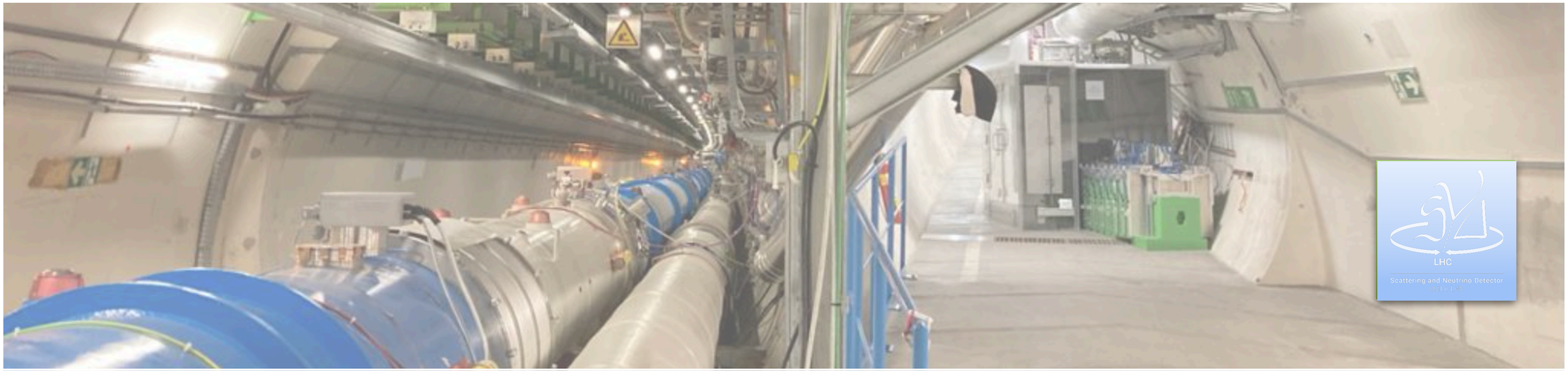
Observation of Collider Neutrinos with SND@LHC



The LIP SHiP/SND@LHC Group: A.Blanco, P.Bordalo, T.Camporesi, P.Fonte, N.Leonardo, L.Lopes, S.Ramos, J.Saraiva, G.Soares, C.Vilela

Nuno Leonardo

LIP&IST, nuno@cern.ch

LIP Seminar, April 6th, 2023, Lisboa

LHC Scattering and Neutrino Detector at the LHC

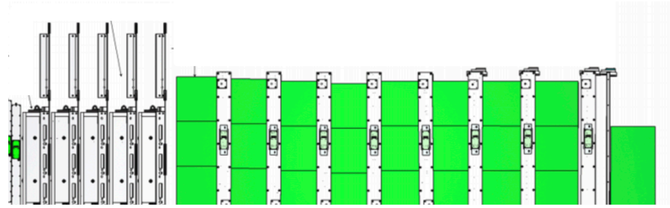
Fundação para a Ciência e a Tecnologia

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Observation of collider neutrinos with the **S**cattering and **N**eutrino **D**etector **— at the LHC**

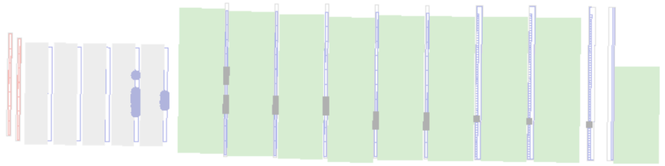
Part I

- Intro to SND@LHC and LIP group



Part II

- First results and ν_μ observation



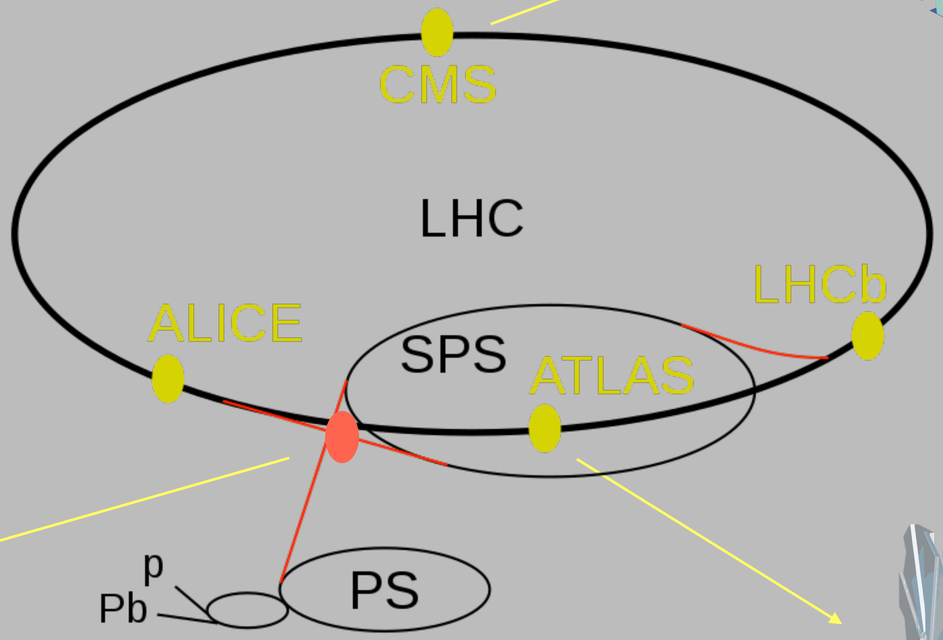
next by C.Vilela

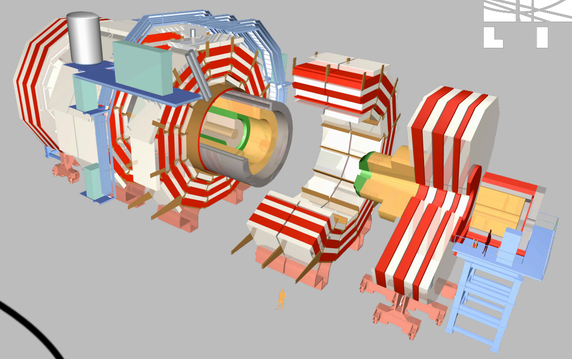
a new LHC experiment (9th)

with LIP's involvement (3rd)

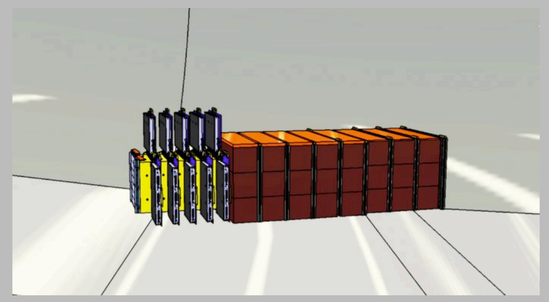
Goal: fully exploit and **extend** the (HL-)**LHC** physics reach.

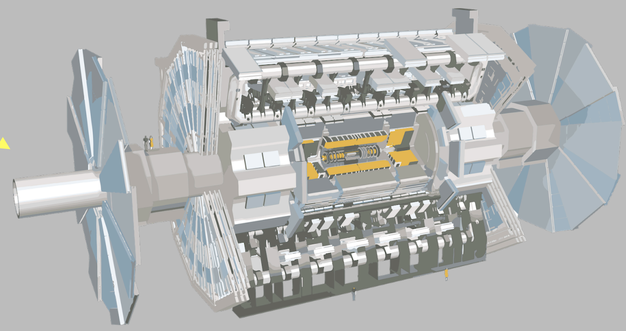
- measure **neutrinos,** and
- search for **new particles**





SND@LHC





Neutrinos at the LHC?

- studies of potential for observing neutrinos at LHC date back to the 1990's
  - **high neutrino energies** (⇒ large νN cross-sections)
  - **high luminosity ⇒ large flux** in the forward region
- ➥ a small-scale experiment *can observe* neutrinos!

ELSEVIER

Nuclear Physics B

Volume 405, Issue 1, 13 September 1993, Pages 80-108

1993

Neutrino fluxes at future hadron colliders

A. De Rújula [a], E. Fernández [b], J.J. Gómez-Cadenas [a]

/.../

We find that in a relatively small target located directly downstream of the interaction point, at about 100 metres distance, a few thousand ν_τ interactions per year, at the current design luminosity of the LHC, could be observed. The number of ν_e and ν_μ interactions will be a factor of 10 higher. **This demonstrates the possibility of a high energy neutrino physics program at the LHC** (and possibly also at the SSC) that would include a direct observation of the as yet unseen tau neutrino.

OPEN ACCESS

IOP Publishing

Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **46** (2019) 115008 (19pp)

https://doi.org/10.1088/1361-6471/ab3f7c

Physics potential of an experiment using LHC neutrinos

2019

OPEN ACCESS

IOP Publishing

Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **47** (2020) 125004 (18pp)

https://doi.org/10.1088/1361-6471/aba7ad

Further studies on the physics potential of an experiment using LHC neutrinos

2020

Available on CMS information server

CMS NOTE -2018/001

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

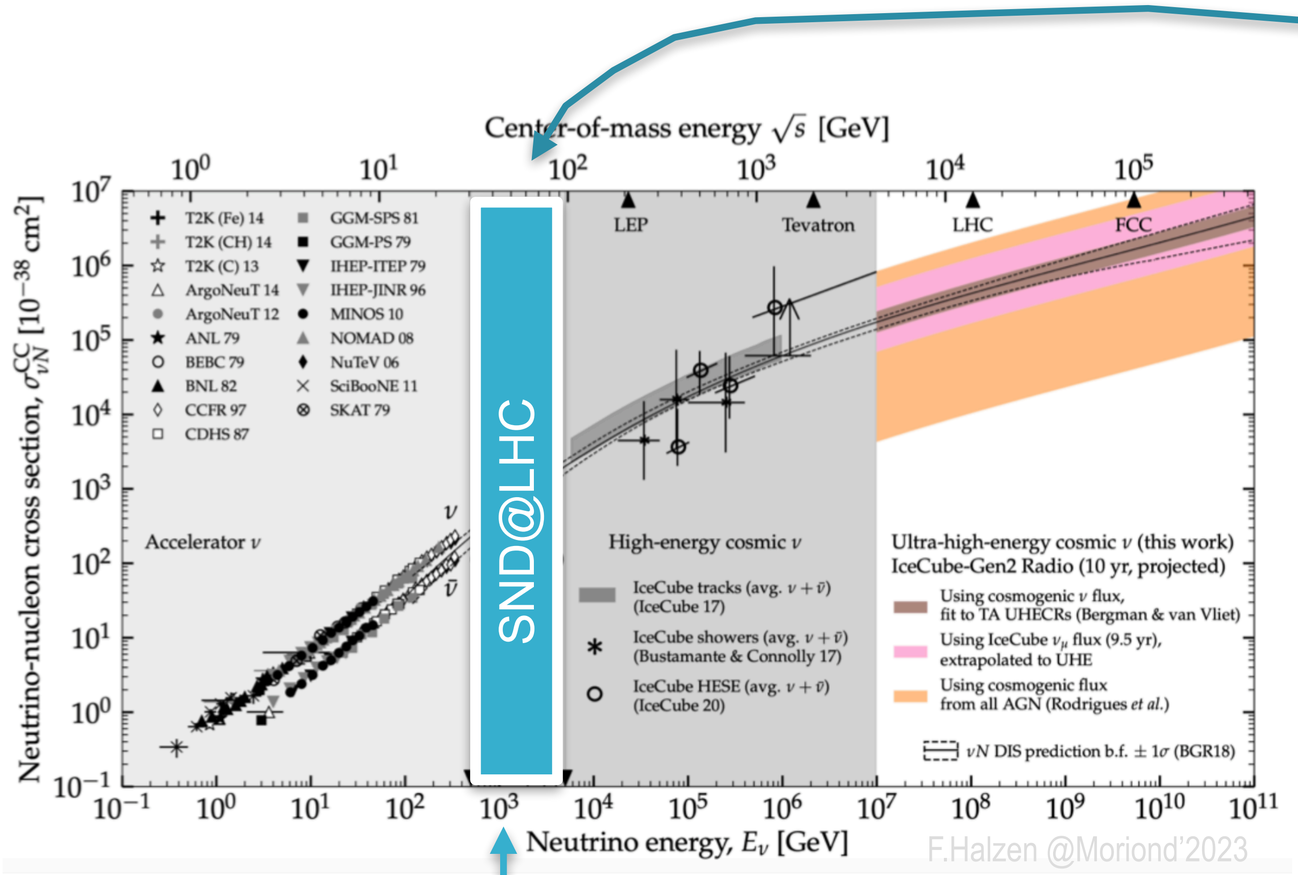
02 March 2018 (v4, 19 March 2018)

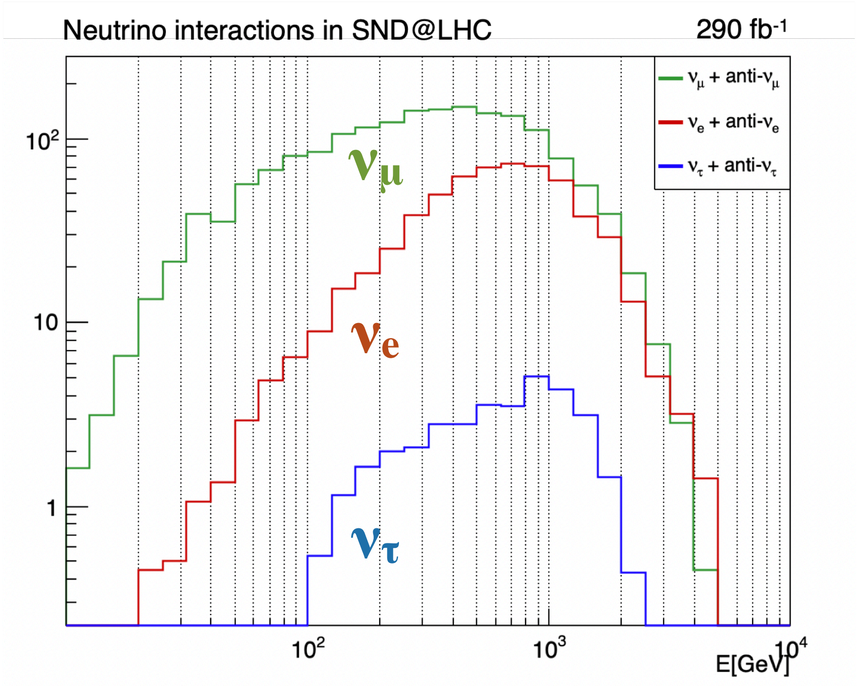
CMS-XSEN: LHC Neutrinos at CMS. Experiment Feasibility Study

S. Buontempo[a], G.M. Dallavalle[b], G. De Lellis[c], D. Lazic[d], F.L. Navarria[e]

2018

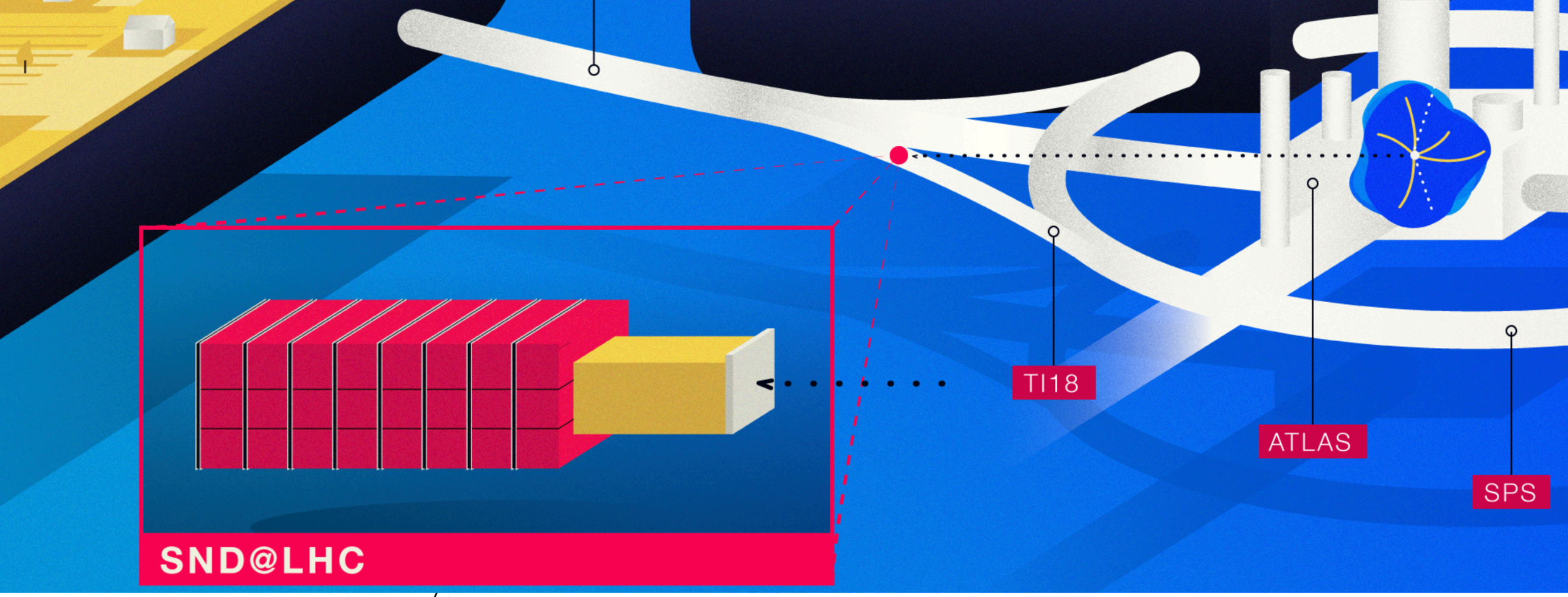
Probing the highest-yet energy lab-made neutrinos

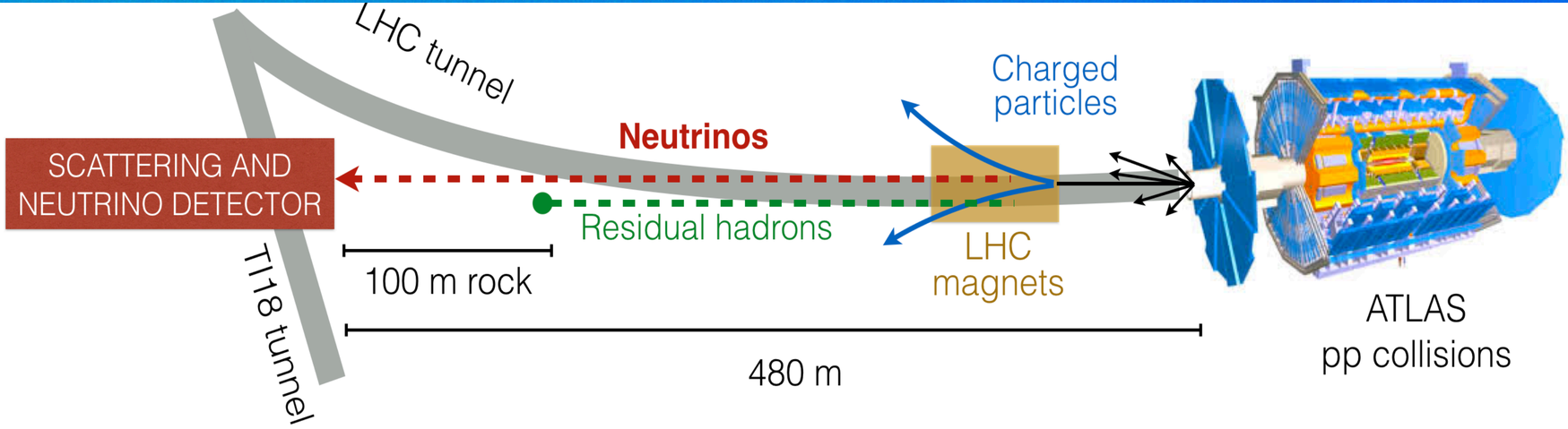




un-probed energy region
300 GeV ~ TeV

all three neutrinos
ν_e, ν_μ, ν_τ


TI18
ATLAS
SPS
SND@LHC


LHC tunnel
Neutrinos
Charged particles
SCATTERING AND NEUTRINO DETECTOR
Residual hadrons
LHC magnets
100 m rock
TI18 tunnel
480 m
ATLAS
pp collisions

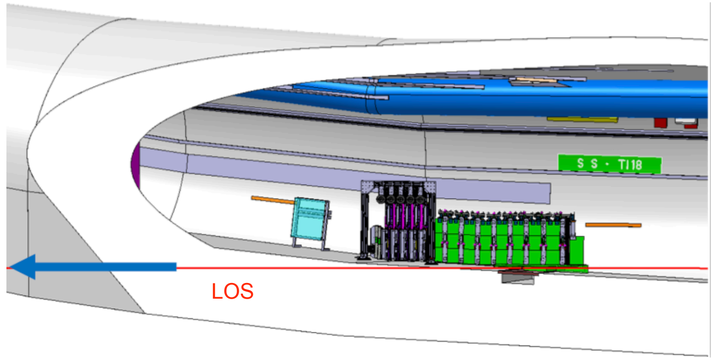
Location

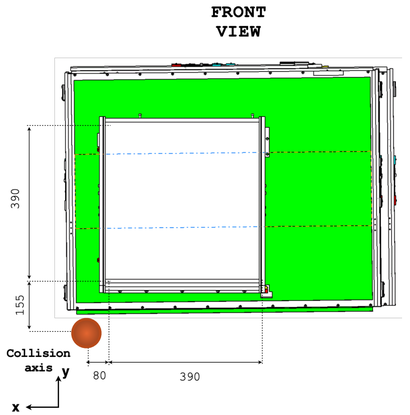
Strategy:

- An existing site (avoid major civil engineering)
- Enough material to shield against collision debris
- Use LHC magnets to deflect charged particles

TI18 location:

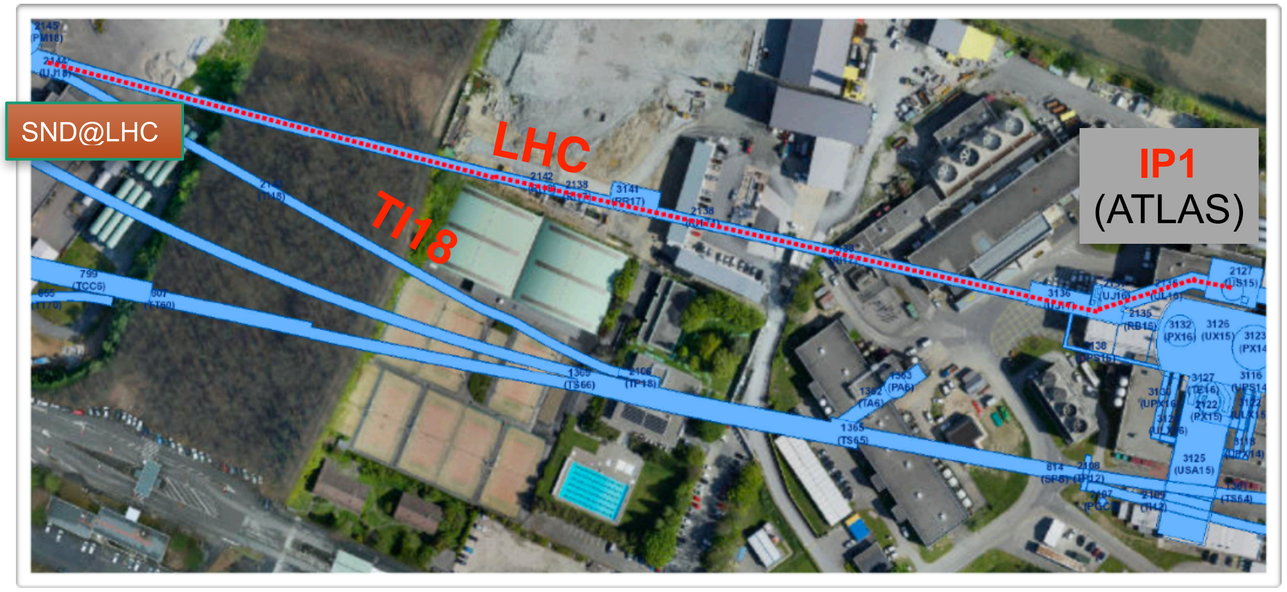
- Old LEP positron transfer line tunnel
- 480 m away from IP1
- 100 m of rock between detector and IP1

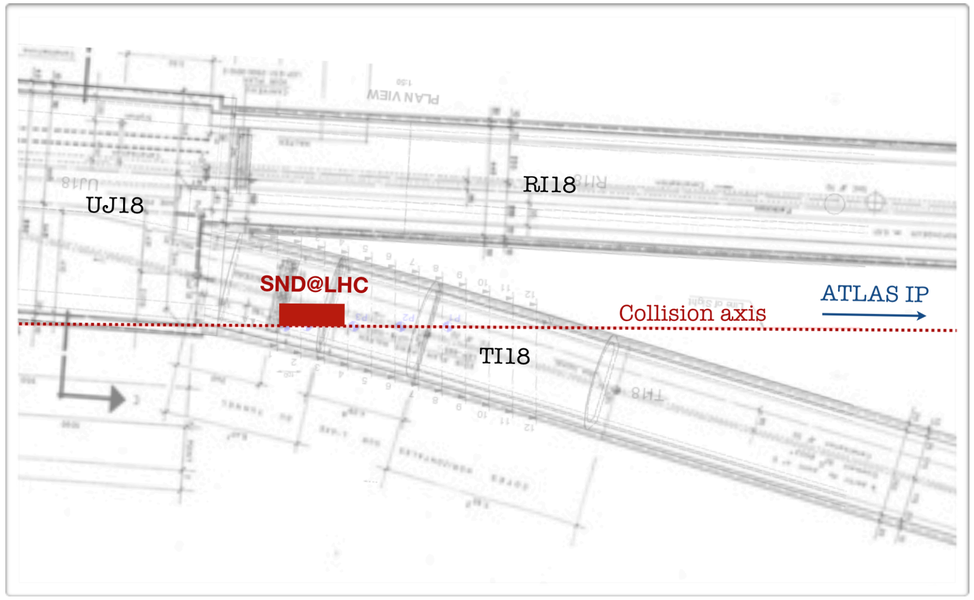




Off-axis position:

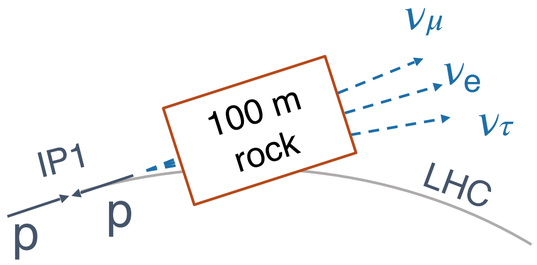
- Rapidity range: $7.2 < \eta < 8.4$
- Enhances ν_e and ν_τ flux from charm decays
- Complementarity with FASERν, located on-axis in symmetric tunnel (TI12)

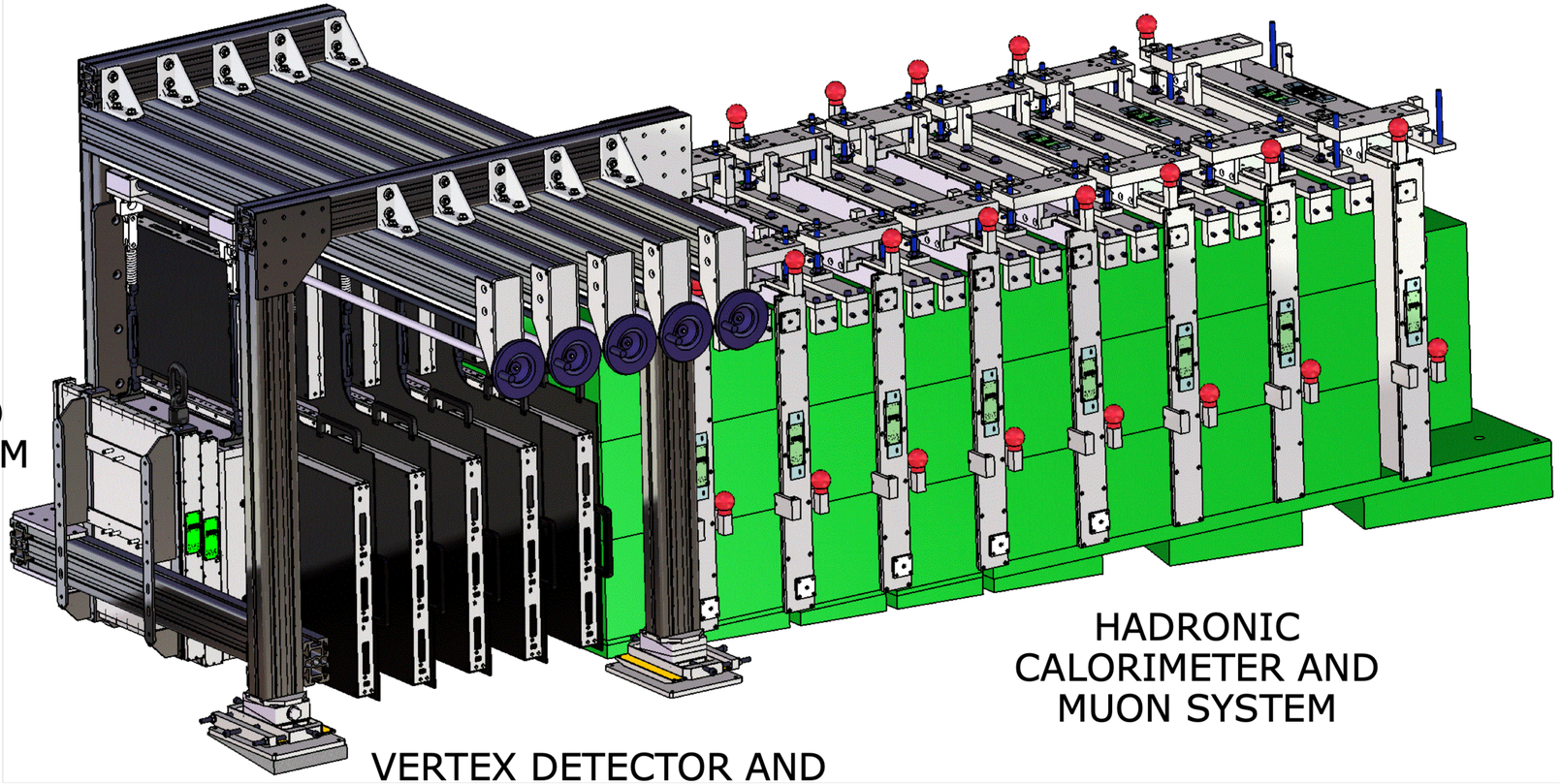


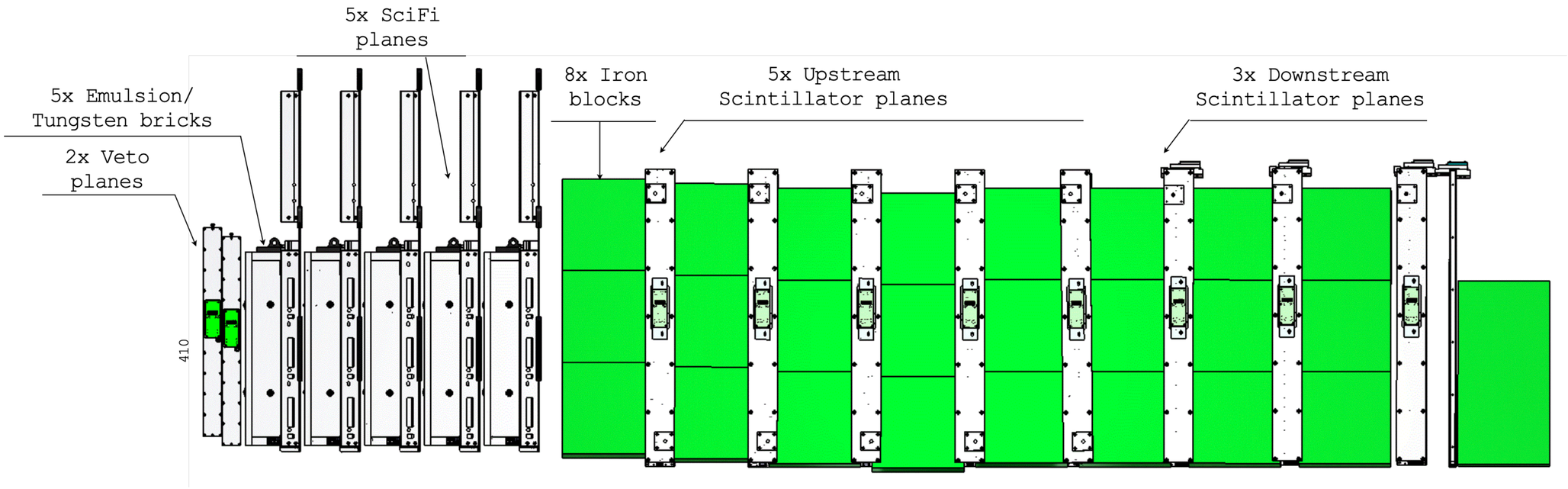


The SND@LHC concept

- Hybrid detector design
- Optimised for the identification of three neutrino flavours and feebly interacting particles







Veto system

Tags incoming charged particles

Scintillator planes

Target

Material: **tungsten**
Mass: 830 Kg
Surface area: 390x390mm^2

Vertex detector

Emulsion cloud chamber (EEC) using tungsten as passive material

Tracker and ECAL

Scintillator Fibre tracker (**SciFi**). Time stamp and electromagnetic shower energy measurement

ECAL ~ 40 X_0

Muon system and HCAL

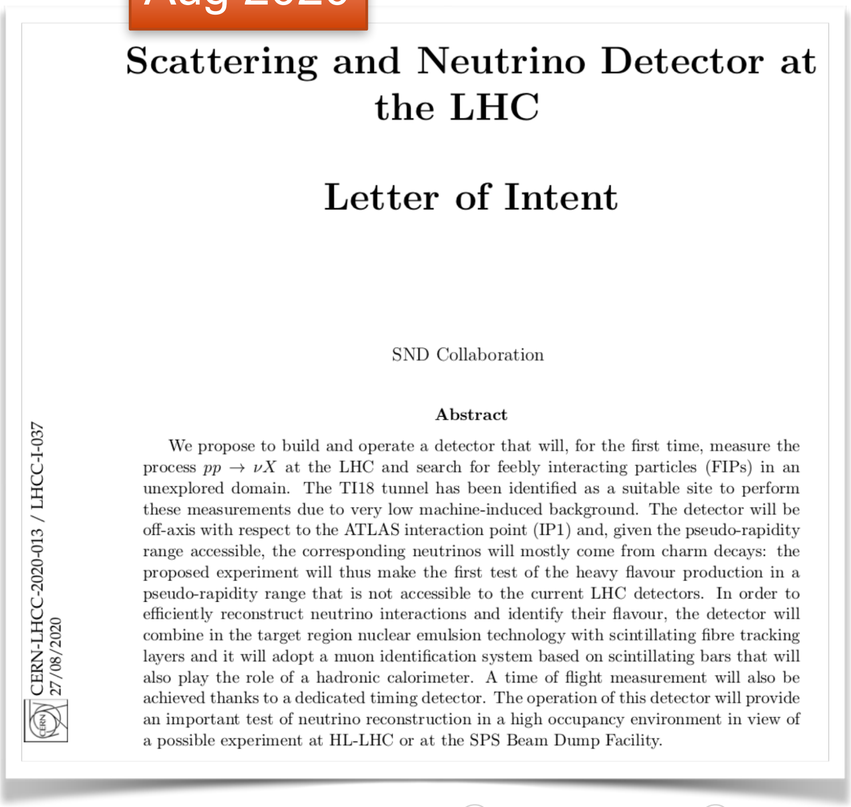
Iron walls interleaved with **scintillator** planes. Downstream tags muons. Upstream doubles as HCAL.

HCAL ~10 λ

Timeline (tight!) — from proposal to construction

- SND@LHC approved and constructed in 2021
- **LIP** was proponent and is **founding member**

Aug 2020



CERN-LHCC-2020-013 / LHCC-I-037
27/08/2020

Scattering and Neutrino Detector at the LHC

Letter of Intent

SND Collaboration

Abstract

We propose to build and operate a detector that will, for the first time, measure the process $pp \to \nu X$ at the LHC and search for feebly interacting particles (FIPs) in an unexplored domain. The TI18 tunnel has been identified as a suitable site to perform these measurements due to very low machine-induced background. The detector will be off-axis with respect to the ATLAS interaction point (IP1) and, given the pseudo-rapidity range accessible, the corresponding neutrinos will mostly come from charm decays: the proposed experiment will thus make the first test of the heavy flavour production in a pseudo-rapidity range that is not accessible to the current LHC detectors. In order to efficiently reconstruct neutrino interactions and identify their flavour, the detector will combine in the target region nuclear emulsion technology with scintillating fibre tracking layers and it will adopt a muon identification system based on scintillating bars that will also play the role of a hadronic calorimeter. A time of flight measurement will also be achieved thanks to a dedicated timing detector. The operation of this detector will provide an important test of neutrino reconstruction in a high occupancy environment in view of a possible experiment at HL-LHC or at the SPS Beam Dump Facility.

Feb 2021

CERN-LHCC-2021-003 / LHCC-P-016
24/02/2021

TECHNICAL PROPOSAL

SND@LHC

Scattering and Neutrino Detector at the LHC

SND@LHC Collaboration

Abstract

SND@LHC is a proposed, compact and stand-alone experiment to perform measurements with neutrinos produced at the LHC in an hitherto unexplored pseudo-rapidity region of $7.2 < \eta < 8.6$, complementary to all the other experiments at the LHC. The experiment is to be located 480 m downstream of IP1 in the unused TI18 tunnel. The first phase aims at operating the detector throughout LHC Run 3 to collect a total integrated luminosity of 150 fb^{-1}.

Following the review of the Letter of Intent [1], submitted in August 2020, LHCC recommended the collaboration to proceed with the preparation of a Technical Proposal (TP), reported herein.

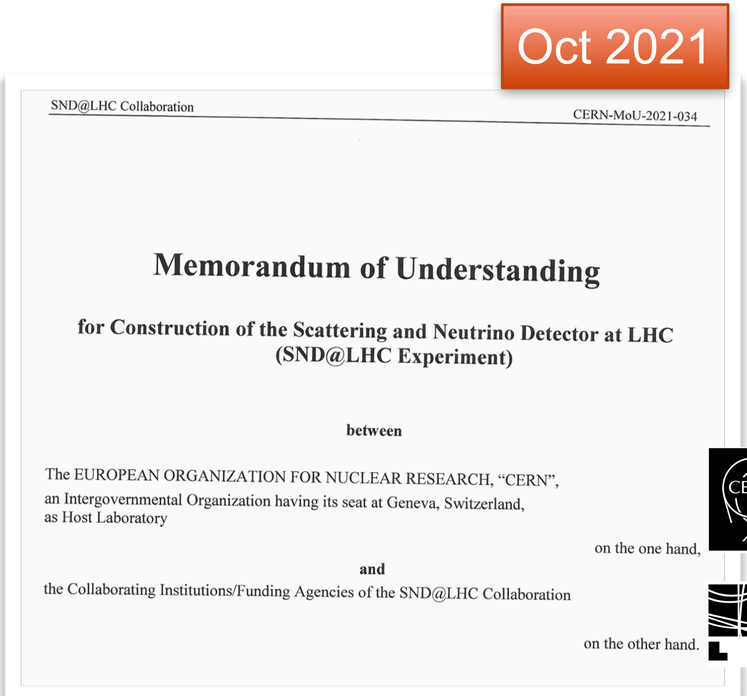
Apr 2021

CERN approves new LHC experiment

SND@LHC, or Scattering and Neutrino Detector at the LHC, will be the facility's ninth experiment

27 APRIL, 2021 | By Ana Lopes

Oct 2021



SND@LHC Collaboration CERN-MoU-2021-034

Memorandum of Understanding

for Construction of the Scattering and Neutrino Detector at LHC (SND@LHC Experiment)

between

The EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH, "CERN", an Intergovernmental Organization having its seat at Geneva, Switzerland, as Host Laboratory

on the one hand,

and

the Collaborating Institutions/Funding Agencies of the SND@LHC Collaboration

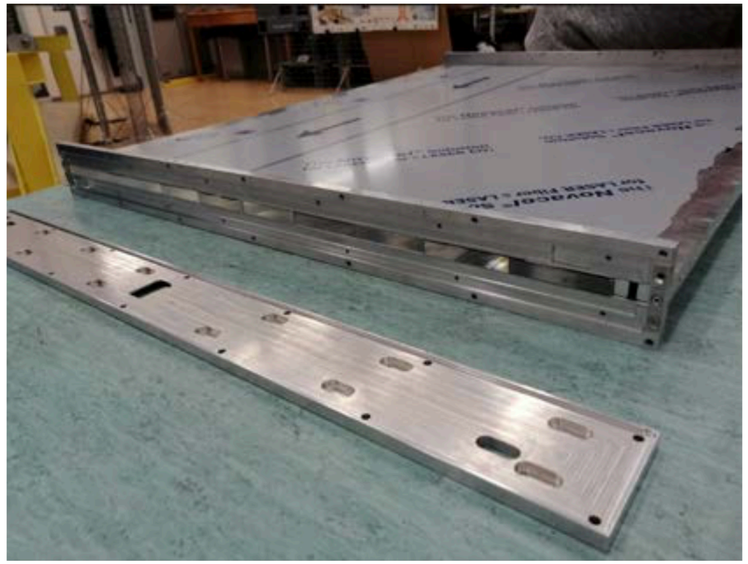
on the other hand.

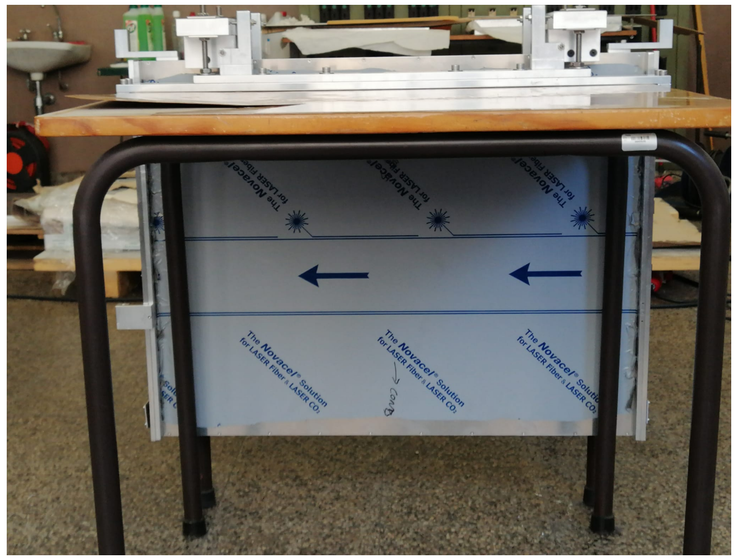
Construction: Muon System

- LIP involved in construction and commissioning of the Muon System / HCAL of the experiment
- Design optimisation and production of mechanical components of the detector and the LIP Workshop
- Detector assembly, testing, commissioning at CERN

production @Coimbra

assembly @CERN



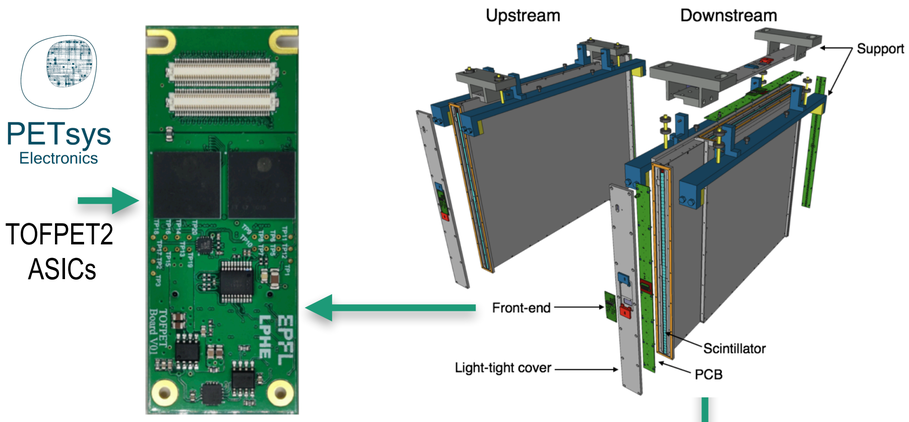


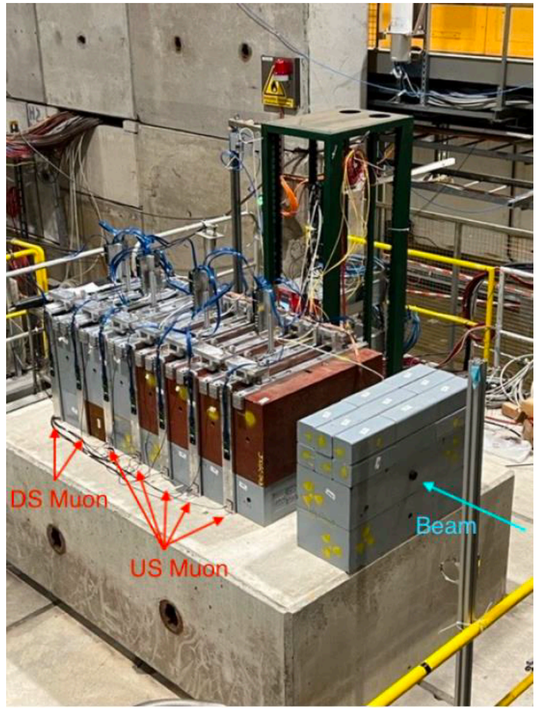
Commissioning & calibration

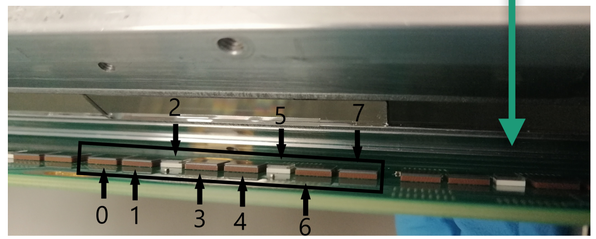
- assembled detector was first put to test in a **test beam**
  - two campaigns (Sep + Oct 2021), pion beams, 4≠energies
  - LIP involvement in assembly, data taking and calibration analysis

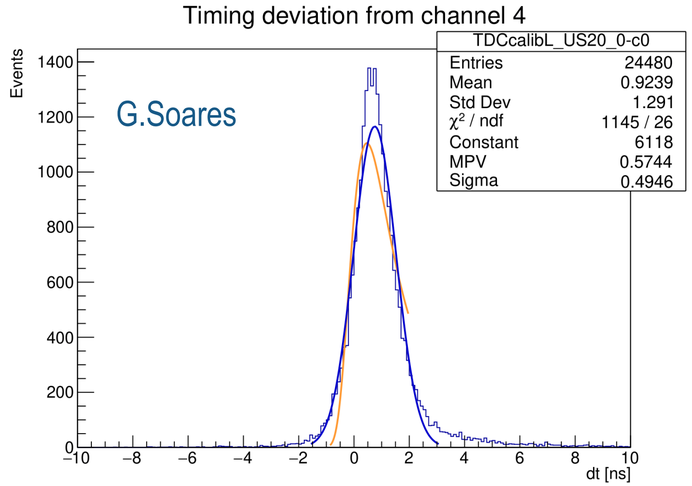
➥ a third campaign upcoming in May 2023

  - detector mechanics produced by LIP, being assembled at CERN







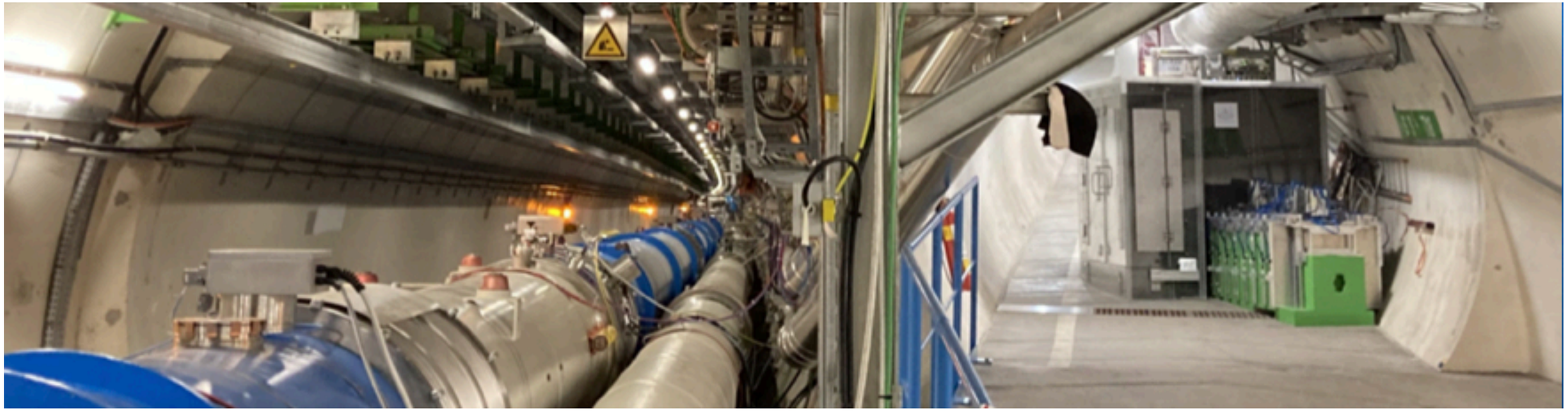


Installation in TI18

Sep 2021

Dec 2021

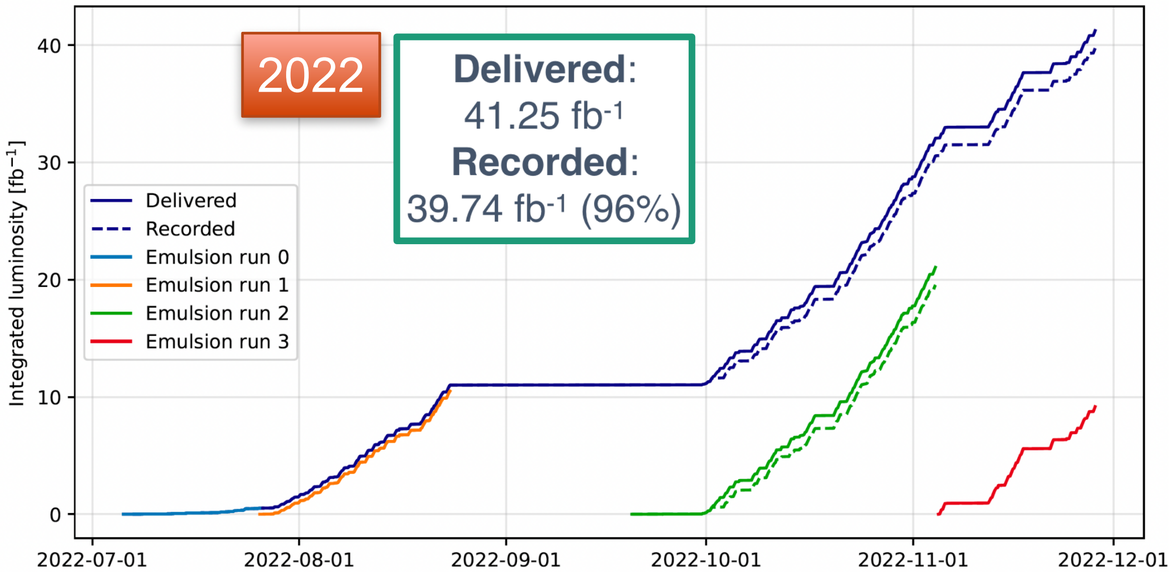
Mar 2022



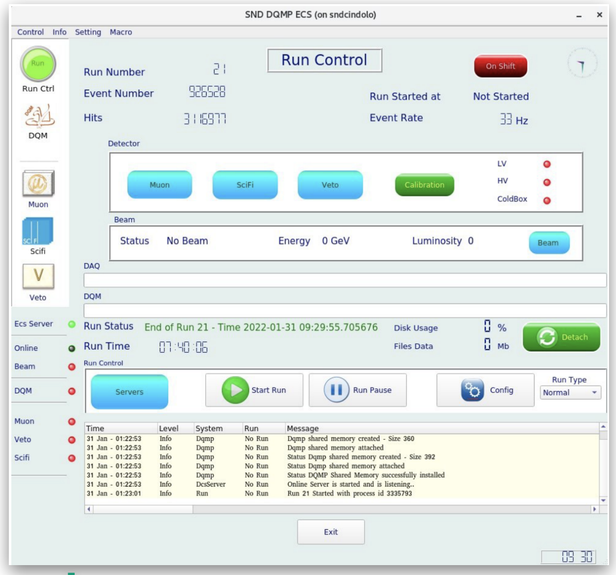
Data taking

June 2023

- experiment was ready to take data from the start of **LHC Run3**
- efficient online system, allow normal remote detector operation
- LIP actively involved in operations, set up CERN control room



(@CMS centre)



➥ Run3 data taking resuming soon!

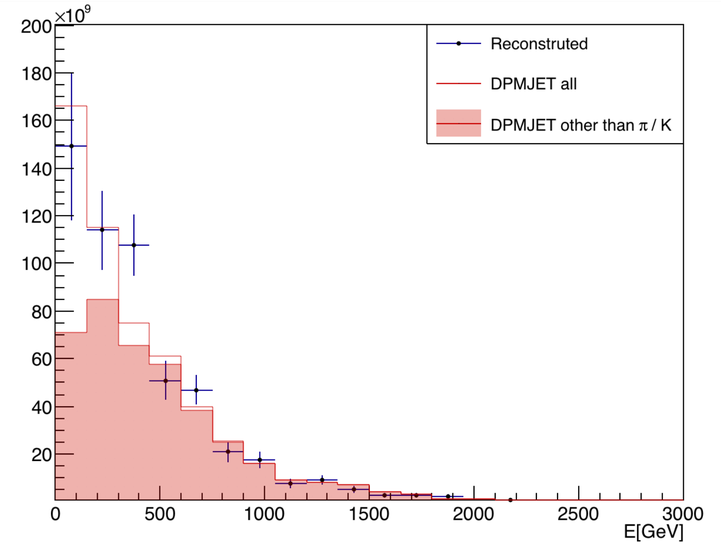
Physics case I Neutrinos from heavy flavour

pp→νX cross-section

- measurement of σ(pp→νX)
- in un-probed high energy region
- and o.w. inaccessible rapidity range

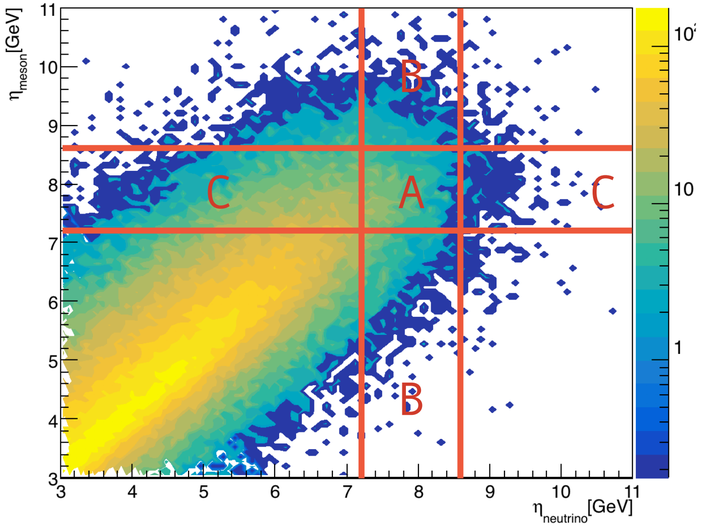
Charm hadron production

- expect 90% of ν_e+ν_e to originate from charm decays
- forward charm production constrains gluon PDFs at low x(10^{-6})
- impact on future HE hadron colliders and neutrino astrophysics



Reconstructed spectrum of ν_e+anti-ν_e flux in SND@LHC acceptance

Pseudo-rapidity correlation between electron neutrino and parent charmed hadron



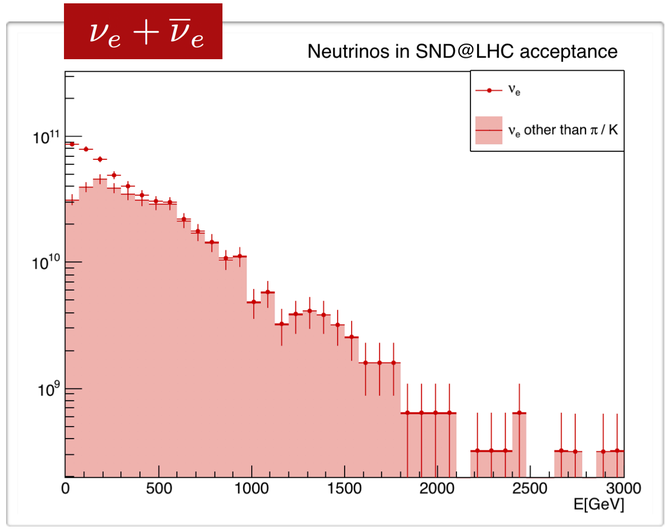
Physics case I Lepton Universality & FIPs

test LFU

search for FIPs

- identification of three neutrino flavors
- offers unique possibility to test LFU in the neutrino sector for first time

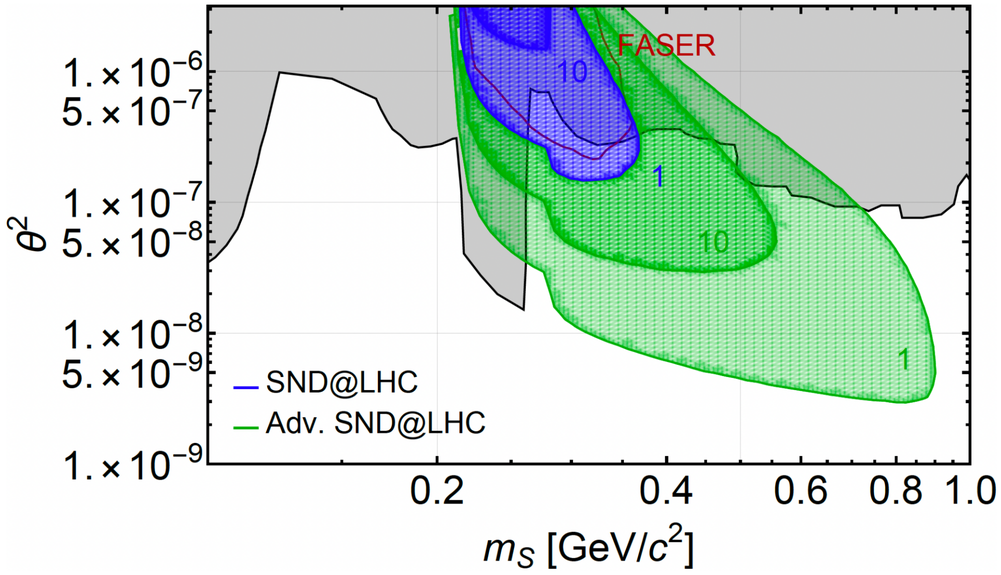
$$R_{13} = \frac{N_{\nu_e+\bar{\nu}_e}}{N_{\nu_\tau+\bar{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i} \tilde{Br}(c_i \to \nu_e)}{\tilde{f}_{D_s} \tilde{Br}(D_s \to \nu_\tau)},$$



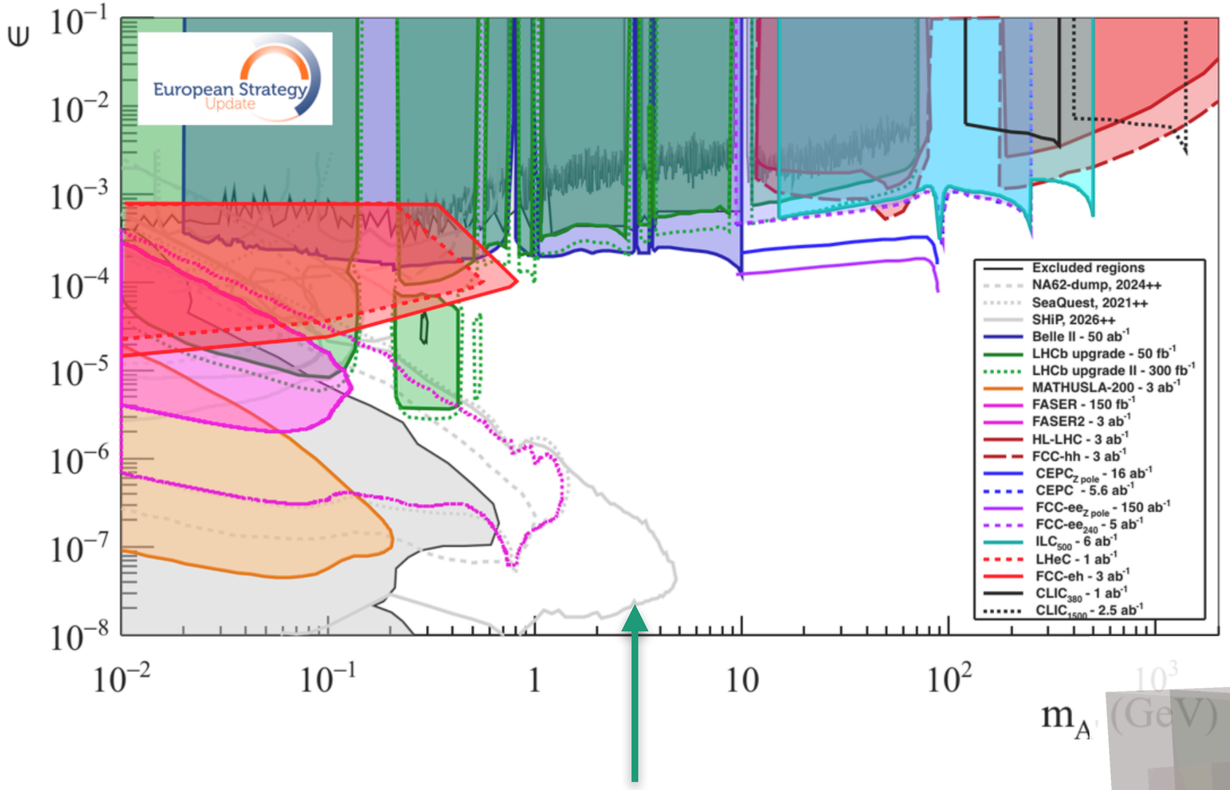
ν_e spectrum in SND@LHC acceptance

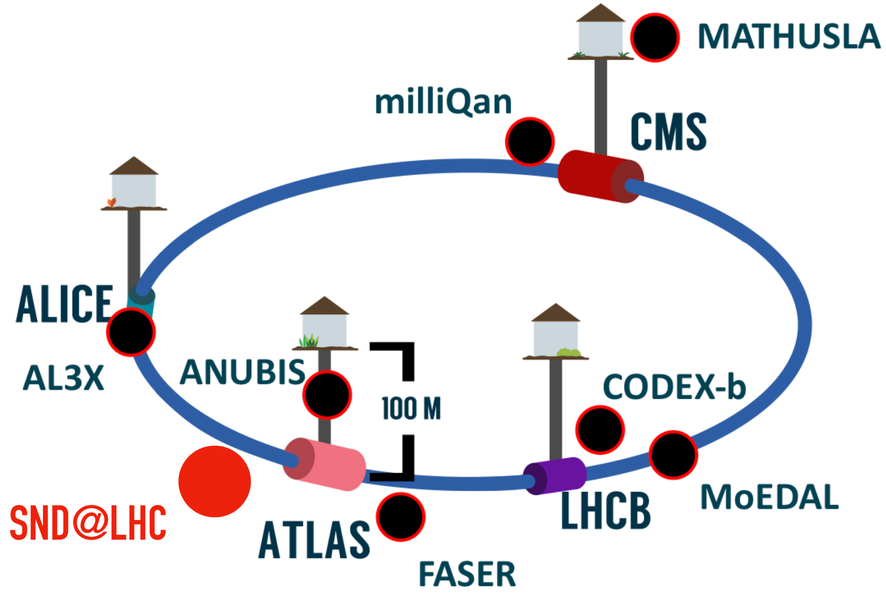
mass-coupling phase space of dark scalar

- can explore large variety of BSM scenarios, Hidden Sector
- via scattering, eg scalar coupled via leptophobic portal
- via decay, e.g. HNLs, DPs decaying to pairs of tracks

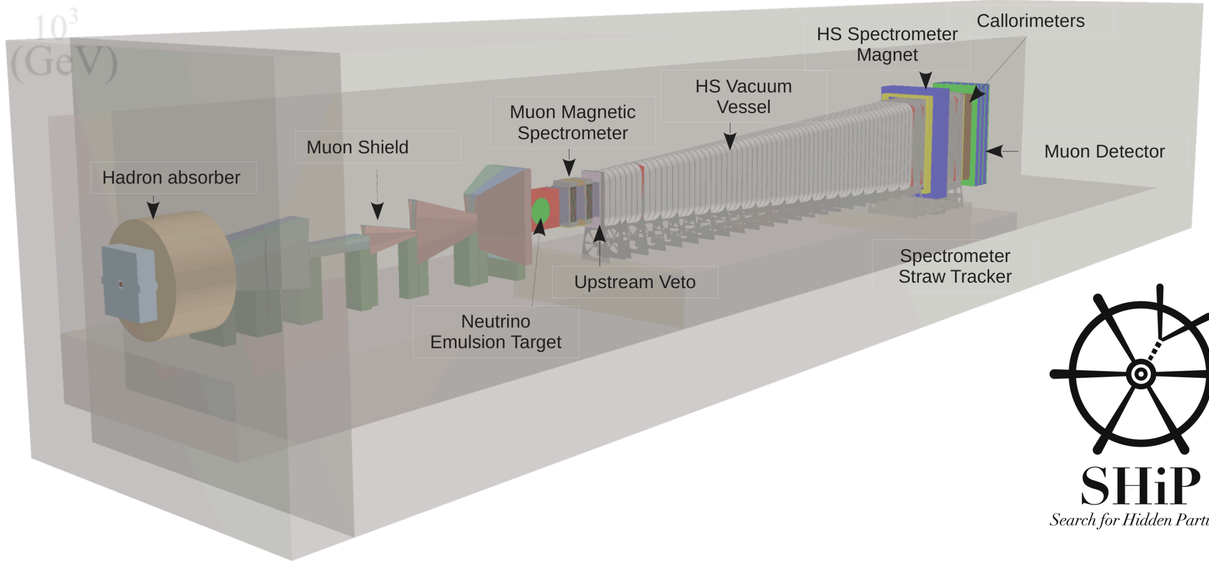


Feebly Interacting Particles: at the LHC and beyond





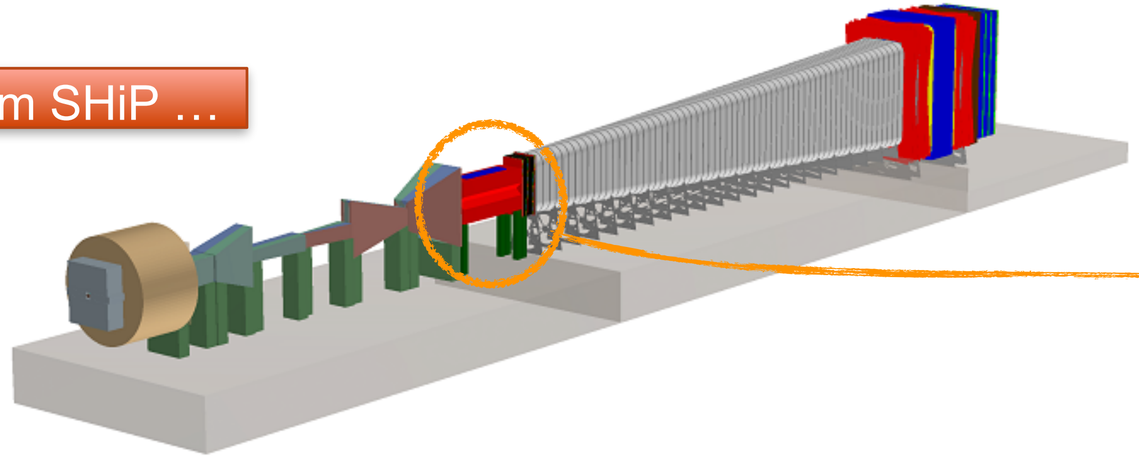
- **SHiP is a next-generation experiment** for **FIP** searches and ν_τ measurements at **SPS**
- general-purpose intensity-frontier experiment facilitating comprehensive investigation of the **hidden sector** of particle physics in GeV scale

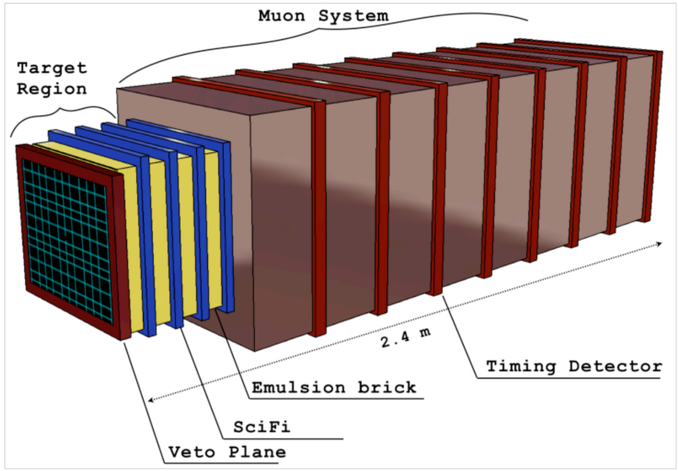


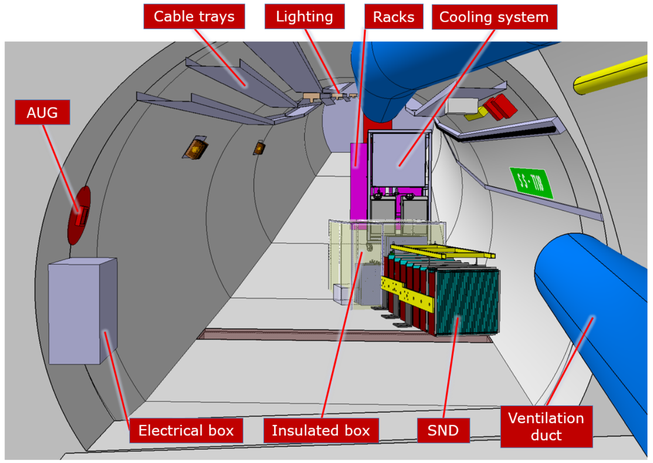
SHiP
Search for Hidden Particles

SND@LHC stems from SND@SHiP

from SHiP …



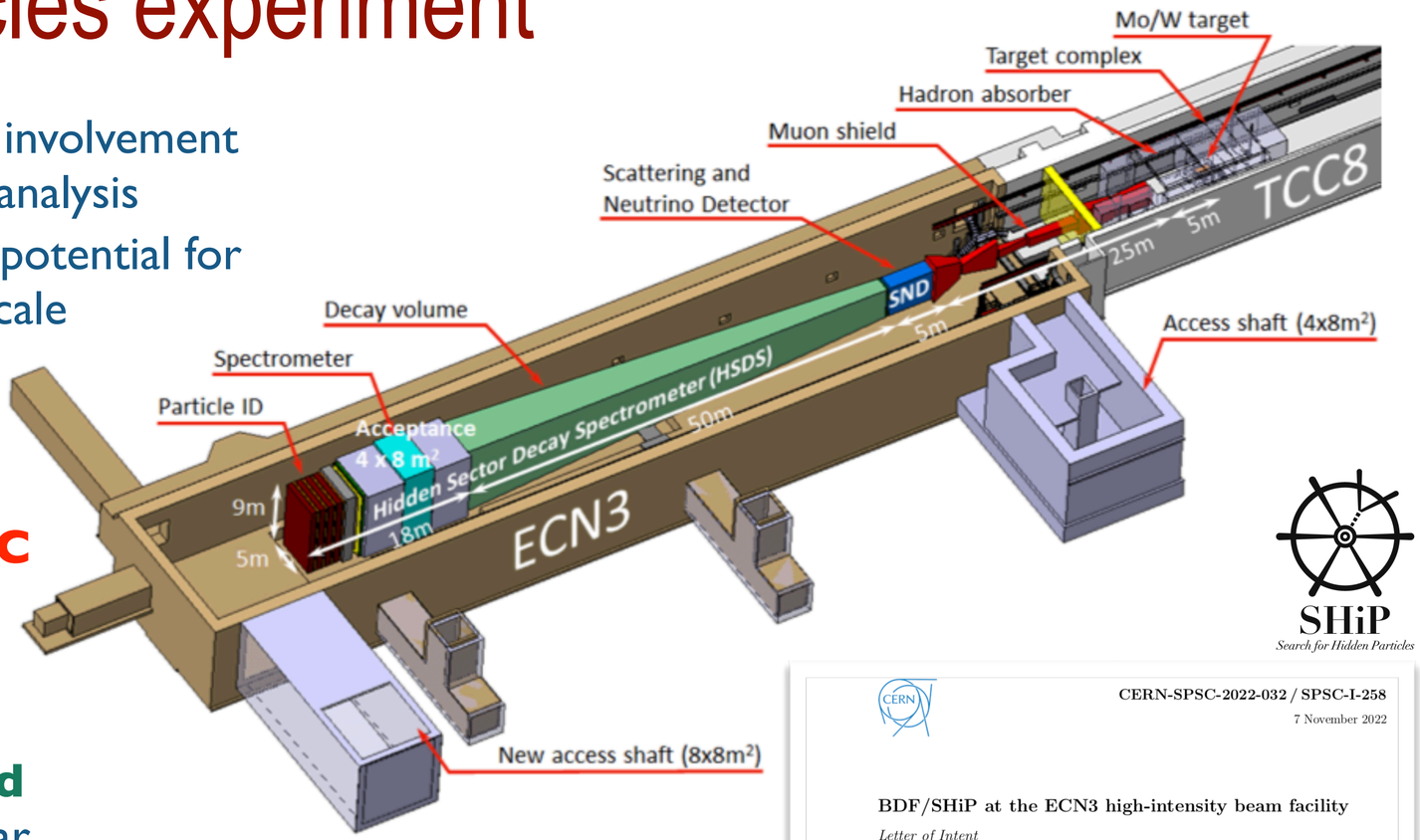




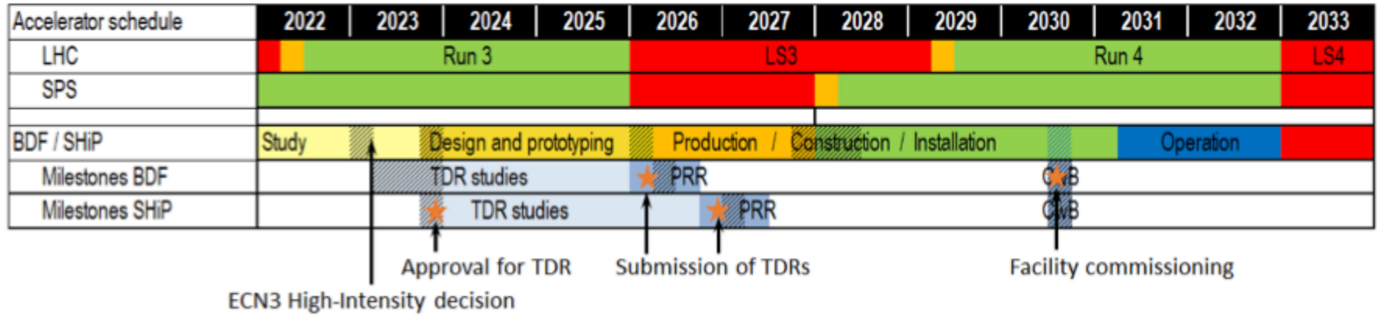
… to the LHC

Search for Hidden Particles experiment

- **LIP is a proponent of SHiP**, with direct involvement in the Timing + Veto detectors and in physics analysis
- it shows **leading sensitivity** and discover potential for broad hidden sector scenarios in GeV mass scale
- **Detector re-optimised for ECN3** existing location at SPS at CERN
- Reducing cost, maintaining physics potential
- **Favourable recommendation by SPSC** for the intensity upgrade at ECN3 (March 2023)
- SHiP/BDF along with SHADOWS+HiKE submitted proposals for installation at ECN3
- **Currently proposals being scrutinised** and iterated towards a decision early next year



SHiP
Search for Hidden Particles



CERN-SPSC-2022-032 / SPSC-I-258
7 November 2022

BDF/SHiP at the ECN3 high-intensity beam facility

Letter of Intent

[1]BDF Working Group, SHiP Collaboration

Abstract

The BDF/SHiP collaboration has proposed a general-purpose intensity-frontier experimental facility operating in beam-dump mode at the CERN SPS accelerator to search for feebly interacting GeV-scale particles and to perform measurements in neutrino physics. BDF/SHiP complements the world-wide program of New Physics searches by exploring a large region of parameter space which cannot be addressed by other experiments, and which reaches several orders of magnitude below existing bounds. The SHiP detector is sensitive both to decay and scattering signatures of models with heavy neutral leptons, dark photons, dark scalars, axion-like particles, light dark matter and other feebly interacting particles. In neutrino physics, BDF/SHiP can perform unprecedented measurements with tau neutrinos and neutrino-induced charm production. Following the Technical Proposal submitted in 2015, the subsequent three-year Comprehensive Design Study (CDS), and the recent study of BDF/SHiP in existing beam facilities around the SPS, this paper restates the motivation and reports on the implementation and physics performance of BDF/SHiP in the SPS ECN3 high-intensity beam facility.

Keywords: Beam Dump Facility, BDF, SHiP, SPS, ECN3

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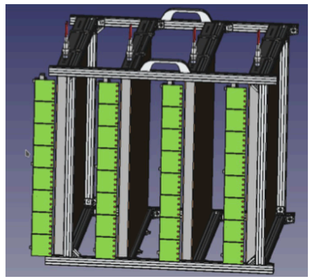
Student involvement

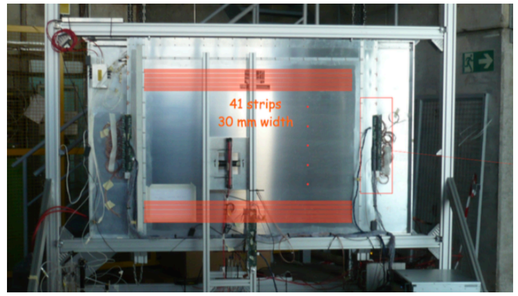
- **students actively involved**
  - PhD: 1 ongoing (SND@LHC)
  - MSc: 1 concluded (SHiP), 1 starting (SND@LHC)
  - Internships: 4 (SHiP), 1 (SND@LHC)
  - PICs: 1 concluded, 2 ongoing (SND@LHC)
- several **opportunities** for student projects/theses
  - in various fronts and levels: **detector** development and commissioning, and **physics analysis** of fresh LHC ν data

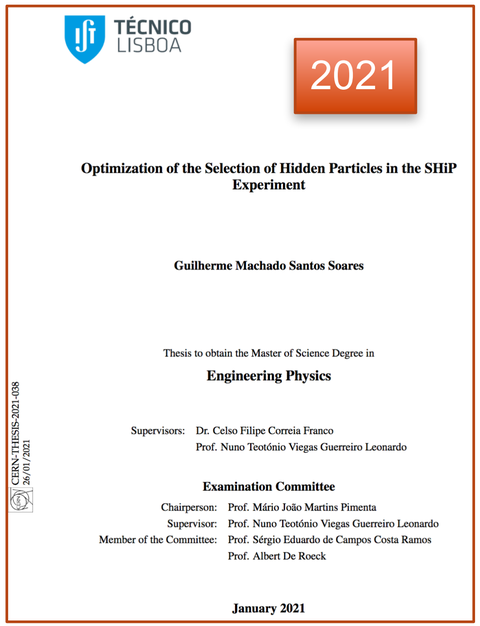


μ telescope SND@LHC

timing detector for SHiP@SPS

JINST **15** (2020) C10017





TÉCNICO LISBOA

2021

Optimization of the Selection of Hidden Particles in the SHiP Experiment

Guilherme Machado Santos Soares

Thesis to obtain the Master of Science Degree in

Engineering Physics

Supervisors: Dr. Celso Filipe Correia Franco
Prof. Nuno Teotónio Viegas Guerreiro Leonardo

Examination Committee

Chairperson: Prof. Mário João Martins Pimenta
Supervisor: Prof. Nuno Teotónio Viegas Guerreiro Leonardo
Member of the Committee: Prof. Sérgio Eduardo de Campos Costa Ramos
Prof. Albert De Roeck

January 2021

CERN-THESIS-2021-038 26/01/2021

LIP-STUDENTS-20-17

Search for dark matter and supersymmetry using machine learning at SHiP

Francisco Safara[1,a] and Raúl Santos[2,b]

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[2] *Instituto Superior Técnico, Lisboa, Portugal*

Project supervisors: N. Leonardo, G. Soares

2020

LIP-STUDENTS-21-06

Distinguishing Hidden Sector Particles with Machine Learning at SHiP

Henrique Santos[1,a] and André Branco[1,b]

[1] *Instituto Superior Técnico, Lisboa, Portugal*

Project supervisors: N. Leonardo, G. Soares

2021

LIP-STUDENTS-22-30

Distinguishing decay processes for Heavy Neutral Leptons with Machine Learning at SHIP

Rui Santos[1,a]

[1] *Faculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal*

Project supervisor: N. Leonardo, G. Soares

2022

LIP-STUDENTS-22-03

First sudies with SND@LHC

Bruno Semião[1,a] and Pedro Figueiredo[1,b]

[1] *Instituto Superior Técnico, Lisboa, Portugal*

Project supervisors: Nuno Leonardo and Guilherme Soares

2022

LIP-STUDENTS-23-00

Caracterização de eletrónica de aquisição de dados em SND@LHC

Beatriz Candeias[1,a]

[1] *Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal*

Project supervisors: N. Leonardo, G. Soares

2023

SND@LHC = Collaboration

- the new collaboration brings together colleagues from diverse backgrounds
  - other LHC experiments, fixed-target experiments, neutrino experiments
  - SHiP (neutrino detector prototype), OPERA (emulsion expertise), FASER (share emulsion facilities), DUNE (neutrino simulations), LHCb (ScFi tracker), ATLAS (luminosity measurements), CMS (shared assembly space, control room), CMS/ALICE (upgrade tracker), …
  - a smaller-size collaboration in the LHC environment where to contribute and learn about detector development and operations and physics analysis
- similarly at LIP
  - very close collaboration between Lisbon and Coimbra nodes
  - already existing synergies: SHiP, RPC, Workshop, TagusLIP/PETsys, …
  - backgrounds: detector, collider, fixed target, neutrino, FIPs, machine learning, …
  - facilitates framework where LIP members from different groups and infrastructures can collaborate, many opportunities in framework of ongoing Run3 and upcoming Phase2 upgrades

CERN Accelerating science

New LHC experiments enter uncharted territory

The first observation of collider neutrinos at the LHC paves the way for exploring new physics scenarios

22 MARCH, 2023 | By Kristiane Bernhard-Novotny & Chetna Krishna

Primeira observação de neutrinos produzidos em colisões de partículas num acelerador por SND@LHC e FASER

LIP-ECO/CERN/N.Leonardo | 23 Março, 2023

"As novas experiências SND@LHC e FASER apresentaram a primeira observação de neutrinos produzidos em colisões de partículas num acelerador. Os resultados foram anunciados nos Rencontres de Moriond que estão a decorrer esta semana em La Thuile, Vale d'Aosta, Itália."

2023

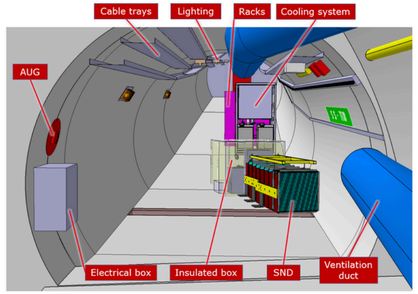
Embora os neutrinos sejam produzidos abundantemente nas colisões do LHC, por interagirem muito fracamente com a matéria atravessam sem serem vistos detectores gigantes como ATLAS e CMS. De facto, até agora nunca tinham sido detectados directamente neutrinos produzidos em colisões de partículas em aceleradores.

Apenas nove meses após o início do Run 3 do LHC e das respectivas campanhas de tomada de dados, as colaborações FASER e SND@LHC

Neutrinos@LHC

LIP-ECO/N. Leonardo | 04 Setembro, 2020

"O protótipo de um detector de neutrinos desenvolvido para a experiência SHiP está preparado para ser instalado no LHC antes do próximo run. A proposta, subscrita pelo LIP, foi recentemente submetida ao CERN. "



2020

Durante as palestras introdutórias da edição em curso do Programa de Estágios LIP, foi dito aos alunos que os neutrinos não são detectados no LHC (sendo a sua presença inferida apenas por via da energia em falta). Mas e se os conseguíssemos detectar? É exatamente isso que se pretende fazer com um novo detector, recém-proposto para o LHC. Para tal, precisamos de um detector com características muito específicas, contendo em particular um alvo com uma emulsão em que os neutrinos poderão interagir e ser detectados.

SHiP é uma nova experiência complementar às experiências do LHC na busca de nova física (NP). Usará o feixe de protões de alta intensidade de 0.4 TeV do acelerador SPS. Foi desenhada para estudar partículas de NP que interagem muito pouco com a matéria (Feebly Interacting Particles, FIPs) e neutrinos. A experiência deverá ser instalada numa nova zona de beam-dump ainda a ser construída. No entanto, o protótipo de um dos seus componentes, o SND — Scattering and Neutrino Detector, foi agora proposto para começar a tomada de dados mais cedo, e a uma energia uma ordem de grandeza mais alta. Mais precisamente, no próximo run (Run 3) do LHC.