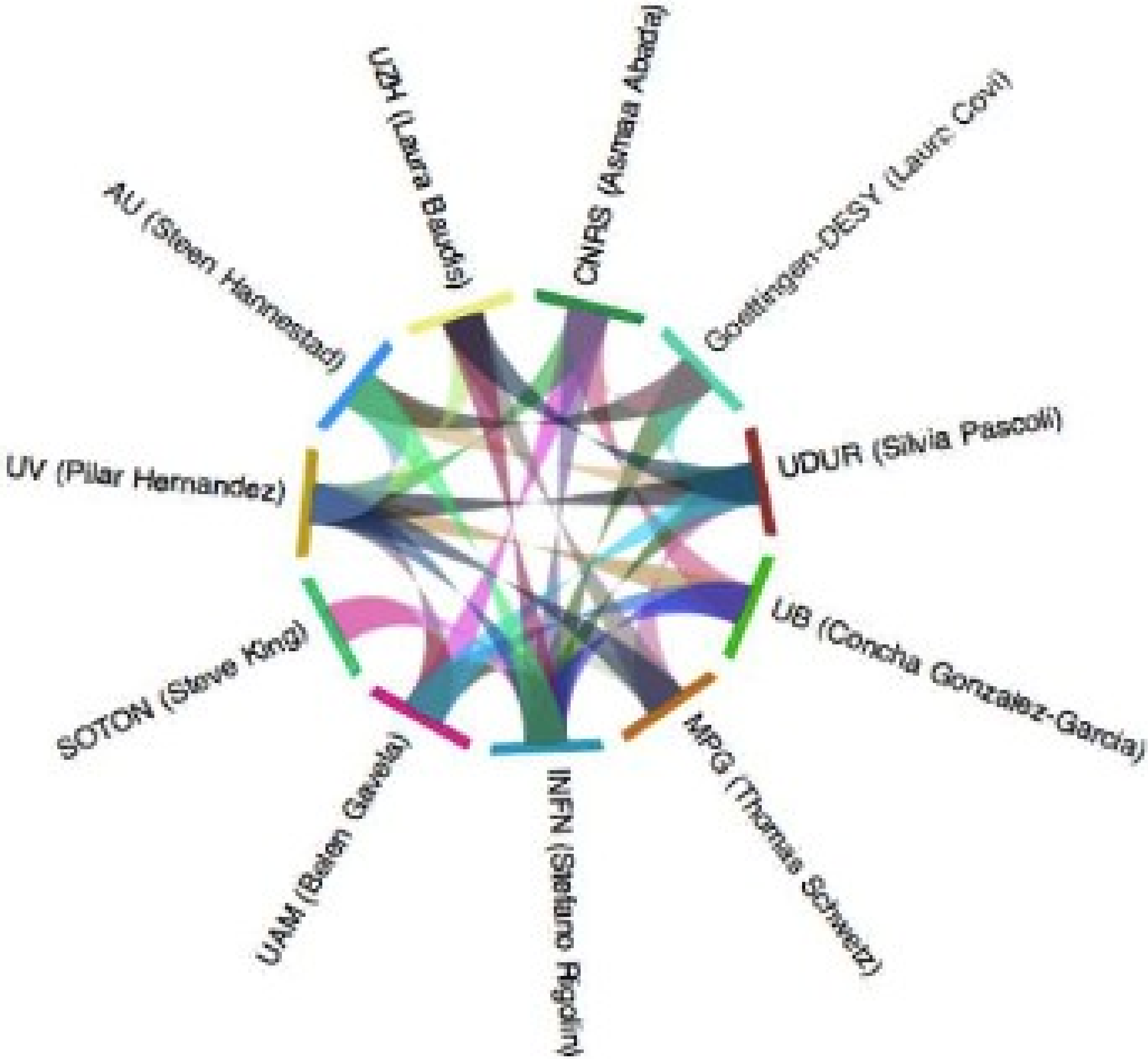
An overview of the EU nodes in Invisibles

24 June 2012

GGI
Arcetri - Italy

Silvia Pascoli

IPPP – Durham University



I would like to thank the PIs of the EU nodes for the presentations at the Madrid meeting from which the material for these slides has been obtained and to apologise for possible omissions.

Aarhus University

PI: S. Hannestad

AARHUS UNIVERSITET

PEOPLE

- STEEN HANNESTAD
- JAN HAMANN (postdoc)
- OLE EGGERS BJÆLDE (postdoc)
- THOMAS TRAM (PhD student)
- CHRISTIAN SCHULTZ (PhD student)
- TOBIAS BASSE (PhD student)
- RASMUS SLOTH HANSEN (PhD student)
- IO ODDERSKOV (PhD student, FROM 8/12)
- MARIA ARCHIDIACONO (postdoc, FROM 10/12)

- Aarhus is part of the EUCLID mission

CNRS

PI: A. Abada

Orsay	Saclay	Lyon	Clermont	Grenoble
LPT	IPhT	IPNL	LPC	LPSC

- **Orsay**
  Laboratoire de Physique Théorique: U. Paris-Sud 11 & CNRS
  Asmaa Abada, Ulrich Ellwanger, Yann Mambrini, Grégory More
- **Saclay**
  Institut de Physique Théorique and IRFU CEA
  Stéphane Lavignac, Philippe Brax, Thierry Lassere (Double Cho
- **Lyon**
  Institut de Physique Nucléaire de Lyon and CRAL: U. Claude Bernard & CNRS
  Sacha Davidson and Alexandre Arbey
- **Clermont**
  Laboratoire de Physique Corpusculaire: U. Blaise Pascal & CNRS
  Nazila Mahmoudi, Jean Orloff, Ana Teixeira
- **Grenoble**
  Laboratoire de Physique Subatomique et Cosmologie: U. Joseph Fourier & CNRS
  Sabine Kraml

- Postdocs: D. Das, D. Lopez-Fogliani, A. Vicente, Ch. Smith, A. Wingerten
- PhD students: A. Figueiredo, P. Mitropoulos, J. Quevillon, C. Weiland

University of Goettingen-DESY

PI: L. Covi

Torsten Bringmann, Wilfried Buchmüller, Laura Covi, Jörn Kersten, Jens Niemeyer, Andreas Ringwald, Günther Sigl,
2(Goe)+4(DESY)+5(SFB,AvH) PostDocs, ~10 students

Our goal:

- A better understanding of the history of our Universe and the mechanisms at work there

- Ultimately, a new Standard Model including and extending the present Standard Models of Particle Physics and Cosmology

INFN

PI: S. Rigolin

Istituto Nazionale di Fisica Nucleare

PADOVA@invisibles

- PHENO-COSMO = Feruglio, Passera, Pietroni, Rigolin
- EXP-Neutrino = Bettini, Mezzetto;

TRIESTE@invisibles

- PHENO-DM = Petcov, Romanino, Ullio (SISSA) Senjanovic, Smirnov (ICTP);

MILANO-BICOCCA@invisibles

- EXP-Neutrino = Brofferio, Capelli, Cremonesi, Pavan;

MPG
PI: T. Schwetz

- Max-Planck-Institut für Kernphysik (MPIK), Heidelberg
  Thomas Schwetz (PI)
  Nassim Bozorgnia (from Sept. 2012)
- Max-Planck-Institut für Physik (MPP), Munich
  Georg Raffelt
- Univ. Würzburg
  Walter Winter

University of Southampton

PI: S. King

Southampton High Energy Physics (SHEP) Theory

SHEP is one of the largest theoretical particle physics groups in the UK: 11 Faculty

- Steve King: Neutrinos and Flavour Models, GUTs and Strings, Cosmology, SUSY Models
- Pasquale Di Bari: Leptogenesis, Neutrinos, GUTs
- Sasha Belyaev (CMS): BSM, Collider Phenomenology

2 Postdocs, 8 students in Invisibles areas

- Alex Stuart (Postdoc): Neutrinos and Family Symmetry Models, GUTs
- Iain Cooper (Student) Neutrinos and Family Symmetry Models, GUTs
- David Jones (Student) Neutrinos and Leptogenesis
- Plus 5 other students: Leptogenesis, BSM, Collider
- Alex Merle (MC Postdoc, starts 1st June): Neutrinos, Family Symmetry and Cosmology
- Thomas Neder (Invisibles Junior ESR PhD student)

Universitad Autonoma Madrid

PI and Coordinator: B. Gavela

The background: very large group ~130 170

In spite of its name the "Department of Theoretical Physics" (and IFT) includes:

-- **Particle theory**: Gravitation -> Strings -> BSM -> DM -> neutrino physics -> SM -> LHC phenom.

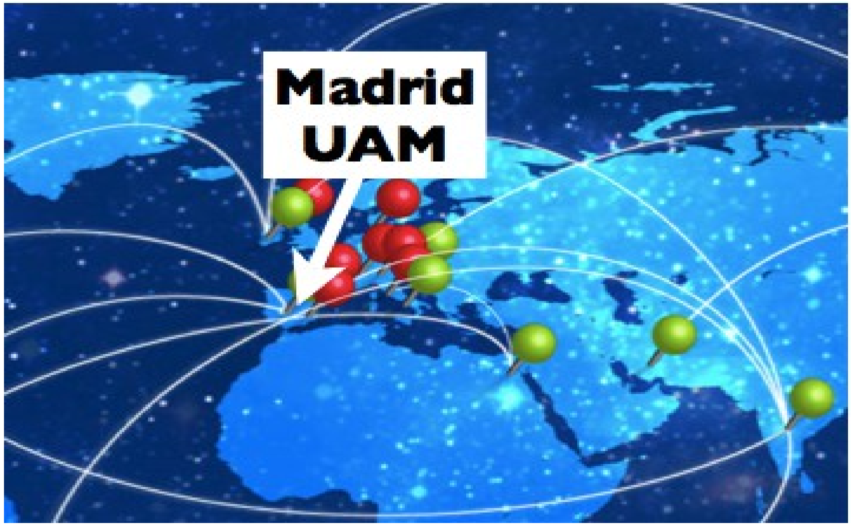
-- **Particle physics experiments**: ATLAS, CMS, SuperKamiokande, NEXT

-- **Theoretical Nuclear Physics**

-- **Theoretical Astrophysics and Cosmology (computational and inflationary)**

-- **Observational Astrophysics (Galactic, Planets)**

-- **Neuroscience, Quantum computing**...



* ν **oscillation phenomenology**:
M. Maltoni --> E. Fdez-Martinez --> A. de Rujula-->B. Gavela
closer to expt.-------------> closer to theory

* ν **theory, lepton flavour viol. and BSM**:
AdR, EFM, B. Gavela, M.J. Herrero

* ν **experiments**: SuperKamiokande, NEXT
L. Labarga

* **Nuclear matrix elements for 00ν-betadecay**:
A. Poves

* **DM physics... DE phen.**:
A. Knebe, E. Majerotto.... EFM, B. Gavela

* **Gravitation and DE, cosmology**
Enrique Alvarez

* **LHC phenomenology**:
Alvaro de Rujula

University of Barcelona

PI: C. Gonzalez-Garcia

The group at UB is widely recognized expert on the characterization of the low energy parameterization of neutrino properties -- either masses and mixings, or more exotic properties like new interactions and tests of fundamental theories-- as obtained from direct comparison with existing and upcoming experimental results. These comparisons require extensive numerical work, in what is called global analysis. Particular care in global analysis is required for statistical meaningful results with correct accounting of all sources of uncertainties. The results are important because the determination of flavor structure of the leptons at low energies, is, at this point, our most precise source of information to decipher the underlying new dynamics at high energy. Along the years this work has been done in collaboration with Michele Maltoni, member of the UAM node and more recently also with Thomas Schwetz from Heidelberg node.

Durham University

Durham University

PI: S. Pascoli

ICC Institute for Computational Cosmology

Institute for Particle Physics Phenomenology

- UDUR hosts two worldclass institutes, the IPPP and the ICC, in which the Invisibles activities will take place.

A large research group is focussed on Neutrino and Dark Matter:

S. Pascoli

C. Boehm: DM

V. Khoze

C. Baugh

C. Frenk

A. Jenkins

S. Cole

J. Jaeckel

S. Abel

T. Theuns

Postdocs and PhD students in the IPPP on Neutrino and DM

C. Luhn

P. Dechant

J. Lopez Pavon

Steven Wong: neutrinoless double beta decay and NF

Chris Wallace: light dark matter

Peter Ballett: Neutrino phenomenology and theory

Jonathan Davis: Dark Matter direct detection

Alexandre Barreira: LSS in modified gravity models

Jascha Schewtschenko: neutrinos and LSS

New Invisibles: Mark Ross-Lonergan
Takashi Toma

UVEG-IFIC

\+ CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CSIC

University of Valencia

PI: P. Hernandez

Institute for Particle and Nuclear Physics

~130 experimentalists
~90 theorists

Invisibles (Theory)

Seniors:

- G. Baremboim
- A. Donini
- P. Hernández
- O. Mena
- S. Palomares-Ruiz
- C. Peña-Garay
- N. Rius
- R. Ruiz de Austri

Postdocs

- S. Agarwalla
- T. Li
- J. Racker
- A Vincent (Invisibles ESR)

Students:

- E. Giusarma
- J. Herrero
- M. Peña-Jimenez
- F. Villaescusa
- M. Cerdà

Invisibles (Exp)

Seniors:

- A. Cervera
- J. Gómez-Cadenas
- M. Sorel

Postdocs

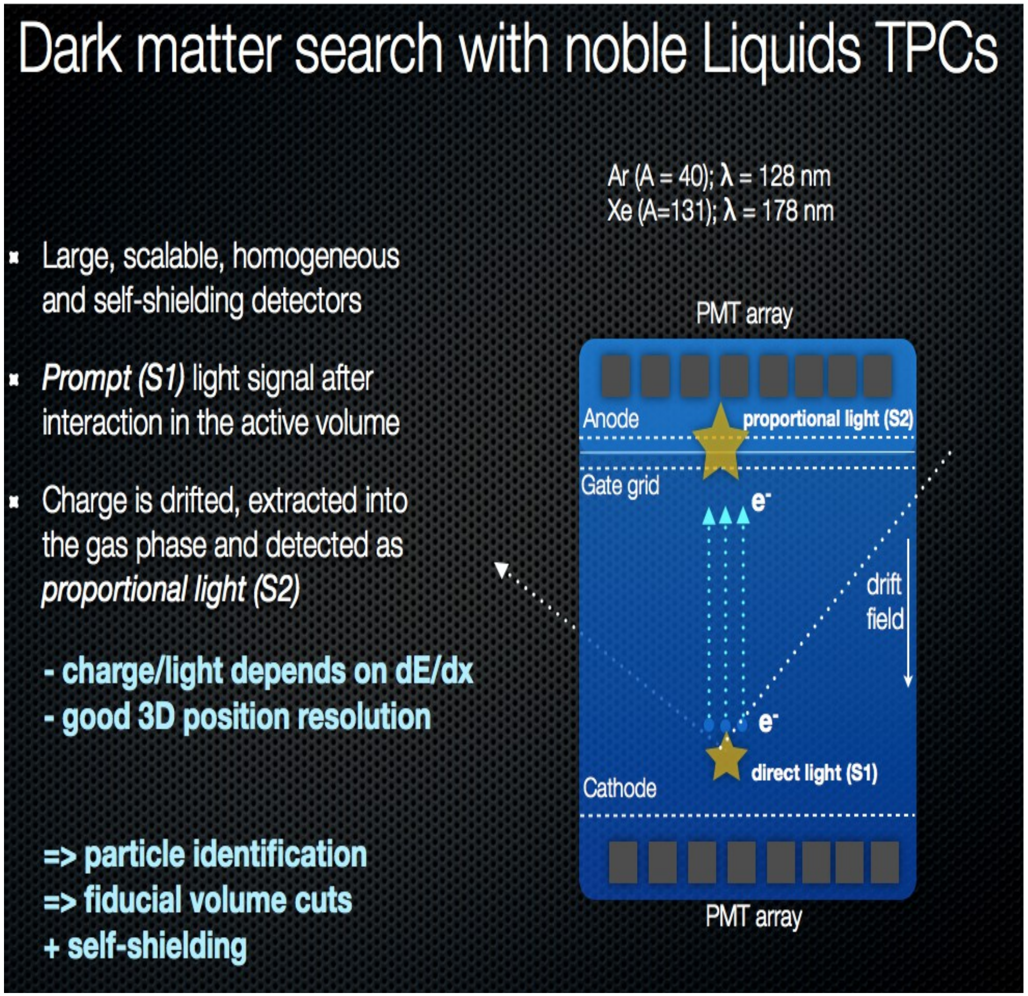
- I. Liubarsky
- P. Ferrario

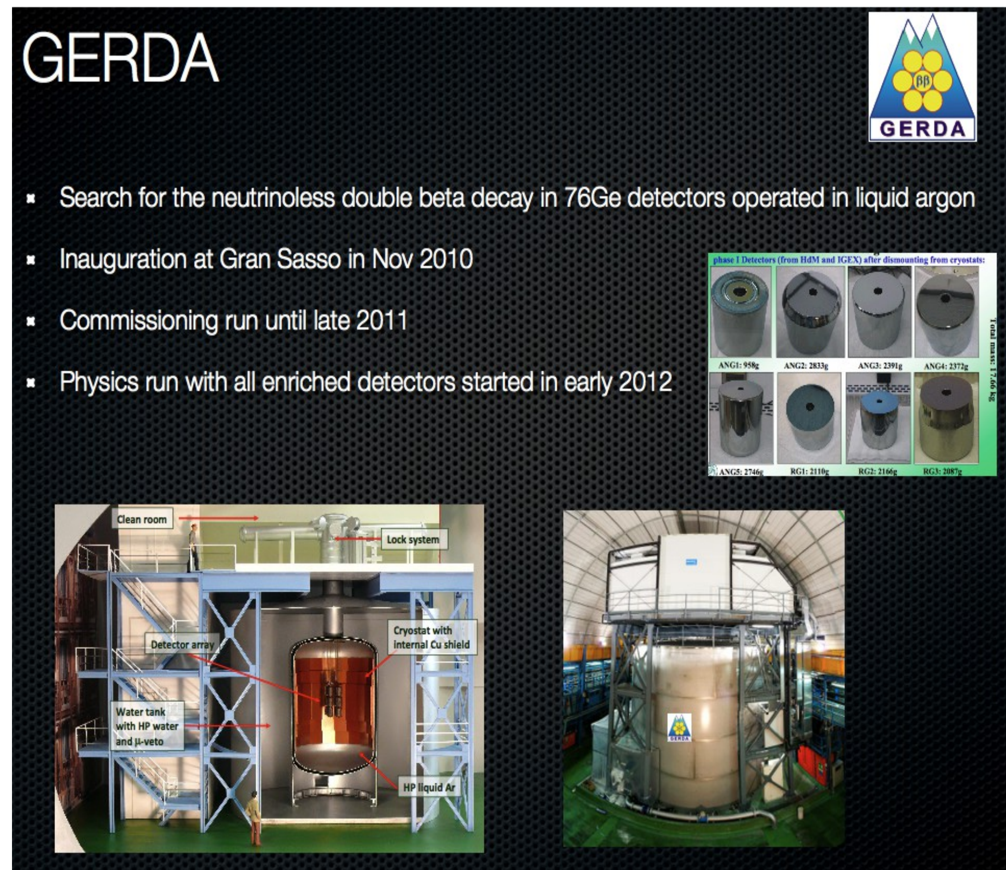
Students:

- L. Escudero
- J. Martín-Albo
- L. Monfregola
- F. Monrabal
- M. Nebot
- D. Lorca
- L. Serra....

University of Zurich
PI: L. Baudis

This is an experimental node providing expertise on



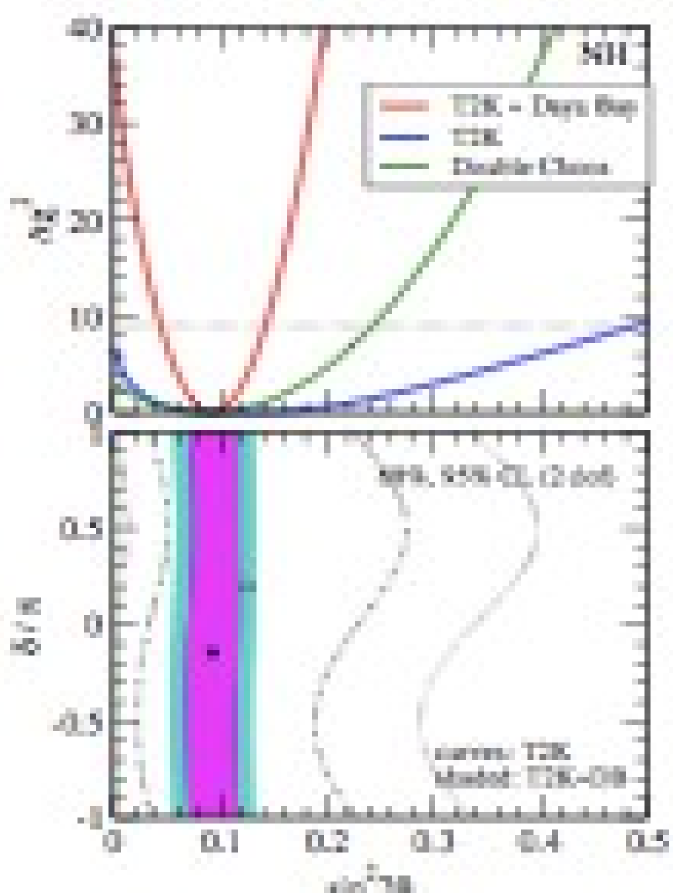


Neutrino physics

Invisibles counts some of the pioneers of the field (MSW...) and some of the most active groups in the world..

Neutrino parameter fits

MPG, UAM, UB are world-leaders in analysing the latest neutrino data and provide some of the "standard" fits.



~~Schwetz, Tortola, Valle, 2011~~

ν-fit: global fit collaboration in the framework of Invisibles in coll. with
C. Gonzalez-Garcia (UB)
M. Maltoni (UAM)

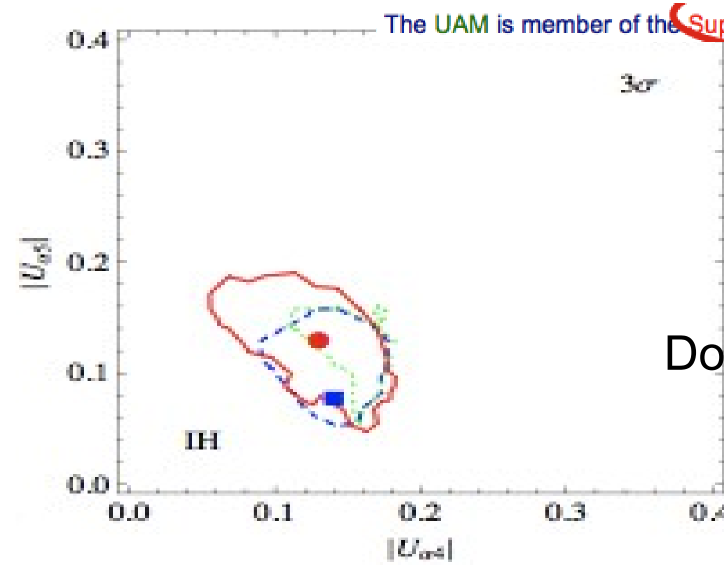
Thierry Lasserre CNRS

Double Chooz experiment

Reactor neutrino anomaly

... neutrino-dedicated experiments...

The UAM is member of the Super-Kamiokande experiment.



Donini et al, 2012

Long baseline neutrino phenomenology

INFN, MPG, UAM, UDUR, UVEG

With the discovery of theta13 (!), the goal of LBL experiments has slightly shifted and now focus on

- Determining the mass hierarchy
- Discovering CP-violation
- Measuring with precision the parameters
- Testing the standard 3-neutrino scenarios.

UAM and UVEG (and INFN) are leaders in this field since '98, joined by MPG and UDUR.

$$P(\bar{P}) \simeq \; s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{13}}{A\mp\Delta_{13}}\right)^2 \sin^2 \frac{(A\mp\Delta_{13})L}{2}$$
$$+\tilde{J}\frac{\Delta_{12}}{A}\frac{\Delta_{13}}{A\mp\Delta_{13}} \sin\frac{AL}{2} \; \sin\frac{(A\mp\Delta_{13})L}{2} \cos\left(\mp\delta + \frac{\Delta_{13}L}{2}\right)$$
$$+c_{23}^2 \sin^2 2\theta_{12} \left(\frac{\Delta_{12}}{A}\right)^2 \sin^2\frac{AL}{2}$$

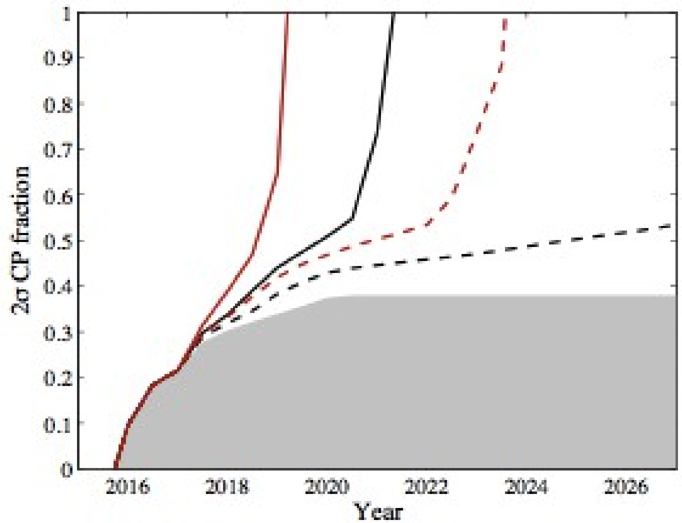
Cervera et al., 2000

International leadership:

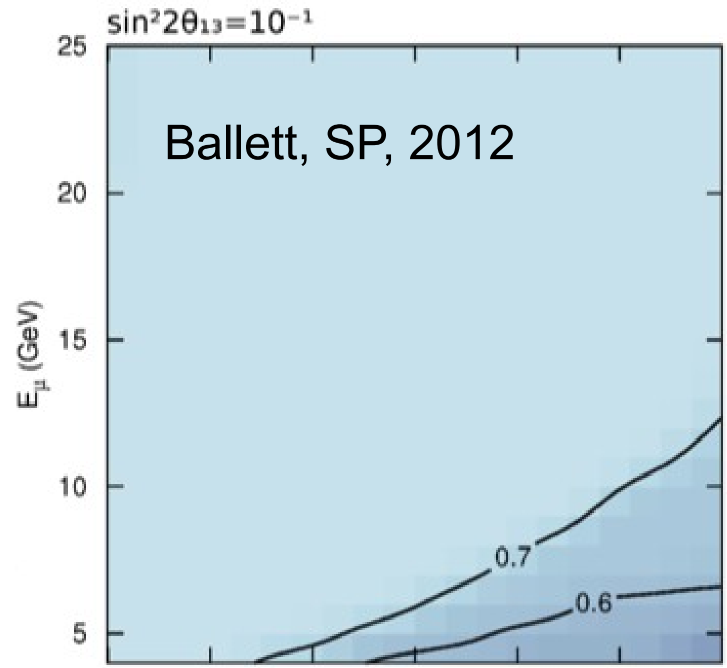
UVEG EUROnu WP6 (Physics) leader

MPG Wurzburg: IDS-NF PPEG leader and developer of GLoBES

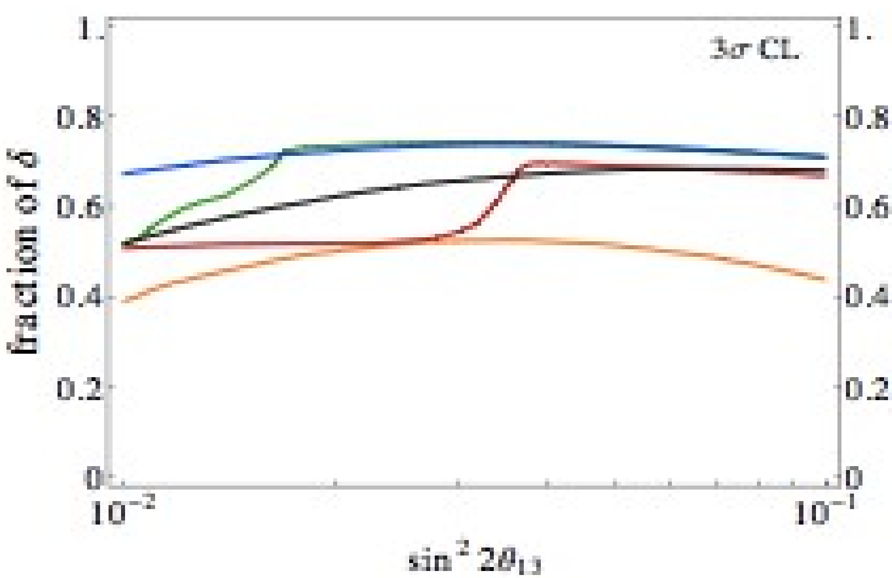
UDUR LAGUNA-LBNO WP5 (Physics) leader



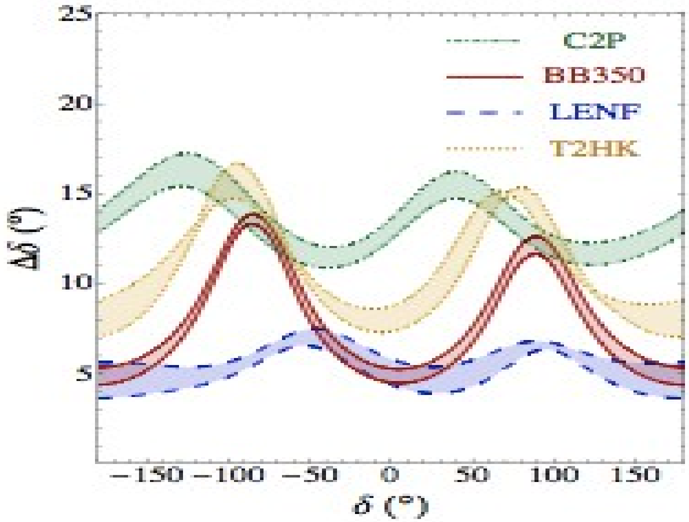
Identifying the mass hierarchy with INO, T2K and NovA.
Blennow, Schwetz, 2012



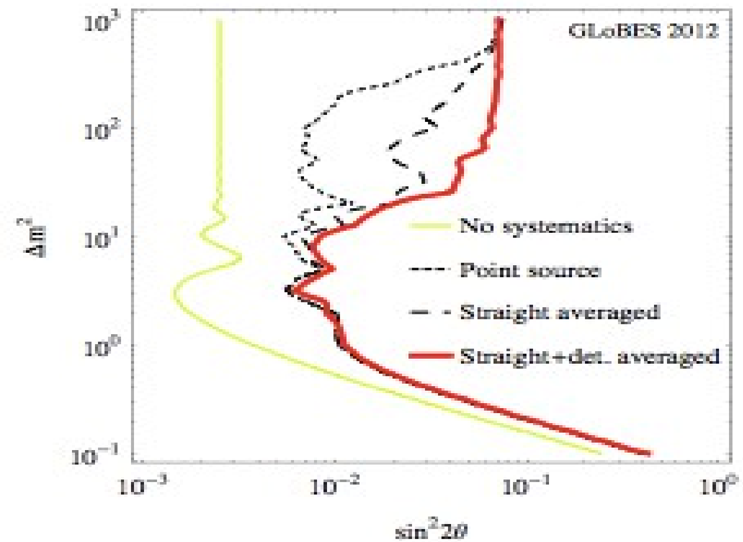
Optimisation of the LENF (first proposed by Fermilab, UDUR, UVEG): the LENF with 2000 km and 10 GeV has become the baseline for the IDS-NF.



CP-discovery for a EU superbeam (LAGUNA-LBNO) sourced at CERN.
Coloma, Li, SP, 2012

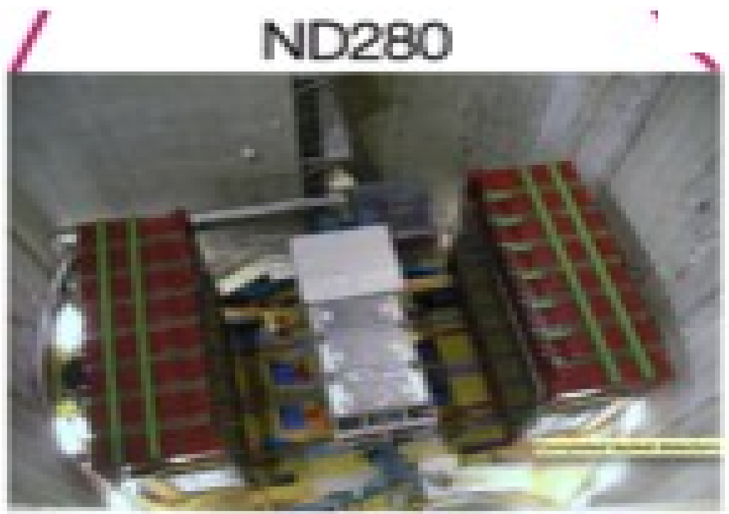


Precision measurements at LBL.
Coloma et al., 2012.



Near detectors for sterile neutrino searches, and NuSTORM.
Winter, 2012

T2K



IFIC has participated in the construction, calibration, reconstruction software and data analysis of the near detector ND280

INFN, UVEG

Other searches for the mass hierarchy and measurement of neutrino parameters: Atmospheric and reactor neutrinos.

Neutrinoless double beta decay

GERDA

INFN, UAM, UDUR, UVEG, UZH

The Detectors

- Closed-ended coaxial detectors
- 8 diodes from HdM and IGEX enriched in ^{76}Ge
- 6 diodes from Genius test facility, natural Ge
- ~ 15 kg of ^{76}Ge

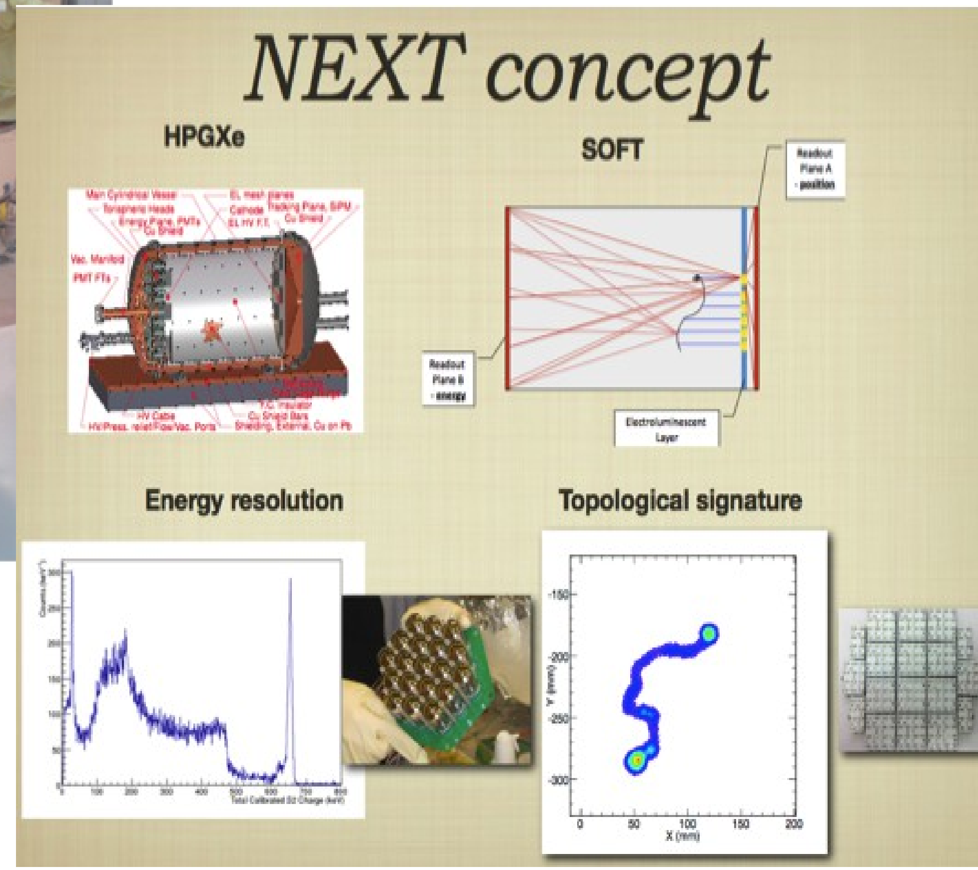
The Goals

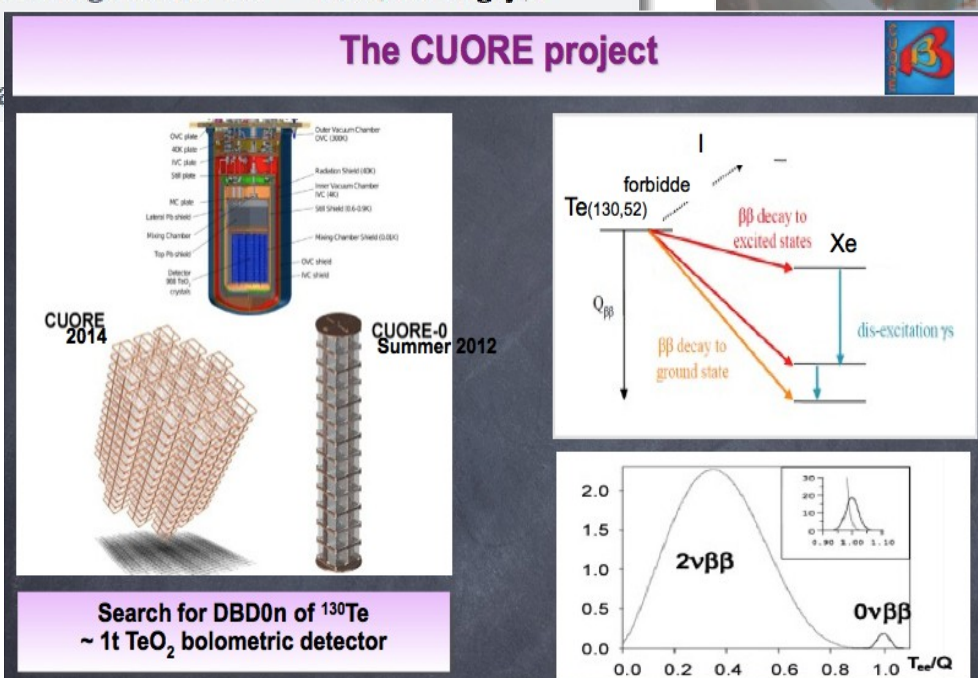
Test Klapdor's Claim

Exposure 15 kg y

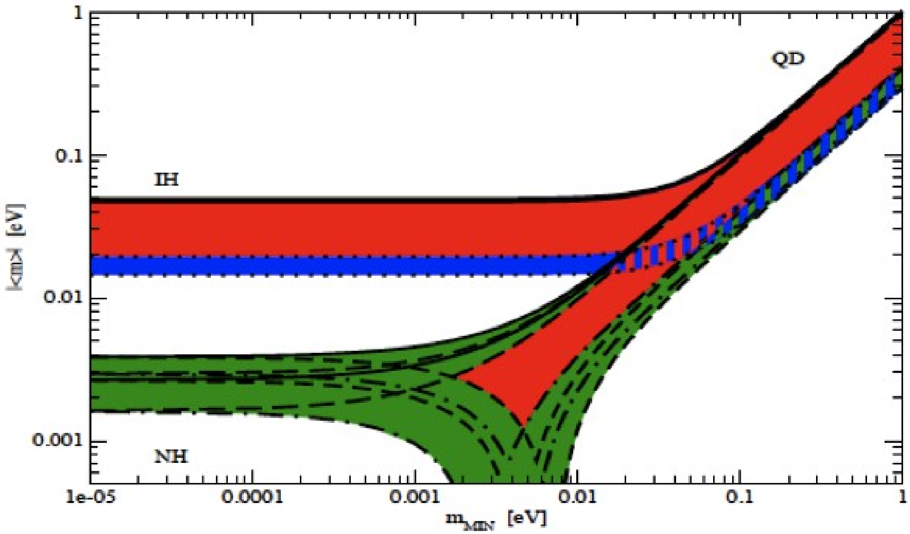
Background 10^{-2} cts/(keV kg y)

Ma





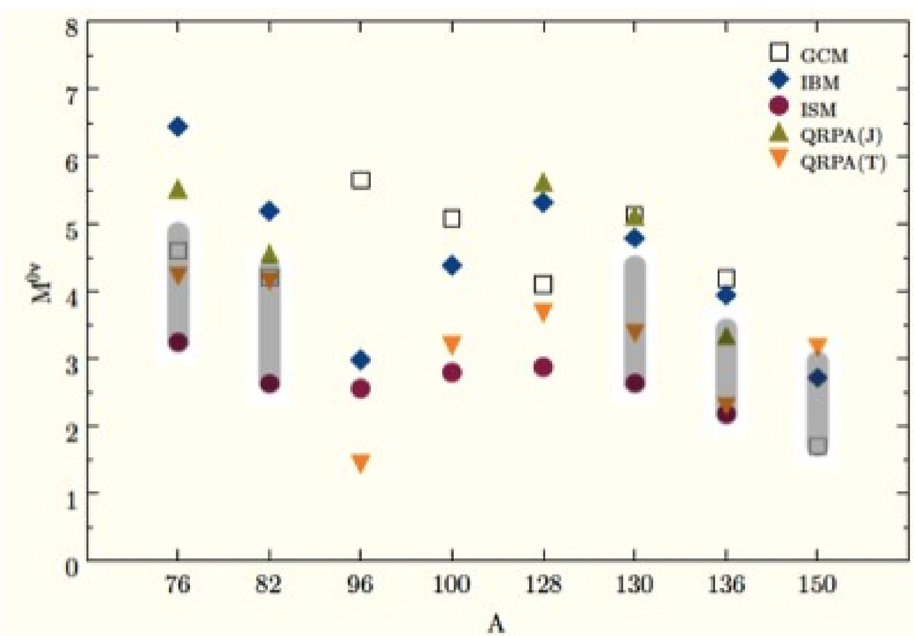
Participation to CUORICINO/CUORE – Measure of 0νββ decays – see Maiano talk (Brofferio, Capelli, Cremonesi, Maiano, Pavan)



SP, Petcov, PRD77

This process is the prime search for lepton number violation and can provide information on neutrino masses and CP-violation.

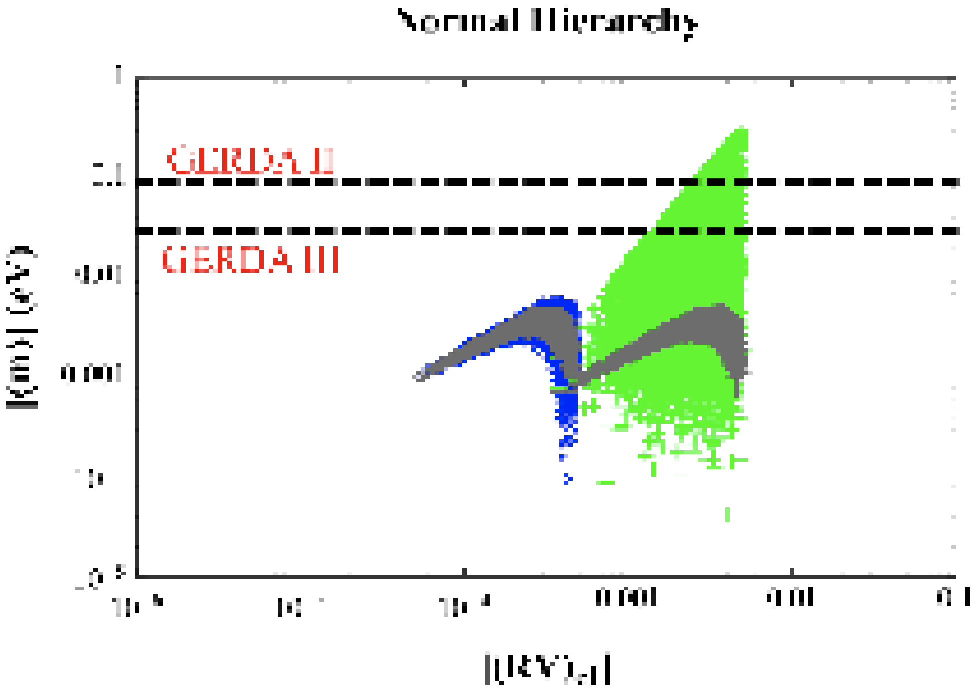
INFN, UDUR



Nuclear matrix elements are crucial in extracting information on neutrino masses and CP-violation.

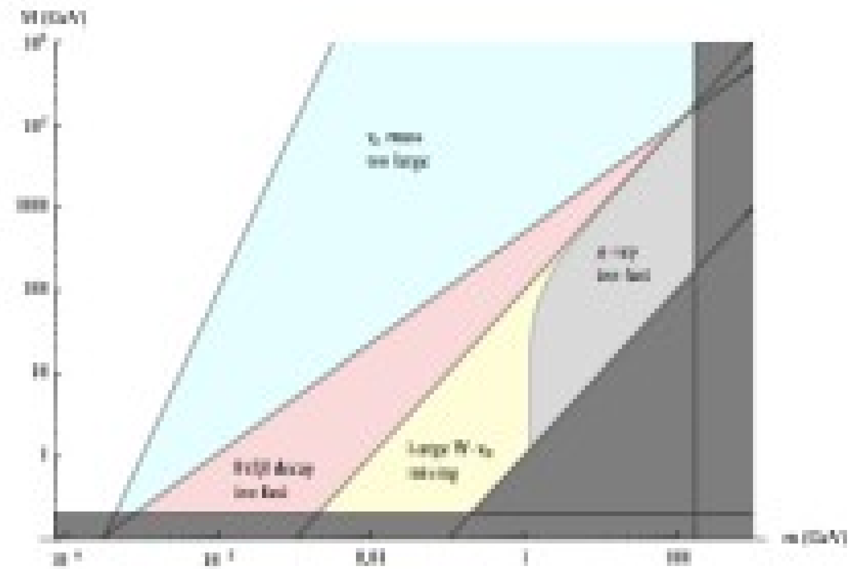
Poves, ISM

UAM



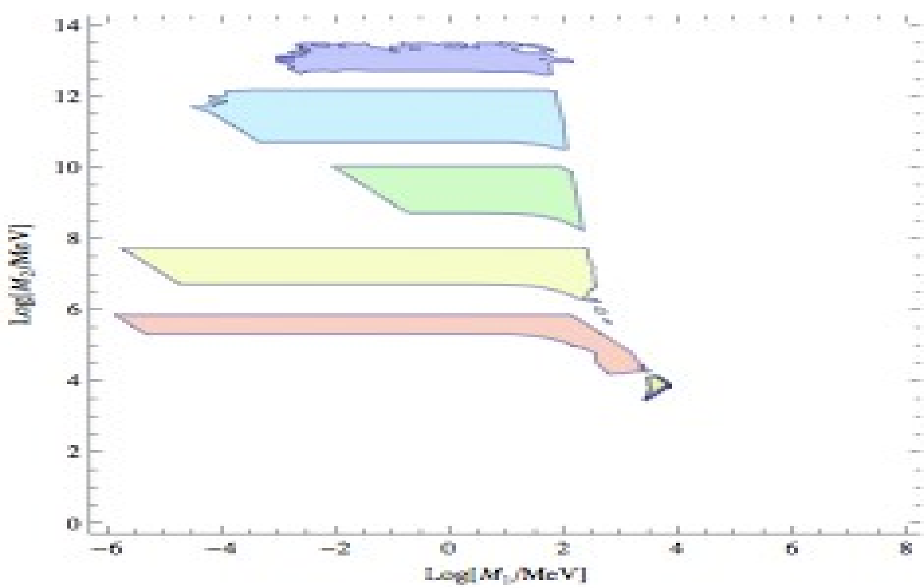
Ibarra, Molinaro, Petcov, '11

Different mechanisms of neutrinoless double beta decay



Mitra, Senjanovic, Vissani, '12

INFN, UDUR



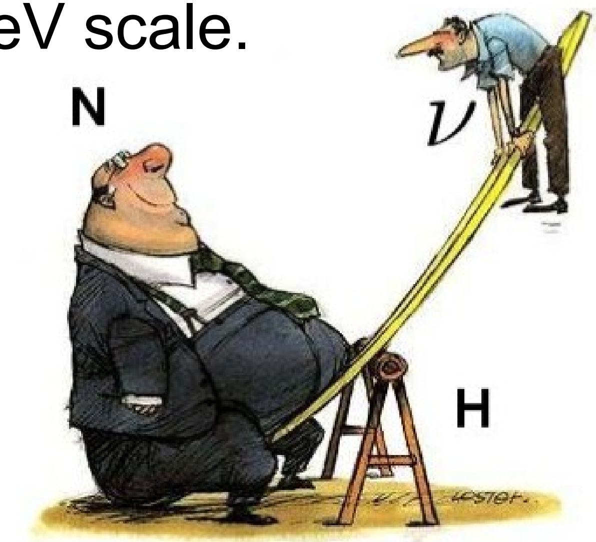
Lopez-Pavon, SP, Wong

Neutrino theory

CNRS, INFN, MPG, SOTON, UAM, UDUR, UVEG

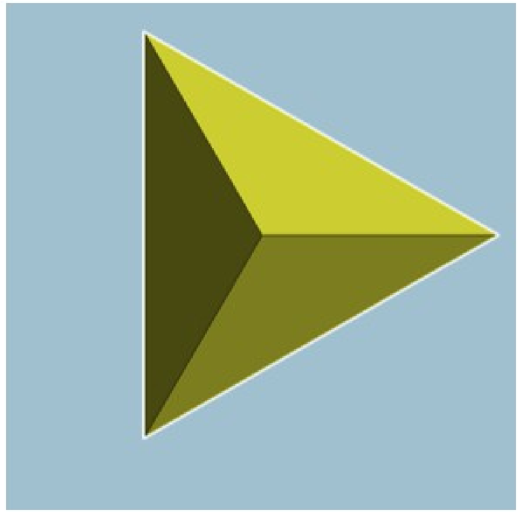
Neutrino masses require new physics BSM. Understanding its properties is one of the main challenges we face: the new scale can be as high as the GUT scale or well below the TeV scale.

The see-saw mechanism provides a natural way to explain small neutrino masses and can be embedded in theoretically motivated extensions of the SM. But alternatives exist (masses at loop-level, extra-dimensions...).



The EU nodes have a very broad range of expertise which covers most areas of interest, including the proposal of new models of neutrino mass generation, the connection with other phenomenological signatures (LFV, LHC...), and their embedding in theoretical models (e.g. GUT theories), Models at the TeV scale...
Strong research also in Higgs and BSM theory and phenomenology.

The other aspect to address is the understanding of the flavour structure.



Why three generations?

Why massive and flavour states are not the same?

Why the angles have the values measured?

What is the origin of CPV?

s = solar   a = atmospheric   r = reactor

☐ **General Mixing**

$$\sin\theta_{12} = \frac{1}{\sqrt{3}}(1+s)\ , \qquad \sin\theta_{23} = \frac{1}{\sqrt{2}}(1+a)\ , \qquad \sin\theta_{13} = \frac{r}{\sqrt{2}}$$

$$U_{\rm PMNS} \approx \begin{pmatrix} \frac{2}{\sqrt{6}}(1-\frac{1}{2}s) & \frac{1}{\sqrt{3}}(1+s) & \frac{1}{\sqrt{2}}re^{-i\delta} \\ -\frac{1}{\sqrt{6}}(1+s-a+re^{i\delta}) & \frac{1}{\sqrt{3}}(1-\frac{1}{2}s-a-\frac{1}{2}re^{i\delta}) & \frac{1}{\sqrt{2}}(1+a) \\ \frac{1}{\sqrt{6}}(1+s+a-re^{i\delta}) & -\frac{1}{\sqrt{3}}(1-\frac{1}{2}s+a+\frac{1}{2}re^{i\delta}) & \frac{1}{\sqrt{2}}(1-a) \end{pmatrix} P$$

☐ **Tri-bimaximal** $s = a = r = 0$

$$U_{TB} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix} P,$$

Excluded by Daya Bay

☐ **Tri-bimaximal-reactor** $s = a = 0,\ r \neq 0$

$$U_{TBR} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}}re^{-i\delta} \\ -\frac{1}{\sqrt{6}}(1+re^{i\delta}) & \frac{1}{\sqrt{3}}(1-\frac{1}{2}re^{i\delta}) & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}}(1-re^{i\delta}) & -\frac{1}{\sqrt{3}}(1+\frac{1}{2}re^{i\delta}) & \frac{1}{\sqrt{2}} \end{pmatrix} P$$

☐ **Tri-maximal 1** $s = 0 \quad a = r\cos\delta$

$$U_{\rm TM_1} = P' \begin{pmatrix} \frac{2}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}}re^{-i\delta} \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}}(1-\frac{3}{2}re^{i\delta}) & \frac{1}{\sqrt{2}}(1+re^{-i\delta}) \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}}(1+\frac{3}{2}re^{i\delta}) & -\frac{1}{\sqrt{2}}(1-re^{-i\delta}) \end{pmatrix} P$$

☐ **Tri-maximal 2** $s = 0 \quad a = -\frac{1}{2}r\cos\delta$

$$U_{\rm TM_2} = P' \begin{pmatrix} \frac{2}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}}re^{-i\delta} \\ -\frac{1}{\sqrt{6}}(1+\frac{3}{2}re^{i\delta}) & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}}(1-\frac{1}{2}re^{-i\delta}) \\ -\frac{1}{\sqrt{6}}(1-\frac{3}{2}re^{i\delta}) & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{2}}(1+\frac{1}{2}re^{-i\delta}) \end{pmatrix} P$$

Thanks to S. King

Trying to understand the leptonic flavour structure and its relation to the one present in the quark sector.

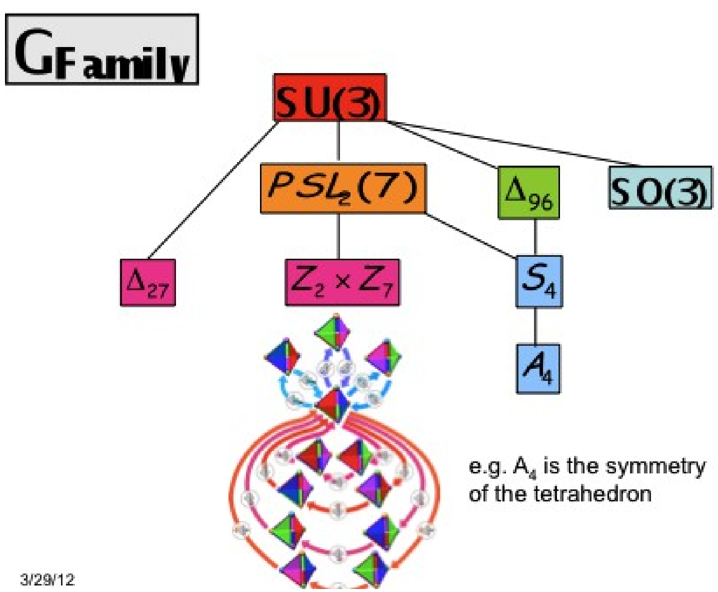
Tri-bimaximal mixing:
implies the existence of flavour symmetries, e.g. A4.

Quark-Lepton complementarity:
quark + lepton mixing ~maximal

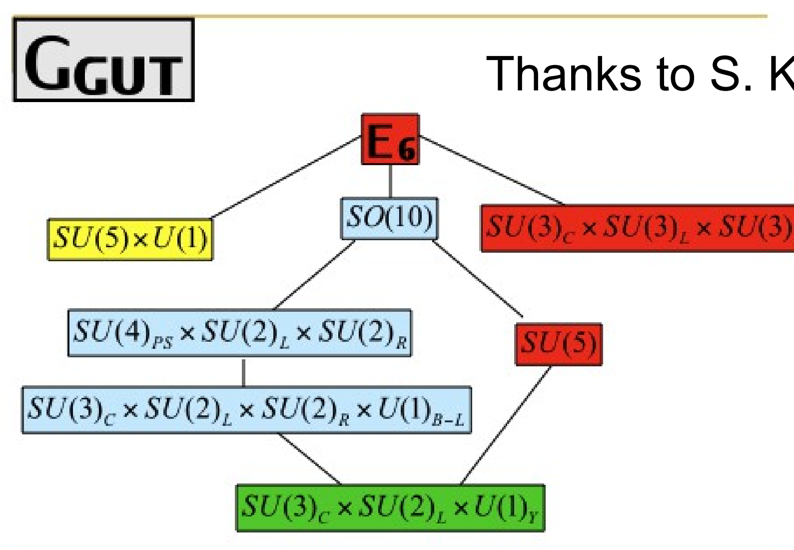
Quark-Lepton universality:
the difference between mixing might be due to smallness of masses and mild hierarchy

Anarchy:
all entries in mass matrix of O(1)

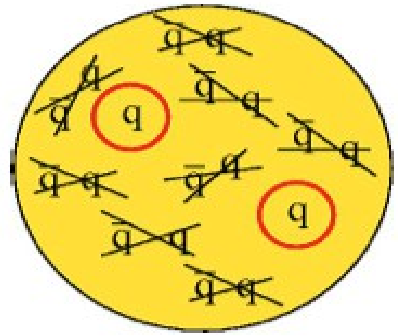
Excellent expertise in all relevant aspects in Invisibles.
CNRS, INFN, SOTON, UAM, UDUR, UVEG



Thanks to S. King



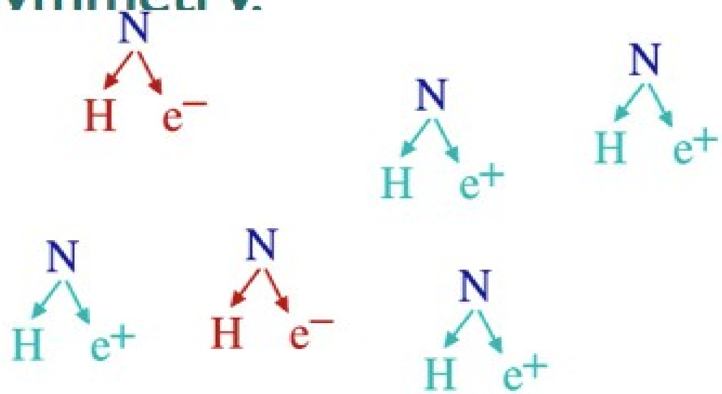
In the Early Universe



As the temperature drops, only quarks are left:

$$Y_B = \frac{n_B}{n_\gamma} = (6.0 \pm 0.2) \times 10^{-10}$$

The excess of quarks can be explained by **Leptogenesis** (Fukugita, Yanagida): the heavy N responsible for neutrino masses generate a lepton asymmetry.



Excess of $e^+ \longrightarrow$ excess of q over $\bar{q}$

Observing L violation and CPV would constitute a **strong hint in favour of leptogenesis as the origin of the baryon asymmetry**.

Many groups have analysed the possibility of leptogenesis in various models of neutrino mass generation and its possible (or not) testability. **CNRS, SOTON, INFN, UB, UDUR, UVEG.**

High energy neutrinos

neutrino flux predictions
simulation of astrophysical sources
NeuCosmA software

MPG - Wurzburg

UAM

Neutrino astrophysics

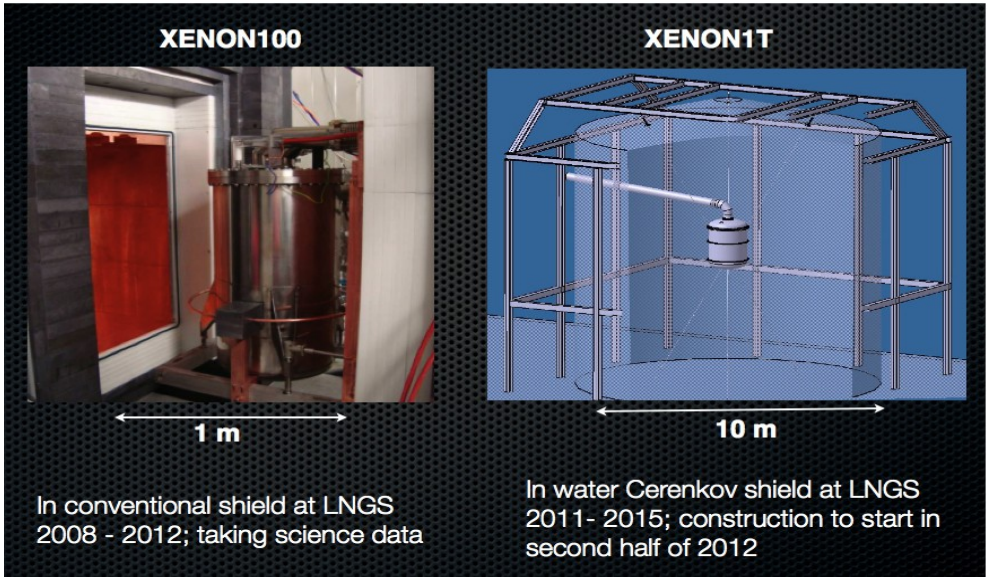
- Aims at fully exploiting the potentialities of forthcoming neutrino telescopes;
- approach:
  - understand the detectors; recognize key features for each task;
  - study the potentialities of atmospheric neutrinos (guaranteed signal);
  - learn about ν properties using astro-ν
    - from diffuse fluxes;
    - from point sources;
  - use collected data to learn about the sources;

Supernova neutrinos

Neutrino astroparticle physics
neutrinos and supernovae
cosmological neutrinos

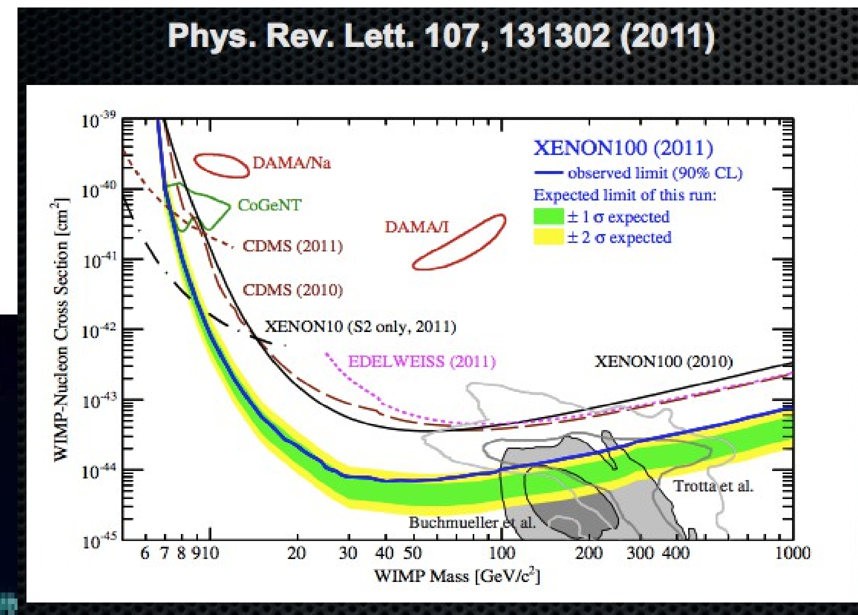
INFN, MPG – MPP Munich

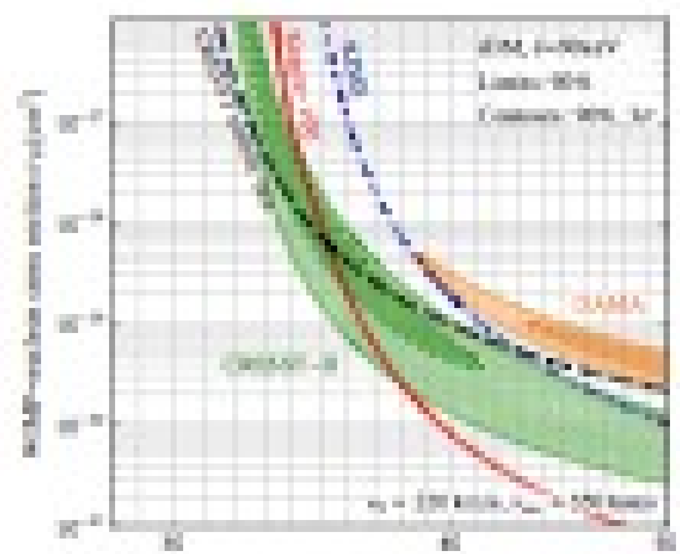
Dark Matter studies: DM direct detection



CNRS, INFN, MPG, UDUR, UZH

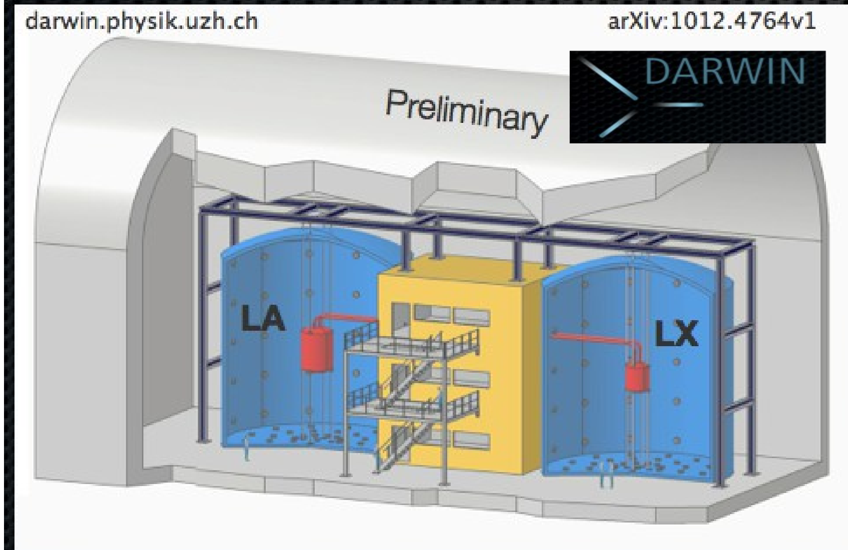
Dark Matter searches with noble Liquid TPCs.
L. Baudis, **UZH**.



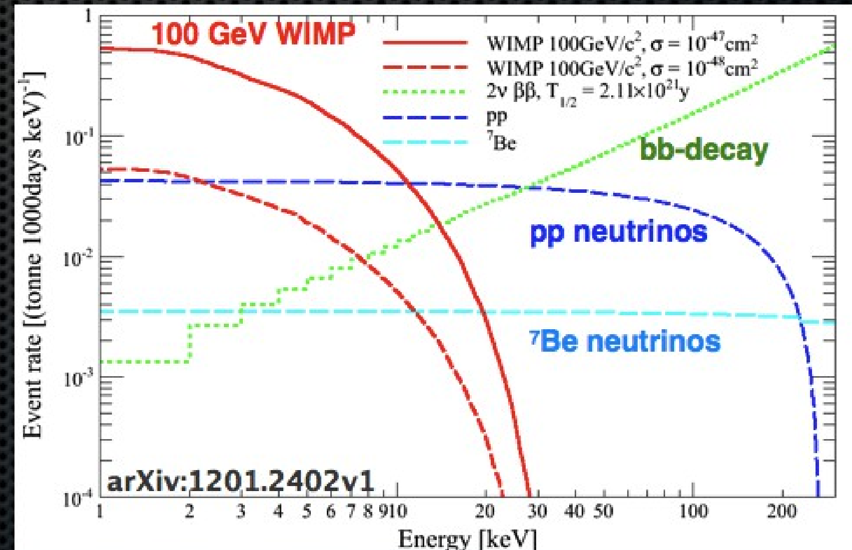


MPG

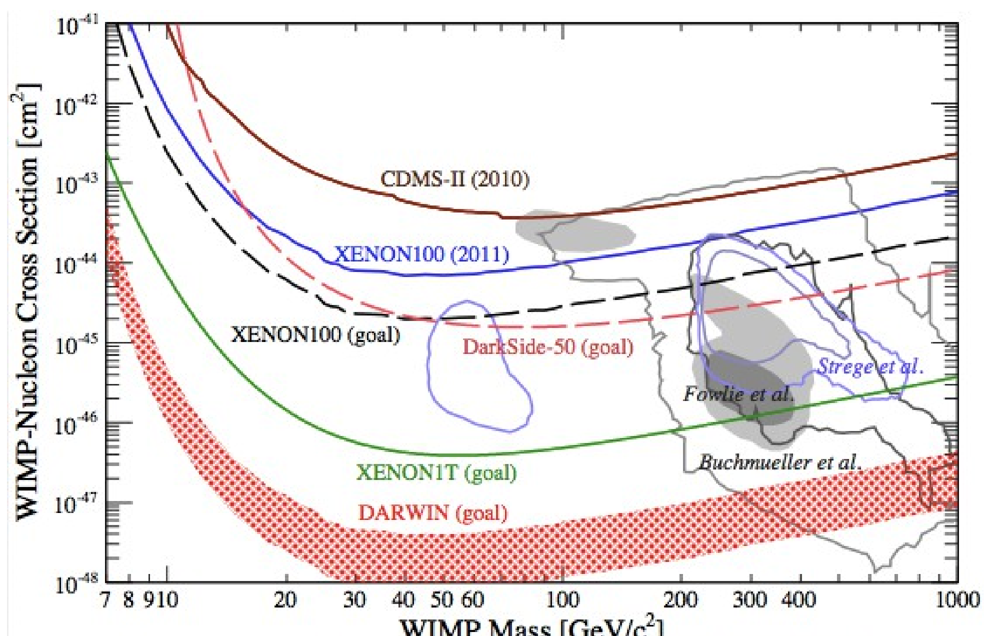
- "Dark matter attempts for CoGeNT and DAMA", TS, Zupan, 1106
- "Light dark matter in the light of CRESST-II", Kopp, TS, Zupan, 1110
- "On the annual modulation signal in dark matter dire detection", Herrero-Garcia, TS, Zupan, 1112
- "Higgs portal, fermionic dark matter, and a Standard Model like Higgs at 125 GeV", Lopez-Honorez, TS, Zupan, 1203

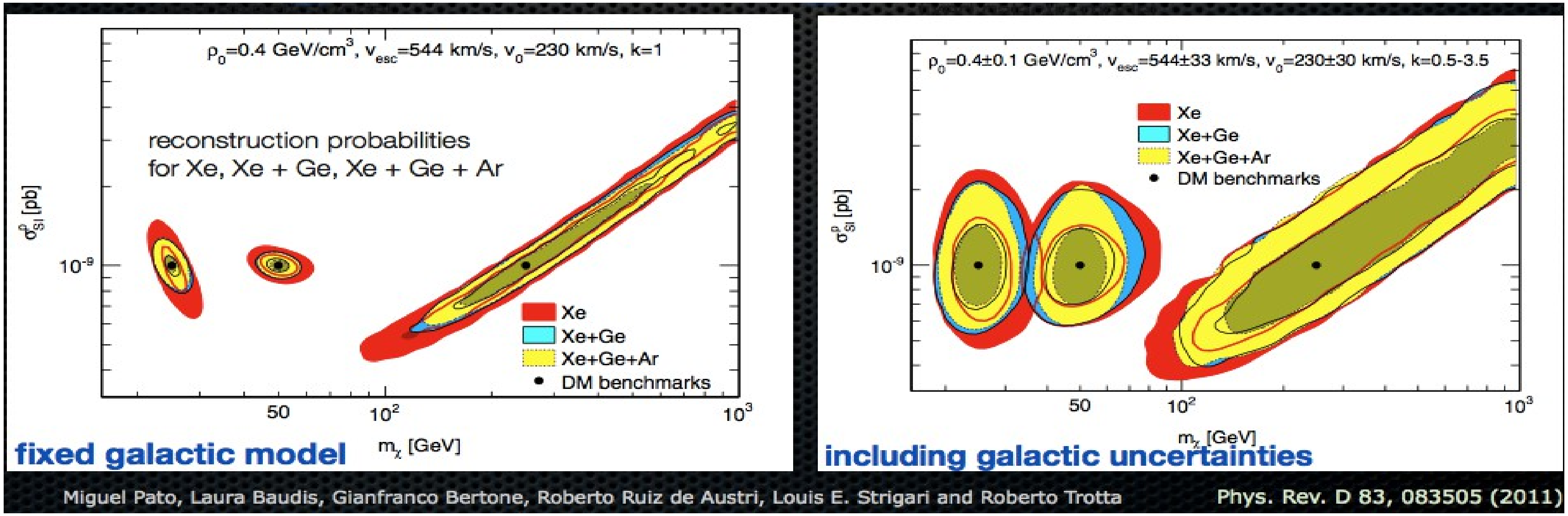


Sketch of possible layout for LAr and LXe cryostats in large water Cherenkov shields



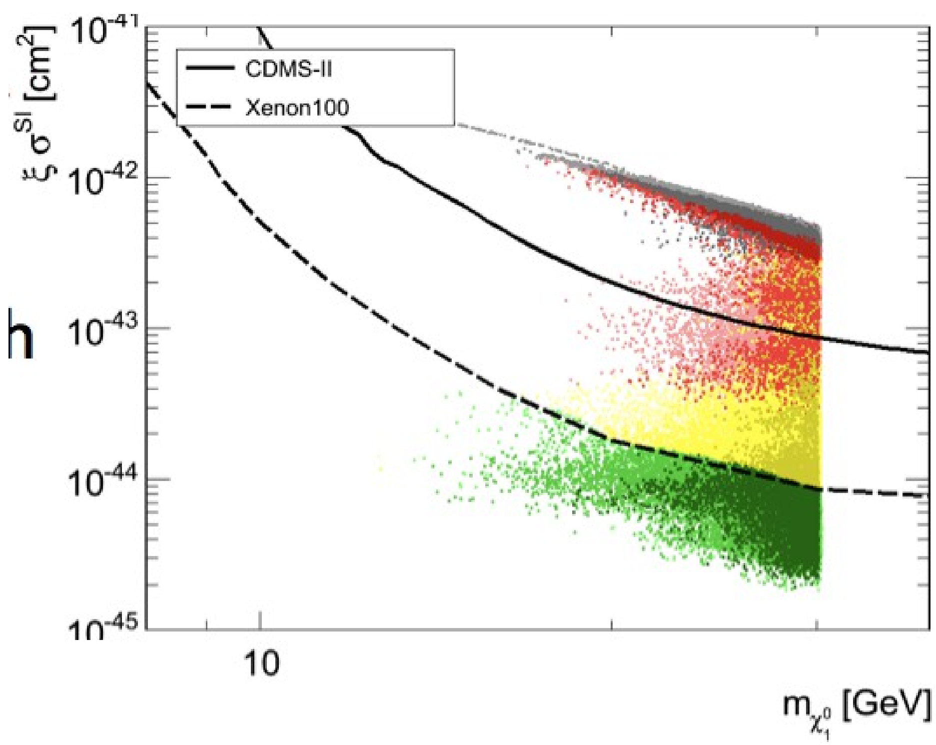
2vbb: EXO measurement of ^{136}Xe $T_{1/2}$
Assumptions: 50% NR acceptance, 99.5% ER discrimination
Contribution of 2vbb background can be reduced by depletion





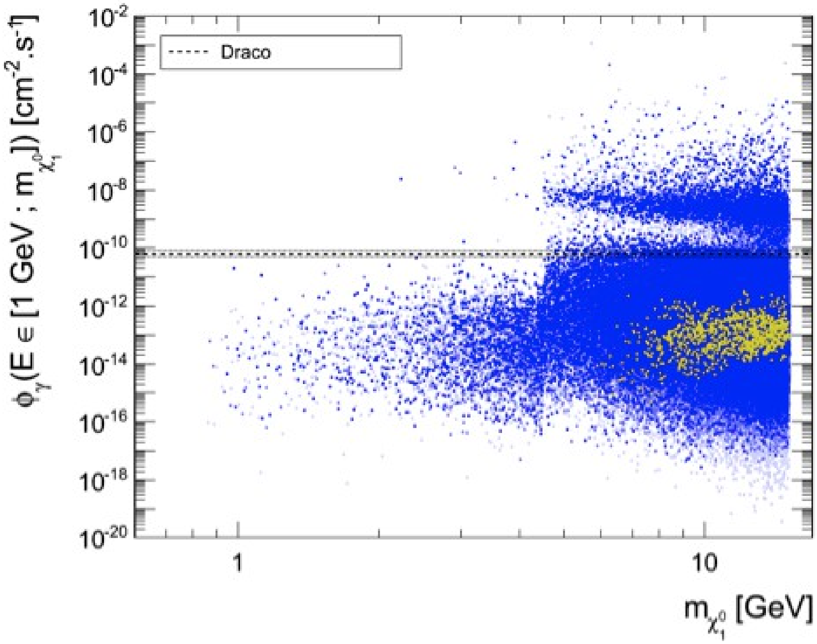
Light neutralinos and their compatibility with experiments

Boehm et al., UDUR



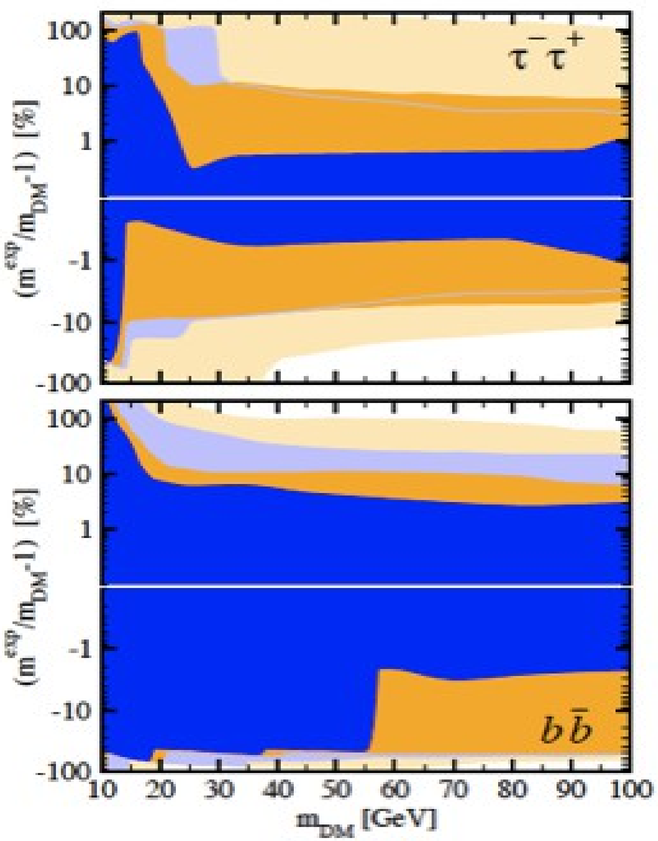
Indirect DM detection

CNRS, MPG, INFN, SOTON, UAM, UDUR, UGOE-DESY, UVEG



Boehm at al.

Indirect detection from gamma-rays in the galaxy



Indirect DM searches with neutrinos

DM annihilations can be searched for in the galaxy and in the Sun with neutrino detectors.

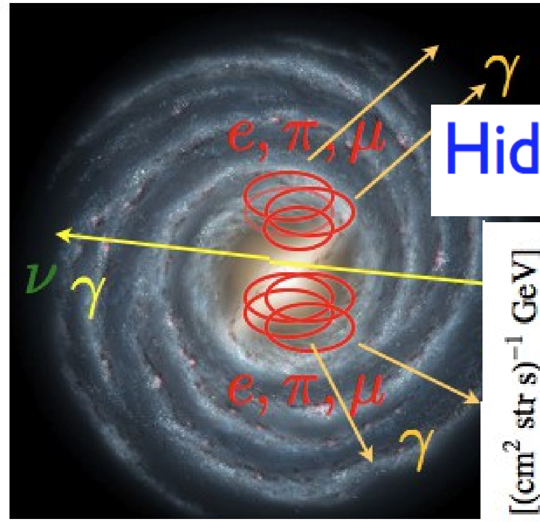
Das, Mena, Palomares-Ruiz, SP.
Collaboration with UVEG.

Gravitino DM connection

Thanks to L. Covi

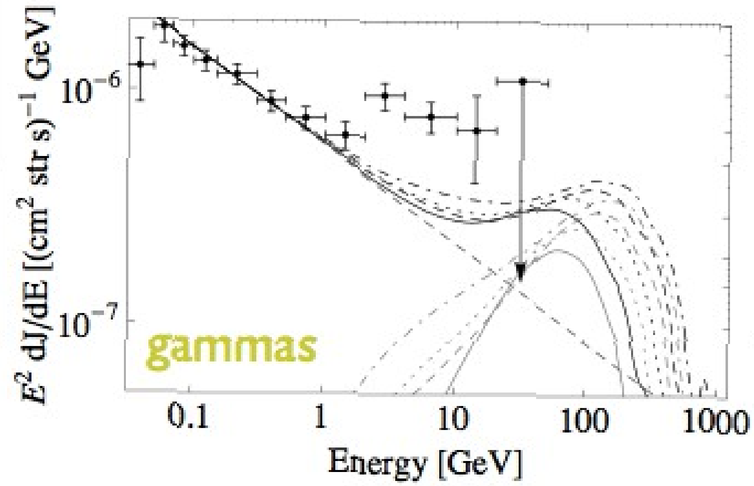
- Signal from DM decay in indirect detection channels: gamma-rays, positrons, antiprotons, neutrinos

➔ FERMI, PAMELA, ICECUBE



Hidden Photino Dark Matter

[Ibarra, Ringwald, Weniger 09]

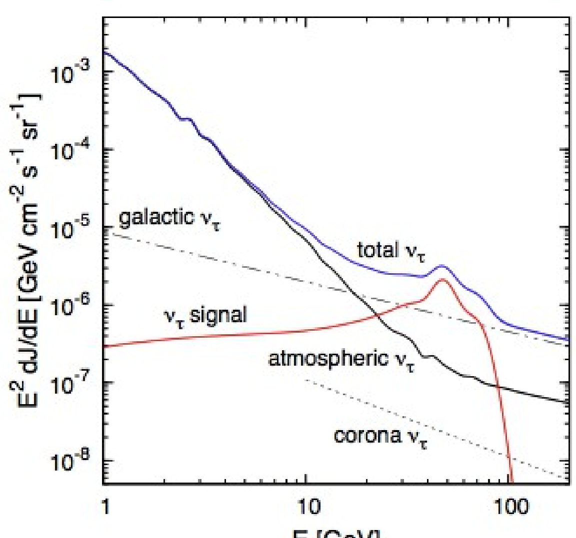


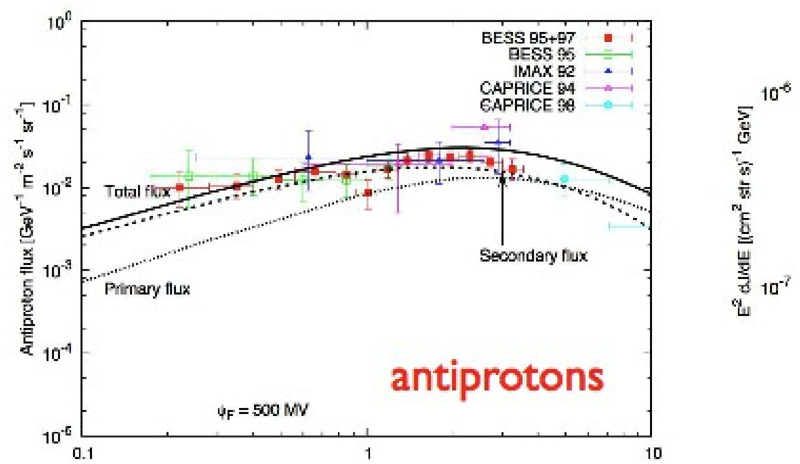
UGOE-DESY

[W. Buchmuller, LC, G. Bertone, A. Ibarra, T. Shindou, F. Takayama, D. Tran]

[Buchmuller, Ibarra, Shindou, Takayama, Tran 09]

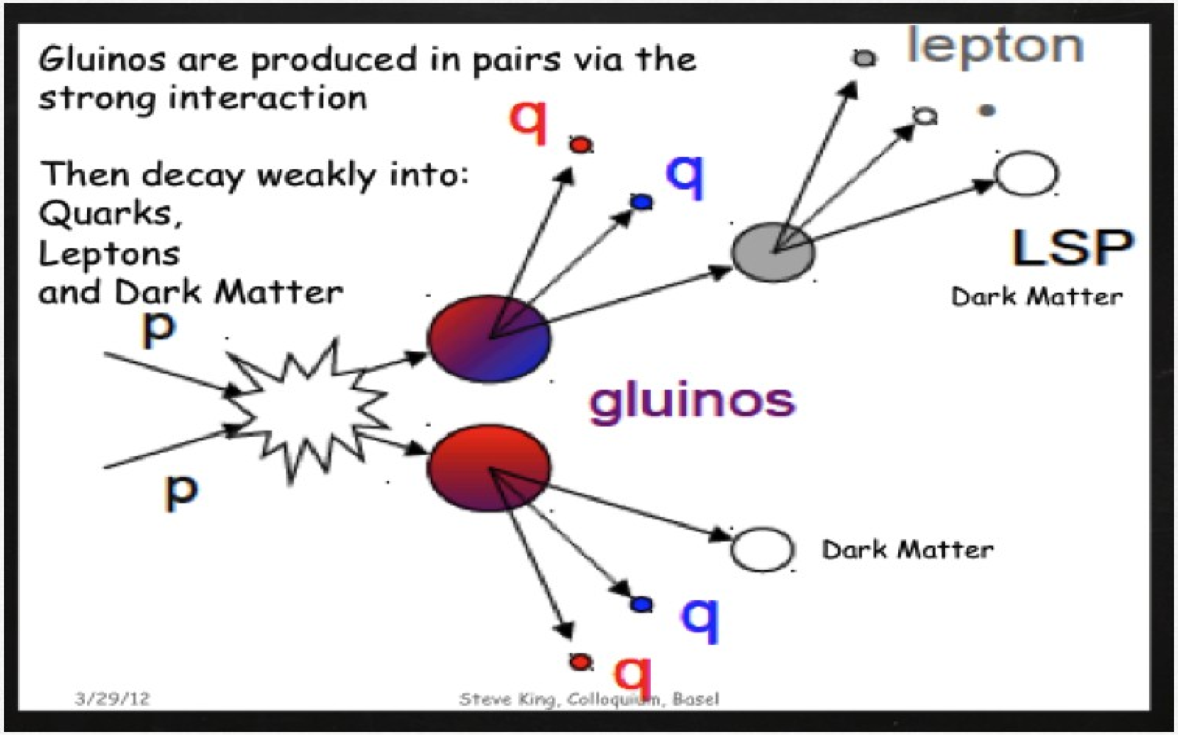
[LC, Grefe, Ibarra & Tran 08]





Gravitino DM without R_p

Dark Matter at Colliders



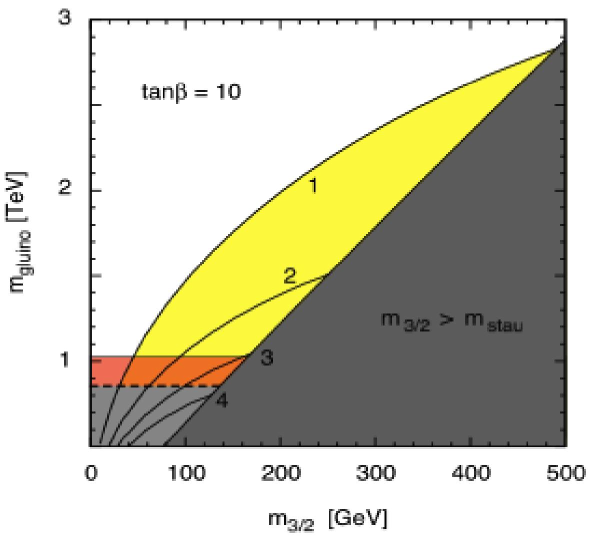
CNRS, INFN, SOTON, UGOE-DESY

Thanks to S. King

SOTON

- We have studied usual CMSSM paradigm
- As well as MSSM with non-universal Higgs, third family sparticles and non-universal gauginos
- We studied USSM with an extra gauged U(1)'
- We studied the E6SSM where Wimp may be either a Bino (as in MSSM) or a new inert singlino/Higgsino combination
- We showed that if WIMP is an inert singlino/Higgsino then the Higgs may decay into it (bad)
- But the gluino may also decay into inert singlino/Higgsino (good) giving distinctive signatures in gluino decay (longer cascade decay chains, more leptons, less missing energy)

- Supersymmetry @ LHC with NLSP as (meta)stable state: stau, neutralino, sneutrino, stop... with or without missing energy !



UGOE-DESY

Thanks to L. Covi

Models of Dark Matter

CNRS, INFN, UAM, UDUR, UGOE-DESY

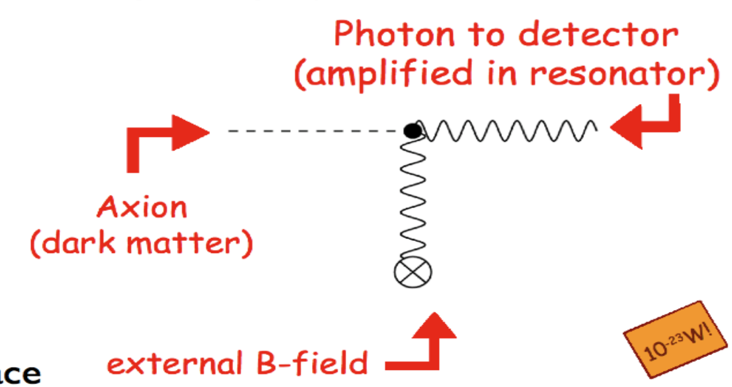
The particle identity of dark matter is one of the fundamental questions in particle physics/cosmology.

Any extension of the SM with a “stable” particle can potentially provide a DM candidate. Typical examples are WIMPs, such as neutralinos etc. It is necessary to study their properties, signatures and mechanisms of production in the EU.

Lighter candidates exist, such as MeV DM (UDUR) or axions (CNRS, UDUR, UGOE-DESY).

They appear naturally in many extensions of the SM
(motivated by to strong CP, string theory…).

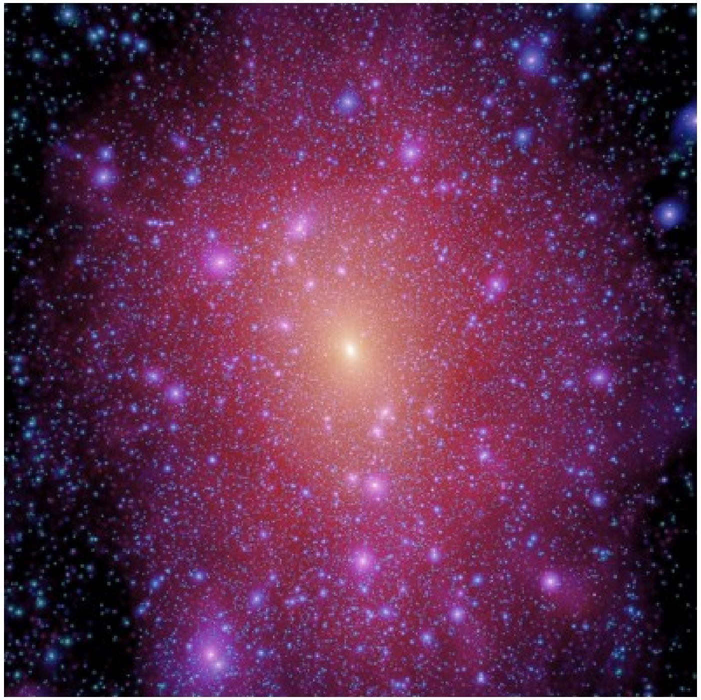
Can and will be tested in lab experiments
- DM detection:
  ADMX, + more soon
- Production and det.:
  ALPS, GammeV, +…



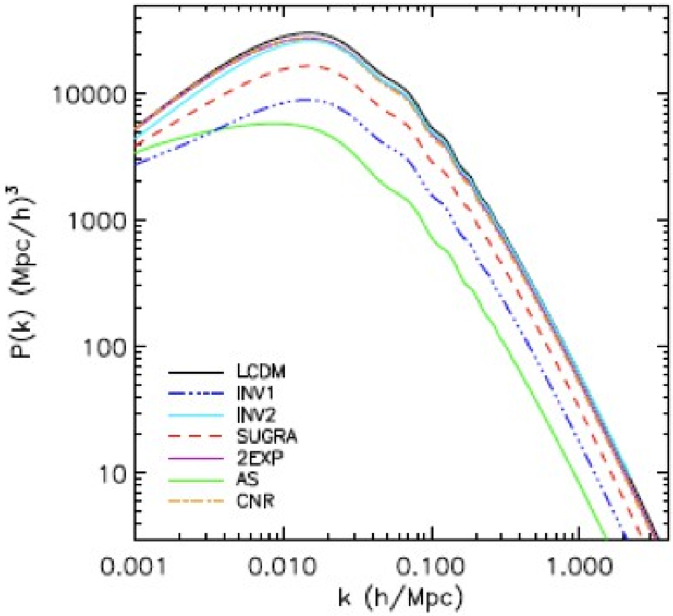
Jaeckel, Wallace

Large scale structure formation

UAM, UDUR (ICC)



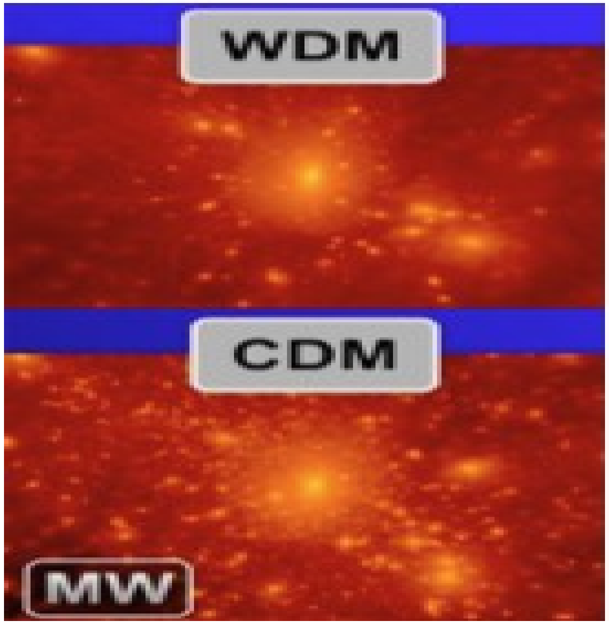
Aquarius DM halo



Jennings et al.

DM and DE

Standard CDM simulations



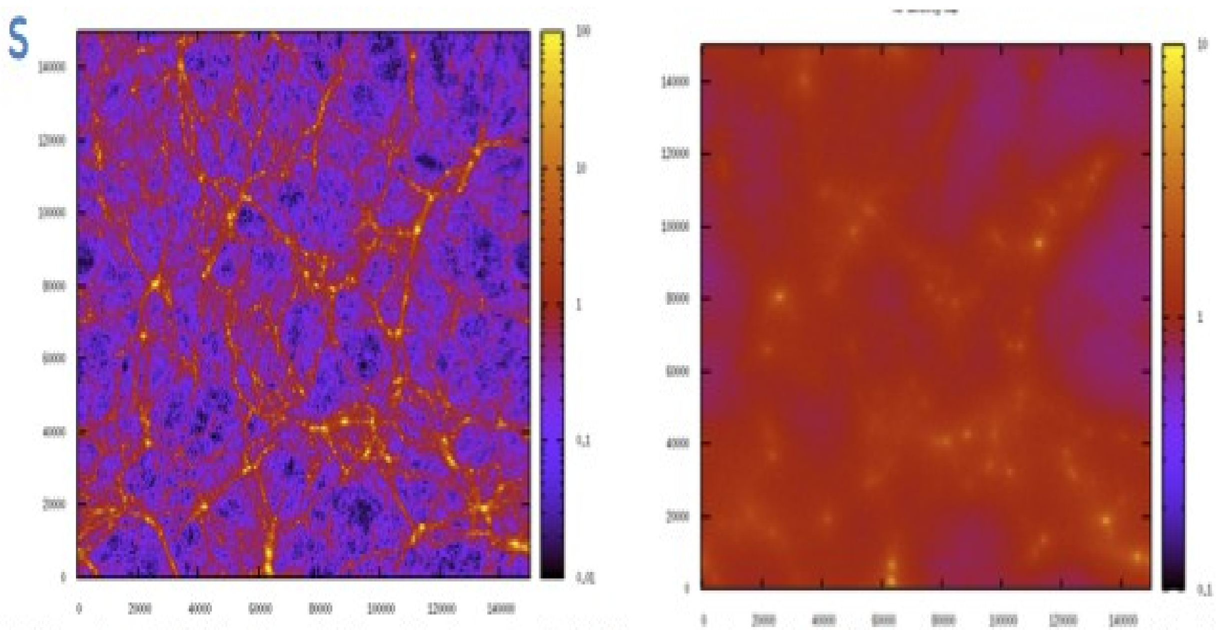
WDM simulations, UAM, UDUR

Knebe.

Neutrino cosmology

AU, UAM, UDUR, UVEG

One of the challenges is to include the effects of neutrinos (and hot DM) in N-body simulations, attaining a precision (~1%) comparable to future observations.

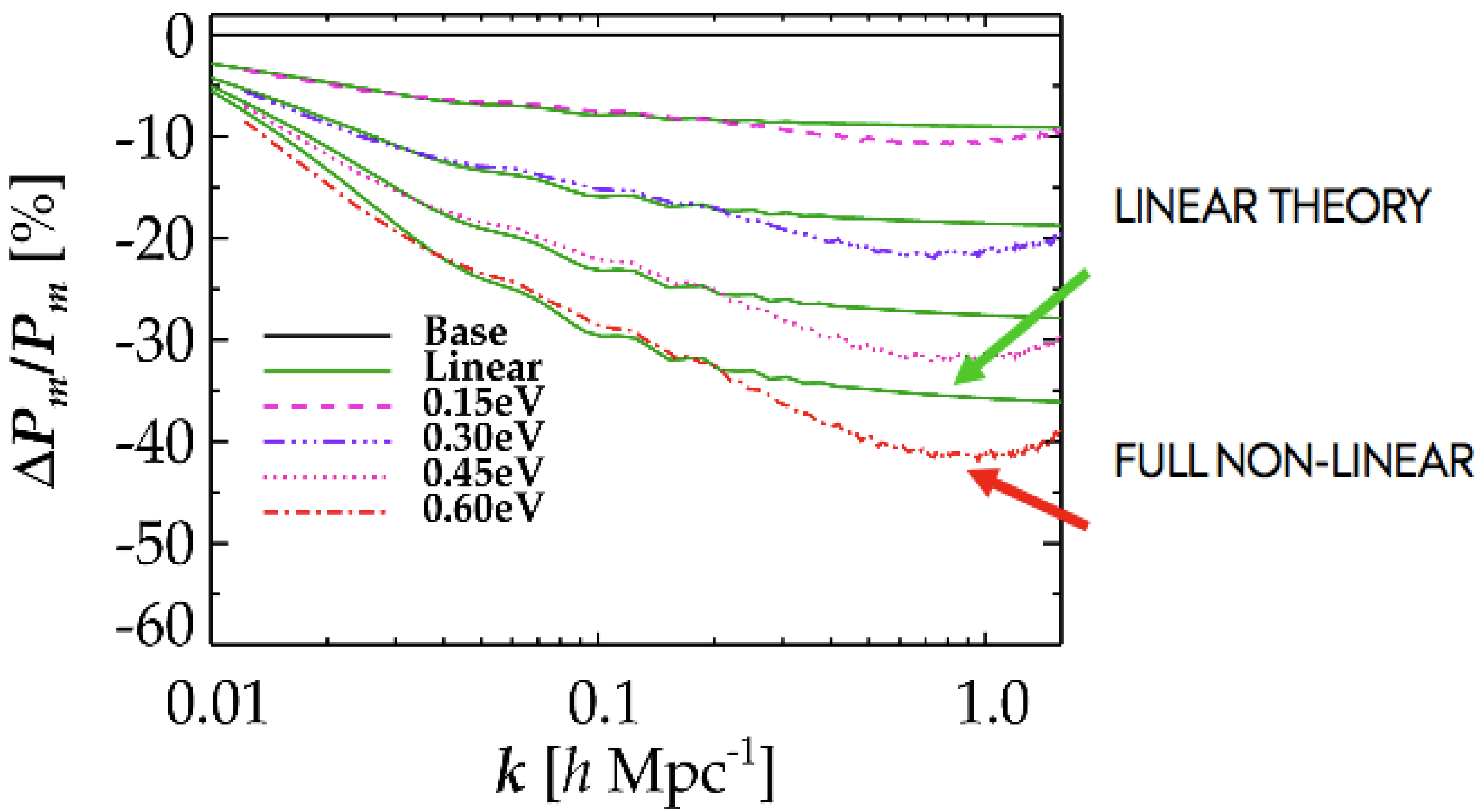


150 Mpc/h x 150 Mpc/h x 10 Mpc/h slice, Dark Matter overdensity (left)and Neutrino overdensity (right).
Simulation: 512^3 CDM and 512^3 n (3x0.2 eV degenerate neutrinos) in 150 Mpc size Box.
Software: CAMB (linear regime)+ GADGET-3 (N-body) + SUBFIND/AMIGA (halo finder)

UVEG

N-body simulations use “particles” which interact gravitationally and form structures hierarchically.
Neutrinos have very large velocities and present specific challenges.

AU (Hannestad) has performed the first simulations of neutrinos in LSS. Work is being carried out also in UVEG, UAM and UDUR (at IPPP and ICC).



Brandbyge, STH, Haugbølle, Thomsen, '08 (JCAP)
Brandbyge & STH '09, '10 (JCAP), Viel, Haehnelt, Springel '10
STH, Haugbølle & Schultz '12
Wagner, Verde & Jimenez '12

NEW NEUTRINO MASS BOUNDS FROM SLOAN DIGITAL SKY SURVEY III DATA RELEASE 8 PHOTOMETRIC LUMINOUS GALAXIES

Roland de Putter[1,2], Olga Mena[2], Elena Giusarma[2], Shirley Ho[3,4], Antonio Cuesta[5], Hee-Jong Seo[3,6], Ashley J. Ross[7], Martin White[3,8], Dmitry Bizyaev[9], Howard Brewington[9], David Kirkby[10], Elena Malanushenko[9], Viktor Malanushenko[9], Daniel Oravetz[9], Kaike Pan[9], Will J. Percival[7], Nicholas P. Ross[3], Donald P. Schneider[11,12], Alaina Shelden[9], Audrey Simmons[9], Stephanie Snedden[9]

UVEG

(Dated: January 11, 2012)
Draft version January 11, 2012

Other areas of work include

- Sterile neutrino cosmology: production in the EU, possible thermalisation and impact on structure formation

- Extra degrees of freedom at CMB and at BBN

- Combining cosmological constraints with direct neutrino mass searches and neutrinoless double beta decay

Dark Energy and Gravity

AU, INFN, UAM, UDUR, UVEG

Invisibles teams have also a strong interest in understanding the origin of the accelerated expansion of the Universe and ultimately of gravity:

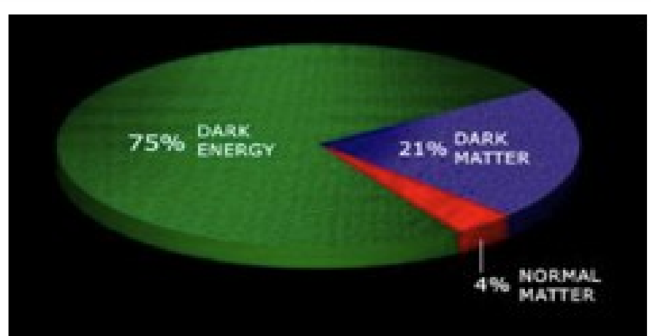
- models of DE (quintessence and modified gravity)

- coupling of DE and DM

- simulations of CDM/WDM with different DE backgrounds

- **Vacuum energy decay** : does Λ has an imaginary part ?

  Transverse gravity : different weight for kinetic and potential energy



The EU nodes in Invisibles cover a wide range of topics, with leading expertise in most of the relevant areas in neutrino and dark matter physics. Thanks to the complementary expertise in the associated nodes, we will try to build the New Standard Model!

Let us turn the

invisibles

neutrinos, dark matter & dark energy physics

to Visibles !

Thanks to L. Covi!