

# Enigmass WP1

**The origin of mass and the search for  
new physics**

# What's the problem

**Standard Model has been completed in 2012 by the discovery of the Higgs boson**

explains mass of fermions and gauge bosons

...but brings a few more questions :

Why is  $m_H$  so different from Planck or GUT scales ?

Is the Higgs potential stable ?

Why are neutrino masses so small ?

## Questions from QCD

Strong interaction is a well established theory

... but :

no theoretical justification for the absence of CP violation in strong interaction

no clear understanding of what happens at low energy

## Plenty of questions from cosmology

Recent observations lead to a well described  $\Lambda$ -CDM cosmological model

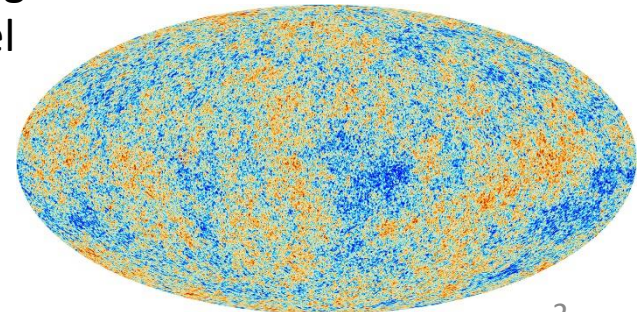
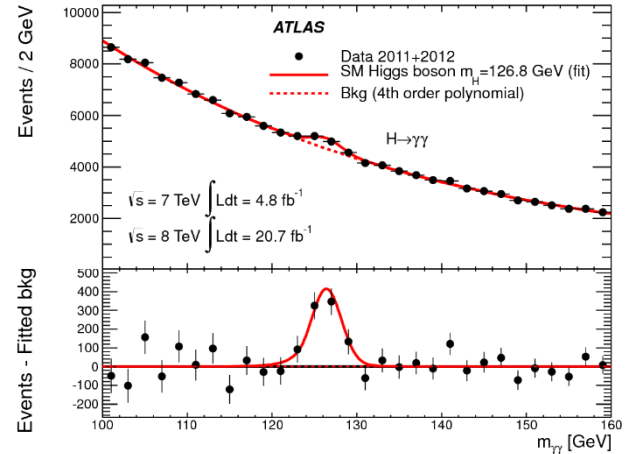
... but a lot of its content isn't described by the standard model

Dark Energy

Dark Matter

Matter-Antimatter Asymmetry

...



# Goal of WP 1

*Expand our understanding the standard model to include those phenomena*

**- at the theoretical / phenomenological level : LAPTH and LPSC**

- \* Models
- \* Numerical tools
- \* Connection to experiments

**- at the experimental level : LAPP and LPSC**

- \* Building of detector
- \* Operation of detectors
- \* Data analysis

By contributing to the worldwide effort on these topics through international collaborations :

nCTEQ, ATLAS, ALICE, LHCb, n2EDM, SuperNEMO, Dune, STEREO, Ricochet...

# Theory @ LPSC

Theory group at LPSC covers two wide domains of activity, closely related to the experimental studies at the lab.

## ***QCD at both high- and low-energy***

Study of the nucleon & nucleus PDFs (contribution to nCTEQ)

Lattice QCD: novel formalism for LQCD renormalization, simulations with 4 dynamical quarks

Axions (strong CP problem) : models, LHC and low-E signatures, cosmological aspects

## ***Beyond Standard Model : from models, to collider phenomenology and to astrophysics and cosmology***

SUSY at colliders, effective approaches & specific models : consistent effort in the establishment of data-interpretation strategies

Generic NP : “simplified-model” approach (code SModelS), calculation of RGE evolution (code Pyr@te)

Dark Matter : diverse expertise, from DM at colliders (EFTs or models) to quantitative predictions for small-scale DM structures

# Theory @ LAPTh

LAPTh is dedicated entirely to theory and covers a large spectrum of WP1 subjects with overlaps to WP 2/3

## *Higher-order computations, and tools*

New method to perform NNLO + parton shower simulations (public codes)  
New approach to 2-loop integrals with complex masses

## *Higgs and new physics*

Automatized tool for BSM at 1 loop through “SloopS”

## *The HEP – Dark Matter interface*

Development of particle-DM calculation tools : MicrOMEGAs and DM@NLO

## *Flavour physics*

Flavour violation within SUSY GUTs & leptonic observables  
*B*- and *K*-physics phenomenology, from models to observables (synergy with **LHCb @ LAPP**)

## *Low-energy frontiers*

Probing Yukawa couplings from atomic physics

# Collider Physics : ATLAS

## Contribution to data analysis :

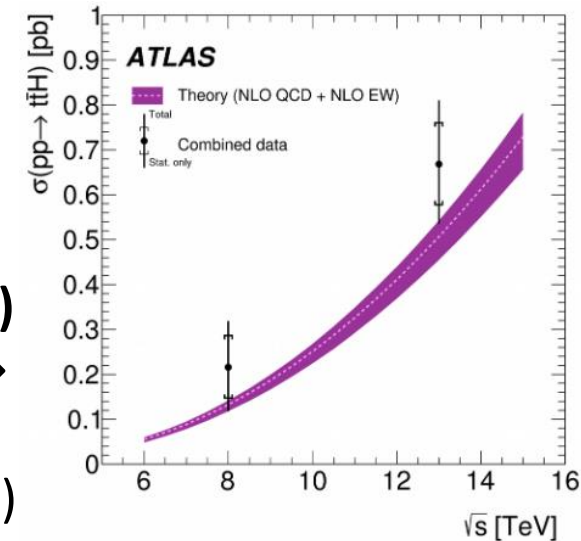
**Standard Model** : di-boson production (WZ and Z $\gamma$ )  
(LAPP)

**New physics** : resonances  $\rightarrow$  di-photons and di-leptons  
(LAPP)

**Higgs** : properties, production, decays (LPSC and LAPP)  
LAPP contributed to 1st evidence of the Higgs (in  $H \rightarrow \gamma\gamma$ )

Evidence of the ttH channel and HH production (LPSC)

**Long-lived particles & “dark” strong sectors** (LPSC)



## Technical contributions :

**Inner Tracker (ITk)** : LAPP & LPSC in charge of 12.5% of pixel outer barrel

**The “CO2 cooling” project** : Cooling of the trajectographs for HL-LHC via di-  
phasic CO2 :

prototype financed by ENIGMASS at LPSC

measurement of the support’s thermal performance at LAPP

**LAr calorimeter** : LPSC Electronics and LAPP collaborating on various tasks  
related to the PCBs

**Many other** : computing...

# Collider Physics : ALICE (LPSC)

How to probe QCD in conditions resembling the most the early Universe ?

***Building and probing a Quark-Gluon Plasma (QCD analog of e.m. plasmas)***

- heavy ion collision at LHC (ALICE detector)
- high energy density causes partons to deconfine.

**merges non-perturbative & finite T QCD**

***LPSC is involved in***

**- Data analysis of jet quenching:**

Jets propagating in a hot & dense medium display a marked reduction in energy

Open topics : Path-length dependence? Differences w.r.t. in-vacuum propagation? Jet substructure?...

**- Detector upgrade : FOCAL**

new improved calorimeter

aiming for clean-er probes (e.g. jet-photon correlations)

# Collider Physics : LHCb (LAPP)

New effects through distortions to can be searched for accurately measured and accurately calculated rare processes

## ***Technical expertise :***

Unique expertise on calorimetry and photon reconstruction

LHCb Upgrade I [leading to a 5x increase in LHCb lumi] & subsequent Run-3 startup (~ 2022)

## ***Physics topics :***

Progress on the CKM angle  $\gamma$  (SM “standard candle”) through analyses of  $B \rightarrow Dh$  ( $h=\pi$  or  $K$ )

$B_s \rightarrow J/\psi \eta(')$  to measure CPV induced by  $B_s - B_s$  mixing (tiny in the SM)

## ***Synergy with LAPTh :***

Collaboration on radiative modes (including students in co-supervision)

Current focus:  $B_s \rightarrow \mu\mu\gamma$  : never measured, will be a new test of  $b \rightarrow s$  transitions



# Intensity frontier: n2EDM

Probing new sources of CP-violation through low energy processes : electric dipole moment of the neutron

***Search for a coupling between the neutron spin and an electric field***

T and P violating process

Look for tiny variations of the neutron Larmor frequency in presence of E and B fields.

Use stored ultracold neutron (large precession times)

Experiment based at PSI (Switzerland)

***nEDM best limit:  $|d_n| < 1,8 \times 10^{-26} e \cdot cm$  [PRL 2020]***

result obtained by double blind analysis by two independent analysis teams, one led by the LPSC group.

unprecedented understanding of the magnetic field and various systematic effects

***New experiment, n2EDM, being assembled ( $\leq 2022$ )***

1 o.o.m. improvement expected over 5 years

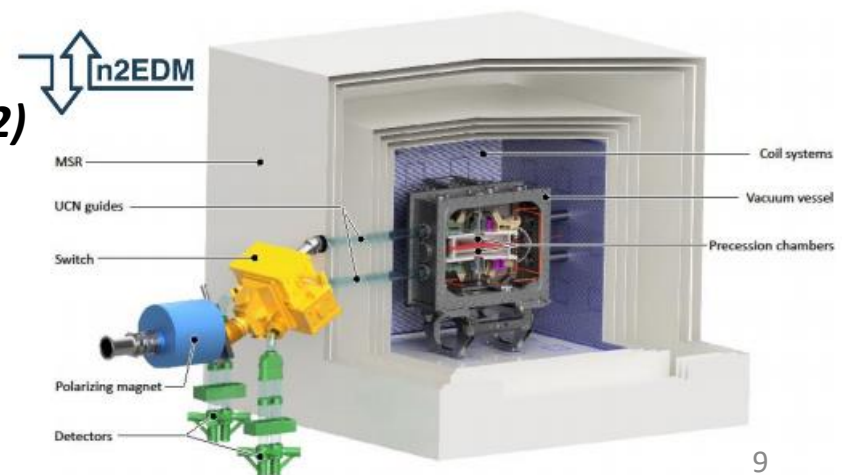
LPSC is in charge of :

building several major components,

performing R&D on Hg magnetometry

has a recognized expertise in the analysis

ERC Grant of G. Pignol



# Neutrino Physics : Stereo and Ricochet

Probing neutrino properties @ILL (research reactor in Grenoble)

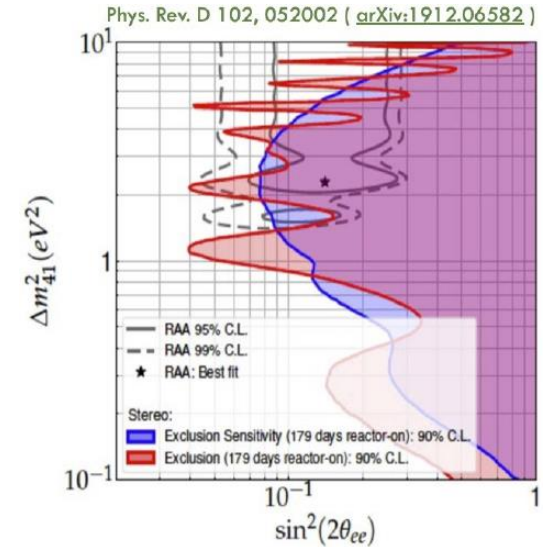
## Search for sterile neutrino : STEREO Experiment

Probing the so called reactor anomaly

Measure absolute flux and spectrum from  $^{235}\text{U}$  fission

Strong local synergy:

**ILL, LAPP, LPSC** with support from ENIGMASS



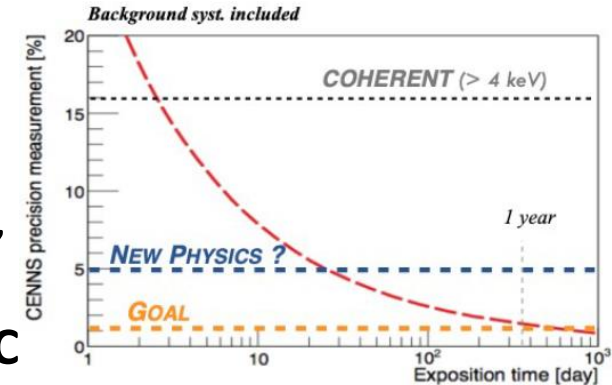
## Coherent Elastic $\nu$ -N Scattering (CE $\nu$ NS) : RICOCHET project

Scattering between a  $\nu$  and all nucleons in a nucleus

Allows a precision measurement of low-E  $\nu$  spectrum

Important measurement for many topics :  $\nu$  properties, non-standard interactions, SNe dynamics, “ $\nu$  floor”, ...

1% precision by 2024 with a strong involvement of **LPSC**



# Neutrino Physics : SuperNEMO and DUNE

## *Search for Majorana neutrino : $0\nu\beta\beta$ decay at SuperNEMO*

Installed at Laboratoire Souterrain de Modane (LSM, part of LPSC)

Use scintillators to fully reconstruct  $\beta\beta$  decays

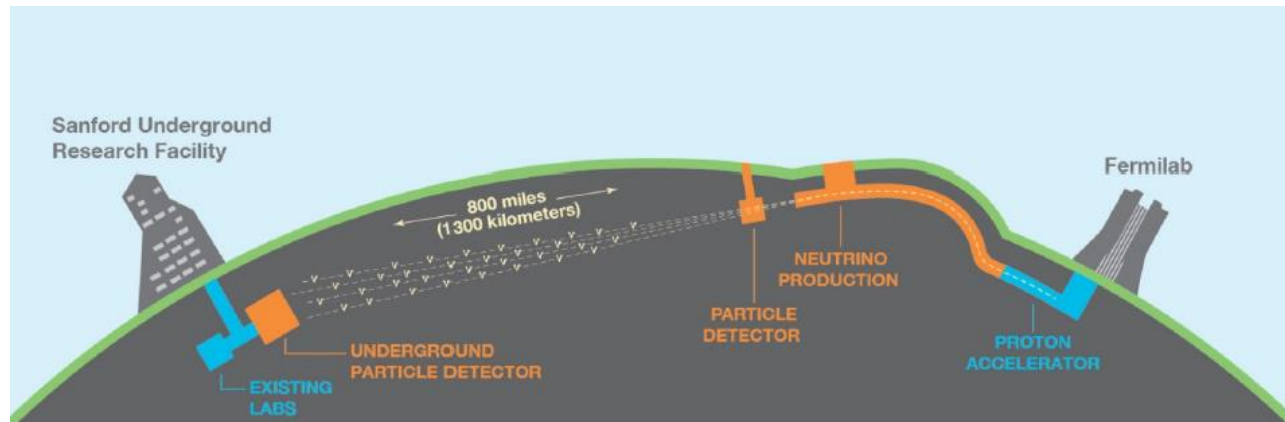
Two phases :

demonstrator (6.3kg of  $^{82}\text{Se}$ , 1st data  $\sim 2021$ ) :  $\tau > 6.5 \cdot 10^{24}$  yrs

“full” SuperNEMO (100kg, multi-module)  $\tau > 10^{26}$  yrs

Important contribution of LAPP : Detector commissioning, coordination, tracker repair

## *DUNE: the ultimate $\nu$ experiment ( $\sim 2026$ )*



Precision  $\nu$  physics : oscillations, mass hierarchy, CP-violation phase

Strong involvement of **LAPP** and **LPSC**

- \* ProtoDUNE-DP (CERN): installation, operation, analysis, CR tagger
- \* Several technical tasks: mechanics, charge readout, simulation

# Conclusion

## ***WP1 is central to ENIGMASS's mission***

- it covers what is traditionally called “particle physics” from low to high energies both from the theoretical and experimental point of view
- the goal is to contribute to expand our understanding the standard model and to look beyond

## ***All ENIGMASS labs are involved in many ambitious, well-recognized projects, much of a larger span :***

nCTEQ, ATLAS, ALICE, LHCb, n2EDM, SuperNEMO, Dune, STEREO, Ricochet...

Major technical and analysis contribution for all labs to these projects

Complementary activities within the labs

Several synergies between labs already exists... but the LABEX can contribute to expand them