FLAVOUR

Heavy & Light

Exploring LHC Intensity Frontier

Nuno Leonardo

LIP & IST

ARTCMS.WEB.CERN.CH

LHC

CMS

9th mini-school

on Particle and Astroparticle Physics

Oeiras 5-6 . FEB . 2024

LIP LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

CFTP Centro de Física Teórica de Partículas

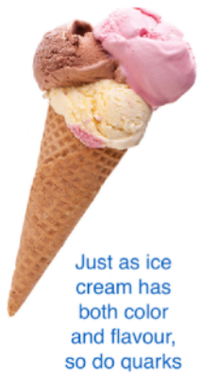
TÉCNICO LISBOA

fct Fundação para a Ciência e a Tecnologia

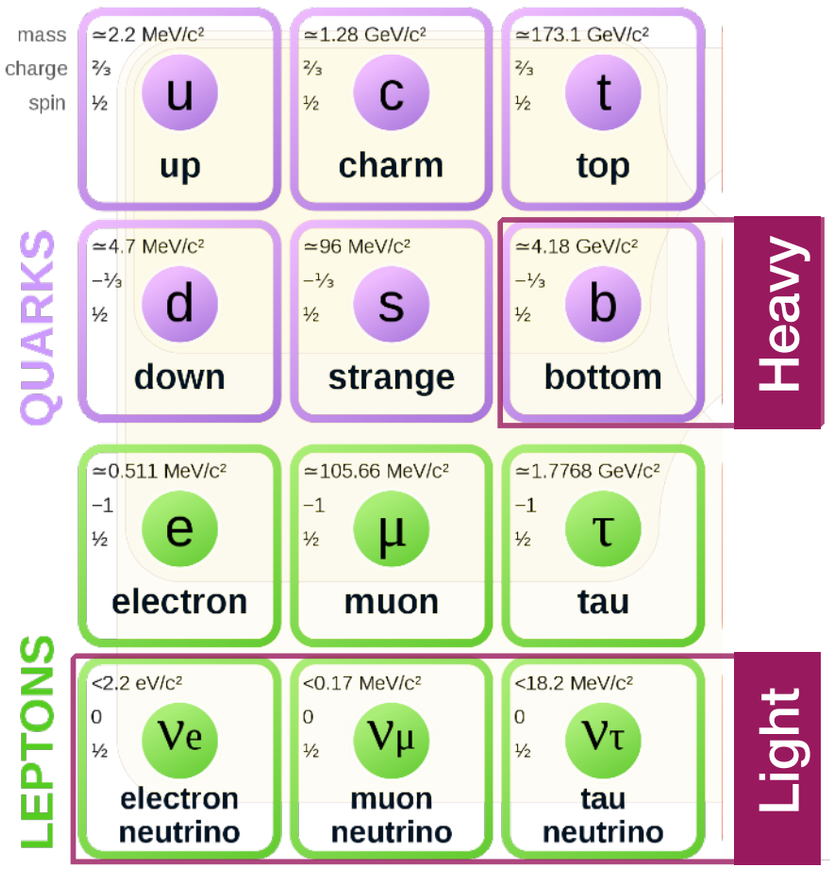
nuno@cern.ch

Flavour

quarks & leptons

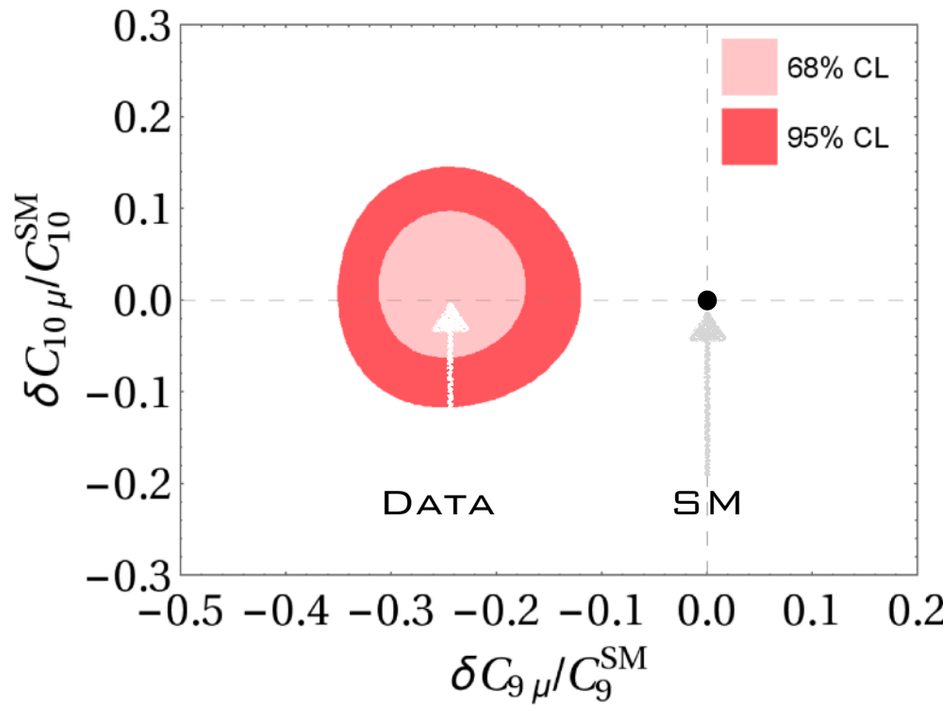


Just as ice cream has both color and flavour, so do quarks



Measurements

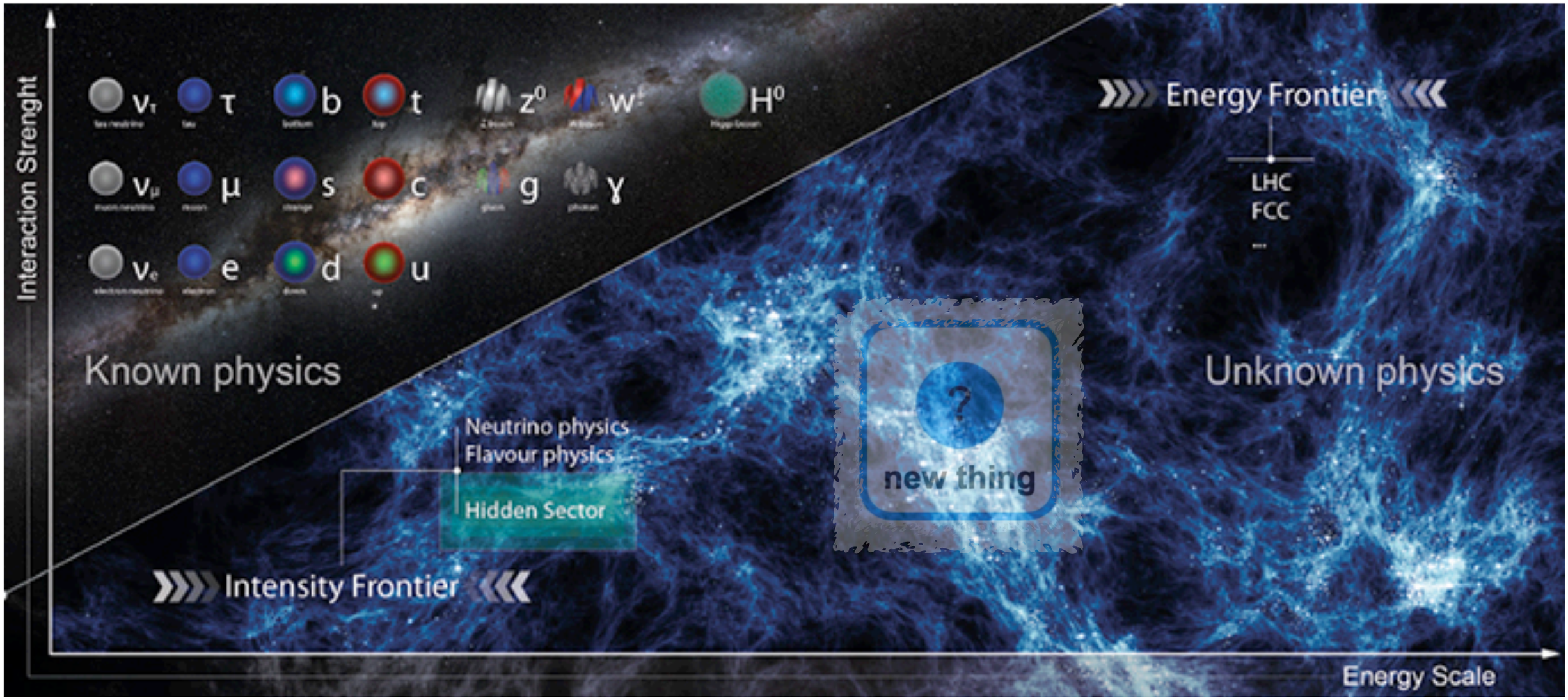
experiment ≠ theory



beyond SM

Flavour = test SM & go BSM

Known *vs* Unknown

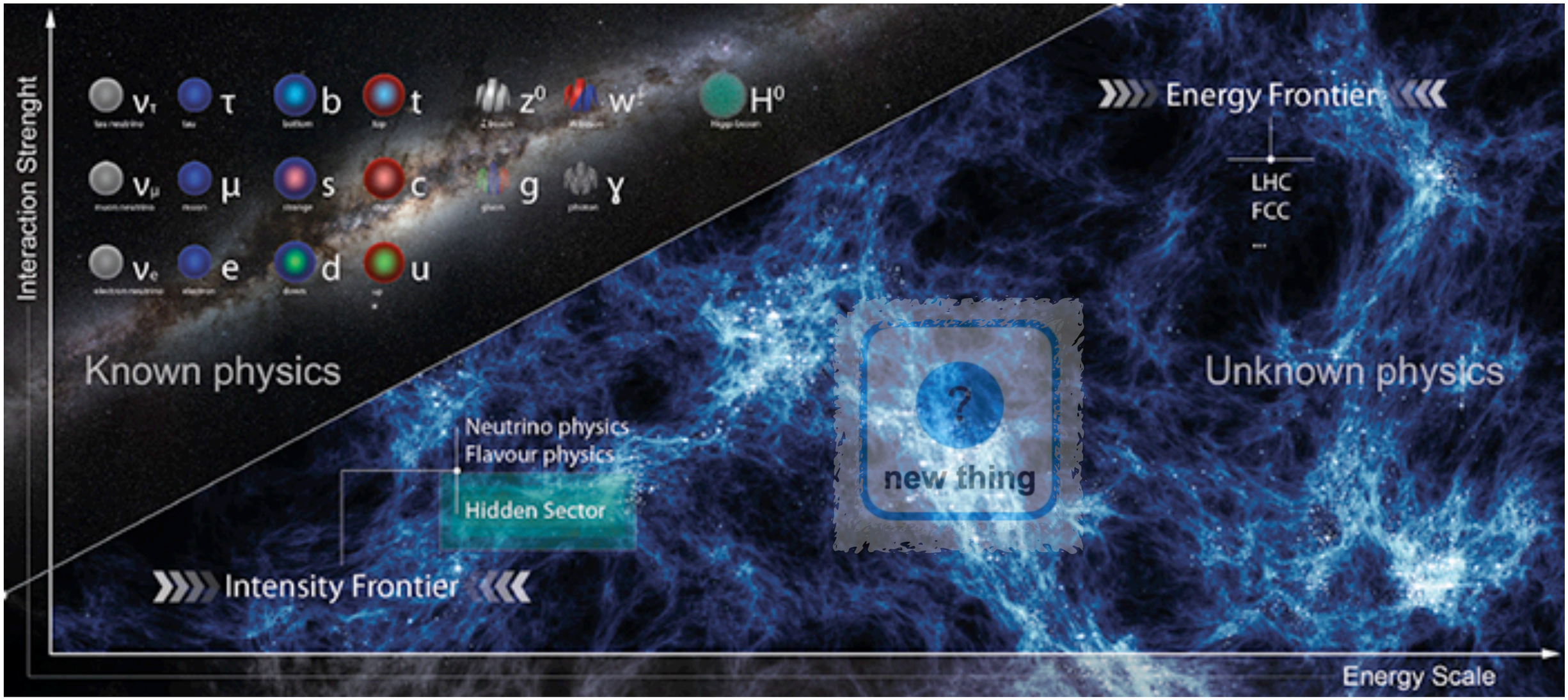


Going beyond the Standard Model

LHC — explore both energy and intensity frontiers

energy frontier →

intensity frontier ↓

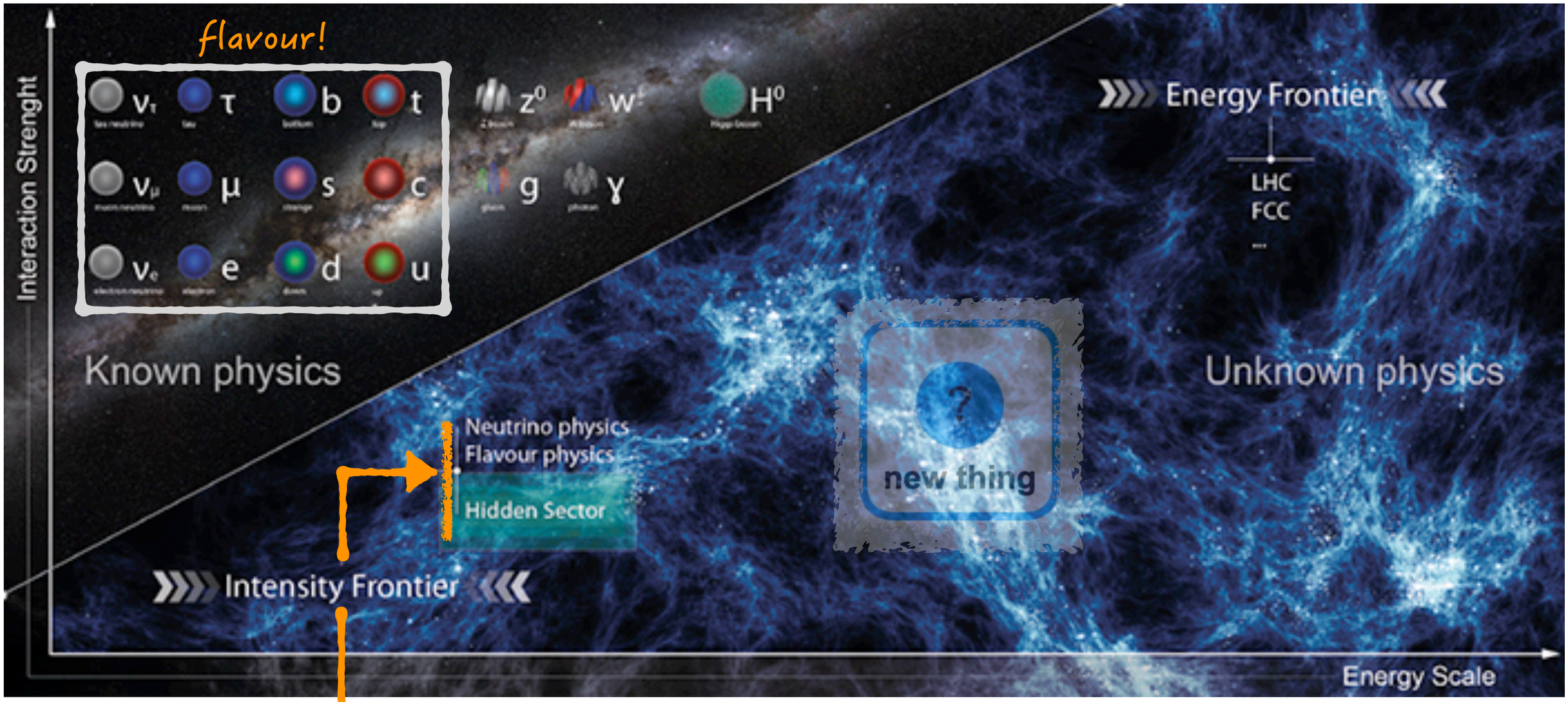


Beam intensity: high luminosity

Beam energy: √s

Going beyond the Standard Model

energy frontier →



LHC (and HL-LHC) as an *intensity frontier* machine

Going beyond the Standard Model

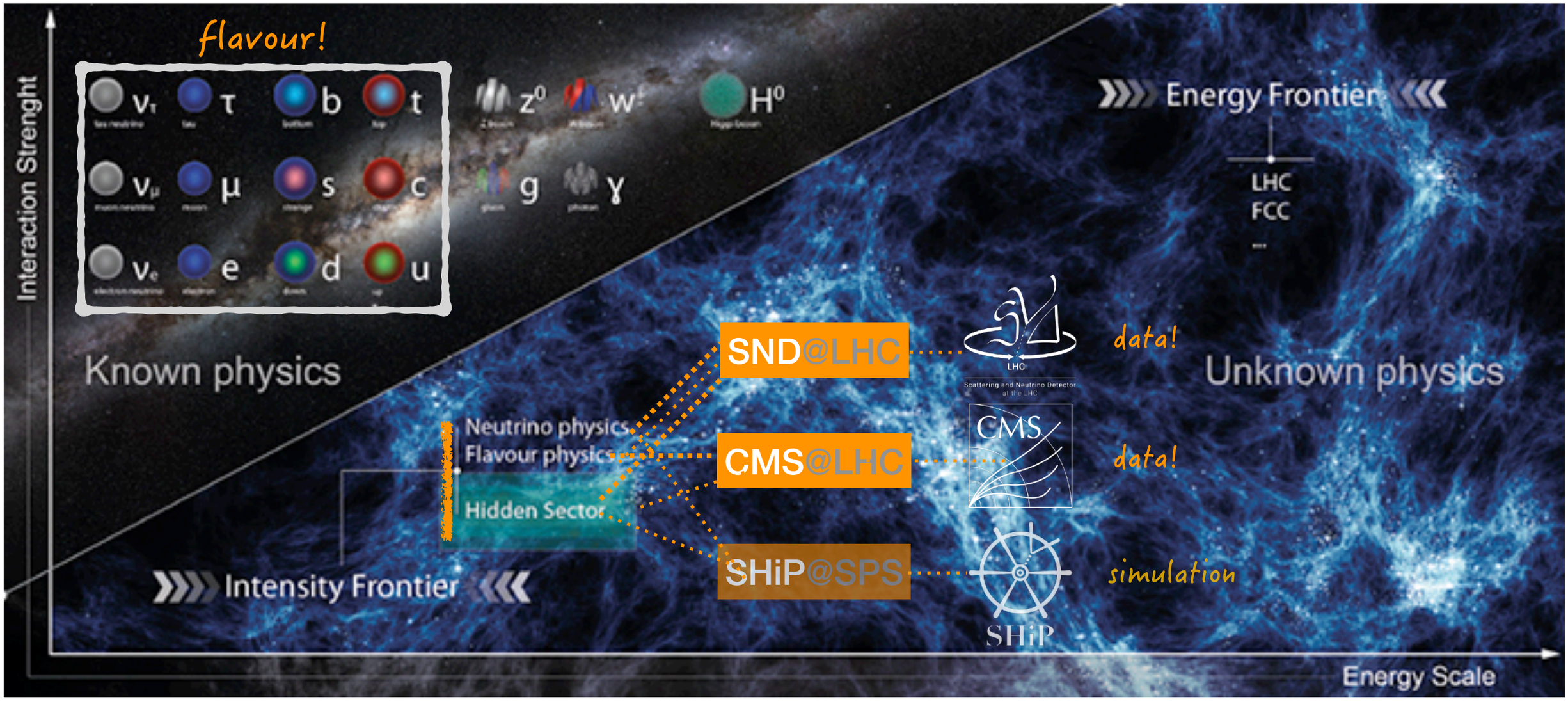
favour

light ν

heavy b

hidden fips

energy frontier



Going beyond the Standard Model

favour

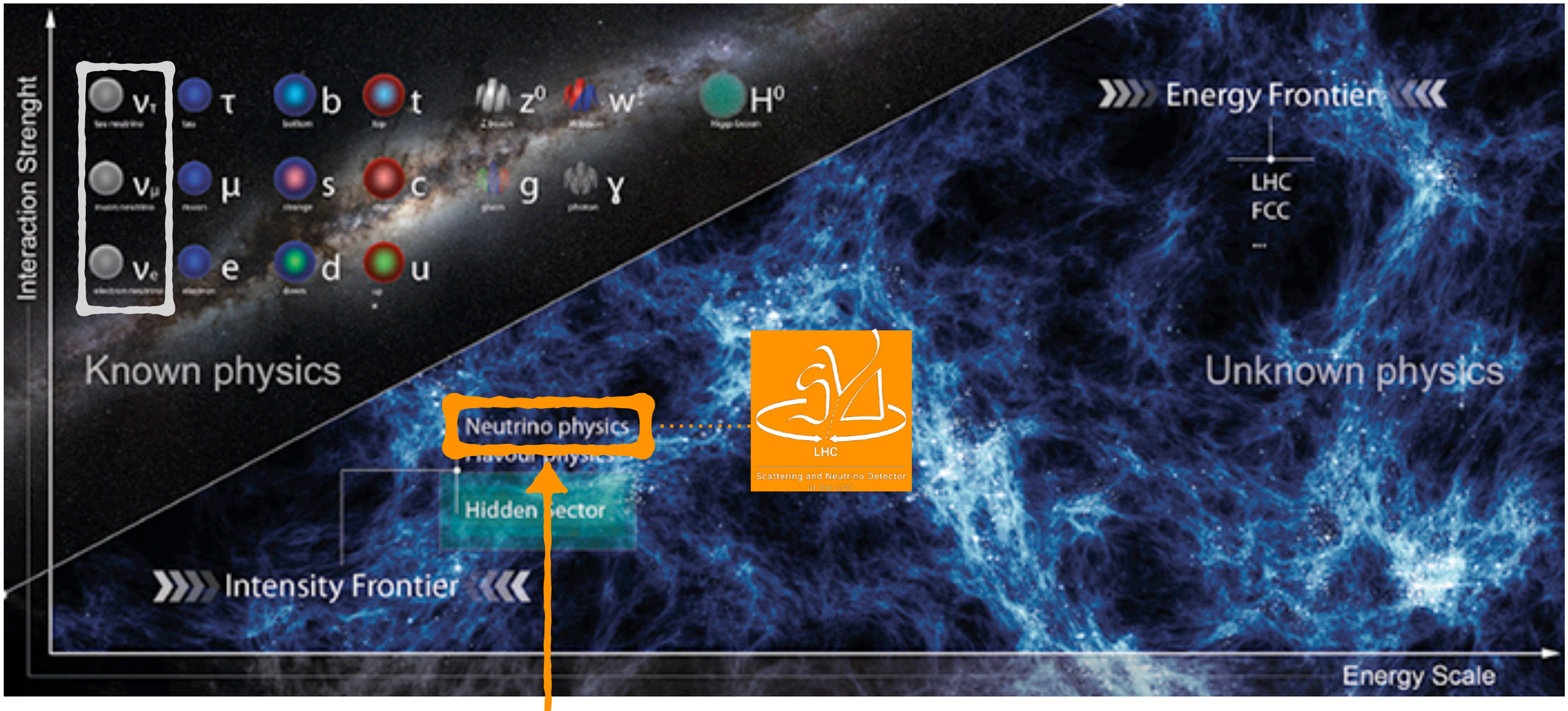
light ν

heavy b

hidden fips

energy frontier →

intensity frontier



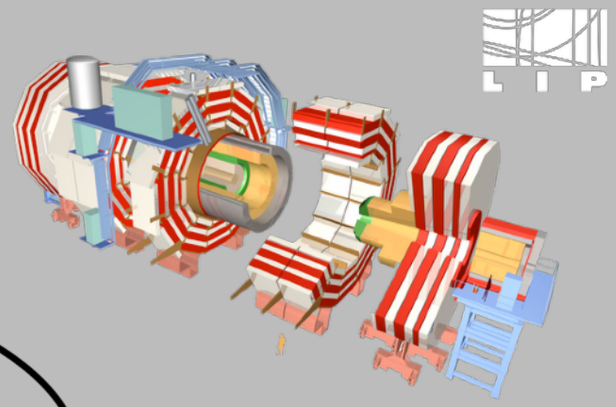
the LHC as a neutrino factory

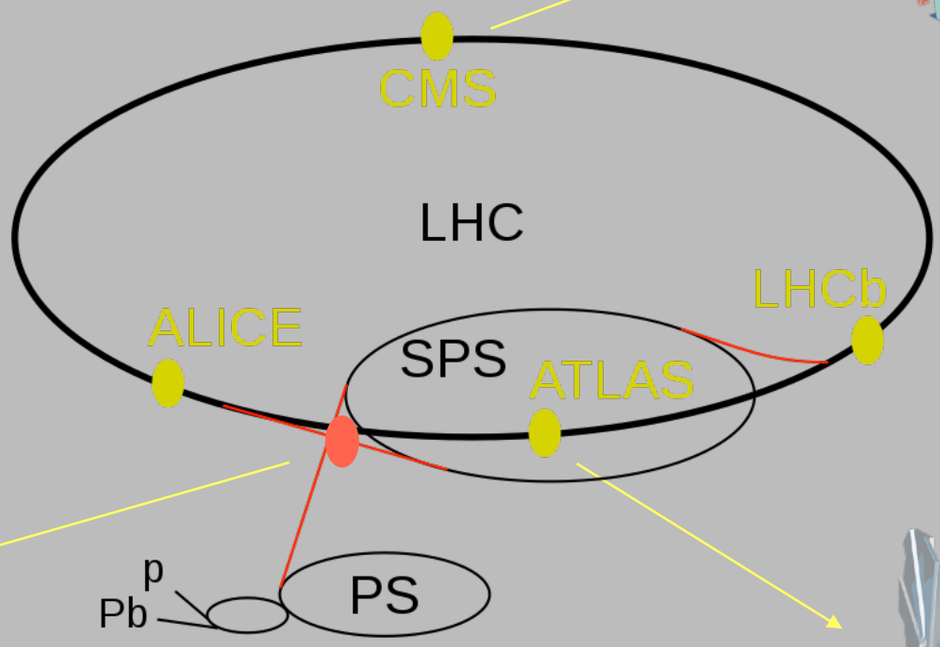
a new LHC experiment (9th)

with LIP's involvement (3rd)

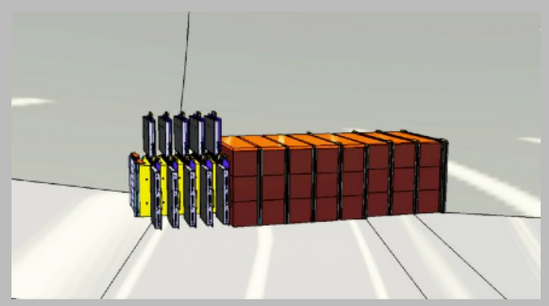
Goal: fully exploit and **extend** the (HL-)**LHC** physics reach.

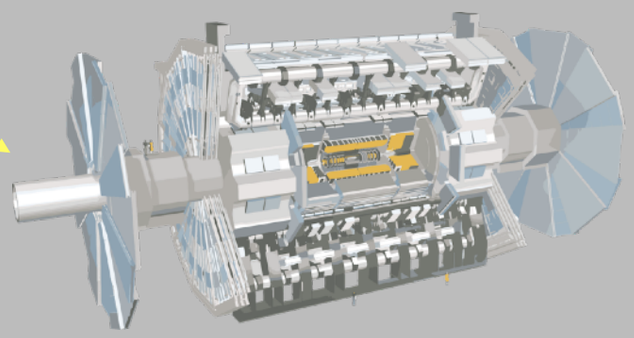
- measure **neutrinos,** and
- search for **new particles**





SND@LHC

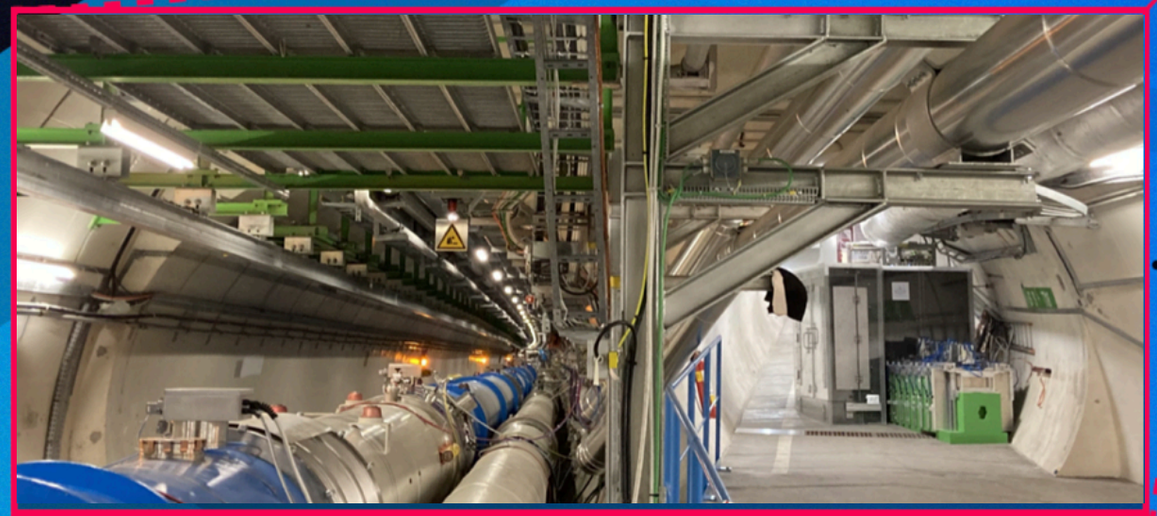




The most recent LHC experiment

SND@LHC: Scattering and Neutrino Detector at the LHC

Neutrinos at LHC !

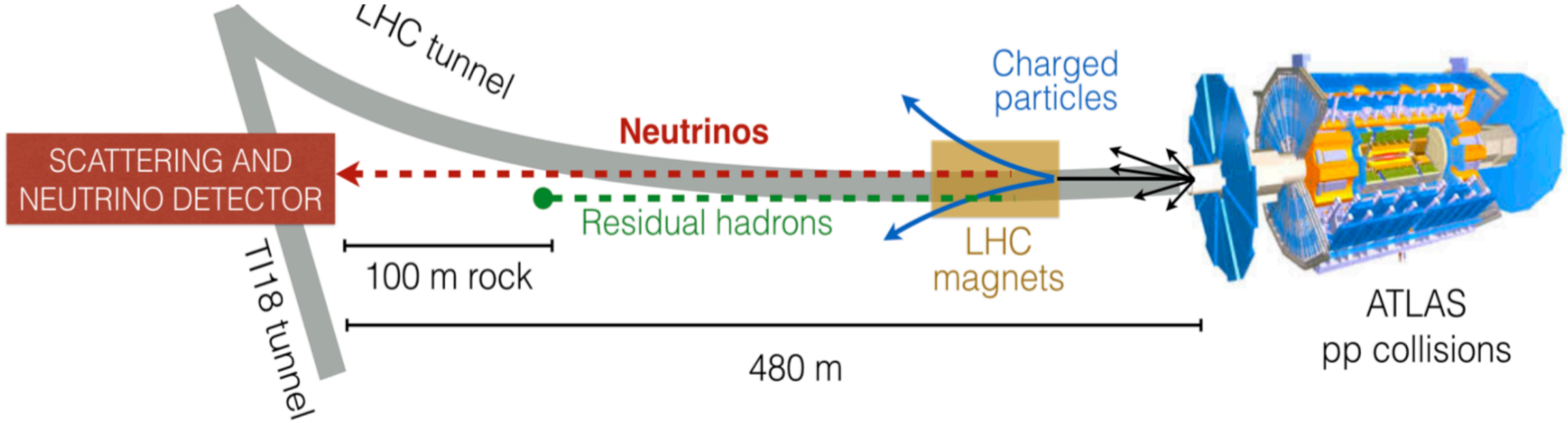


SND@LHC

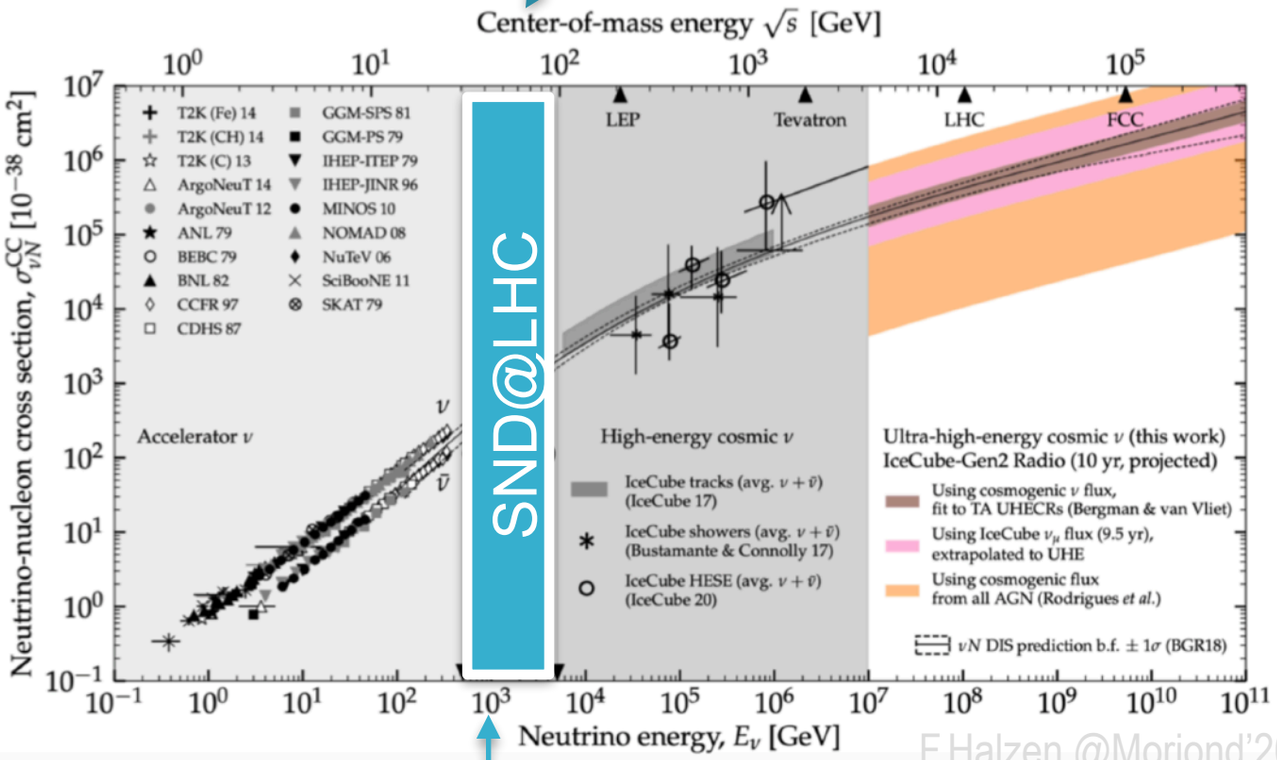
TI18

ATLAS

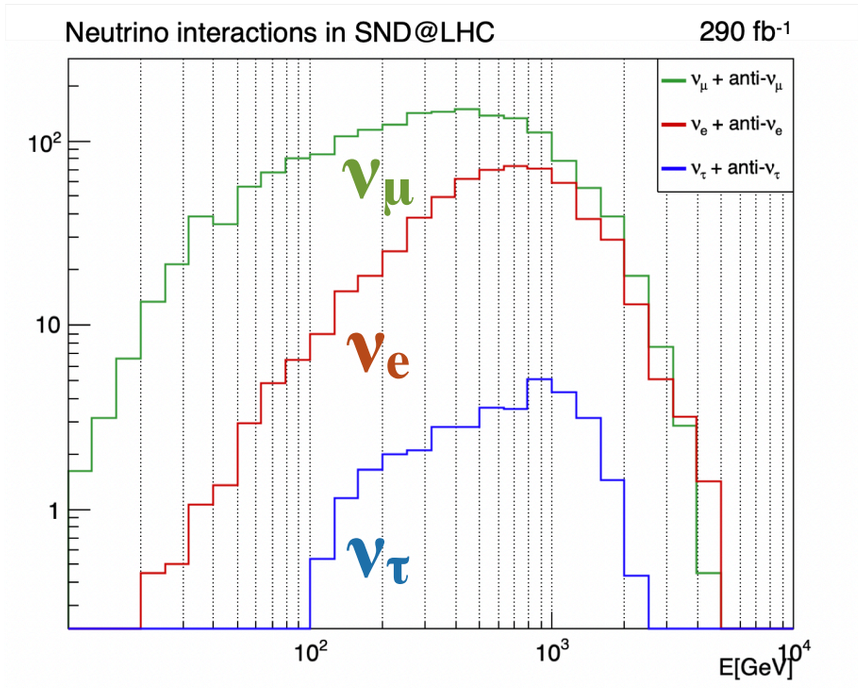
SPS



Exploring the highest energy neutrinos produced in the lab (@LHC)



F.Halzen @Moriond'2023



un-probed energy region
300 GeV ~ TeV

study all three neutrinos
ν_e, ν_μ, ν_τ

the least know SM particle!

HOT OFF THE PRESS

PRL 2023
Editor's choice
Led by LIP

Observation of collider muon neutrinos with the SND@LHC experiment

Observation of collider muon neutrinos with the SND@LHC experiment

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We report the direct observation of muon neutrino interactions with the SND@LHC detector at the Large Hadron Collider. A data set of proton-proton collisions at $\sqrt{s} = 13.6\,\text{TeV}$ collected by SND@LHC in 2022 is used, corresponding to an integrated luminosity of $36.8\,\text{fb}^{-1}$. The search is based on information from the active electronic components of the SND@LHC detector, which covers the pseudo-rapidity region of $7.2 < \eta < 8.4$, inaccessible to the other experiments at the collider. Muon neutrino candidates are identified through their charged-current interaction topology, with a track propagating through the entire length of the muon detector. After selection cuts, 8 ν_μ interaction candidate events remain with an estimated background of 0.076 events, yielding a significance of seven standard deviations for the observed ν_μ signal.

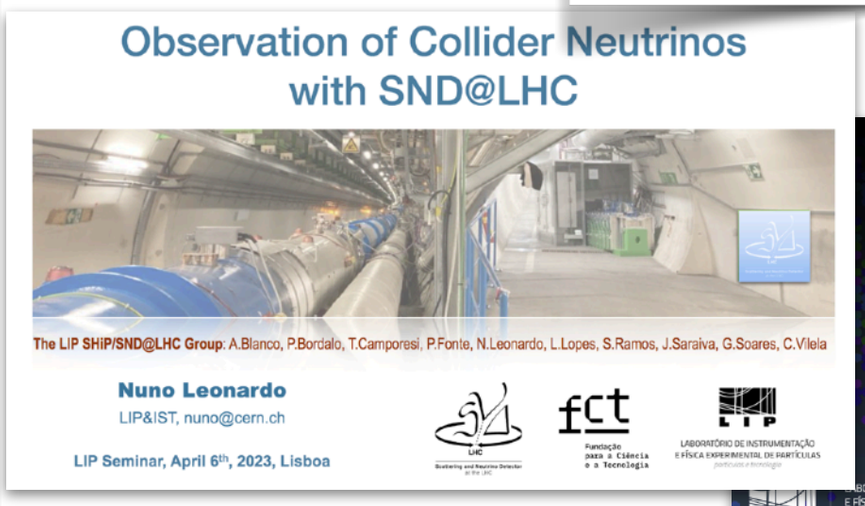

VIEWPOINT

The Dawn of Collider Neutrino Physics

Elizabeth Worcester

Brookhaven National Laboratory, Upton, New York, US

July 19, 2023 • *Physics* 16, 113

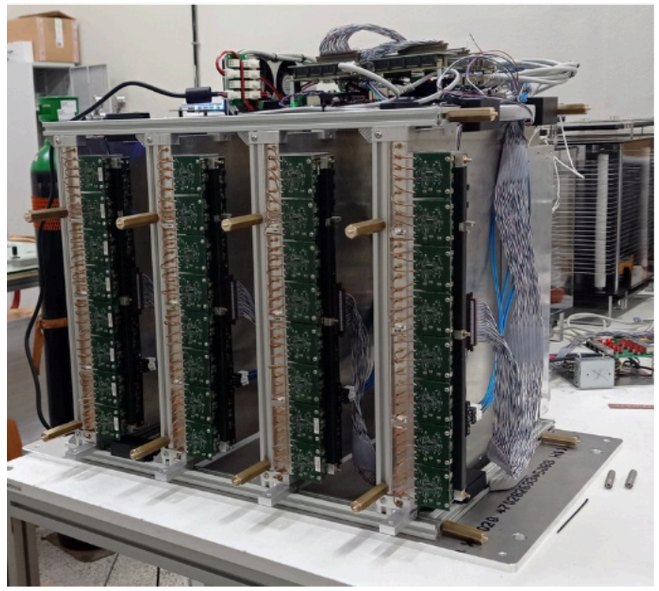


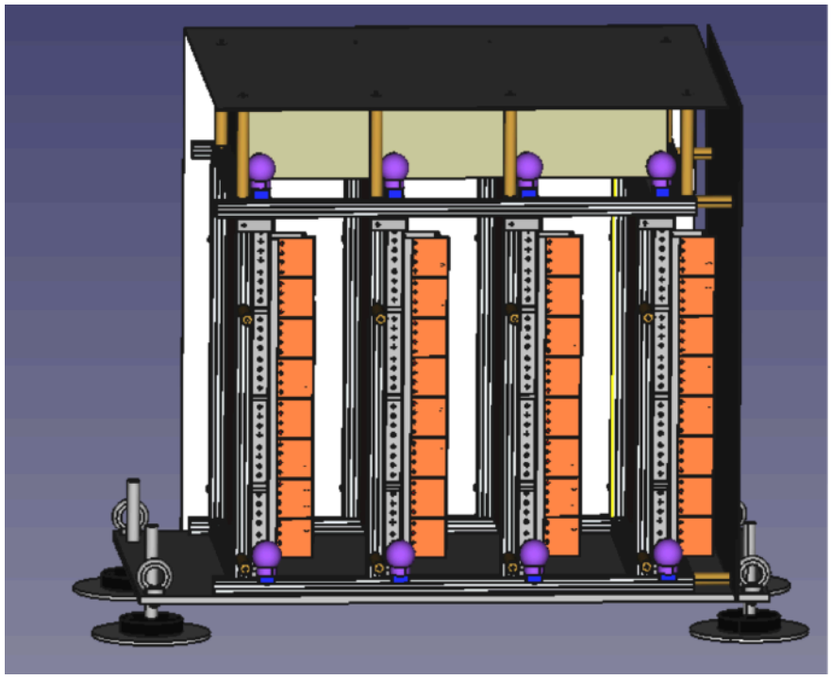
Observation seminar @LIP
https://indico.lip.pt/event/1425/

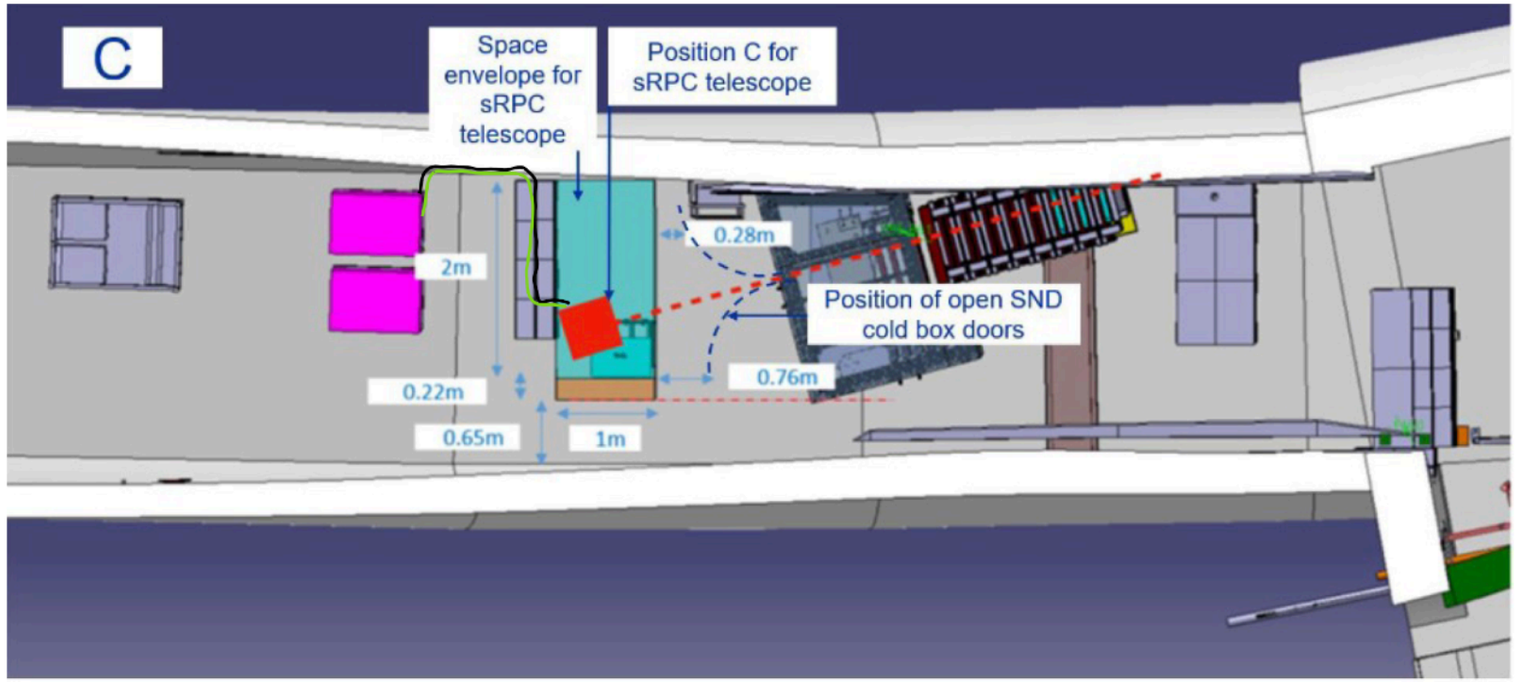
https://arxiv.org/abs/2305.09383

Run3: a muon telescope @LHC

- **Example (ongoing this week!):**
- new detector for measuring **muon flux** at LHC
- establish innovative technology (sRPC), designed and built @LIP, deploying in LHC environment
- being installed in the SND@LHC tunnel this week
- additional uses requested by community, beyond physics measurement (environment, upgrades)







student projects

SND@LHC is a new, small LHC experiment

➥ opportunities for impactful student projects

see poster by Guilherme

- muon neutrino: ν_μ observed ✔, being measured (G.Soares, PhD thesis)
- electron neutrino: ν_e **observation** is next milestone (MSc thesis opportunity)
- ν_τ observation or ν_μ / ν_e ratio (LFU) measurement (PhD thesis opportunity)
- search for new particles (fips): dark higgs, dark photon (H.Santos, MSc thesis)
- sRPC characterisation and **muon flux** measurement (MSc thesis opportunity)

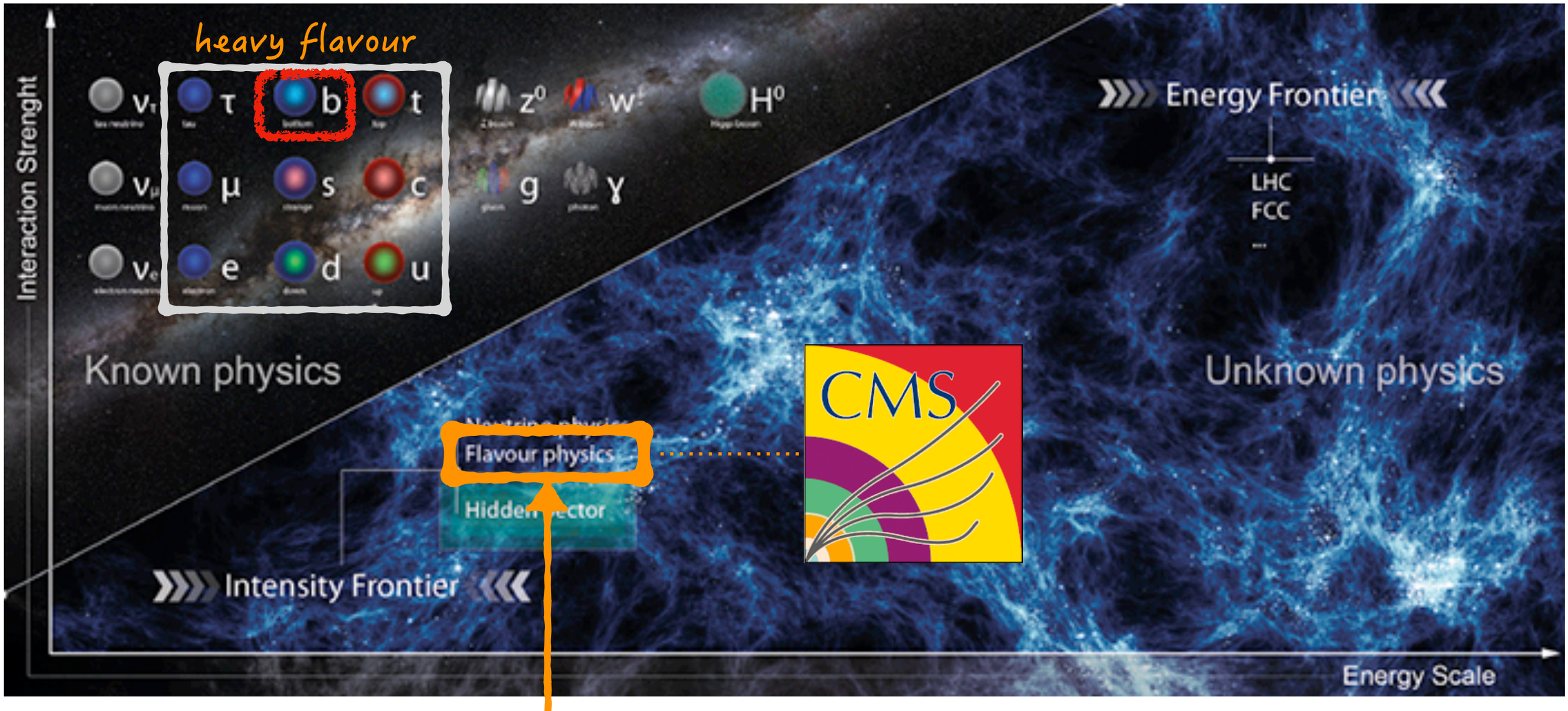
The LIP group is small but has an active wide involvement in the new CERN experiment, ranging from detector development, commissioning, calibration, and HL-LHC upgrades to leadership in physics analyses

➥ Interested students can take part in Internships, PICs, and Theses

Going beyond the Standard Model

favour: light ν | heavy b | hidden fips

energy frontier →



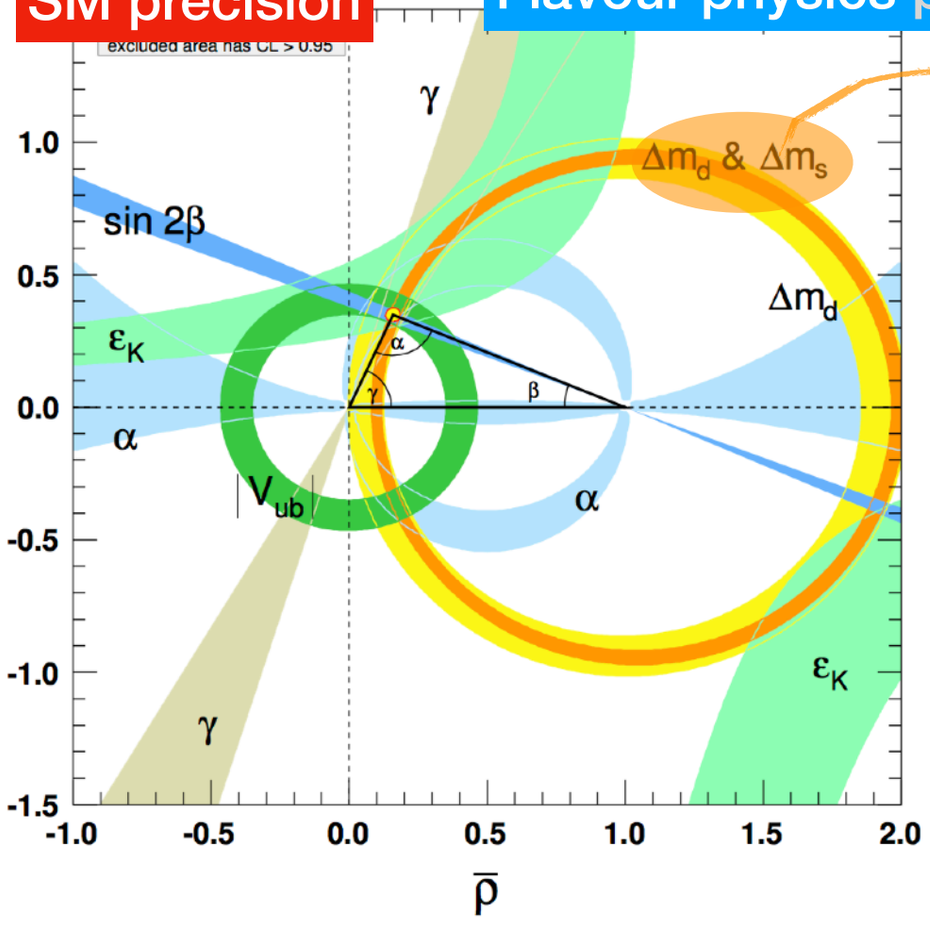
intensity frontier ↓

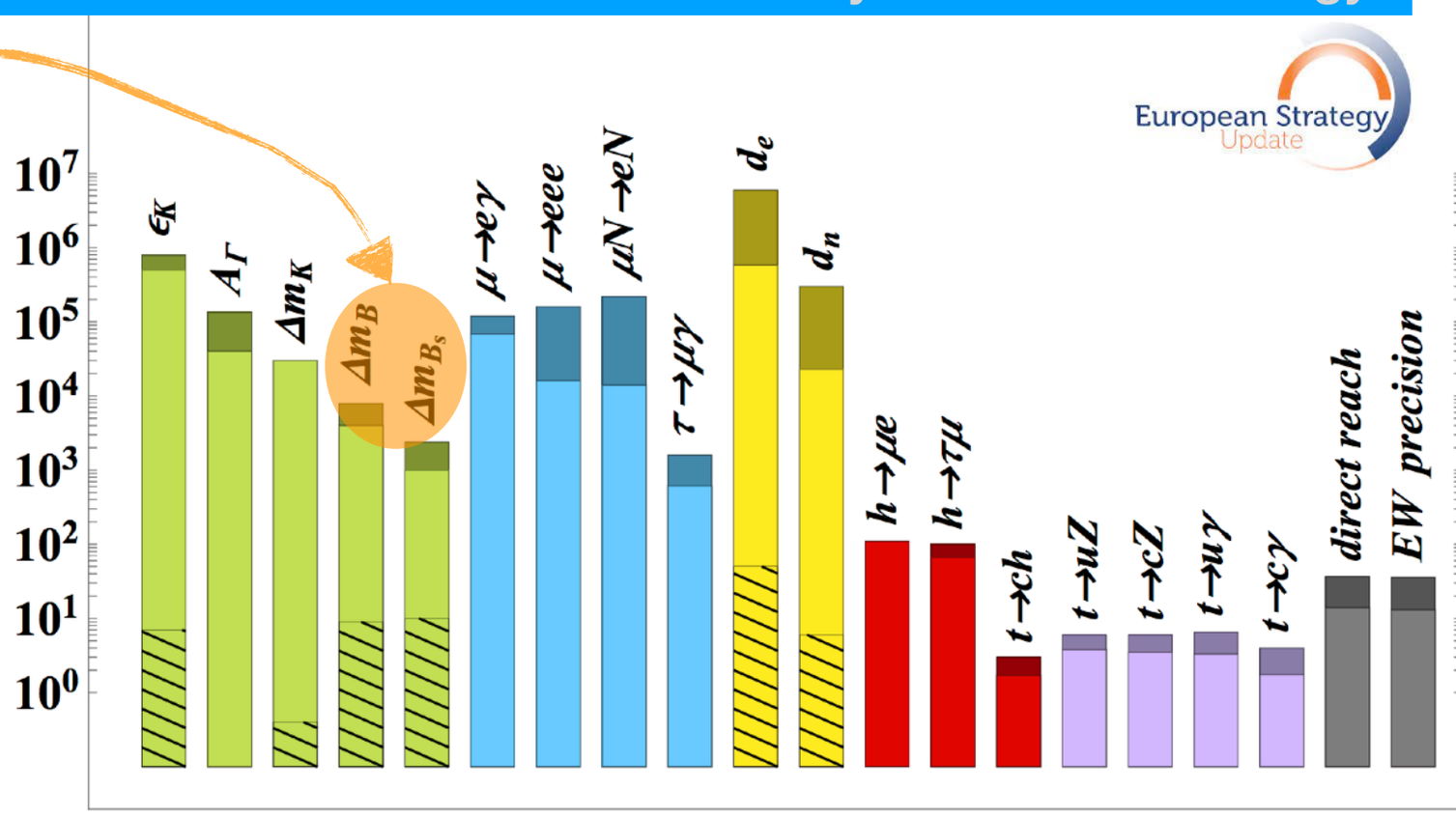
the LHC as a heavy-flavour factory

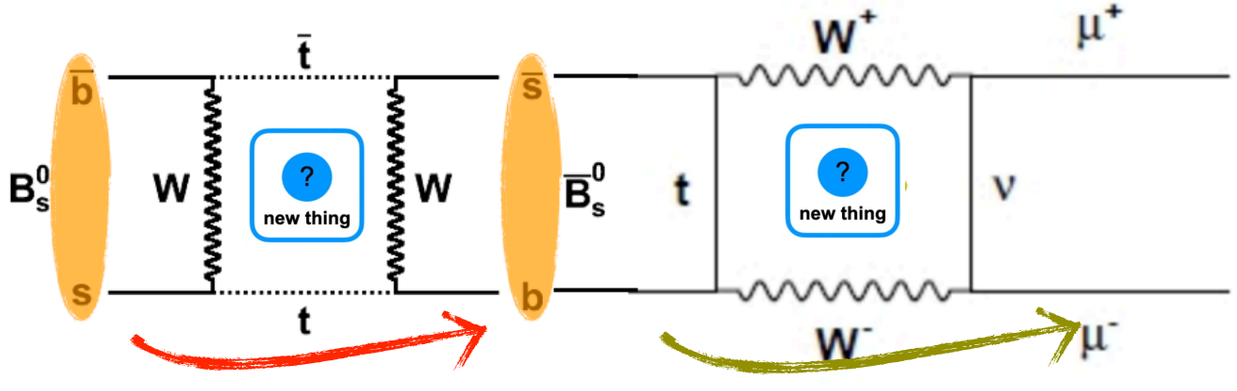
Flavour = SM precision + BSM search

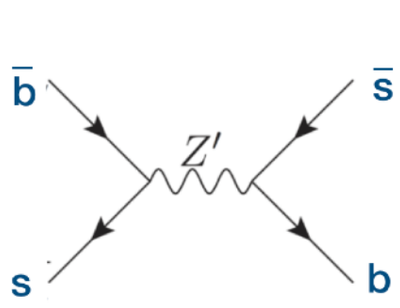
SM precision

Flavour physics provides access to NP scales well beyond collision energy !

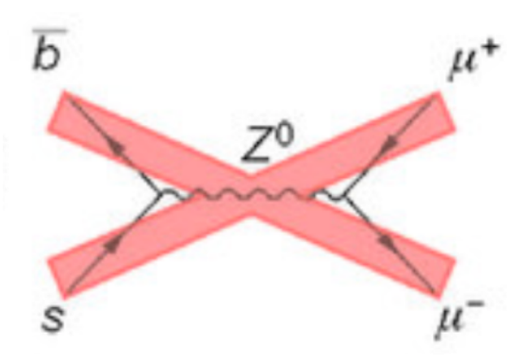








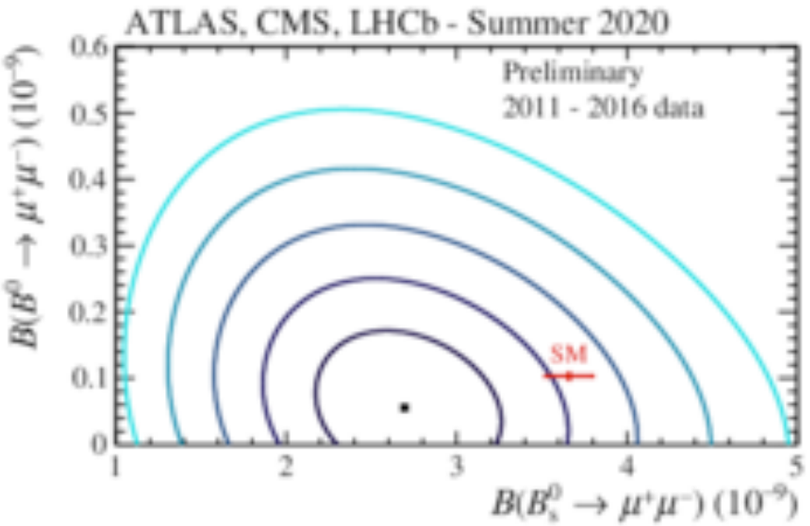
BSM ✓



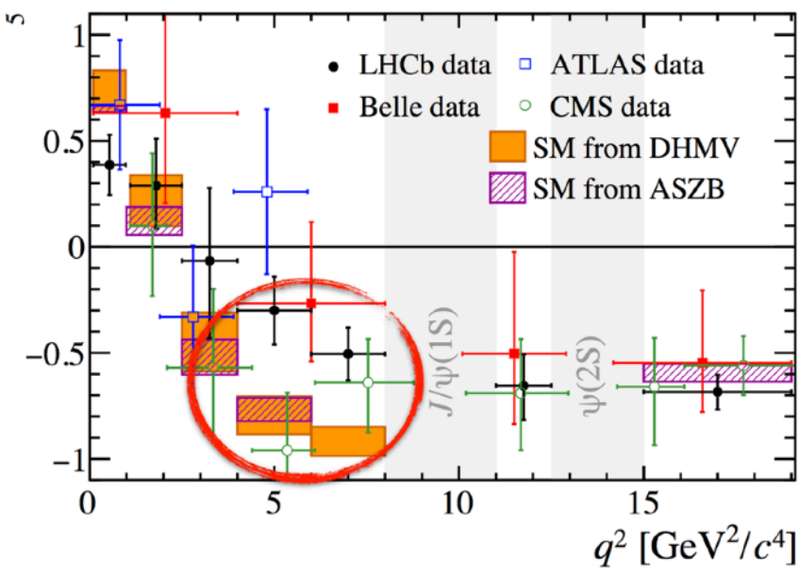
SM ✗

b→sμμ ↠ clarifying the Flavour Anomalies!

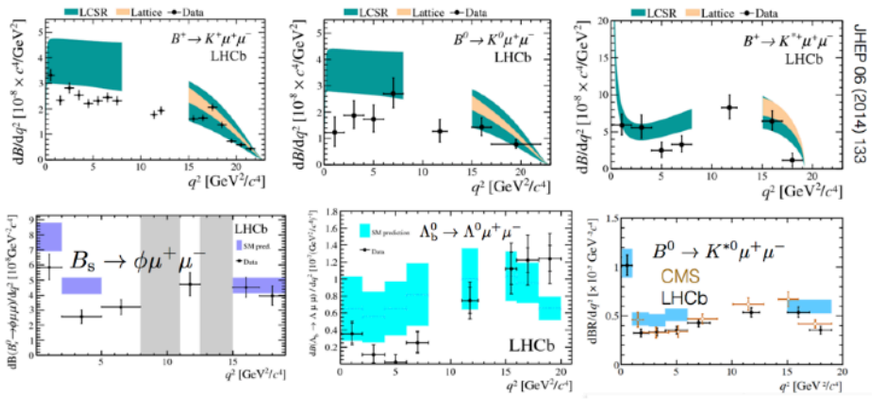
B→μμ



B→K*μμ

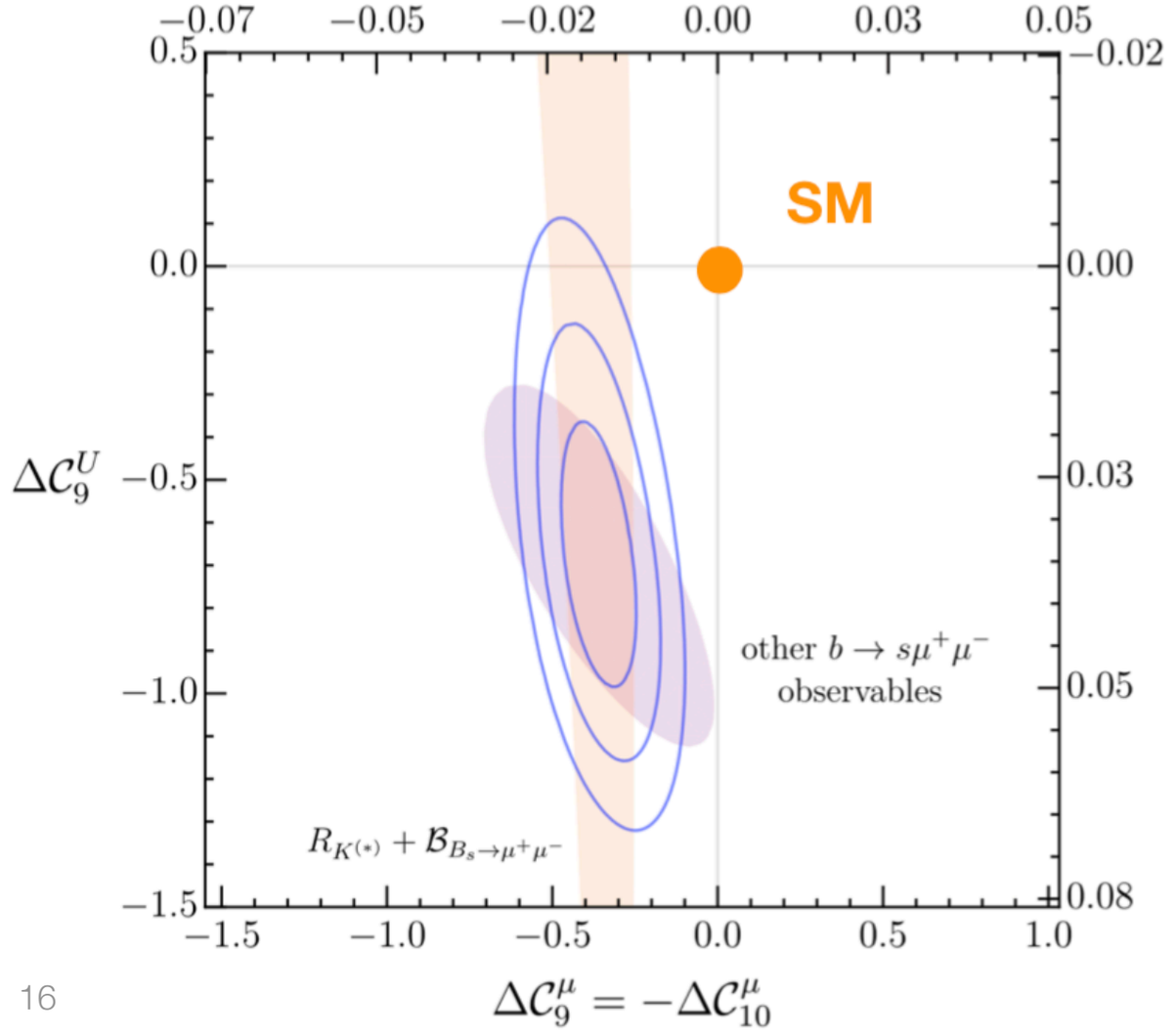


B→Xμμ



SM - Effective Field Theory

$$\mathcal{L}_{SM\text{-}EFT} = \mathcal{L}_{SM} + \Sigma_i C_i O_i$$



thesis opportunity

- **LFU** analysis
- b→sττ / b→sμμ
- anomaly-dedicated dataset by CMS
- machine learning for B and τ reconstruction
- clarify the anomalies, potential for detecting new physics

TÉCNICO LISBOA

Bruno now PhD @ Polytechnique, France

Measurement of b-quark fragmentation fraction ratios at the CMS experiment: a key ingredient for the $B_s^0 \to \mu^+\mu^-$ rare decay analysis

Bruno Afonso Fontana Santos Alves

Thesis to obtain the Master of Science Degree in

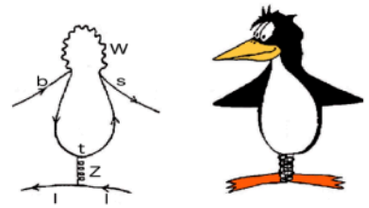
Engineering Physics

CERN-THESIS-2018-274
https://cds.cern.ch/record/2649927
youtube

Golden rare decay

TÉCNICO LISBOA

Maria now PhD @ EPFL, Switzerland



Investigating the flavour anomalies through the rare beauty decay $B^0 \to K^{*0}\mu^+\mu^-$

Maria Carolina Feliciano Faria

Thesis to obtain the Master of Science Degree in

Engineering Physics

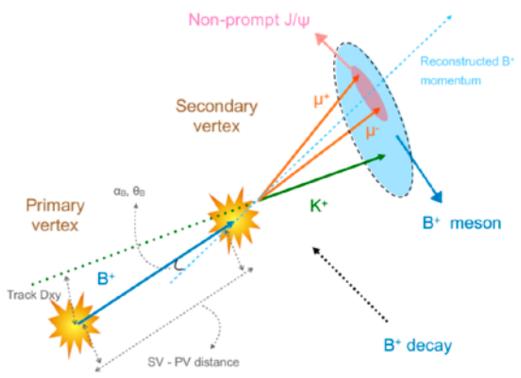
CERN-THESIS-2021-220
https://cds.cern.ch/record/2791778
youtube

Flavour anomalies

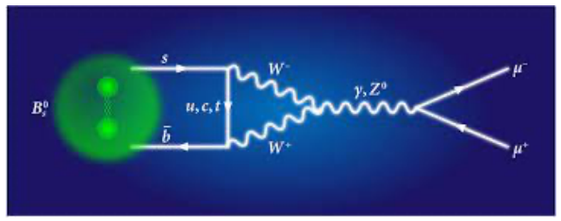
Flavor universality

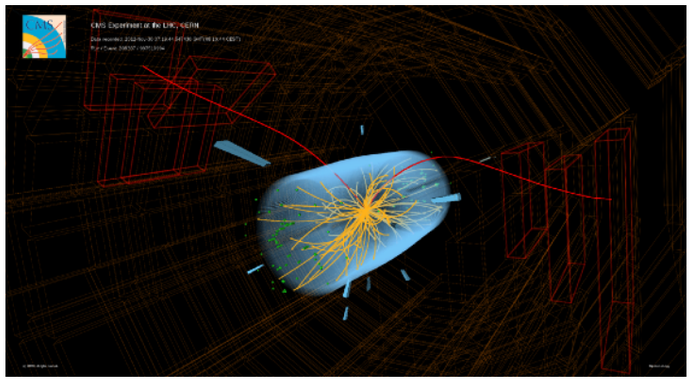
Heavy Flavour : in vacuum & in hot medium

b-quark hadrons

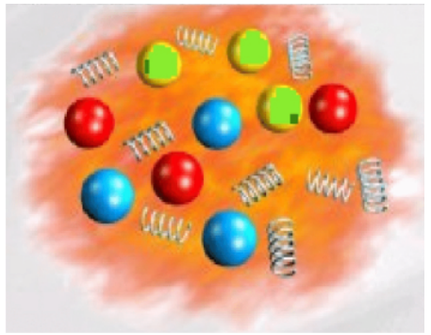


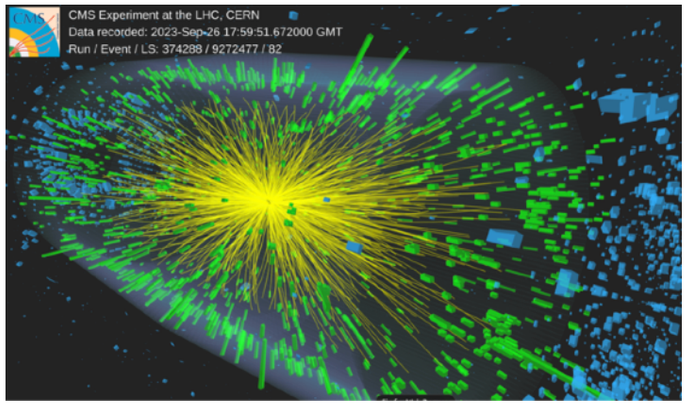
proton-proton collisions





created in ion collisions

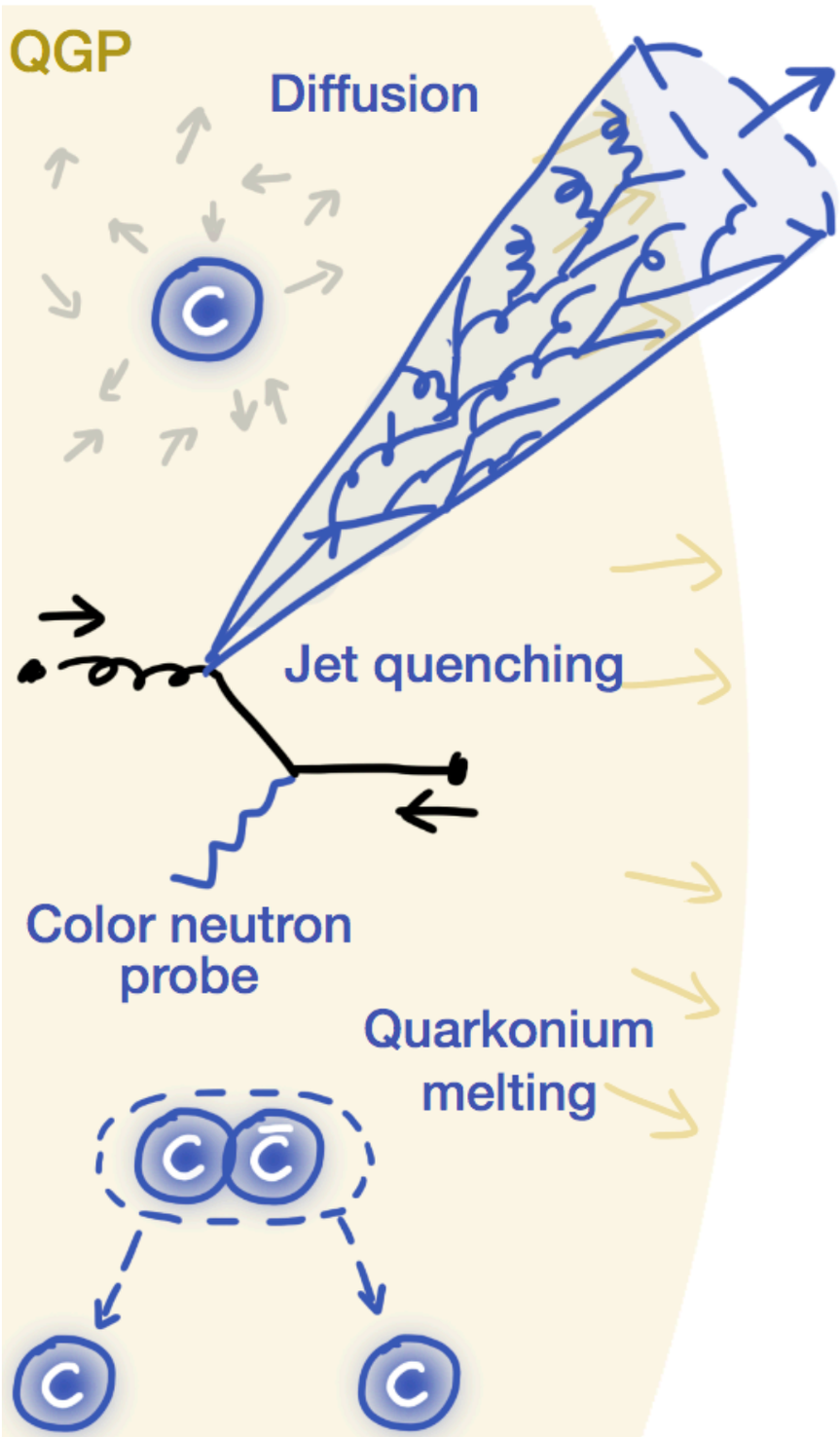


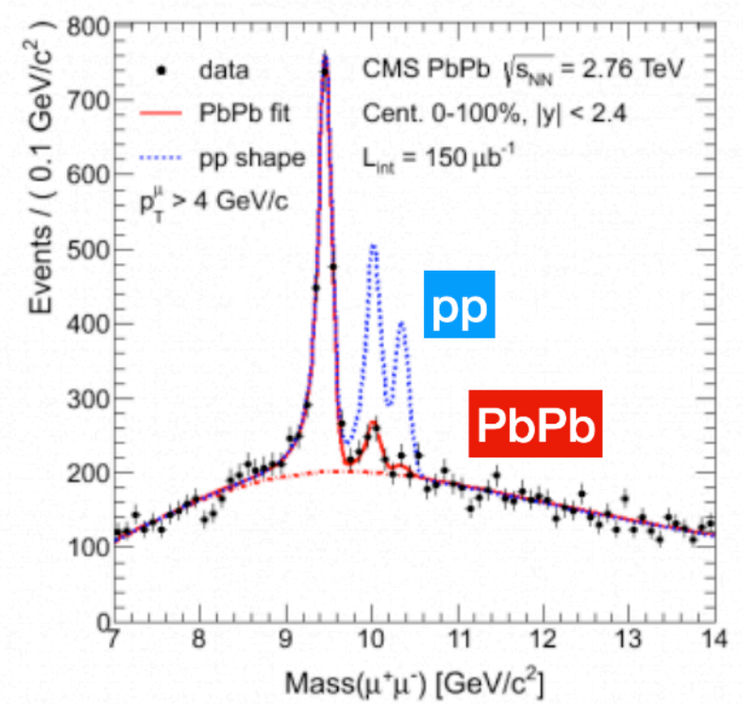


Just collected in October 2023 the first LHC Ion data in Run3!

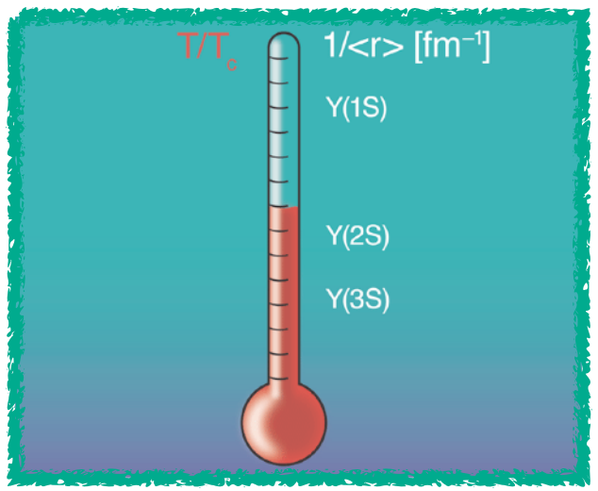
In the QGP, particles loose energy … and even melt!

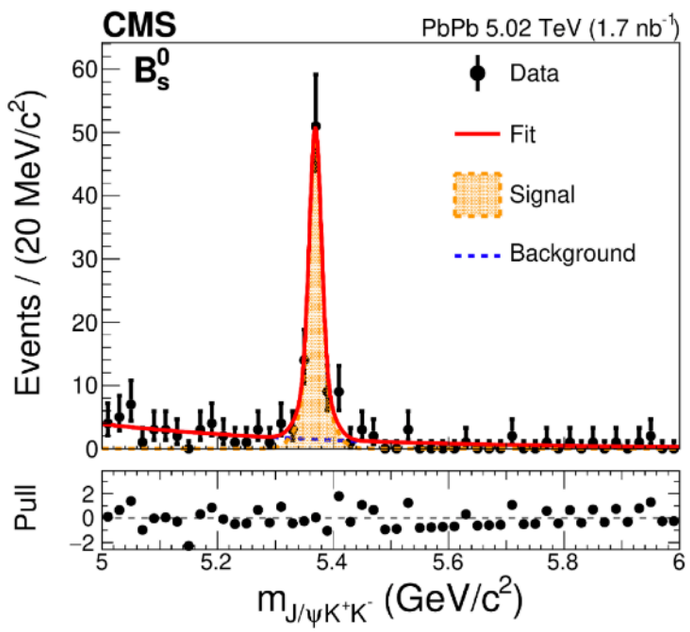
Heavy-flavour hadrons as novel probes of the hot soup of quarks and gluons (QGP)



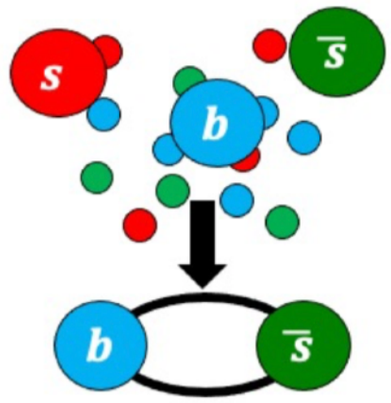


Quarkonia sequential melting
☞ thermometer of the QGP !

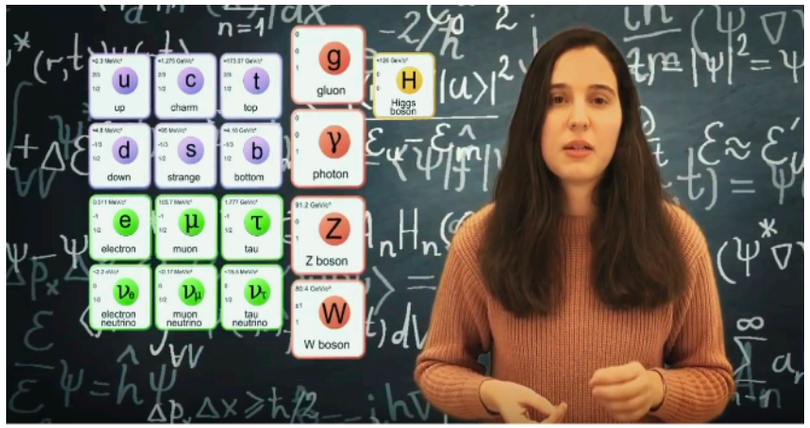


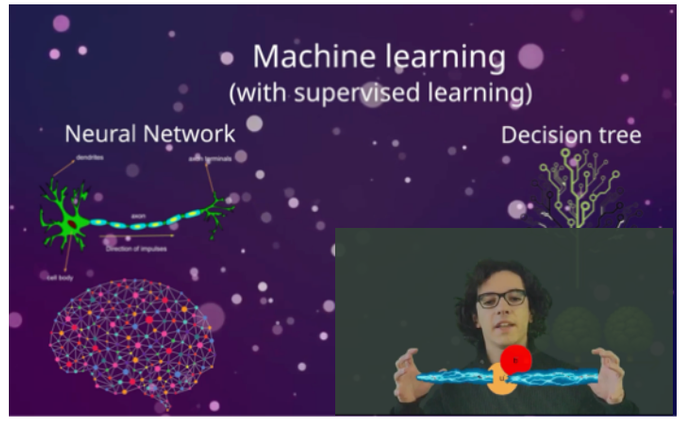


B mesons production PbPb vs pp
☞ how quarks become hadrons?
(in vacuum and medium)



(probing the hot QCD medium with B mesons)





Julia now PhD @ Birmingham, UK

TÉCNICO LISBOA

Probing the quark gluon plasma medium through B meson production measurements in PbPb collisions at the LHC

Júlia Manuela Cardoso Silva

Thesis to obtain the Master of Science Degree in

Engineering Physics

CERN-THESIS-2019-256
https://cds.cern.ch/record/2705630
youtube

Bs observation in PbPb

Bruno starting PhD at IST

TÉCNICO LISBOA

Probing the Quark-Gluon Plasma with B_s^0 and B^+ Mesons

Cross Sections in pp and Nuclear Modification Factors in PbPb

Henrique Miguel Marques Luís Legoinha

Thesis to obtain the Master of Science Degree in

Engineering Physics

CERN-THESIS-2023-064
https://cds.cern.ch/record/2860807
youtube

Nuclear modification factor

Simão chose to go to industry (machine learning)

TÉCNICO LISBOA

Probing Quark Hadronization with B mesons at the LHC

Simão Moreira Costa

Thesis to obtain the Master of Science Degree in

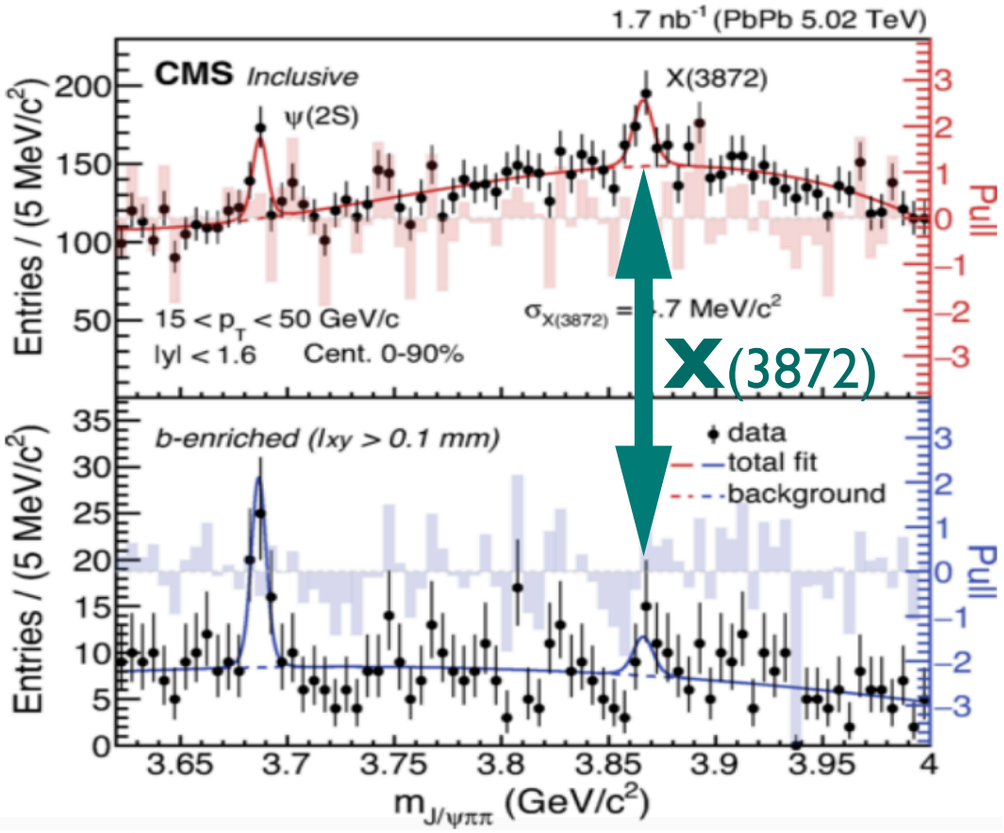
Physics Engineering

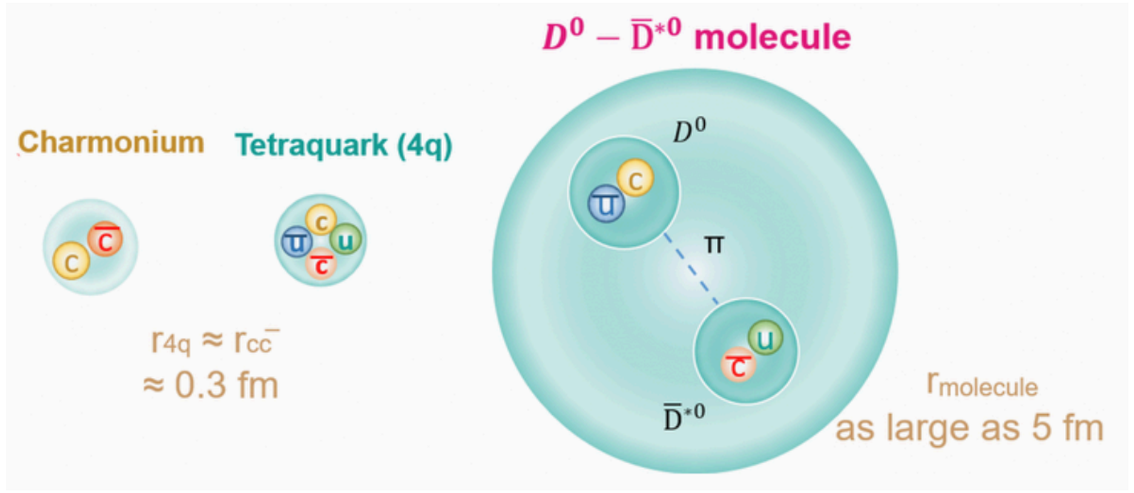
CERN-THESIS-2023-064
https://cds.cern.ch/record/2883330
youtube

Quark hadronization

Exotic hadron in hot medium

thesis opportunity





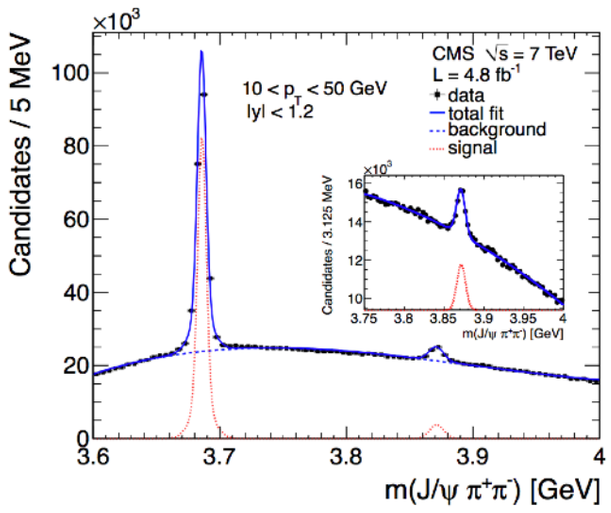
- evidence of **exotic hadron X** in PbPb data (collected in Run2)
- with Run3 data, will perform first measurements in ion collisions
- **2-fold goals**: improve understanding of:
  - 1) **nature** of exotic hadrons
  - 2) properties of QGP **medium**

PbPb

HIN-19-005

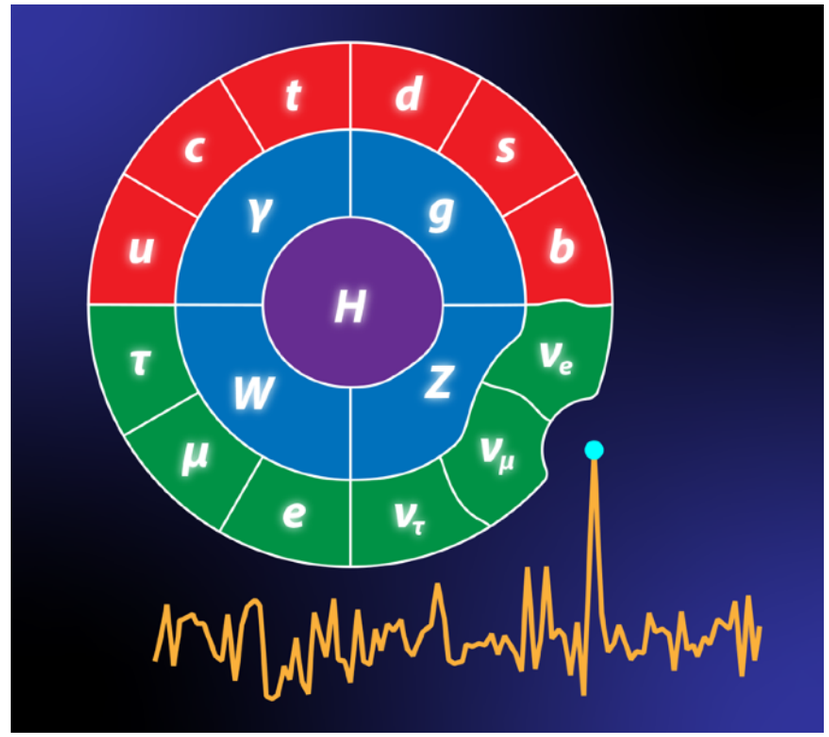
pp

BPH-11-011



Summary

- **flavour** provides a promising portal into new-physics beyond the SM
  - sensitive to new heavy particles beyond √s
  - pattern of **anomalies** revealed in data, hinting contributions from New Physics
  - probe the QGP primordial medium



- Dawn of era of collider **neutrinos**
- great **research** opportunities for students
  - Anomalies, QGP, Neutrinos & other FIPs
  - in large or smaller, well-established or novel experiments in exciting LHC environment

LHC is entering a high intensity phase

➥ **new era of precision and rare processes**
➥ **research opportunities in detector and analysis**

Join the adventure!