

IPPP: recollections on neutrinos and related topics

25 Sep 2025

IPPP@25

Silvia Pascoli

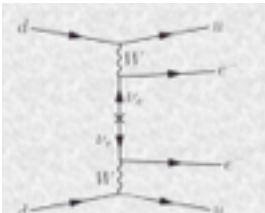


ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



First trip to Durham

I came to Durham to a neutrino workshop in 2004.



IPPP Workshop on
Neutrinoless Double Beta Decay Phenomenology
Grey College, Durham, UK
April 21-23, 2004

Within the Standard Model lepton number is conserved, and so neutrinoless double beta decay ($0\nu\beta\beta$) is forbidden. However, recent neutrino oscillation experiments strongly suggest that neutrinos are massive particles, and imply that the description of neutrinos within the Standard Model is incomplete. To move beyond the Standard Model and formulate a new theoretical framework with which to describe neutrino phenomenology, the mass mechanism must be investigated. $0\nu\beta\beta$ experiments illuminate the nature of the mass term in the neutrino Lagrangian; if $0\nu\beta\beta$ is observed, the neutrino must be a Majorana particle. This represents both theoretical and experimental challenges. The UK has a strong and growing interest in $0\nu\beta\beta$ experiments, and a [strategy document](#) has recently been produced.



The search
for $0\nu\text{BB}$ is
still ongoing!

I got an
excellent
impression of
Durham.

09.00-10.45 **Experiment (1hr talk by, *F. Avignone*) + Discussion**
(Chair : K. Zuber)

10.45-11.15 Coffee

11.15-13.00 **Beyond the SM (1/2 hr talk by *S. Pascoli*) + Discussion**
(Chair : A. Dedes)

13.00-14.00 LUNCH

First years

I was hired to fill the “neutrino” post in 2005.

Neutrino physics:
recent discoveries and
questions for the future

I was allowed and
expected to lead this
area of research.

IPPP - Durham

9 May 2005

Silvia Pascoli

CERN

6 – Conclusions and outlook

- We have strong evidence for **neutrino oscillations**. They imply that **Neutrinos are massive** ($\Delta m^2 \neq 0$) and that they **mix** ($\sin \theta \neq 0$).

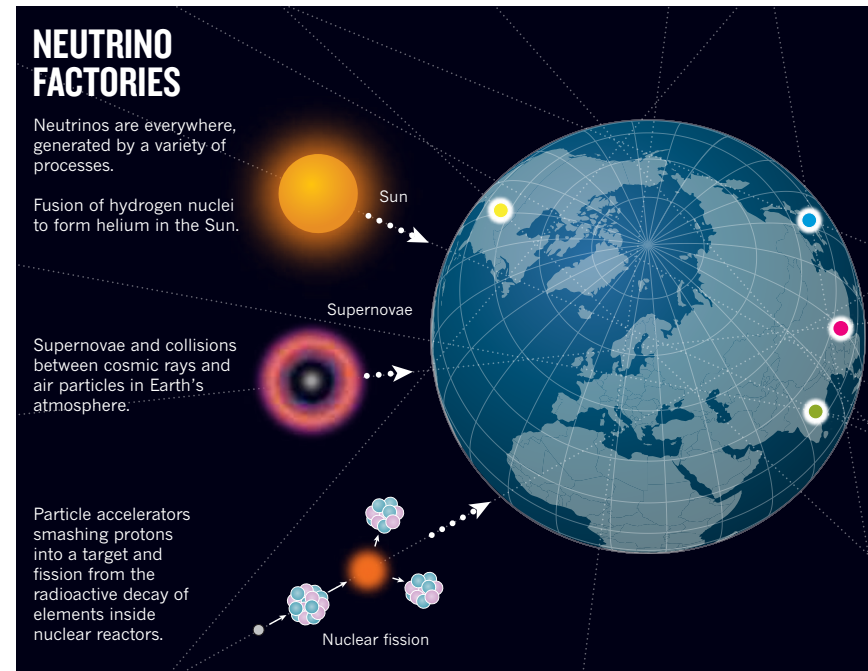
Neutrino masses and mixing requires new **physics beyond the SM**.

Neutrino physics may shed light on the physics at high energy scales
(and possibly on the evolution of our Universe).

1. determination of neutrino parameters: my activity concentrates on LBL and $(\beta\beta)_{0\nu}$ -decay exp.
2. explanation of the origin of neutrino masses and of the flavour structure: I study see-saw models and their implications for low energy parameters and leptogenesis.
3. study of the role of neutrinos in Cosmology and Astrophysics.

Neutrinos

- **Neutrino masses imply new physics BSM.** Their origin is a necessary ingredient for the newSM.
- The least known of all SM fermions.
- Their nature is related to fundamental symmetries of nature.
- The most abundant of all fermions in the Universe.
- Neutrino mass models can explain the baryon asymmetry of the Universe.



@Nature, 2015

Neutrino oscillations have now been established for more than 25 years.



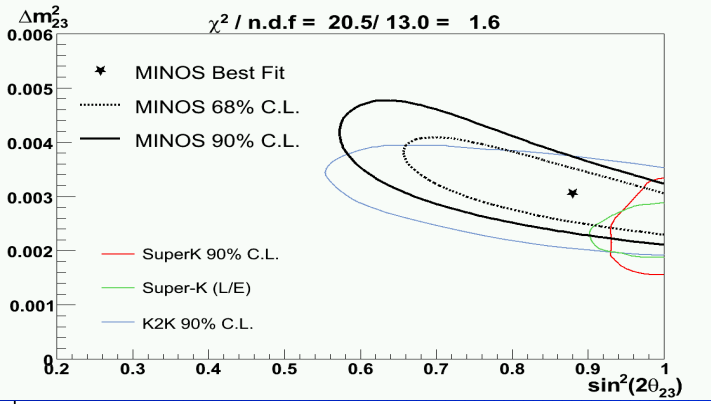
Бруно Понтекорво



Neutrinos can change flavour as they travel.

*How has the field
evolved over these
past 25 years?
And what role has
IPPP had?*

*(with examples of IPPP articles,
apologies for not mentioning all)*

	Normal Ordering ($\Delta\chi^2 = 0.6$)			
	bfp $\pm 1\sigma$	3σ range		
$\sin^2 \theta_{12}$	$0.307^{+0.012}_{-0.011}$	$0.275 \rightarrow 0.345$		
$\theta_{12}/^\circ$	$33.68^{+0.73}_{-0.70}$	$31.63 \rightarrow 35.95$		
$\sin^2 \theta_{23}$	$0.561^{+0.012}_{-0.015}$	$0.430 \rightarrow 0.596$		
$\theta_{23}/^\circ$	$48.5^{+0.7}_{-0.9}$	$41.0 \rightarrow 50.5$		
$\sin^2 \theta_{13}$	$0.02195^{+0.00054}_{-0.00058}$	$0.02023 \rightarrow 0.02376$	$0.02224^{+0.00056}_{-0.00057}$	$0.02053 \rightarrow 0.02397$
$\theta_{13}/^\circ$	$8.52^{+0.11}_{-0.11}$	$8.18 \rightarrow 8.87$	$8.58^{+0.11}_{-0.11}$	$8.24 \rightarrow 8.91$
$\delta_{CP}/^\circ$	177^{+19}_{-20}	$96 \rightarrow 422$	285^{+25}_{-28}	$201 \rightarrow 348$
$\frac{\Delta m_{21}^2}{10^{-5} \text{ eV}^2}$	$7.49^{+0.19}_{-0.19}$	$6.92 \rightarrow 8.05$	$7.49^{+0.19}_{-0.19}$	$6.92 \rightarrow 8.05$
$\frac{\Delta m_{3\ell}^2}{10^{-3} \text{ eV}^2}$	$+2.534^{+0.025}_{-0.023}$	$+2.463 \rightarrow +2.606$	$-2.510^{+0.024}_{-0.025}$	$-2.584 \rightarrow -2.438$

- 2 mass squared differences
- 3 sizable mixing angles,
- mild hints of CPV
- mild indications in favour of NO ($m_3 > m_1$).

M. C. Gonzalez-Garcia et al., 2410.05380
<http://www.nu-fit.org/>

What do we still need to know?

- What is the nature of neutrinos? Dirac vs Majorana?

$$\nu = \nu^c (= C\bar{\nu}^T)$$

Neutrinoless
dbeta decay

- What are the values of the masses? Absolute scale (KATRIN, ...?) and the ordering.

- Is there CP-violation? Its discovery in the next generation of LBL depends on the value of delta.

LBL:T2K, NOvA,
DUNE, T2HK, ESSnuSB,
nuFACT..., ORCA,
JUNO

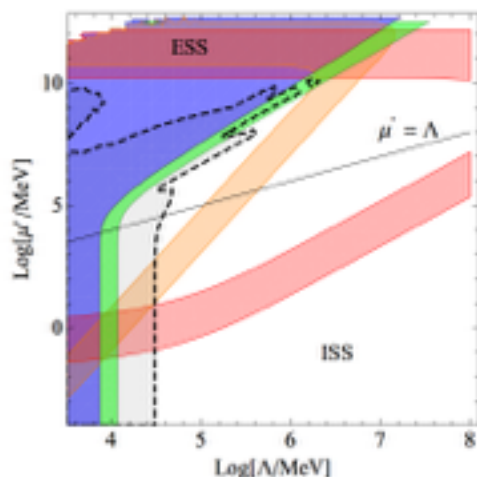
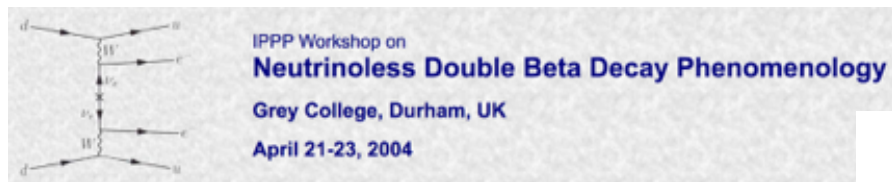
- What are the precise values of mixing angles? Do they suggest an underlying pattern?

reactor SBL and MBL,
atm, LBL, ...

- Is the standard picture correct? Are there NSI? Sterile neutrinos? Other effects? MicroBooNE, SBN, reactor SBL...

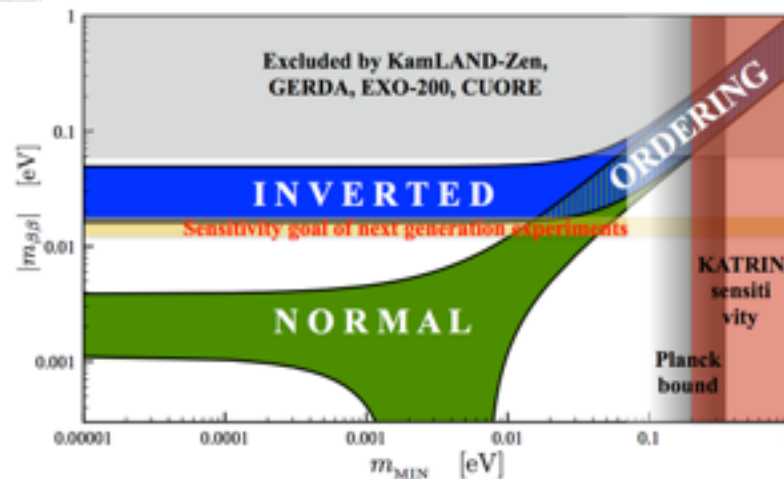
Neutrinoless double beta decay

APPEC 0nuBB
Committee, I910.04688



J. Lopez-Pavon, SP, C-F Wong,
1209.5342, See works with M. Mitra

It remains an open
question but there a much
more intense search.
Problem of NME.



Scalability	Fluid embedded source	Xe-based TPC	EXO-200	SuperNEMO	
			NEXT-10	NEXT-100 PandaX-III	NEXT-2.0 PandaX-III 1t
High ΔE and ϵ	Crystal embedded source	Liquid scintillator as a matrix	KamLAND-Zen 800	KamLAND2-Zen	
			SNO+ phase I	SNO+ phase II	
		Germanium diodes	GERDA-II	LEGEND 200	LEGEND 1000
			MJD		
		Bolometers	AMoRE pilot, I	AMoRE II	
			CUORE CUPID-0, CUPID-Mo	CUPID	

A. Giuliani, Neutrino 2018

The quest for MO and CPV: LBL exp

In 2000-2010 great emphasis on pheno studies of physics reach of LBL experiments.

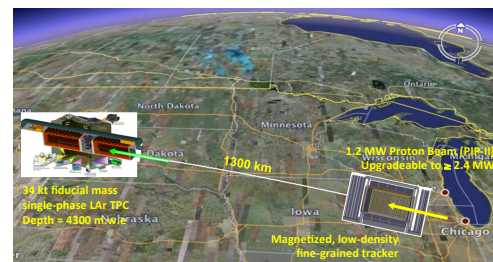
Determining the neutrino mass hierarchy and CP violation in NoVA with a second #16 off-axis detector

Olga Mena (Fermilab), Sergio Palomares-Ruiz (Vanderbilt U.), Silvia Pascoli (CERN and Durham U., IPPP) (Oct, 2005)

Published in: *Phys.Rev.D* 73 (2006) 073007 • e-Print: [hep-ph/0510182](https://arxiv.org/abs/hep-ph/0510182) [hep-ph]

People involved: C. Orme, P. Ballett, S. Palomares-Ruiz, SP, Contribution to IDS-NF and later NuSTORM.

An intense effort by the exp community to focalise the next gen experiments.



DUNE in prep, with Durham U. membership

T2K running and T2HK in prep

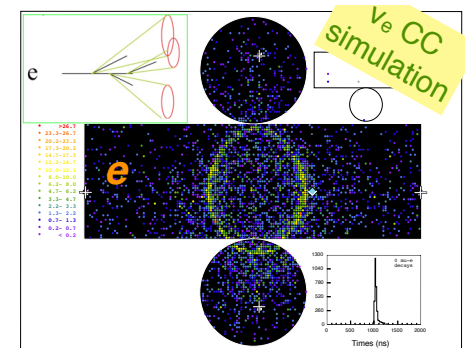


Fig. 2. Map of the Europe showing the three possible underground sites selected for the LAGUNA-LBNO DS.

The quest for MO and CPV: LBL exp

In 2000-2010 great emphasis on pheno studies of physics reach of LBL experiments.

Determining the neutrino mass hierarchy and CP violation in NoVA with a second off-axis detector #16

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An intense effort by the community to localise the next generation experiments.

Great collaboration discussions with UK experimentalists: 0nuBB, LBL, NA62, NA64, MicroBooNE

DUNE in prep, with Durham U. membership



T2K running and T2HK in prep

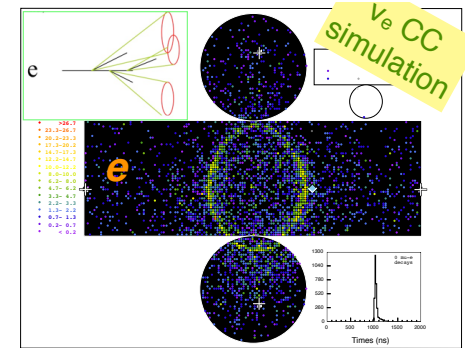


Fig. 2. Map of the Europe showing the three possible underground sites selected for the LAGUNA/LBNB DS.

Testing the standard 3-neutrino picture

Are there sterile neutrinos? Non-standard interactions? Using neutrinos as a portal BSM.

Present and future bounds on nonstandard neutrino interactions

#7

S. Davidson (Durham U., IPPP), C. Pena-Garay (Princeton, Inst. Advanced Study), N. Rius (Valencia U. and Valencia U., IFIC), A. Santamaria (Valencia U. and Valencia U., IFIC) (Feb, 2003)

Published in: *JHEP* 03 (2003) 011 • e-Print: [hep-ph/0302093](#) [hep-ph]

Collaboration
with
MicroBooNE.

A dark seesaw solution to low energy anomalies: MiniBooNE, the muon ($g - 2$), and BaBar

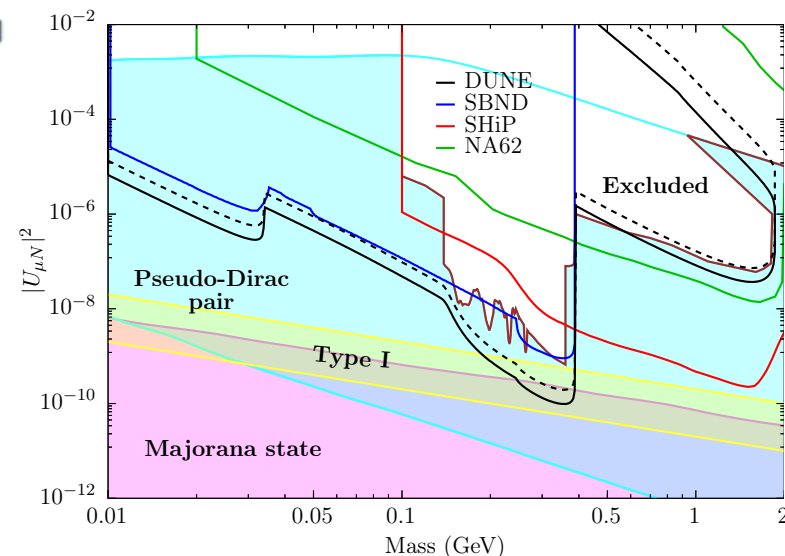
#9

Asli Abdullahi (Durham U., IPPP), Matheus Hostert (Minnesota U. and Minnesota U., Theor. Phys. Inst. and Perimeter Inst. Theor. Phys.), Silvia Pascoli (Durham U., IPPP) (Jul 23, 2020)

Published in: *Phys.Lett.B* 820 (2021) 136531 • e-Print: [2007.11813](#) [hep-ph]

Ballett, Boschi, SP,
1905.00284

With new exp opportunities, this area of research is blooming. MicroBooNE, ICARUS, SBND are ongoing.

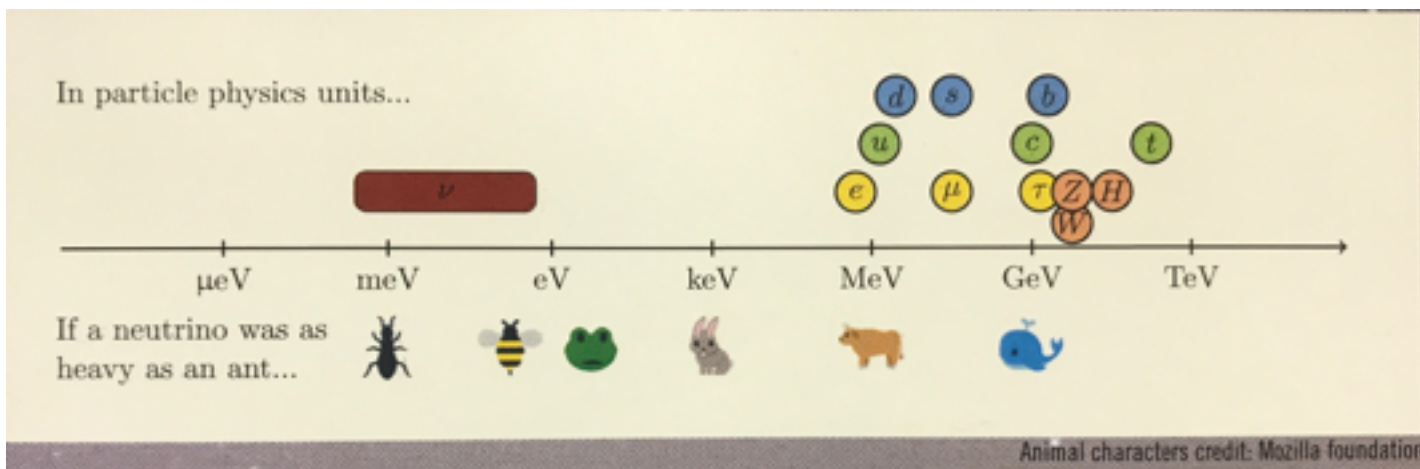


*What can neutrino
tell us about the
most fundamental
rules of Nature?*

*Game-changing
information*

Open window on Physics beyond the SM

In the SM neutrino masses cannot be explained.



@Ghosts in the Universe, Exhibition at the Royal Society with M. Stadler, C. Weiland, R. Ruiz, P. Ballett, Y-L Zhou and all the IPPP neutrino team

Why neutrinos have mass?
and why are they so much lighter than other fermions?

Problem of flavour: Why leptonic mixing is so different from quark mixing?

Neutrinos give a new perspective on physics BSM.

Neutrino mass origin: A new physics scale

The search of the origin of neutrino masses remains a key goal. In 2000's the emphasis was on high see-saw.

The field has broadened and now intense study of lower scales and in connection with other areas.

Problem of leptonic flavour.

Is it possible to explain neutrino masses with scalar dark matter? #7

Celine Boehm (Annecy, LAPTH), Yasaman Farzan (IPM, Tehran), Thomas Hambye (Madrid, Autonoma U.), Sergio Palomares-Ruiz (Durham U., IPPP), Silvia Pascoli (Durham U., IPPP) (Dec, 2006)

Published in: *Phys.Rev.D* 77 (2008) 043516 • e-Print: [hep-ph/0612228](#) [hep-ph]

Monopoles at future neutrino detectors

Pablo M. Candela (Valencia U., IFIC), Valentin V. Khoze (Durham U., IPPP), Jessica Turner (Durham U., IPPP) (Apr 21, 2025)

Published in: *JHEP* 07 (2025) 034 • e-Print: [2504.14918](#) [hep-ph]

Neutrino Portals to Dark Matter #2

M. Blennow (Madrid, IFT and Royal Inst. Tech., Stockholm), E. Fernandez-Martinez (Madrid, IFT), A. Olivares-Del Campo (Durham U., IPPP), S. Pascoli (Durham U., IPPP), S. Rosauo-Alcaraz (Madrid, IFT) et al. (Feb 28, 2019)

Published in: *Eur.Phys.JC* 79 (2019) 7, 555 • e-Print: [1903.00006](#) [hep-ph]

Mixing angle and phase correlations from A5 with generalized CP and their prospects for discovery #35

Peter Ballett (Durham U., IPPP), Silvia Pascoli (Durham U., IPPP), Jessica Turner (Durham U., IPPP) (Mar 25, 2015)

Published in: *Phys.Rev.D* 92 (2015) 9, 093008 • e-Print: [1503.07543](#) [hep-ph]

eV

keV

MeV

GeV

TeV

Intermediate scale

GUT scale

Low E see-saw
Min/Rich Dark
sectors

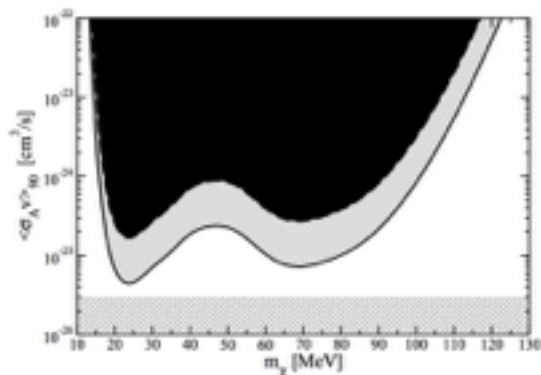
At TeV SUSY MSSM, split
SUSY, Composite Higgs,
Technicolor....

GUT theories

Dark sector searches

LLP searches LHC searches

GW from $U(1)_L$
breaking



S. Palomares-Ruiz,
SP, 0710.5420

Probing right-handed neutrinos via trilepton signals at the HL-LHC

Manimala Mitra (Bhubaneswar, Inst. Phys. and HBNI, Mumbai), Subham Saha (Bhubaneswar, Inst. Phys. and HBNI, Mumbai), Michael Spannowsky (Durham U., IPPP), Michihisa Takeuchi (Zhongshan U., Zhuhai and Osaka U. (main)) (Aug 16, 2024)

Published in: Phys.Rev.D 111 (2025) 1, 015005 • e-Print: 2408.08565 [hep-ph]

Heavy neutrinos with dynamic jet vetoes: multilepton searches at $\sqrt{s} = 14, 27,$
and 100 TeV

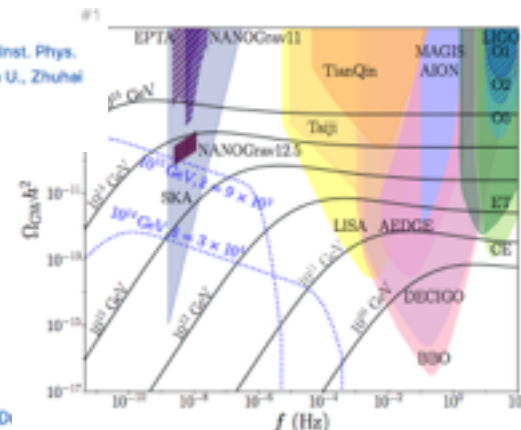
Silvia Pascoli (Durham U., IPPP and Durham U.), Richard Ruiz (Durham U., IPPP and Durham U. and Louvain U., CP3), Cedric Weiland (Durham U., IPPP and Durham U. and Pittsburgh U.) (Dec 20, 2018)

Published in: JHEP06 (2019) 049 • e-Print: 1812.08750 [hep-ph]

Type-II Seesaw Model and Multilepton Signatures at Hadron Colliders

Manimala Mitra (IISER, Mohali), Saurabh Niyogi (Delhi U.), Michael Spannowsky (Durham U. and D U., IPPP) (Nov 20, 2016)

Published in: Phys.Rev.D 95 (2017) 3, 035042 • e-Print: 1611.09594 [hep-ph]



S. King, SP, J. Turner, Y-L
Zhou, PRL 126 (2021)

A dark seesaw solution to low energy anomalies: MiniBooNE, the muon ($g - 2$),
and BaBar

Asli Abdullahi (Durham U., IPPP), Matheus Hostert (Minnesota U. and Minnesota U., Theor. Phys. Inst. and Perimeter Inst. Theor. Phys.), Silvia Pascoli (Durham U., IPPP) (Jul 23, 2020)

Published in: Phys.Lett.B 820 (2021) 136531 • e-Print: 2007.11813 [hep-ph]

Sensitivity of W -boson measurements to low-mass right-handed neutrinos

Rodrigo Alonso (Durham U., IPPP), Michael Spannowsky (Durham U., IPPP), Sam Bates (Oxford U.), Chris Hays (Oxford U.), Chris Pollard (Warwick U.) (Aug 12, 2025)

e-Print: 2508.08903 [hep-ph]

Leptogenesis

Leptogenesis as the origin of the baryon asymmetry.

A Lower bound on the right-handed neutrino mass from leptogenesis

Sacha Davidson (Durham U.), Alejandro Ibarra (Oxford U.) (Feb, 2002)

Published in: *Phys.Lett.B* 535 (2002) 25-32 • e-Print: [hep-ph/0202239](#) [hep-ph]

Leptogenesis and Neutrino Oscillations in the Classically Conformal Standard Model with the Higgs Portal

Valentin V. Khoze (Durham U., IPPP), Gunnar Ro (Durham U., IPPP) (Jul 14, 2013)

Published in: *JHEP* 10 (2013) 075 • e-Print: [1307.3764](#) [hep-ph]

Can the low energy CPV phases be connected with leptogenesis?

Connecting low energy leptonic CP-violation to leptogenesis

S. Pascoli (CERN and Durham U., IPPP), S.T. Petcov (SISSA, Trieste and INFN, Trieste), Antonio Riotto (CERN and INFN, Padua) (Sep, 2006)

Published in: *Phys.Rev.D* 75 (2007) 083511 • e-Print: [hep-ph/0609125](#) [hep-ph]

Three-flavored nonresonant leptogenesis at intermediate scales

K. Moffat (Durham U., IPPP), S. Pascoli (Durham U., IPPP), S.T. Petcov (INFN, Trieste and SISSA, Trieste and Tokyo U., IPMU), H. Schulz (Cincinnati U.), J. Turner (Fermilab) (Apr 13, 2018)

Published in: *Phys.Rev.D* 98 (2018) 1, 015036 • e-Print: [1804.05066](#) [hep-ph]

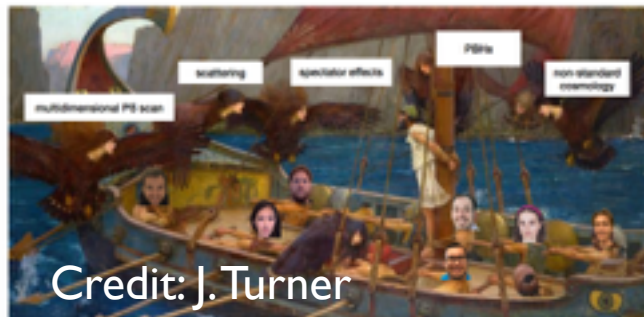
#27

Hot leptogenesis

Michael J. Baker (Massachusetts U., Amherst), Ansh Bhatnagar (Durham U., IPPP), Djuna Croon (Durham U., IPPP), Jessica Turner (Durham U., IPPP) (Sep 13, 2024)

Published in: *JHEP* 05 (2025) 082 • e-Print: [2409.09113](#) [hep-ph]

ULYSSES: Universal Leptogenesis Equation Solver



Credit: J. Turner

Leading effort in ULYSSES.

ULYSSES, universal LeptogeneSiS equation solver: Version 2

#22

Alessandro Granelli (Bologna U. and INFN, Bologna), Christopher Leslie (Durham U., IPPP), Yuber F. Perez-Gonzalez (Durham U., IPPP), Holger Schulz (Unlisted, UK), Brian Shuve (Harvey Mudd Coll.) et al. (Jan 13, 2023)

IPPP: a supportive environment



James Stirling



Nigel Glover



Alan Martin



IPPP: a really exciting scientific environment

Great students and postdocs and collaborators

In neutrinos there have been many postdoctoral researchers at **IPPP** funded by the IPPP, LAGUNA, EUROnu, Invisibles, Elusives and the ERC NuMass grants: Sergio Palomares-Ruiz, Michael Schmidt, Chris Orme, Jacopo Lopez- Pavon, Takashi Toma, Manimala Mitra, Ninetta Saviano, Peter Ballet, Ye-Ling Zhou, Richard Ruiz, Cedric Weiland, Arsenii Titov, Sabya Chatterjee, Y. Perez-Gonzalez, A. De Giorgi and others working in related areas...

...and great students: Chris Orme, Elise Jennings, Tracey Li, Chan-Fai Wong, Peter Ballett, Alexander Barreira, Jascha Schwetchenko, Mark Ross-Lonergan, Jessica Turner, Tse-Chun Wang, Matteo Leo, Andres Olivares, Julia Stadler, Matheus Hostert, Kris Moffat, Asli Abdullahi, J. Franklin, Dhruv Pasari and others

Collaboration with ICC



Simulations of Quintessential Cold Dark Matter: beyond the cosmological constant

Elise Jennings, Carlton M. Baugh, Raul E. Angulo, Silvia Pascoli (Aug, 2009)

Published in: *Mon.Not.Roy.Astron.Soc.* 401 (2010) 2181 • e-Print: [0908.1394](#) [astro-ph.CO]

Linear perturbations in Galileon gravity models

#19

Alexandre Barreira (Durham U. and Durham U., IPPP), Baojiu Li (Durham U.), Carlton M. Baugh (Durham U.), Silvia Pascoli (Durham U., IPPP) (Aug, 2012)

Published in: *Phys.Rev.D* 86 (2012) 124016 • e-Print: [1208.0600](#) [astro-ph.CO]



Negative neutrino masses as a mirage of dark energy

#1

Willem Elbers (Durham U., ICC), Carlos S. Frenk (Durham U., ICC), Adrian Jenkins (Durham U., ICC), Baojiu Li (Durham U., ICC), Silvia Pascoli (Bologna U. and INFN, Bologna) (Jul 15, 2024)

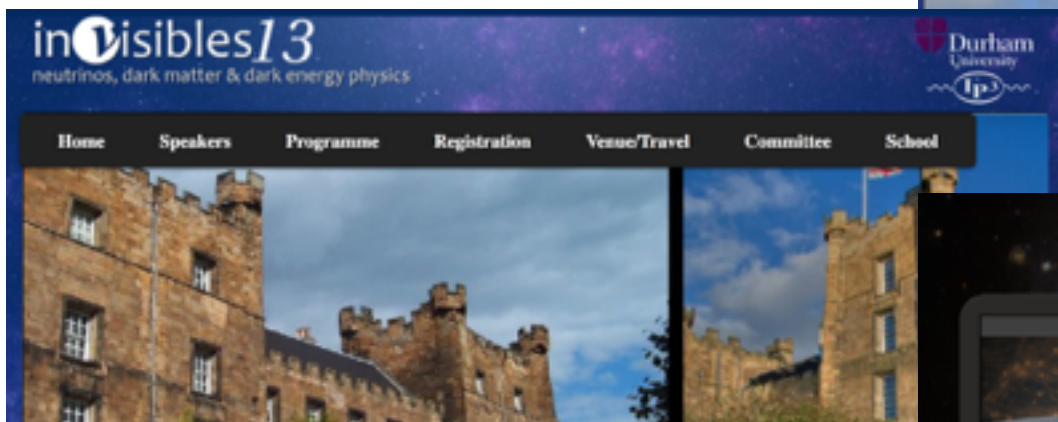
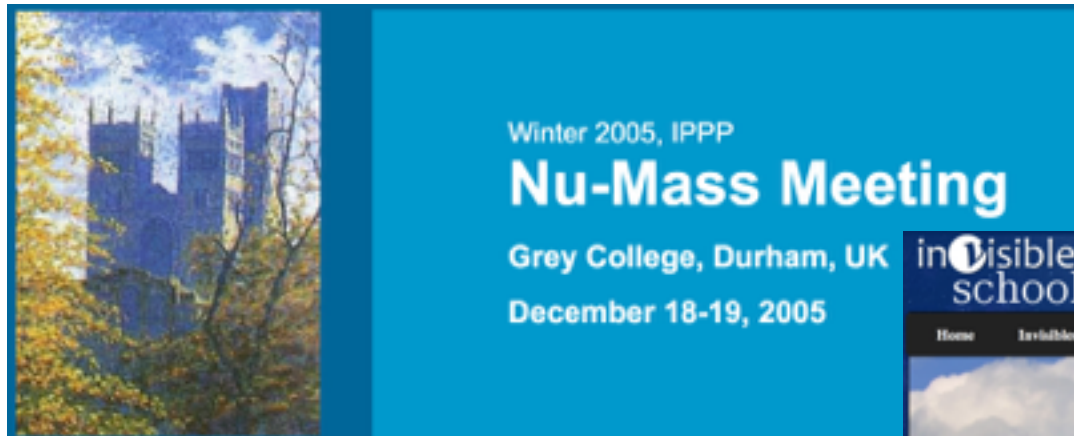
Published in: *Phys.Rev.D* 111 (2025) 6, 063534 • e-Print: [2407.10965](#) [astro-ph.CO]



...and great students: E.
Jennings, A. Barreira, J.
Schewtchenko, W. Elbers



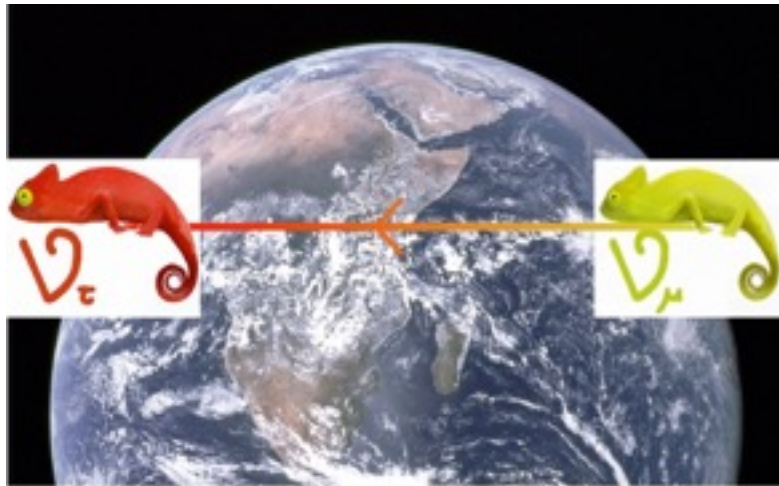
IPPP: an exciting scientific environment



A whirlwind of workshops and events.

Conclusions

Neutrinos are the most elusive and mysterious of the known particles.



The discovery of neutrino oscillations has been a game-changer because it means that neutrinos have mass and the Standard Model is incomplete.

New emphasis on connecting neutrinos with other areas of research.

IPPP has been and still is a leading centre for neutrino physics and related areas of research.

Conclusions

Neutrinos are the most elusive and mysterious of the known particles.



**Happy Anniversary IPPP!!!
And Thank you very much!!!**

The neutrino is a particle that is so elusive that it is difficult to detect. Neutrinos have mass, but it is very small. The Standard Model of particle physics is incomplete. Neutrinos are being studied with other particles in the hope of understanding the universe better.

IPPP is and still is a leading centre for neutrino physics and related areas of research.