

MU Topic 1: Fundamental particles and forces

Overview

Priscilla Pani (DESY)

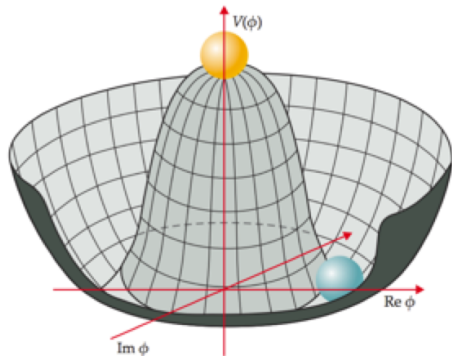


HELMHOLTZ

Topic mission and strategy

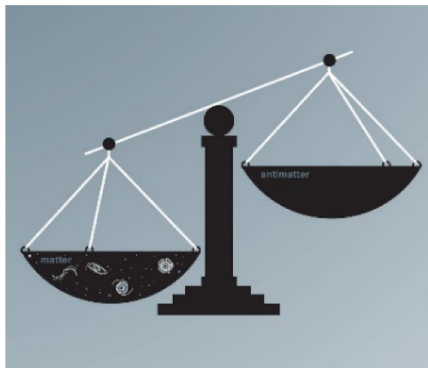
Study the fundamental laws of Nature in our Universe, governed by quantum physics and the dynamics of space-time

Science drivers

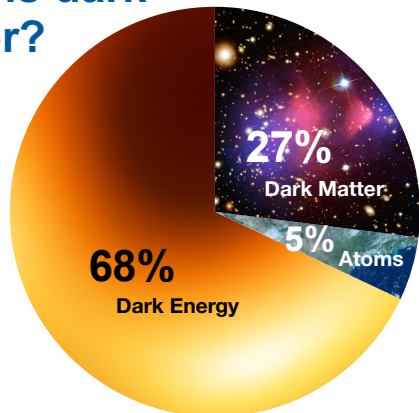


What is the structure of the vacuum?

Where did the anti-matter go?



What is dark matter?



Guiding themes for PoF IV

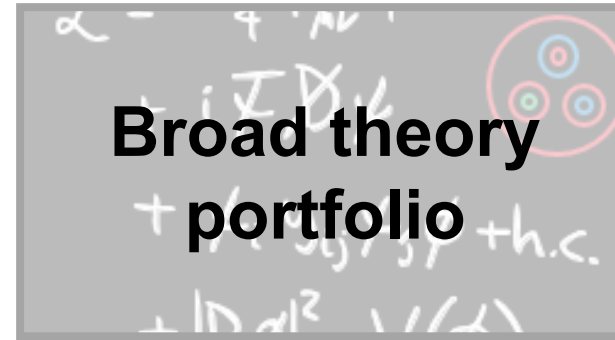
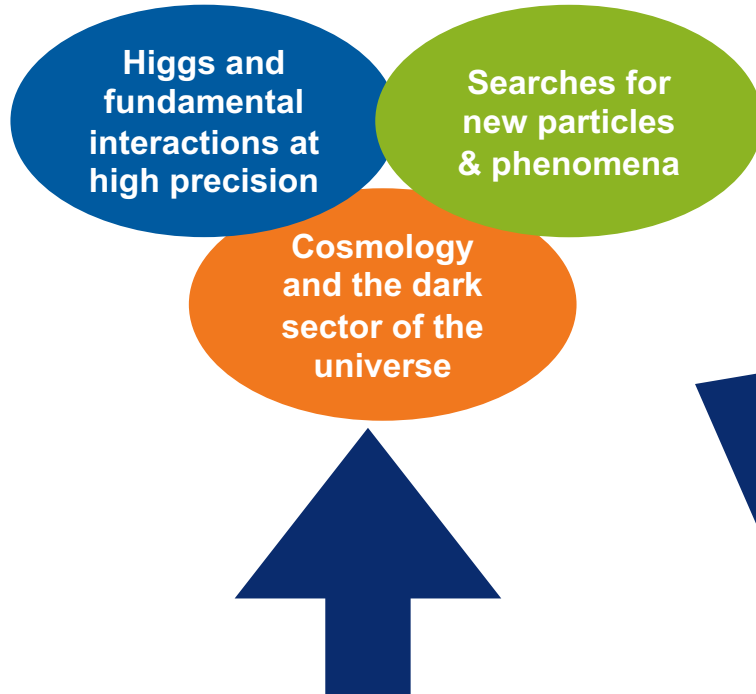
Higgs and fundamental interactions at high precision

Searches for new particles & phenomena

Cosmology and the dark sector of the universe

Topic mission and strategy

Guiding themes for PoF IV



- Collider Physics
- Particle Cosmology
- Lattice Gauge Theory
- String Theory



- Off-site experiments: ATLAS & CMS @CERN, Belle II @KEK
- Attractive on-site program: ALPS-II, Baby-IAXO, MADMAX, LUXE

Preparation of future facilities/
experiments

Infrastructures

- Testbeam
- Wolfgang Pauli Center
- Detector Assembly Facility (DAF)
- Computing centres (GridKa, IDAF)

LHC Run-3 status

Goal: double Run-2, 300fb⁻¹

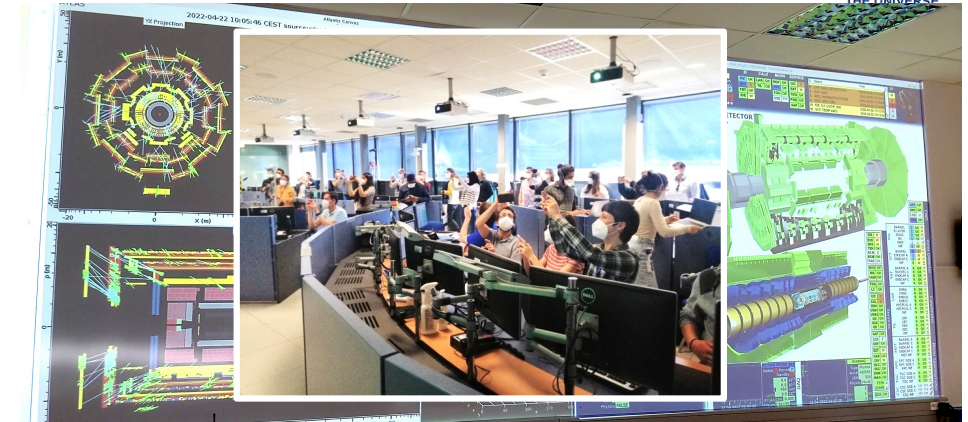
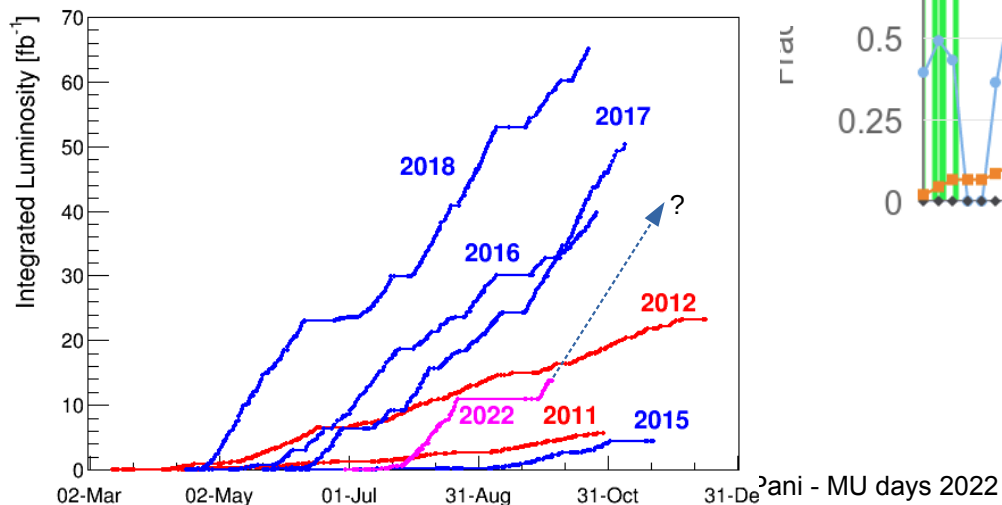
Begin of Run 3 commissioning on 22 April 2022

Begin of Run 3 13.6 TeV collisions on 5 July 2022

LHC approaching 50% stable beam availability

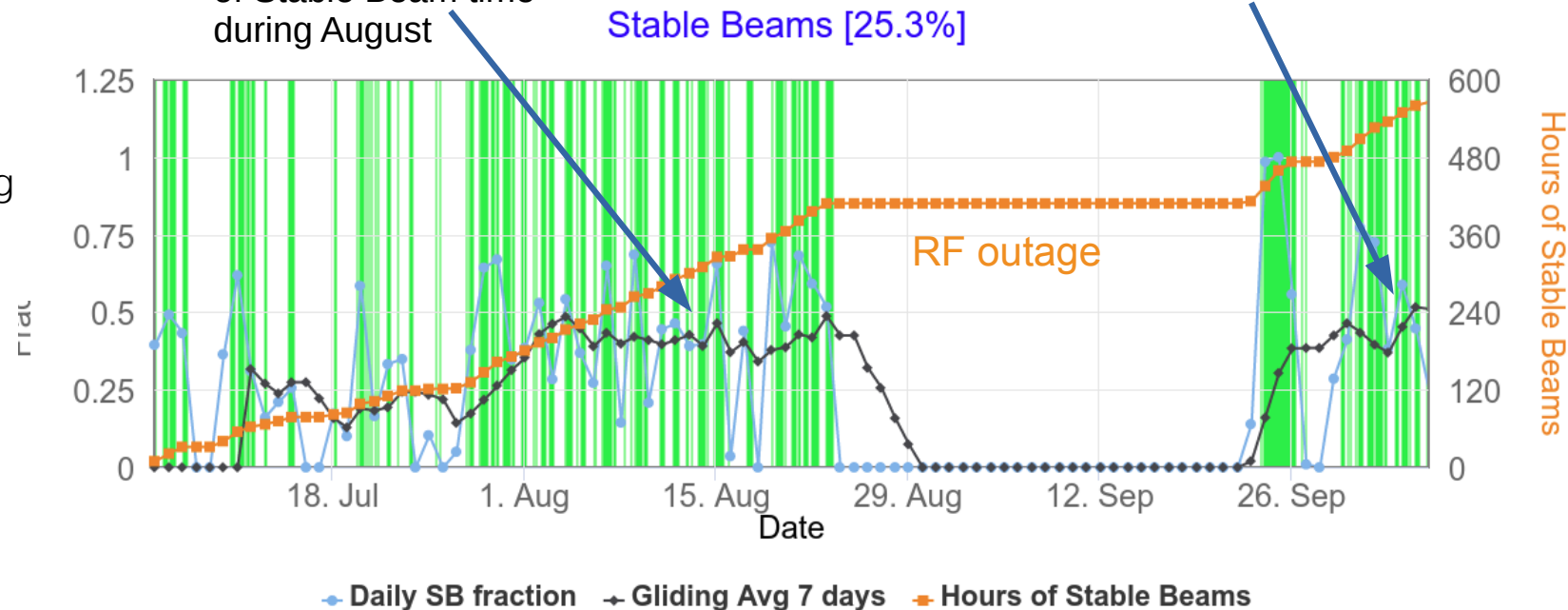
Peak luminosity limited by LHC cooling power to absorb heat load from beams

Mixed filling schemes being tested to maximise integrated luminosity within cooling and pileup constraints



Averaging around 40% of Stable Beam time during August

Reached 50% last week



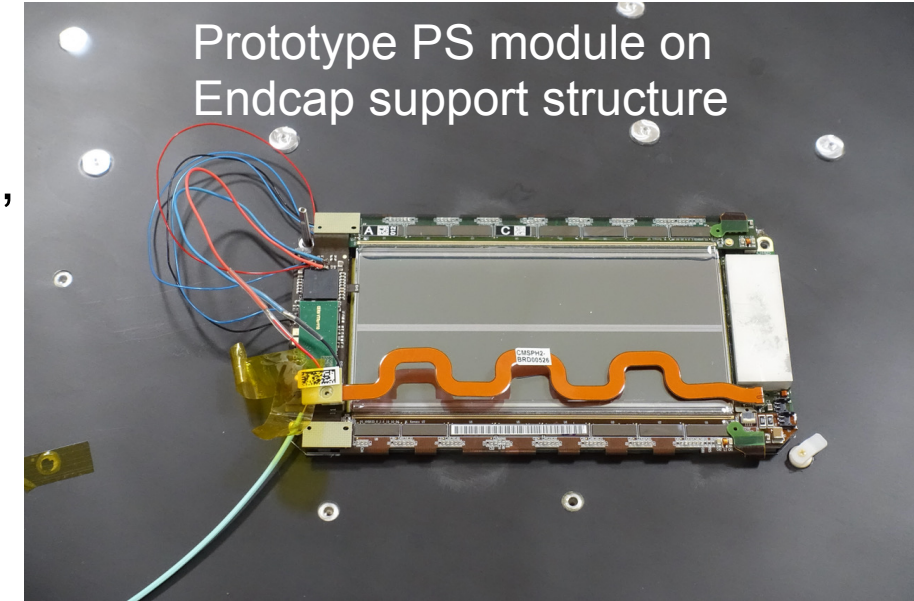
Energy saving measures:

end-of-the-year stop 2 weeks earlier

HL-LHC Upgrades status

- **ATLAS Endcap tracker upgrade:**

- Strong and highly appreciated collaboration with HU Berlin, TU Dortmund and Uni Freiburg for module production
- Site qualification almost complete and already build fully functional, special request, pre-production module



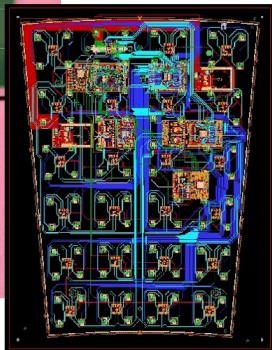
- **CMS Outer Tracker Upgrade**

- preparing for module pre-production to start in Q2/23
- expecting first pre-production endcap support structure (Dee) in Q1/23
- finalizing design of endcap integration tooling

- **CMS Endcap calorimeter upgrade (SiPM-on-Tile)**

- Turning page to production: 4000 SiPM for prototype stack and cassette arrived in summer, new system performance tests

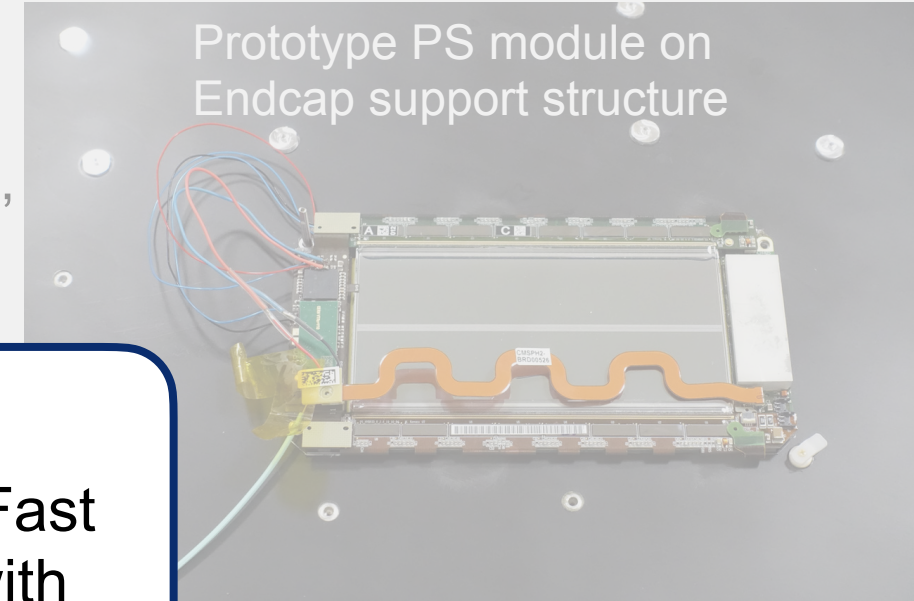
Tileboard



HL-LHC Upgrades status

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Flash talk: P. Mc Keown "Fast calorimeter simulations with Machine Learning techniques"

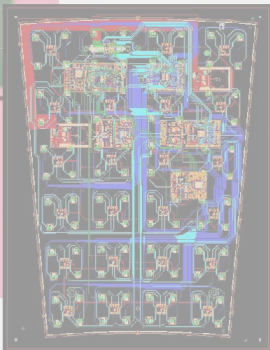
- **CMS**

- pre
- ex
- finalizing design of endcap integration tooling

- **CMS Endcap calorimeter upgrade (SiPM-on-Tile)**

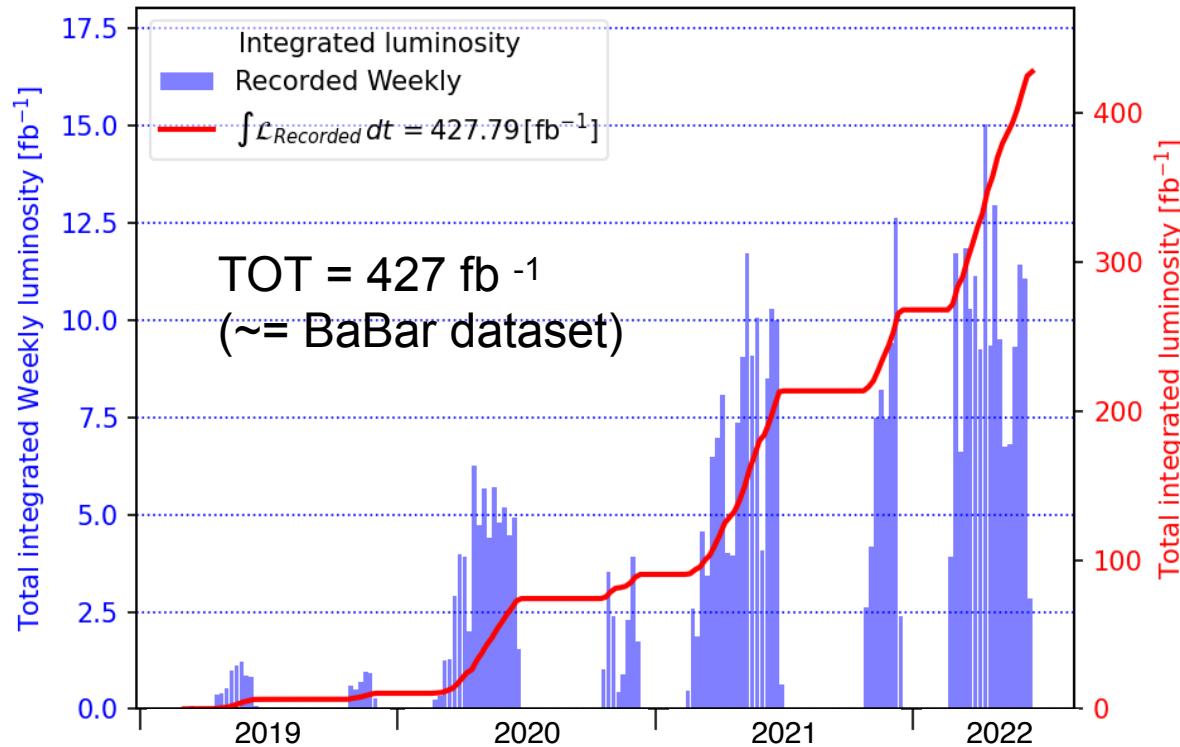
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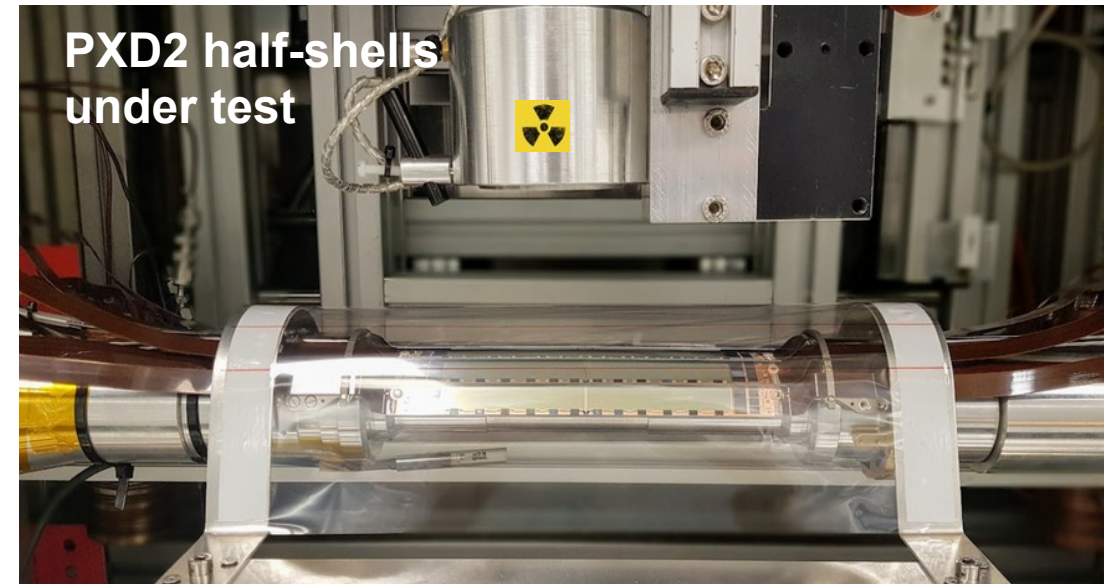
Belle II PXD2 installation status

- Despite many challenges, the first years of operation of SuperKEKB / Belle II were very successful



World-record specific luminosity! $4.65 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$
Next milestone (after Long Shutdown): $10^{35} \text{cm}^{-2} \text{s}^{-1}$

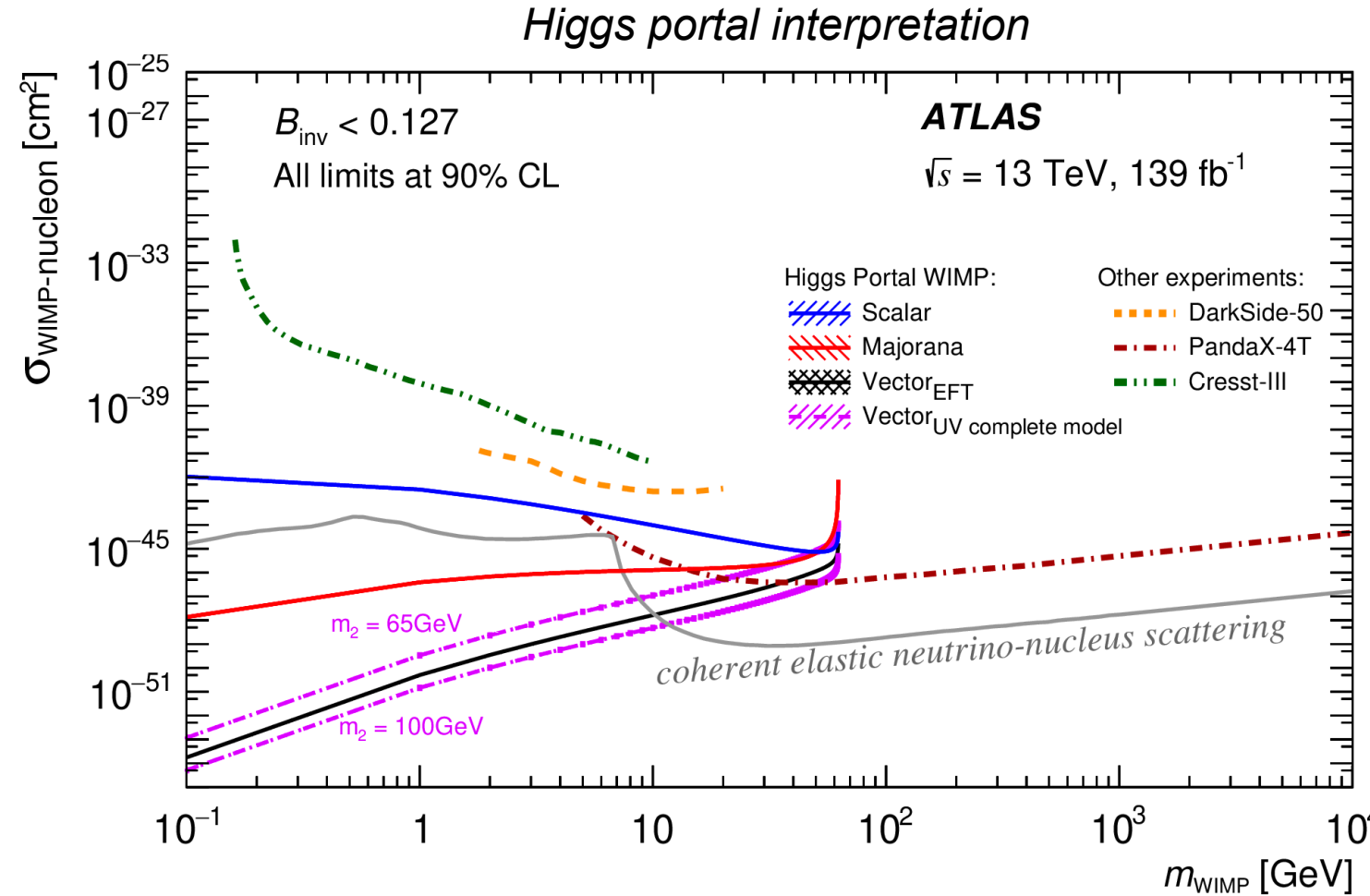
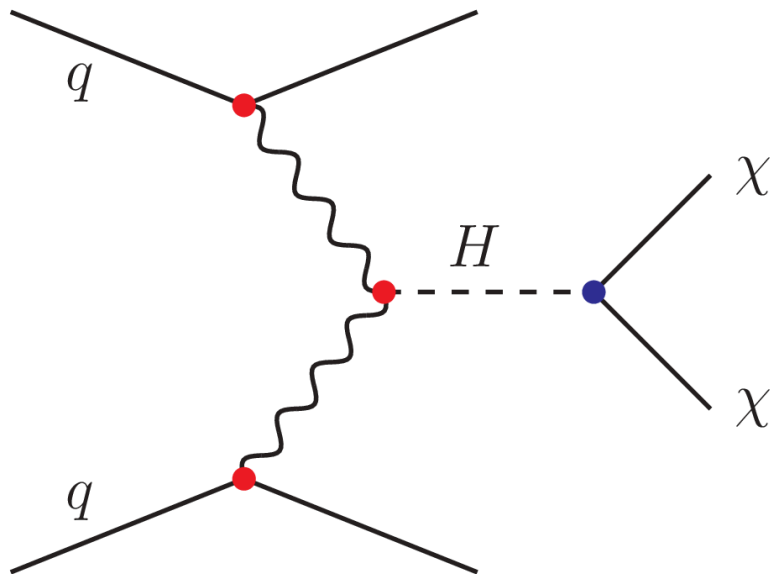
- Both PXD2 half-shells successfully assembled at MPP Munich and safely transported to DESY for commissioning
- Passed full electrical tests, optimisation with source ⁹⁰Sr
- Recent issue with two bent L1 ladders under intense investigation



Atlas highlights: invisible Higgs

Search for invisible Higgs decays with vector-boson fusion or ZH signatures

- VBF: $\text{BR}(H \rightarrow \text{inv}) < 14.5\%$
([JHEP 08 \(2022\) 104](#))
- ZH: $\text{BR}(H \rightarrow \text{inv}) < 19\%$
([PLB 829 \(2022\) 137066](#))



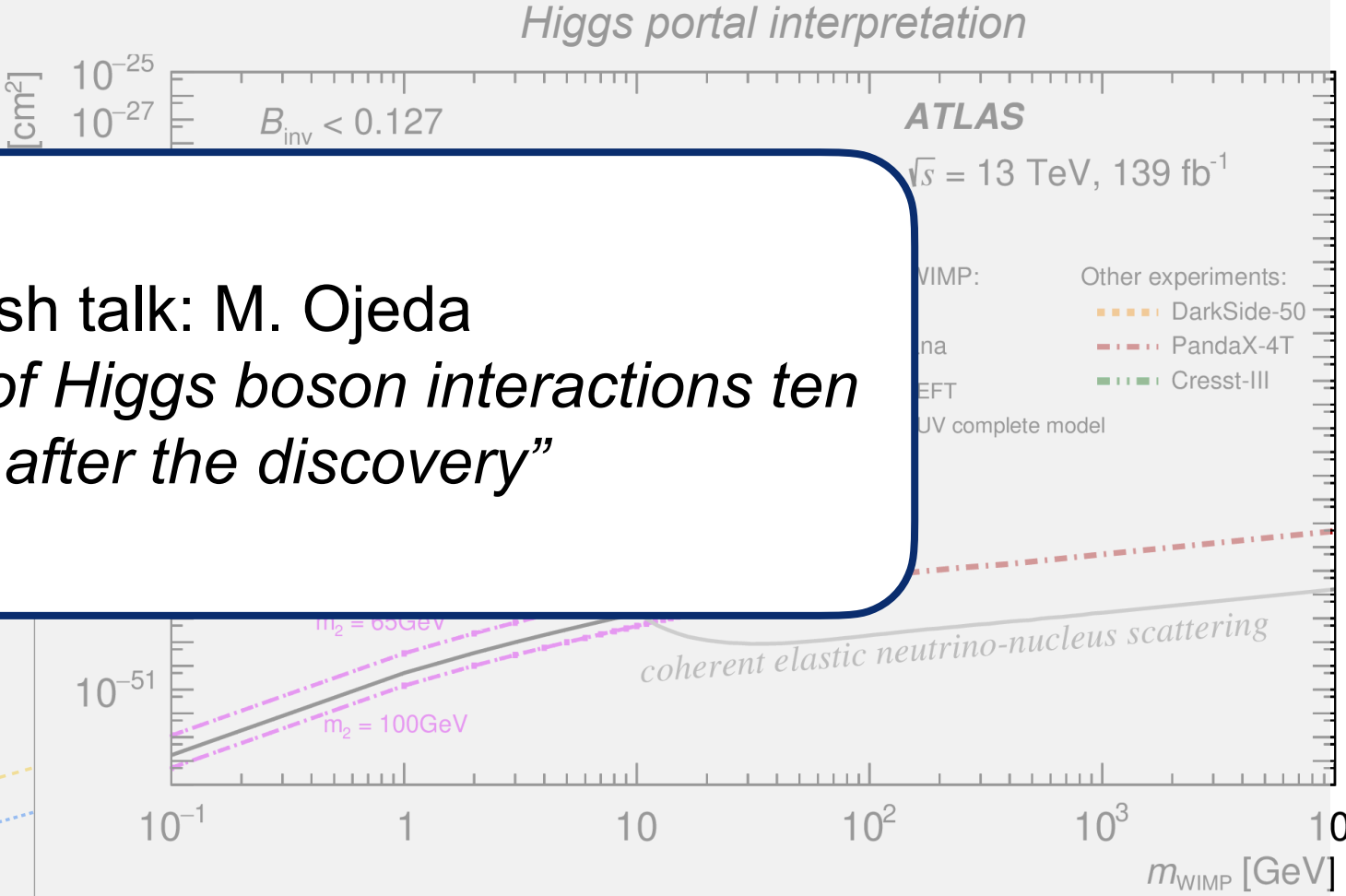
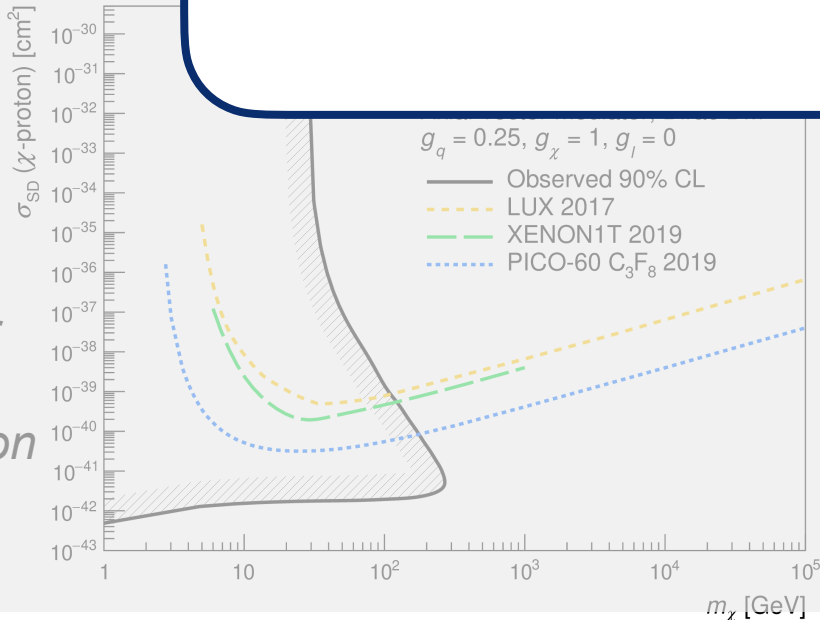
WIMP = Weakly Interactive Massive Particles

Search for invisible Higgs decays with vector-boson fusion or ZH signatures

- VBF: BR ($H \rightarrow \text{inv}$) (JHEP 08 (2022))
- ZH: BR ($H \rightarrow \text{inv}$) (PLB 829 (2022))

Flash talk: M. Ojeda
“A detailed map of Higgs boson interactions ten years after the discovery”

dark matter scattering interpretation



CMS highlights: first Run-3 result

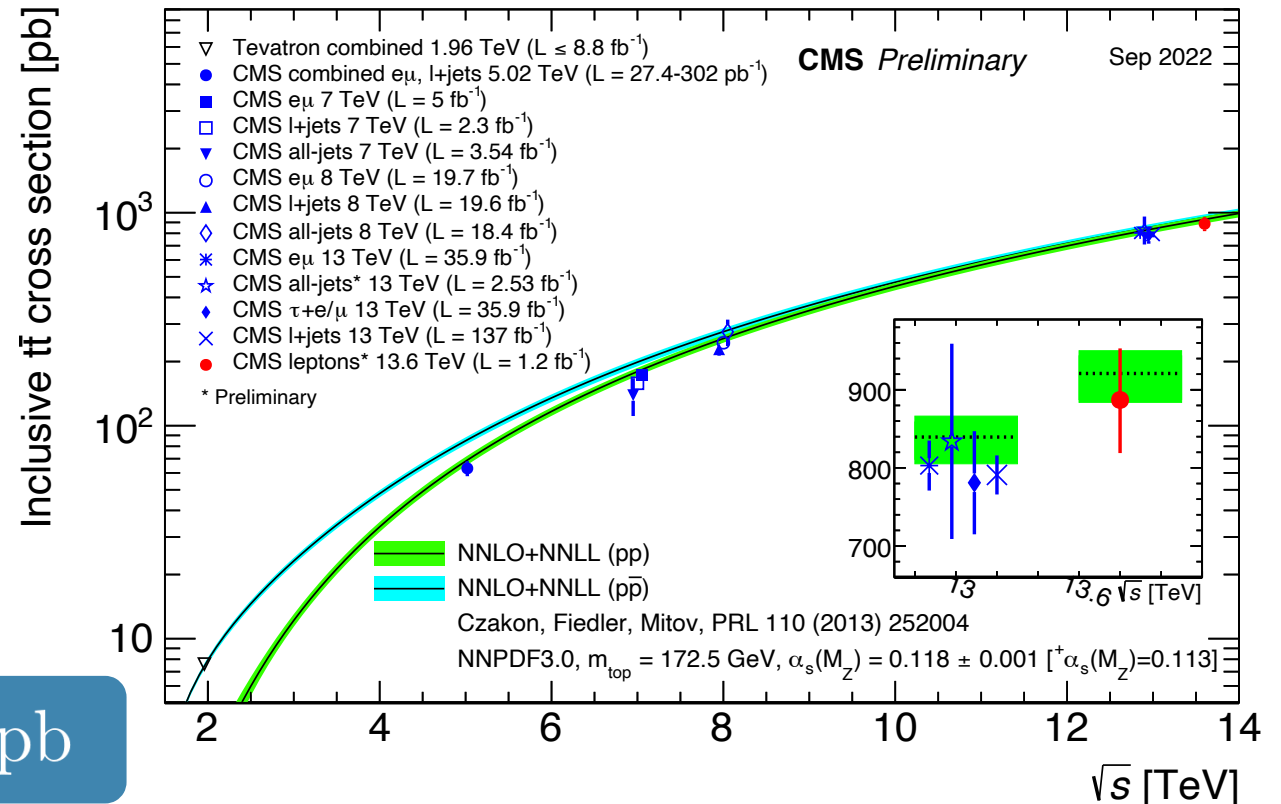
First measurement of the top quark pair production cross section in pp collisions at 13.6 TeV

- New technique: by combining multiple channels,
- Method validated on Run 2 data, use also for in situ calibration
- Measurement consistent with prediction

$$\sigma_{t\bar{t}} = 887^{+43}_{-41}(\text{stat} + \text{sys}) \pm 53(\text{lumi}) \text{ pb}$$

Presented at
TOP 2022

CMS-PAS-TOP-22-012



CMS highlights: harvest of Run-2

VH→bb full Run 2 analysis Simplified Template Cross Sections

- Brand new result at HiggsHunting conference
- CMS-PAS-HIG-20-001

Search for heavy neutral Higgs bosons in the $\tau\tau$ final state in the MSSM scenario

- Two excesses in $gg\rightarrow\phi$, local significance 3σ at masses of 0.1 and 1.2 TeV
- arXiv:2208.02717, submitted to JHEP

Flash talk: S. Amoroso

“From the precision frontier to physics beyond the SM”

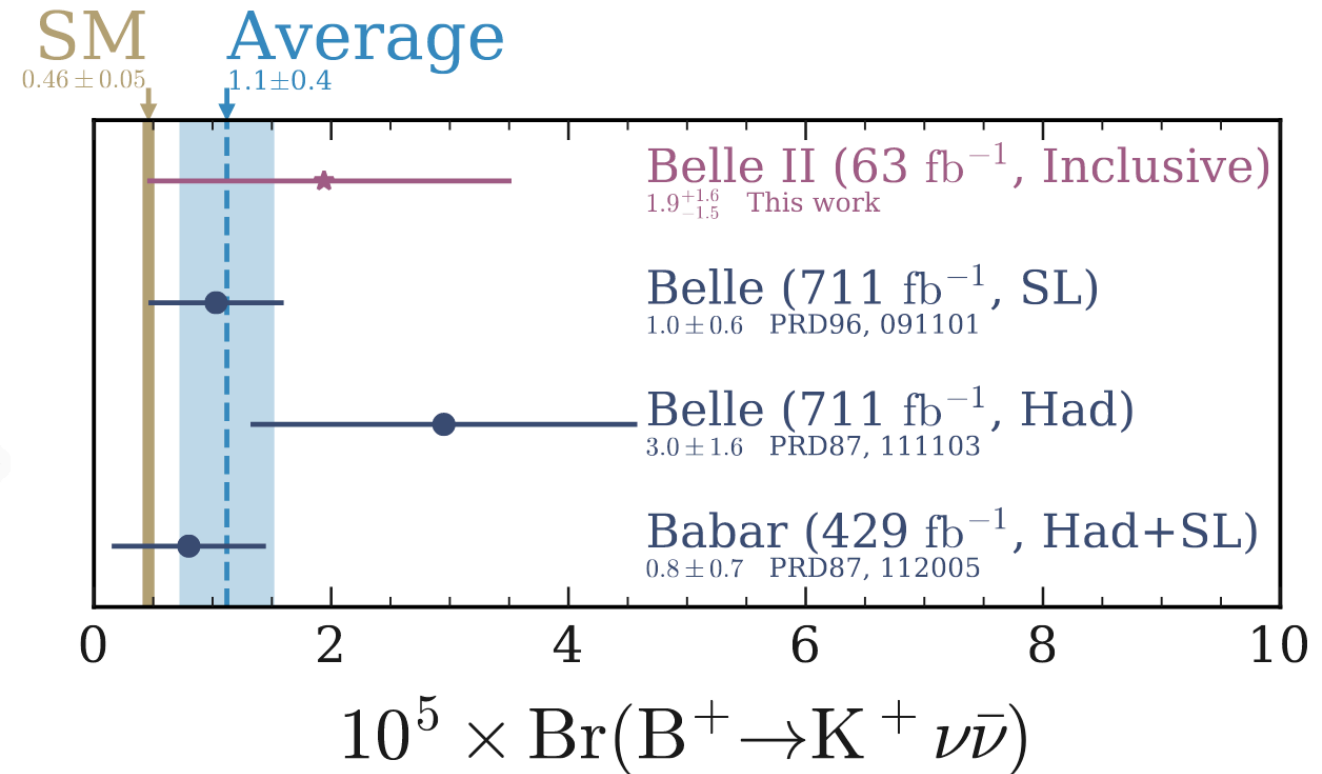
Belle II highlight: Search for $B^+ \rightarrow K^+ \nu \bar{\nu}$

- FCNC $b \rightarrow s \nu \bar{\nu}$ powerful probe of the Standard Model, highly sensitive to new physics
 - Complementary to $b \rightarrow s \ell \ell$ results, which show a tension with respect to SM
 - No charged leptons in the final state \rightarrow clean and accurate theoretical predictions

- Publication to be ready by December 2022 - Moriond 2023 with both inclusive and hadronic K^+ tag, full 400/fb dataset

Also Flash talk: E. Ganiev
"LFU violation and prospects
at Belle II"

MU days 2022

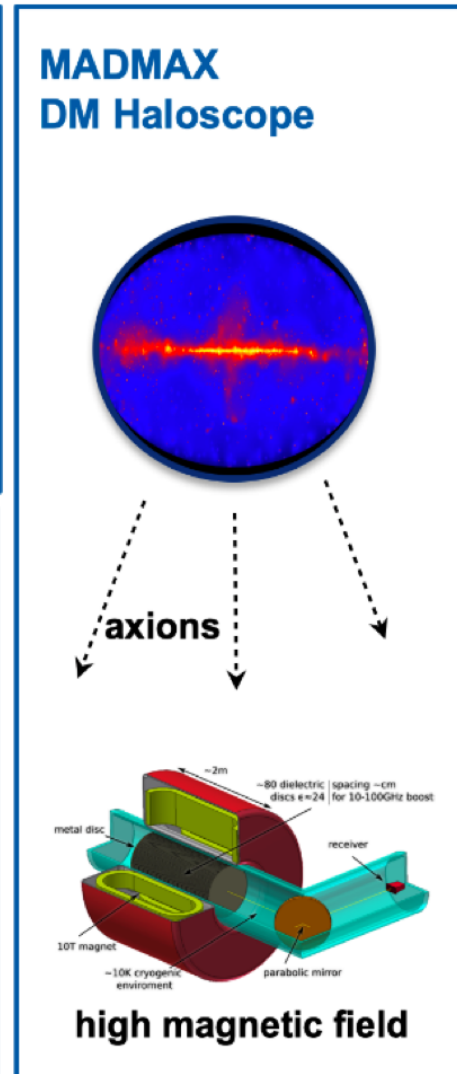
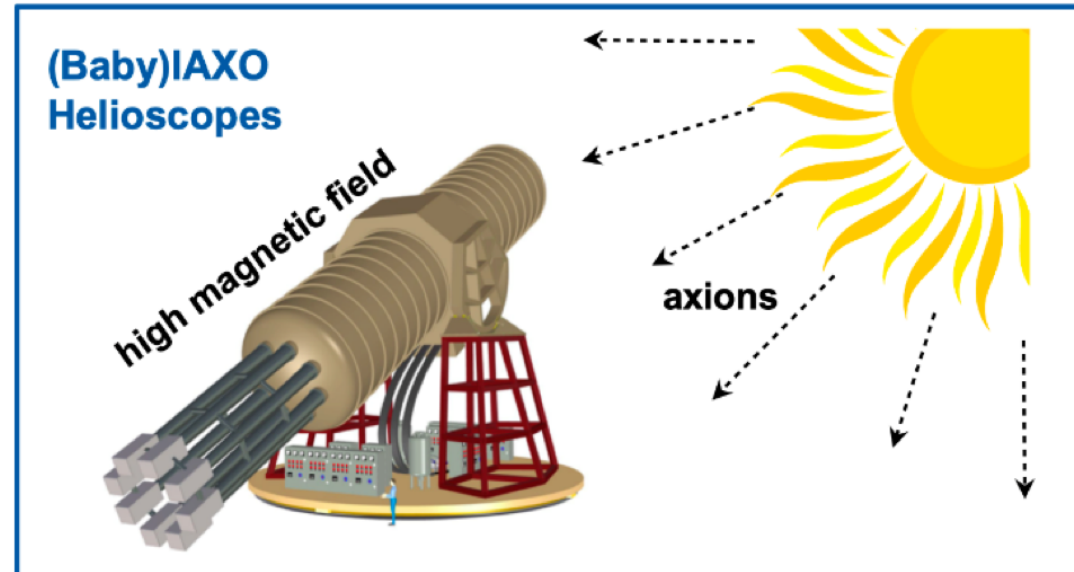
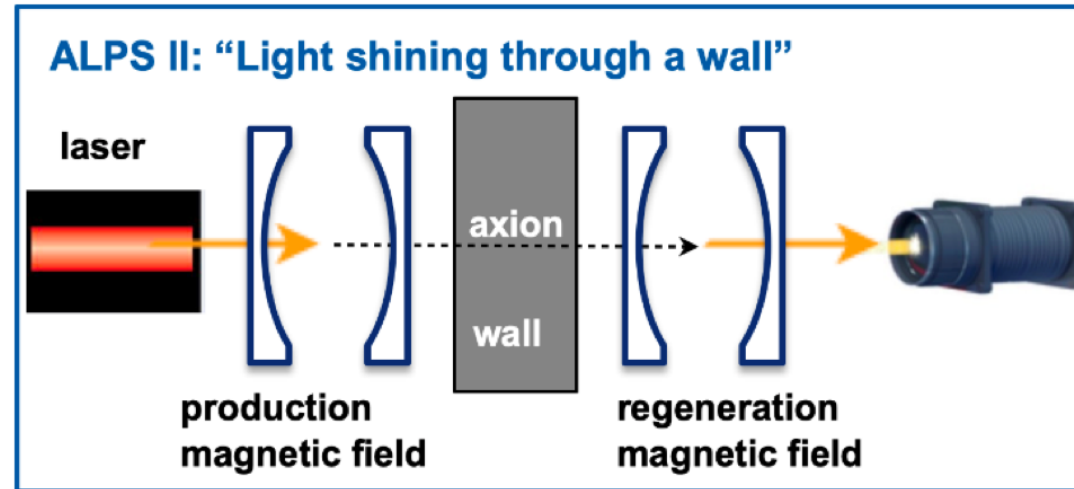


Competitive results already with 63 fb⁻¹

On-site Axions experiments

Towards Axions/ALPs
observation

- Haloscopes: looking for dark matter constituents
- Helioscopes: Axions emitted by the sun
- Purely laboratory experiments “light-shining-through-walls”



On-site Axions experiments

MADMAX

MAagnetized **D**isc and **M**irror **A**xion **eX**periment

- Status: significant progress in the prototyping phase
- Magnet Conceptual Design and successful tests CEA
- Booster prototyping (CERN) and calibration
- Enabling technologies: dielectric disks handing/ mounting, piezo motor tests



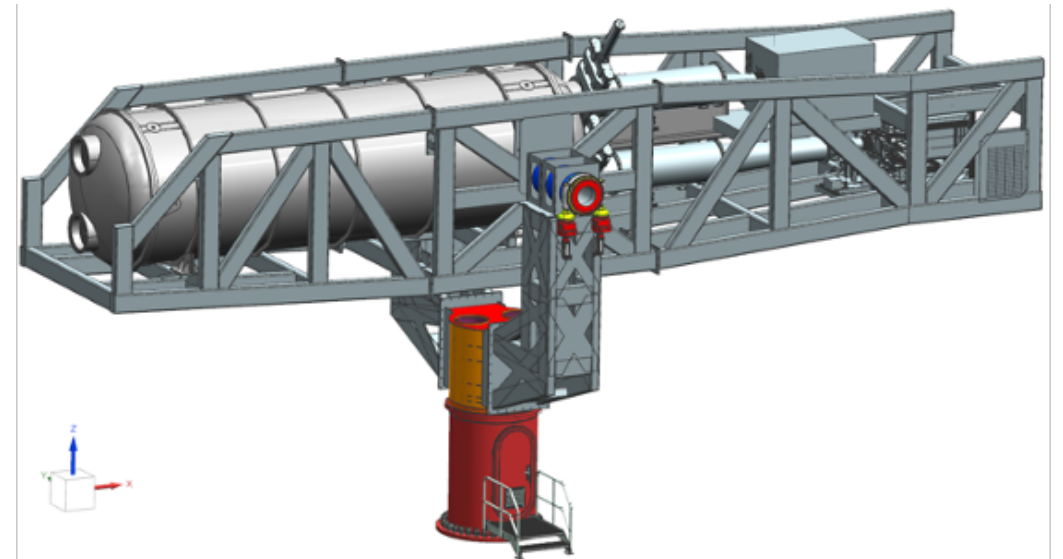
Further schedule beyond using MOPURGO prototype at CERN subject to funding

On-site Axions experiments

BabyIAXO

International AXion Observatory

- Status: ready for construction but no magnet conductor
- X-ray optics, low-background detector and structure and drive all finished or close to be
- Magnet providing dipole fields in the bores, challenging concept, “dry” detector magnet. No vendor for Al-stabilized superconducting cables since Russian invasion of Ukraine



On-site Axions experiments

ALPSII Any Light Particle Search II

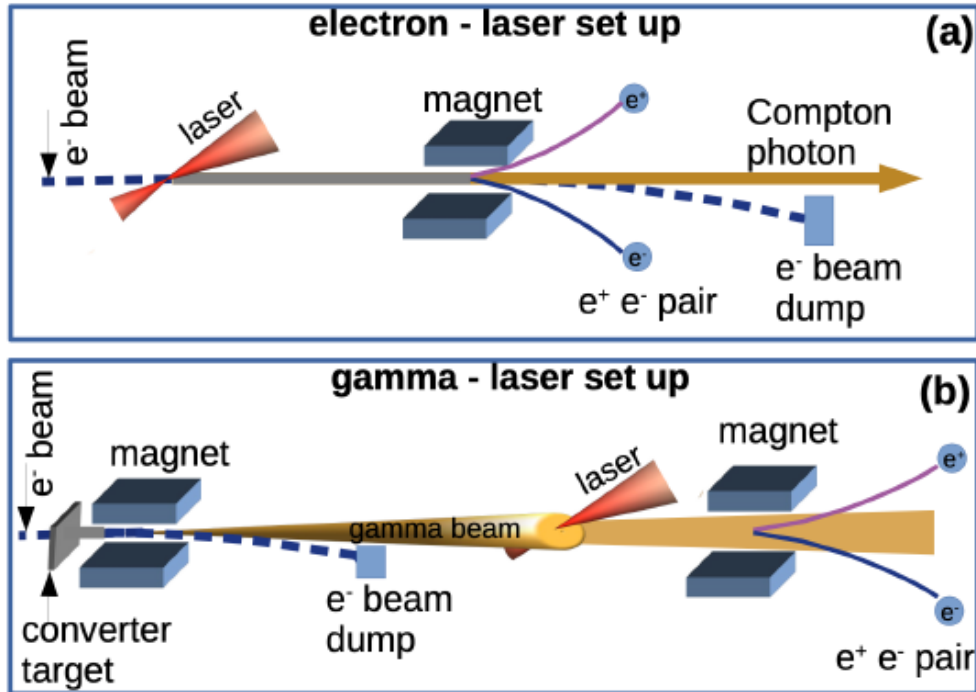


125 m regeneration
cavity storage time:
6 ms! (world record)

- Installation completed, all components operational
- 2022 / early 2023 start of the first science run!



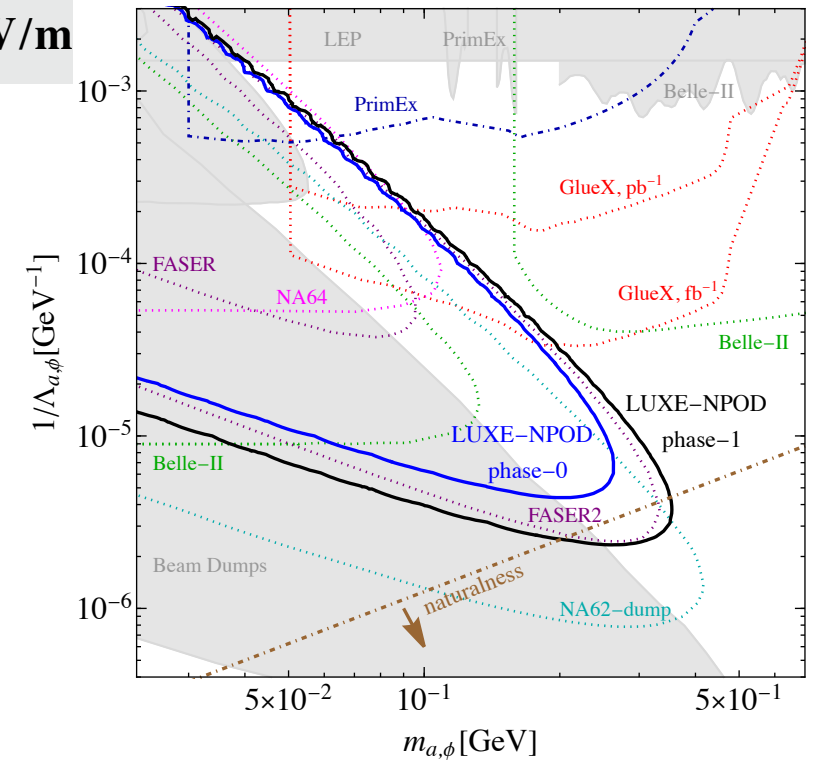
On-site experiments: LUXE



- First time measurement of non-perturbative QED in strong fields (Schwinger critical field)

$$\varepsilon_{crit} = \frac{m_e^2 c^3}{\hbar e} \simeq 1.3 \cdot 10^{18} \text{ V/m}$$

- Discovery potential for axions



- Collaboration of particle, accelerator and laser physicists
- Ongoing infrastructure and detector designs

2022

2024

2025-

Review
process

Construction

Installation &
commissioning

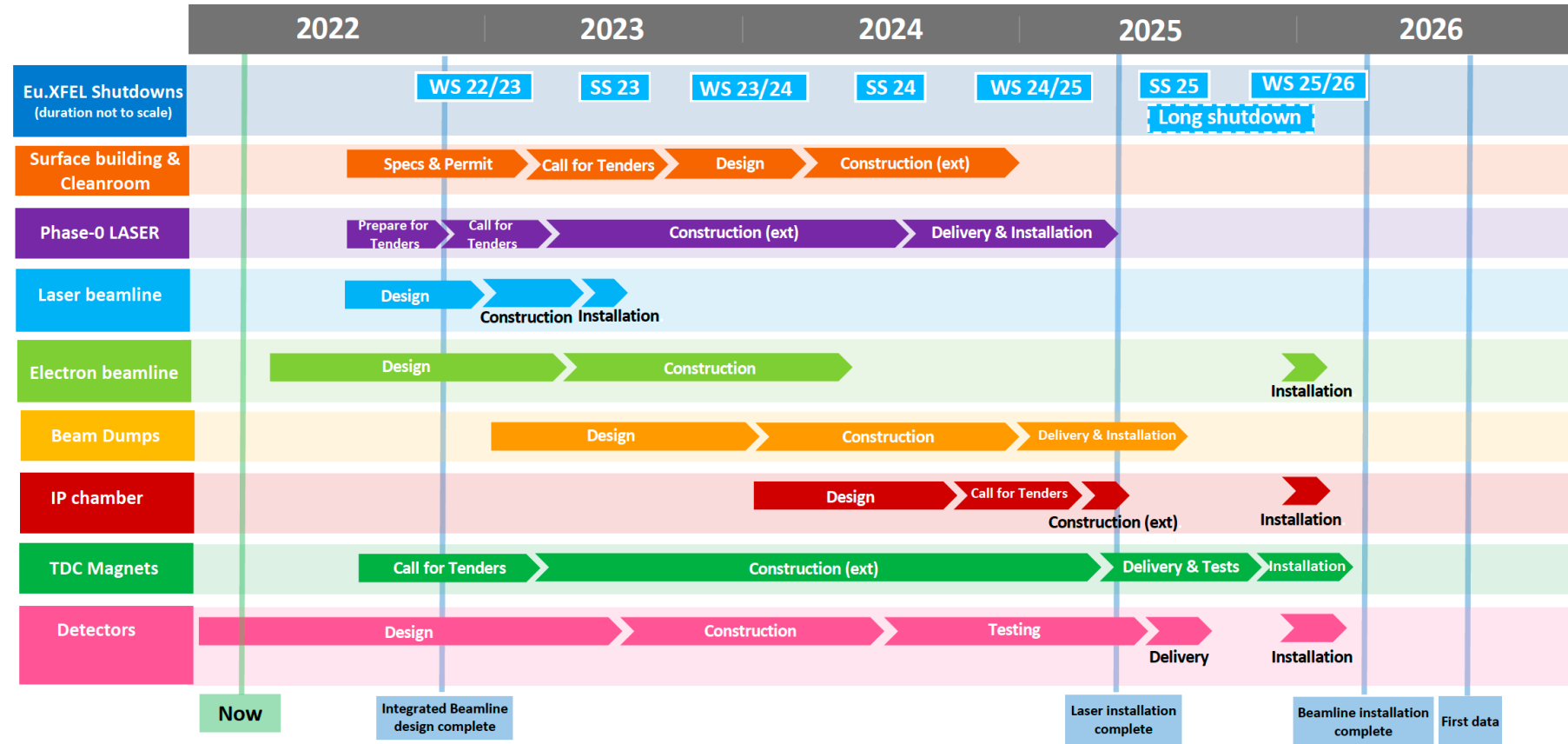
Physics Run

On-site experiments: LUXE

- Conceptual Design Report, passed DESY CD0
- Undergoing CD1 review

Flash talk: Yee Chinn Yap
"Updates on LUXE and quantum computing"

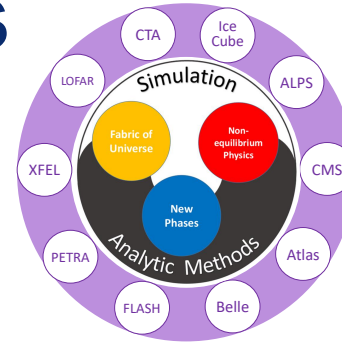
LUXE bare-bones major items timeline



DESY. Note: Integrated design of experiment beamline needed early to start survey, markings etc.. Production design of individual components can be staggered. Page 6

Theoretical developments

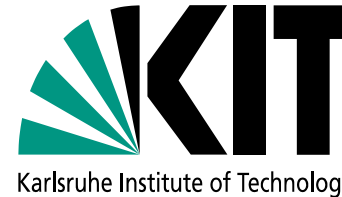
- Building construction for the Wolfgang Pauli Center
- Coherent interfaces between theory and experiments for Higgs physics, B-physics and new particles models
- Cosmological implications of Higgs and dark matter
- Precise predictions for Standard Model physics and beyond



Higgs and
fundamental
interactions at
high precision

Searches for
new particles
& phenomena

Cosmology
and the dark
sector of the
universe



Flash talk: J. Braathen
“New constraints on extended Higgs sectors from the trilinear Higgs coupling”

Flash talk: L. Biermann
“Electroweak Baryogenesis in extended Higgs sectors”

Constraining the CP structure of Higgs-fermion couplings

- Comparison with existing EDM constraints
- Could work for CP violation just in the τ couplings (optimistic scenario)
- Collaboration between experiment (ATLAS) and theory

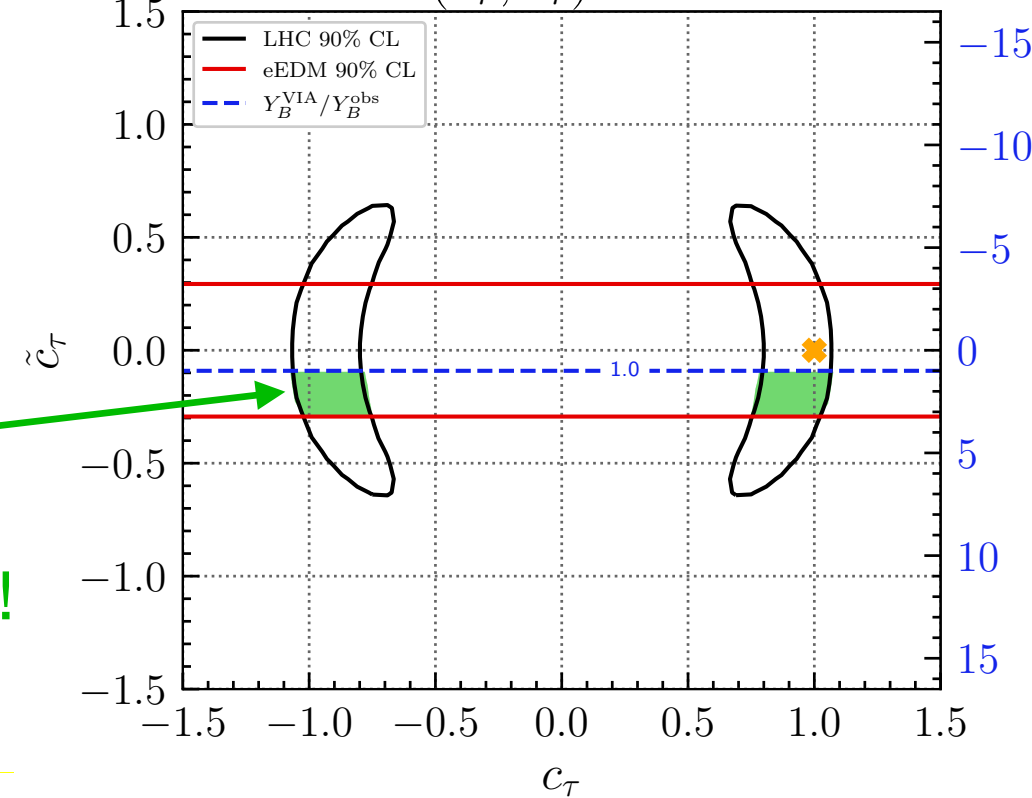
Eur.Phys.J.C 82 (2022) 7, 604

$$\mathcal{L}_{\text{yuk}} = - \sum_{f=u,d,c,s,t,b,e,\mu,\tau} \frac{y_f^{\text{YIA}}}{\sqrt{2}} \bar{f} (c_f + i\gamma_5 \tilde{c}_f) f H$$

(c_τ, \tilde{c}_τ) free

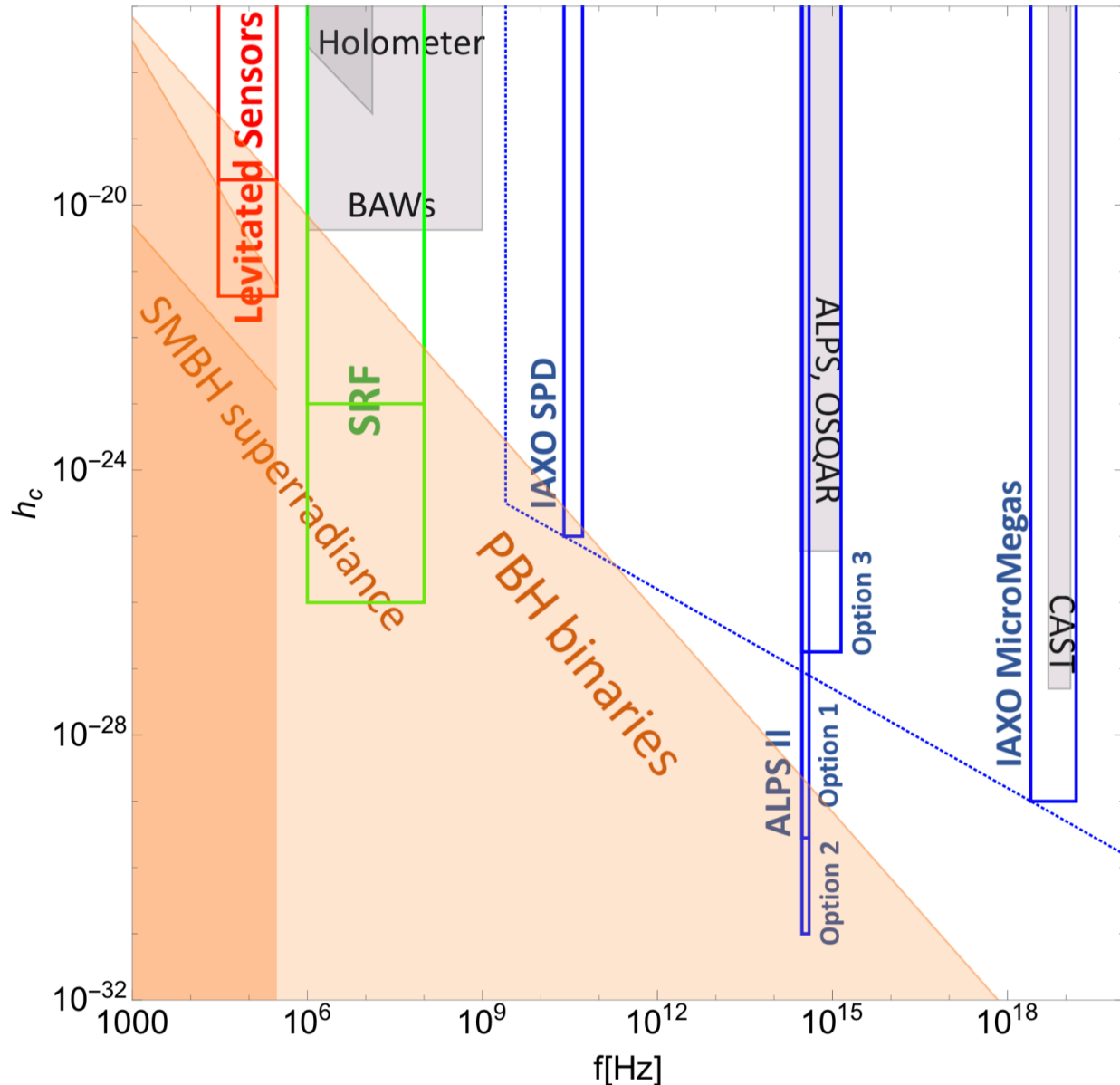
Electron electric
dipole moment
 $d_e \propto \tilde{c}_f$

Allowed by LHC,
EDM constraints
and baryogenesis!



⇒ Can predict correct amount of baryon asymmetry!

Bonus: Gravitational wave experiments & particle physics

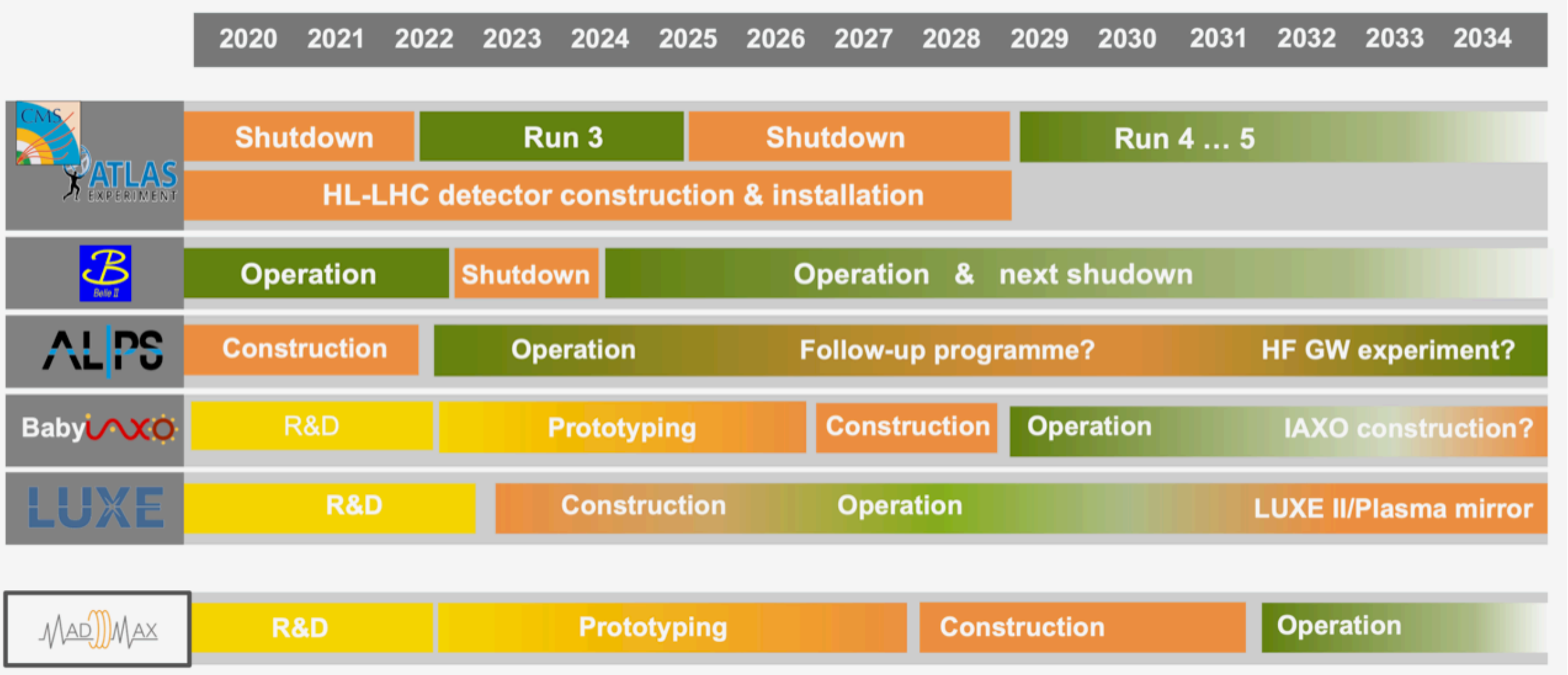


- Task force assessed particle physics opportunities of high-frequency Gravitational Waves
- Good potential in the exploitation of local axion experiments (and infrastructures) for the detection of coherent (in the plot) and stochastic sources of GW
- Explore further local follow-ups based on levitated sensors and SRF cavities
 - R&D required
 - large additional sensitivity

Sources:

Planetary or asteroid mass primordial black holes (PBH)
Stellar mass Black Holes (SMBH)

Conclusions



Looking forward to the exciting scientific program ahead!

backup

The ALPS II program

A very tentative schedule

- 2023, Q1+2: initial HET science run without the production cavity (optimized for stray light search)
- 2023, Q3+4: HET science run with full optical system
- 2024, Q1+2: HET science run with upgraded optics

The further scheduling depends on the outcome of the HET science run, results of ongoing R&D, resources and world-wide science advancements.

The future program will include (from today's perspective):

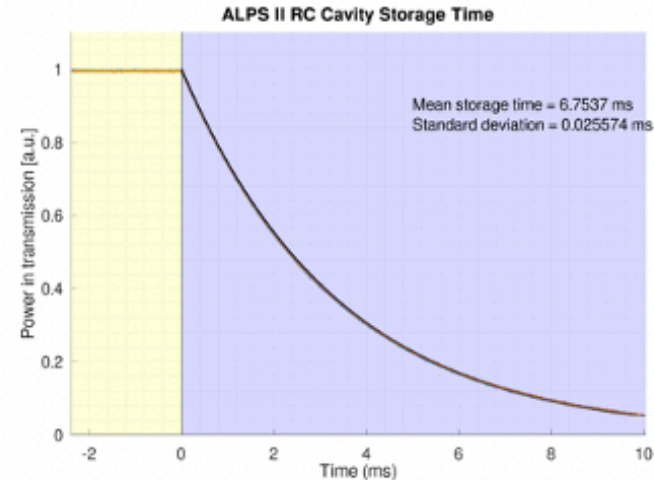
- TES based science run
- Vacuum magnetic birefringence measurement
- WISP searches with optimized optics and/or extension of the ALP mass reach
- Dedicated search for high frequency gravitational waves

ALPS II might turn into a multi-purpose research infrastructure.

Any Light Particle Search II

Recent milestones

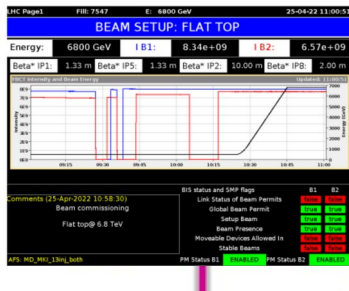
- Spring 2021: start of optics installation.
- June 2021: lock of 250 m long optical resonator, characterization of optics and seismic noise studies.
- September 2021: all magnets aligned and connected.
- December 2021: magnet string reaches operation temperature of 4 K.
- March 2022: magnet string reaches full operation current of 5.7 kA.
- May 2022: regeneration cavity test-installation and -lock.
- June 2022: world-record cavity storage time.
- September 2022: installation of central optical bench for first science run.
- **Late 2022 / early 2023: start first science run (hopefully)!**



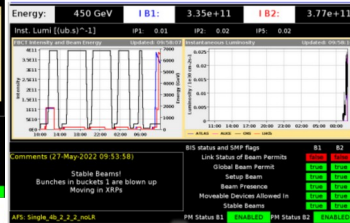
125 m regeneration
cavity storage time:
6 ms! (world record)

LHC run 3 so far

April 25th
First protons at 6.8 TeV



May 27th
Collisions at injection



July 5th
Start of Run 3 physics



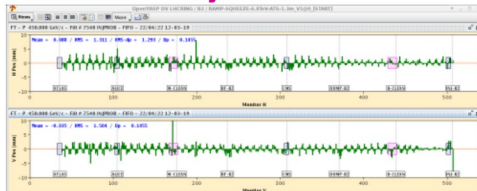
August 23rd
Accidental cooling stop leads to Helium release from RF cavities – warm up and conditioning of RF cavities required – 4 week stop



November 28th
End of 2022 run

April May June July August September October November

April 22nd
First beam injection



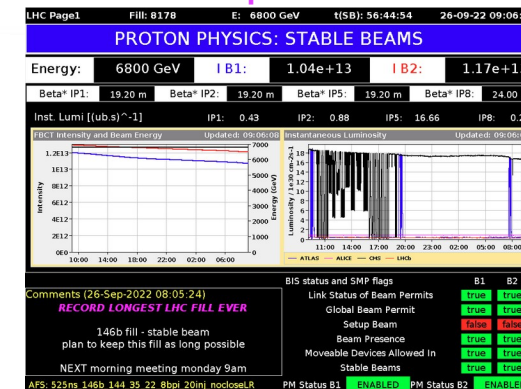
June 1st
Collisions at 6.8 TeV



August 3rd
> 2000 bunches



September 23rd
Restart with longest ever fill for LHCf special run



**Vielen
Dank**