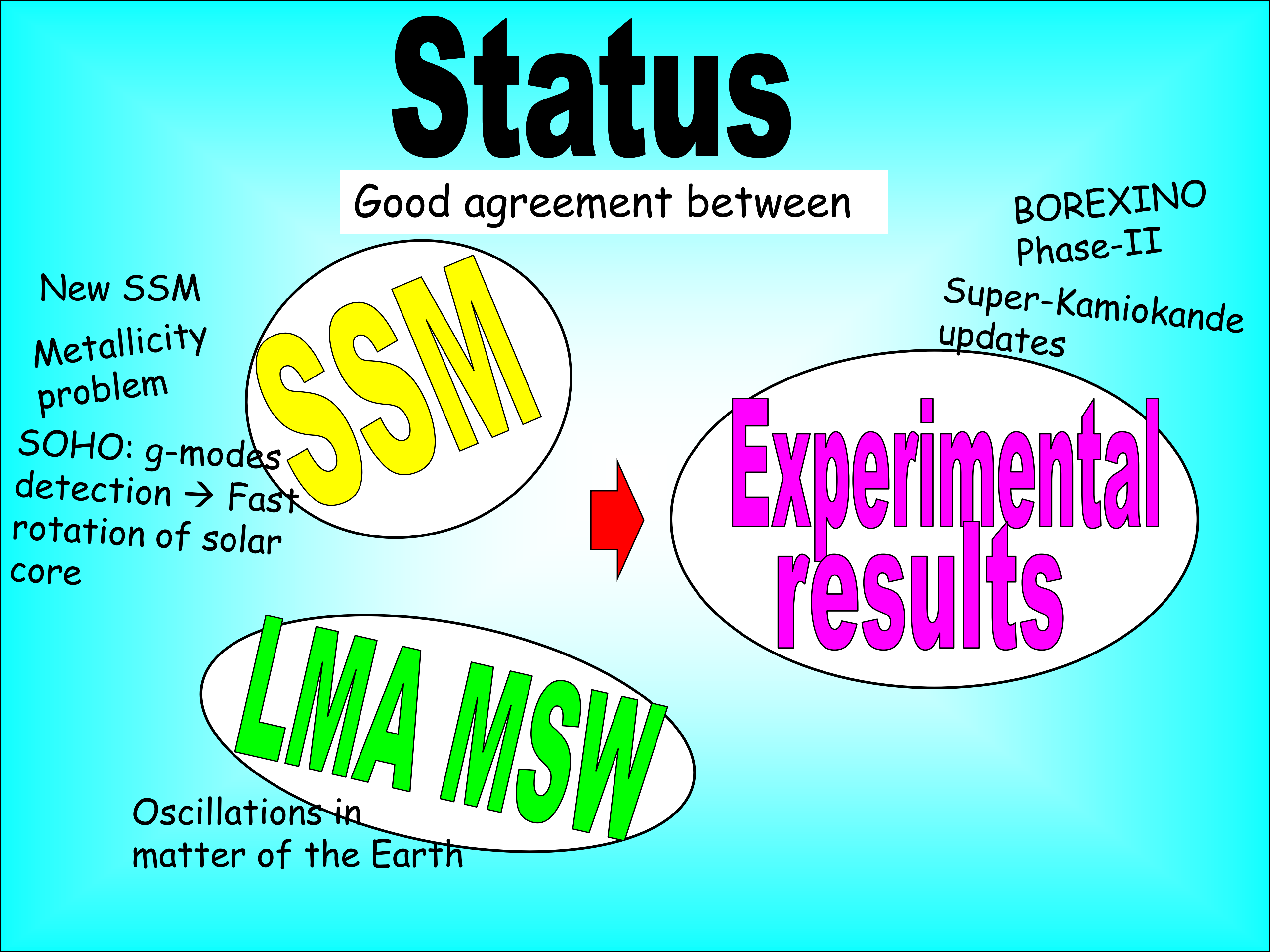
Cosmic neutrinos

...

with comments on

1. Solar Neutrinos

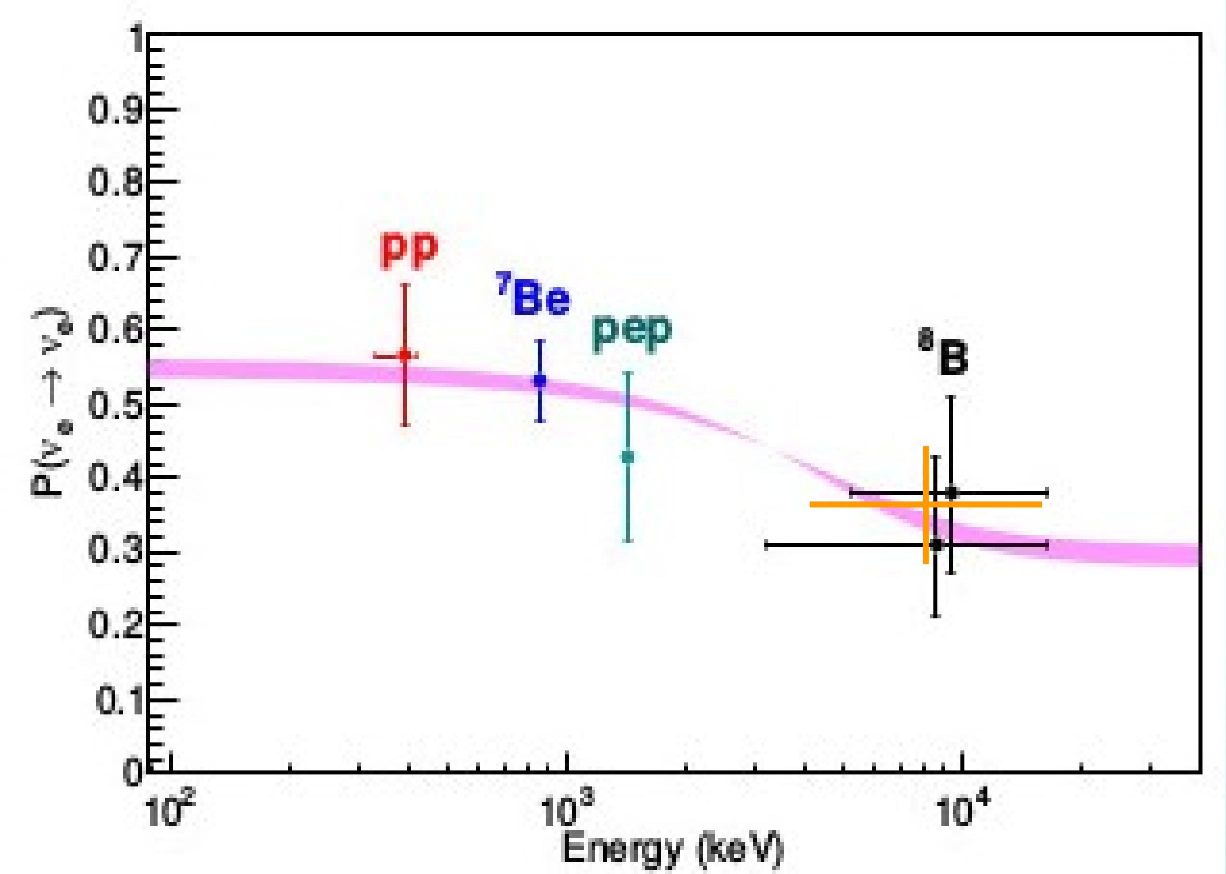



Status
Good agreement between
SSM
Experimental results
LMA MSW
New SSM
Metallicity problem
SOHO: g-modes detection → Fast rotation of solar core
BOREXINO Phase-II
Super-Kamiokande updates
Oscillations in matter of the Earth

BOREXINO - Solar

Borexino Collaboration (Agostini, M. et al.) arXiv:1707.09279 [hep-ex]

G. Bellini
B. Caccianiga



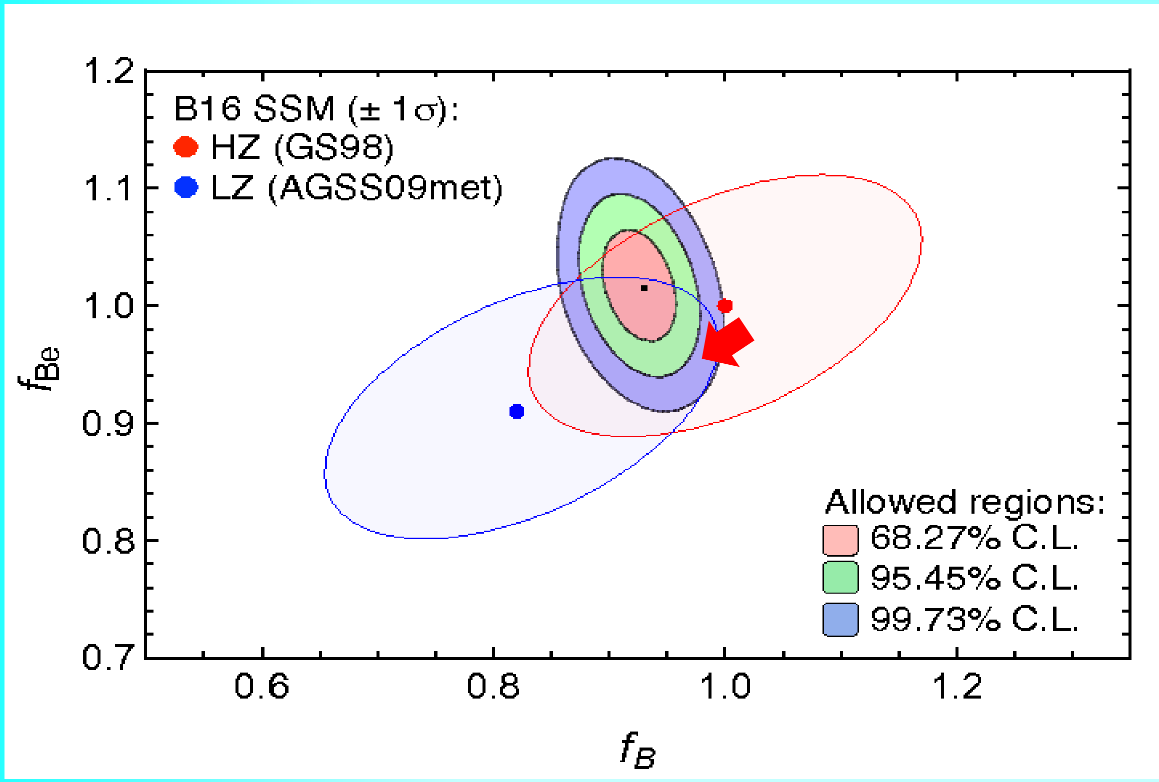
Energy profile of the effect is determined by mixing in matter in production point + oscillations inside the Earth

D. Franco

Scaring agreement

Problems in details
% level precision

Distinguishing metallicity models with neutrinos



Borexino Collaboration (Agostini, M. et al.) arXiv:1707.09279 [hep-ex]

Theoretical uncertainties should be reduced

LZ is disfavored at 3.1σ level

with new models

A. Di Leva

Allowed contours obtained by combining the new result on 7Be ν's with solar and KamLAND data. $\sin^2\theta_{13} = 0.02$

Testing Flux- Luminosity relation

$$F_\nu = \frac{2 L_{sun}}{Q - 2\langle E\rangle}$$

$Q = 26.73$ MeV

$$\langle E\rangle = \Sigma_i E_i \frac{F_i}{F^{tot}} = 0.265 \text{ MeV}$$

$F^{tot} = \Sigma_i F_i$

Test of the relation – test of assumptions

1. Photon diffusion time: $t_{diff} \sim 10^5$ years →

$F_\nu(t_0)$ ⇔ $L_{sun}(t_0 + t_{diff})$

The present luminosity can be used if changes in the energy release and diffusion parameters can be neglected

2. No additional sources of energy exist.
3. Fraction of unterminated chains is negligible.

Presently $L_{sun}^{inf} / L_{sun} = 1.03 +/- 0.08$ *A. Serenelli*

g - modes and core rotation

E Fossat et al, A&A 604, A40 (2017)

SOHO, GOLF 16.5 years data, observation (via modulation of p-modes) of g-modes : 100 at 1 deg, > 100 2deg (buoyancy as restoration force)

Mean rotation rate of core	3.8+/- 0.1	Mean rotation rate of the radiation envelope

1644+/-23 nHz (T = 7days)

Difficult to explain by models describing a pure angular momentum evolution without adding new dynamical processes (e.g. internal magnetic breaking at earlier)

implications

Rotation → diffusion of elements in core → lower neutrino fluxes??

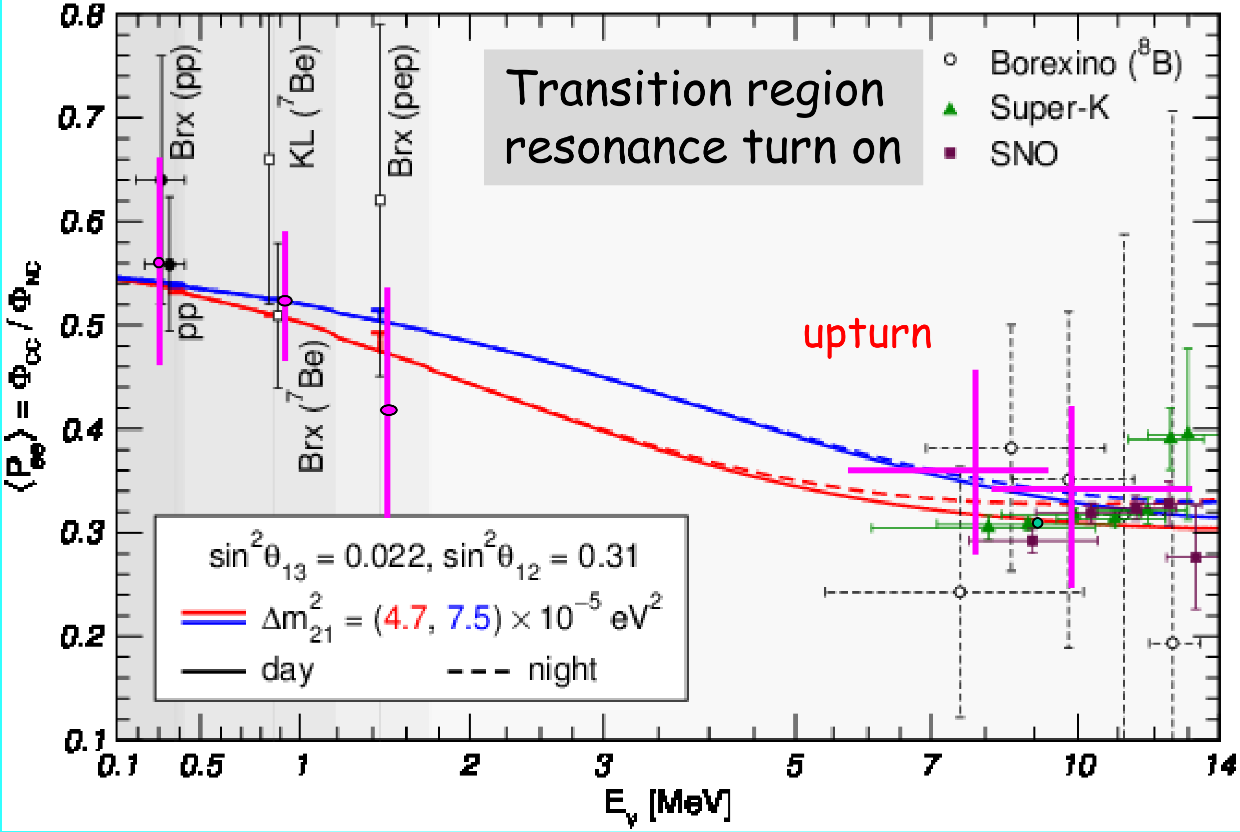
Change of SSM
In substantial way →
Affect neutrino fluxes

New problem or a way to resolve existing problems?

BOREXINO spectroscopy

M. Maltoni, A.Y.S. 1507.05287 [hep-ph]

Borexino Collaboration (Agostini, M. et al.) arXiv:1707.09279 [hep-ex]



LMA MSW predicion for two different values of Δm_{21}^2

best fit value from solar data

best global fit

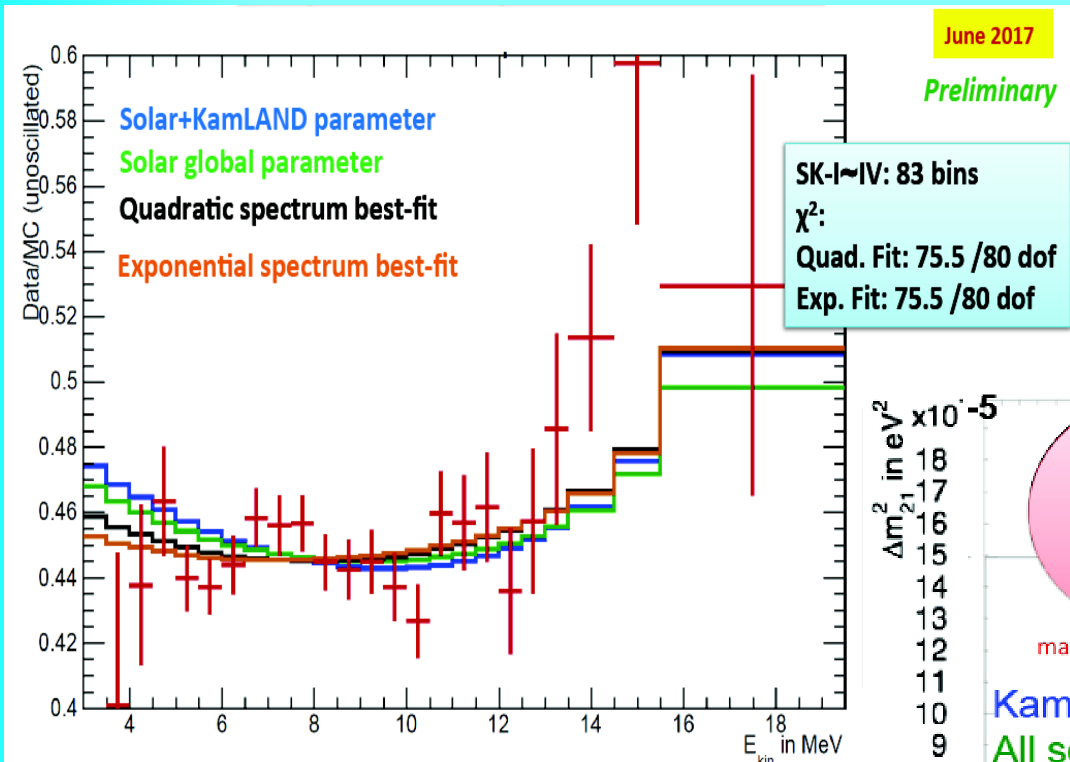
Reconstructed exp. points for SK, SNO and BOREXINO at high energies

BOREXINO

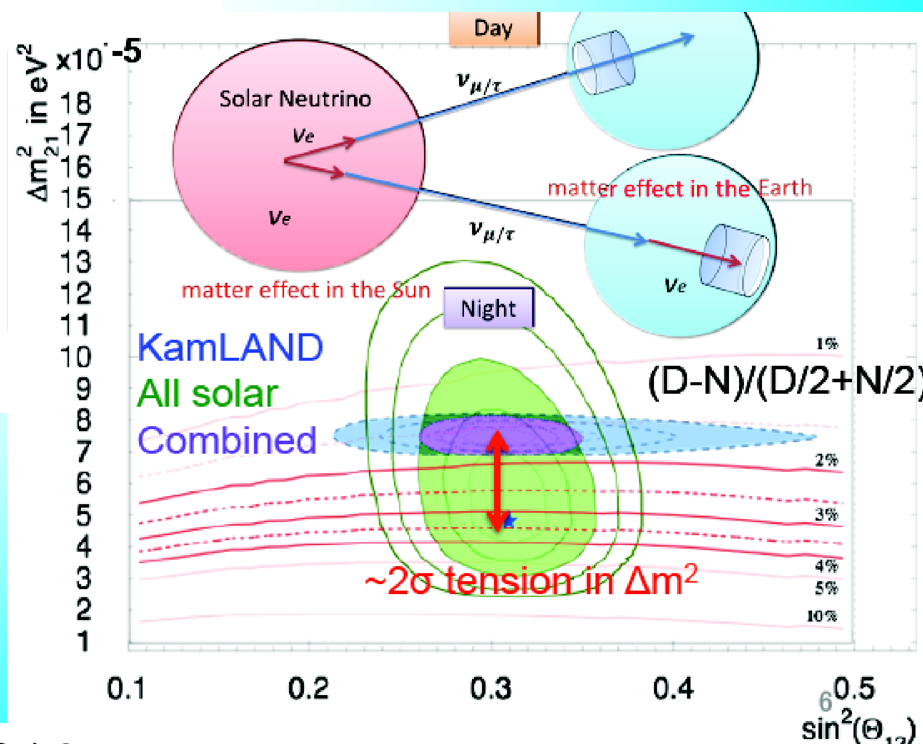
pp: agreement with global fit result
Be: higher accuracy
pep: (phase I + phase II – ideal agreement)
B: 2 times smaller errors, upturn...

Precision measurements in 5 – 10 MeV

Super-Kamiokande results



T. Yano. ICRC 2017



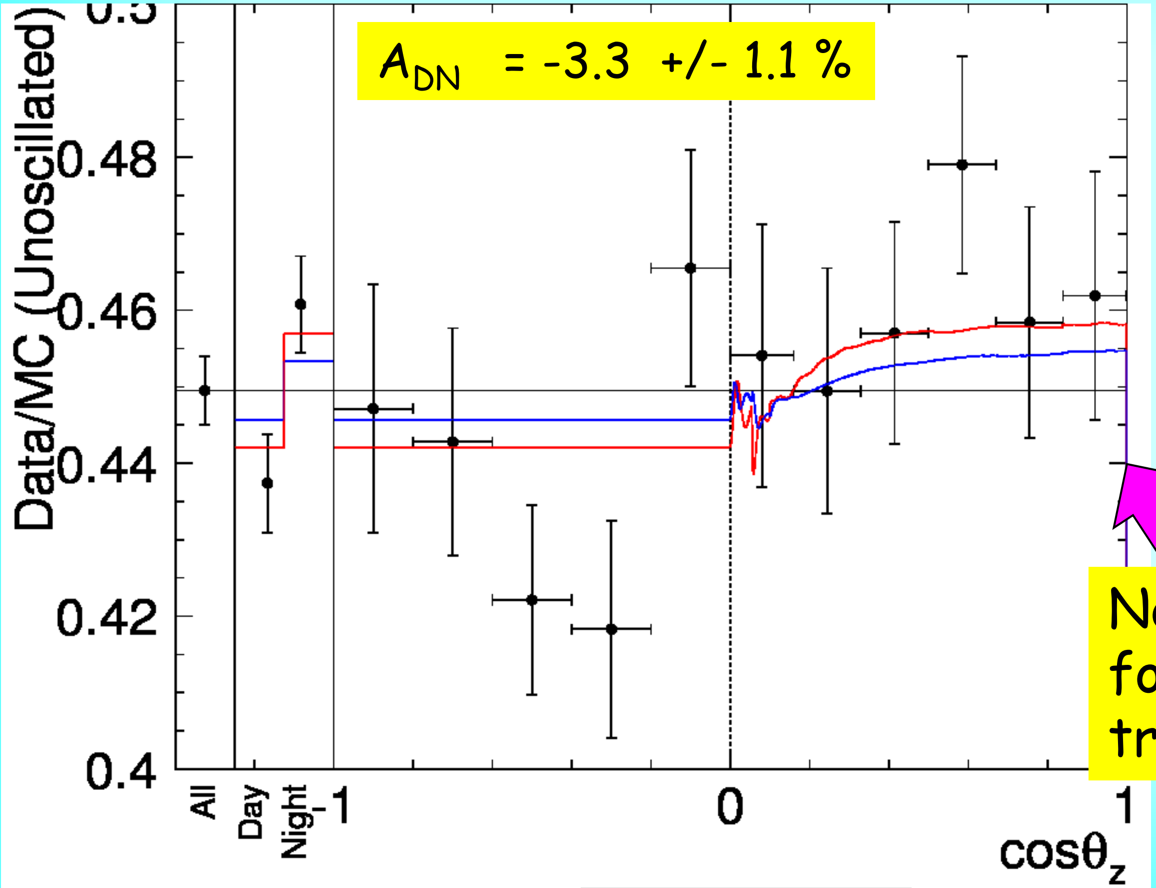
SK-IV 18 events/day
+ 280 days until march 17,
E = 3.5 – 19.5 MeV
SK I – IV total 5480 days

Data/MC(no-osc) = 0.4486 +/- 0.0062

SK: Earth matter effect

SK Collaboration (Abe, K. et al.)
arXiv:1606.07538 [hep-ex]

SK-IV solar zenith angle dependence



No enhancement for core crossing trajectories

Generic features:

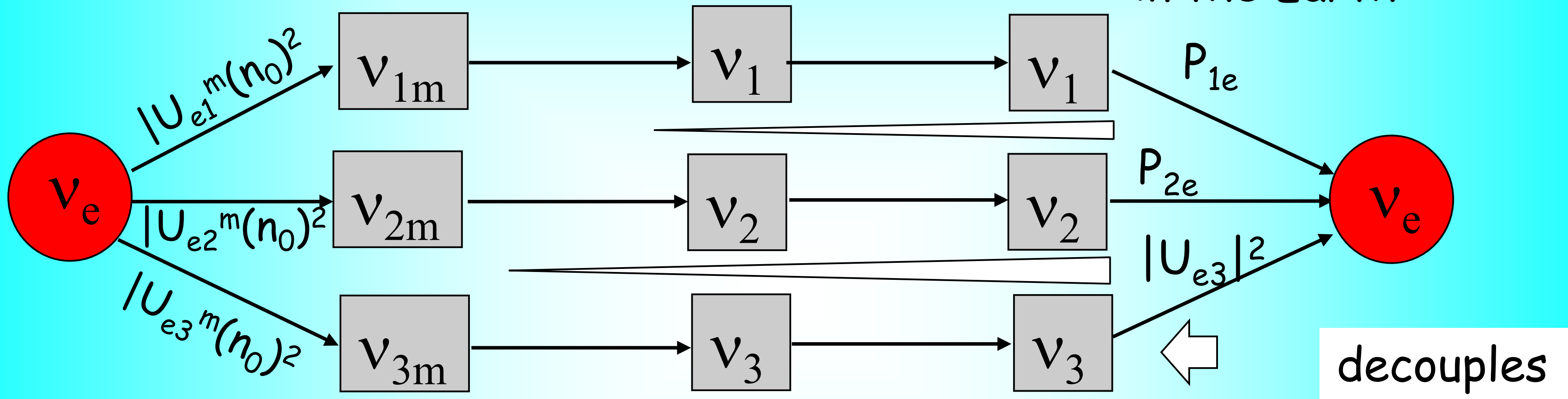
Oscillatory pattern

dip

Explained by the Attenuation effect

LMA-MSW physics

projection | propagation in the Sun | from the Sun to the Earth | propagation in the Earth



mixing at production

adiabatic conversion

loss of coherence

oscillations in multi-layer medium

$$P_{ee} = \Sigma_i |U_{ei}^m(n_0)|^2 \, P_{ie}$$

during a day $P_{ie} = |U_{ei}|^2$

Scale invariance: no dependence on distance, phase...

Oscillations in the Earth

Incoherent fluxes of mass state arrive at the Earth.
They split into eigenstates in matter and oscillate.

Mixing of the mass states in matter

$$U^{mass} = U_{PMNS}^{+} U^{m}$$

For 2ν case

$$\sin 2\theta' = \frac{c_{13}^2 \varepsilon_{21} \sin 2\theta_{12}}{\sqrt{(\cos 2\theta_{12} - c_{13}^2 \varepsilon_{21})^2 + \sin^2 2\theta_{12}}} = c_{13}^2 \varepsilon_{21} \sin 2\theta_{12}^m$$

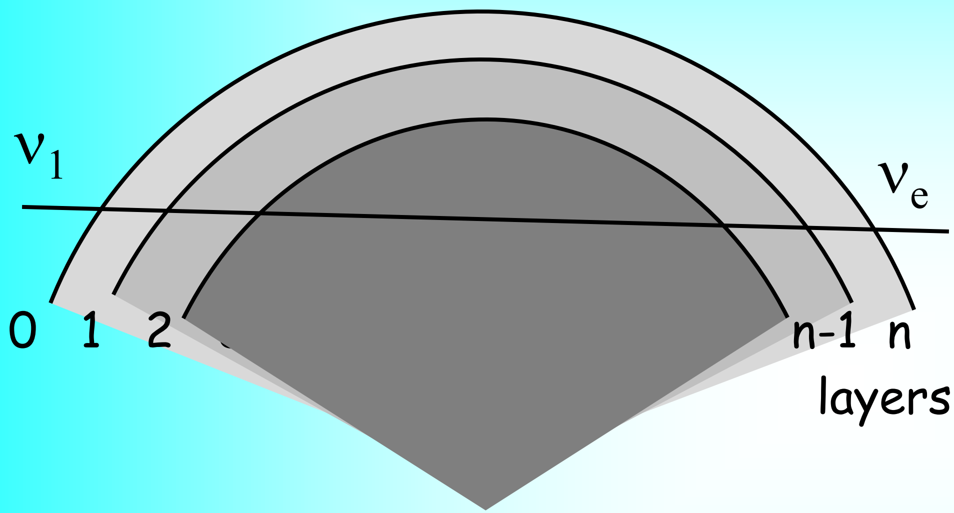
$$\varepsilon_{21} = \frac{2VE}{\Delta m_{21}^2} = 0.03\, E_{10}\, \rho_{2.6}$$

determines smallness of effects

MeV g/cm^3

Low density regime

Regeneration



Layers with slowly changing density and density jump

Evolution matrix (matrix of transition amplitudes)

$S = U^m{}_n \Pi_k D_k U_{k,k-1}$

$U^m{}_n$ - flavor mixing matrix, projects onto flavor state in the end

D_k - describe the adiabatic evolution within layers

$D_k = \mathrm{diag}\,(e^{-0.5i\phi_\kappa},\ e^{0.5i\phi_\kappa})$

$\phi_\kappa = \int dx(H_{2m} - H_{1m})$

adiabatic phase acquired in k layer

$U_{k,k-1}$ - describes change of basis of eigenstates between k and k-1 layers

$U_{k,k-1} = U(-\Delta\theta_{k-1})$

$\Delta\theta_{k-1}$ -change of the mixing angle in matter after k-1 layer

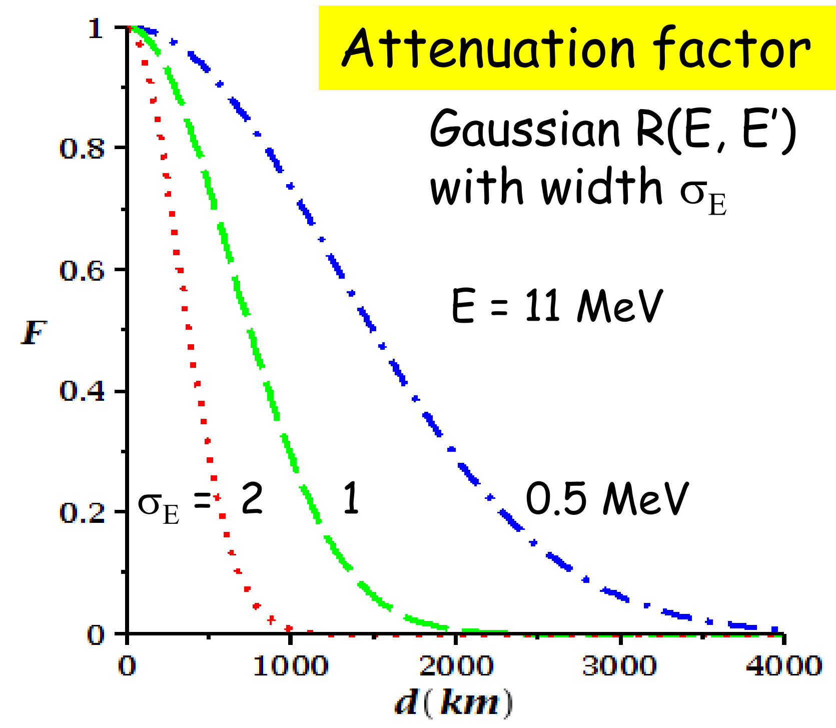
Attenuation effect

Integration with the energy resolution function R(E, E′):

$$\langle f_{reg} \rangle = \int dE' \, R(E, E') \, f_{reg}(E')$$

$$\langle f_{reg} \rangle = 0.5 \sin^2 2\theta \int_{x_0}^{x_f} dx \, F(x_f - x) \, V(x) \sin\Phi^m(x \rightarrow x_f)$$

F(d)



The sensitivity to remote structures d $> \lambda_{att}$ is suppressed

Attenuation length

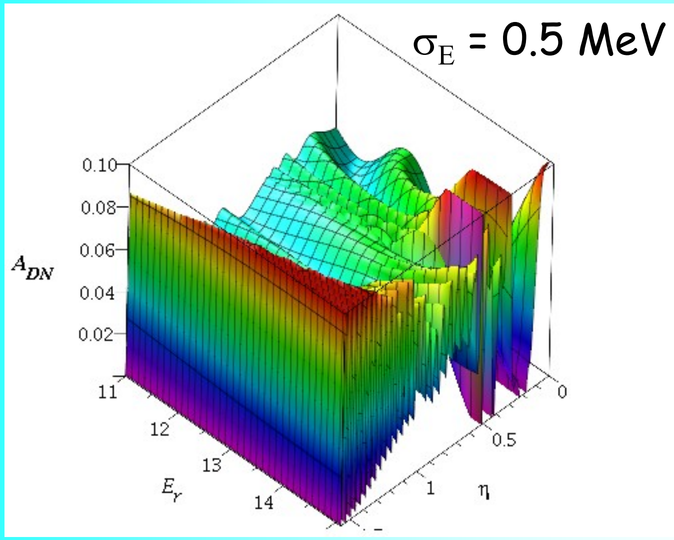
$$\lambda_{att} = l_\nu \frac{E}{\pi \sigma_E}$$

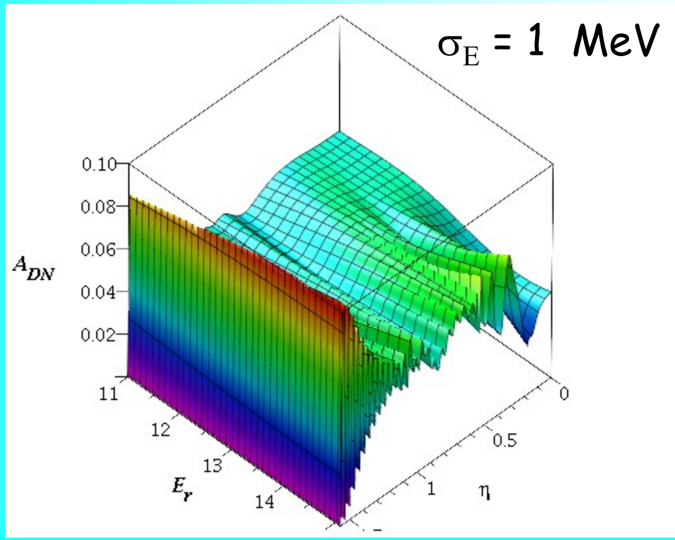
l_ν is the oscillation length

The better the energy resolution, the deeper penetration

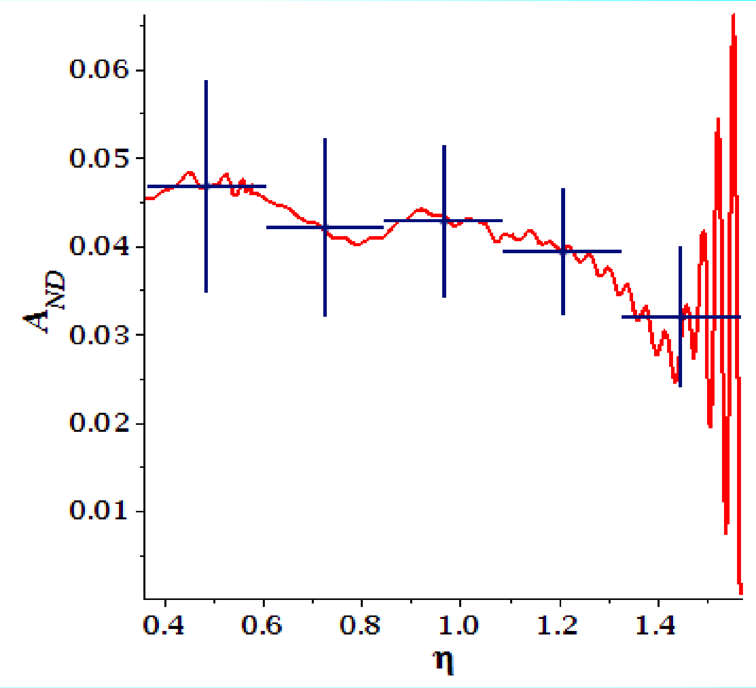
Attenuation effect

A. Ioannisian, A.Y.S., D. Wyler
1702.06097 [hep-ph]





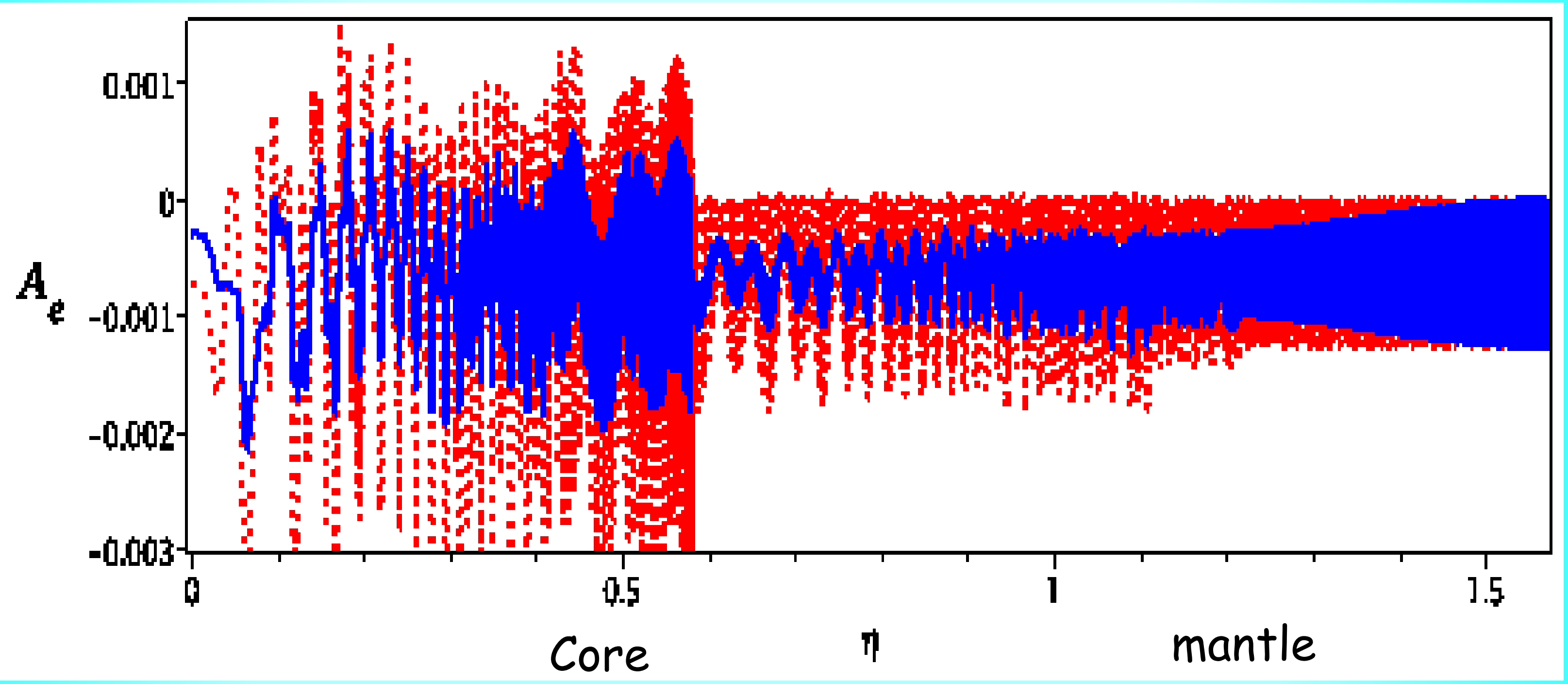
$$A_{DN} = \frac{N - D}{D}$$



Relative excess of the night events integrated over E > 11 MeV
Sensitivity of DUNE experiment

Variations of the ν_{Be}- flux

A. Ioannisian, AYS



Nadir angle

Again 0.1% effect

CNO neutrinos

Chemical composition metallicity problem

correlate

Conversion in the transition region

Evolution of stars

1% contribution to energy

40% difference for two metallicities

Tensions

Absence of spectral upturn

SK, SNO, BOREXINO

Large Day-night asymmetry

SK

Closer look is needed

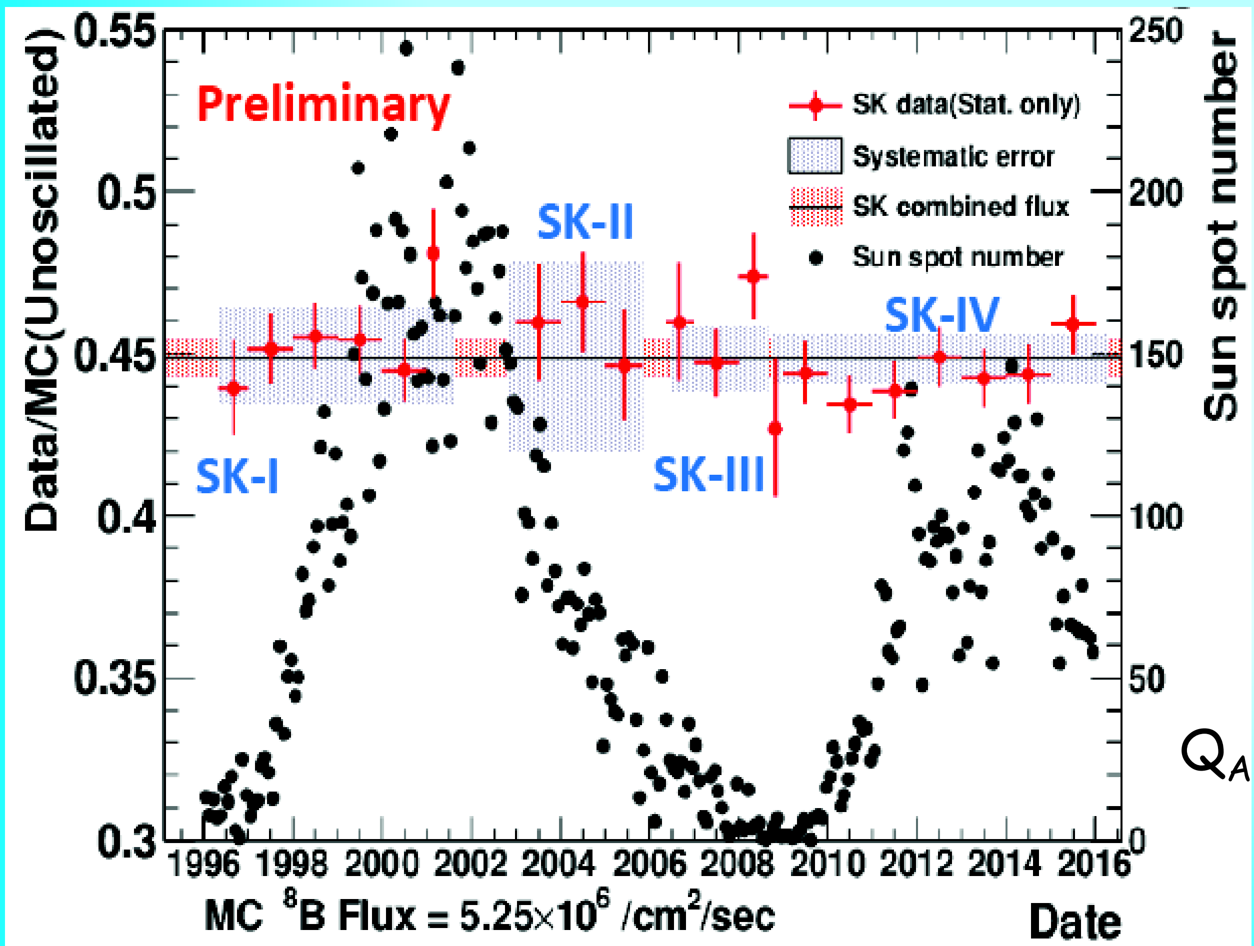
Different Δm_{21}^2 from solar and KamLAND

1.6 Larger V

$P = P(\Delta m_{21}^2 / V)$

Super-Kamiokande

Y. Koshio



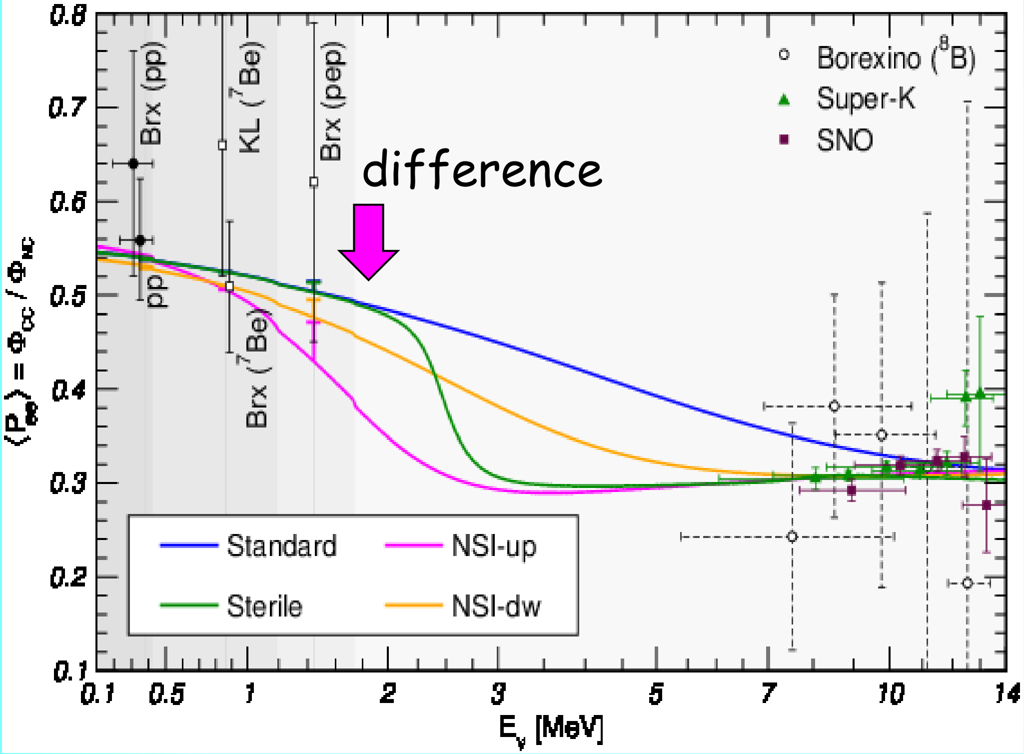
Compare with Homestake signal anti-correlations with solar activity

Related to lower Ar production rate?

Q_{Ar}^{LMA}= 3.1 SNU

Q_{Ar}^{Hom} = 2.56 +/- 0.25 SNU

New physics effects



M. Maltoni, A.Y.S.
1507.05287 [hep-ph]

Extra sterile neutrino with
$\Delta m^2_{01} = 1.2 \times 10^{-5}$ eV^2, and
$\sin^2 2\alpha = 0.005$

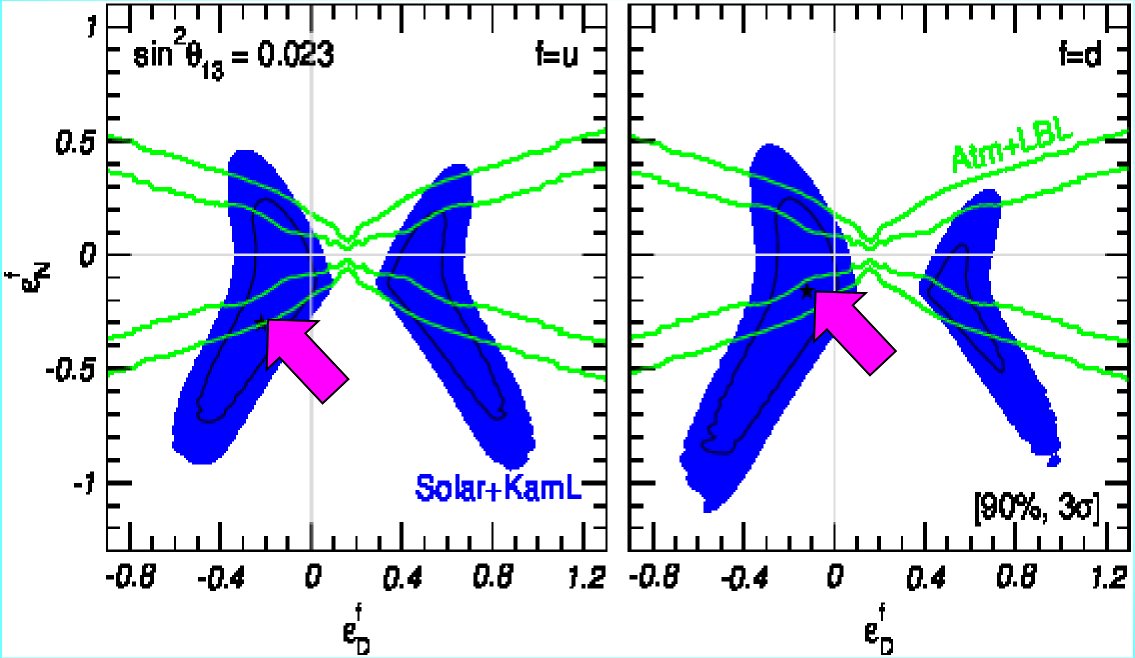
Non-standard interactions with
$\varepsilon^u_D = -0.22$, $\varepsilon^u_N = -0.30$
$\varepsilon^d_D = -0.12$, $\varepsilon^d_N = -0.16$

Non-standard interactions

Additional contribution
to the matrix of potentials
in the Hamiltonian

M C. Gonzalez-Garcia ,
M. Maltoni
arXiv 1307.3092

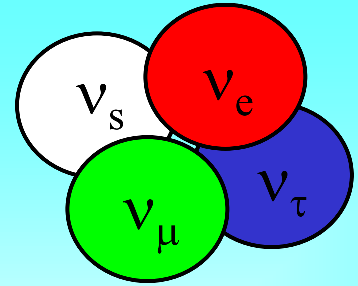
$$V_{NSI} = \sqrt{2}\, G_F\, n_f \begin{pmatrix} \varepsilon^f_D & \varepsilon^f_N \\ \varepsilon^f_N & \varepsilon^f_D \end{pmatrix} \qquad f = e, u, d$$



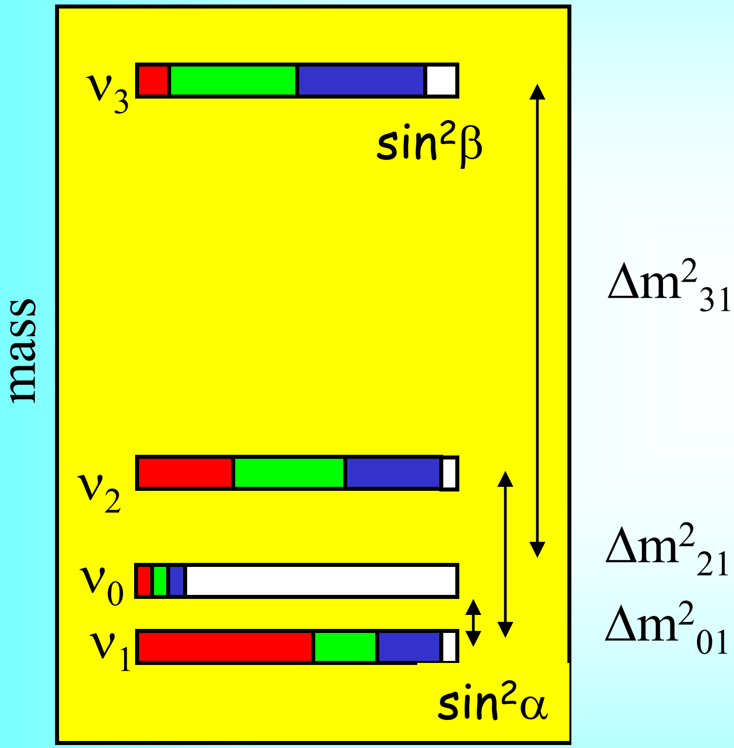
Allowed regions of parameters of NSI

In the best fit points the D-N asymmetry is 4 - 5%

meV physics



sterile neutrino $m_0 \sim 0.003$ eV



For solar nu: $\sin^2 2\alpha \sim 10^{-3}$

For dark radiation
$\sin^2 2\beta \sim 10^{-3}$ (NH)
$\sin^2 2\beta \sim 10^{-1}$ (IH)

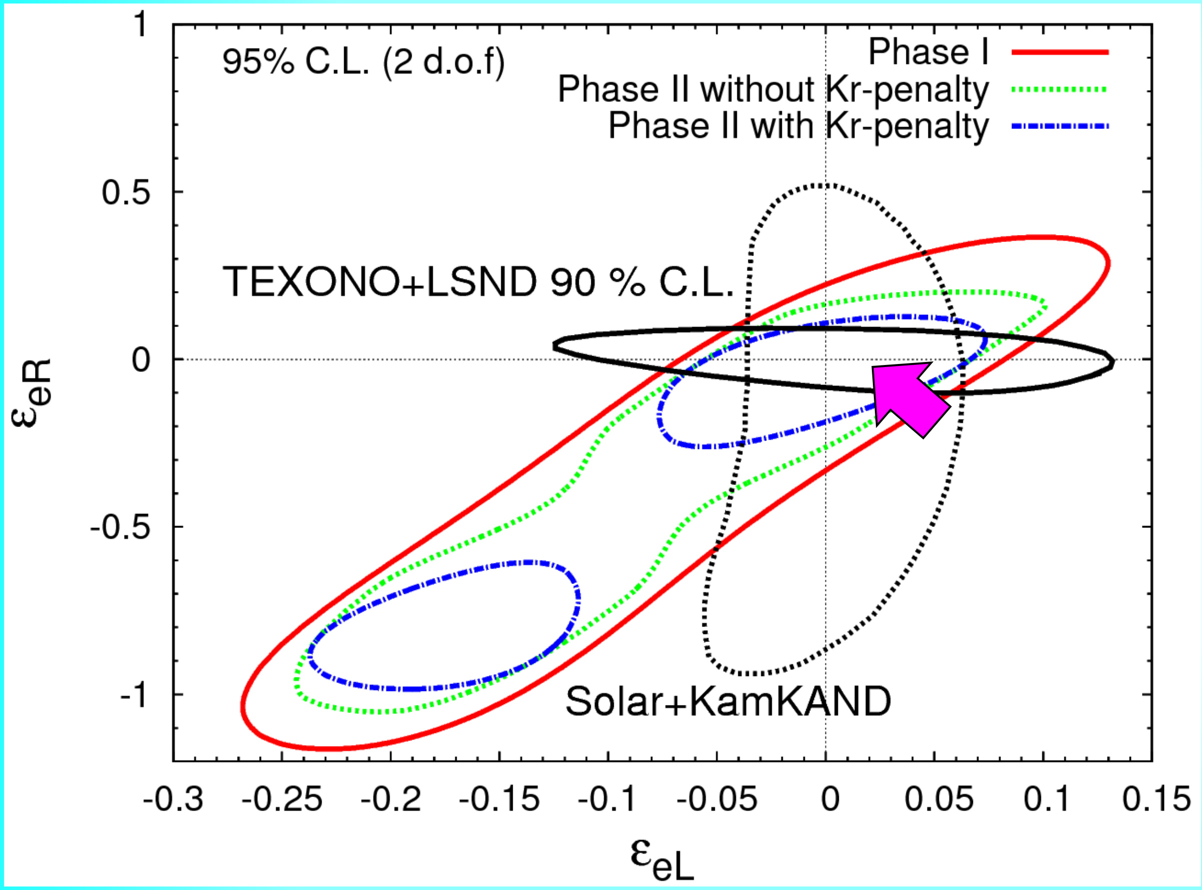
Adiabatic conversion
for small mixing angle
Adiabaticity violation

Allows to explain absence
of upturn and reconcile
solar and KAMLAND
mass splitting but not large
DN asymmetry

additional radiation
in the Universe if mixed in ν_3

no problem with LSS
bound on neutrino mass

BOREXINO: NSI in interactions



S. Agarwalla

Excludes
1.6 bigger potential,
dark solution on
electrons

ε_e < 0.05 - 0.1

COHERENT

COHERENT Collaboration ,
D. Akimov et al, 1708.01294 [nucl-ex] |

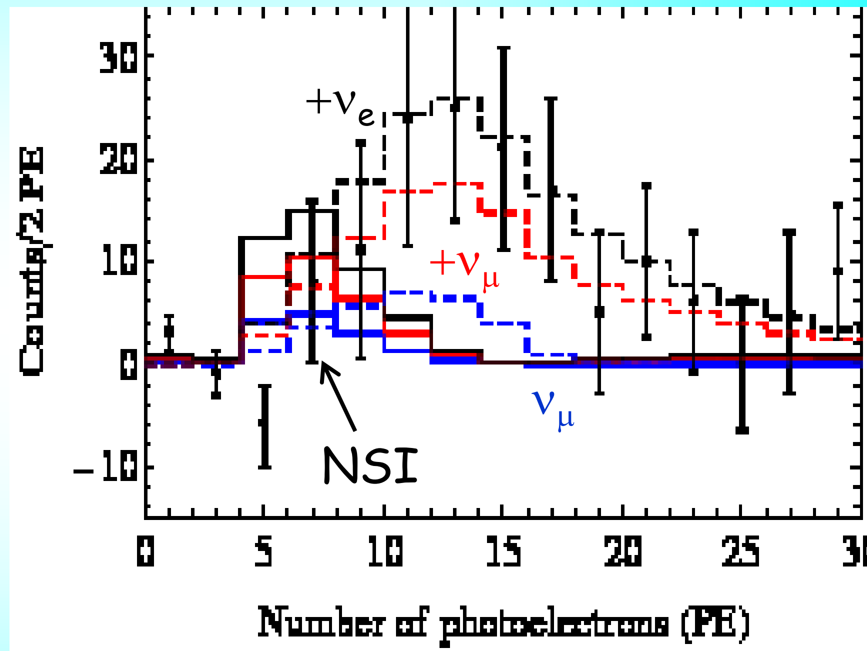
The coherent elastic scattering of neutrinos off nuclei observed 6.7σ CL

Observed : 134 +/-22 Expected 173 +/-48

Neutrinos: from the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (pion decay at rest)

Detector: low-background, 14.6-kg CsI[Na] scintillator

Characteristic signatures in energy and time



1.17 photoelectrons per kev

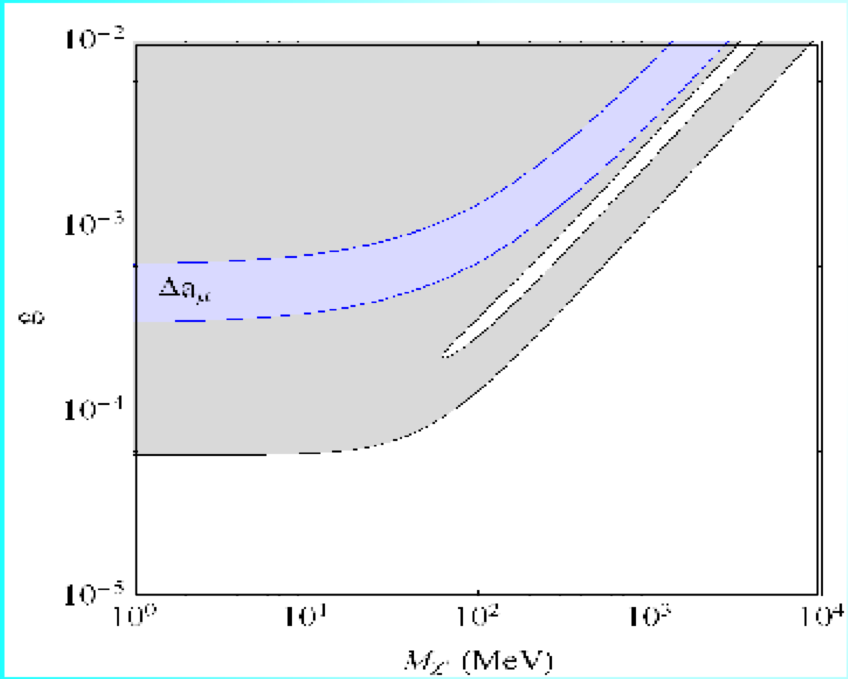
New opportunities:

- to study neutrino properties (oscillations to sterile neutrinos, NSI with quarks...)
- to a miniaturization of detector size, with potential technological applications.

Coherent and NSI

Liao, Jiajun et al. 1708.04255 [hep-ph]

the NSI case with light mediator Z′
$M(Z')$ =10 MeV and $g = 10^{-4}$.

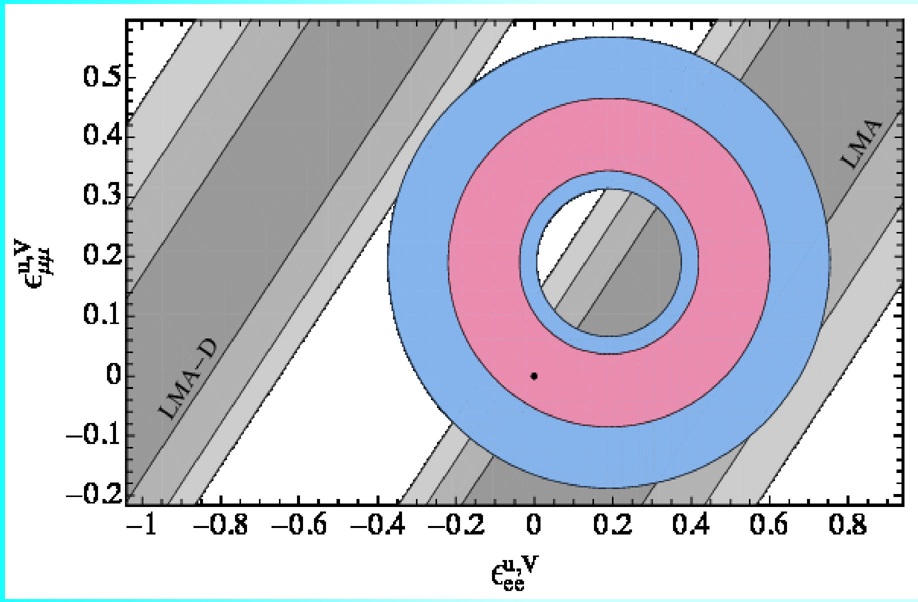


The 2σ exclusion region in $M(Z')$ -g -plane from the COHERENT data.
The 2σ allowed region that explains the discrepancy in the anomalous magnetic moment of the muon $\Delta a_\mu = (29 \pm 9) \times 10^{-10}$ is shown for comparison

perspectives

Bounds on NSI

P. Coloma, M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz, 1708.02899 [hep-ph]



Allowed regions from the COHERENT experiment and allowed regions from the global oscillation fit.

Diagonal shaded bands correspond to the LMA and LMA-D regions as indicated, at 1σ, 2σ, 3σ (2~dof).
The COHERENT regions are at 1σ and 2σ only. 3σ region extends beyond the boundaries of the figure

How things may develop

Value of Δm_{21}^2 fluctuates

Re-analysis of KamLAND with measured reactor neutrino spectra

JUNO: precise measurements of Δm_{21}^2 with 0.7 -1% accuracy

$\sigma(\Delta m_{21}^2) = (0.05 - 0.07) \times 10^{-5}\ eV^2$

Difference of solar and KamLAND: $\Delta(\Delta m_{21}^2) = 2.5 \times 10^{-5}\ eV^2$

If

- $\Delta m_{21}^2(JUNO) = \Delta m_{21}^2(solar)$ — problem solved
- $\Delta m_{21}^2(JUNO) = \Delta m_{21}^2(KL)$ — problem sharpens

Stronger bounds on NSI from COHERENT and other experiments

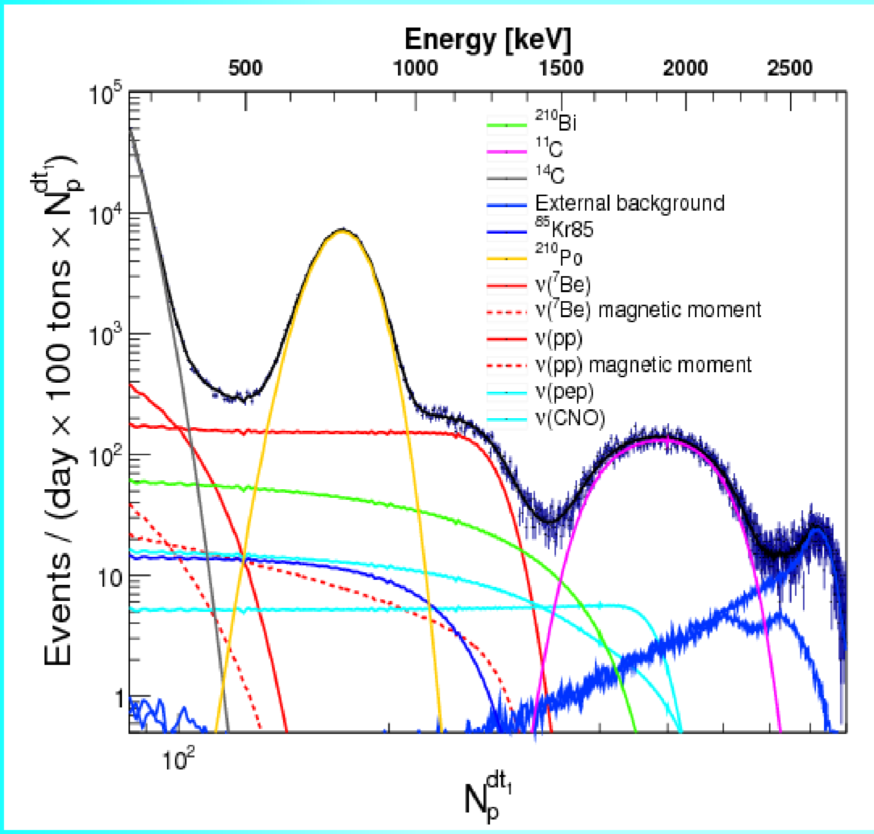
SNO+ spectrum measurements above 3 MeV (testing upturn)

Hyper-Kamiokande — Day-night asymmetry, spectrum

Neutrino magnetic moment

Borexino Collaboration, M. Agostini et al., arXiv:1707.09355

O. Smirnov



Spectral fit with the neutrino effective moment fixed at the upper limit

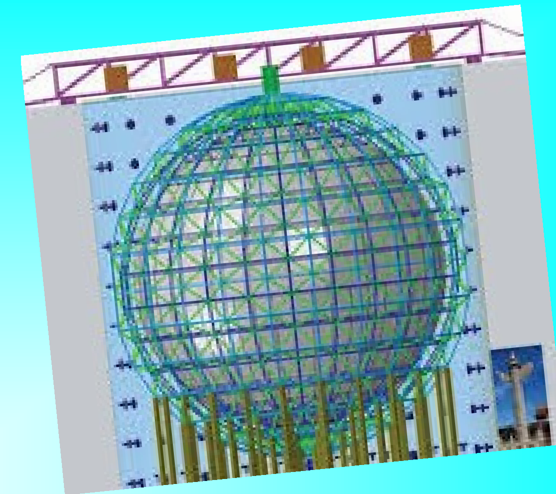
data from 1291.5 days exposure during phase II of the Borexino. No significant deviations from the expected shape of the electron recoil spectrum have been found .

upper limit on the effective neutrino magnetic moment:

$\mu_{eff} < 2.8 \cdot 10^{-11}\ \mu B$, 90\% C.L.

(constraints on the sum of the solar neutrino fluxes implied by gallium experiments has been used)

Future experiments



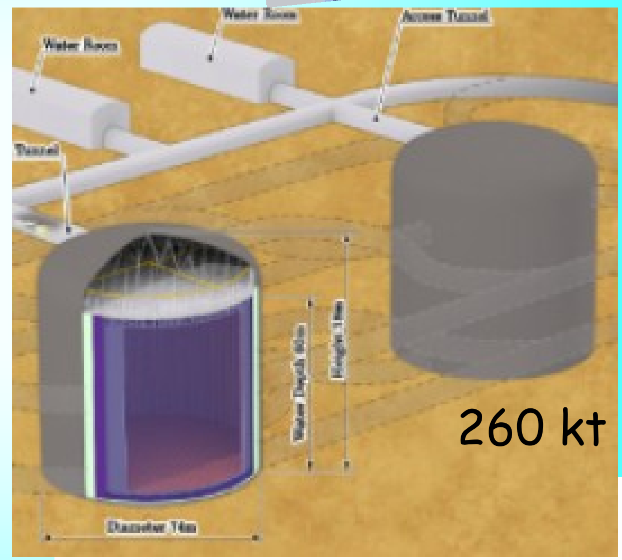
SNO+

870 tons
Double beta decay of Te
Simultaneously solar with E > 3 MeV, upturn
later pep- CNO- later

JUNO

LS 20 kt, too shallow,background?

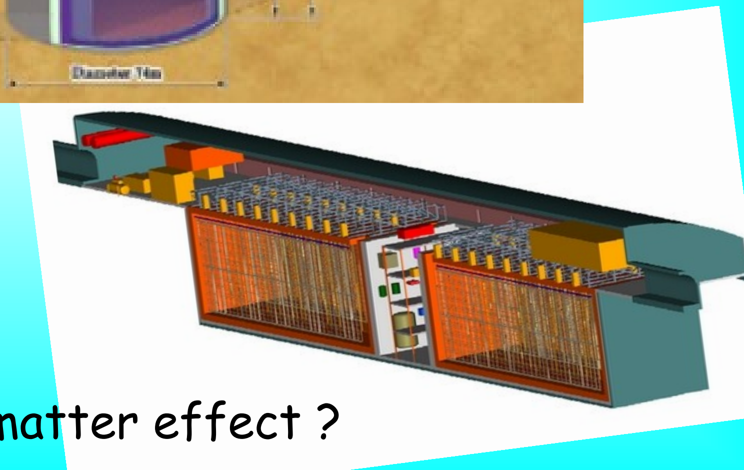
HyperKamiokande



260 kt each

17 times larger SK. 100 000 νe events/y,
lower PMT coverage, E > 4-5 MeV
shallower than SK, larger background,
> 5 σ D-N in 10 y

DUNE



4 x 11.6 kt (fv) LiAr TPC

$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e$

Earth matter effect ?

... continued

JinPing

The deepest lab - lowest background

$\nu + e \rightarrow \nu + e$

ASDC (WbLS)
(water based
Liquid scintillator)

Combining advantages of scintillator (good energy resolution) and cherenkov (directionality) experiments

$\nu + e \rightarrow \nu + e$

Theia

30 t f.v. also 1% Li doped

$\nu_e + {}^7Li \rightarrow {}^7Be + e$

pep, N, O, B Be

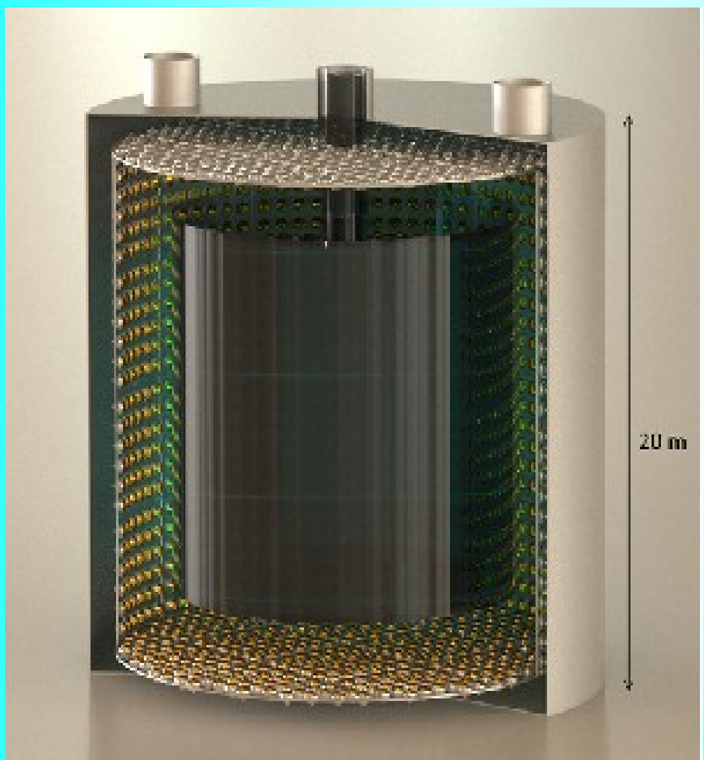
DARWIN

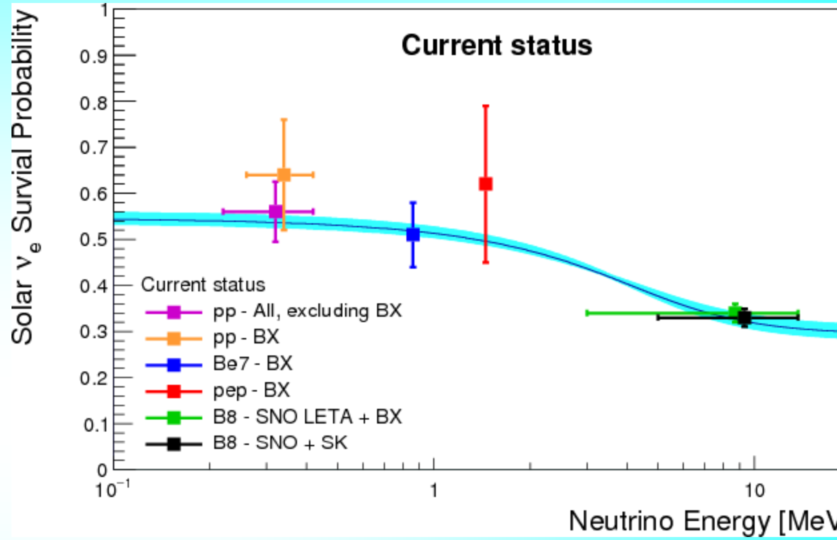
DM experiments hitting neutrino floor
Liquid Xe TPC, 30 t fiducial volume

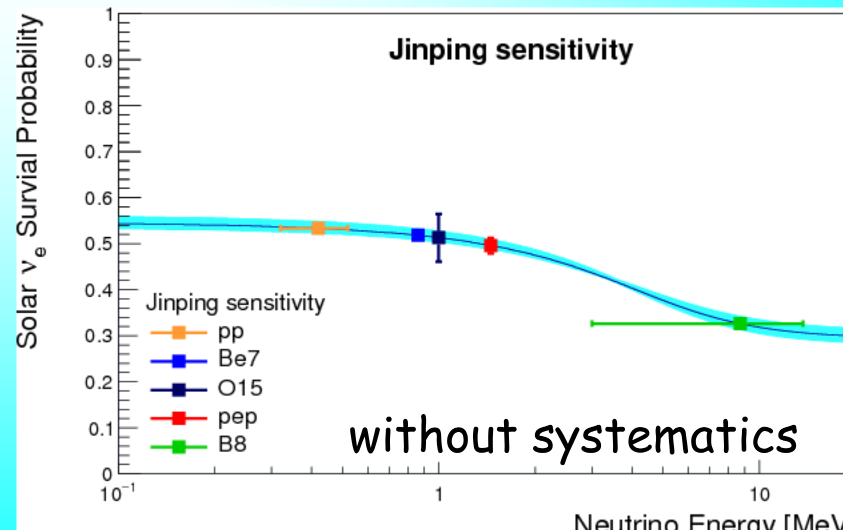
$\nu + e \rightarrow \nu + e$ pp (1%)

JinPing underground lab

scintillator uploaded
water detectors?







FV: 100 times bigger than
BOREXINO

Deeper than SNO

Summarizing

Opinion: Physics of solar neutrinos is essentially done. Problem solved, what is left is just further checks, small corrections...

Actually, there is continuous progress in the field with new important experimental and theoretical results

Rich physics of neutrino propagation (much richer than e.g. of reactor neutrinos)

Interesting physics of neutrino production

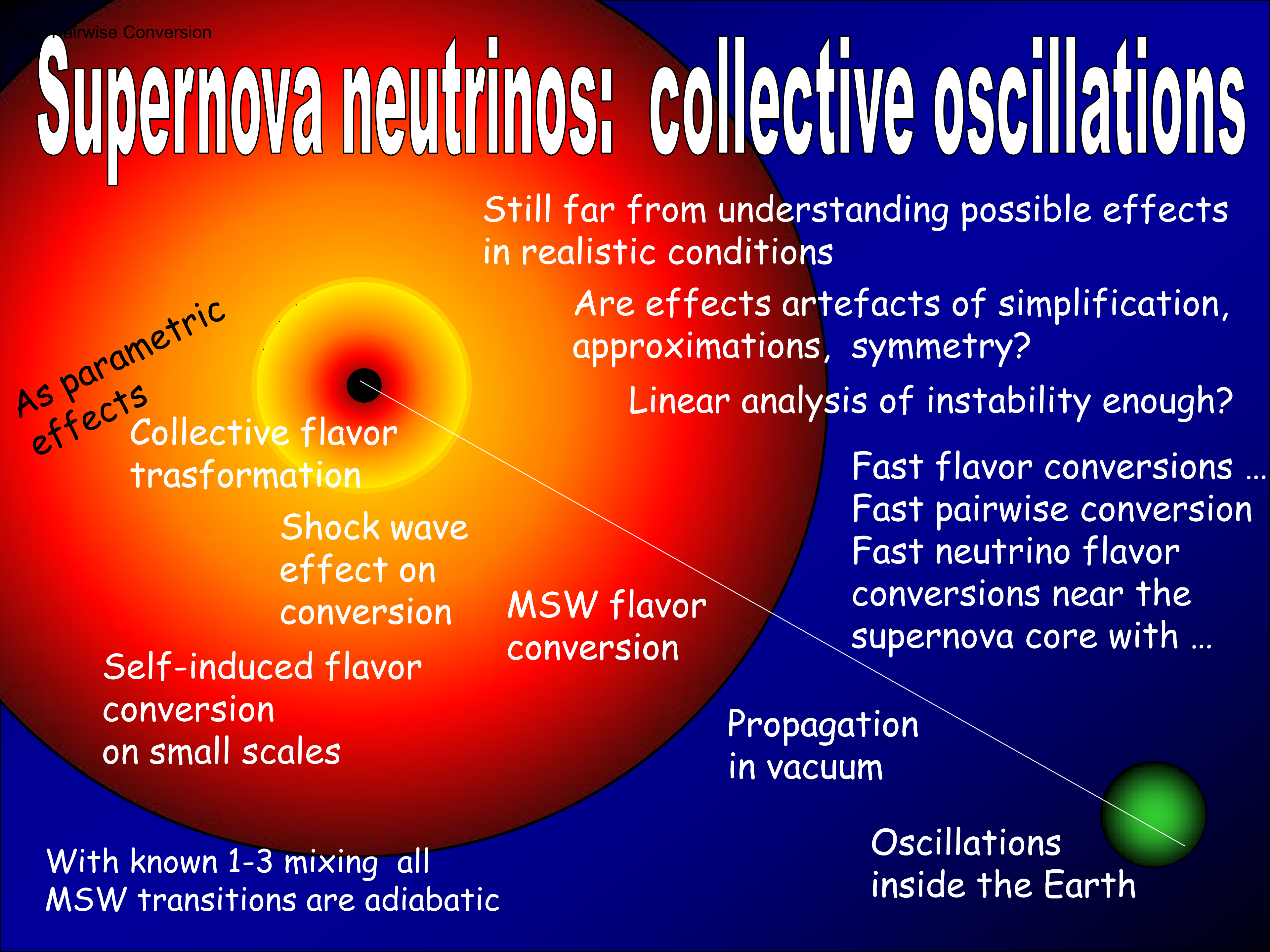
Applications

New phase of the field with % - sub % accuracy

New physics, new opportunities,
In particular, full 3 neutrino framework is the must

2. Comments

SN1987A
30 years



Fast pairwise Conversion
Supernova neutrinos: collective oscillations
Still far from understanding possible effects in realistic conditions
Are effects artefacts of simplification, approximations, symmetry?
Linear analysis of instability enough?
As parametric effects
Collective flavor trasformation
Shock wave effect on conversion
MSW flavor conversion
Self-induced flavor conversion on small scales
Fast flavor conversions …
Fast pairwise conversion
Fast neutrino flavor conversions near the supernova core with …
Propagation in vacuum
Oscillations inside the Earth
With known 1-3 mixing all MSW transitions are adiabatic

Gravitational waves detection

Searches for correlations with neutrino signals

KamLAND
BOREXINO

Origins of nake black holes

Collapses of massive stars at the end of evolution?

Collapses in binaries

Independent collapses and then merging

Neutrino signal much before GW and small.

Fast evolution, No Fe core formation

Primordial?

Connection with DM

Not enough time for evolution?

Contribution to diffuse low (MeV) energy neutrino flux

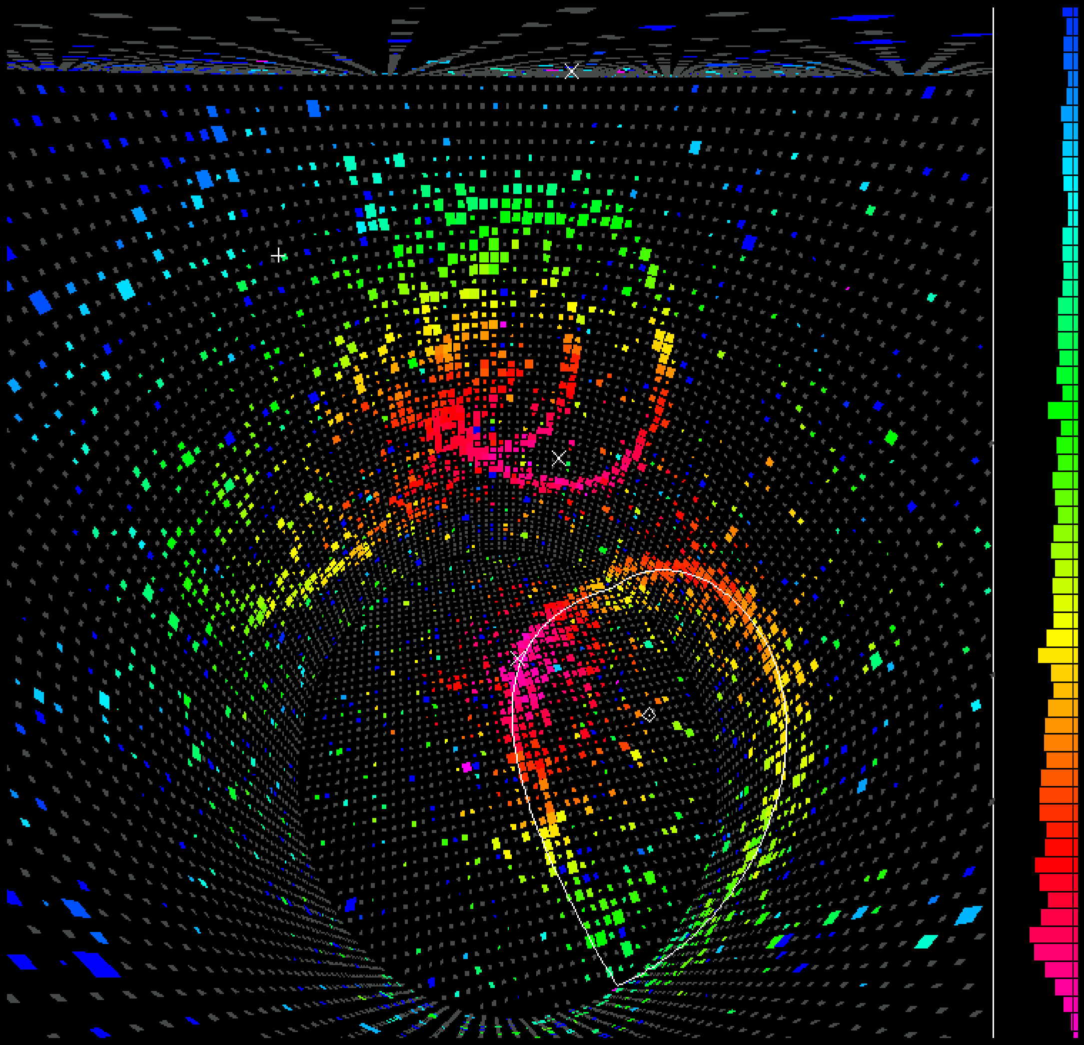
Bounds on this possibility?

In future: GW from SN neutron stars: Correlated with neutrino signals more plausible

Atmospheric Neutrinos

Hierarchy

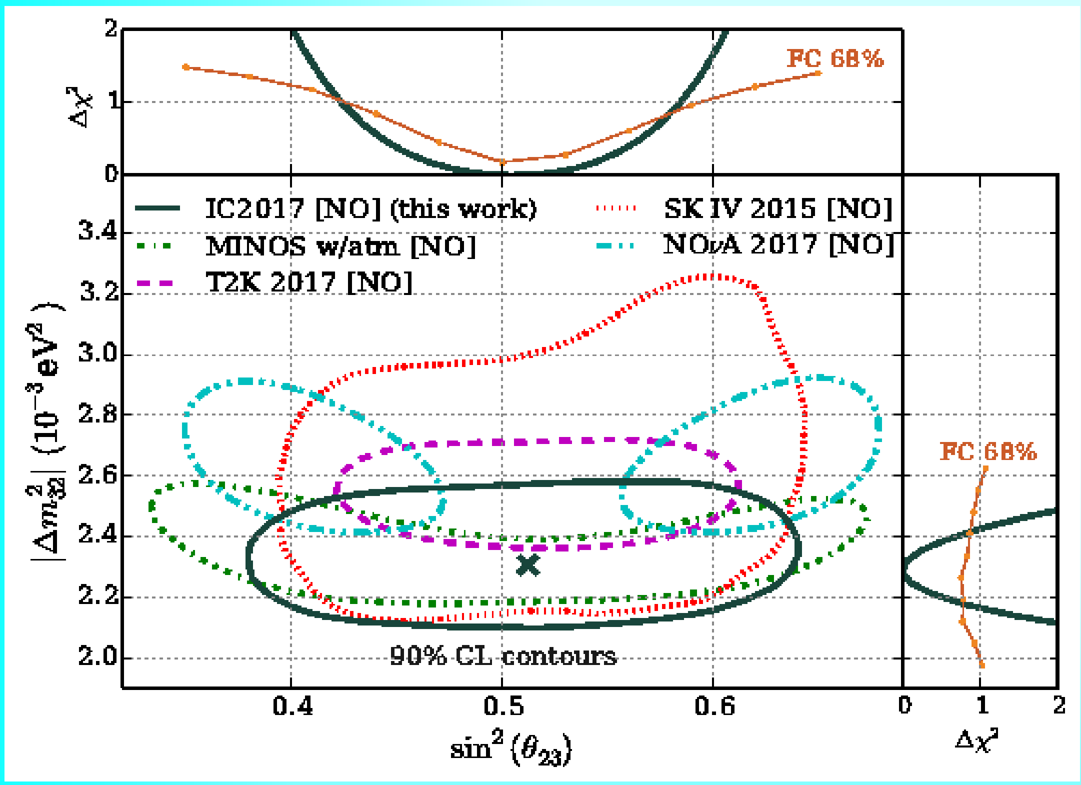
LBL etc.



Deep-Core IC result

Atmospheric Neutrino Oscillations at 6-56 GeV with IceCube DeepCore

IceCube Collaboration
M.G. Aartsen et al.
arXiv:1707.07081 [hep-ex]



Three years data
normal ordering

consistent with, and of similar precision to, those from accelerator and reactor-based experiments

Best fit – close to maximal mixing

$\sin^2\theta_{23}$ = 0.51 +0.07/-0.09

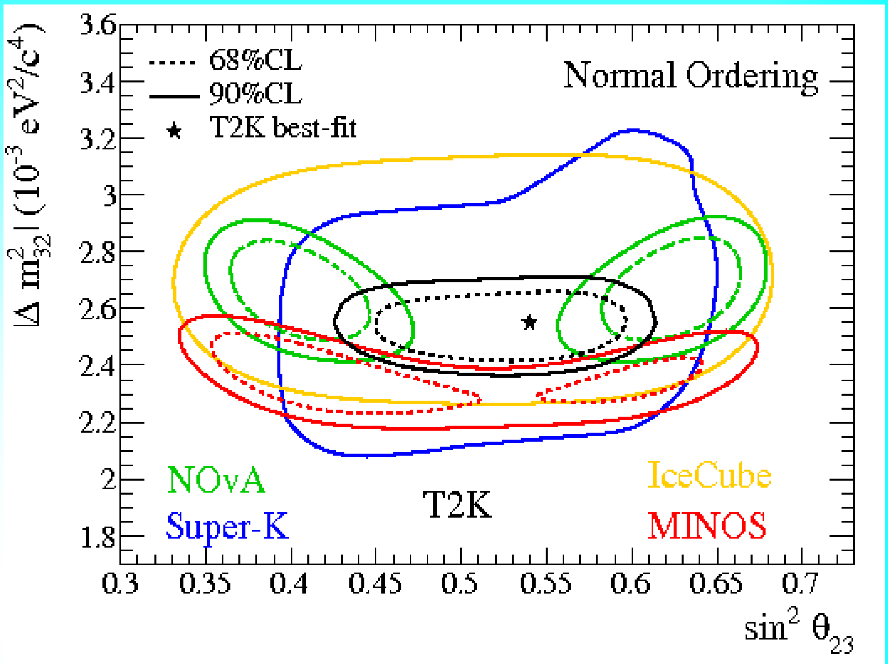
Δm^2_{32} = (2.31 +0.11/-0.13)$^{-3}$ eV^2

T2K-update

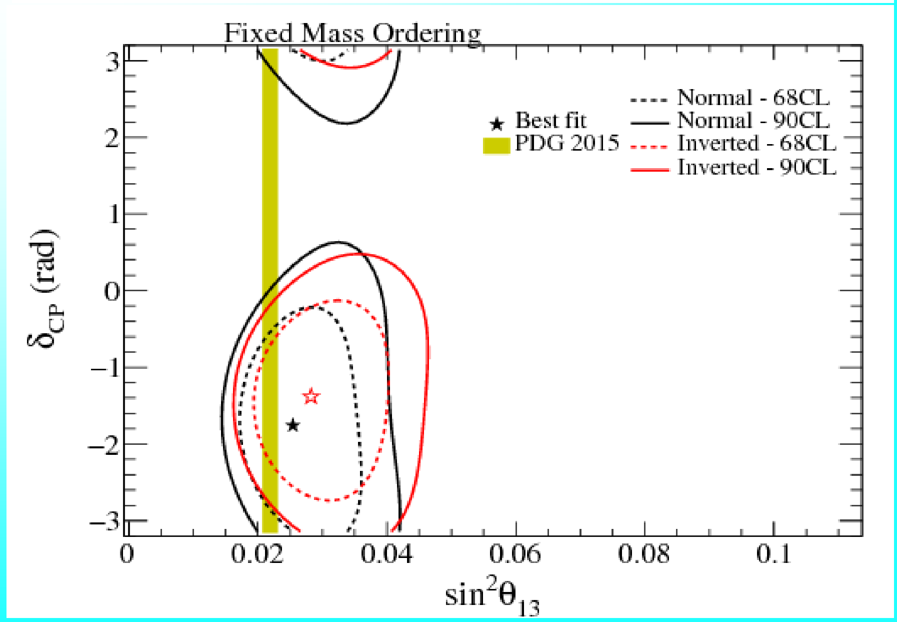
T2K Collaboration K. Abe, et al. 1707.01048 [hep-ex]

Neutrino and antineutrino oscillations with additional sample of *ve* interactions

T2K data with the reactor constraint sin2(2θ13)=0.085±0.005



Two-dimensional constant Δχ2 contours for oscillation parameters *δCP* and sin2θ13 using T2K data only.



Oscillation parameters

Daya-Bay

J.Cao

1-3 mixing: $\sin^2 2\theta_{13}$ = 0.0841 +/-0.0033 3.9%

3.0% by 2020

2-3 mixing Maximal-non-maximal

C. Gonzalez-Garcia, NuFIT 2017

Maximal mixing

NOvA: excluded at 3σ

Global: in particular inclusion of reactor data disfavored at less than 2σ

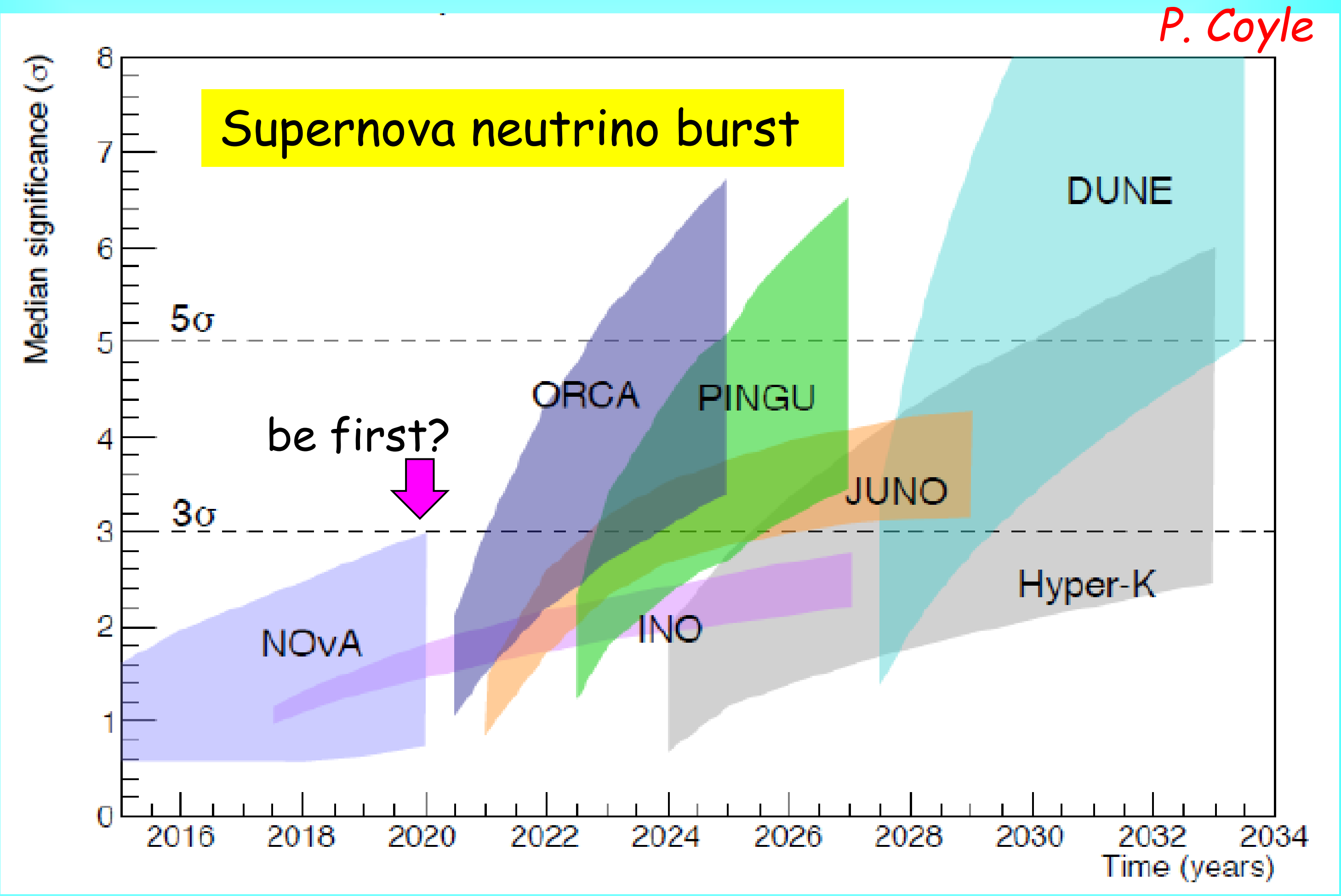
Deep Core: agrees with maximal –restricts NSI explanation of difference of T2K – NOvA tension

Mass hierarchy χ^2 (IO) - χ^2 (NO) = 3 NO is preferred at less than 2σ

CP violation bf δ_{CP} = 240^o

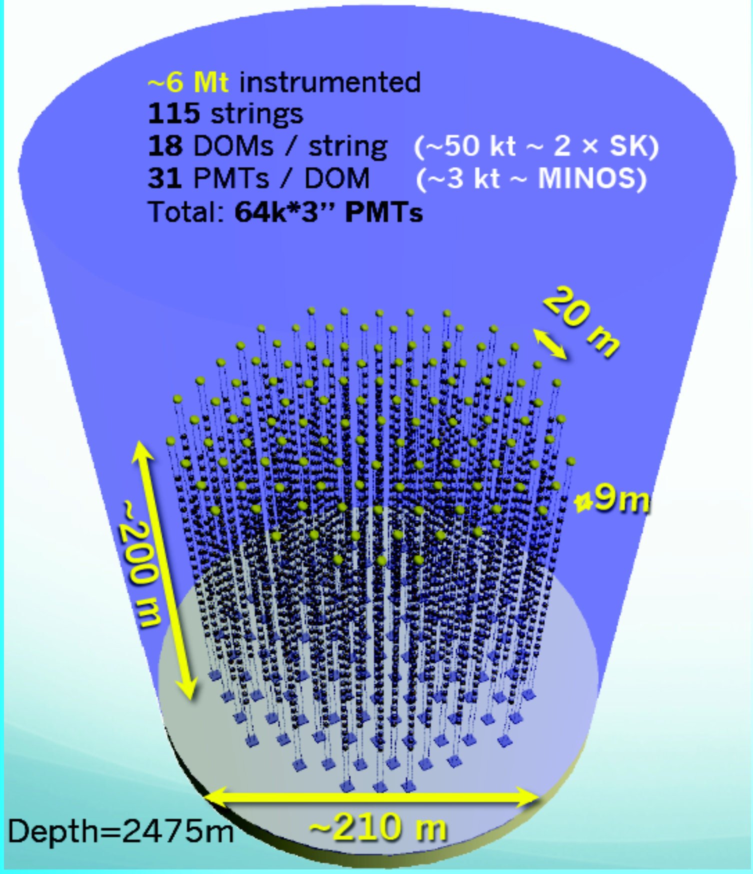
No violation excluded at about 2σ

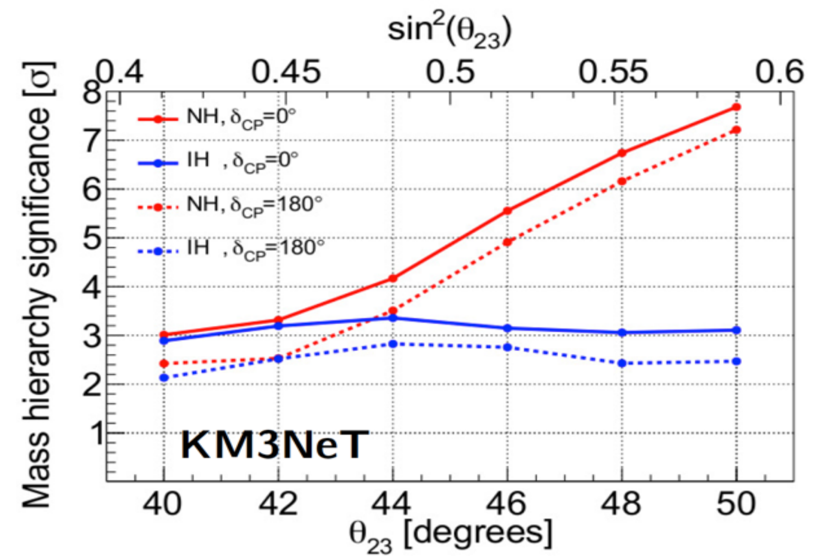
Race for the mass hierarchy

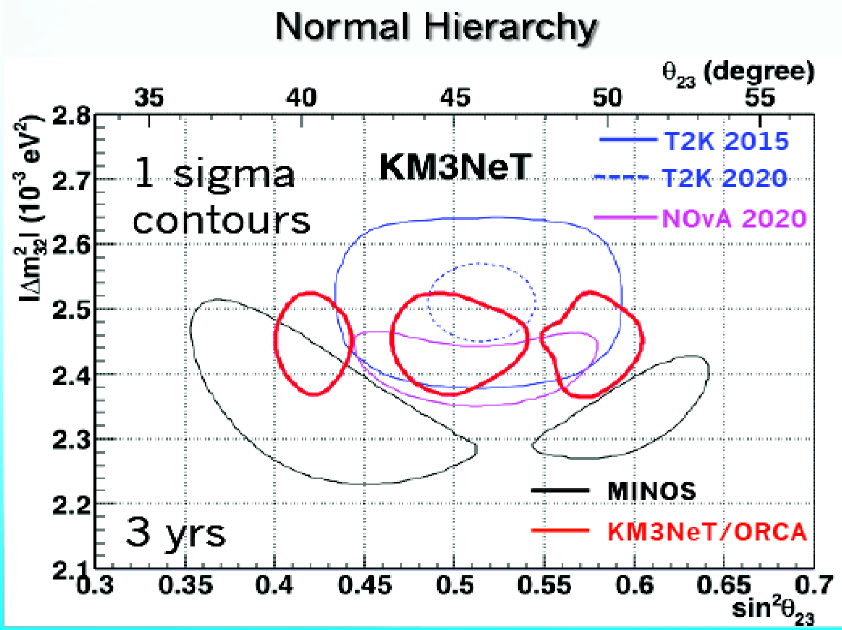


ORCA, oscillations, mass hierarchy

A. Kouchner, ICRC 2017



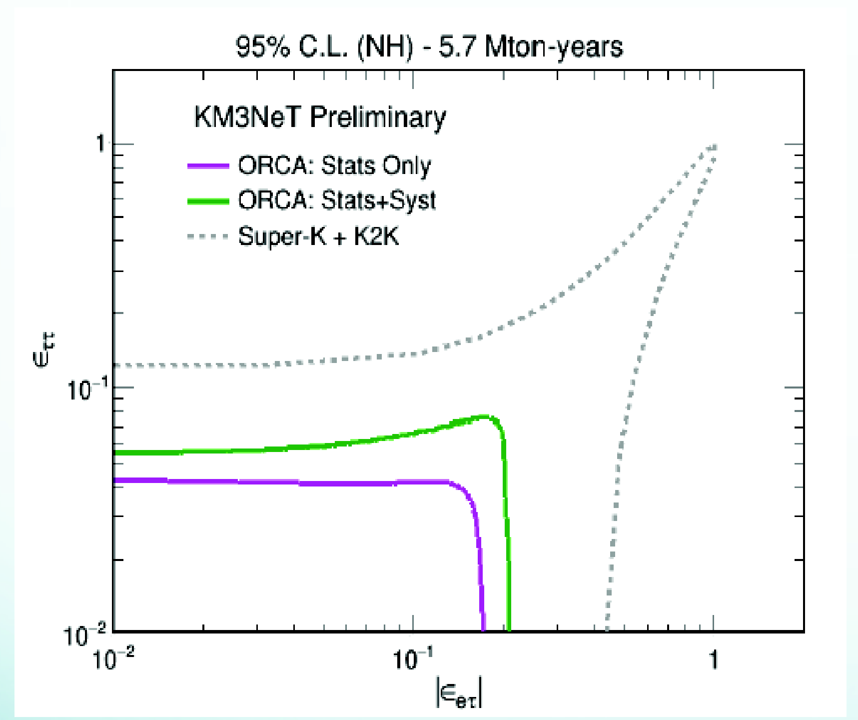


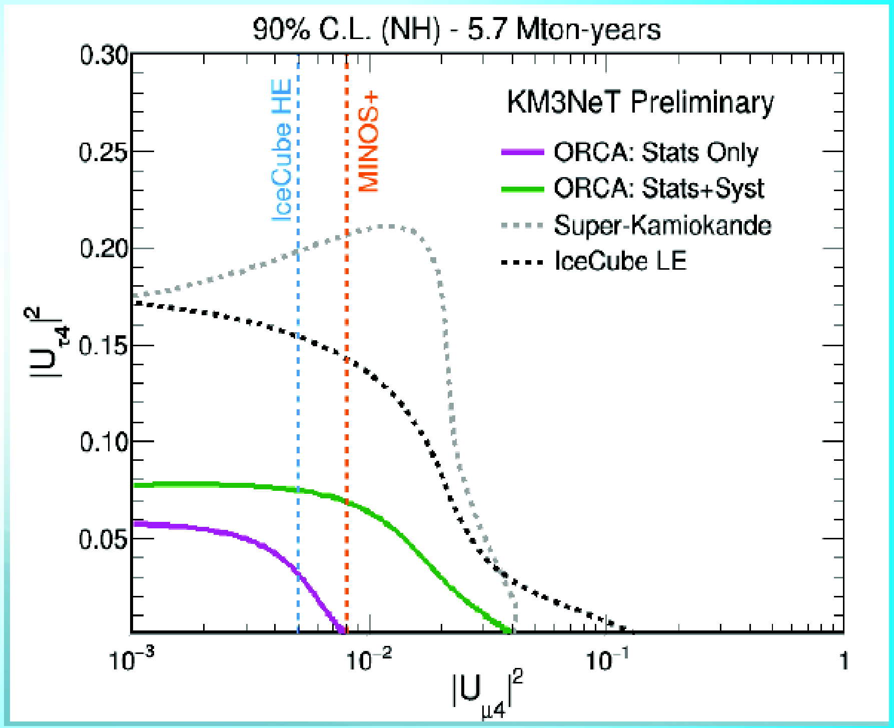


2 strings ready for deployment
full detector - 2020

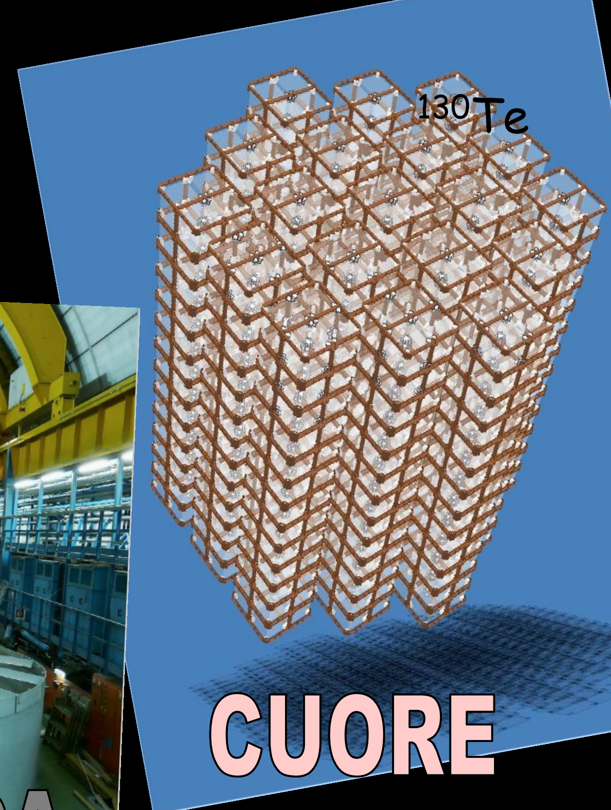
ORCA: new physics search

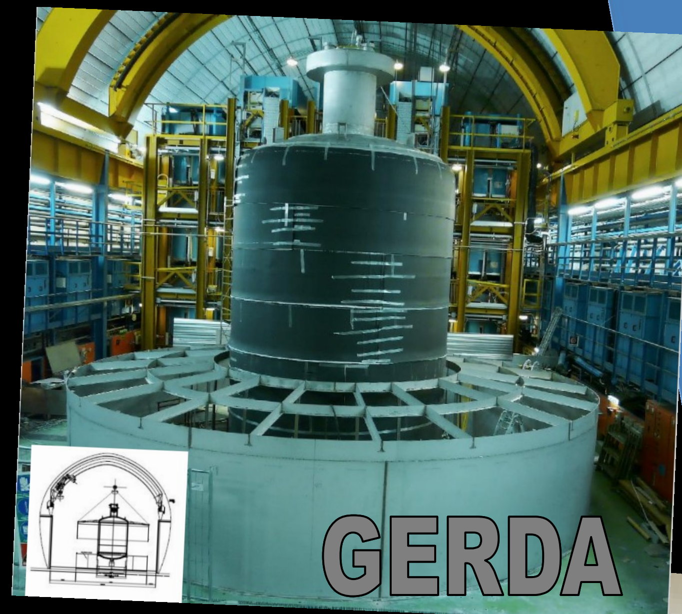
A Kouchner

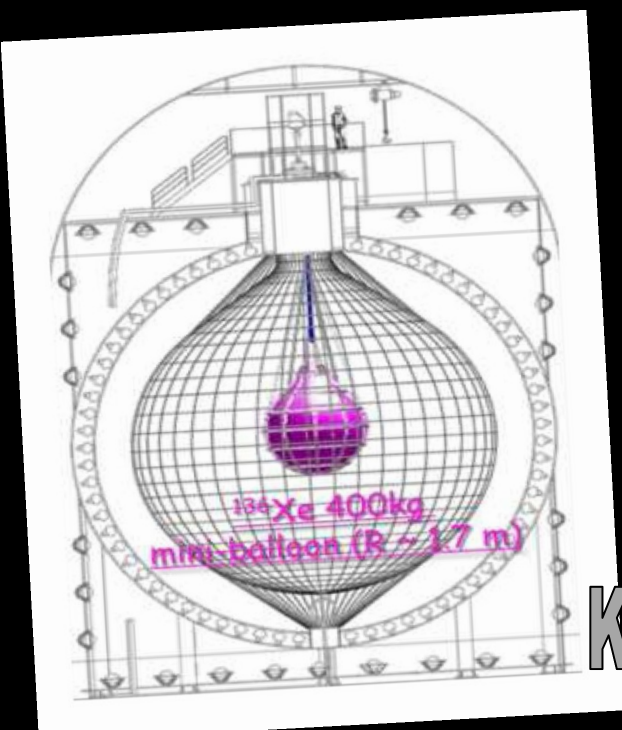




Neutrinoless $\beta\beta$ – decay





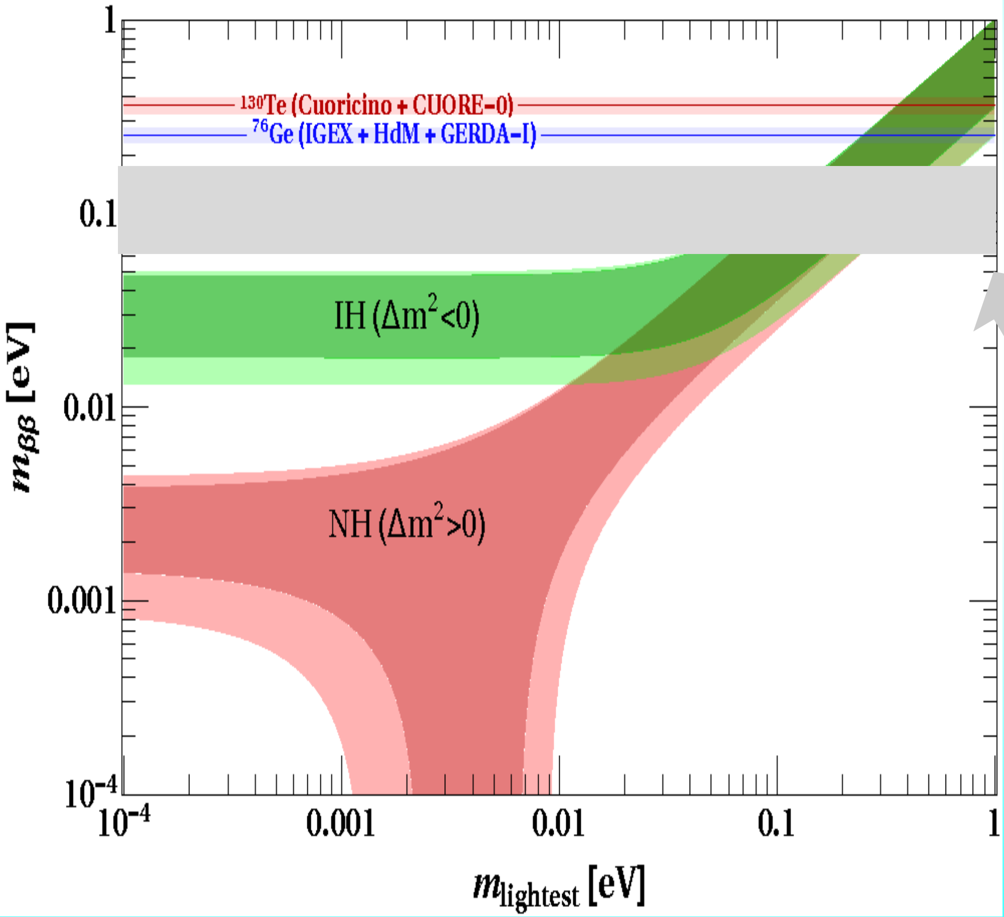


KamLAND-Zen

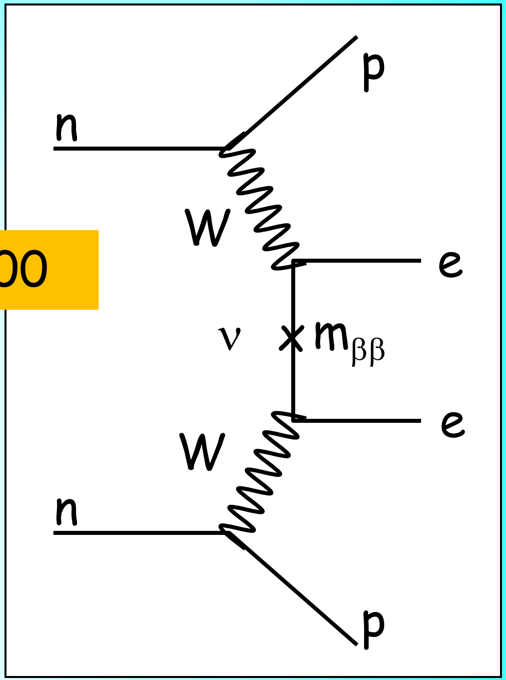
EXO-200

Double beta decay

$m_{\beta\beta} = U_{e1}^2 m_1 + U_{e2}^2 m_2 e^{i\alpha} + U_{e3}^2 m_3 e^{i\phi}$



EXO-200



KamLAND-Zen

$m_{\beta\beta}$ < (60 – 161) meV, 90% CL
Depending on NME

A.Gando, et al, 1605.02889 [hep-ex]

Approaching IH band

The case of normal mass hierarchy

A. Barabash

m_{ee} = 3 meV

$T_{1/2}$ = 10^{29} - 10^{30} years

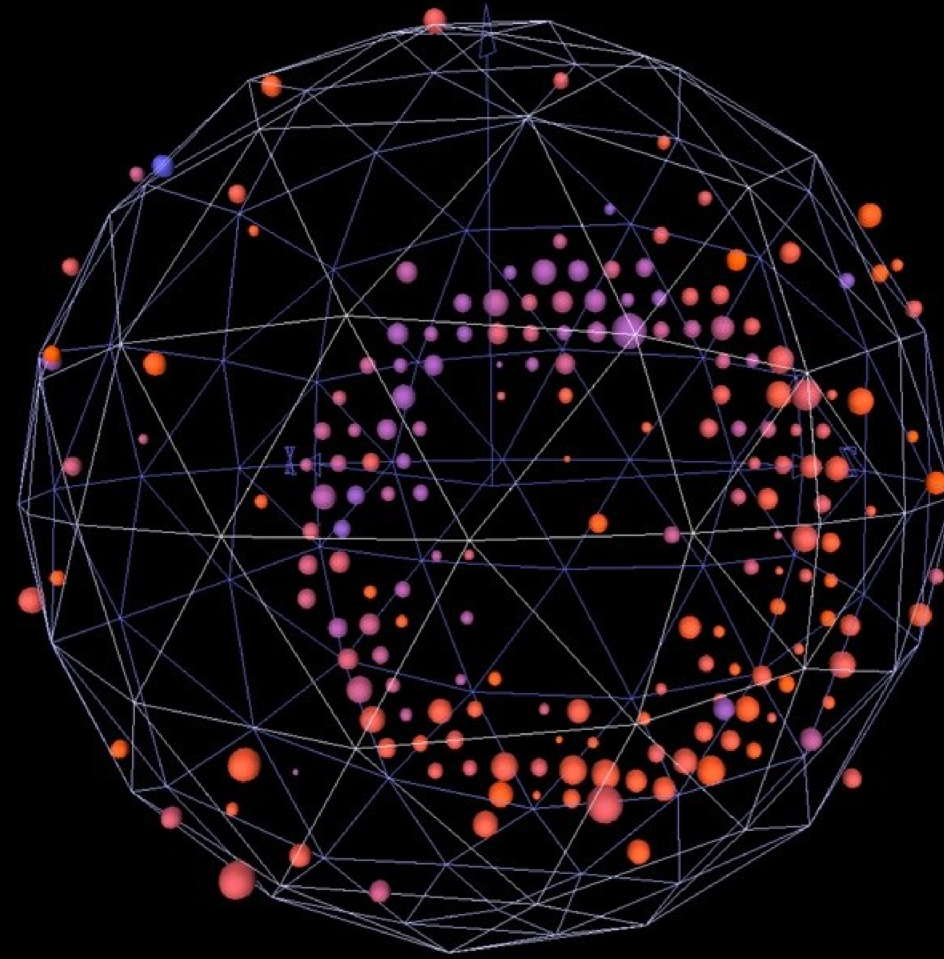
10 - 20 t of enriched material → produced in 5 – 10 years

10 years measurements

Background: 0-2 events during measurements

Number of events per 10 t×10 y		cost
^{48}Ca	8.6	
^{76}Ge	5.5	
^{82}Se	5.0	800 mln
^{100}Mo	4.1	
^{116}Cd	3.6	
^{130}Te	3.2	200 mln
^{136}Xe	3.0	50 – 100 mln

Sterile Neutrinos



Race for Nothing?

Sterile revolution 2012. After discovery of 1-3 mixing

- Rich phenomenology
- Relatively cheap, and fast realization
- Little chance to discover compensated by strong impact of positive result

Redundant negative results

Crucial for theory

Daya-Bay

IceCube, DC

MINOS, MINOS+

ICARUS

MicroBooNE

SBND

JSNS (J-PARC E-56)

SOX

PROSPECT

NEOS

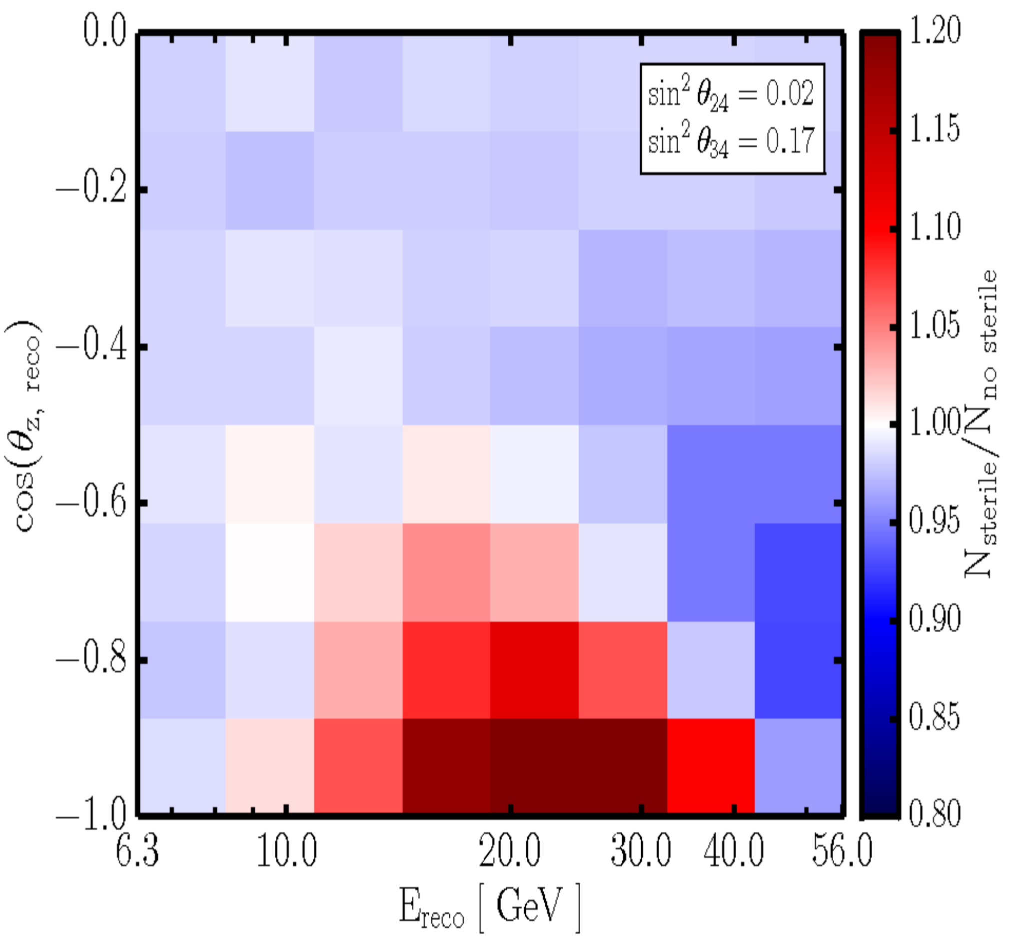
SoLid

DANSS

Stereo

Neutrino-4

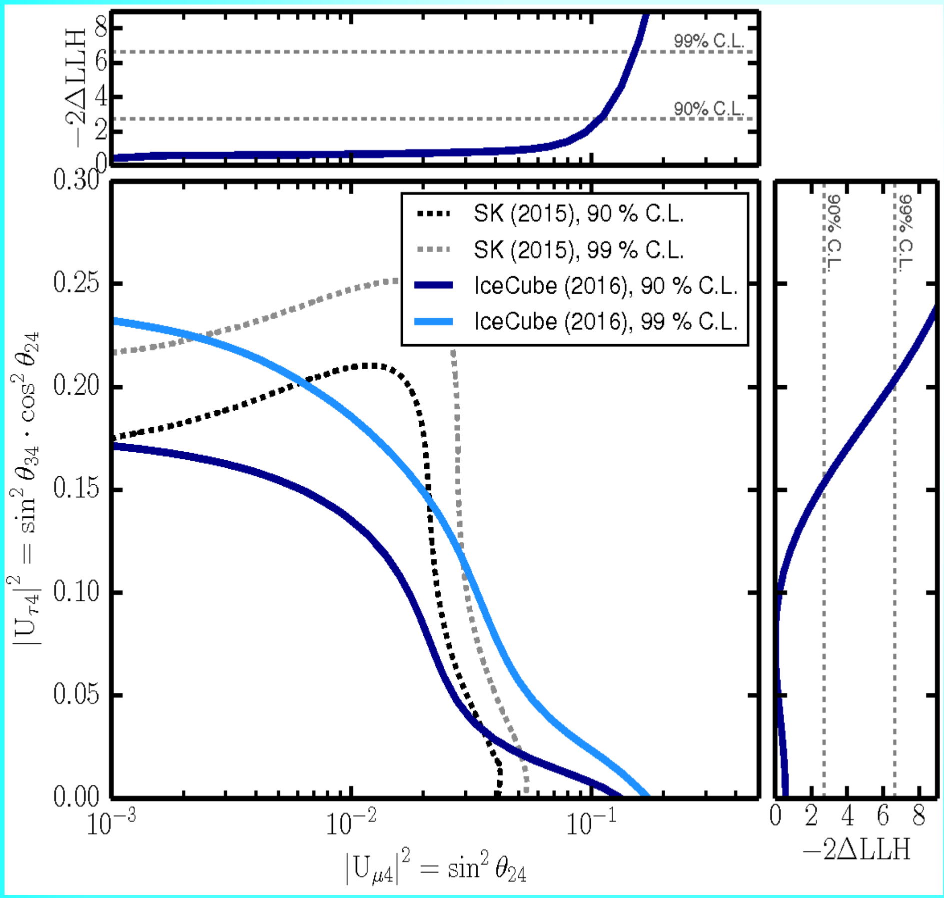
DeepCore and steriles



The ratio of the expected event counts for a sterile neutrino hypothesis and the case of no sterile neutrino. Sterile neutrino mixing parameters sin2θ24=0.02 and sin2θ34=0.17 are assumed. The values Δm232=2.52·10−3 eV2 and sin2θ23=0.51 are assumed for the standard atmospheric mixing parameters. Both expectations are normalized to the same total number of events.

Sterile neutrino bound

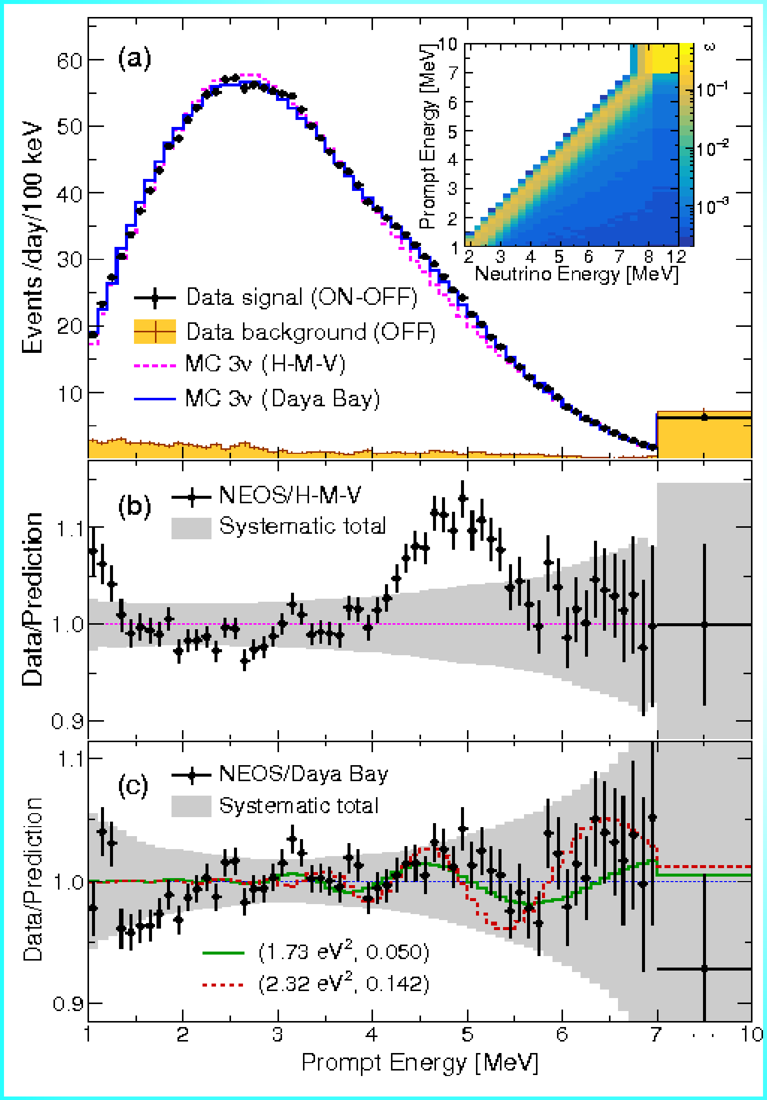
Search for sterile neutrino mixing using three years of IceCube DeepCore data



IceCube Collaboration,
M.G. Aartsen, et al.,
Phys.Rev. D95 (2017) no.11, 112002
arXiv:1702.05160 [hep-ex]

The exclusion limits at 90 % (dark blue) and 99 % C.L. (light blue) using critical values from $\chi 2$ with 2 d.o.f. The dashed lines show the exclusion from the Super-Kamiokande experiment

Neos: new hint?



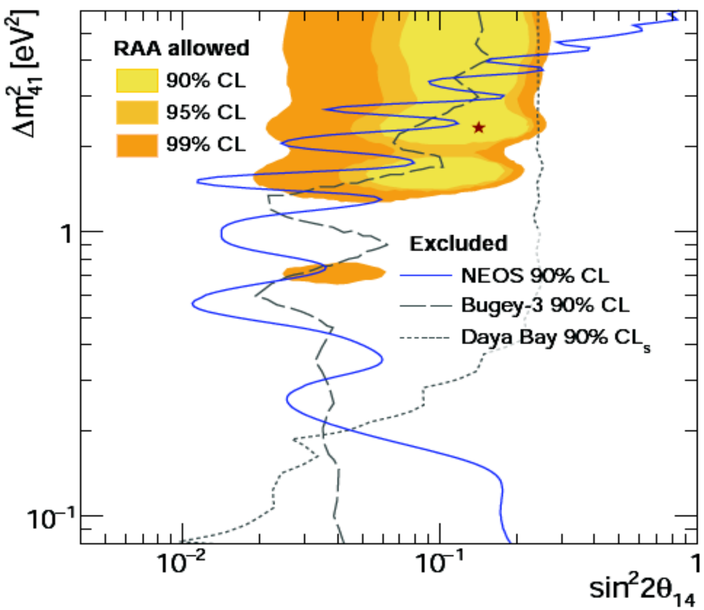
(a) The IBD prompt energy spectrum. The last bin is integrated up to 10~MeV. The orange shaded histogram is the background (reactor-off)

(b) The ratio of the observed prompt energy spectrum to the Huber-Muller flux prediction weighted by the IBD cross section for 3ν . The predicted spectrum is scaled to match the area of the data excluding the 5~MeV excess region (3.4--6.3~MeV).

(c) The ratio of the data to the expected spectrum based on the Daya Bay result with 3ν, scaled to match the whole data area.
The solid green line is the expected for the 3+1 with (sin22θ14,Δm241) is (0.05, 1.73~eV2). The dashed red line is the expected oscillation pattern for the RAA best fit parameters (0.142, 2.32~eV2).
The gray error bands in (b) and (c) total systematic uncertainties.

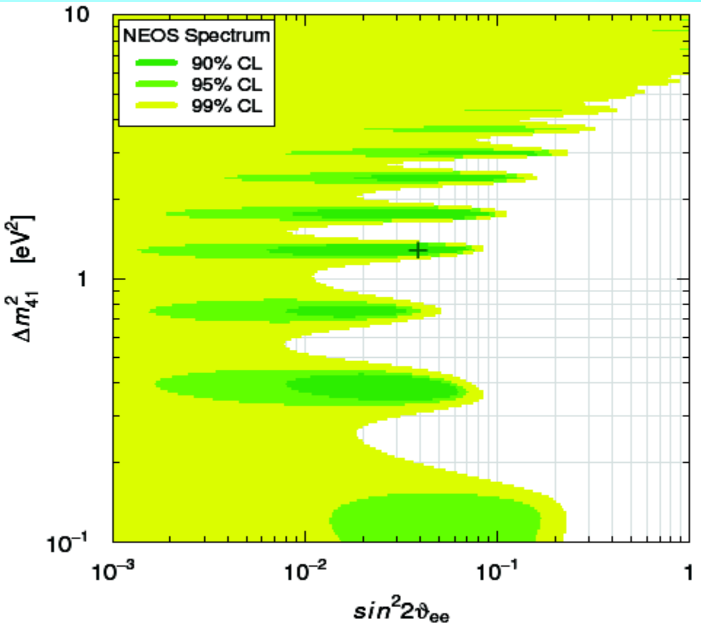
ν_e - disappearance

C. Giunti



Raster Scan

[NEOS, PRL 118 (2017) 121802 (arXiv:1610.05134)]



2-D χ^2 Analysis

Best Fits:

$\Delta m^2_{41} = 1.7\,\text{eV}^2 \quad \sin^2 2\theta_{14} = 0.05$

$\Delta m^2_{41} = 1.3\,\text{eV}^2 \quad \sin^2 2\theta_{14} = 0.04$

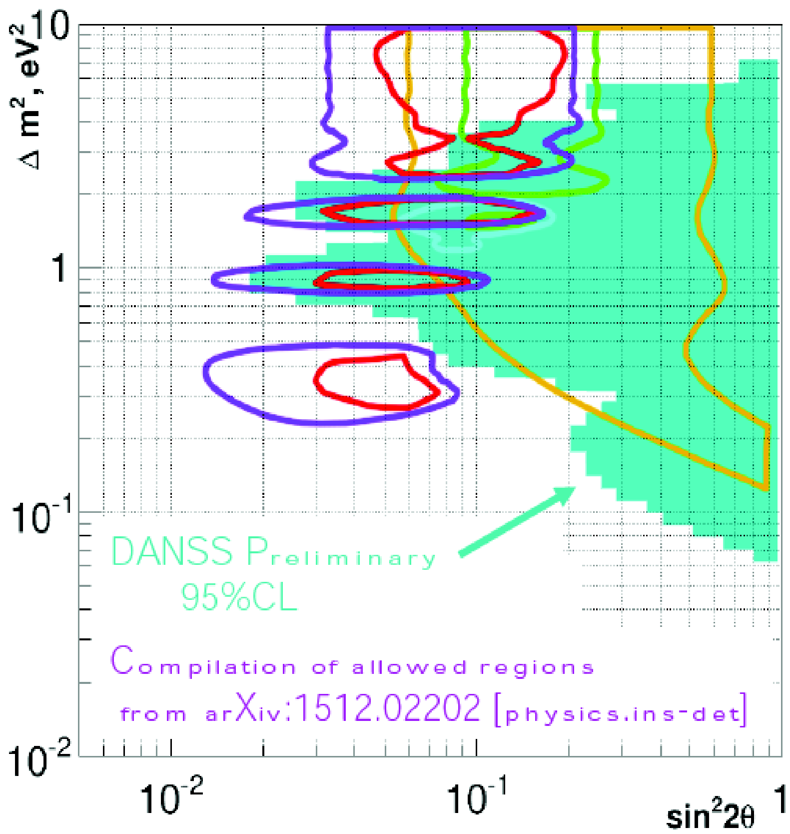
$\chi^2_{\text{no osc.}} - \chi^2_{\text{min}} = 6.5$

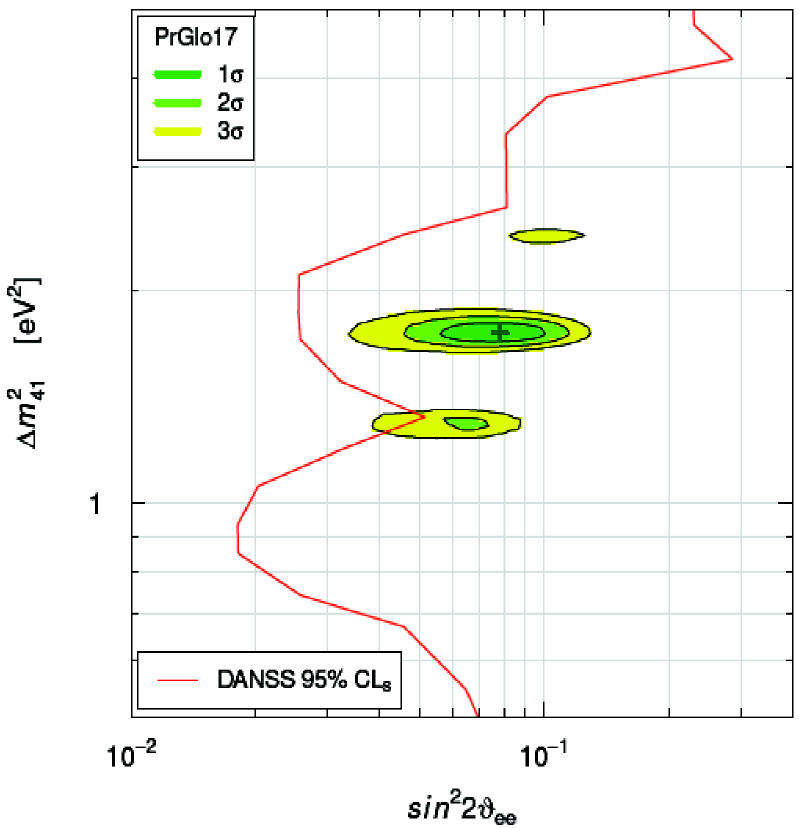
χ^2 distribution: $\approx 2.1\sigma$ anomaly

NEOS Monte Carlo: $\approx 1.2\sigma$ anomaly

ν_e - disappearance

C Giunti

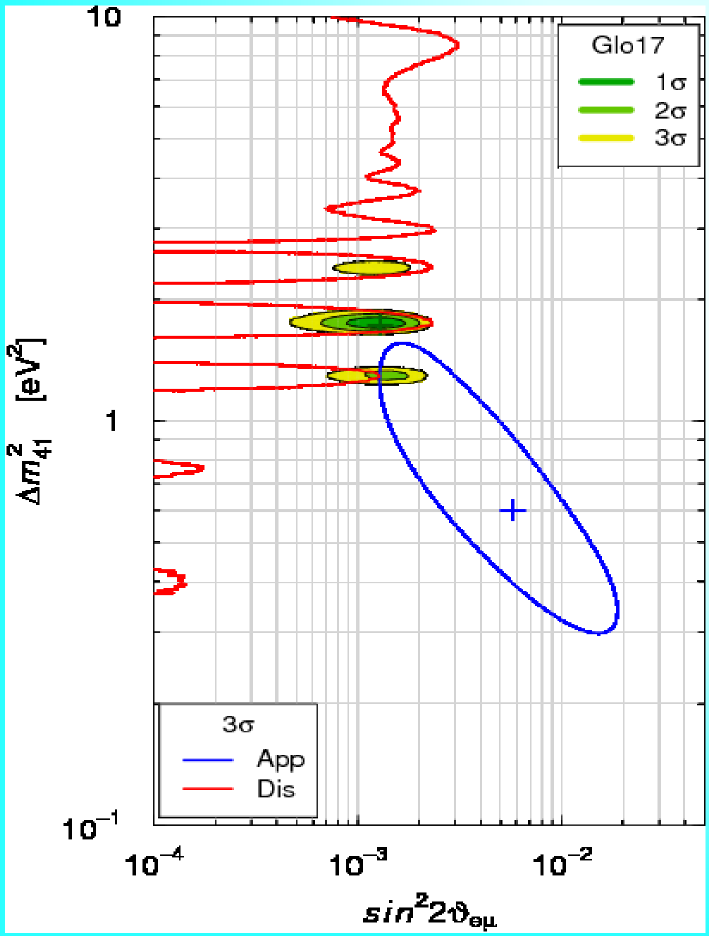




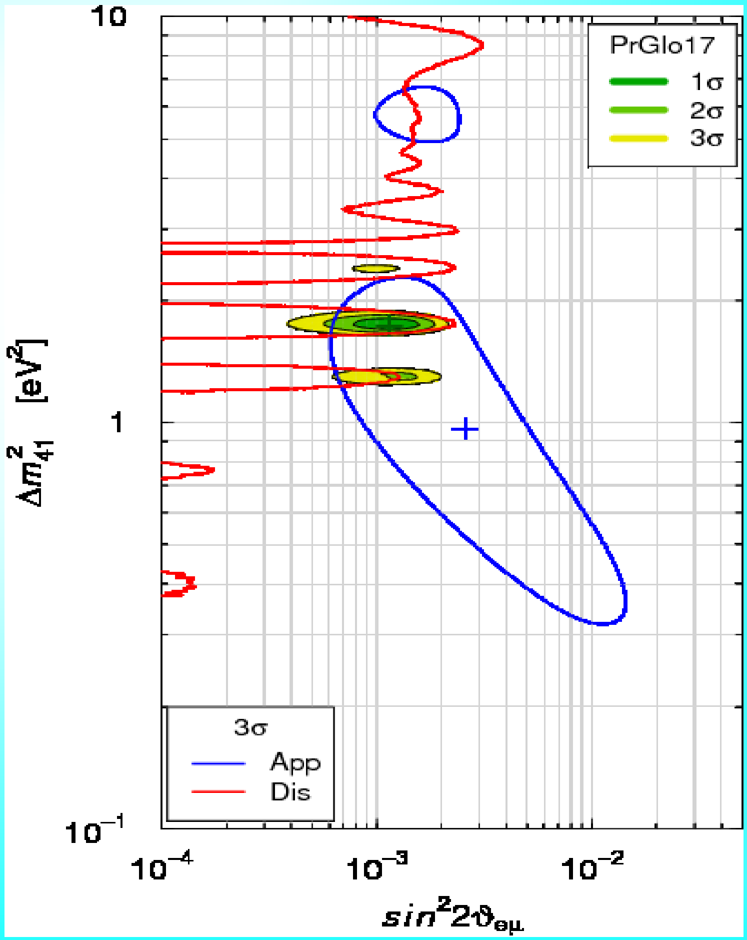
Global fit

S. Gariazzo, C. Giunti, M. Laveder, Y.F. Li, arXiv:1703.00860 [hep-ph]

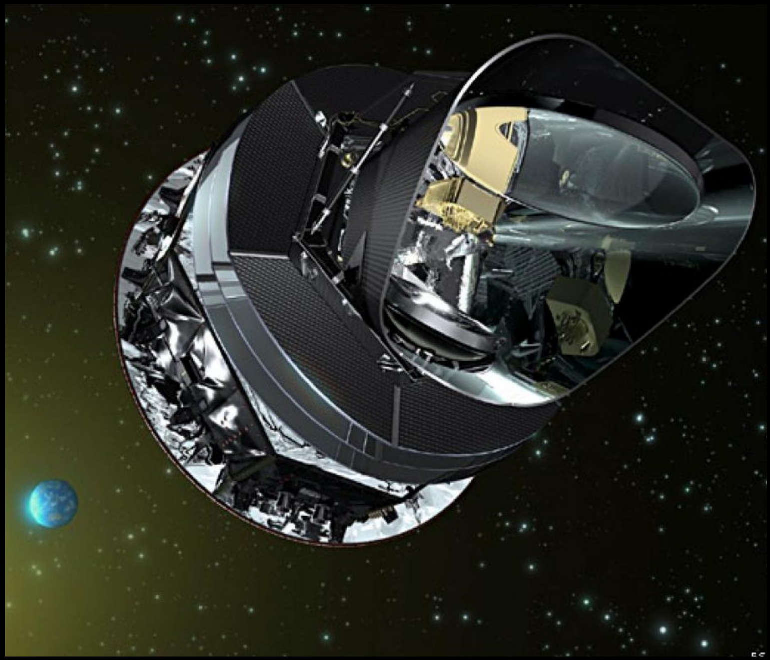
All the data

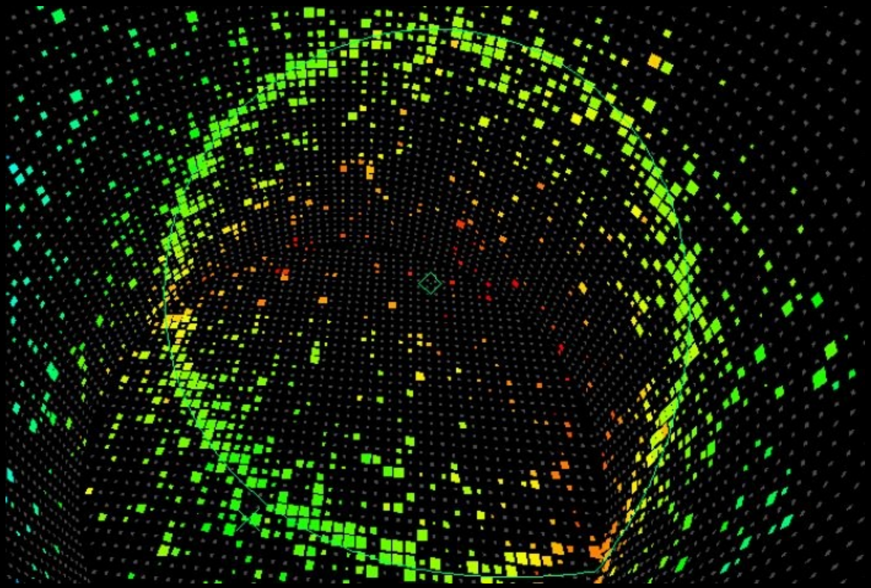


"Pragmatic" global fit (without MiniBooNE low energy excess)



Neutrinos and Dark matter





Evidences: pro and contra

Still controversial

D. Iakubovskyi

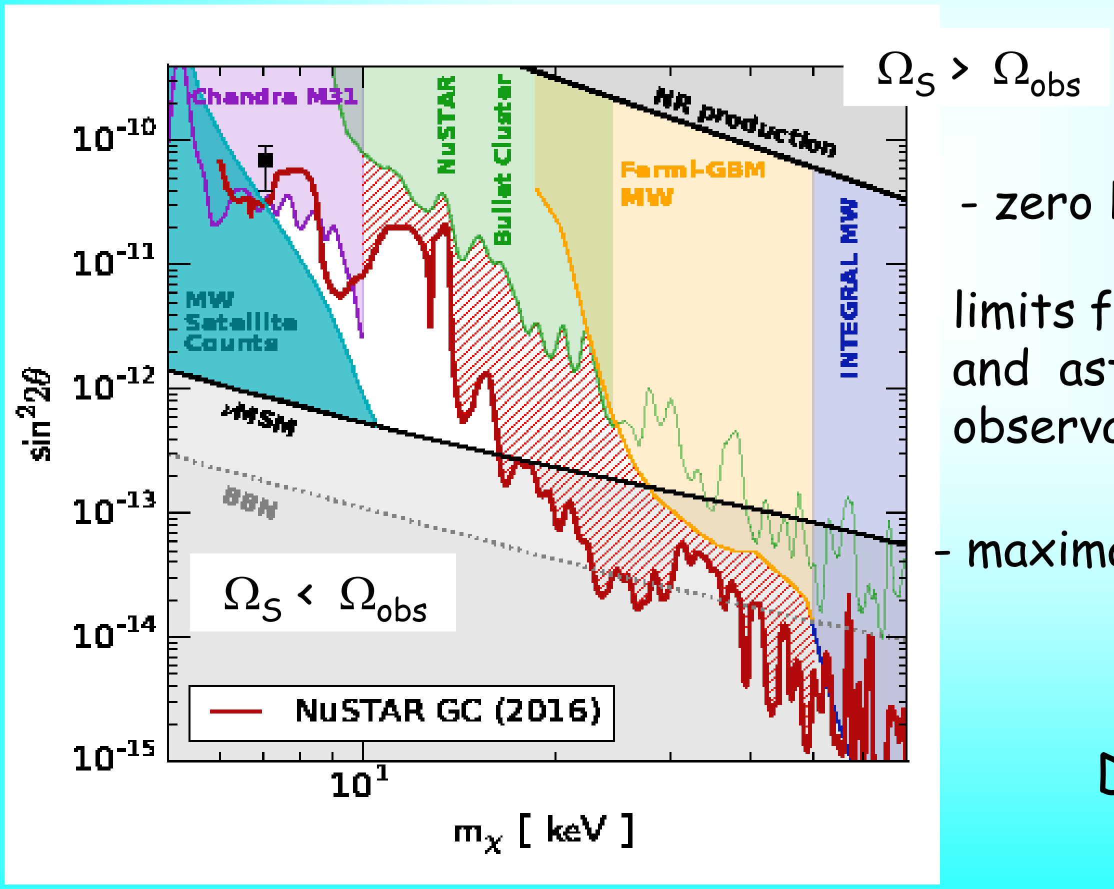
Ref.	Object	Instrument	Decaying DM, PRO	Decaying DM, CONTRA
Bulbul+14	Perseus core; stacked 73 clusters	XMM, Chandra	Correct dependence on DM density and z	—
Boyarsky+14a	M31; Perseus outskirts; blank-sky	XMM	Correct dependence on DM density and z	—
Riemer-Sorensen'14	Galactic Centre (GC)	Chandra	Signal consistent with DM	Signal consistent with anomalously large K abundance
Jeltema+14	GC; M31	XMM	Signal consistent with DM	Signal consistent with anomalously large K abundance
Boyarsky+14b	GC	XMM	Signal consistent with DM	Signal consistent with anomalously large K abundance
Malyshev+14	Stacked dSphs	XMM	—	No line in stacked dSph (still consistent with DM!)
Anderson+14	Stacked galaxy outskirts	XMM, Chandra	—	$\sim 3\sigma$ dip in XMM (systematics?)
Urban+14	Perseus core; Coma; Virgo; Ophiuchus	Suzaku	Perseus signal consistent with DM	No line in Virgo, Coma, Ophiuchus
Tamura+14	Perseus core	Suzaku	—	No line at XMM/Chandra level, systematics? (but see Franse+16)
Carlson+14	GC; Perseus core	XMM	—	3.5 keV photon distribution correlates with astro lines
Sekiya+15	Blank-sky	Suzaku	—	No line (consistent at 2σ)
Iakubovskyi+15	8 nearby clusters (incl. Perseus & Coma)	XMM	Correct dependence on DM density and z	—
Gu+15	M31, clusters	XMM, Suzaku	—	S charge exchange
Jeltema+15	Draco dSph (prolonged)	XMM	—	No line in PN; $\sim 2\sigma$ dip in MOS
Ruchayskiy+15	Draco dSph (prolonged)	XMM	2.3σ excess in PN as expected from DM	$\sim 1\sigma$ excess in MOS2; no line in MOS1
Franse+16	Perseus core & outskirts	Suzaku	8σ excess consistent with DM	discrepancy with Tamura+14 (systematics? analysis??)
Bulbul+16	Stacked 47 clusters	Suzaku	2σ excess consistent with DM	—
Hofmann+16	Stacked 33 clusters	Chandra	—	no excess (consistent with Bulbul+14, Bulbul+16)
Aharonian+16	Perseus core	Hitomi	No anomalously large abundances of elements (consistent with DM)	No excess
Neronov+16	Blank-sky	NuSTAR	11σ excess consistent with DM	At the edge of energy range (systematics?)
Perez+16	GC	NuSTAR	Consistent with DM	found in smaller Earth-occulted subset (systematics?)
Cappelluti+17	Blank-sky	Chandra	3σ excess, no nearby instr. features (same sky region/flux as in NuSTAR)	—

Sterile Neutrinos as Dark matter

(Almost) Closing the Sterile Neutrino Dark Matter Window with NuSTAR

K. Perez, et al.
arXiv:1609.00667 [astro-ph.HE]

Nuclear Spectroscopic Telescope Array, Galactic Center



- zero lepton asymmetry

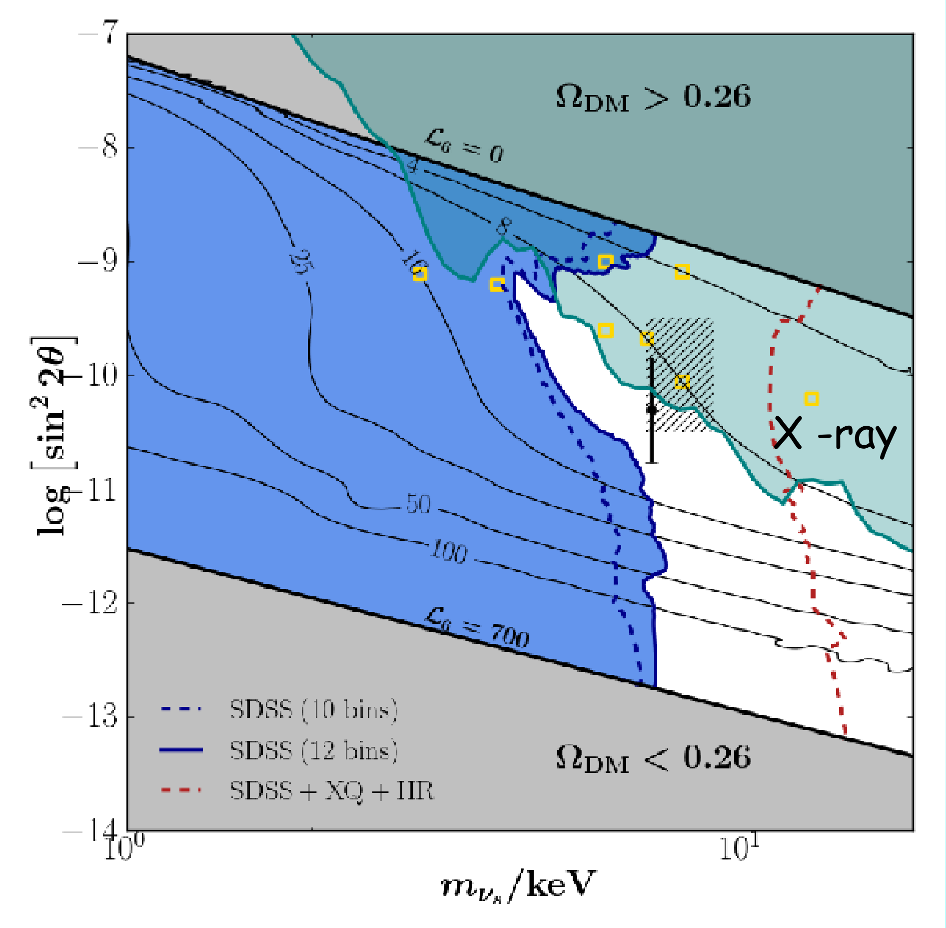
limits from structure formation and astrophysical X-ray observations the colored, regions.

- maximal lepton asymmetry

Deep sky

WDM&Ly-alpha

Julien Baur, et al,
1706.03118 [astro-ph.CO] |,



Constraints from Ly-α forest

The blue shade - excluded by over 3σ by the Ly-α forest BOSS power spectrum.

The green shade are models inconsistent beyond 3σ with a compilation of X-ray data from the Milky Way, Andromeda and other galaxies.

Red dashed with assumption about temperature of medium

In conclusion

BOREXINO: Congratulations!

and good luck with CNO neutrinos