ENIGMASS
WP1:
The Origin of Mass and the Search for New Physics
– Overview –

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The WP1

Within the Standard Model, every mass scale originates from the spontaneous breaking of a symmetry (SSB)

- *The SSB of gauge $SU(2)_L \times U(1)_Y$ due to the Higgs vev*

  ⇨ Mass to fundamental particles

  quarks, leptons, massive gauge bosons, the Higgs

- *The chiral (global) SSB due to the chiral condensate*

  ⇨ Λ_{QCD} : the fundamental dynamical scale of low-energy QCD

More questions than answers

SSB $SU(2)_L \times U(1)_Y$

- Realized through a scalar.

  What if there were a new physical scale $M \gg$ Higgs vev?

  (ex: M_{Planck} , M_{GUT} , …)

  In general, one would then expect

  $\delta M_{\text{Higgs}} \propto M \gg M_{\text{Higgs}}$

  ⇨ What mechanisms keeps M and M_{Higgs} apart?

- Do neutrinos receive their mass through the Higgs mechanism or otherwise?

More questions than answers

Strong interactions

- Low-energy QCD, in all its manifestations,
  is only calculable through non-perturbative methods

  Methods that, at present, are accessible to a limited number of quantities

⇨ Lots of low-energy phenomenology which is not understood quantitatively

or not understood at all

More questions than answers

Strong interactions

- Why don't they violate *CP*?

  In spite of the fact that

  - Strong *CP* and electroweak *CP* are related through the Yukawa couplings
  - Small *CP* violation is not required on anthropic arguments – rather the converse

- Maybe the answer is the axion?

  ⇨ The axion would even be an excellent DM candidate

More questions than answers

Plenty of questions from cosmology

- Dark Energy?
- Dark Matter?
- Matter-Antimatter Asymmetry?
- The microphysical nature of Inflation
- …

As concerns the WP1 :

- Can we make progress on these questions
  with the tools we use to inquire about the origin of mass?

  For example: can we produce DM at colliders?

Probing the origin of mass

and the presence of new effects

directly

LAPP / ATLAS : 3 physics streams

- SM: di-boson production (*WZ* and $Z\gamma$)

  Crucial channels for the understanding of the gauge sector

- New physics: resonances → di-photons and di-leptons

  "Bump-hunt"

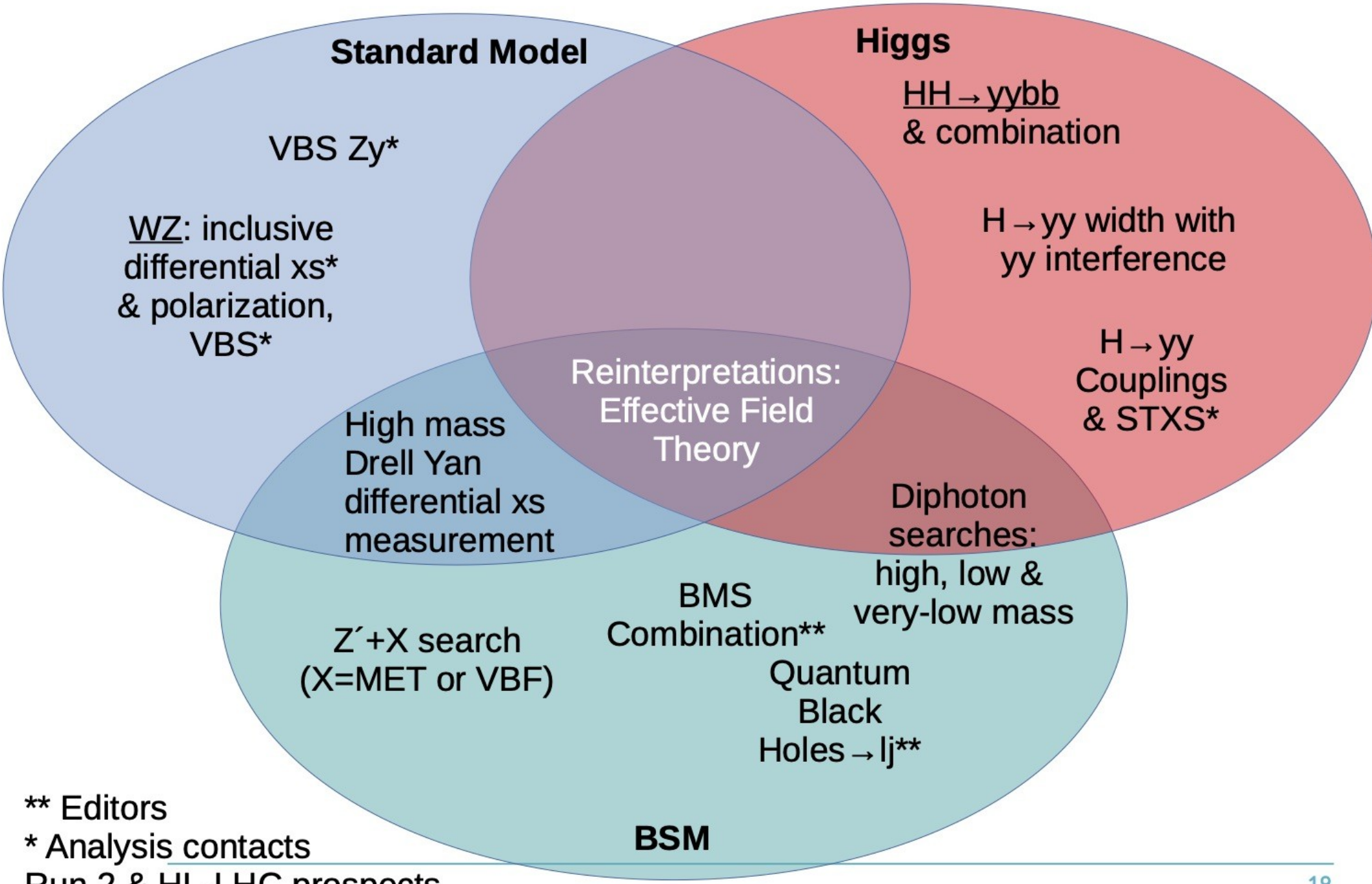
- Higgs (properties, production, decays)

  Central to WP1

LAPP contributed to 1st evidence of the Higgs (in H → $\gamma\gamma$)

[LAr calibration; event selection; stat. analysis]

Analyses de physique actuelles Run 2 et au dela



** Editors
* Analysis contacts

Run 2 & HL-LHC prospects

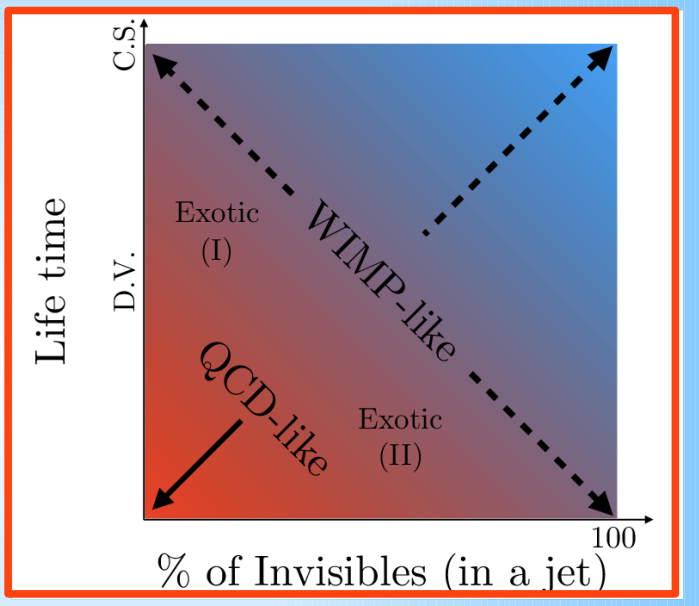
LPSC / ATLAS

- New-physics searches now orbiting around:

  Long-lived particles

  &

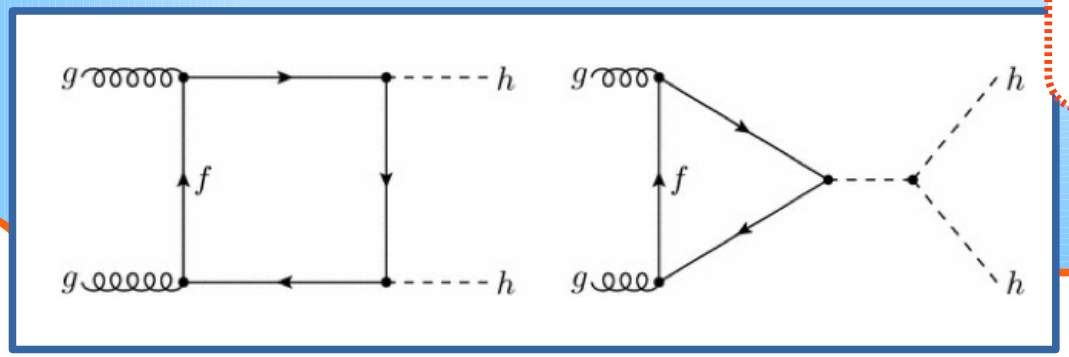
  “dark” strong sectors



- Higgs sector

  Evidence of the $t\,t\,H$ channel

  $H\,H$ production



Nice complementarity w.r.t. LAPP

Technical contrib's include LAPP – LPSC synergies

- **Inner Tracker (ITk)**

  LAPP & LPSC in charge of 12.5% of pixel outer barrel

- **The "CO_2 cooling" project**

  Cooling of the trajectographs for HL-LHC via di-phasic CO_2

  LPSC: involved in a prototype (financed by ENIGMASS)

  LAPP: measurement of the support's thermal performance

- **LAr calorimeter**

  Key detector for precision measurement of electrons, γ, jets, MET

  LPSC Electronics and LAPP collaborating on various tasks related to the PCBs

- **Overlooking many aspects, in particular Computing**

ALICE at LPSC

- Challenging yet important to probe QCD in conditions resembling more the early Universe.

  The "medium": Quark-Gluon Plasma

  the high energy density of the collisions causes partons to deconfine. QCD analog of e.m. plasmas

  ⇨ merges non-perturbative & finite T QCD

- Jets propagating in a hot & dense medium display a marked reduction in energy ("jet quenching")

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

- **Focus at LPSC:** aim for clean-er probes, e.g. jet-photon correlations

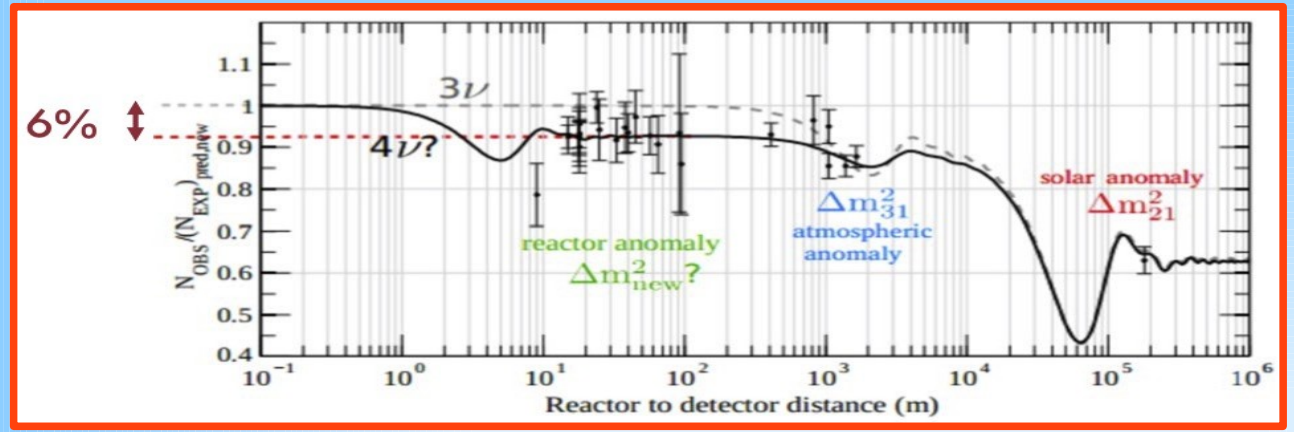
Neutrinos:

a trivial SM extension

or the first messengers of a new scale?

Note:
the *only* dim=5 interaction in the SMEFT
(the “Weinberg operator”)
is precisely what can explain neutrino masses

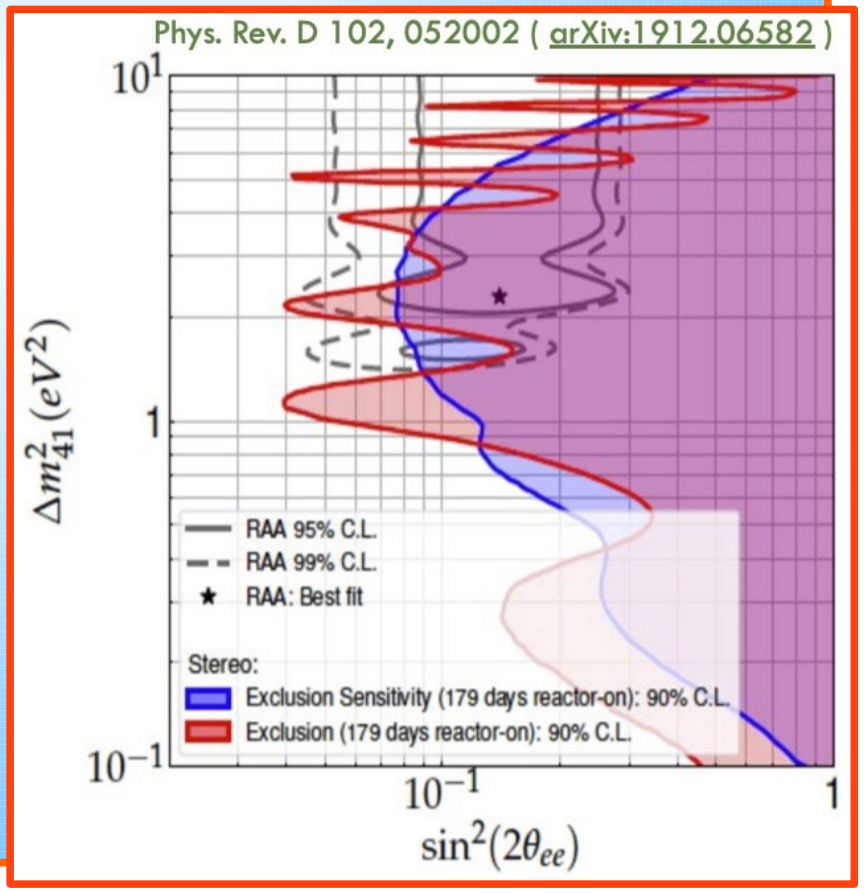
Question 1: sterile ν's ?



STEREO at ILL

- Measure absolute flux and spectrum from ^{235}U
- Disentangle flux vs. oscillation measurements

⇨ Strong local synergy:
ILL, LAPP, LPSC, ENIGMASS



Question 2: Are ν their own antiparticles?

In a $\beta\beta$ decay, two ν could annihilate: ultra-rare $0\nu\beta\beta$ decay

SuperNEMO at LSM

[idea: full event reconstruction will tell apart $\beta\beta$ *decays*]

- *"demonstrator"* ⇨ $\tau_{0\nu\beta\beta} > 6.5 \cdot 10^{24}$ *yrs*
  [6.3kg of ^{82}Se] [1st data ~ 2020]
- *"full" SuperNEMO* ⇨ $\tau_{0\nu\beta\beta} > 10^{26}$ *yrs*
  [100kg, multi-module]

*Strong involvement of **LAPP***

[Detector commissioning; coordination; tracker repair]

Question 3: Coherent Elastic ν-N Scattering (CEνNS)

Scattering between a ν and all nucleons in a nucleus

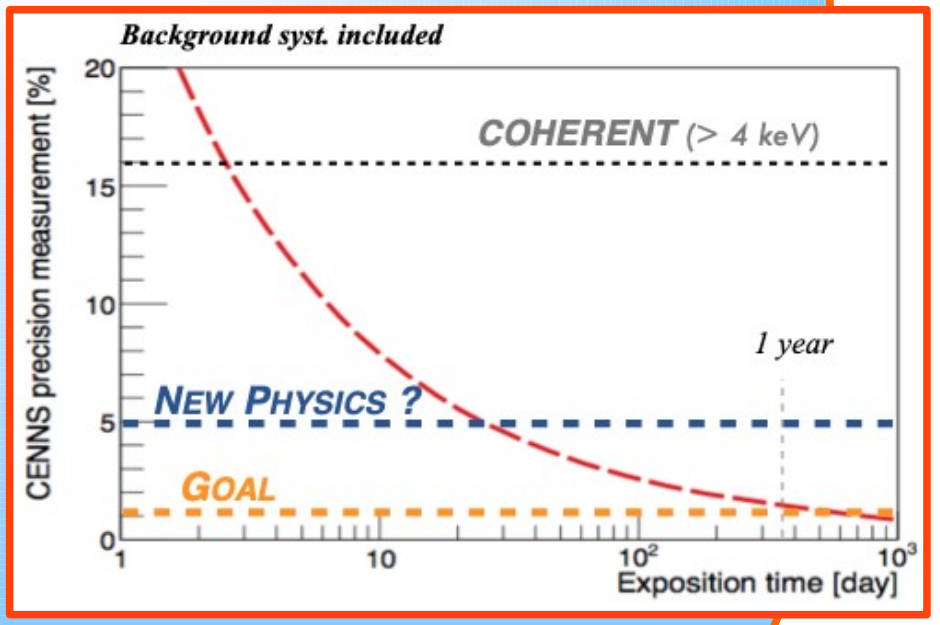
- *Possible if mom transfer < few tens MeV*
- *Interaction x-section $\propto$ (# neutrons)^2 !*

⇨ *Allows a precision measurement of low-E ν spectrum*

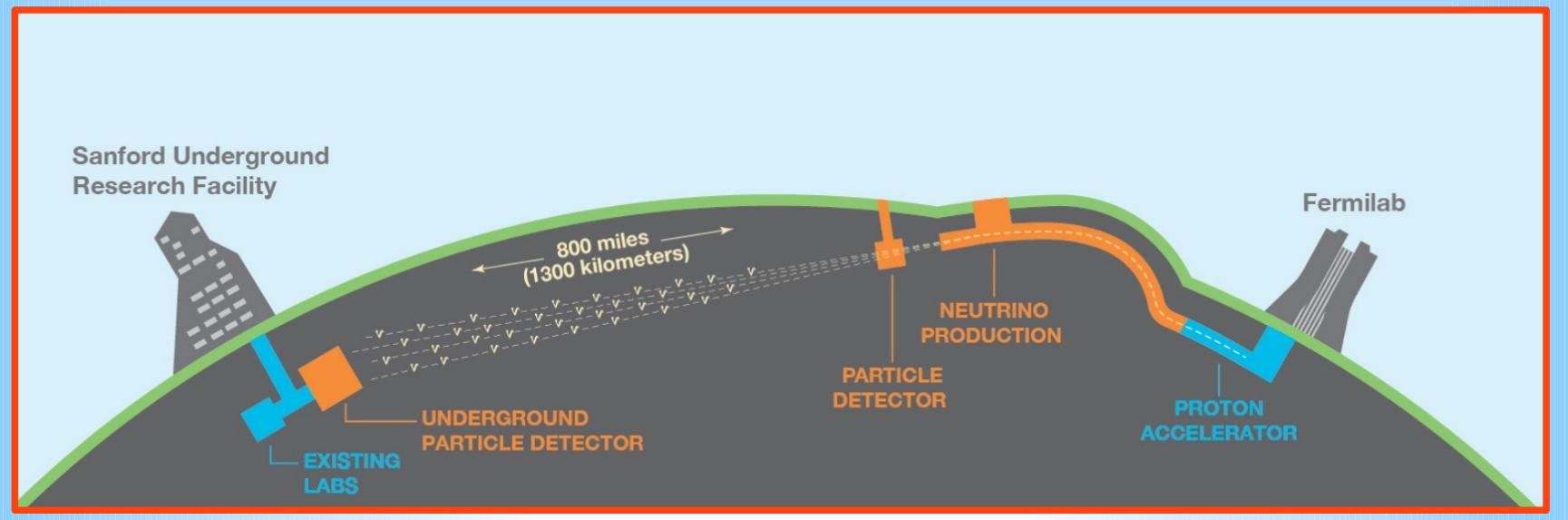
Manifold relevance:
ν properties; NSI; SNe dynamics;
"ν floor", …

RICOCHET at ILL
1% precision by ~ 2024

*Strong involvement of **LPSC***



DUNE: the ultimate ν experiment



Beam by 2026. Precision ν physics: oscillations; MH; CPV

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

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

The Strong CP Problem

is the neutron EDM’s fault

nEDM: major progress

- **New nEDM best limit:** $|d_n| < 1.8 \cdot 10^{-26}$ e·cm [PRL 2020]

  Unprecedented understanding of the magn. field & syst. effects

  Two independent analysis teams. One led by the **LPSC group**

- **New experiment, n2EDM**, being assembled (≤ 2022)

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

LPSC team:

- in charge of three major components
- performing R&D on Hg magnetometry
- recognized expertise in the TH understanding of syst. effects

New effects

can be searched for

through distortions to

accurately measured
and accurately calculated

rare processes

Runs 1 & 2 proved the LHCb design successful

A plenitude of interesting results on:

rare decays, CKM metrology, CPV, spectroscopy,
… even *K* decays

At LAPP

- unique expertise on calorimetry
  and photon reconstruction

- strong involvement in

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

LAPP / LHCb: 3 main physics streams

- Progress on the CKM angle γ (SM "standard candle") through analyses of $B \rightarrow D\,hh$ (h = π or K)

- $B_s \rightarrow J/\psi\ \eta(')$ to measure CPV induced by $B_s - \overline{B}_s$ mixing [tiny in the SM]

- A consistent **LAPTh – LAPP** collaboration on radiative modes [including students in co-supervision]

  Current focus: $B_s \rightarrow \mu\mu\ \gamma$

  - never measured
  - novel test of b $\rightarrow$ s transitions

Theory

LAPTh. A large spectrum of WP1 subjects – many of which interdisciplinary

- Higher-order computations, and tools
  - New method to perform NNLO + parton shower simul's
    ⇨ public code & plethora of generalizations ahead
  - New approach to 2-loop integrals w/ complex masses
    [with potential spin-offs to/from phys-math]

- Higgs and new physics
  - automatizing BSM at 1 loop through "SloopS"
    [CT calculation; gauge fixing; low-velocity limit]
    ⇨ countless potential applications in HEP, astro/cosmo

LAPTh. A large spectrum of WP1 subjects – many of which interdisciplinary

- The HEP – Dark Matter interface
  - MicrOMEGAs – arguably “the” particle-DM calculation tool
  - DM@NLO – including (large) QCD corr’s to $\overline{\chi}$ DM
- Flavour physics
  - Flavour violation within SUSY GUTs & leptonic obs.’s
  - *B*- and *K*-physics pheno, from models to observables [proven synergy with **LAPP / LHCb**]
- Low-energy frontiers
  - One example: probing Yukawas from atomic physics

HEP theory at LPSC

Two wide domains of activity, closely related to LPSC exp

- QCD: both high- and low-energy
  - Study of the nucleon & nucleus PDFs

    [unified approach through nCTEQ]
  - Lattice QCD: novel formalism for LQCD renormalization; simulations w/ 4 dynamical quarks

HEP theory at LPSC

- Beyond-SM: from models, to collider pheno, to astro-cosmo
  - SUSY at colliders, effective approaches & specific models

    Consistent effort in the establishment of data-interpretation strategies
  - generic NP:

    “simplified-model” approach through SModelS

    calculation of RGE evolution through Pyr@te
  - Dark Matter

    Diverse expertise, from DM at colliders (w/ EFTs or models) to quantitative predictions for small-scale DM structures
  - Axions: models, LHC and low-E signatures, cosmo aspects

Conclusions

- WP1 is central to ENIGMASS' mission
- Our equipes span a wide, ambitious, well-recognized, range of complementary activities
- Several synergies between labs

  … yet we're still far from the upper bound