

# LOOKING FORWARD TO NEW PHYSICS: THE **FASER** EXPERIMENT AT THE CERN LHC

From searches for weakly interacting particles  
to first measurements of collider neutrinos



HEP 2022

15-18 June 2022

ARISTOTLE  
UNIVERSITY  
OF THESSALONIKI



Άννα Σφύρλα

UNIVERSITÉ  
DE GENÈVE

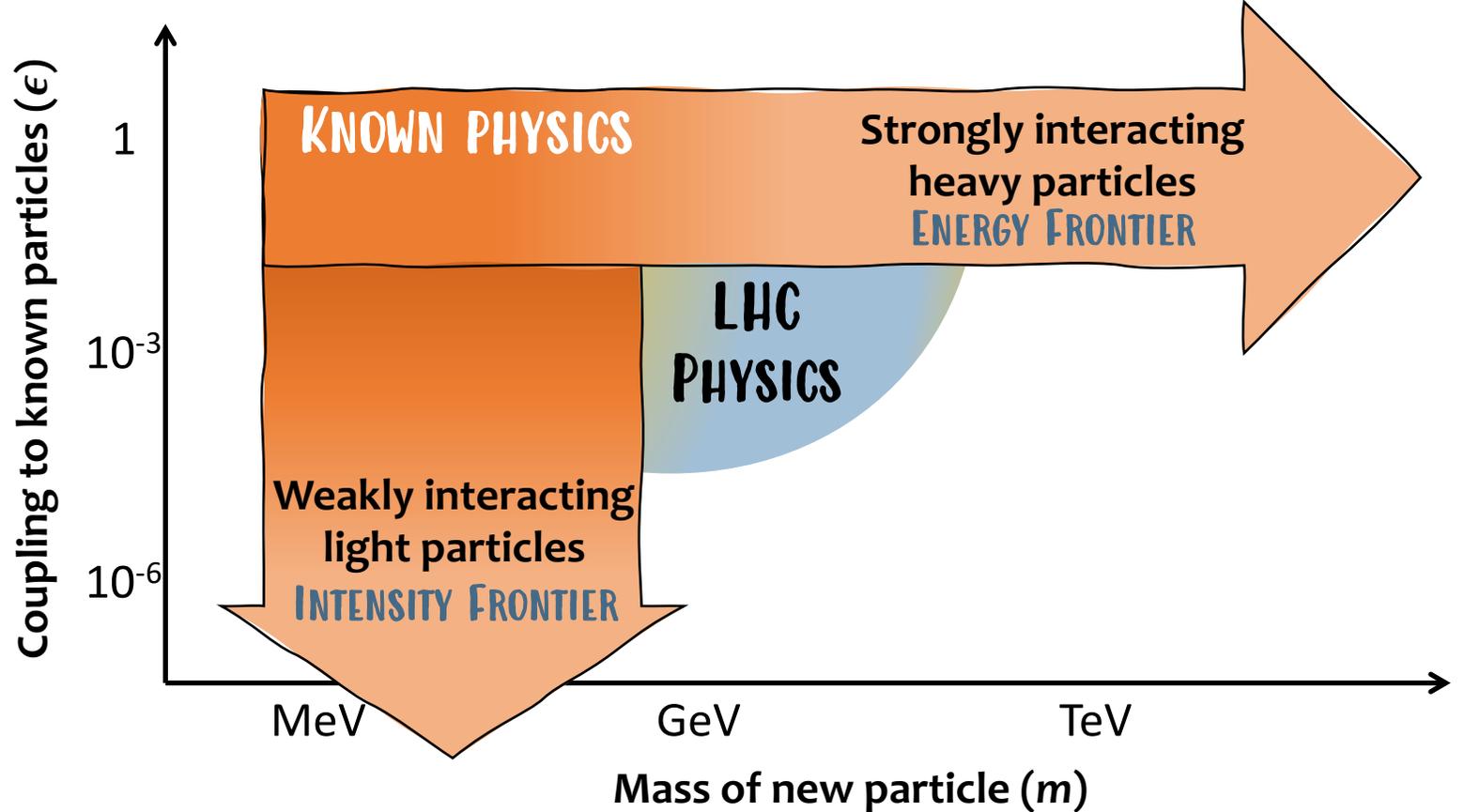
FACULTY OF SCIENCE

# THE LANDSCAPE OF NEW PARTICLES @ COLLIDERS

# THE LANDSCAPE OF NEW PARTICLES @ COLLIDERS

- Collider physics: a plethora of measurements and searches
- The Standard Model is complete and confirmed; Burning questions still remain!

	2.4 MeV	1.3 GeV	170 GeV	0
	u	c	t	$\gamma$
	4.8 MeV	104 MeV	4.2 GeV	0
	d	s	b	g
	<2 eV	<2 eV	<2 eV	91 GeV
	$\nu_L$	$\nu_M$	$\nu_H$	Z
	0.5 MeV	16 MeV	1.8 GeV	80 GeV
	e	$\mu$	$\tau$	W
				126 GeV
				H



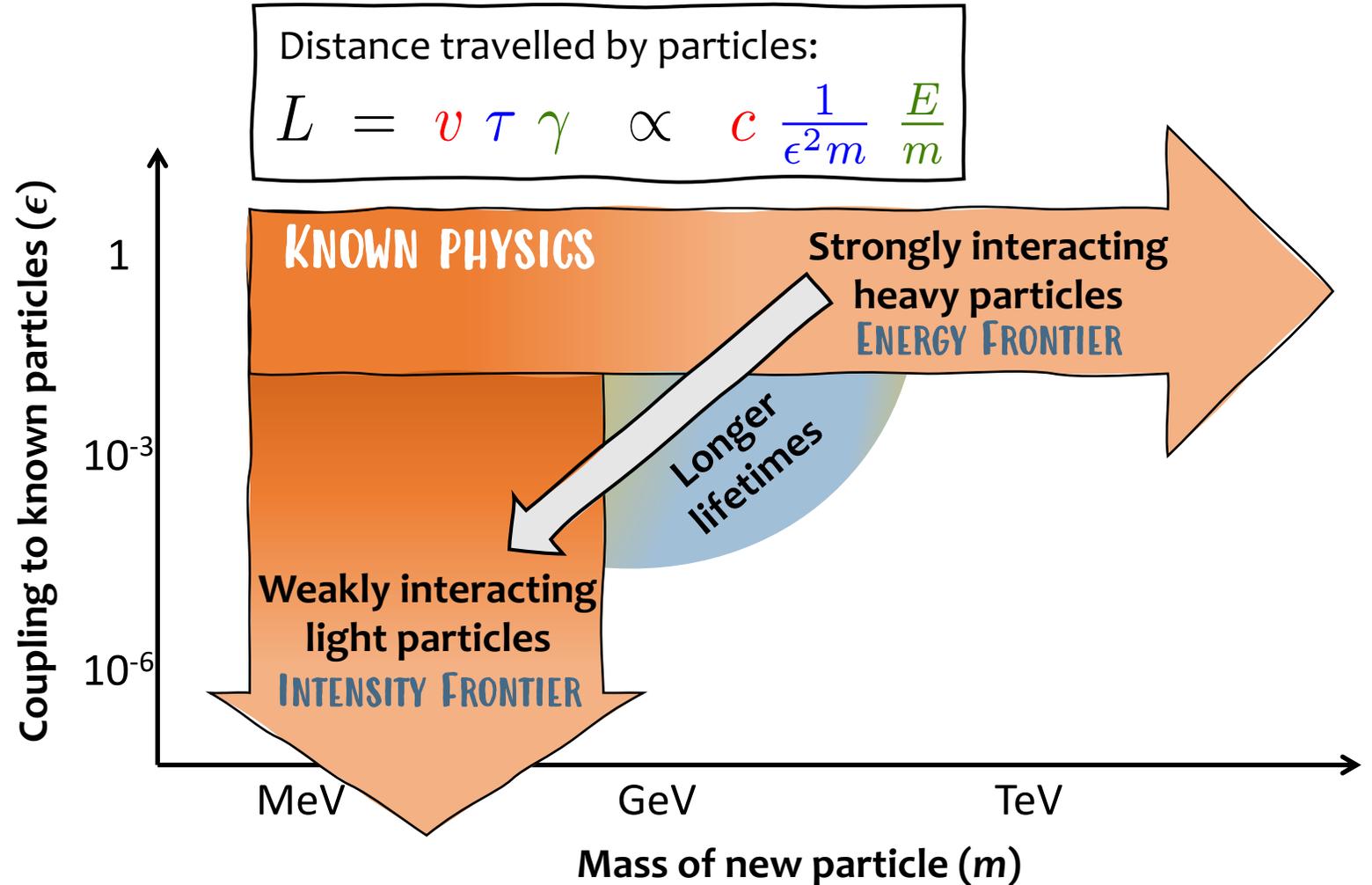
# THE LANDSCAPE OF NEW PARTICLES @ COLLIDERS

## Lifetime

a characteristic of weakly interacting light particles

Distinct signatures

Opportunity for exploration!

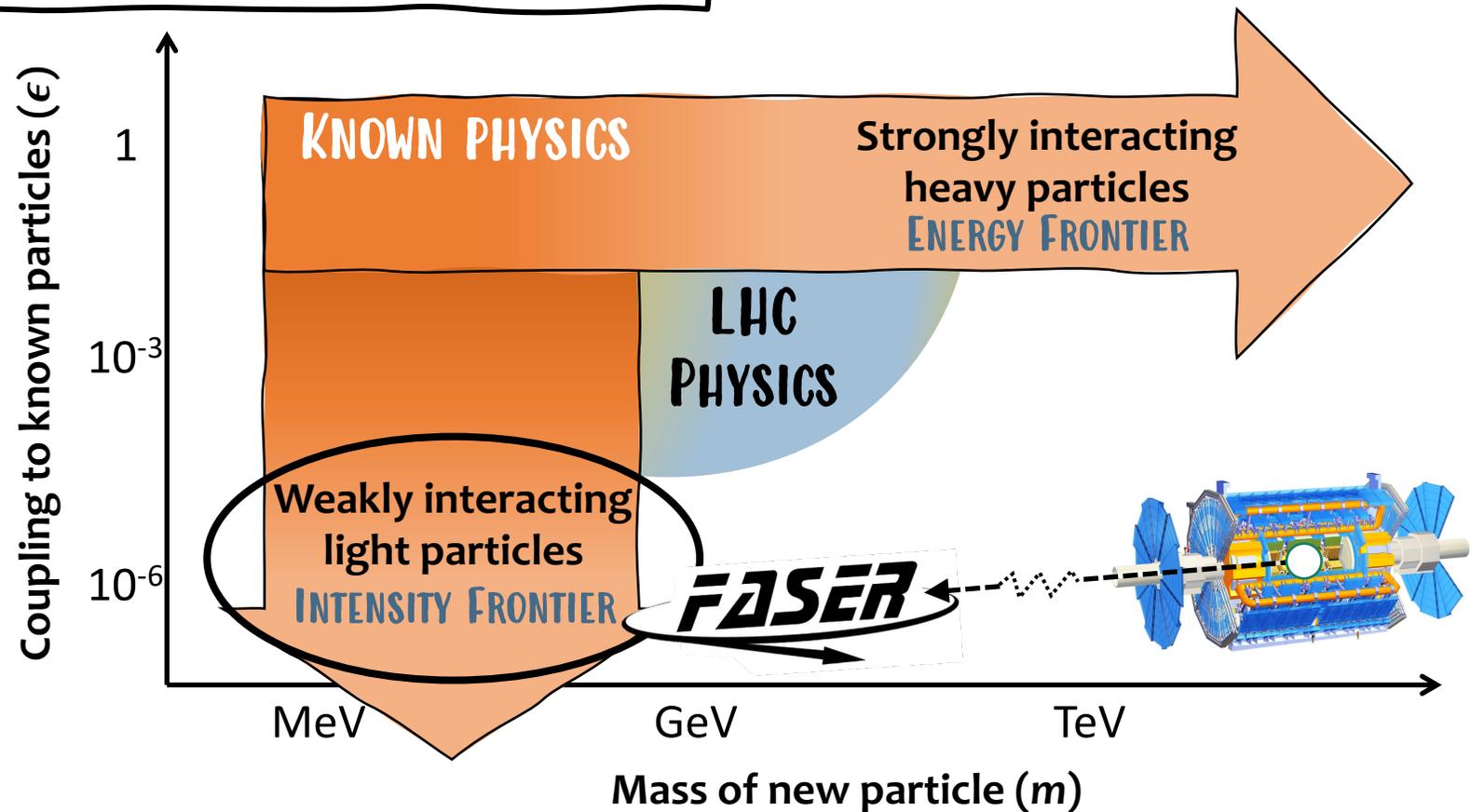


# THE *FASER* EXPERIMENT

## SEARCHES FOR NEW WEAKLY-INTERACTING LIGHT PARTICLES

New particles produced in decays of light mesons (e.g.  $\pi$ ,  $K$ ), copiously present at zero angle, escaping detection in ATLAS/CMS

$2 \times 10^{-6}\%$  solid angle but still  $O(10^{14}) \pi$  in 150/fb!

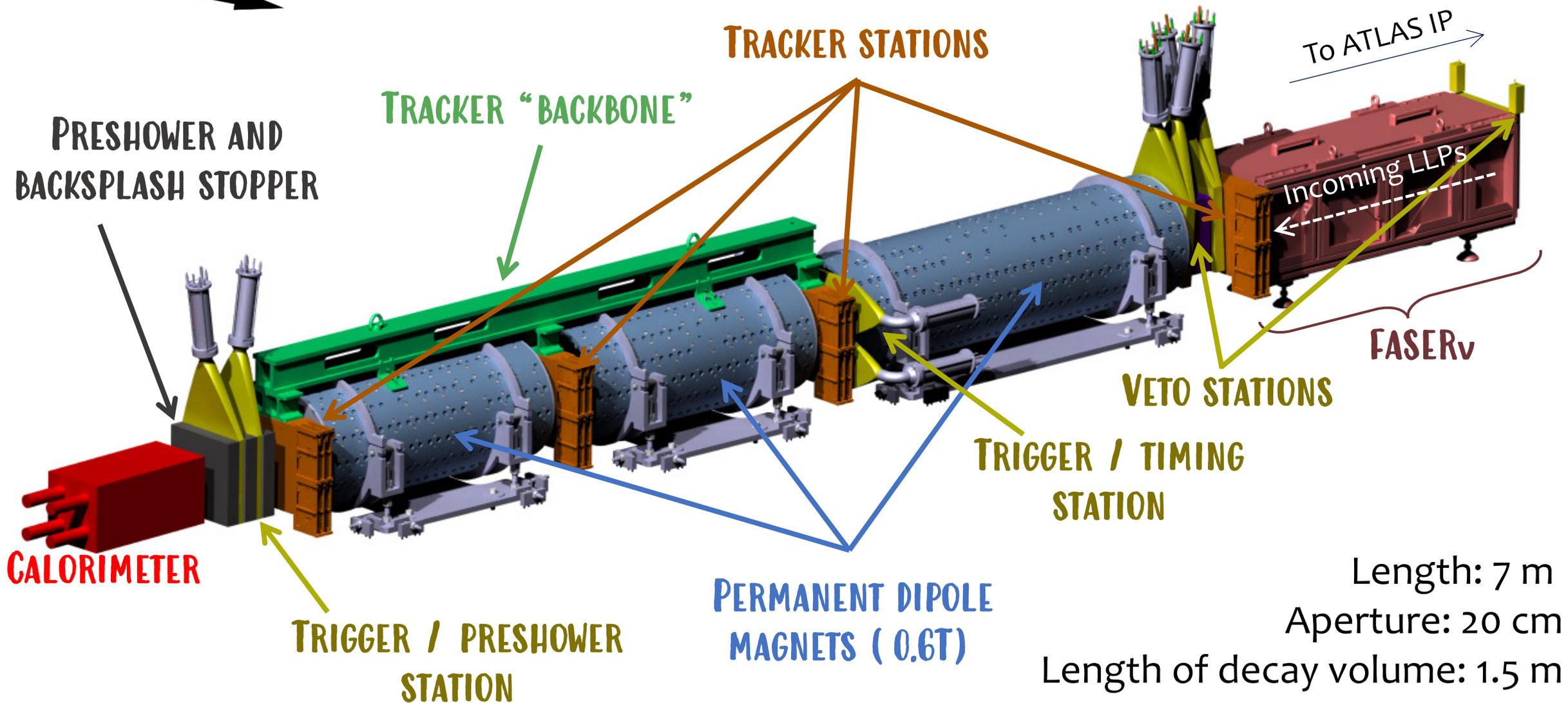
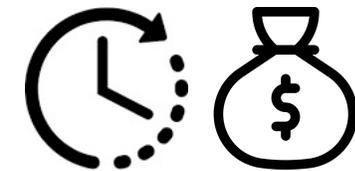


THE ***FASER*** EXPERIMENT



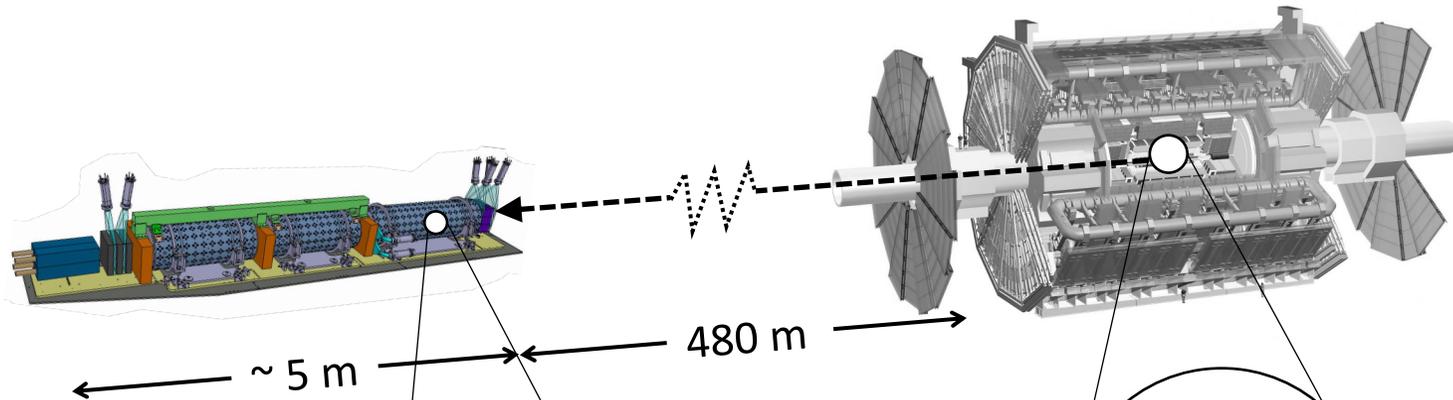
# ***FASER***

# DETECTOR



# KEY SIGNATURES

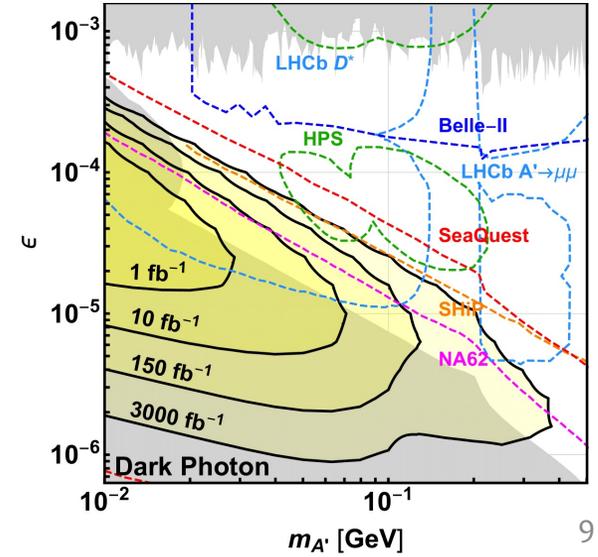
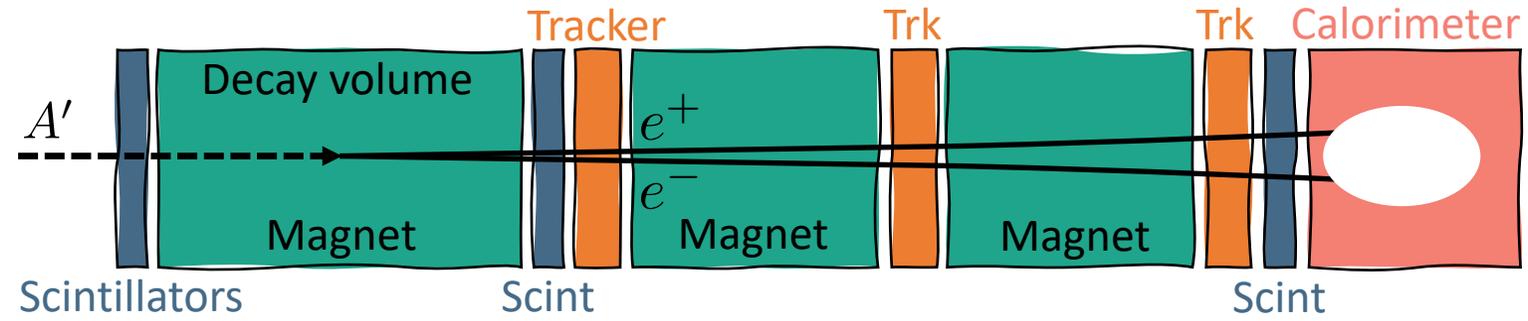
# Dark photon ( $A'$ )



## Ballpark numbers for $A'$ :

- Momentum of 1 TeV
- Mass of 100 MeV

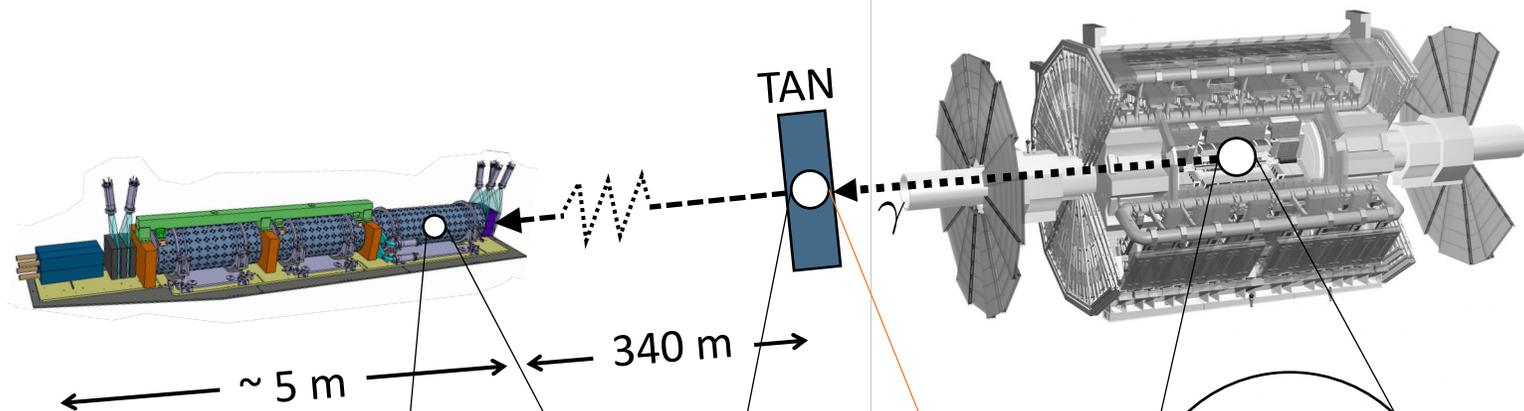
Decay products collimated requirements for magnetic field & high resolution tracker



Assuming 3 signal events and no backgrounds

# KEY SIGNATURES

# Axion-like particle (ALP, $a$ )

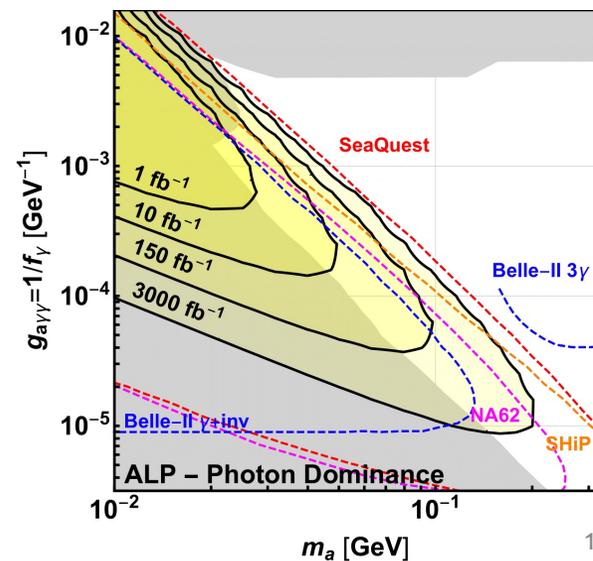
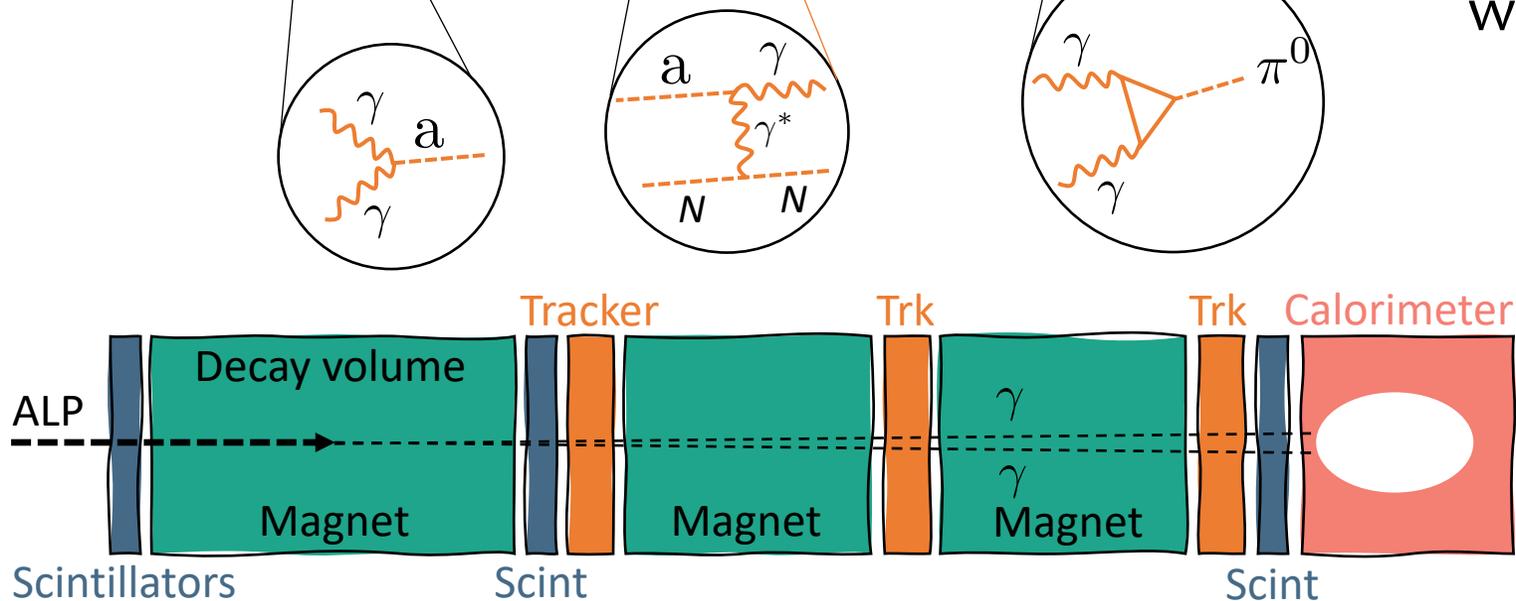


Ballpark numbers for ALPs:

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Decay products collimated

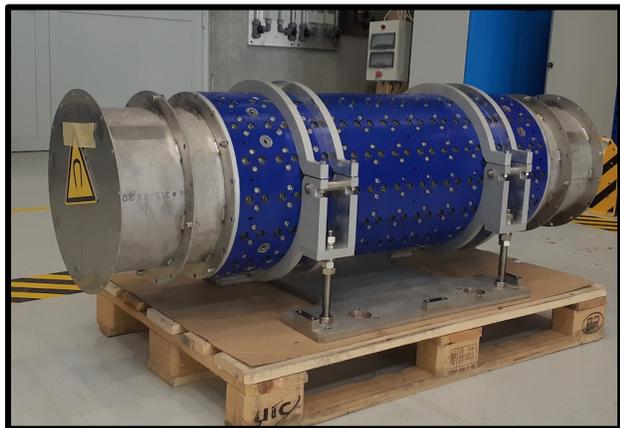
2- $\gamma$  signature can't be resolved with present detector: upgrade



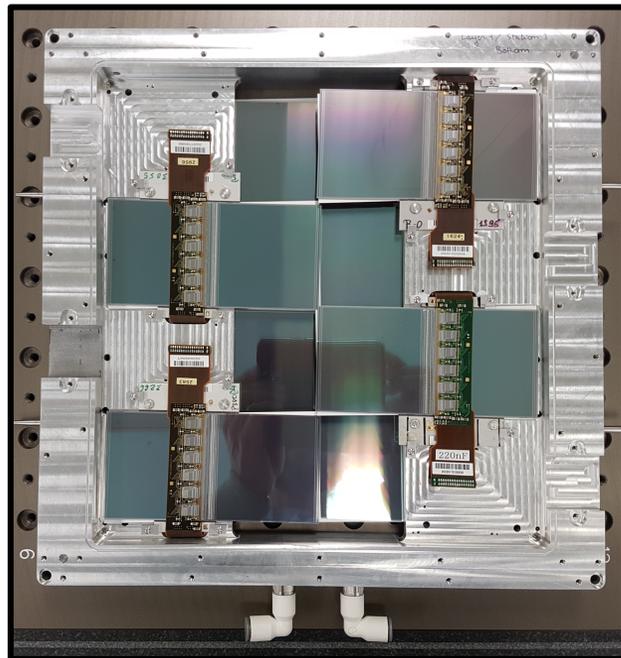
Assuming 3 signal events and no backgrounds



# DETECTOR COMPONENTS



Magnet (x3)



A tracker layer made of ATLAS  
SCT modules (x12 in 3 stations)



FASER scintillators mounted  
in their support

Two very high efficiency veto stations  
A timing station  
A preshower station for photon reco



Triggers from  
scintillators and  
calorimeter  
Expected **trigger  
rate** about 500 Hz,  
dominated by  
muons from the IP



Calorimeter modules  
mounted in their support

# COMMISSIONING

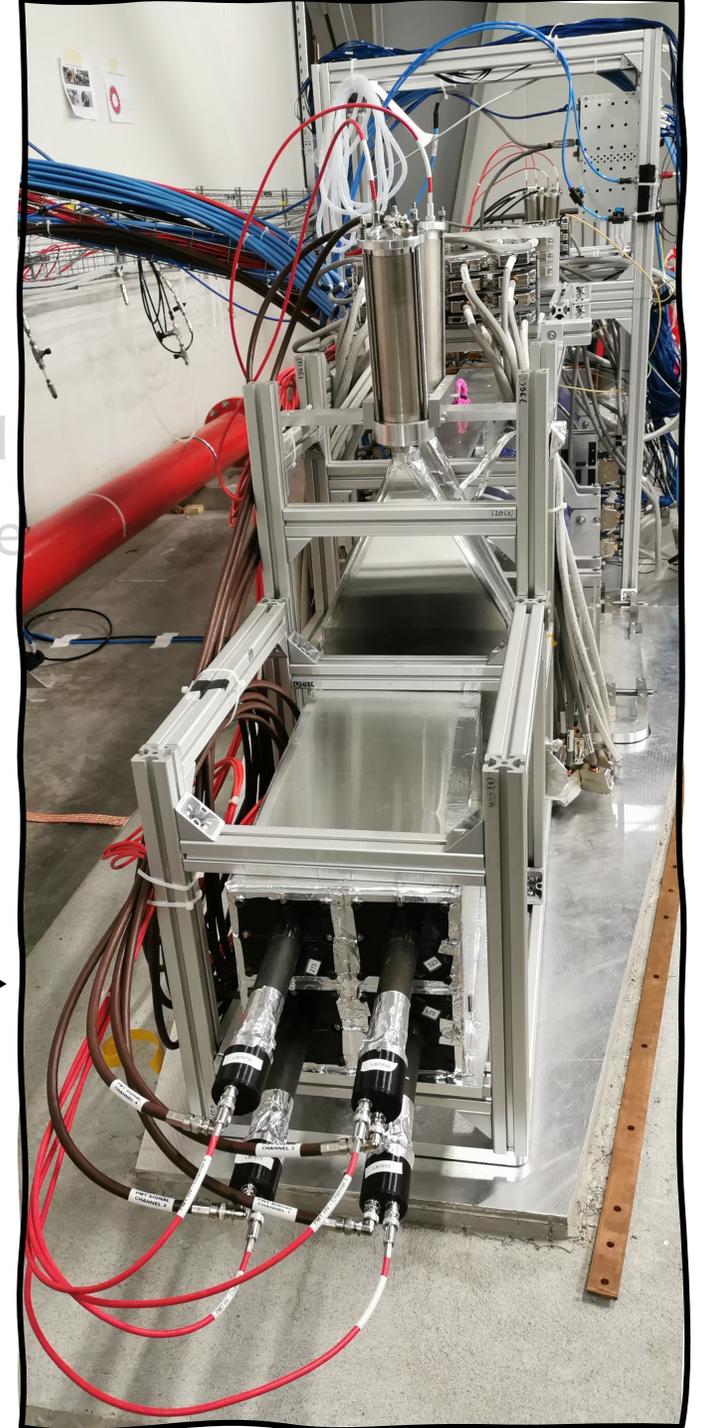
- Dedicated labs available at CERN and the UniGe for individual component testing
- Dedicated area at CERN’s Preveessin site (“EHN1”) for full-detector commissioning

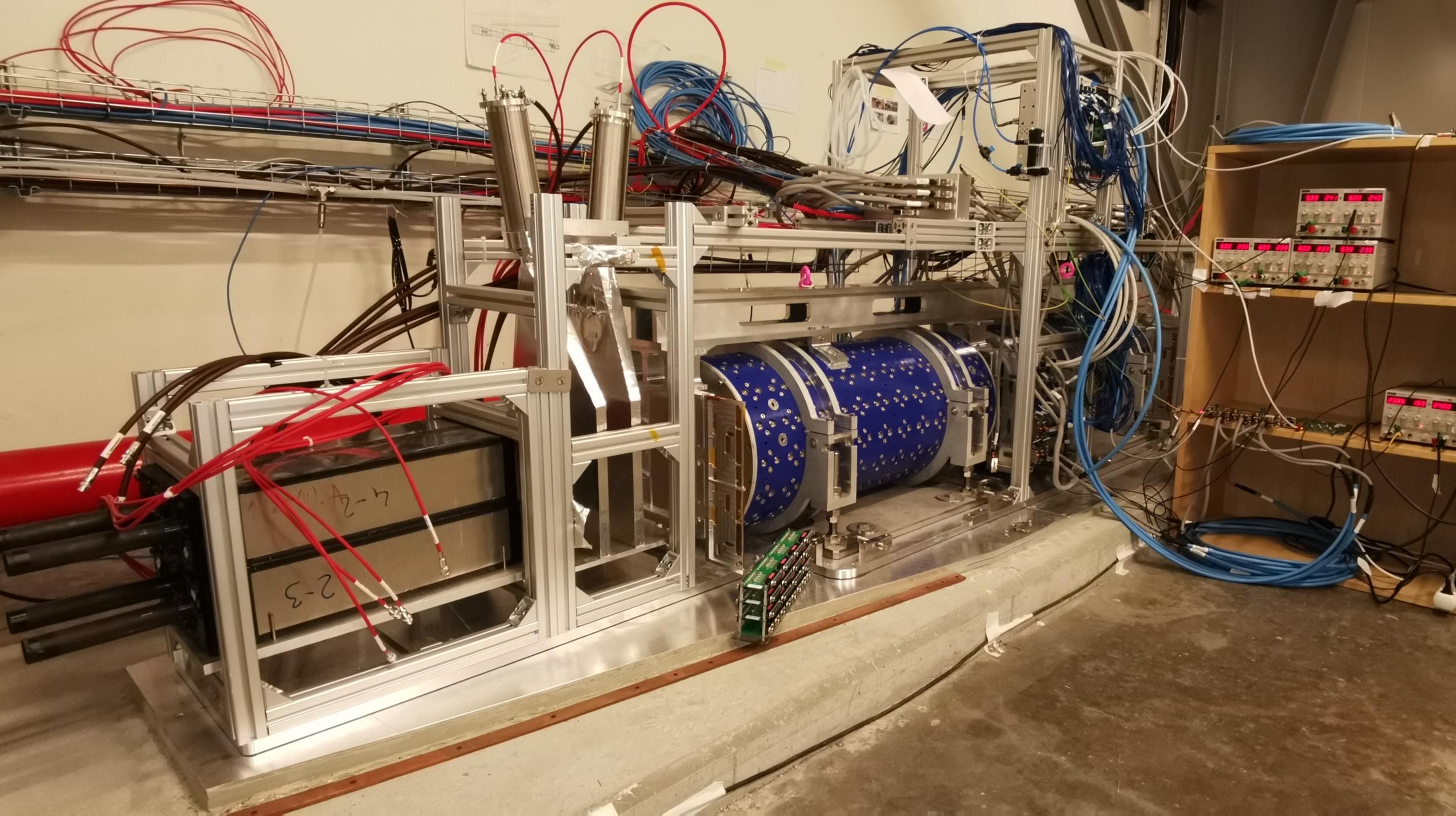
Milestone	Where	When
Individual component commissioning	labs	July 2020
Surface commissioning – part 1	EHN1	Oct 2020
Detector installation – part 1	TI12	Nov 2020
Surface commissioning – part 2	EHN1	Feb 2021
Detector installation – part 2	TI12	March 2021
In-situ commissioning	TI12	2021/2022

# **FAZER** COMMISSIONING

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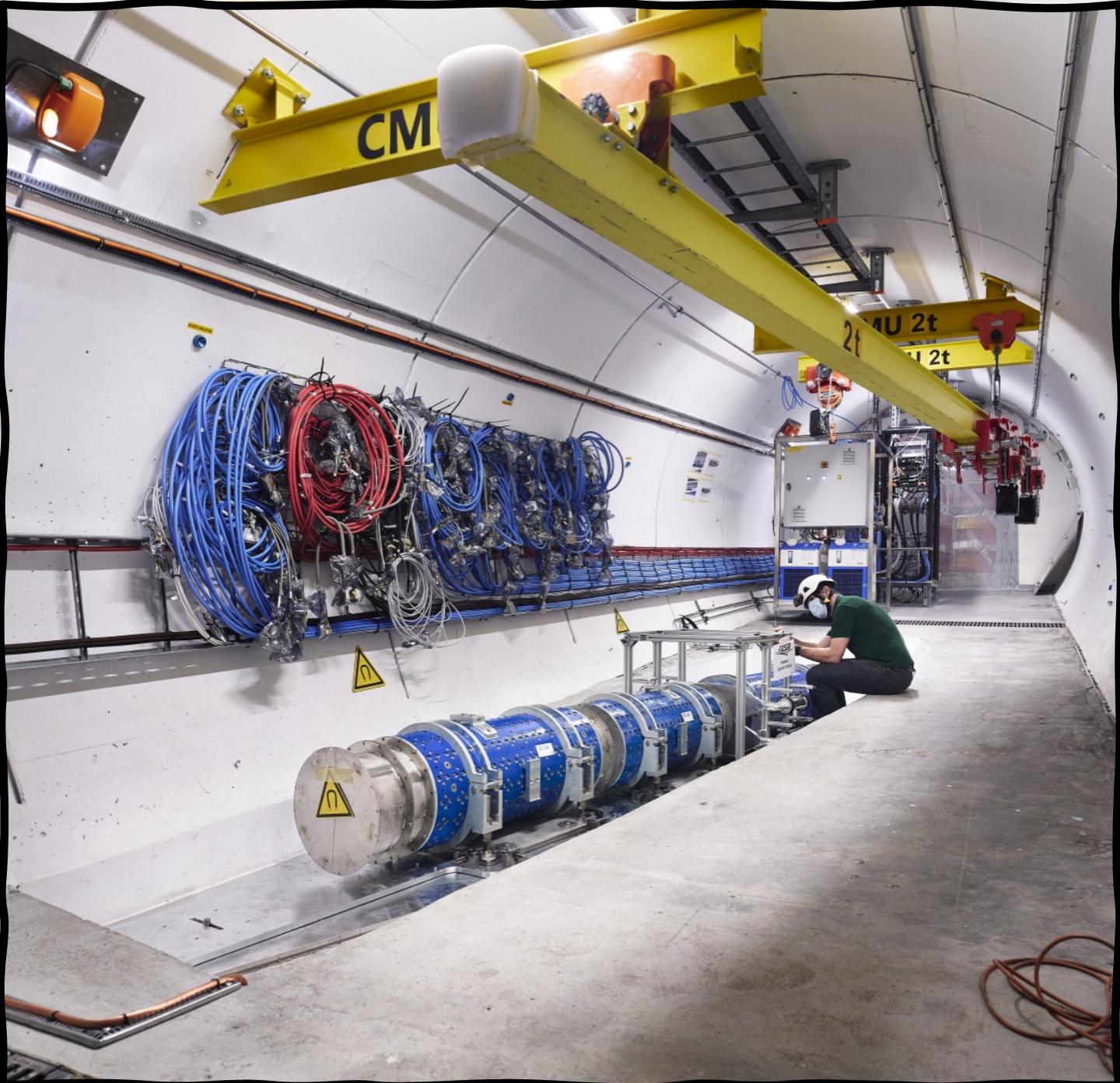
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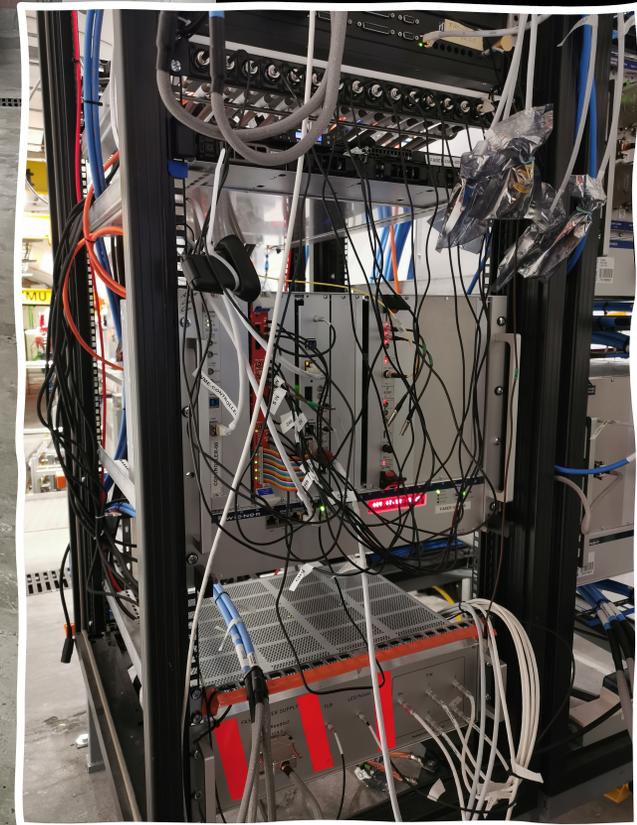
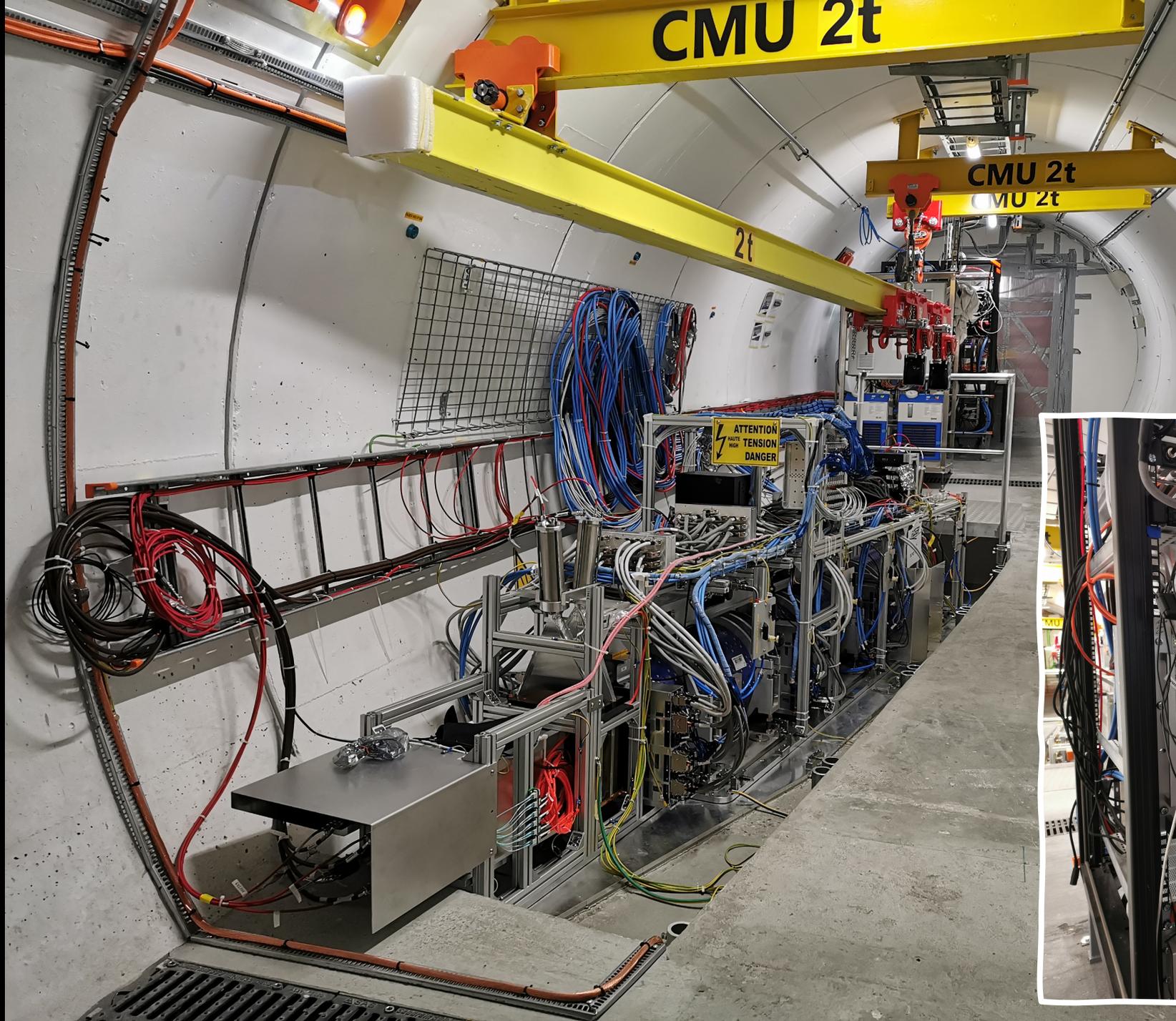
# INSTALLATION TO T112

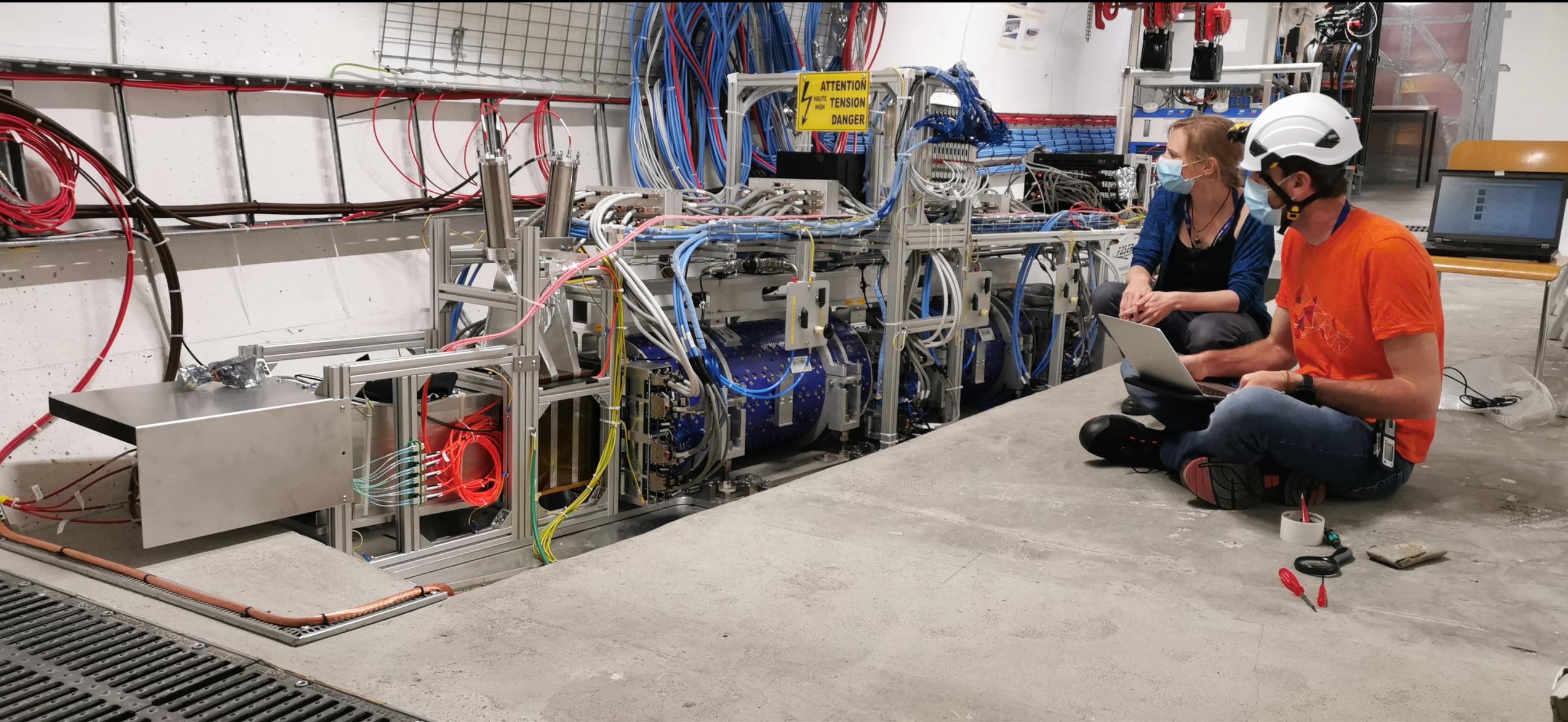
End 2020



CMU 2t

March 2021

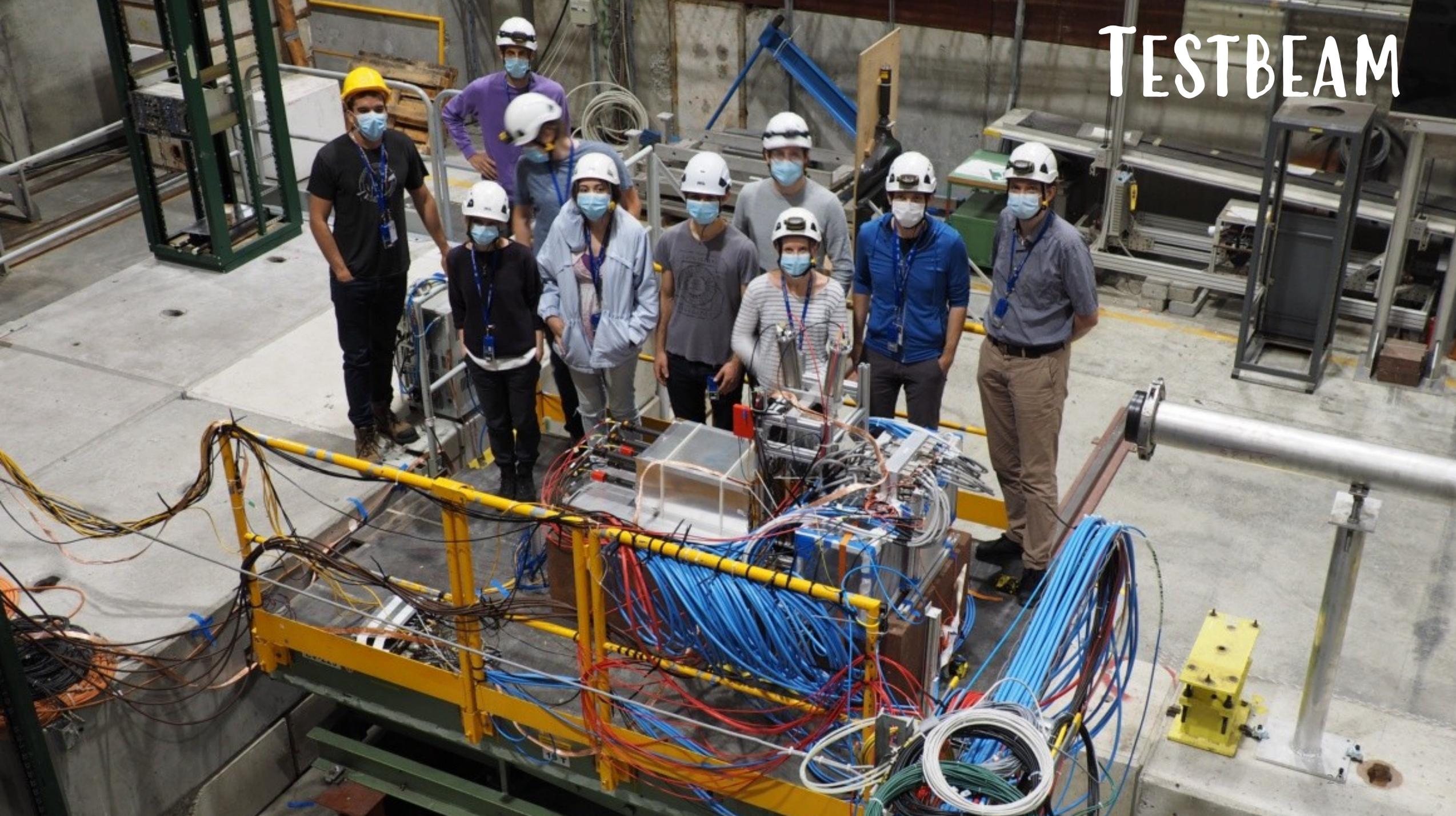




***FAZER*** EXPERIMENT

**COMMISSIONING WITH BEAMS!**

# TESTBEAM

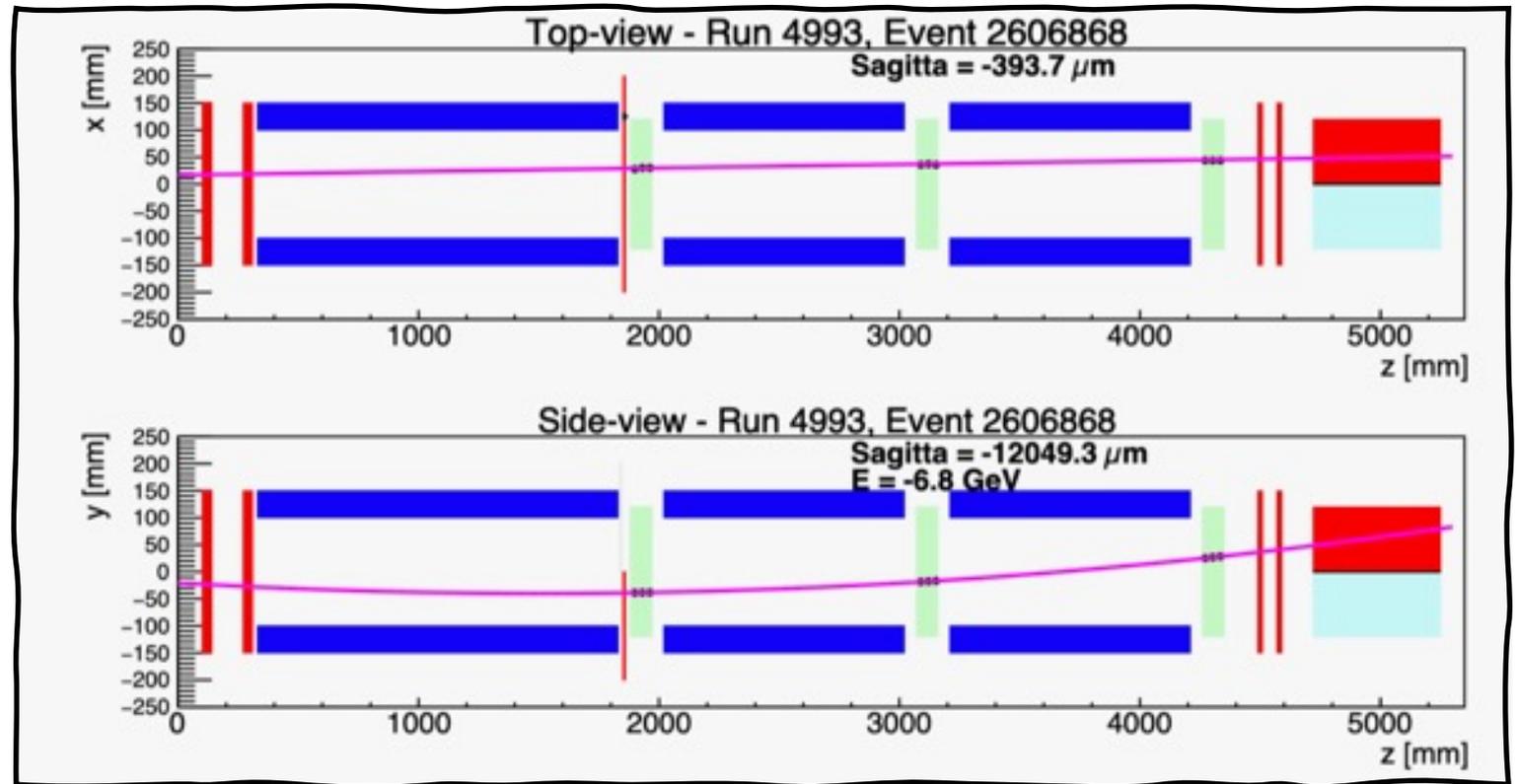




# OCTOBER 2021: FIRST LHC BEAMS SINCE 2018

2 week pilot beam test, with 450 GeV beams circulated and collided

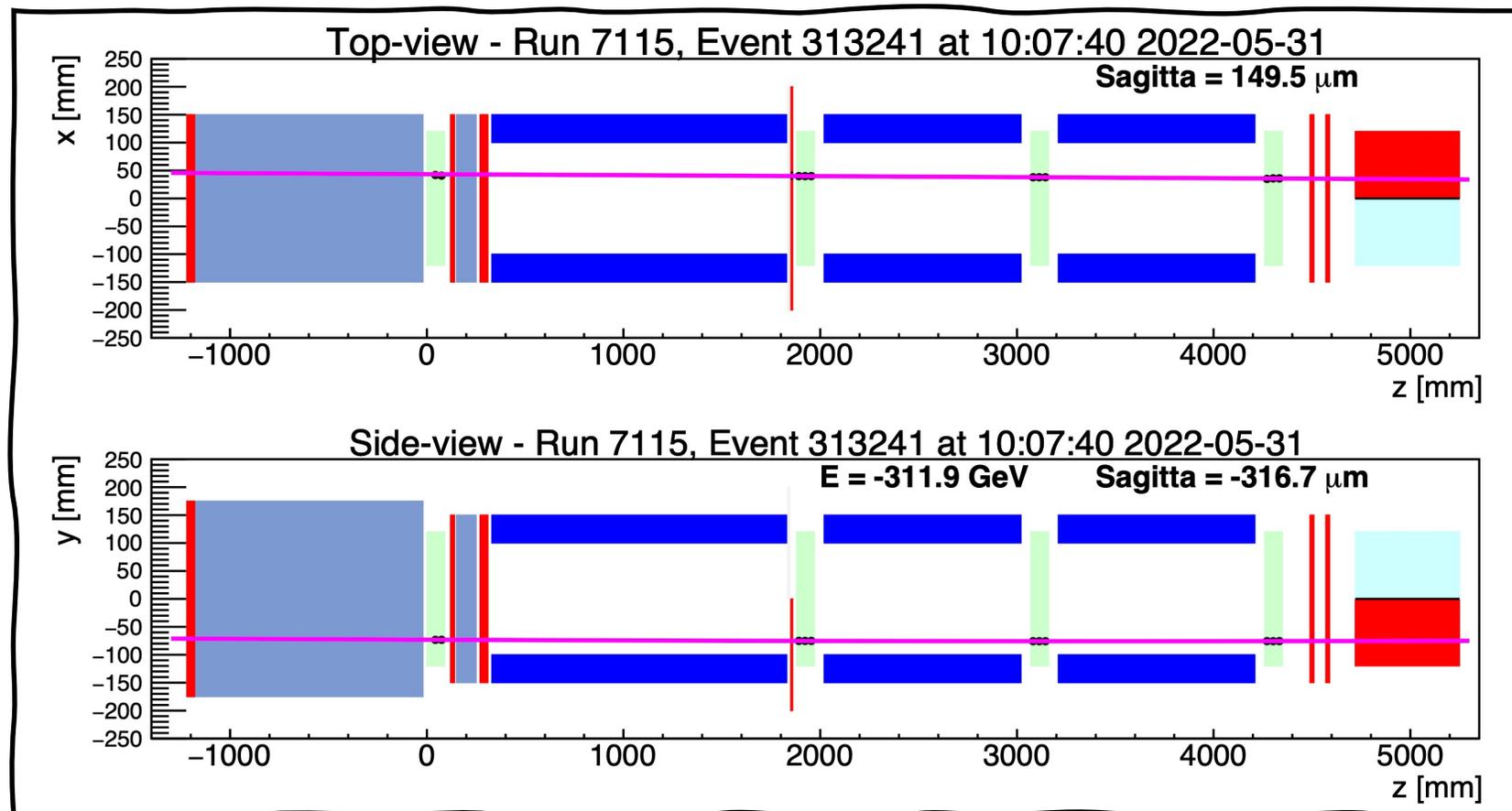
- FASER saw beam-related activity during various operations (beam splash, collimator alignment, single beam and colliding beams)
- Data used to time in the trigger, and for performance and background studies
- **First time we saw particles traversing the full detector!**



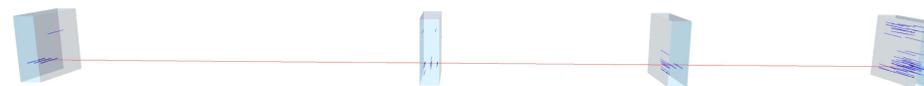
# FIRST RUN3 TEST COLLISIONS

**HOT OFF THE PRESS**

- Muon background
- Extremely useful for exercising **offline and analysis software**, which is now progressing very rapidly



Offline tracking





# HUGE FLUX OF HIGH-ENERGY NEUTRINOS

- Why not exploit FASER to also measure properties of neutrinos at the highest man-made energies ever recorded!

## A BIT OF HISTORY

Experiments to study collider neutrinos have been proposed since the 80s, e.g.:

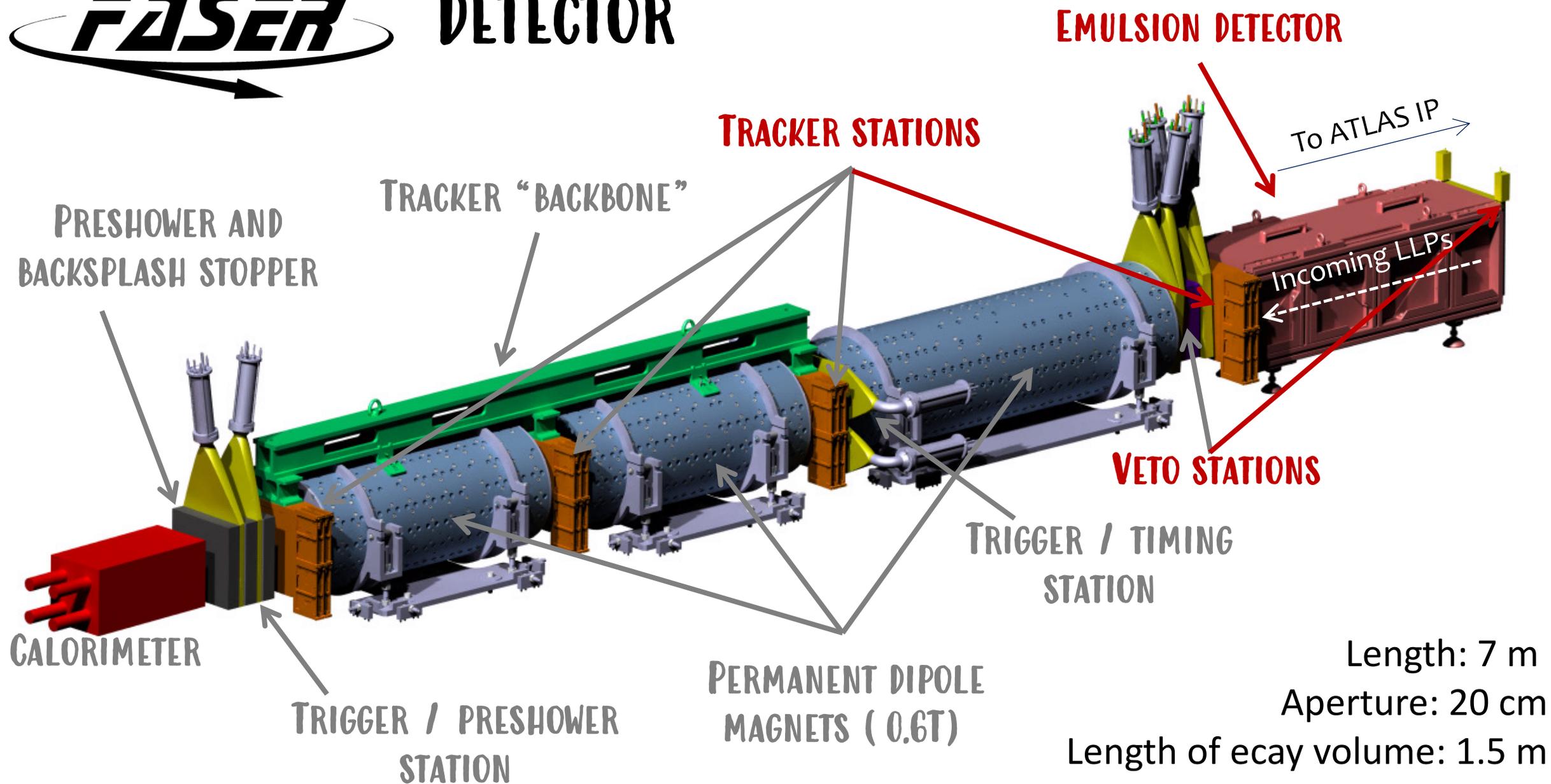
- A. De Rujula and R. Ruckl, “Neutrino and muon physics in the collider mode of future accelerators” ECFA-CERN Workshop on large hadron collider in the LEP tunnel, pp. 571–596, 1984.
- Klaus Winter, “Observing tau neutrinos at the LHC”, LHC workshop, 1990.

Other recent concrete experiment proposals include XSEN and SND@LHC.





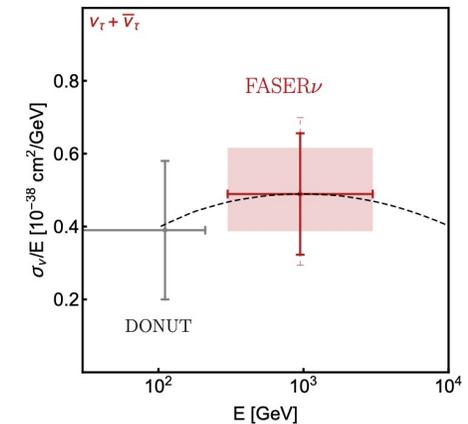
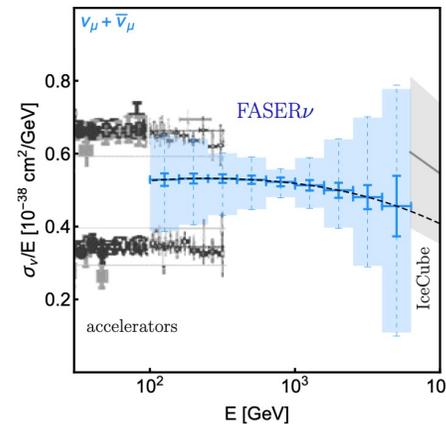
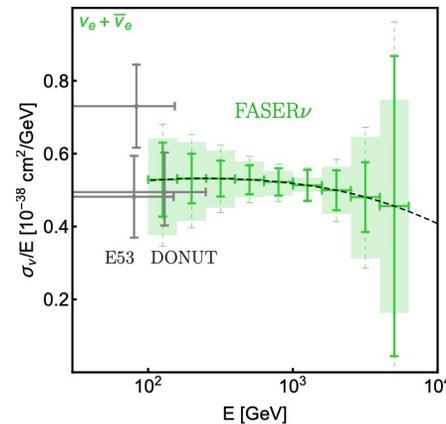
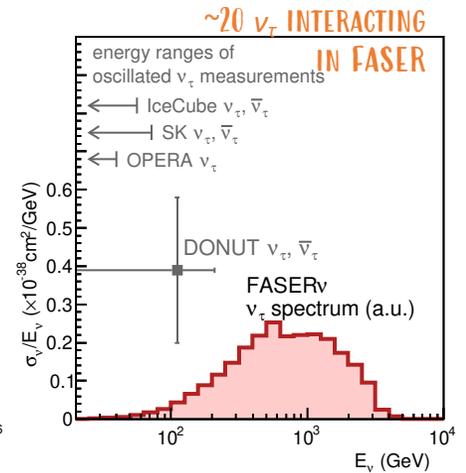
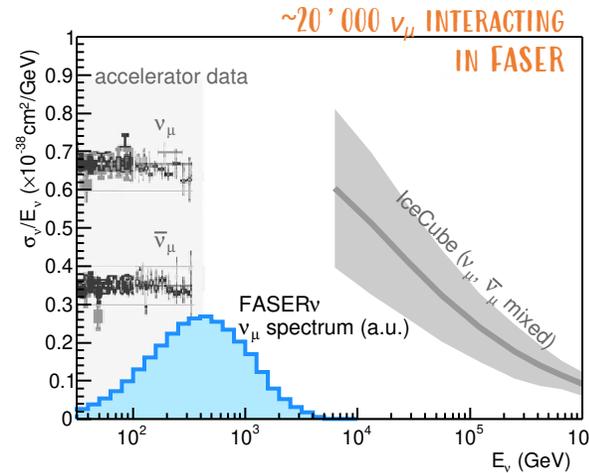
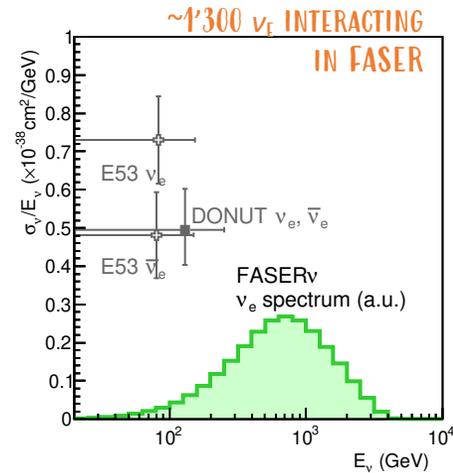
# DETECTOR



# HUGE FLUX OF HIGH-ENERGY NEUTRINOS

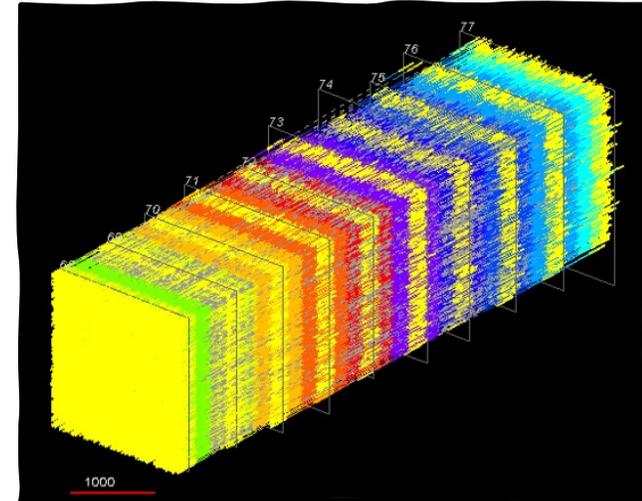
- Why not exploit FASER to also measure properties of neutrinos at the highest man-made energies ever recorded!

- Expected spectra: complementary to existing experiments
- Expected cross section reach: extends current measurements already with 150/fb
- Uncertainty from neutrino production important
- Neutrino energy with 30% resolution (simu)

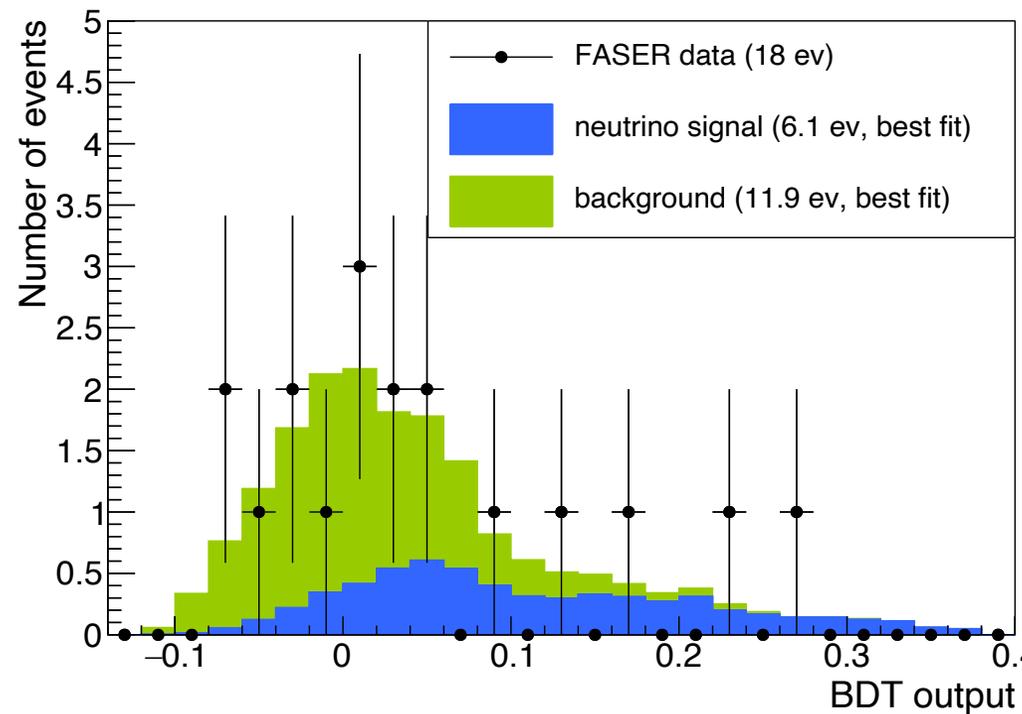




# PILOT RUN IN 2018



- A 11 kg detector at T118
- Collected  $\sim 13/\text{fb}$
- About 3.3 neutrino interactions expected to have occurred after selections
- BDT developed to distinguish neutrino signal from neutral hadron background
  - The background-only hypothesis is rejected with significance of  $2.7\sigma$
- Excellent testbed for future data analysis



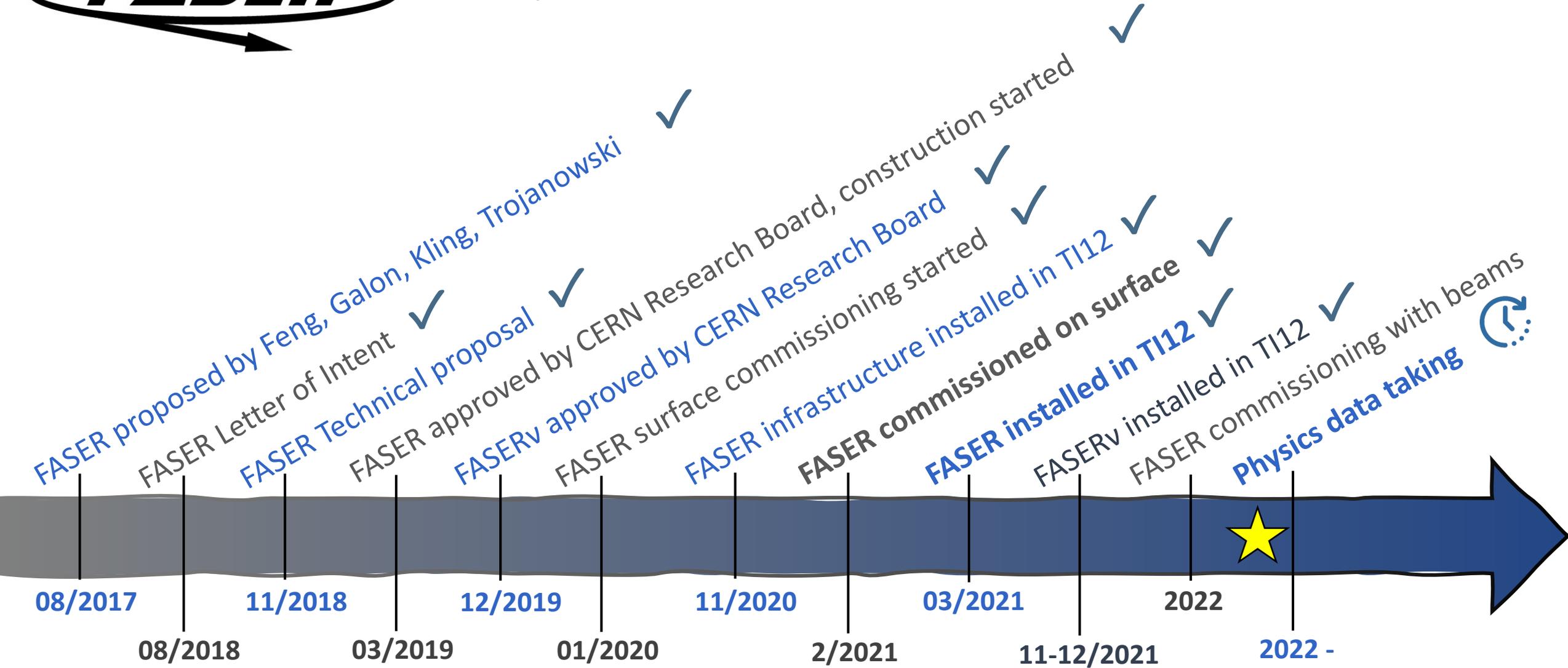
PUBLISHED IN PRD

arXiv: 2105.06197

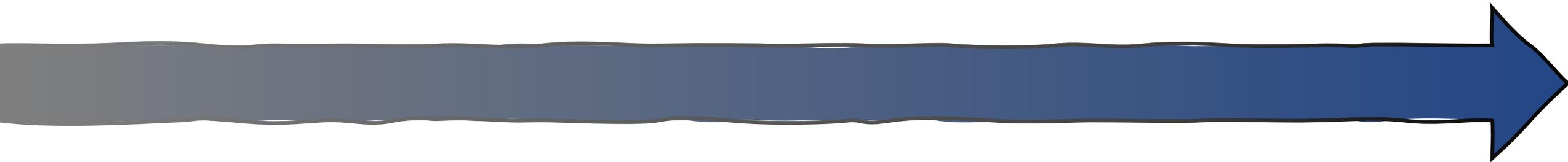
**FÄSER** **TIMELINE**



# GLOBAL TIMELINE



**WHAT'S BEYOND 2022 ?**



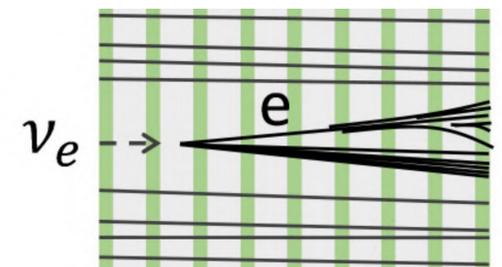
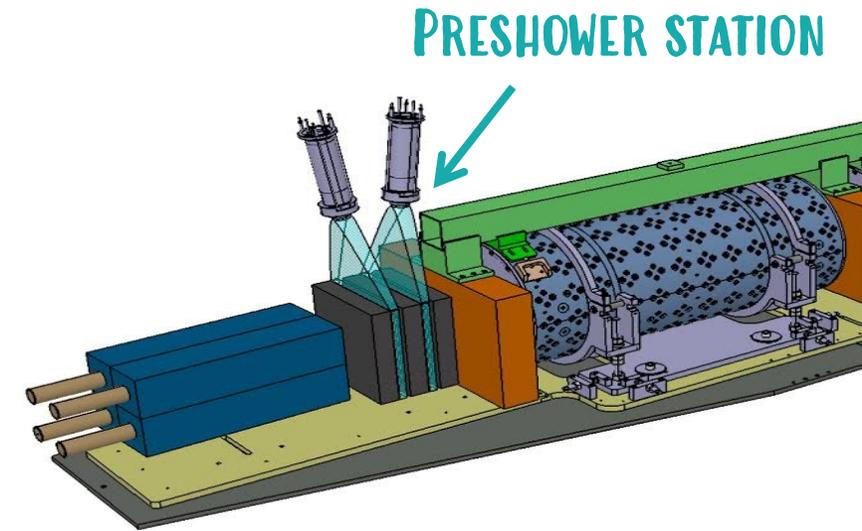
# CURRENT DETECTOR LIMITATION

## • CURRENT FASER PRE-SHOWER

- two layers of scintillators, each preceded by a  $1X_0$  lead-radiator plane
- will create a photon shower to help distinguish photons from electrons coming from deep inelastic scattering (DIS) of very energetic neutrinos in the calorimeter.

## • LIMITATIONS

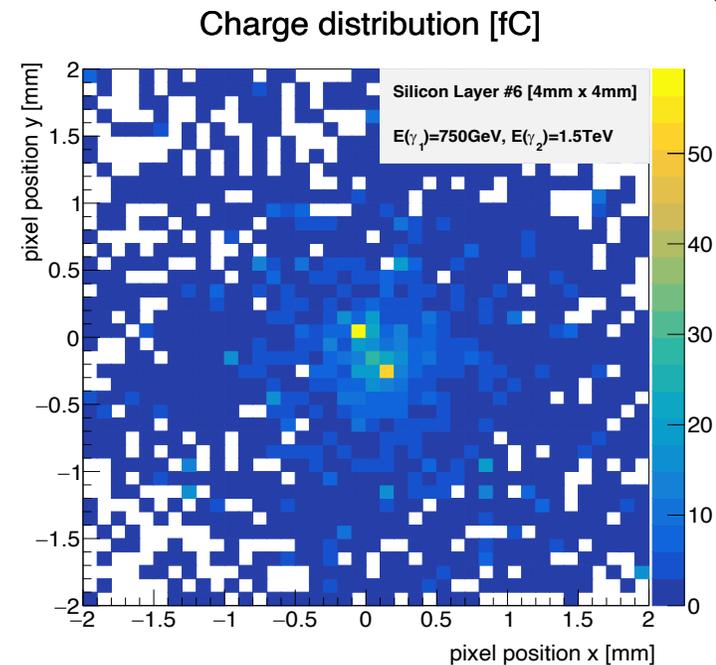
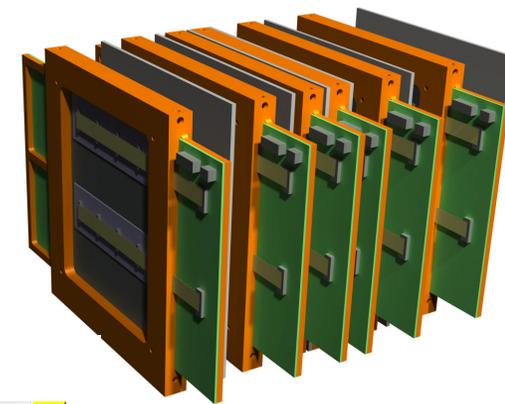
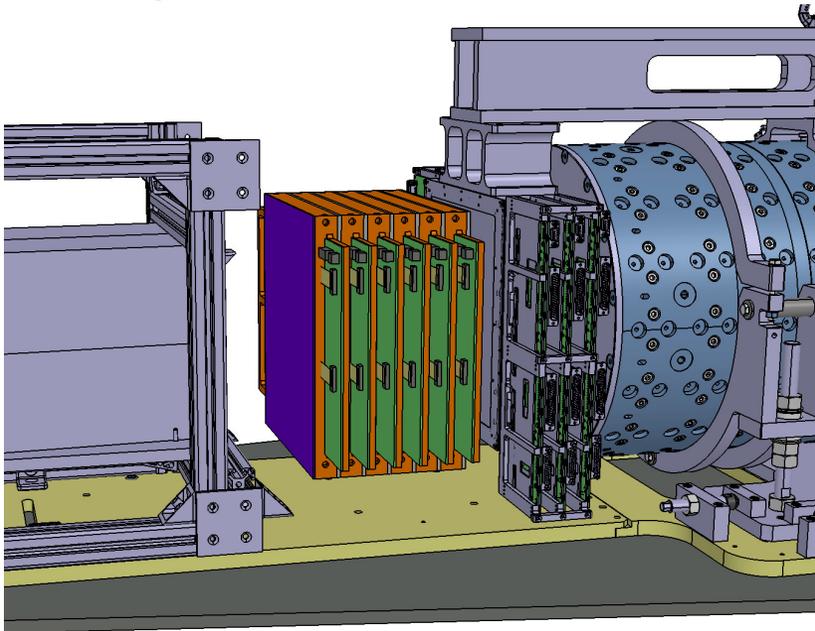
- no information about the multiplicity of the photons or the topology of the event
- neutrino DIS events produced in the  $2 X_0$  lead of the present pre-shower will be undistinguishable from a photon (LLP) signature
  - About 10 such events expected in 150/fb



Cartoon of  $\nu_e$  DIS  
in FASERv

# UPGRADE TO ENABLE $2-\gamma$ PHYSICS

- Existing pre-shower to be replaced with a high-resolution silicon pre-shower detector using monolithic pixel ASICs
  - hexagonal pixels of  $65\ \mu\text{m}$  side

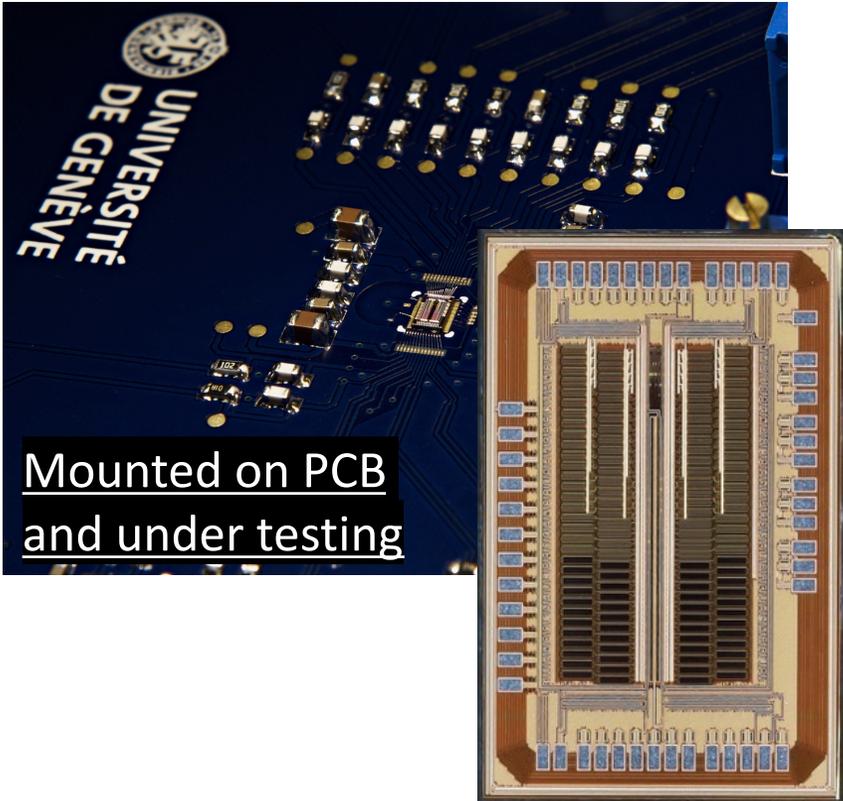


- Distance between two photons:  $200\ \mu\text{m}$
- Distinguishable!

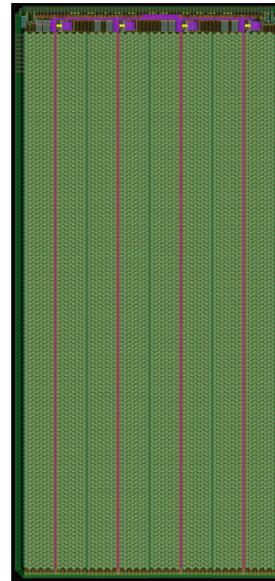
Detector to be used for  
2024 & 2025 data taking  
(70% of Run3 data)

# FROM PIXELS TO LAYERS OF MODULES

Prototype ASIC available end 2020

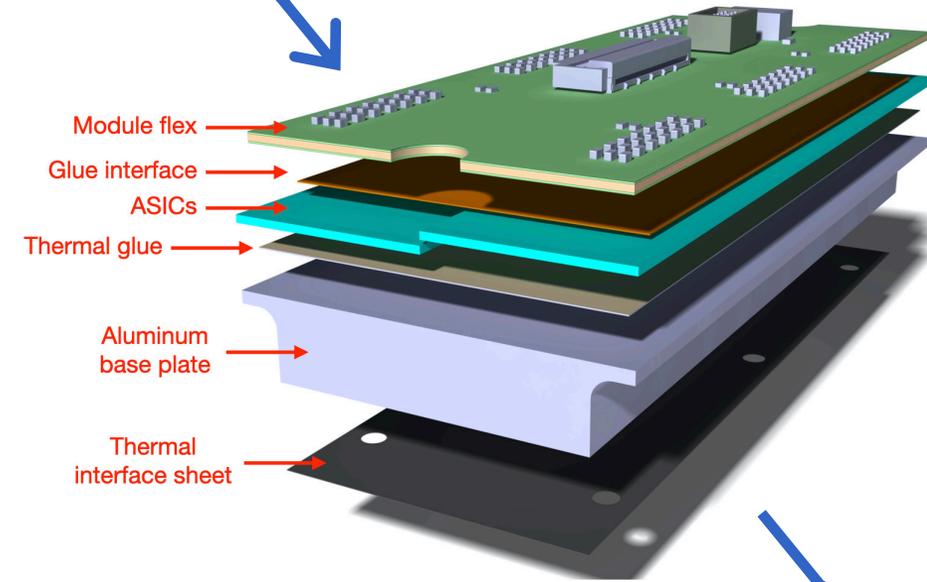


Mounted on PCB  
and under testing

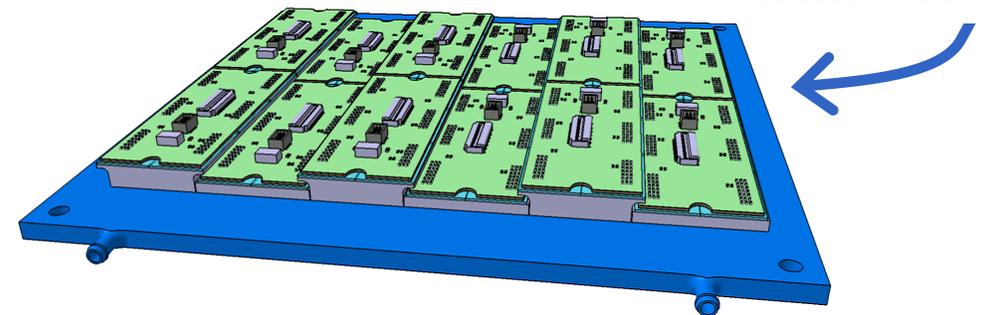


Pixel chips into  
sensor wafers

... into modules  
of pixels



... into layers  
of modules



Proposed layout of 1 layer  
with 12 modules.

# UPGRADED PRE-SHOWER

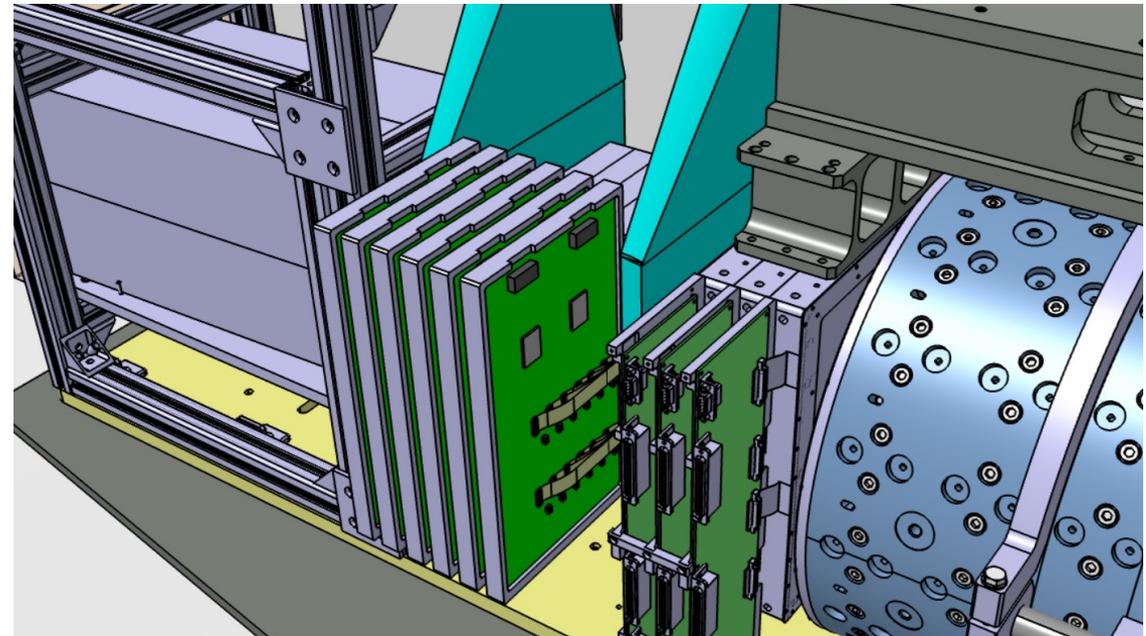
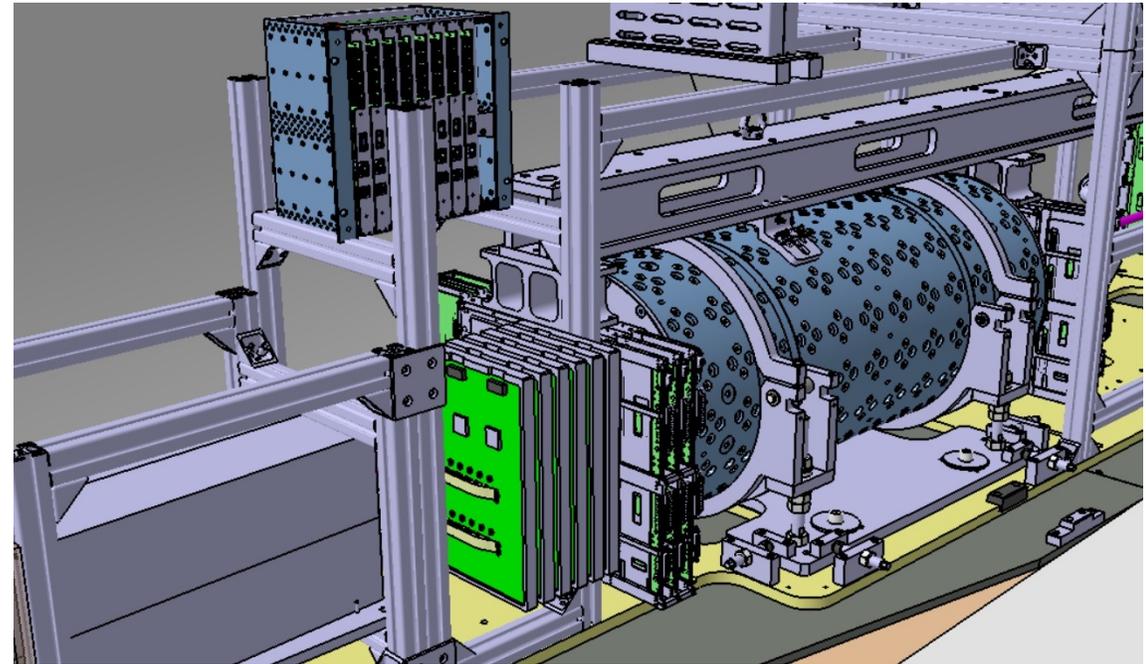
## Status:

- Technical proposal approved in March
- Pre-production ASICs just back from foundry
- Design of modules, planes, mechanics, read-out in progress
- Simulation and reconstruction in progress

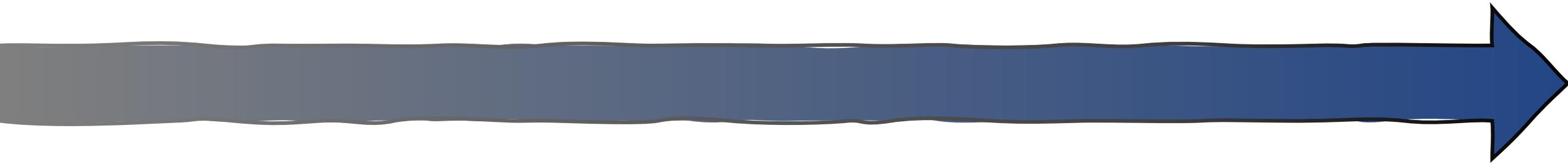
## Plan:

- Install the detector end of 2023 for data taking in 2024 and the rest of Run3

More: <https://cds.cern.ch/record/2803084>



**WHAT'S BEYOND RUN3 ?**

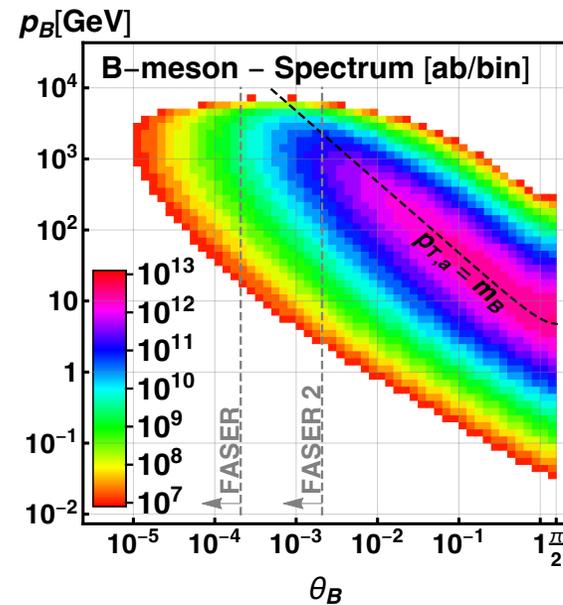
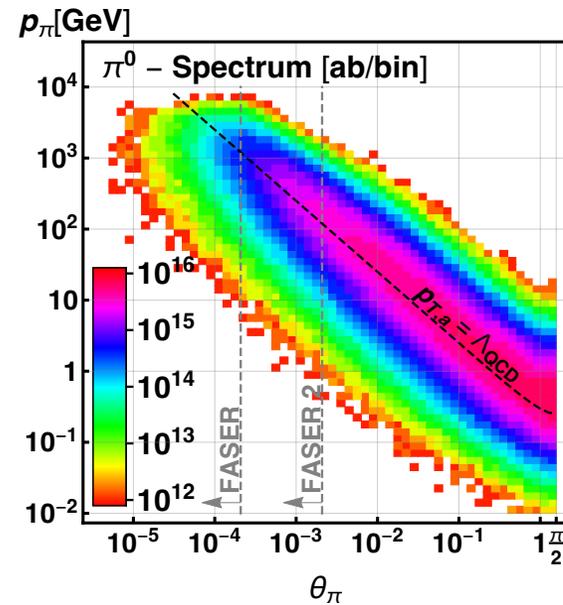


# BEYOND FASER?

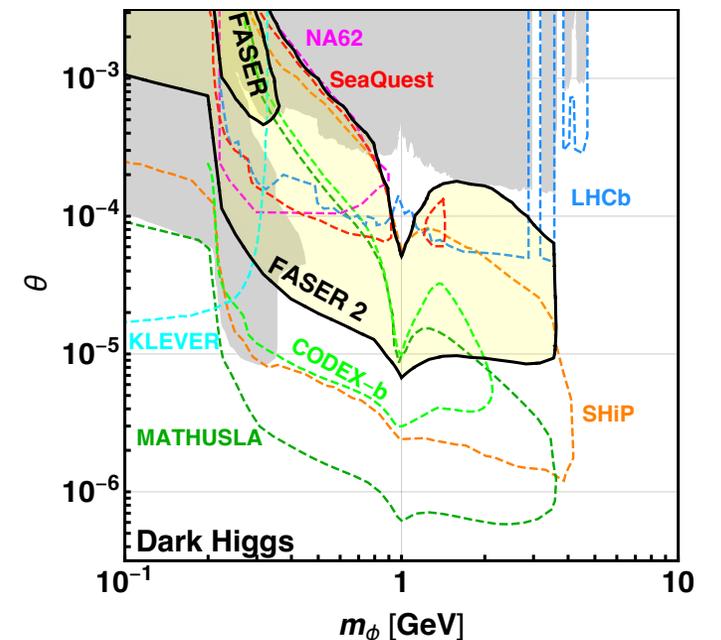
# FASER2

Benchmark model	FASER	FASER 2
Dark photons	✓	✓
$B - L$ gauge bosons	✓	✓
$L_i - L_j$ gauge bosons	...	...
Dark Higgs bosons	...	✓
Dark Higgs bosons with $hSS$	...	✓
HNLs with $e$	...	✓
HNLs with $\mu$	...	✓
HNLs with $\tau$	✓	✓
ALPs with photon	✓	✓
ALPs with fermion	...	✓
ALPs with gluon	✓	✓
Dark pseudoscalars	...	✓

More: <https://arxiv.org/abs/1811.12522>

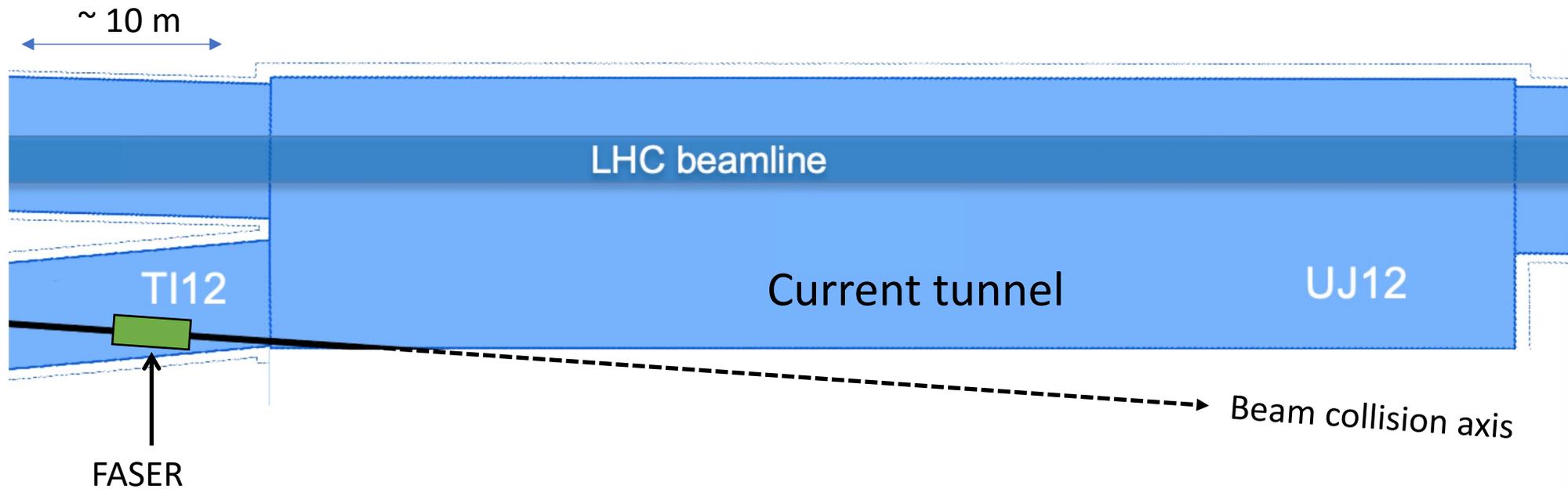


Increased detector radius to 1 m allows sensitivity to particles produced in heavy meson (B, D) decays increasing physics case beyond just increased luminosity

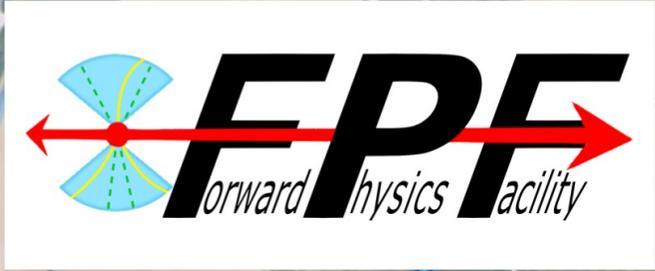
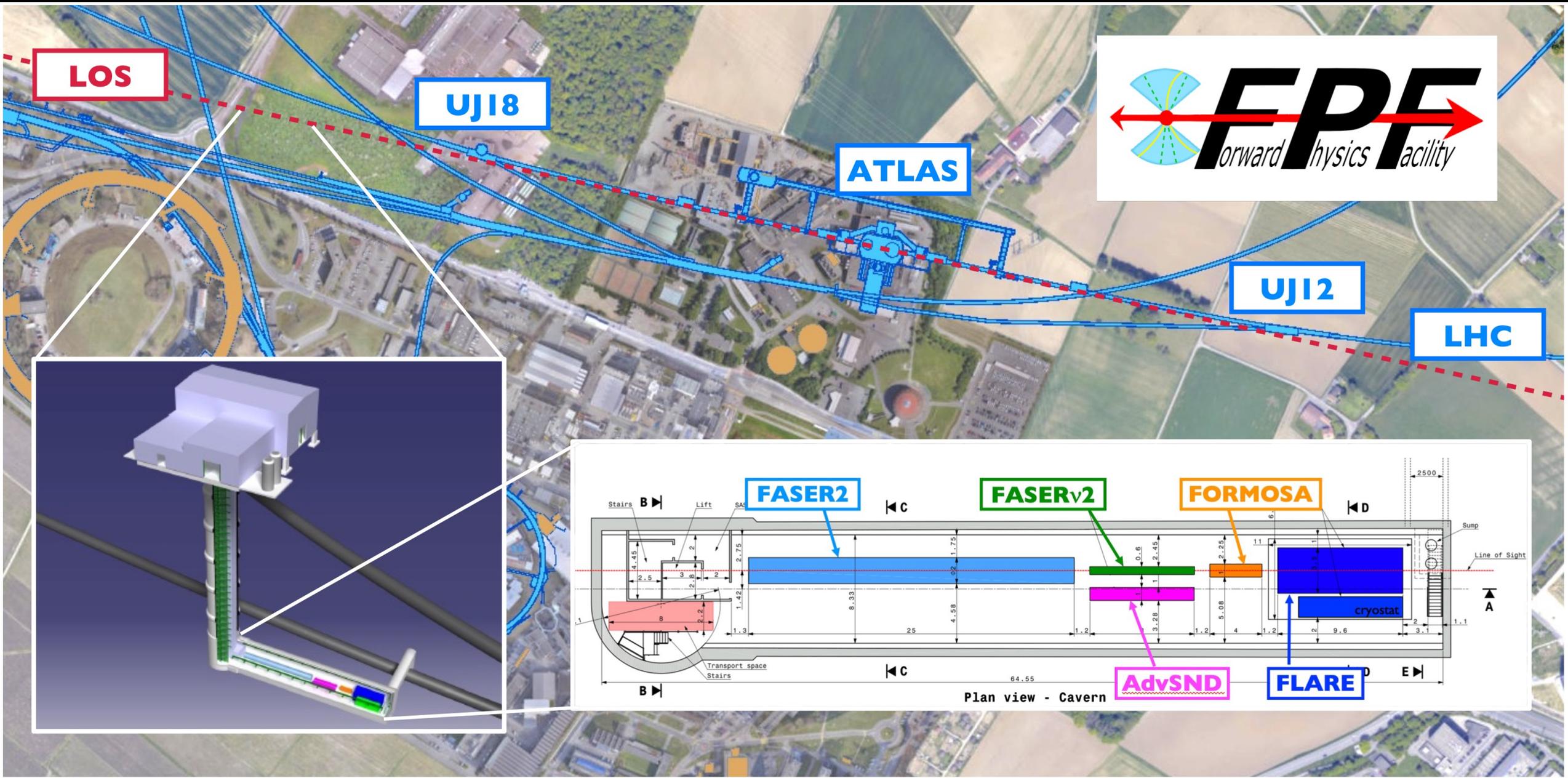


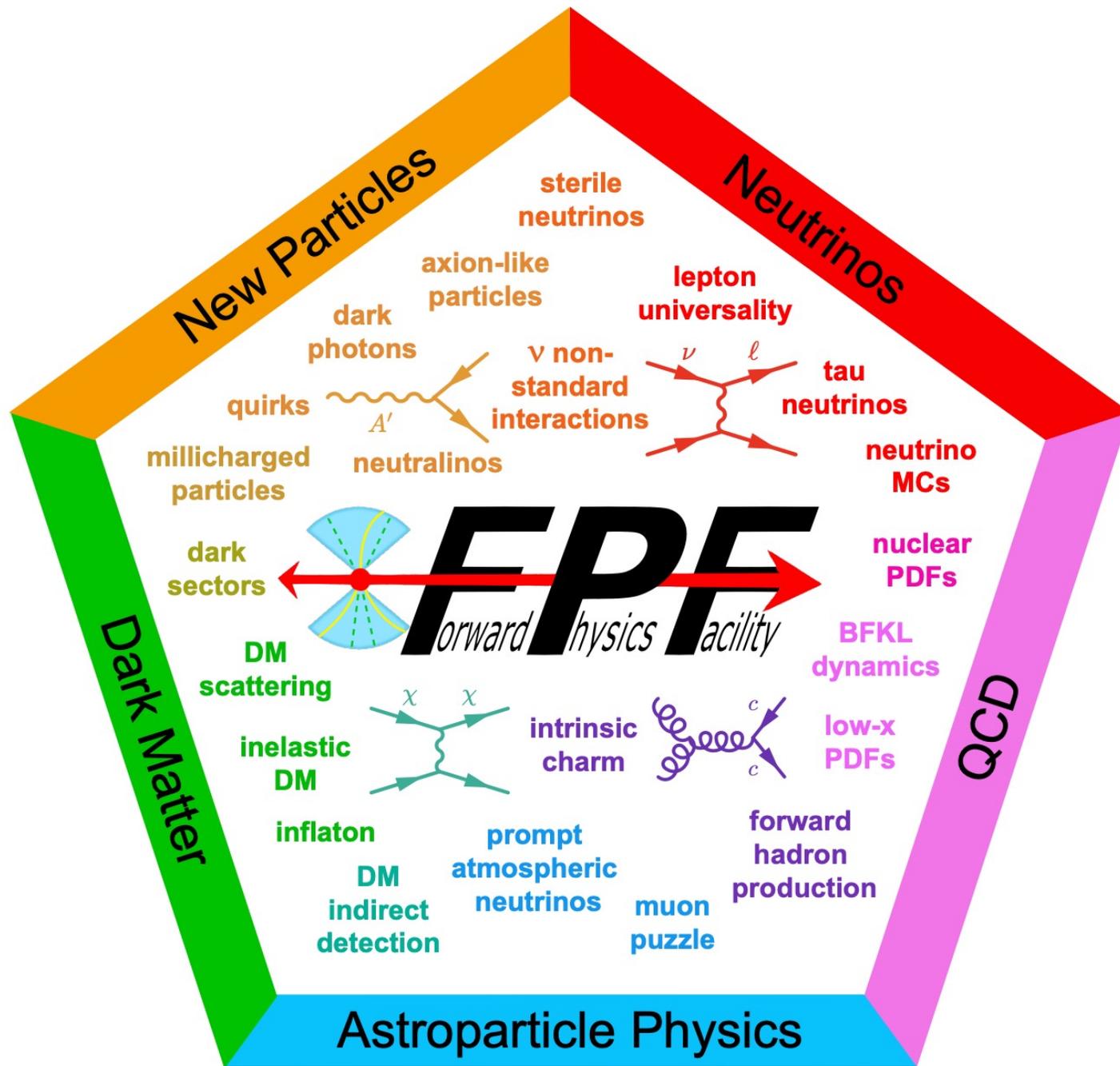
# BEYOND FASER?

## A TEASER FOR THE PROPOSED FORWARD PHYSICS FACILITY



More: [LoI for SNOWMASS-2021](#)  
[FPF – Kickoff workshop](#)  
[FPF – 4<sup>th</sup> \(latest\) workshop](#)





# OUTLOOK

- The FASER experiment introduces a **novel approach** to exploit LHC collisions, to:
  - either **make a new discovery or constrain parts of phase-space which no current experiment has access to**; and
  - make the first **collider-originated neutrino measurements**
- Collaboration (& CERN technical teams) have worked feverishly to construct, commission and install the detector over the current Long Shutdown
- **Goal: physics data taking with the start of Run3!**
- Have started planning upgrades, and thinking about FASER2 & a future facility to further exploit forward production in LHC collisions!
- **LOTS OF EXCITING PHYSICS AHEAD!**

Stay in touch:



<https://faser.web.cern.ch/>

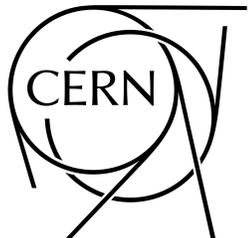


@FASERexperiment

# FASER THANKS!

- Many thanks to my collaborators for providing material & great pictures from testing & installation, in particular Claire Antel (UniGe), Jamie Boyd (CERN) and Brian Petersen (CERN)
- And to the Heising-Simons foundation, Simons foundation, SNSF and CERN for their financial support

FASER Collaboration: 8 countries, 19 institutes, about 70 members



# REFERENCES



## FASER collaboration:

- Letter of Intent [arXiv:1811.10243](https://arxiv.org/abs/1811.10243)
- Technical Proposal [arXiv:1812.09139](https://arxiv.org/abs/1812.09139)
- FASER's Physics Reach for Long-Lived [arXiv:1811.12522](https://arxiv.org/abs/1811.12522)
- Input to the European Strategy for Particle Physics Update [arXiv:1901.04468](https://arxiv.org/abs/1901.04468)
- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC [arXiv:1908.02310](https://arxiv.org/abs/1908.02310)
- Technical Proposal of FASERν neutrino detector [arXiv: 2001.03073](https://arxiv.org/abs/2001.03073)
- Forward Physics Facility [Snowmass LoI](https://www.snowmass.gov/)
- First neutrino interaction candidates at the LHC [arXiv:2105.06197](https://arxiv.org/abs/2105.06197)
- The trigger and data acquisition system of the FASER experiment [arXiv:2110.15186](https://arxiv.org/abs/2110.15186)
- The tracking detector of the FASER experiment [arXiv.org:2112.01116](https://arxiv.org/abs/2112.01116)
- The FASER W-Si High Precision Preshower Technical Proposal [LHCC-P-023](https://arxiv.org/abs/2108.02310)

**Plus several theory papers**

**More information:**  <https://faser.web.cern.ch/physics/publications>