Discussion Panel: Neutrinos 8

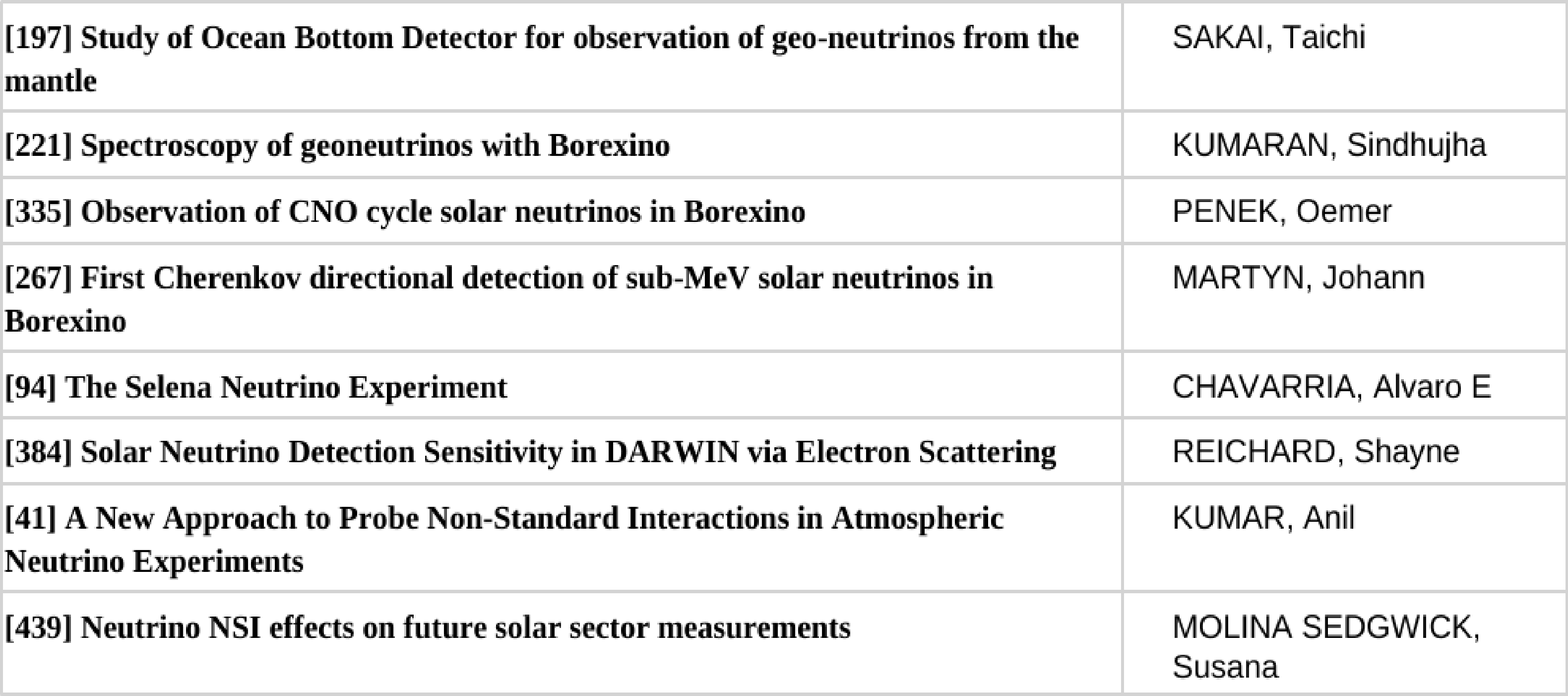
Solar, atmospheric and geo-neutrinos

TAUP 2021

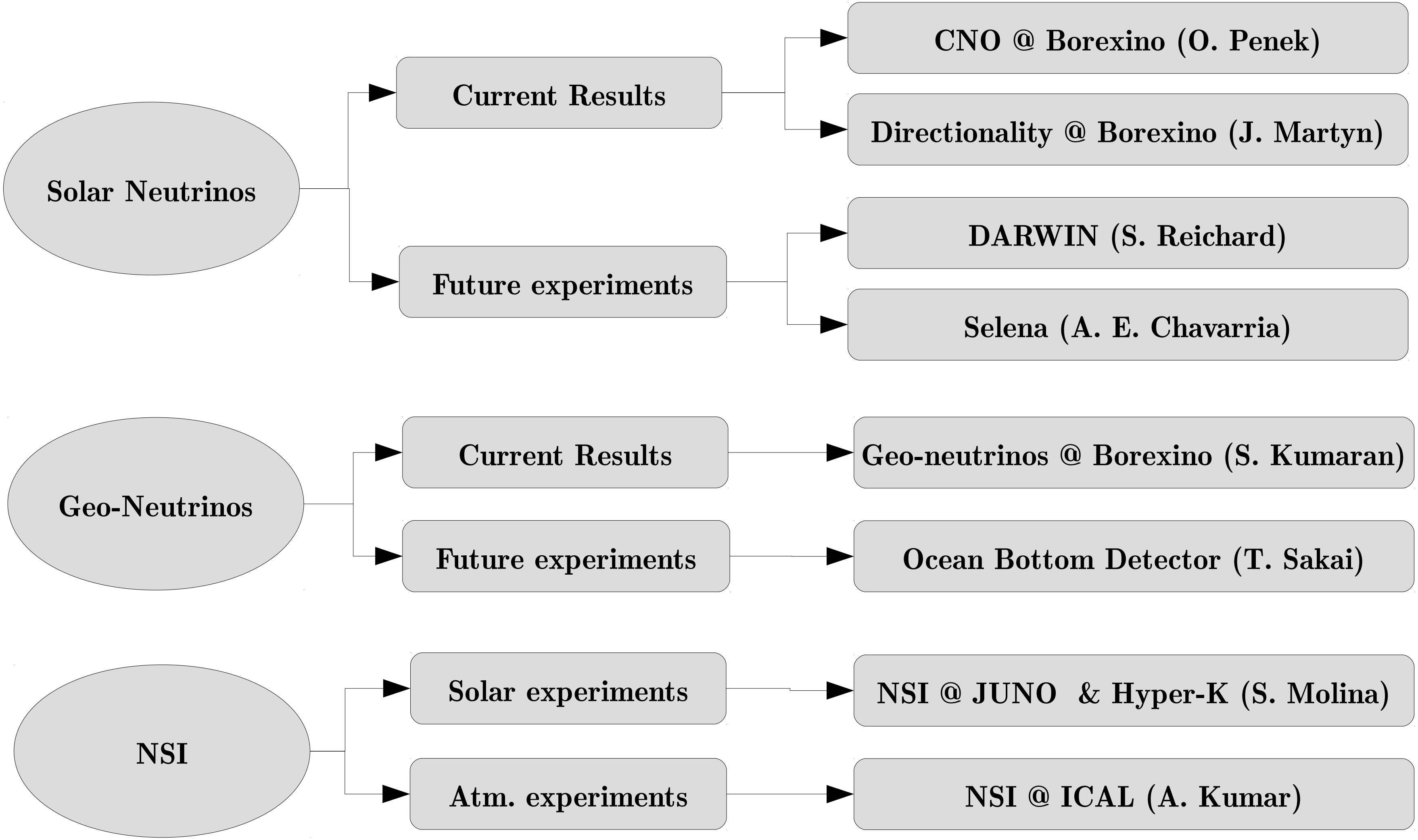
Chair: Pau Novella, IFIC (CSIC & U.V.)

Talks in the session

Indico: https://indico.ific.uv.es/event/6178/sessions/2324/



[197] Study of Ocean Bottom Detector for observation of geo-neutrinos from the mantle	SAKAI, Taichi
[221] Spectroscopy of geoneutrinos with Borexino	KUMARAN, Sindhujha
[335] Observation of CNO cycle solar neutrinos in Borexino	PENEK, Oemer
[267] First Cherenkov directional detection of sub-MeV solar neutrinos in Borexino	MARTYN, Johann
[94] The Selena Neutrino Experiment	CHAVARRIA, Alvaro E
[384] Solar Neutrino Detection Sensitivity in DARWIN via Electron Scattering	REICHARD, Shayne
[41] A New Approach to Probe Non-Standard Interactions in Atmospheric Neutrino Experiments	KUMAR, Anil
[439] Neutrino NSI effects on future solar sector measurements	MOLINA SEDGWICK, Susana

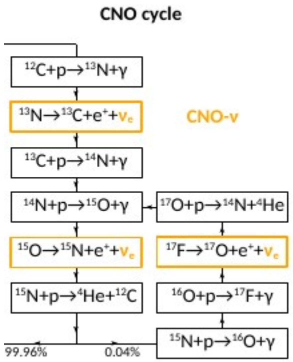

Solar Neutrinos
Current Results
CNO @ Borexino (O. Penek)
Directionality @ Borexino (J. Martyn)
Future experiments
DARWIN (S. Reichard)
Selena (A. E. Chavarria)
Geo-Neutrinos
Current Results
Geo-neutrinos @ Borexino (S. Kumaran)
Future experiments
Ocean Bottom Detector (T. Sakai)
NSI
Solar experiments
NSI @ JUNO & Hyper-K (S. Molina)
Atm. experiments
NSI @ ICAL (A. Kumar)

Live Discussion

- Discussion driven along the previous blocks/topics
- Brief (1-2 min) summary of the talks by each one of the speakers, followed by questions or comments (raise hands o write in chat)
- Final discussion on more general issues, concerning for instance the state-of-the-art of the field or the expectations from future experiments

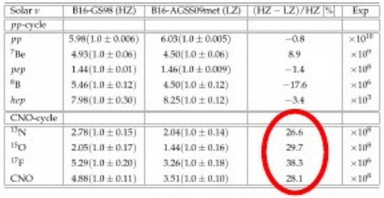
Observation of CNO cycle solar Neutrinos in Borexino – Ömer Penek – TAUP2021

Nuclear Fusion →



Metallicity Problem →

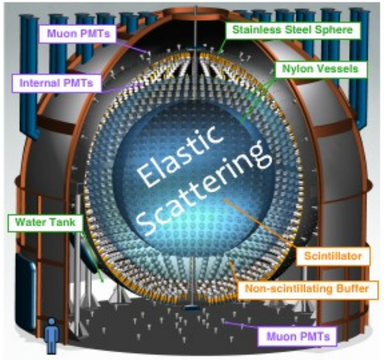
= Helioseismology consistent with older HZ but in tension with newer LZ description



Solar ν	B16-GS98 (HZ)	B16-AGSS09met (LZ)	(HZ − LZ)/HZ [%]	Exp
pp-cycle				
pp	5.98(1.0 ± 0.006)	6.03(1.0 ± 0.005)	−0.8	$\times 10^{10}$
^{7}Be	4.93(1.0 ± 0.06)	4.50(1.0 ± 0.06)	8.9	$\times 10^{9}$
pep	1.44(1.0 ± 0.01)	1.46(1.0 ± 0.009)	−1.4	$\times 10^{8}$
^{8}B	5.46(1.0 ± 0.12)	4.50(1.0 ± 0.12)	−17.6	$\times 10^{6}$
hep	7.98(1.0 ± 0.30)	8.25(1.0 ± 0.12)	−3.4	$\times 10^{3}$
CNO-cycle				
^{13}N	2.78(1.0 ± 0.15)	2.04(1.0 ± 0.14)	26.6	$\times 10^{8}$
^{15}O	2.05(1.0 ± 0.17)	1.44(1.0 ± 0.16)	29.7	$\times 10^{8}$
^{17}F	5.29(1.0 ± 0.20)	3.26(1.0 ± 0.18)	38.3	$\times 10^{6}$
CNO	4.88(1.0 ± 0.11)	3.51(1.0 ± 0.10)	28.1	$\times 10^{8}$

For CNO: $\frac{\mathrm{HZ}-\mathrm{LZ}}{\mathrm{HZ}} \sim 30\%$

The Borexino Detector →



Signal + Backgrounds →

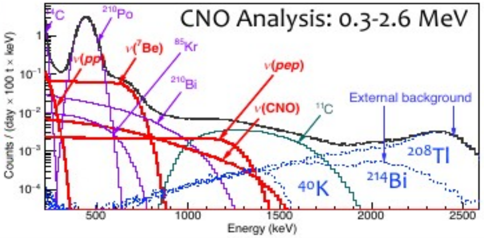
Signals $\nu(pp), \nu(^{7}Be), \nu(pep), \nu(CNO)$

Internal Bkg (scintillator): ^{14}C, ^{85}Kr, ^{210}Bi, ^{210}Po

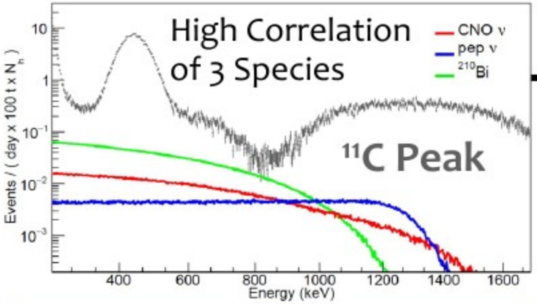
External Bkgs (γs): ^{40}K, ^{214}Bi, ^{208}Tl

Cosmogenic Bkg ($\mu + {}^{12}C \to \mu + {}^{11}C + n$): ^{11}C

→ ^{11}C treatment TFC algorithm



→ Spectral Correlation →



pep-ν rate constraint

⇔ Global Analysis of Solar Neutrino Data

+ Luminosity constraint

(Bergström et al., JHEP, 2016:132, 2016)

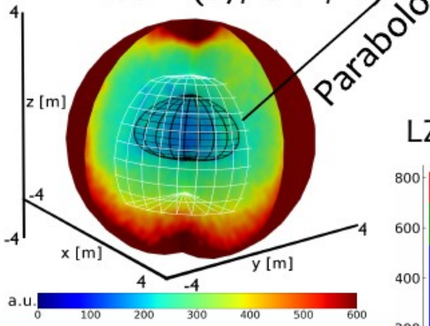
Result: (2.74±0.04) counts/day/100t (HZ-SSM ≈ LZ-SSM)

^{210}Bi rate constraint → Challenging

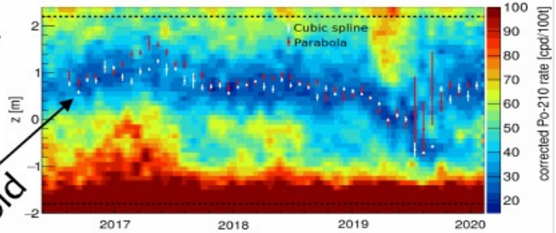
Identify Low ^{210}Po Field (LPoF) →

Thermal Insulation + Active Temperature Control System

→ Stopped Convective Currents in Bx Phase-III (07/16-02/20)



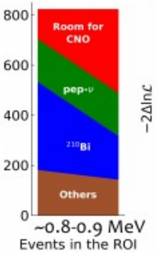
$R(^{210}\mathrm{Bi}) \leq (11.5 \pm 1.3)$ counts/day/100t

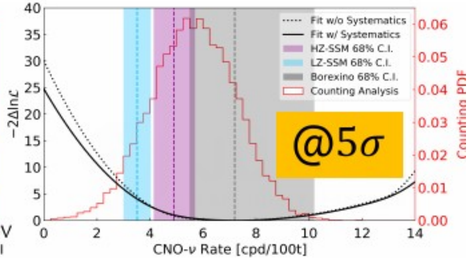


→ Spectral Fit → CNO Profile

$\Phi_{\mathrm{CNO}} = (7.0^{+3.0}_{-2.0}) \times 10^{8}\ \mathrm{cm^{-2}s^{-1}}$

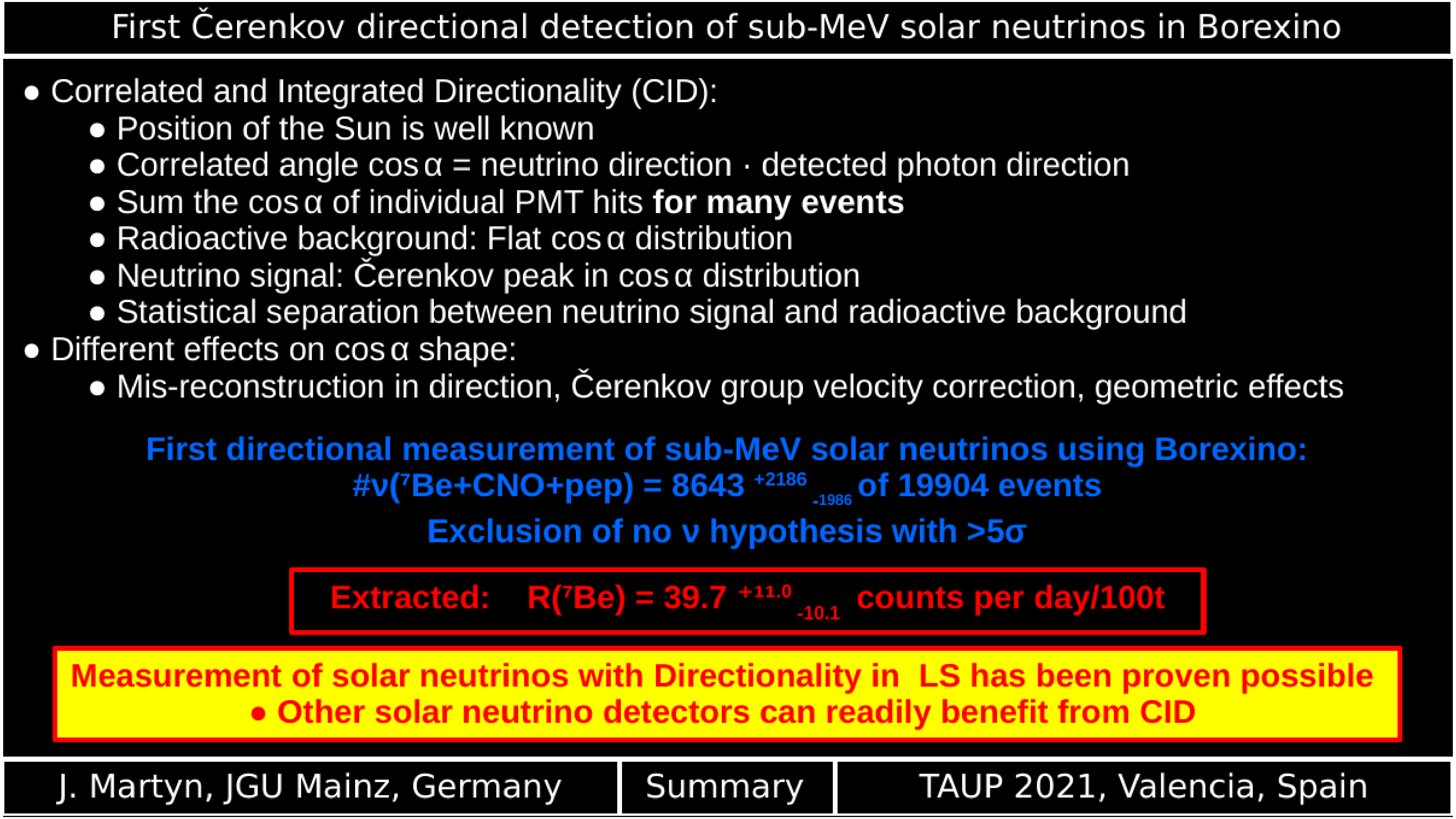
LZ for Bx data only: Disfavored at 2.1σ





@5σ

Solar ν



First Čerenkov directional detection of sub-MeV solar neutrinos in Borexino

- Correlated and Integrated Directionality (CID):
  - Position of the Sun is well known
  - Correlated angle cos α = neutrino direction · detected photon direction
  - Sum the cos α of individual PMT hits **for many events**
  - Radioactive background: Flat cos α distribution
  - Neutrino signal: Čerenkov peak in cos α distribution
  - Statistical separation between neutrino signal and radioactive background
- Different effects on cos α shape:
  - Mis-reconstruction in direction, Čerenkov group velocity correction, geometric effects

First directional measurement of sub-MeV solar neutrinos using Borexino:
#ν(^{7}Be+CNO+pep) = 8643 $^{+2186}_{-1986}$ of 19904 events
Exclusion of no ν hypothesis with >5σ

Extracted: R(^{7}Be) = 39.7 $^{+11.0}_{-10.1}$ counts per day/100t

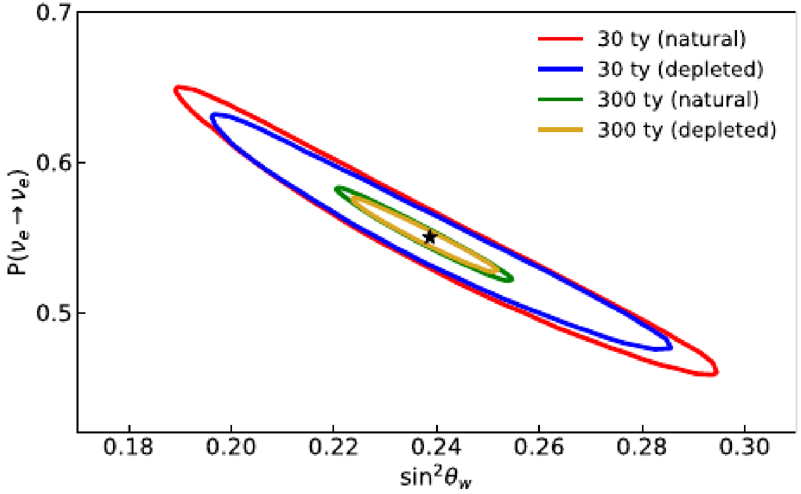
Measurement of solar neutrinos with Directionality in LS has been proven possible
● Other solar neutrino detectors can readily benefit from CID

J. Martyn, JGU Mainz, Germany | Summary | TAUP 2021, Valencia, Spain

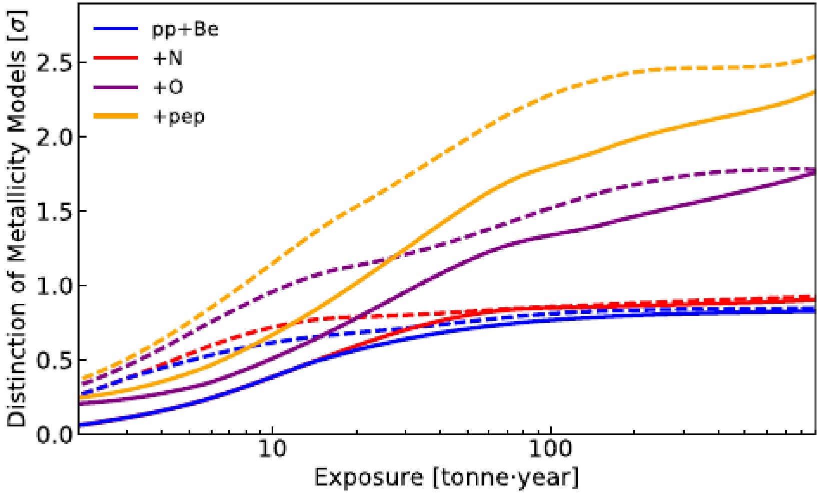
Summary

- Measurements of pp and ^{7}Be flux, scattering and oscillation parameters
- Distinction of metallicity models at 2.0-2.5σ (theory-limited)

Broader implications for neutrino physics?



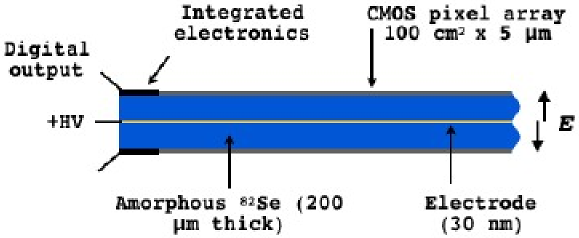
Overcome theoretical limits?

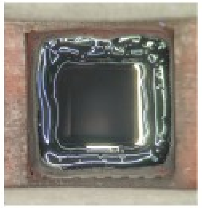


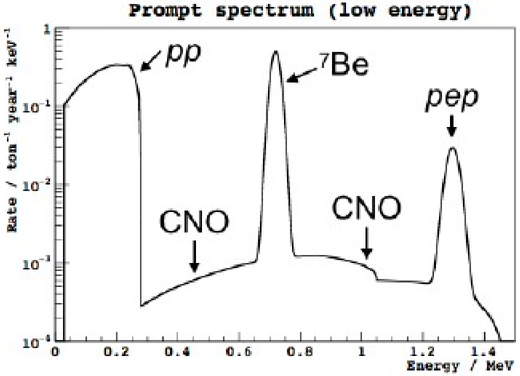
The Selena Neutrino Experiment

A.E. Chavarria, U. Washington

- Amorphous ^{82}Se (aSe) coupled to a CMOS pixel array to image particle tracks with high energy and spatial resolution.
- **Goals**: to perform *zero background* search for $0\nu\beta\beta$ decay and solar ν spectroscopy in 100 ton-year.
- Triple sequence (ν_e capture → ^{82}Br* deexcitation → ^{82}Br decay) allows to tag solar ν captures.
- Background suppression from event topology, particle and decay sequence ID.
- **$T_{1/2} > 10^{28}$** years for ^{82}Se ($m_{\beta\beta} < 10$ meV).
- Measure solar properties with improved precision: **luminosity** (pp flux ~%), **metallicity** (CNO flux ~10%) and core **temperature** (~25%).
- **R&D Program status**: Characterizing the first prototype sensors!

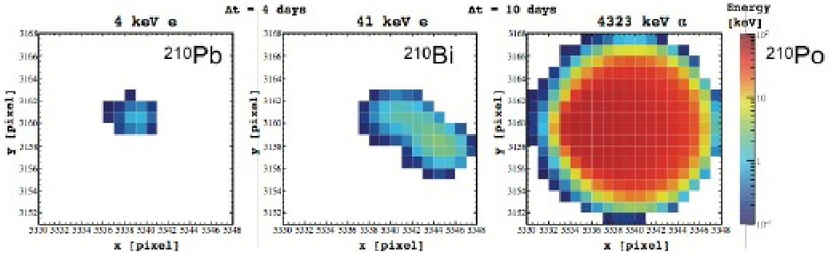


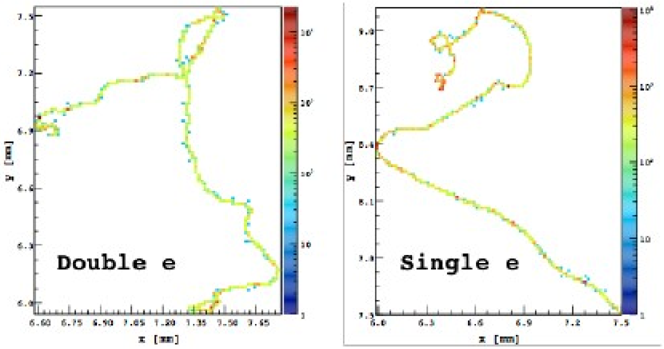




$$\nu_e + {}^{82}\mathrm{Se} \longrightarrow {}^{82}\mathrm{Br}^* + e^- + \mathrm{C.E.}\ (29\ \mathrm{keV})$$

$$\searrow E_\nu - 172\ \mathrm{keV}$$





Geo-ν

SPECTROSCOPY OF GEONEUTRINOS WITH BOREXINO – SINDHUJHA KUMARAN Phys. Rev. D 101 (2020)

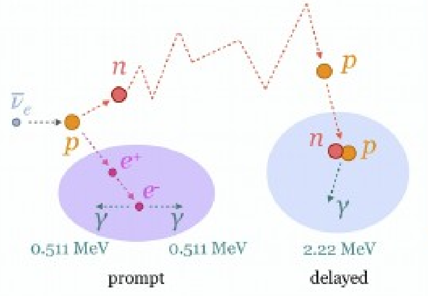
INTRODUCTION

Geoneutrinos: Emitted in radioactive decays inside Earth

Main goals: Radiogenic heat, mantle properties, Th/U ratio

Borexino detector: Liquid scintillator detector.
One of the two detectors measuring geoneutrinos

Detection via **Inverse Beta Decay (IBD)**



ANALYSIS

Improved Selection cuts:
→ Enlarged Fiducial Volume
→ Sophisticated muon vetoes
→ Enlarged energy window for delayed event
→ Enlarged time and space coincidence windows
→ Improved α/β discrimination

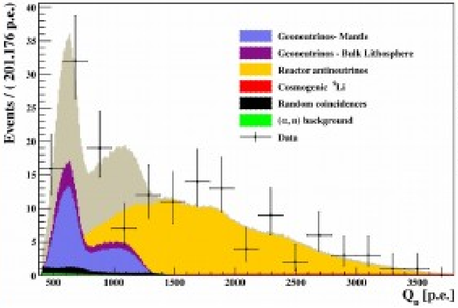
Antineutrino backgrounds
→ Reactor antineutrinos (left free in spectral fit)
→ Atmospheric neutrinos (systematic uncertainty)

Non-antineutrino backgrounds
(constrained in spectral fit)
→ Residual cosmogenic ^{9}Li
→ (α,n) background
→ Accidental background

RESULTS

Improved Precision:
24-27% from previous measurement (2015) to **17-18%** current measurement (Dec'07-Apr'19): **$47.0^{+8.7}_{-7.9}$ TNU**

First no-mantle signal exclusion at 99% C.L.
$21.2^{+9.6}_{-9.1}$ TNU
after constraining well-known lithosphere signal

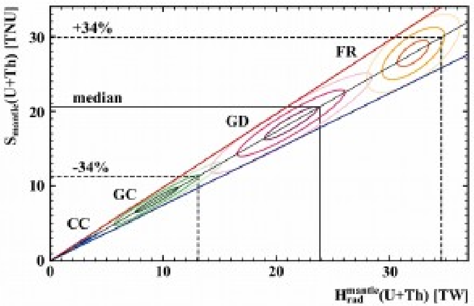


INTERPRETATIONS

Radiogenic heat:
$38.2^{+13.6}_{-12.7}$ TW
Inferred from mantle signal

2.4σ tension with Earth models predicting low mantle heat

Stringent **upper limits** for a **hypothetical georeactor** inside Earth



Mitglied der Helmholtz-Gemeinschaft

RWTH AACHEN UNIVERSITY

JÜLICH Forschungszentrum

Geo-ν

Study of **Ocean Bottom Detector** for observation of geo-neutrinos from mantle, Taichi SAKAI for OBD working group

Introduction

Mantle geo-neutrino:
can reveal Earth's big questions

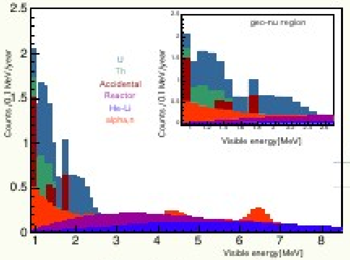
Ocean Bottom Detector:
Now under developing , next generation detector especially aimed at direct measurement of mantle geo-neutrinos

Final goal:10-50kt
Location:2-5km deep sea

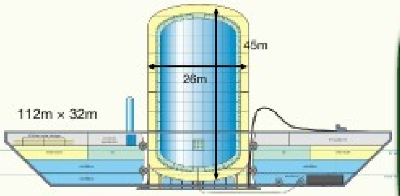
Performance:
OBD 1.5kt detector can observe mantle geo-neutrinos in 3.5σ/3 year measurement(middle-Q model)

Current status:
In 2019, Tohoku Univ. & *JAMSTEC joint research was started. We are working to realize OBD

* Japan Agency for Marine-Earth Science and Technology



Simulation result



"Hanohano":detector design @Univ. Hawaii 2005

Technical development

PMT shield

PMTs receive high-pressure, we need to put shield.
Material candidates : glass and acrylic

Glass:
We select the low-radioactive material and develop the manufacturing process

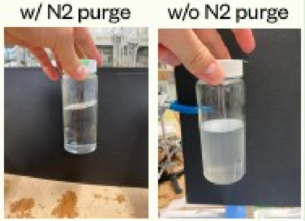
	^{238}U	^{232}Th	^{40}K
Our glass	**$1.4*10^{-8}$g/g**	**<$5.0*10^{-9}$g/g**	**$3.4*10^{-9}$g/g**
Target value	$1*10^{-8}$g/g	$1*10^{-8}$g/g	$1*10^{-8}$g/g

Acrylic:
We did pressure test with prototype ball.
Now we are developing new design of acrylic shield and pressure test again.

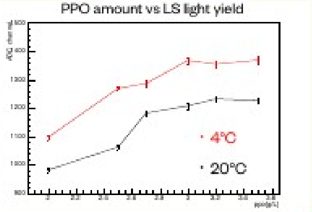
Liquid Scintillator(LS)

LS which performs well under low-temperature is needed.

In low-temperature, LS becomes cloudy for contained water, so we need to do sufficient N2 purge.



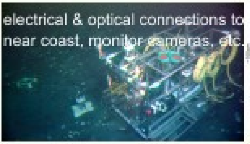
We also checked LS light yield with ^{137}Cs back scattering.



Future plan

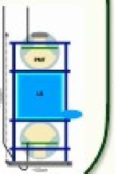
Technical test & world's first measurement in the ocean with LS detector

*install detector into 1km seafloor(JAMSTEC's Hatsushima Observatory)
*technical developments are in progress
*Performance testing for the next detector.
*We will install this detector in 2022 !



electrical & optical connections to near coast, monitor cameras, etc.

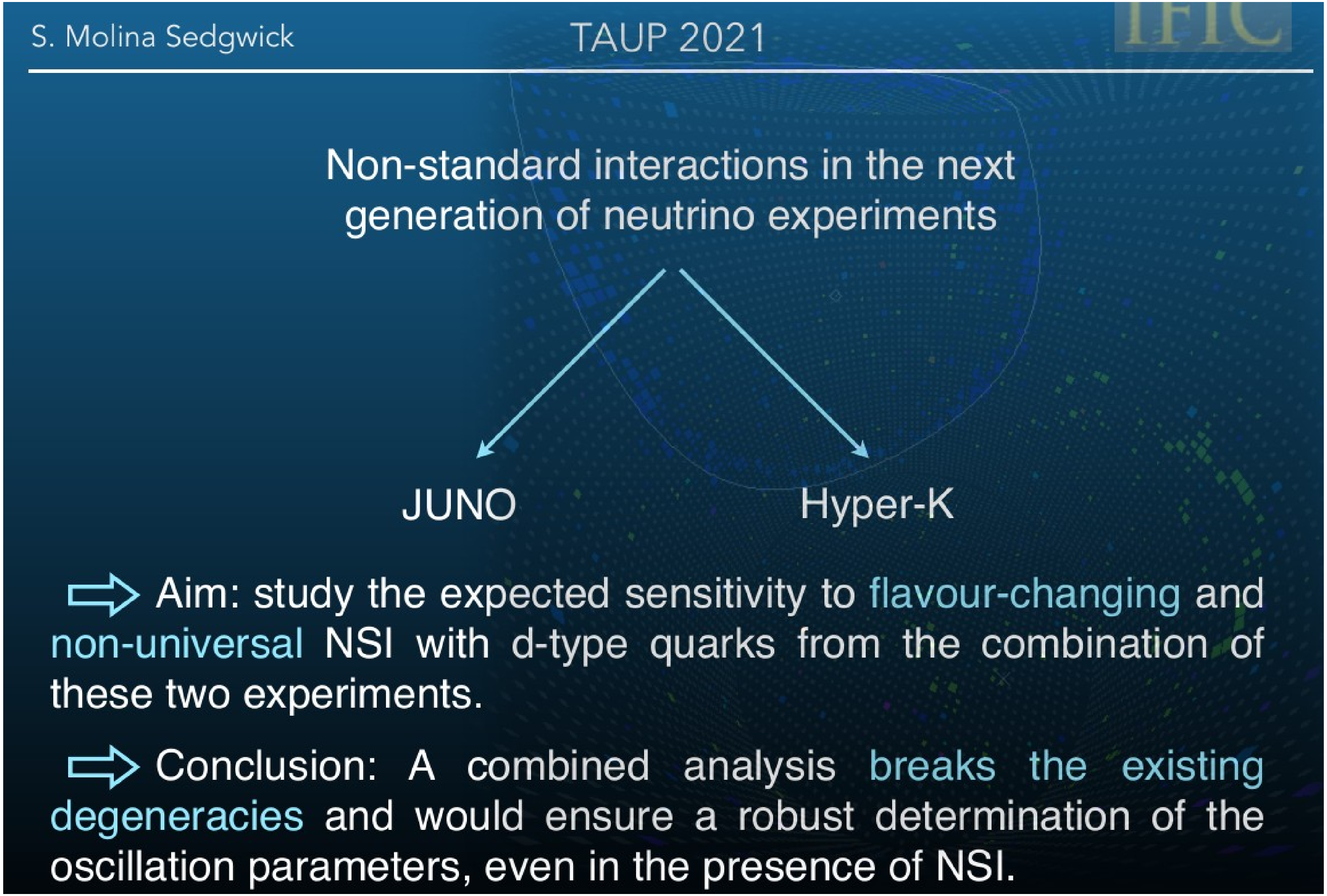
Detector design



TOHOKU UNIVERSITY

GPPU GRADUATE PROGRAM ON PHYSICS FOR THE UNIVERSE

NSI



S. Molina Sedgwick TAUP 2021

Non-standard interactions in the next generation of neutrino experiments

JUNO Hyper-K

⇨ Aim: study the expected sensitivity to flavour-changing and non-universal NSI with d-type quarks from the combination of these two experiments.

⇨ Conclusion: A combined analysis breaks the existing degeneracies and would ensure a robust determination of the oscillation parameters, even in the presence of NSI.

A New Approach to Probe Non-Standard Interactions in Atmospheric Neutrino Experiments

Anil Kumar et. al. JHEP 04 (2021) 159, arXiv: 2101.02607

- Oscillation dip shifts and oscillation valley bends in presence of neutral-current NSI
- Introducing a new variable Δd representing the difference of dip locations in μ^- and μ^+ channels
- Δd is sensitive to magnitude as well as sign of $\varepsilon_{\mu\tau}$
- The contrasts in the curvatures of valleys in μ^- and μ^+ is used to estimate $\varepsilon_{\mu\tau}$
- Measurement of $\varepsilon_{\mu\tau}$ using **500 kt.yr** simulated datasets at **ICAL** including **statistical fluctuations**, **uncertainties in oscillation parameters** and **systematics**

The expected 90% C.L. allowed range of $\varepsilon_{\mu\tau}$

$\text{Log}_{10}\,(L_\mu^{rec}/E_\mu^{rec})$	$-0.025 < \varepsilon_{\mu\tau} < 0.024$
$(E_\mu^{rec}, \cos\theta_\mu^{rec})$	$-0.022 < \varepsilon_{\mu\tau} < 0.021$