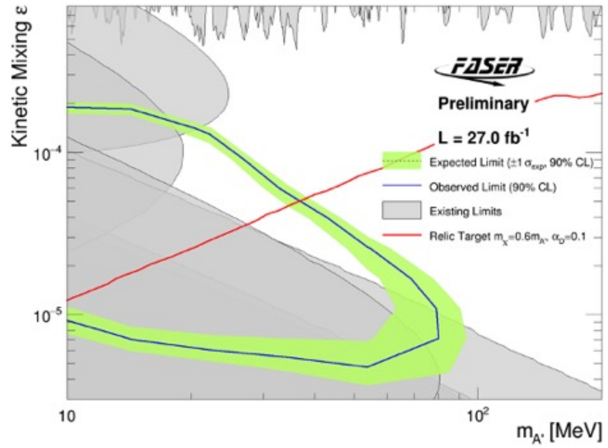

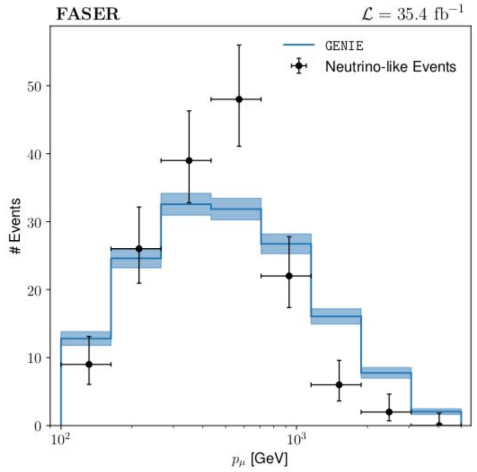

First results from the FASER experiment at the LHC and prospect toward Forward Physics Facility in HL-LHC era

Hidetoshi OTONO (Kyushu University)

CNS + RNC RHIC Phys Res Lab seminar
15th Sep, 2023

PRL published the neutrino paper on 19th July

Featured in Physics | Editors' Suggestion | Open Access

First Direct Observation of Collider Neutrinos with FASER at the LHC

Henso Abreu *et al.* (FASER Collaboration)
Phys. Rev. Lett. **131**, 031801 – Published 19 July 2023

Physics See Viewpoint: The Dawn of Collider Neutrino Physics

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

We report the first direct observation of neutrino interactions at a particle collider experiment. Neutrino candidate events are identified in a 13.6 TeV center-of-mass energy pp collision dataset of $35.4\,\mathrm{fb}^{-1}$ using the active electronic components of the FASER detector at the Large Hadron Collider. The candidates are required to have a track propagating through the entire length of the FASER detector and be consistent with a muon neutrino charged-current interaction. We infer 153^{+12}_{-13} neutrino interactions with a significance of 16 standard deviations above the background-only hypothesis. These events are consistent with the characteristics expected from neutrino interactions in terms of secondary particle production and spatial distribution, and they imply the observation of both neutrinos and anti-neutrinos with an incident neutrino energy of significantly above 200 GeV.

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VIEWPOINT

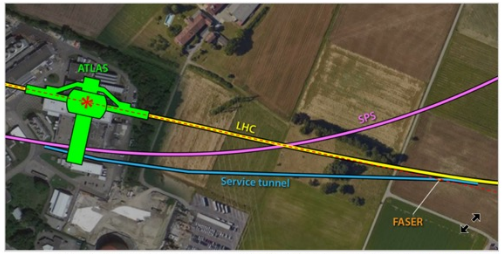
PDF Version

The Dawn of Collider Neutrino Physics

Elizabeth Worcester
Brookhaven National Laboratory, Upton, New York, US

July 19, 2023 • *Physics* 16, 113

The first observation of neutrinos produced at a particle collider opens a new field of study and offers ways to test the limits of the standard model.



Google Earth, imagery (c)2023 Maxar Technologies, map data (c)2023; CERN; adapted by APS/Alan Stonebraker

Figure 1: The Forward Search Experiment (FASER) is installed in a service tunnel that connects the Large Hadron Collider (LHC) and the Super Proton Synchrotron (SPS). Proton collisions at the ATLAS experiment's interaction point (red star) generate beams of ne... Show more

First Direct Observation of Collider Neutrinos with FASER at the LHC
Henso Abreu *et al.* (FASER Collaboration)
Phys. Rev. Lett. 131, 031801 (2023)
Published July 19, 2023
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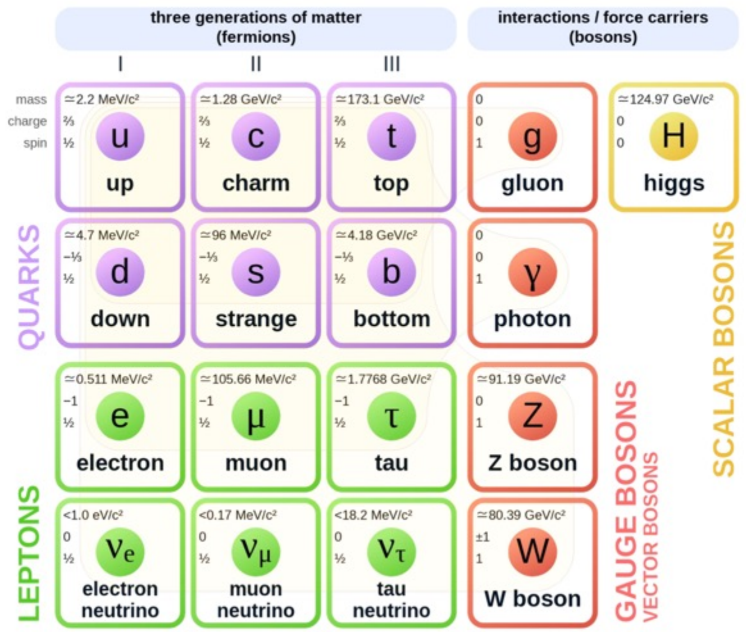
Introduction



Most people belive physics beyond SM due to:

- no explanation of dark matter, neutrino mass, baryon assmmetry..
- theoritical issues, like hierarchy problem, quantum gravity, ….

Also, intensive discussion on several experimental anomalies:

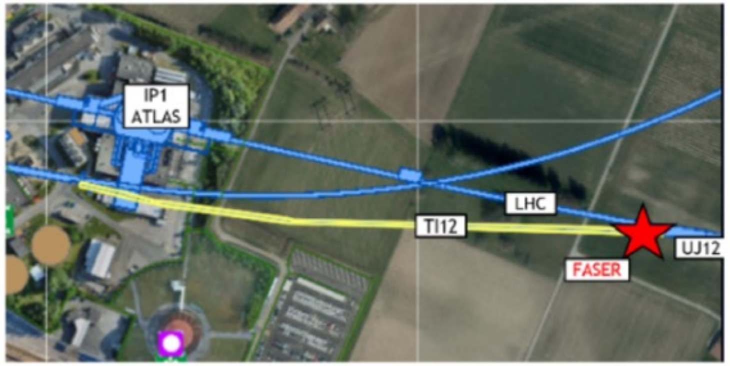
- muon g-2, flavor anomaly, W mass…

Discovery of a new particle followed by detailed measurement must help this situation

- LHC has been a great energy-frontier collider, which could both produce and detect new particles
- however optimistic scenario used for designing experiments has not been successful
  - e.g, SUSY should have discovered already in LHC Run 1 (2010-)
- I joined ATLAS experiment in 2012, and also started FASER experiment in 2018.

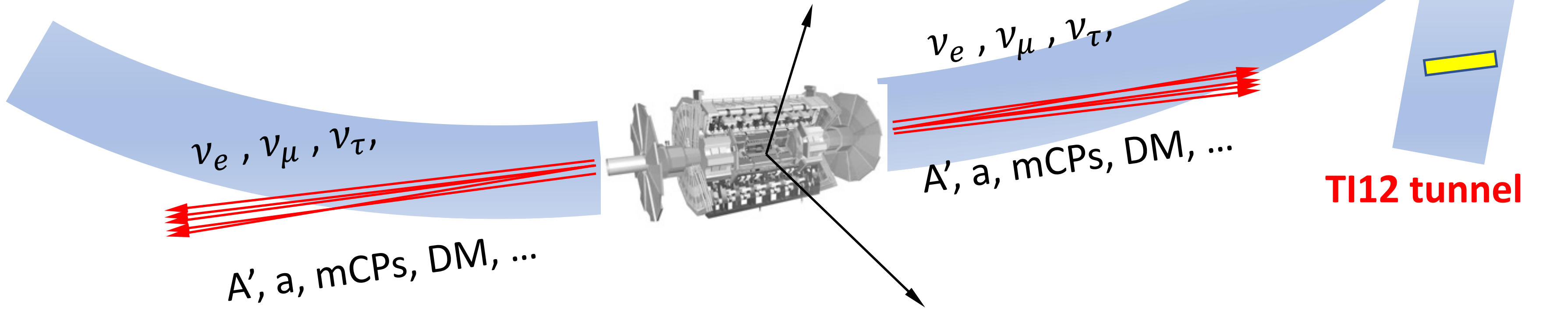
New challenge would be definitely needed !

FASER experiment



FASER is a new forward experiment of LHC, located 480 m downstream from the ATLAS IP.
Successfully started data taking in Run 3 from July 2022 for:

- Search for new weakly-coupled particles in the MeV-GeV range
  - proposed to CERN in 2018, approved by CERN in 2019
- Study of all flavors of neutrinos at the TeV-energy frontier
  - proposed to CERN in 2019, approved by CERN in 2020

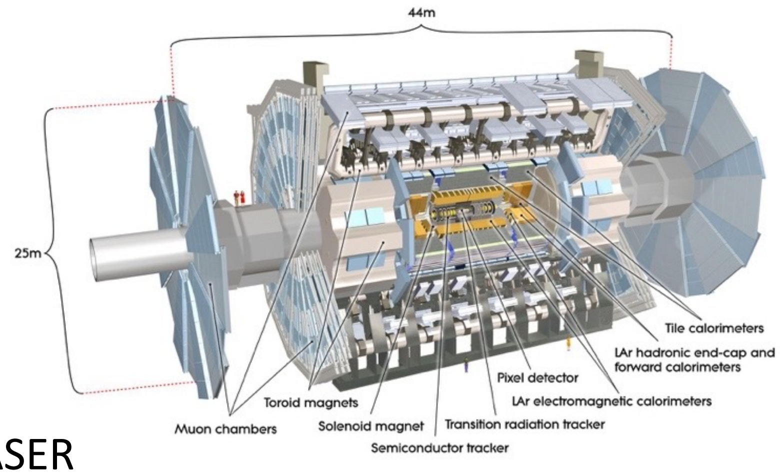


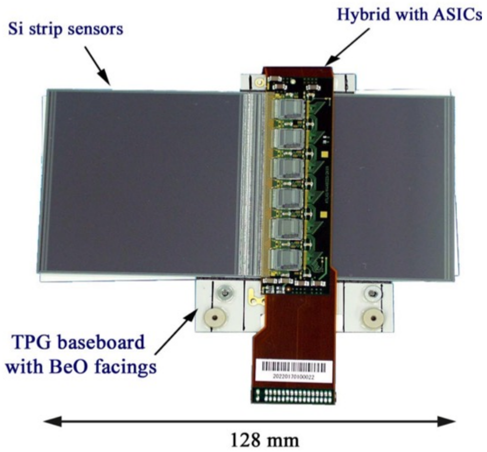
Favorable location, except that refurbishment is needed to be an experimental site.

- Background from collision point is only high-energy muon at about 1 /cm^2/sec, thanks to ~100-m rock
- Radiation level from LHC is quite low, around 4×10^{-3} Gy/year (= 4×10^7 *1*-MeV neutron/cm^2/year)

LHC Run2

2017
10 ATLAS SCT run coordinator
11
12
1 Leave
2



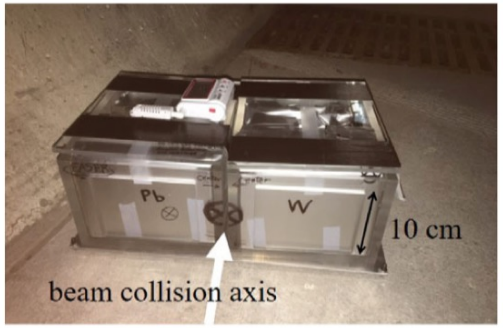


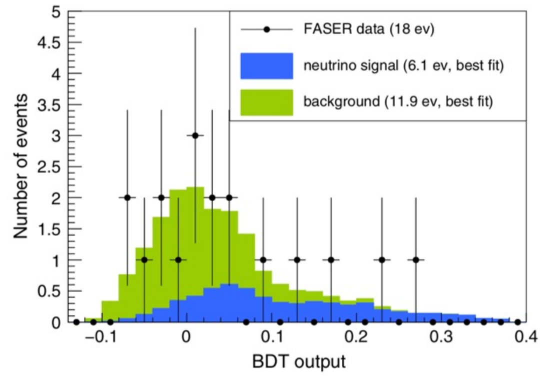
2018
3 Attend Aspen Conference in US, knowing FASER
4 Propose to use ATLAS SCT modules for FASER tracker, joining FASER as 5th experimentalist
5 Propose to use emulsion detector for background measurement
6 Install emulsion detectors for background measurement of the tunnels →

7 Submit LoI of FASER experiment to CERN (14 authors)
8 Install emulsion detectors with W and Pb for LHC neutrino
9
10

Long shutdown 2

11 Submit Technical Proposal to CERN (35 authors)
12





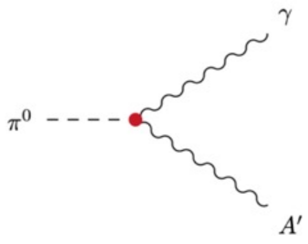
2021 Nov: LHC neutrino candidates (2.7 σ)

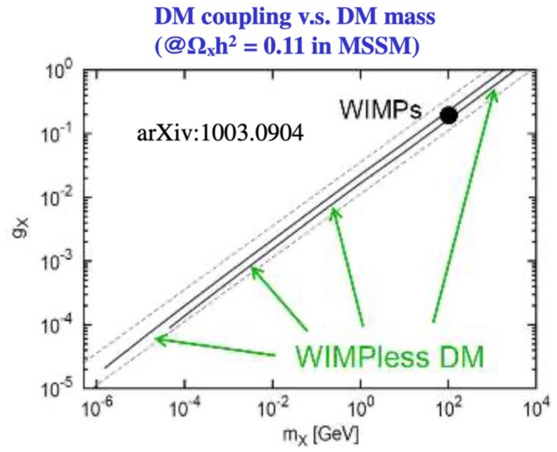
2019
1
2 Receive grant from Simon/Heising-Simon foundation (2.5 M$)
3 FASER approved, aiming to start data taking from LHC Run3 (expected to be 2021, but delayed to 2022)

Searching for new particles in MeV-GeV range

Motivated by dark matter

- Example is a dark photon (A') – vector portal to dark sector
- Could be produced very rarely in decay of a π^0
- Could be long-lived due to small coupling constant



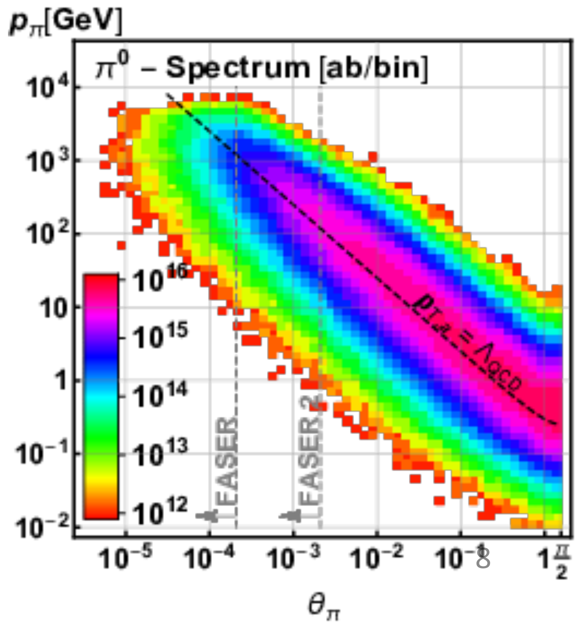


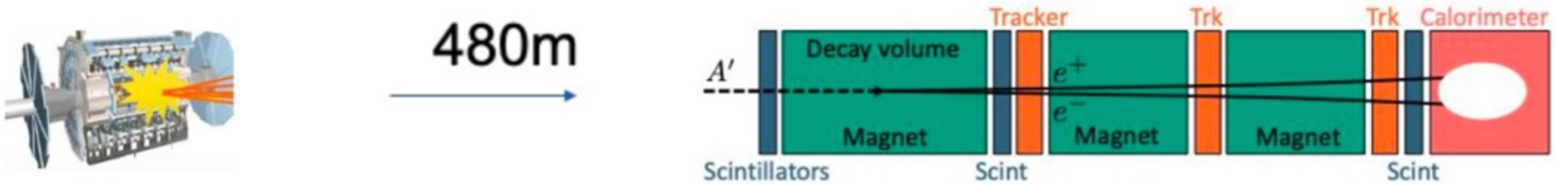
Huge flux of π^0 produced in LHC collision provides strong opptunity

- O(10^{15}) of π^0 in FASER acceptance (r = 10 cm) in Run 3
  - corresponding to 10^{-8} solid angle
- Very energetic - typically E > 1 TeV

Dark photon (A') decays into a collimated pair of charged paritcle

- $m_{A'}$ = 200 MeV and E = 2 TeV, the separation is O(200) um at the first tracker
- $e^+ e^-$ for most of the $m_{A'}$ range relevant for FASER





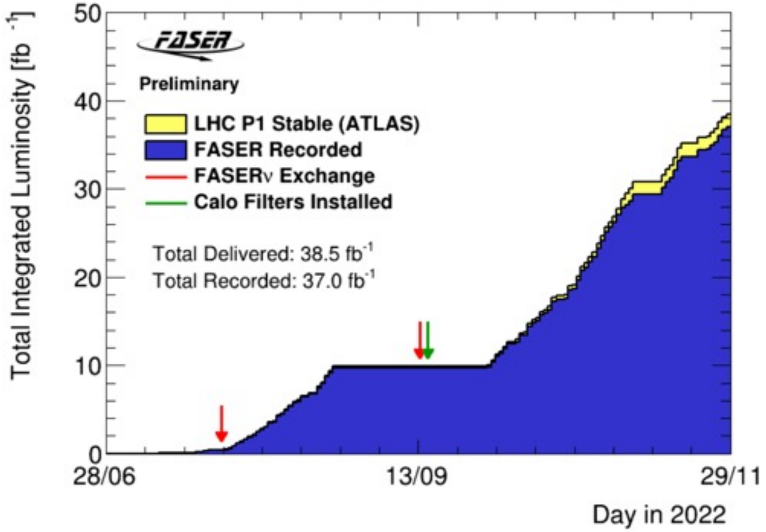
Searching for new particles in MeV-GeV range

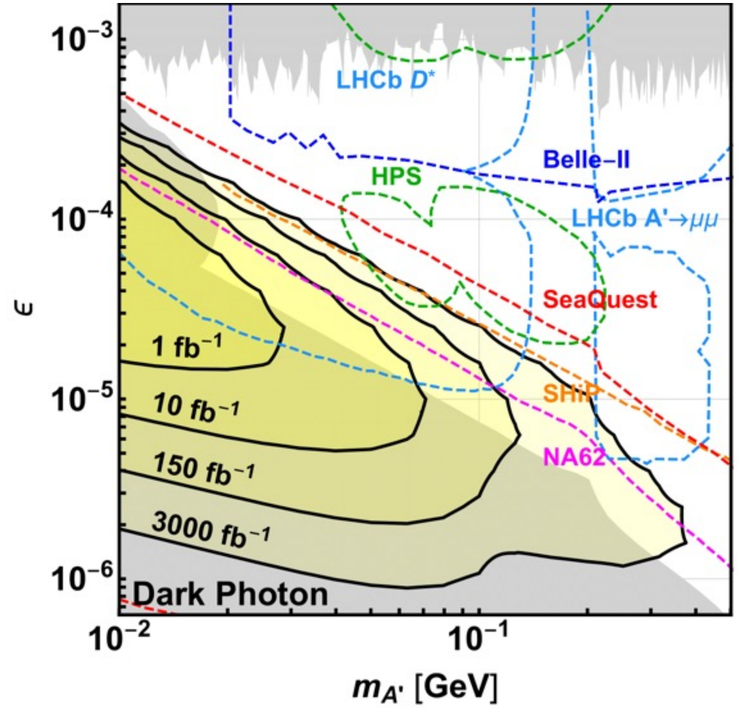
FASER is the first far collider experiment for new particle searches

- Unique approach provides senstivity to unexplored region with the first 1 fb^{-1} of the LHC collision

LHC finished the 2022 operation end of November

- About 40 fb^{-1} delivered at the ATLAS interaction point
- FASER successfully collected the data
  - 96.1% delivered lumi recorded
  - red arrow: emulsion exchanged
  - green arrow: calo gain optimized





FASER will also have sensitivity to other dark sector scenarios including ALPs, other gauge bosons, …

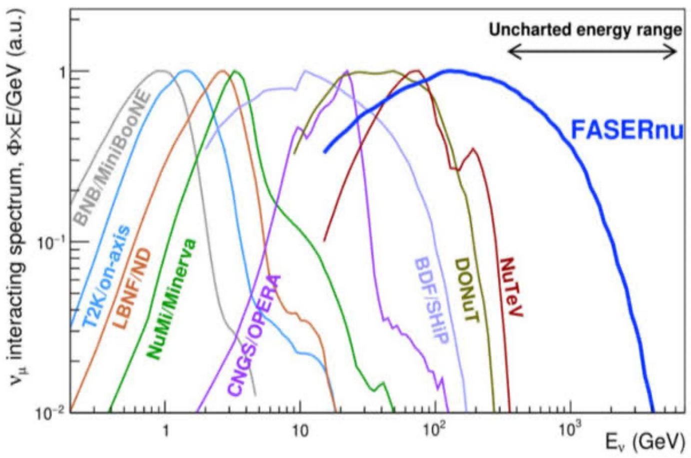
- Comprehensive summary found in Phys. Rev. D 99, 095011 (2019)

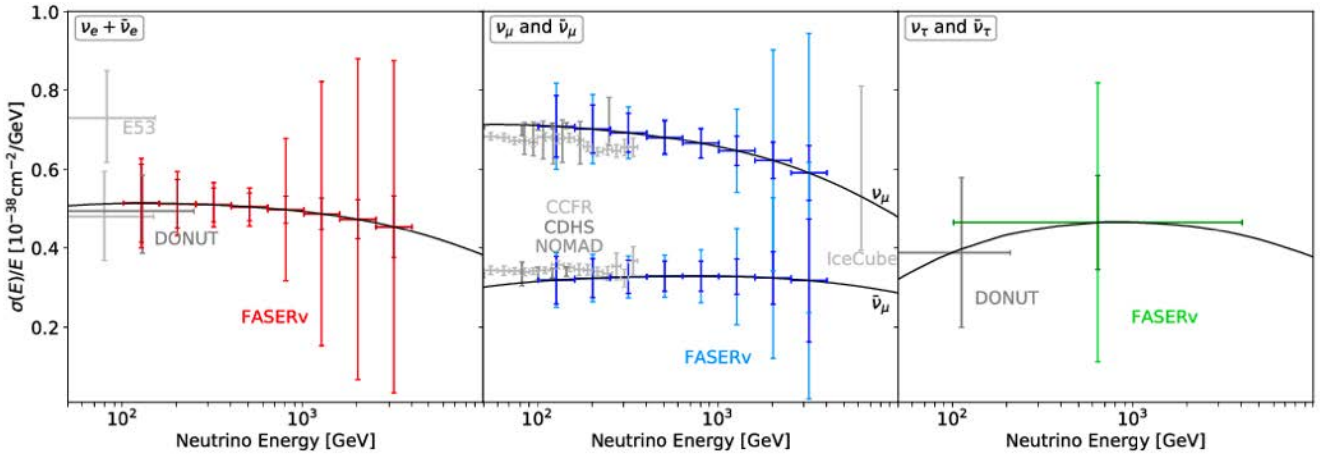
Exploring neutrinos at the TeV-energy frontier

Sensitive to new physics by measuring scattering cross sections and studying the final states

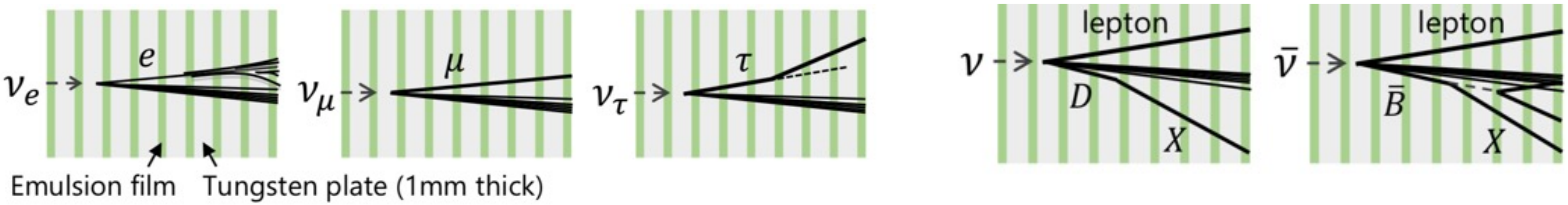
- Expected number of CC neutrino interaction with 250 fb^{-1} in Run 3

based on PhysRevD.104.113008

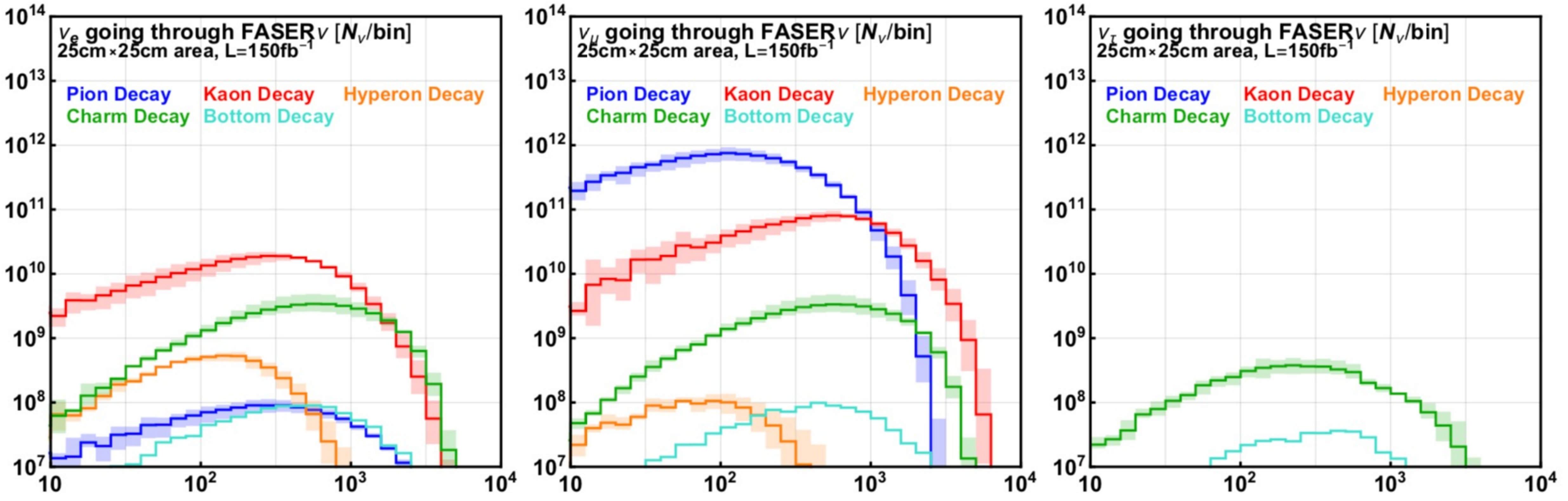




- Emulsion detector provides great ID for all leptons and heavy flavor hadrons from neutrino interaction



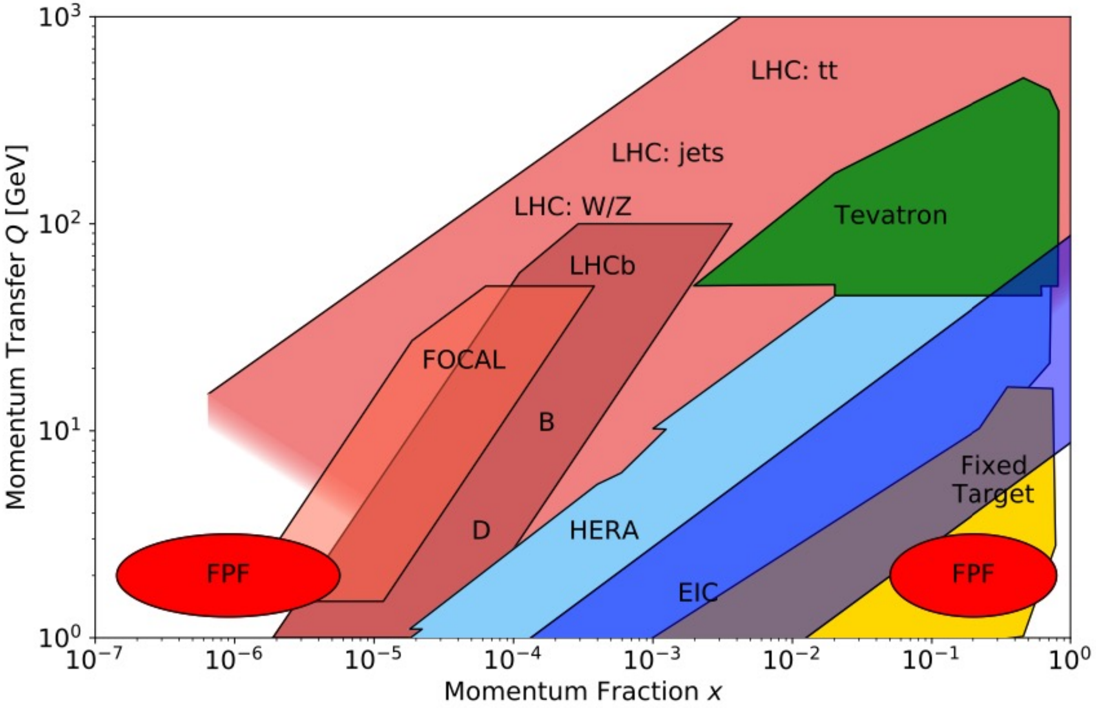
Breakdown of the LHC neutrino production

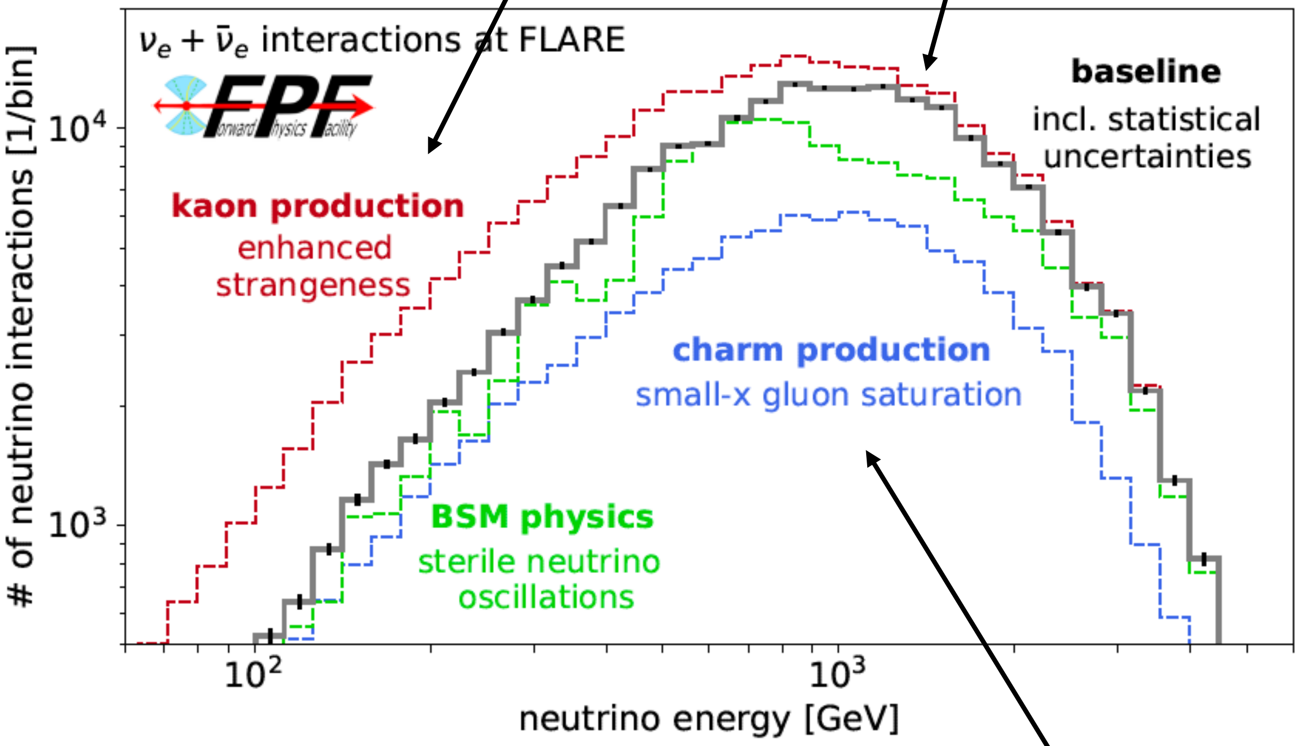


A new approach to measure proton PDFs (Parton Distribution Function)

- Gluon saturation
- Strange quark
- Charm quark

Unique inputs to QCD





ν_e energy spectrum

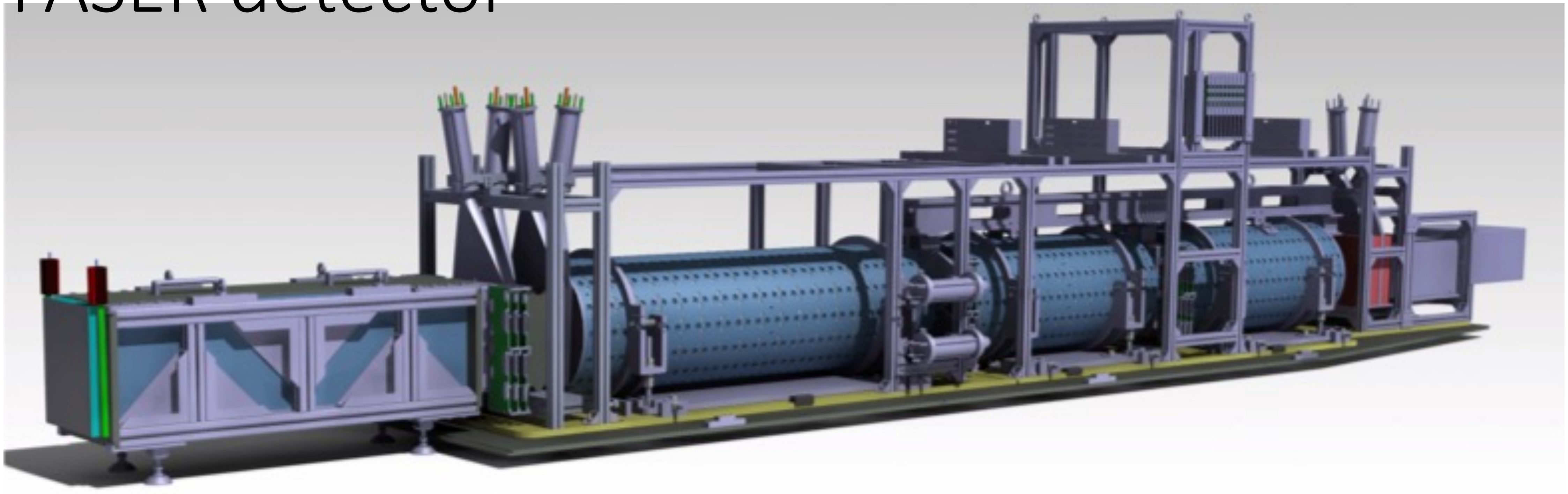
Could be constraind by ν_μ measurement

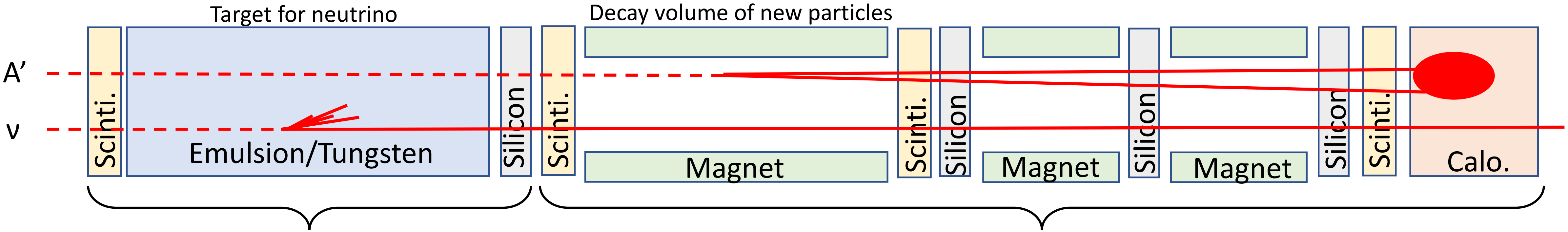
Could be constraind by ν_τ measurement

Important to have good energy resolution of ν_e, ν_μ, ν_τ

- Combined measurments with Emulsion, tracker and calorimeter (see next pages)

FASER detector

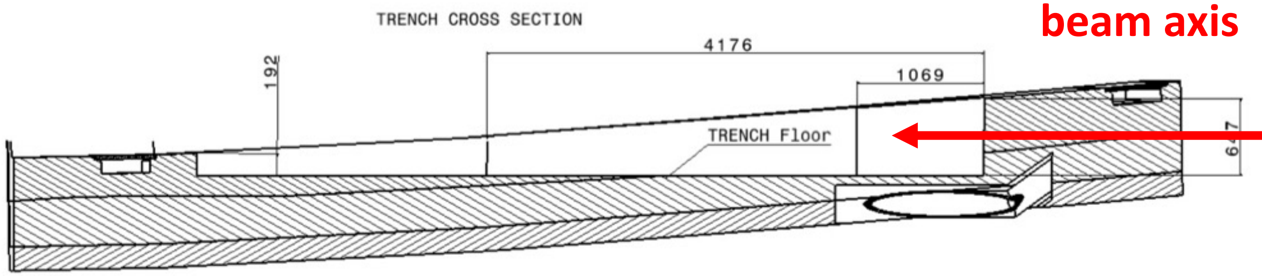




For neutrino physics:
Installation completed 2022 March

For new particle search:
Installation completed 2021 March

Civil engineering work



Aug 2018

Nov 2020

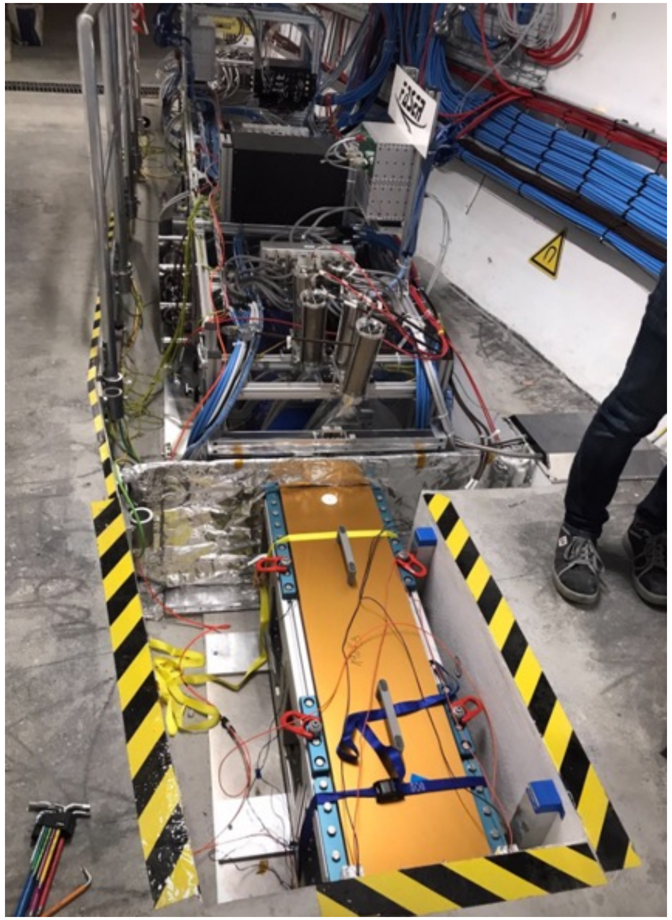
The floor in TI12 excavated by ~50 cm to have the FASER detector on beam axis

FASER detector installation

FASER spectrometer (magnets and tracker), scintillators and calorimter

April 2021

Emusion/Tungsten detector, IFT and scintillator

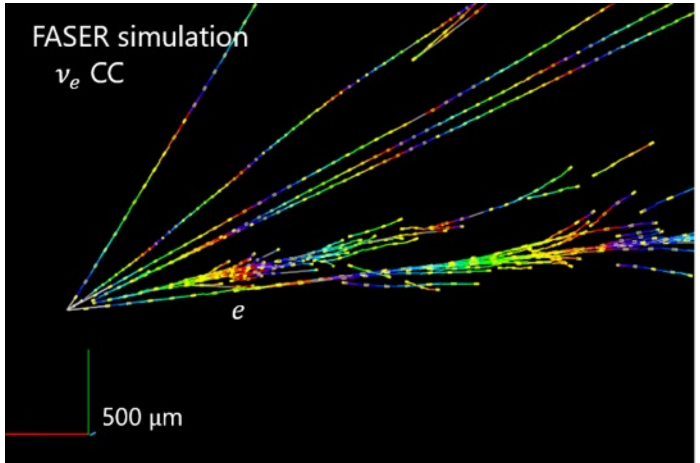


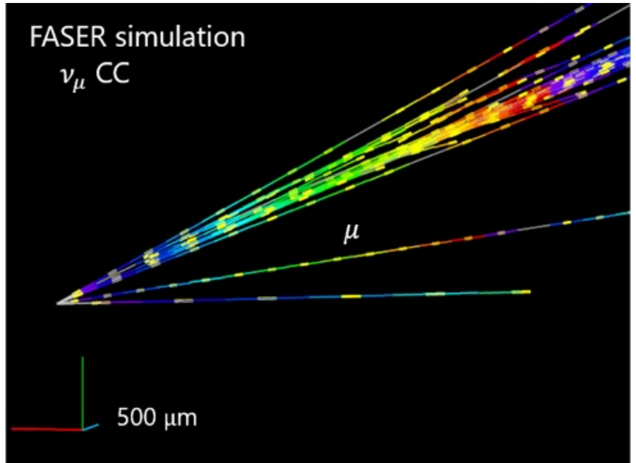
March 2022

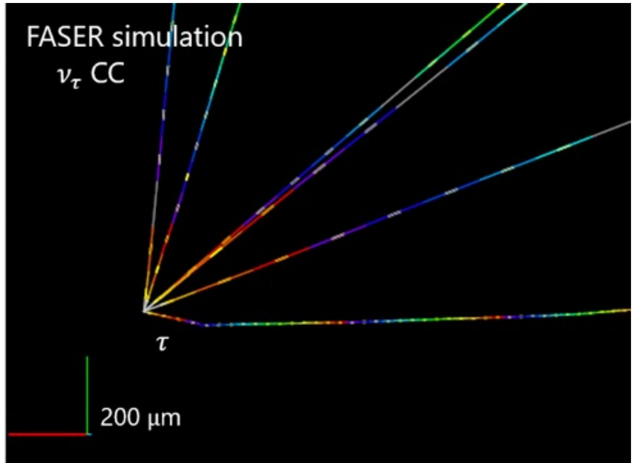
Emulsion/Tungsten detector

All flavors of neutrino interactions can be identified

- Heavy quark production also can be distinguished
- 730 x 1.1-mm-thick tungsten plates, interleaved with emulsion films
- 25 x 30 cm^2, 1.1 m long, 1.1 ton detector (220 X_0 / 8 λ_{int})
  - ~10000 ν_μ, ~1000 ν_e and ~10 ν_τ expected in Run 3
- 3 replacements each year
  - emulsion will be produced a few months before installation





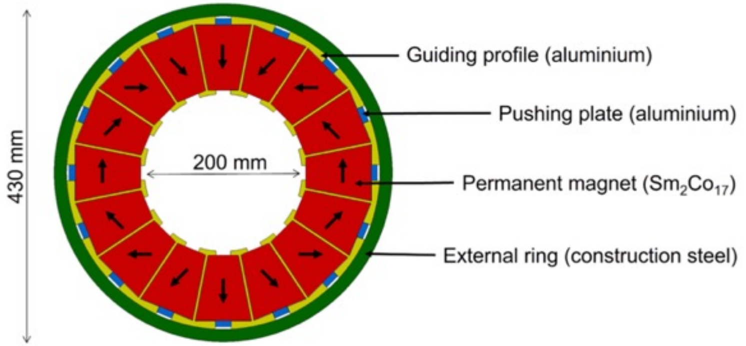


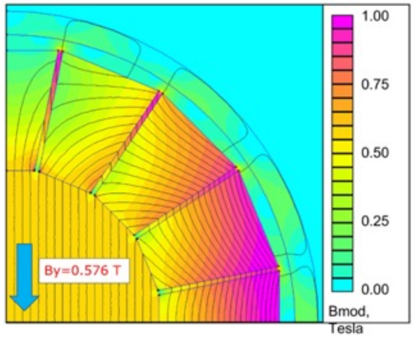
Magnet system

The magnets were designed, constructed and measured by the CERN magnet group

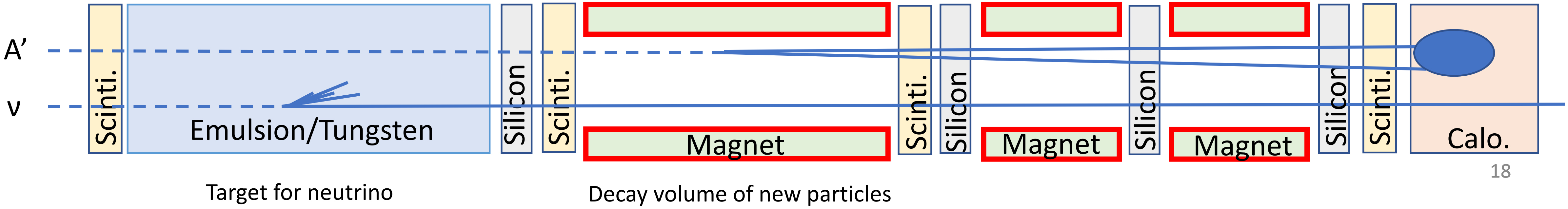
Three 0.57 T permanent dipole magnets (1.5m-long x 1 and 1m-long x 2)

- Sufficient magnetic field to separate a pair of charged particles, assuming tracking detectors with good resolution
- Compact and robust design adapted to cope with limited space in the tunnel and limited access during Run3
- The assembled dipoles were measured with single-stretched wire (SSW) and 3D Hall probe mapper





Magnet	Dipole 1 (short)	Dipole 2 (short)	Dipole 3 (long)	Unit
$\int$ Bx dl	-0.57692	-0.57840	-0.86150	Tm
$\int$ By dl	0.00021	0.00040	-0.00250	Tm
Roll Angle	1.57045	1.57008	1.57366	rad

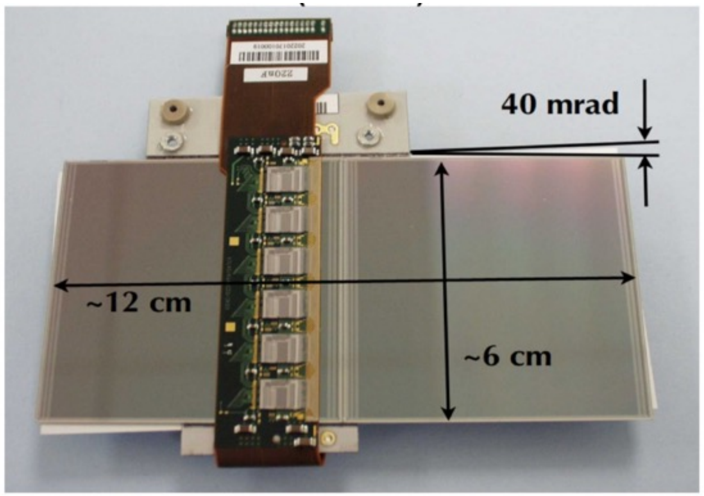


Tracker station

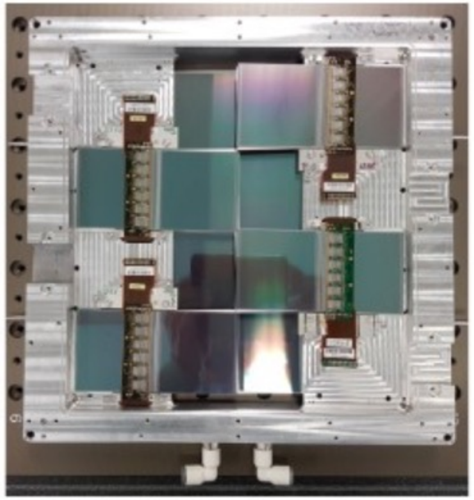
ATLAS SCT module:
- 6cm x 12cm x 2 sides (40 mrad)
- 80 um pitch/ 768 strips per side
- Resolution: 17 um x 580 um
- 6 ASICs per side

Four stations; one station as an interface tracker to emulsion detector and three stations for spectrometer

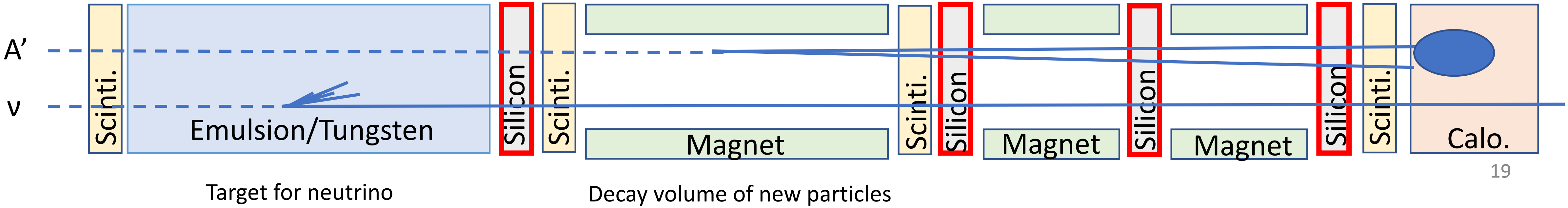
- Based on ATLAS SCT modules - 4 stations x 3 layers x 8 modules = 96 modules



Tracker plane



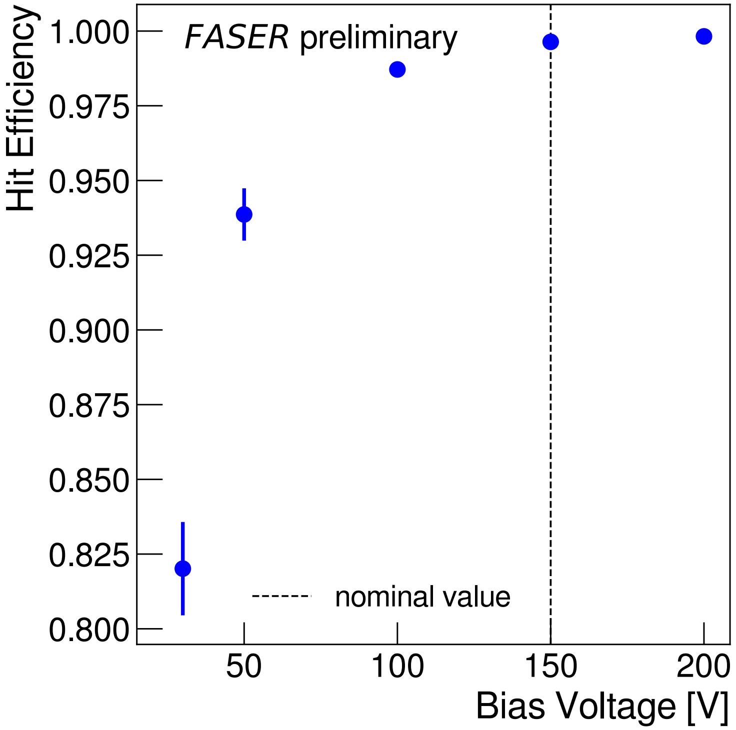
Tracker station

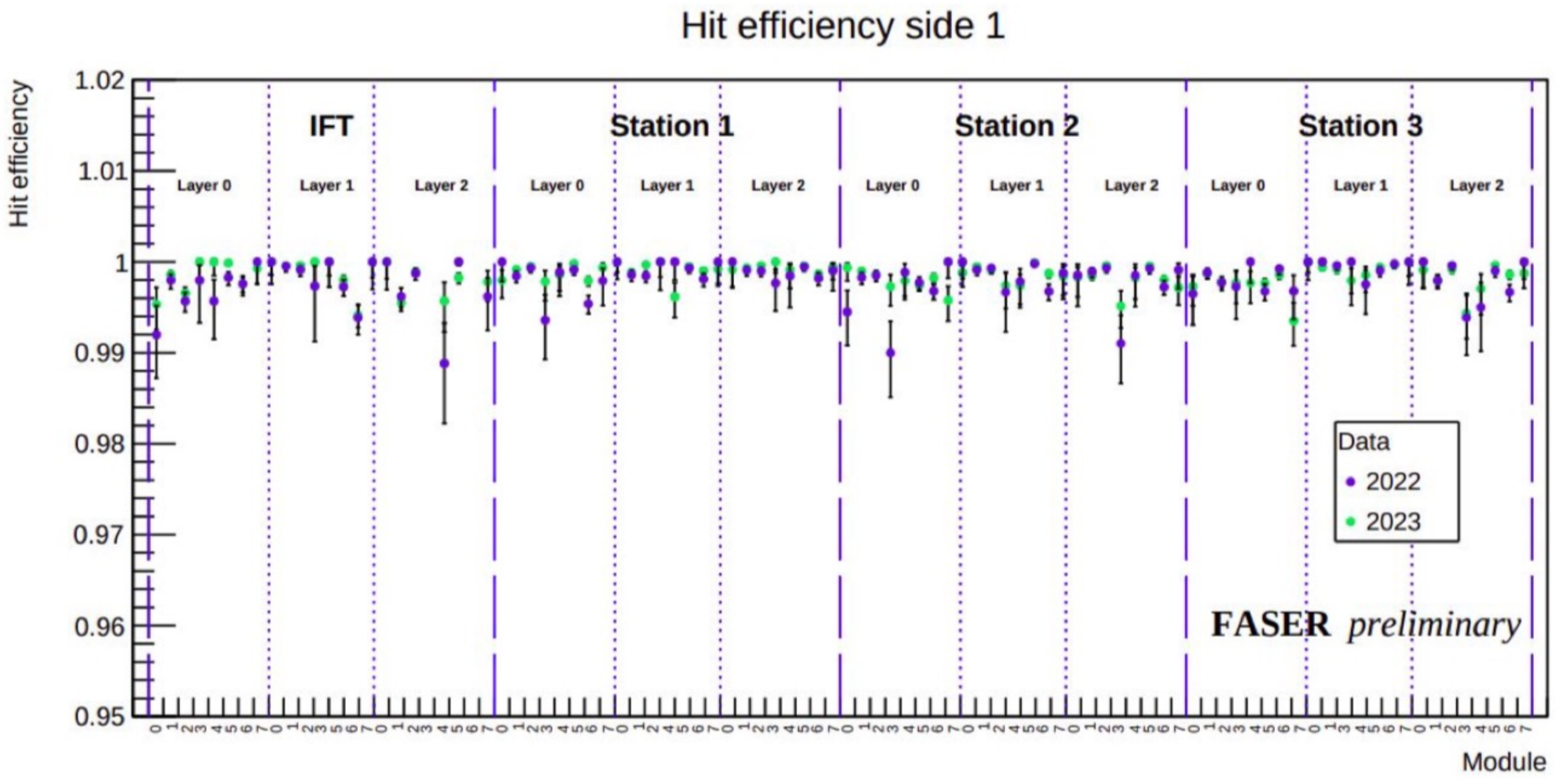


Tracker station performance

Hit efficiency of 99.64 ± 0.10% at 1.0 fC threshold and 150V

- 99.7% strips are active
- Consistent performance to ATLAS SCT

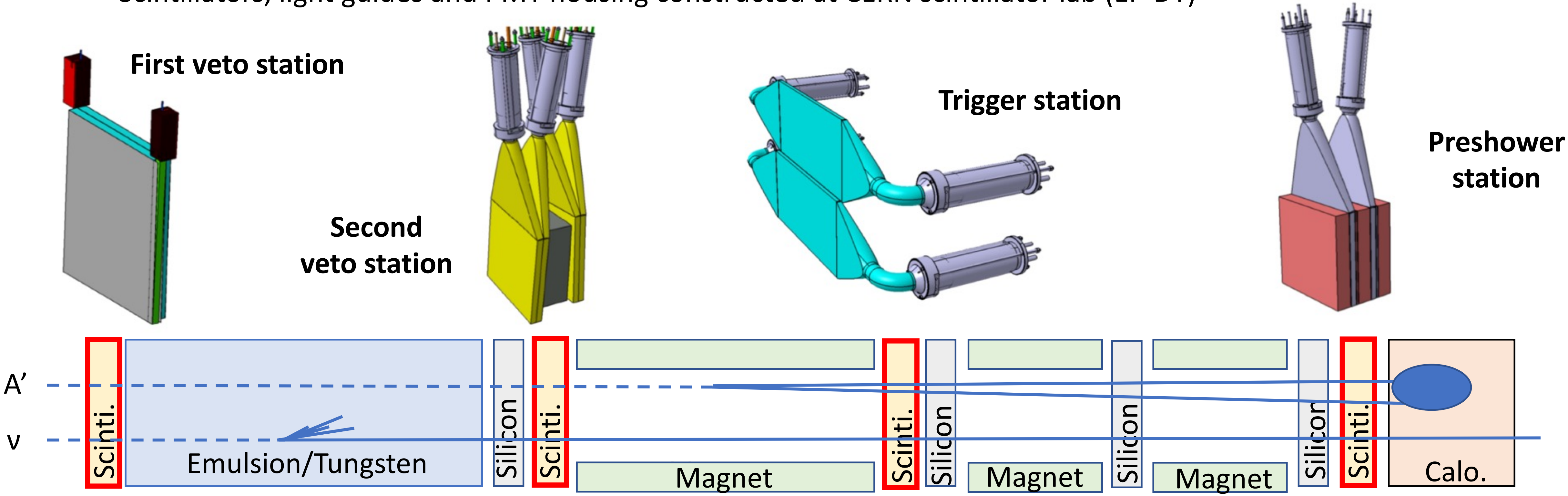




Scintillation detectors

Four scintillator stations are assembled and installed

- Veto incoming charged particle, precise timing, and pre-shower for calorimeter
- Scintillators, light guides and PMT housing constructed at CERN scintillator lab (EP-DT)

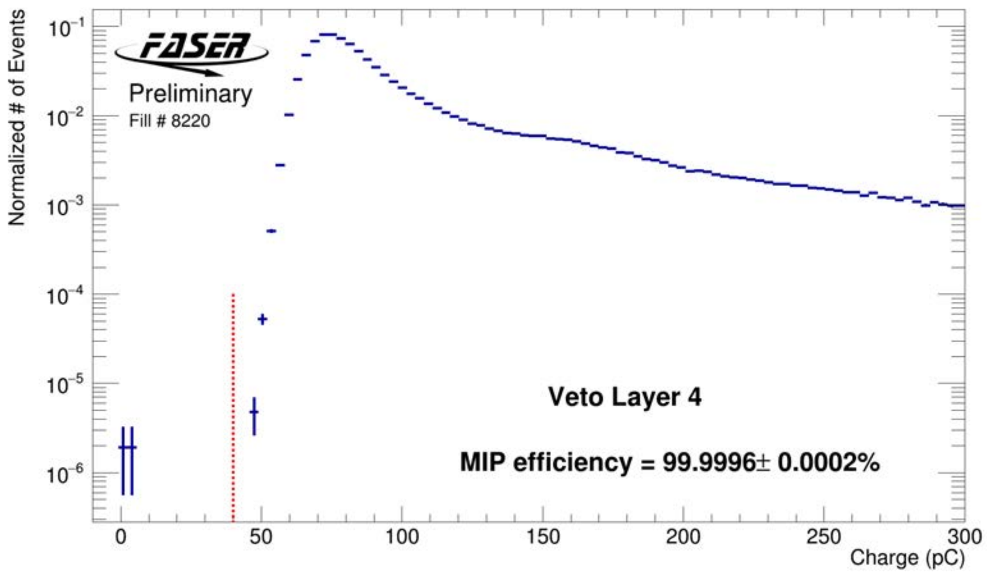


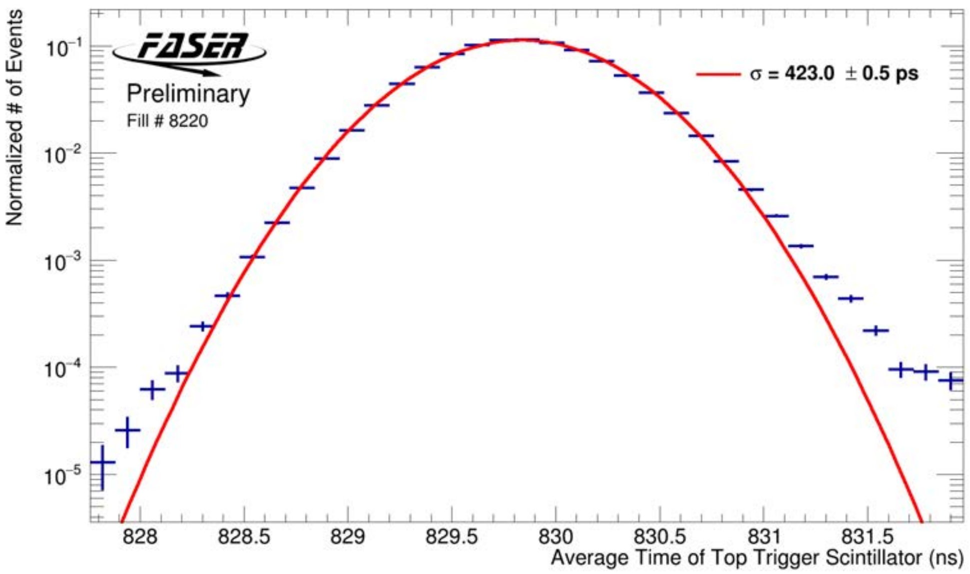
Scintillator performance

Scintillator	Efficiency
NuVeto-0	0.9999805(5)
NuVet0-1	0.9999810(5)
Veto-0	0.9999985(1)
Veto-1	0.9999984(1)
Veto-2	0.9999986(1)

More than 99.99% efficiency achieved for each scintillator, resulting in veto inefficiency less than 10^{-12}

- O(10^8) muon expected in Run3 would be rejected; sufficient for zero background in new particle searches





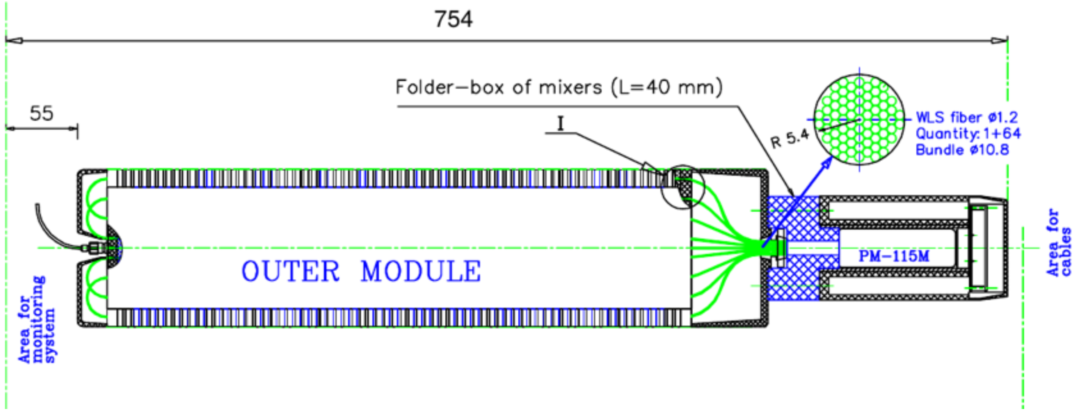
Trigger scintillator provides timing resolution of 423 ps, sufficinet to identify bunch crossing ID of LHC

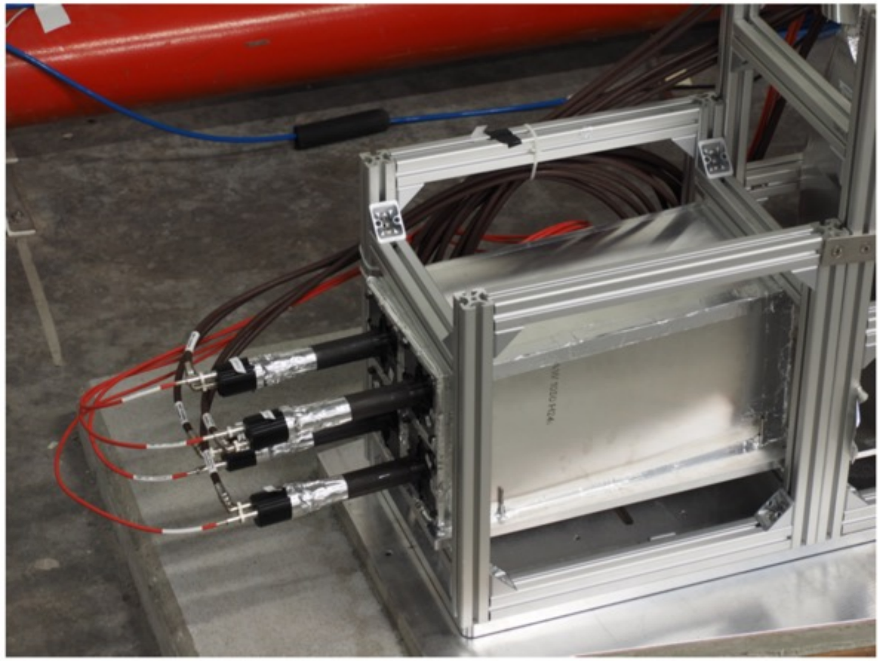
- Average time of two PMTs on both ends of the trigger scintillator to correct for timewalk

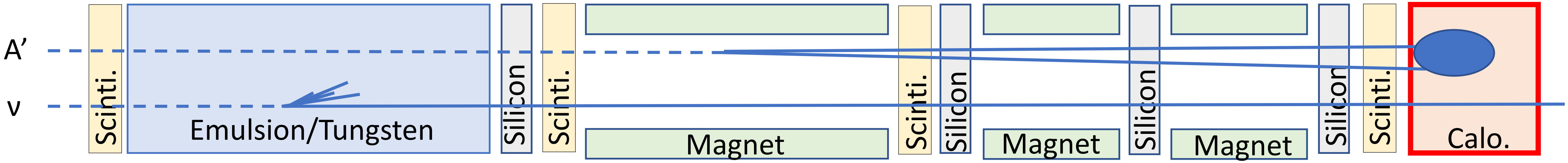
Electromagnetic calorimeter

Calorimeter utilizes spare LHCb ECAL module x 4

- one module has:
  - 12 cm x 12 cm x 75 cm (25 X_0)
  - 66 layers of (2mm lead and 4mm scintillator)



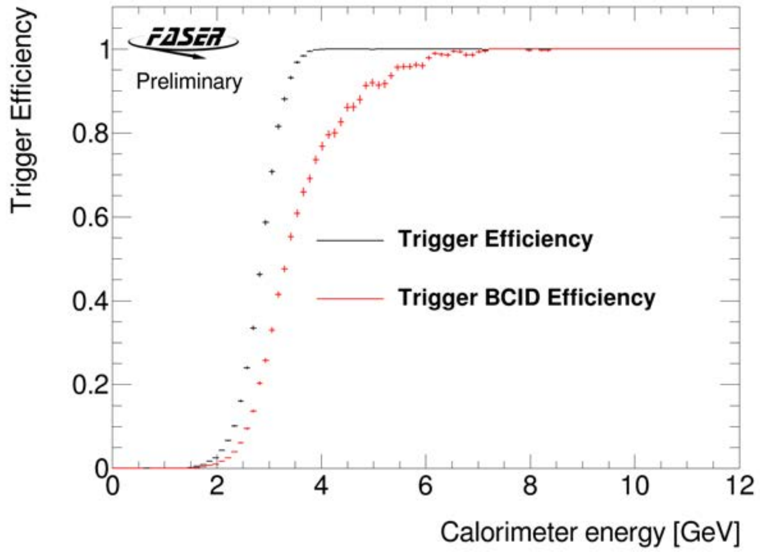




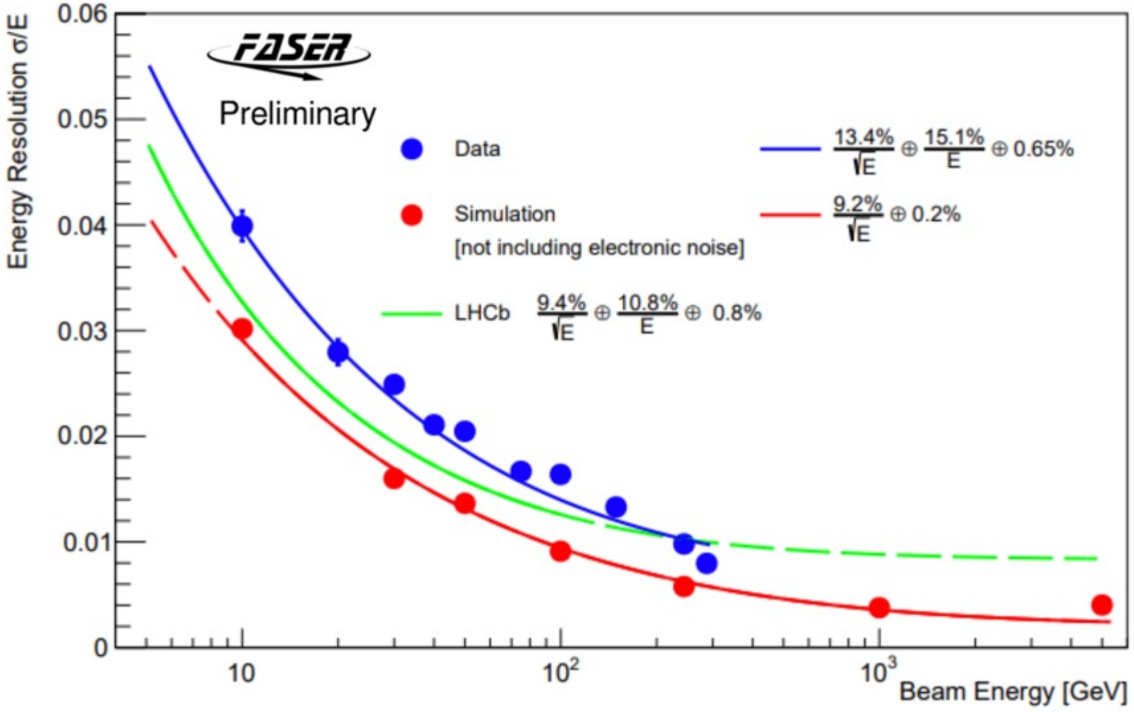
EM Calorimeter – performance

LHC collision data shows calorimeter provides timing resolution of 256 ps, requiring:

- EM energy is above 4 GeV
- only events with unsaturated PMT signals
- BCID to be consistent with a colliding bunch ID



Testbeam at SPS in 2021 summer

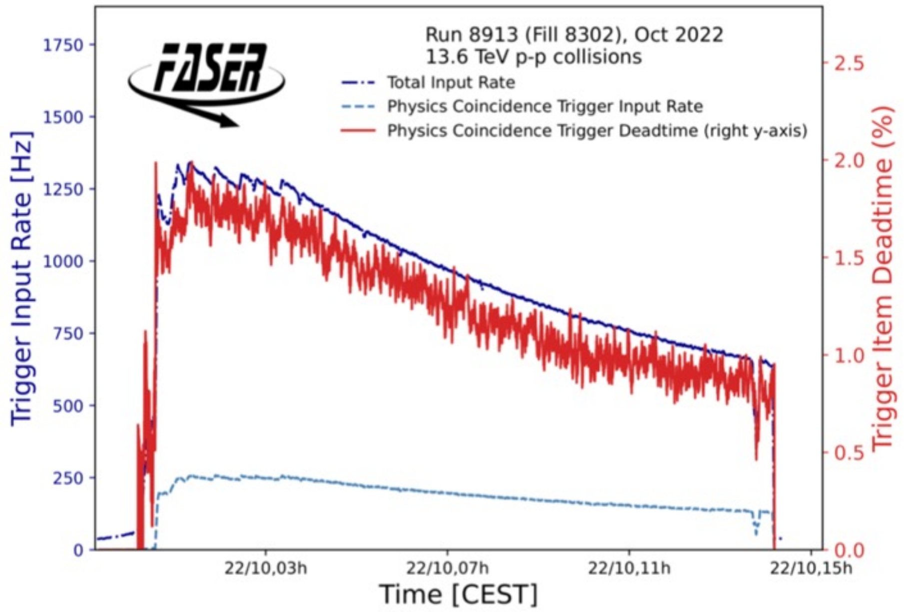


Close to the intrinsic 239 ps timing resolution of the LHC

Stable data taking thoughout 2022

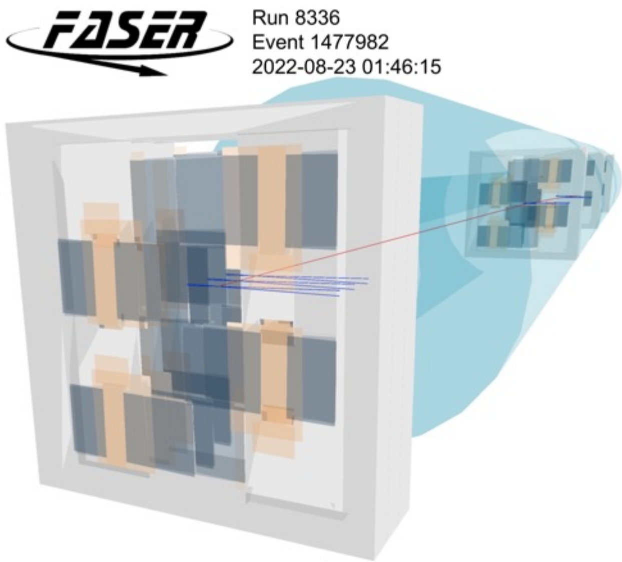
The number of bunches in LHC has reached 2400 since August 2022

- Maximum trigger rate around 1.2 kHz, giving dead time less than 2%
- Physics coincidence trigger (foremost veto and the preshower scintillator station) around 200Hz
    - our main triggered background is not muons passing through from IP1 but particles triggering individual trigger stations



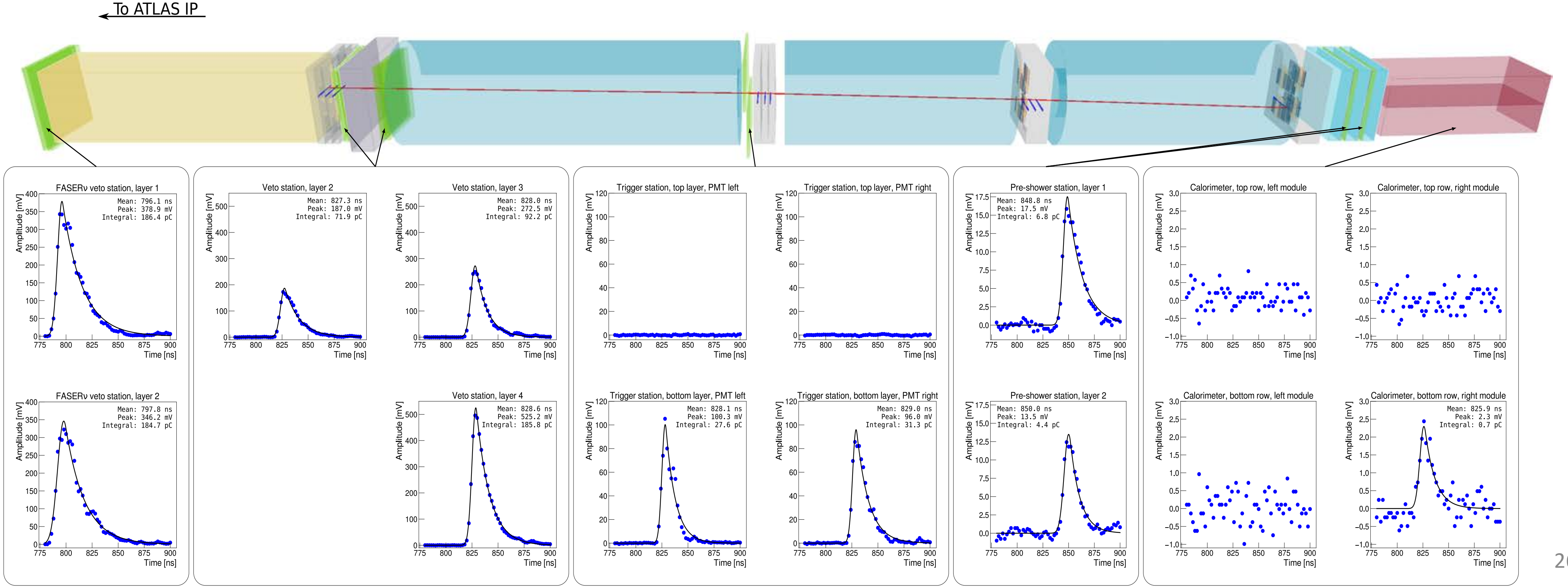
- only 850 pb^{-1} (< 2.5% of full dataset) data lost due to operational issues

Muon event from LHC collission



Run 8336
Event 1477982
2022-08-23 01:46:15

Reconstructed momentum 21.9 GeV



Dark photon search

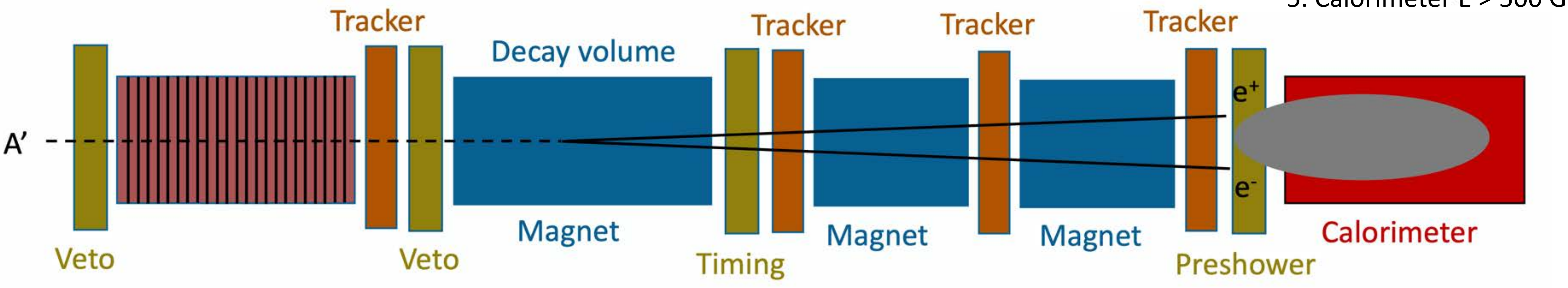
Analysis was **blinded for E>100 GeV** events **without any veto signals**

Signal: select e+e- pairs appearing in the decay volume

1. Events in collision crossing, during good physics data period

3. Timing and preshower scintillators consistent with ≥2 MIPs

5. Calorimeter E > 500 GeV



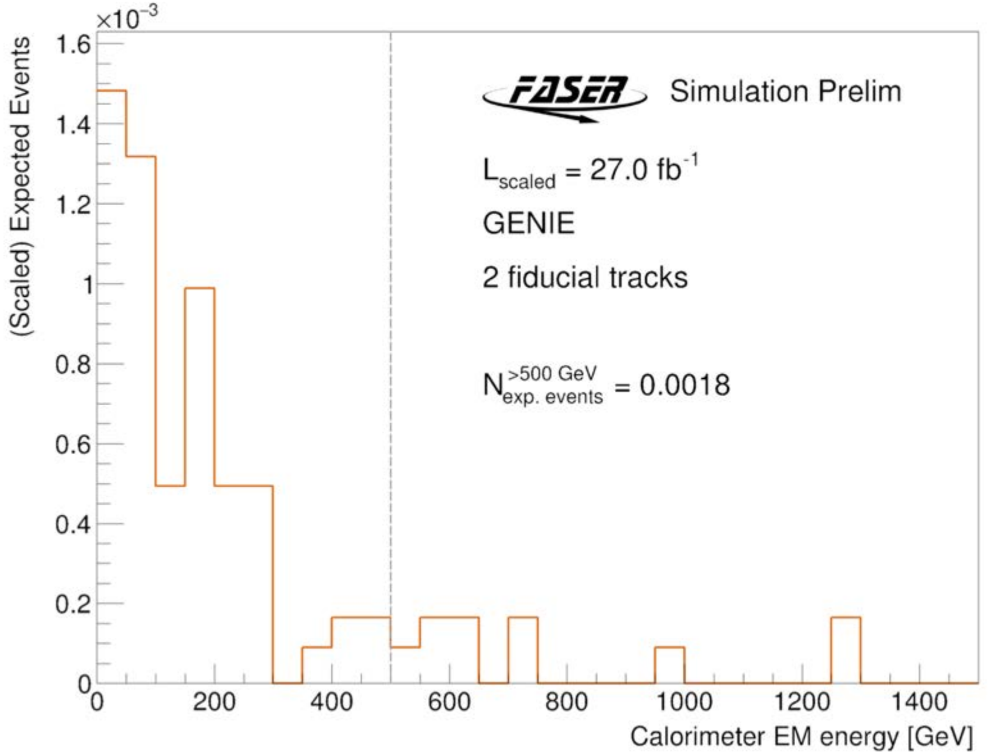
2. No signal in any of veto scintillators (<40 pC ~ 0.5 MIP)

4. Exactly two good quality tracks with p > 20 GeV
- Both tracks in fiducial tracking volume, r < 95mm
- Both tracks extrapolate to r < 95mm in veto scintillators

Background estimation

Major background - Neutrino background

- Estimated from Genie simulation (300 ab^{-1})
  - Uncertainties from neutrino flux & mismodeling
- Predicted events with E(calo)>500GeV: **0.0018±0.0024 events**
  - *Largest background in analysis*



Minor backgrounds

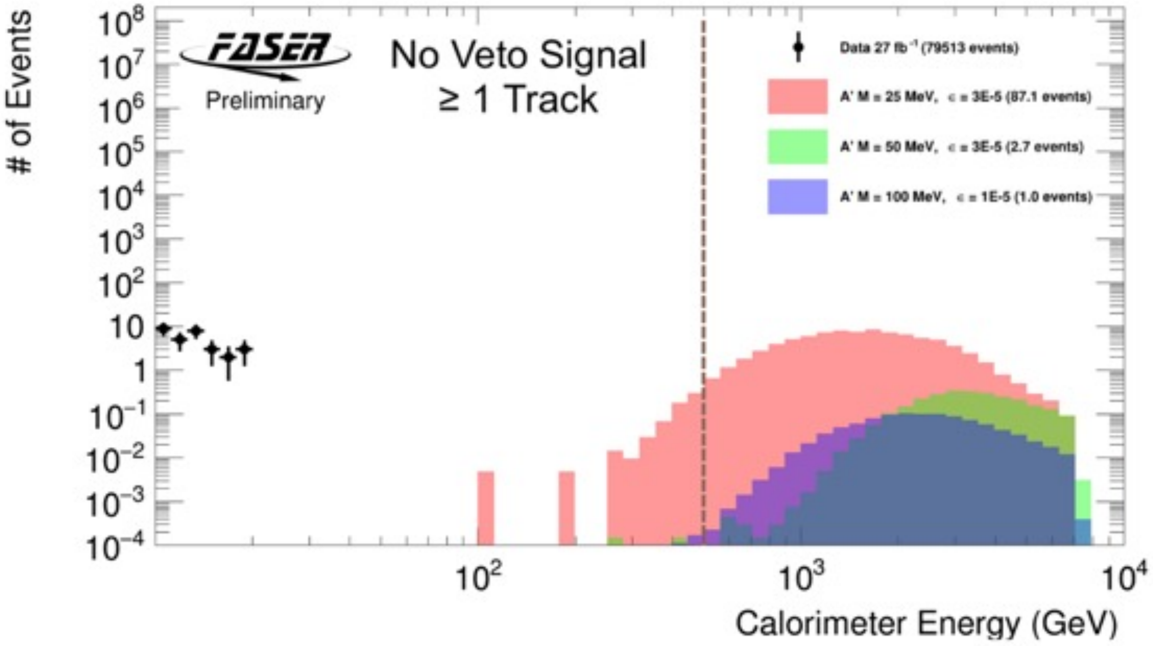
- Neutral hadrons (e.g. Ks) from upstream muons interacting in decay volume : **(2.2±3.1)×10^{-4} events**
- Veto inefficiency: negligible
- Non-collision background: negligible

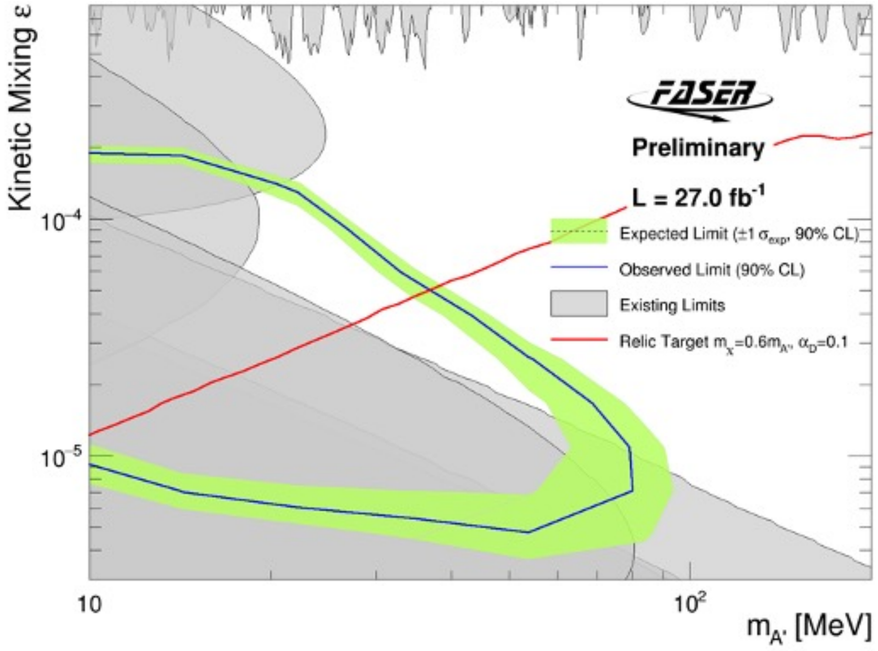
Result

Source	Systematic Uncertainty	Typical Effect on Signal Yield
Theory, Statistics and Luminosity		
A' cross section	$\frac{0.15+(E_{A'}/4\,\text{TeV})^3}{1+(E_{A'}/4\,\text{TeV})^3}$	15-45%
Luminosity	2.2%	2.2%
MC statistics	$\sqrt{\sum W^2}$	1-2%
Tracking		
Momentum scale	5%	< 0.5%
Momentum resolution	5%	< 0.5%
1-track efficiency	3%	3%
2-track efficiency	15%	15%
Calorimetry		
Energy scale	6%	< 1%

No events seen in unblinded signal region

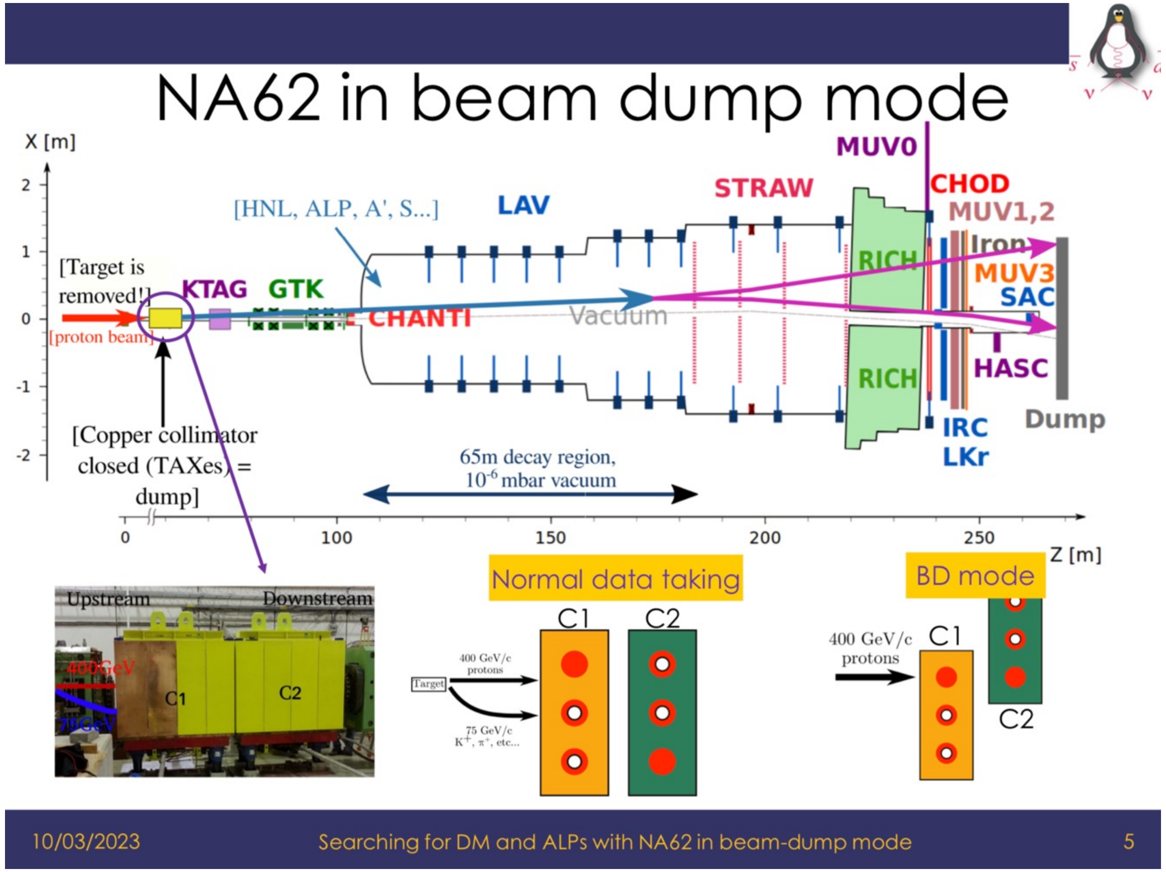
- Total background: **0.0020±0.0024 evts**,

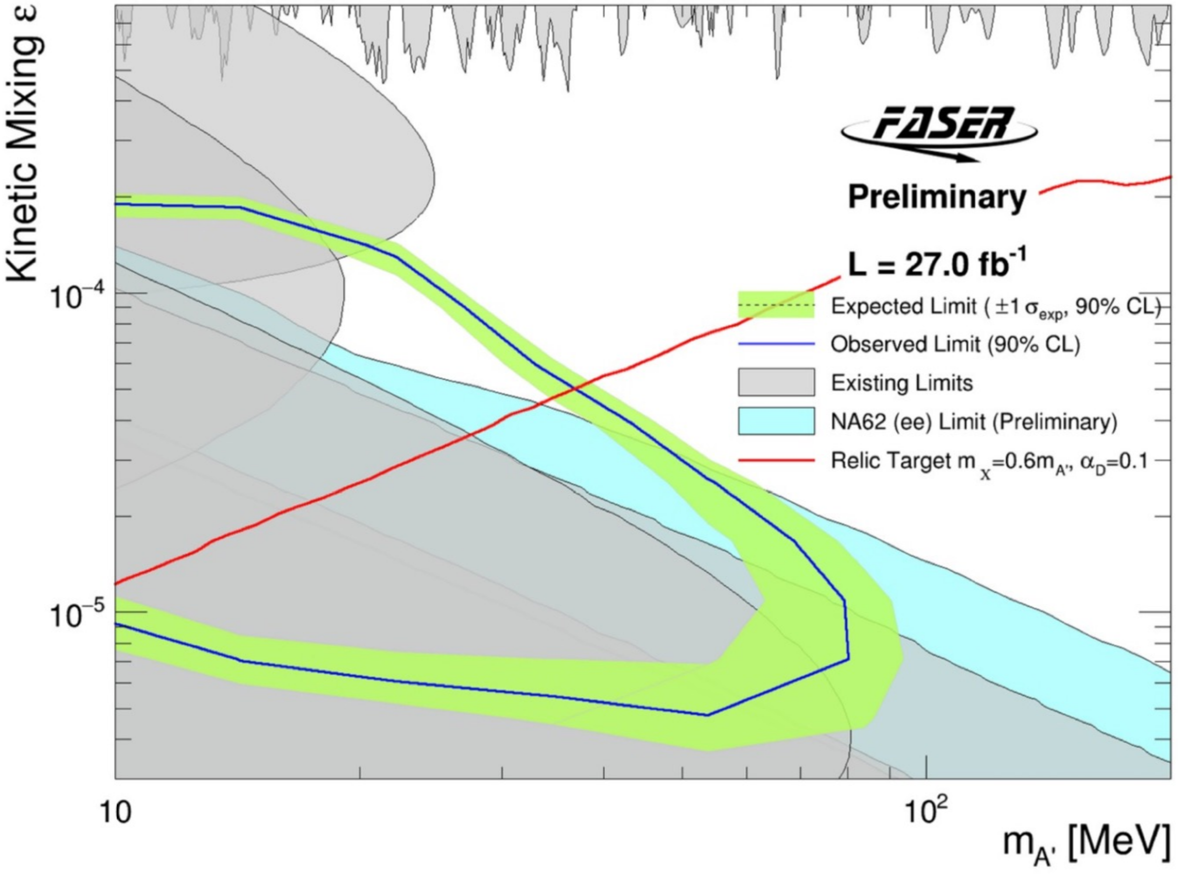




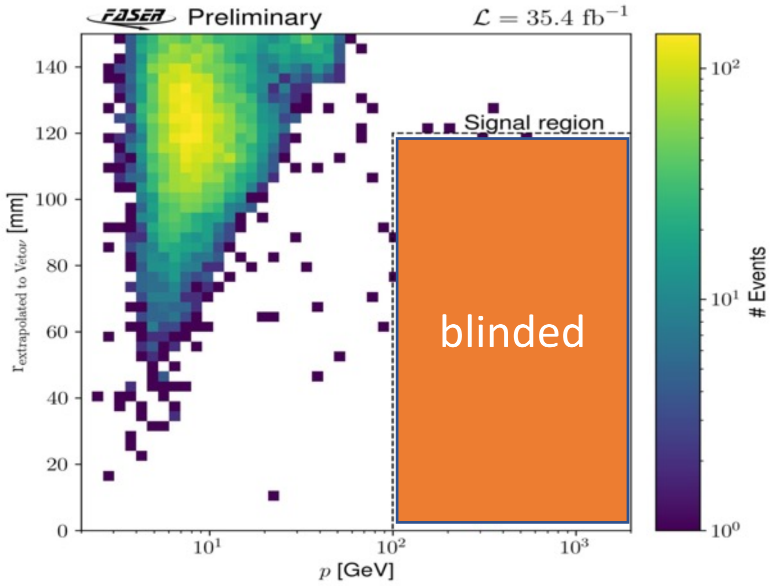
Competition with NA62

Time scale:
2014 – Pilot run
2015 – Commissioning run: ~1% of design intensity, no beam tracker
2016 - Commissioning run + Physics run (30 days)
2017 – Physics run (161 days)
2018 – Physics run (217 days)
2019-2020 – LS2
2021 – Physics run (85 days, ~10 days for beam dump)
2022 – Physics run (203 days)





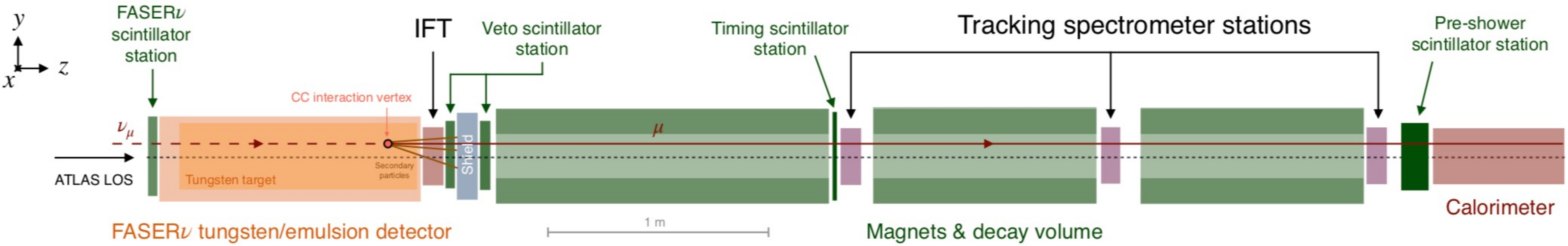
LHC neutrino search



Signal: no signal in front veto and one high momentum track

1. Good collision events

4. Timing and preshower consistent with ≥1 MIP

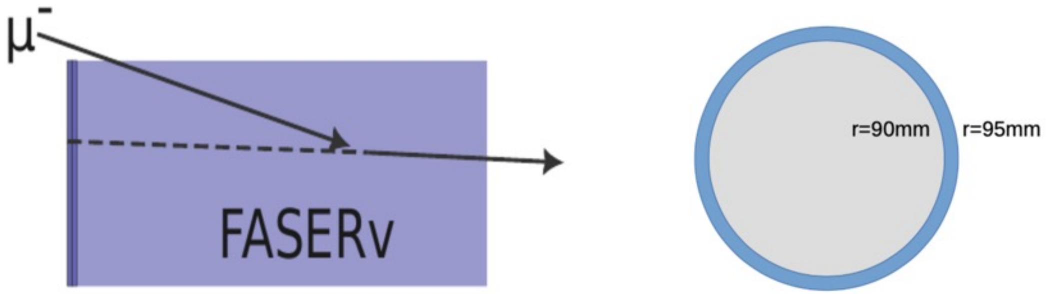


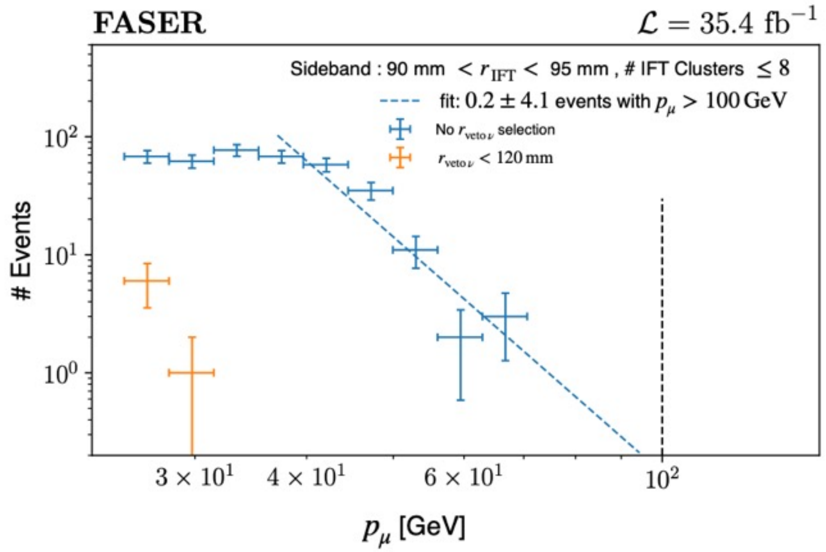
2. No signal (<40 pC) in 2 front vetos
3. Signal (>40 pC) in other 3 vetos

5. Exactly **1 good fiducial** (r < 95 mm) track
- p_T>100 GeV and θ<25 mrad
- Extrapolating to r<120 mm in front veto

Background estimation

Geometric background: 0.08 ± 1.83 events expected

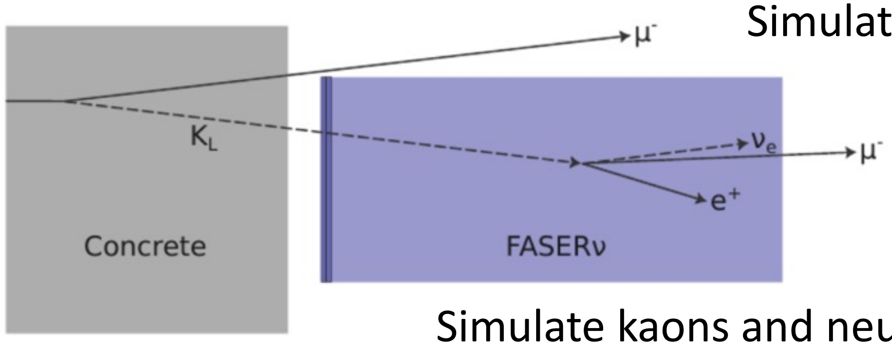




Sideband region determined from r=90-95mm, scaled to full acceptance with muon simulation

Neutral hadron background: 0.11 ± 0.06 events expected

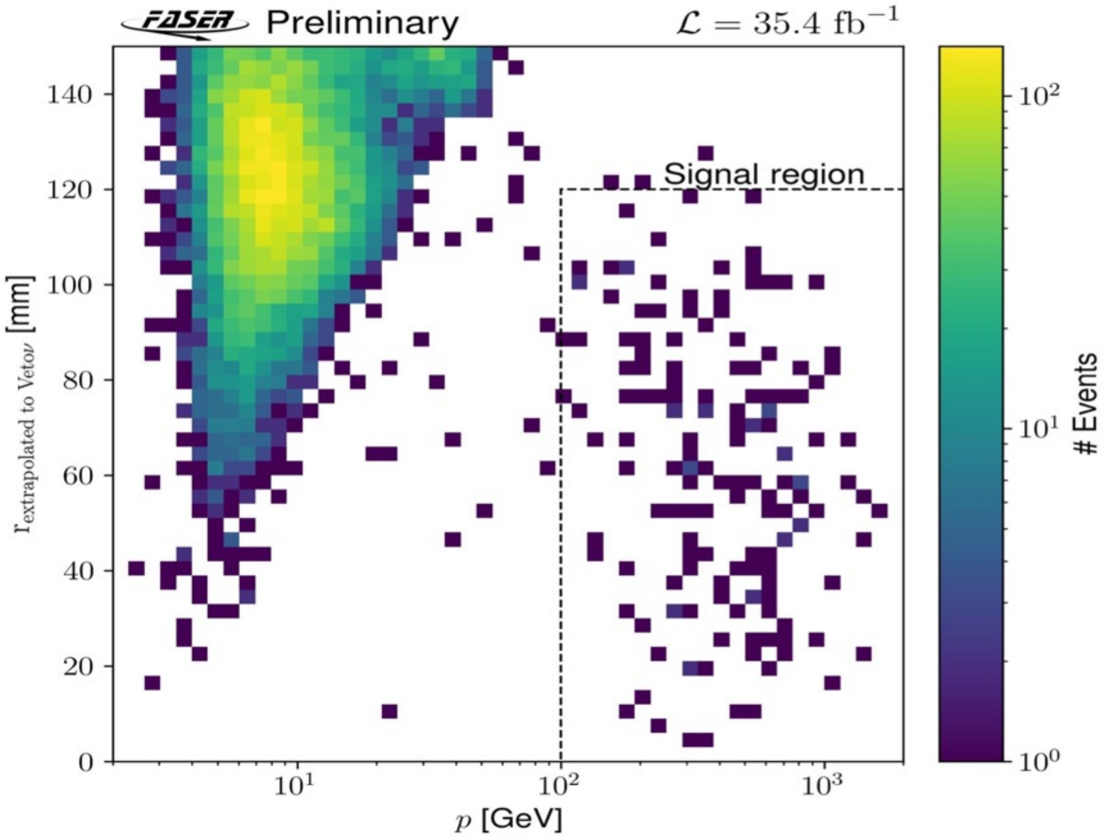
Simulated 10^9 μ+ and μ- events



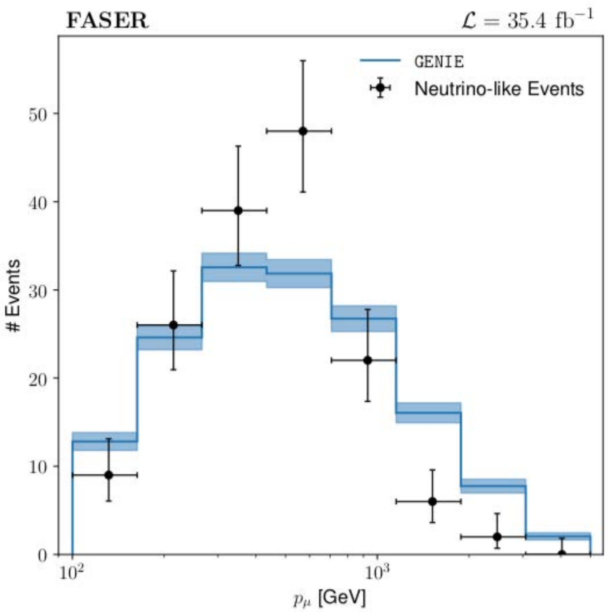
Simulate kaons and neutrons with p > 100 GeV following expected spectra

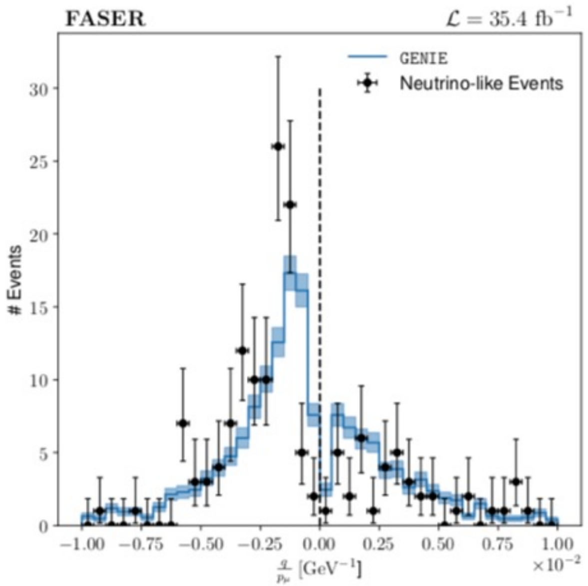
Results – the first observation of LHC neutrino

Find 153 event after unblindig, corresponding to signal significance of 16 σ !!



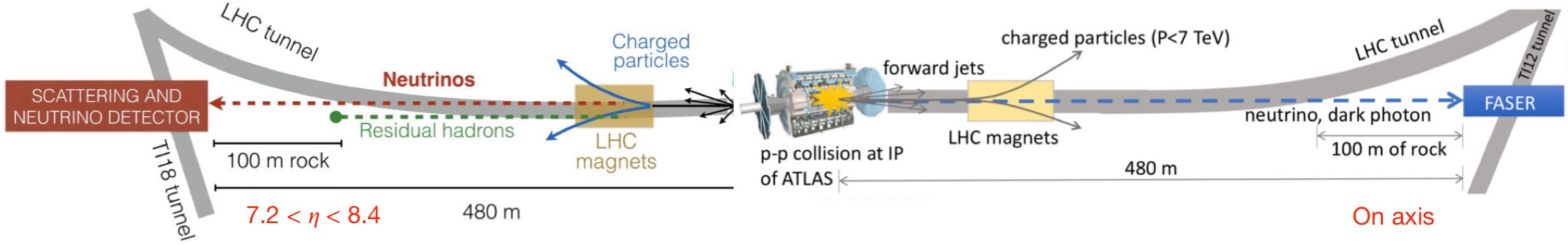
Luminosity-normalized prediction agrees well with data





Opening up a new filed – neutrino physics at collider

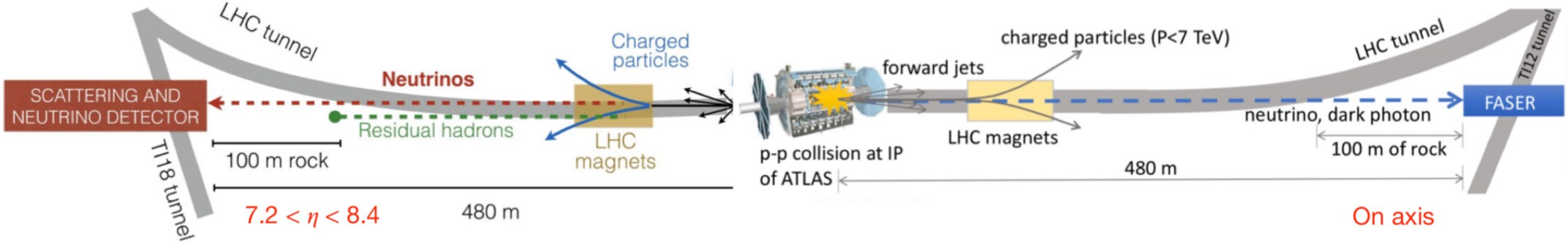
The birth of Collider Neutrinos (at the LHC)



SND

Faser-ν

The birth of Collider Neutrinos (at the LHC)

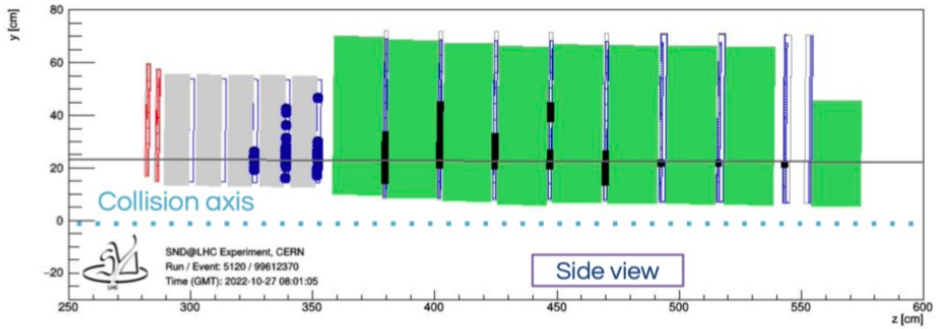


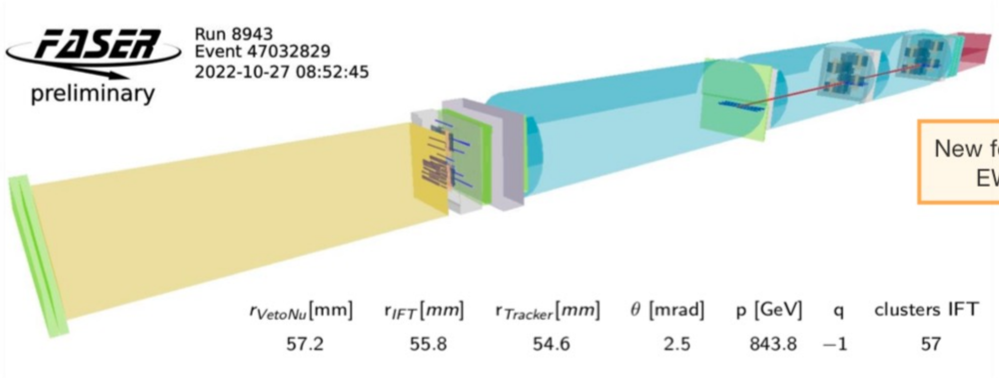
SND

New for Moriond EW 2023

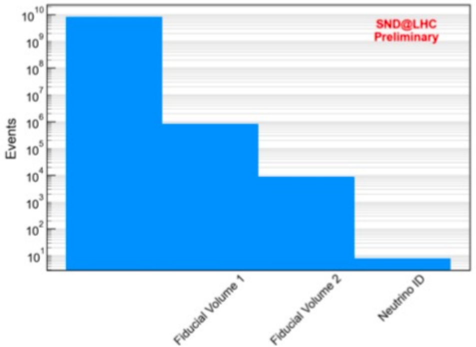
First results from SciFi/Silicon tracking devices

Faser-ν





New for Moriond EW 2023

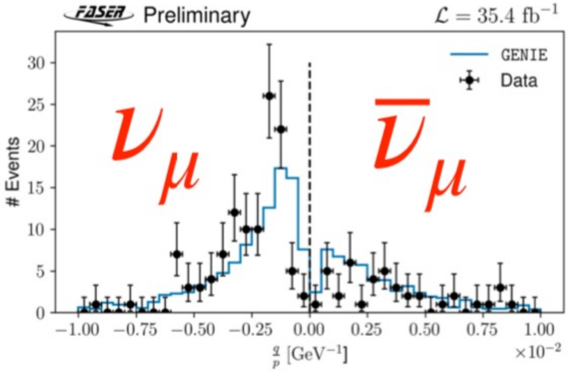


5 events expected and 8 observed (0.2 background)

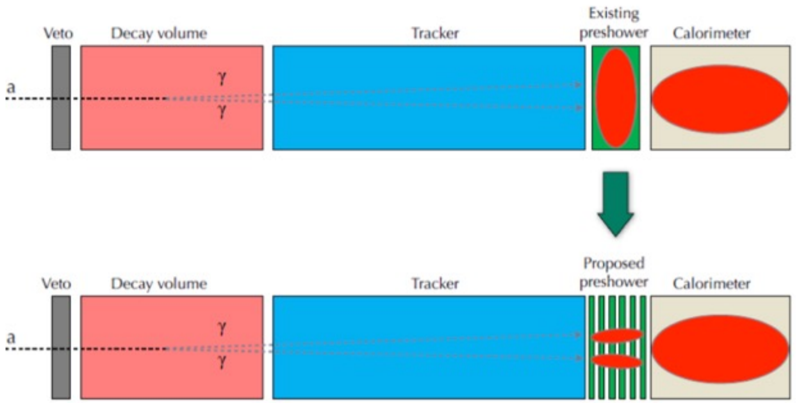
Approximately 5σ observation!

150 events expected and 153 observed (0.2 background!!)

16σ observation!

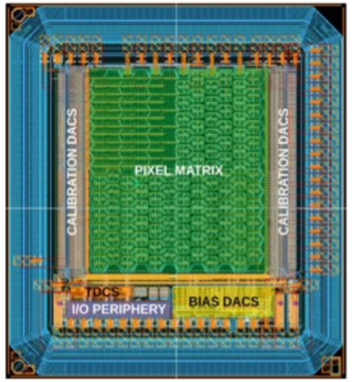


Upgrade planned for 2025

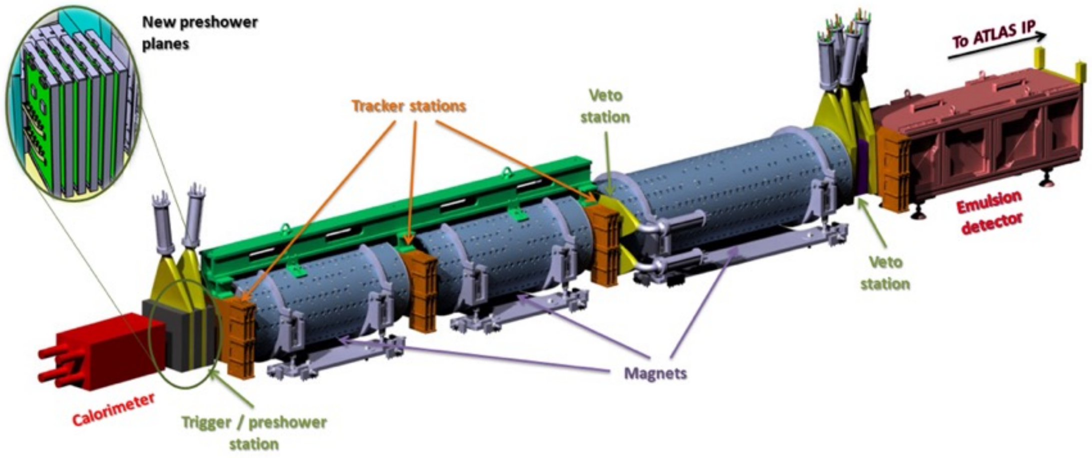


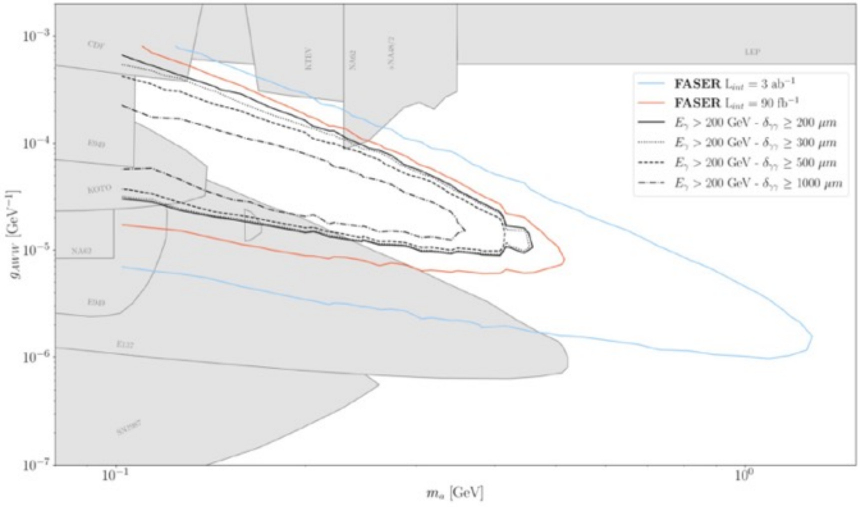
The preshower scintillator will be replaced by silicon pixel detector

- Installation is planned at the end of 2024, aiming to take data in 2025 (the last year of Run3)
- Separation of 2 close-by gammas down to 200 um enables us to get strong sensitivity for ALP -> 2 gamma
- Monolithic Active Pixel Sensors (MAPS) with SiGe BiCMOS technology developed by University of Geneve



JINST 17 P02019





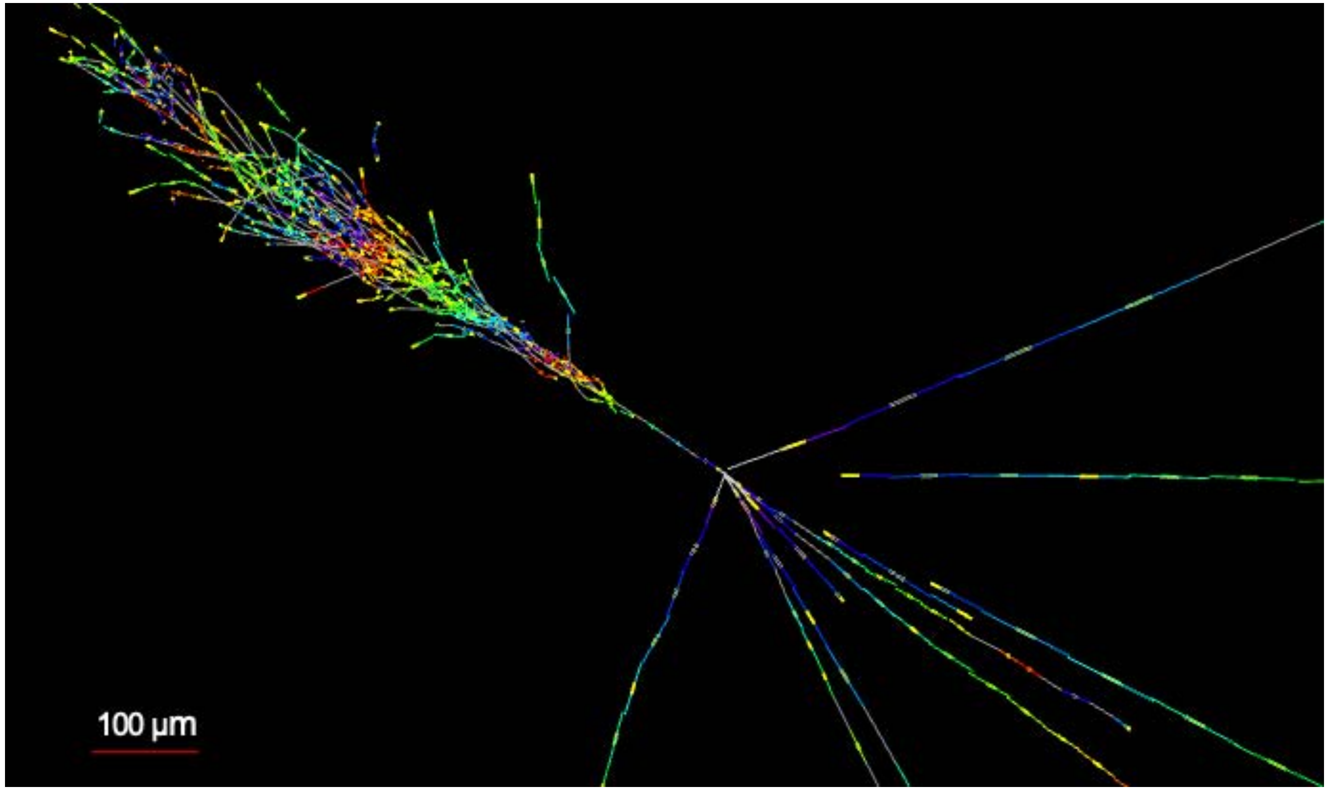
CERN research board formally approved this preshower project in April 2022

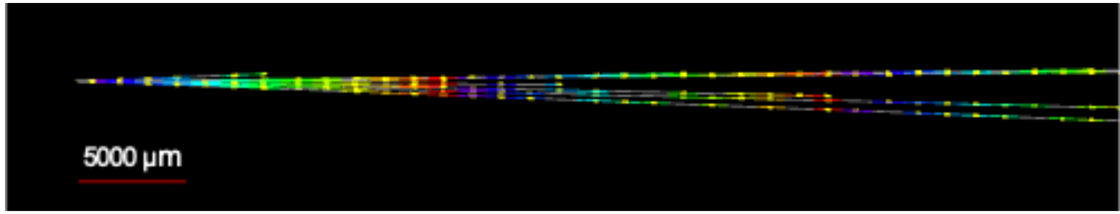
- Technical proposal is public: https://cds.cern.ch/record/2803084/

Electron Neutrino Event “Candidate”

Analysis of FASERν emulsion detector underway

- Have multiple candidates including highly νe like event





Vertex with 11 tracks

e-like track from vertex

- Single track for $2X_0$
- Shower max at $7.8X_0$
- Θ_c = 11mrad to beam

Back-to-back topology

- 175° between e & rest

New results from FASERν: statistical significance

New result this summer

FASERν Preliminary

	Expected background		Expected signal	**Observed**	
	Hadron int.	ν NC int.			
ν_e CC	0.002±0.002	-	$1.2^{+4.0}_{-0.6}$	3	$p = 1.6 \times 10^{-7}$ (5.1σ)
ν_μ CC	0.32±0.16	0.19±0.15	$4.4^{+4.2}_{-1.4}$	4	$p = 5.2 \times 10^{-3}$ (2.5σ)

3 ν_e CC candidate events are observed.
→ Probability to be explained by background is 1.6×10^{-7}, corresponding to 5σ exclusion of the background-only hypothesis.

First direct observation of electron-neutrino CC interactions at the LHC

The performance of ν_μ detection will be improved in future analysis using a longer range for μ ID.

Reminder: Jan 30th

FASER VIP VISIT

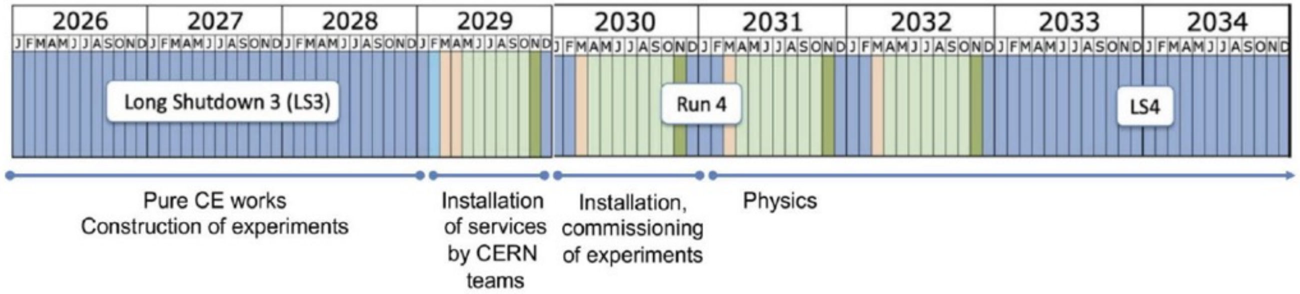
Left to right:
Jamie Boyd, Mike Lamont, Mark Heising, Joachim Mnich, Jim Simons, Jonathan Feng, Greg Gabadadze

Left to right: Mark Heising, Fabiola Gianotti, Jim Simons

More photos: http://cds.cern.ch/record/2847893?ln=en

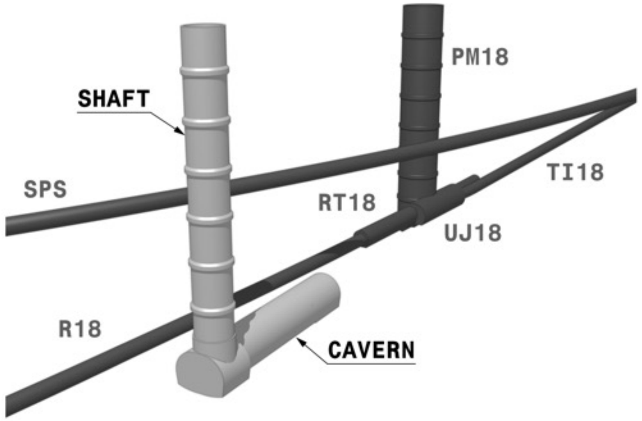
2203.05090 (to appear in J Phys G)

Toward HL-LHC



A new facility called the Forward Physics Facility (FPF) under intensive discussion

- FASER progressing well, however TI12 is too small to exploit full physics potential in the forward region of the LHC
- Discussion started since 2020, summarizing white paper in March 2022 for snowmass
  - 5th FPF Meeting, Nov 2022: https://indico.cern.ch/event/1196506/
- 617 m from ATLAS interaction point (opposite side of FASER) near SM18
- 65m long, 9.7m wide, 7.7m high cavern; 88m high shaft and surface building



CERN civil engineering team provides a preliminary cost estimation of 40 MCHF including services

- ongoing drilling of a core at the proposed FPF location to assess the geological conditions.

2023 March/April – site investigation work

➤ Drilling machine in place

➤ Works started

➤ Core samples

Done by CERN Site and Civil engineering group

Vibrations etc…

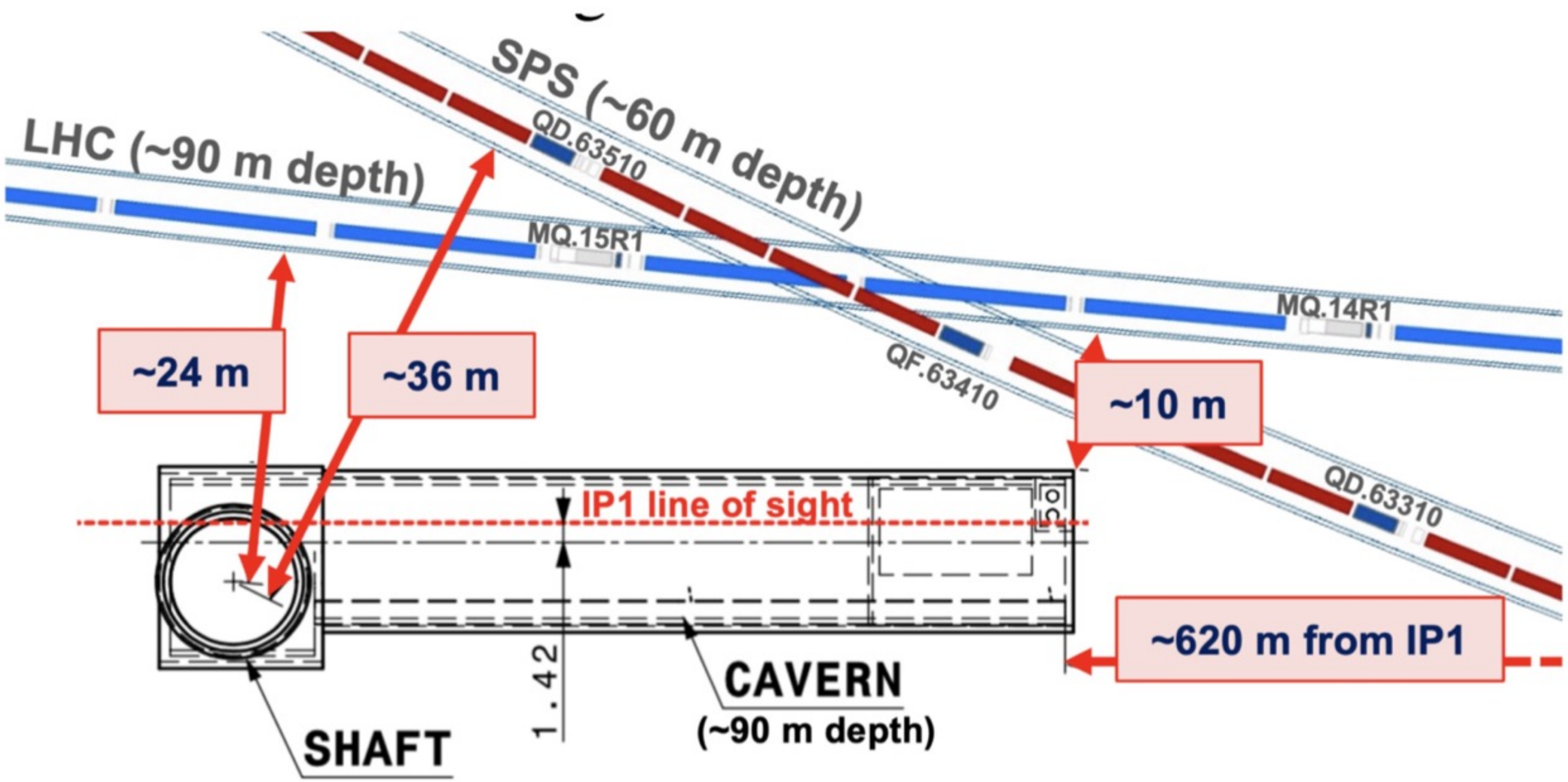
https://www.ipac23.org/preproc/pdf/THPA039.pdf

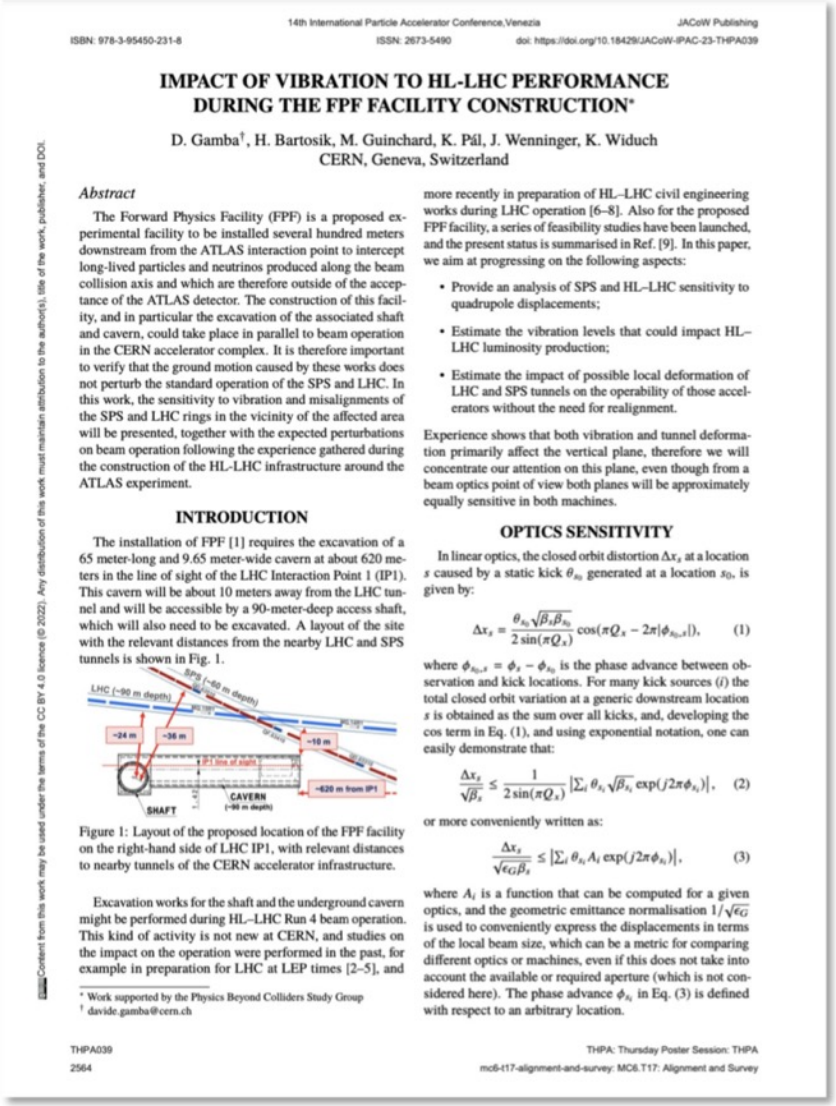
D. Gamba - CERN BE-ABP, M. Guinchard – CERN EN-MME

Study on effect of excavation work on HL-LHC (& SPS) operations in terms of vibrations and possible tunnel movements.

Preliminary results presented at IPAC conference in May and public document available.

Relevant parameters….





14th International Particle Accelerator Conference,Venezia JACoW Publishing
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IMPACT OF VIBRATION TO HL-LHC PERFORMANCE DURING THE FPF FACILITY CONSTRUCTION*

D. Gamba†, H. Bartosik, M. Guinchard, K. Pál, J. Wenninger, K. Widuch
CERN, Geneva, Switzerland

Abstract

The Forward Physics Facility (FPF) is a proposed experimental facility to be installed several hundred meters downstream from the ATLAS interaction point to intercept long-lived particles and neutrinos produced along the beam collision axis and which are therefore outside of the acceptance of the ATLAS detector. The construction of this facility, and in particular the excavation of the associated shaft and cavern, could take place in parallel to beam operation in the CERN accelerator complex. It is therefore important to verify that the ground motion caused by these works does not perturb the standard operation of the SPS and LHC. In this work, the sensitivity to vibration and misalignments of the SPS and LHC rings in the vicinity of the affected area will be presented, together with the expected perturbations on beam operation following the experience gathered during the construction of the HL-LHC infrastructure around the ATLAS experiment.

INTRODUCTION

The installation of FPF [1] requires the excavation of a 65 meter-long and 9.65 meter-wide cavern at about 620 meters in the line of sight of the LHC Interaction Point 1 (IP1). This cavern will be about 10 meters away from the LHC tunnel and will be accessible by a 90-meter-deep access shaft, which will also need to be excavated. A layout of the site with the relevant distances from the nearby LHC and SPS tunnels is shown in Fig. 1.

Figure 1: Layout of the proposed location of the FPF facility on the right-hand side of LHC IP1, with relevant distances to nearby tunnels of the CERN accelerator infrastructure.

Excavation works for the shaft and the underground cavern might be performed during HL–LHC Run 4 beam operation. This kind of activity is not new at CERN, and studies on the impact on the operation were performed in the past, for example in preparation for LHC at LEP times [2–5], and more recently in preparation of HL–LHC civil engineering works during LHC operation [6–8]. Also for the proposed FPF facility, a series of feasibility studies have been launched, and the present status is summarised in Ref. [9]. In this paper, we aim at progressing on the following aspects:

- Provide an analysis of SPS and HL–LHC sensitivity to quadrupole displacements;
- Estimate the vibration levels that could impact HL–LHC luminosity production;
- Estimate the impact of possible local deformation of LHC and SPS tunnels on the operability of those accelerators without the need for realignment.

Experience shows that both vibration and tunnel deformation primarily affect the vertical plane, therefore we will concentrate our attention on this plane, even though from a beam optics point of view both planes will be approximately equally sensitive in both machines.

OPTICS SENSITIVITY

In linear optics, the closed orbit distortion Δx_s at a location s caused by a static kick θ_{s_0} generated at a location s_0, is given by:

$$\Delta x_s = \frac{\theta_{s_0}\sqrt{\beta_s \beta_{s_0}}}{2\sin(\pi Q_x)}\cos(\pi Q_x - 2\pi|\phi_{s_0,s}|), \quad (1)$$

where $\phi_{s_0,s} = \phi_s - \phi_{s_0}$ is the phase advance between observation and kick locations. For many kick sources (i) the total closed orbit variation at a generic downstream location s is obtained as the sum over all kicks, and, developing the cos term in Eq. (1), and using exponential notation, one can easily demonstrate that:

$$\frac{\Delta x_s}{\sqrt{\beta_s}} \le \frac{1}{2\sin(\pi Q_x)}\left|\sum_i \theta_{s_i}\sqrt{\beta_{s_i}}\exp(j2\pi\phi_{s_i})\right|, \quad (2)$$

or more conveniently written as:

$$\frac{\Delta x_s}{\sqrt{\epsilon_G \beta_s}} \le \left|\sum_i \theta_{s_i} A_i \exp(j2\pi\phi_{s_i})\right|, \quad (3)$$

where A_i is a function that can be computed for a given optics, and the geometric emittance normalisation $1/\sqrt{\epsilon_G}$ is used to conveniently express the displacements in terms of the local beam size, which can be a metric for comparing different optics or machines, even if this does not take into account the available or required aperture (which is not considered here). The phase advance ϕ_{s_i} in Eq. (3) is defined with respect to an arbitrary location.

* Work supported by the Physics Beyond Colliders Study Group

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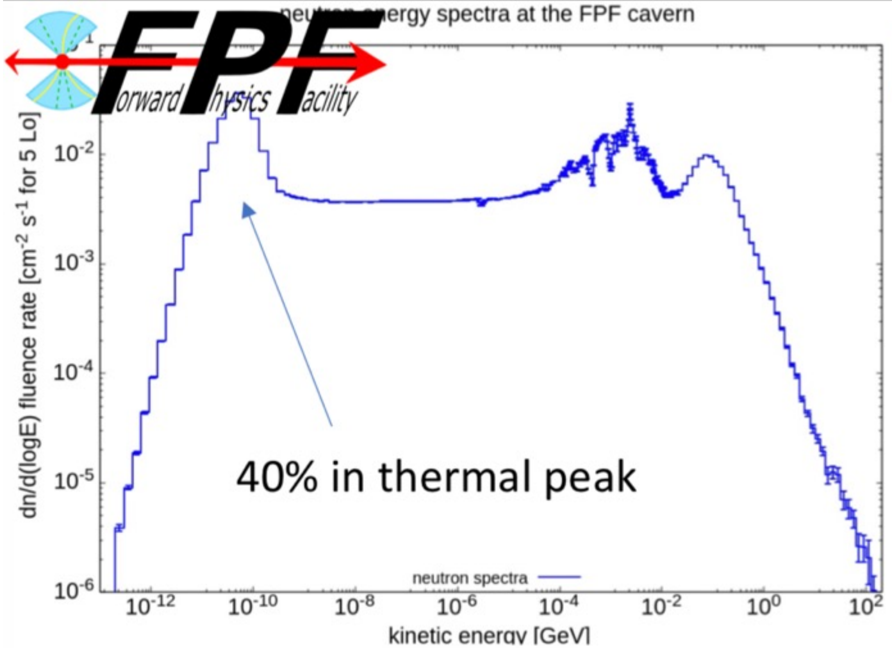
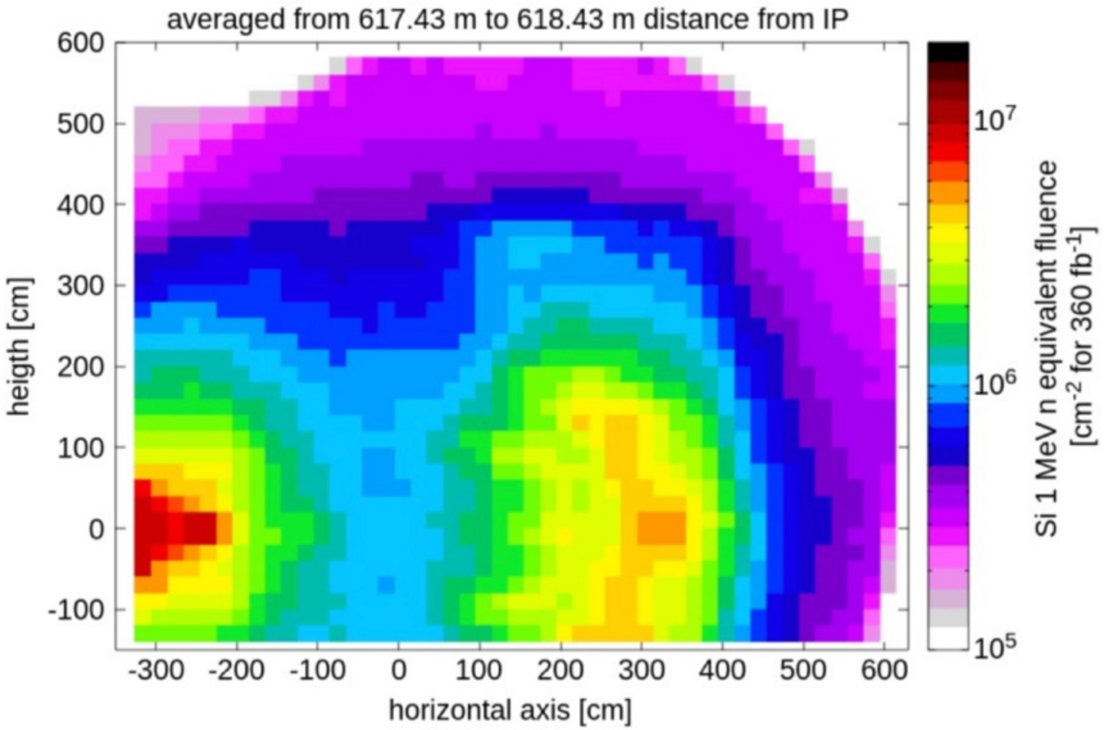
Neutron Dose at FPF

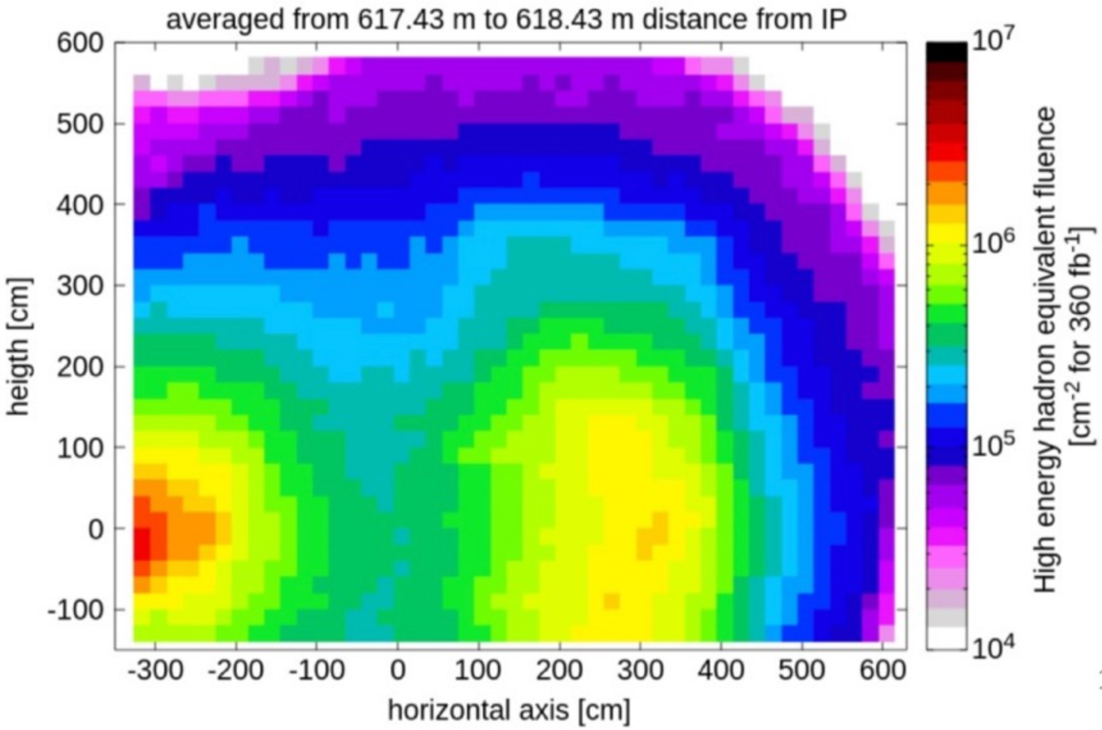
F. Cerutti, M. Sabate-Gilarte
SY-STI



FLUKA simulations used to look at neutron dose level in FPF (relevant for radiation to electronics and radiation damage).
Neutron dose ~0.2Hz/cm^2 at L=5e34.

Also shown:
1MeV n equiv fluence (relevant for silicon radiation damage)
High energy hadron fluence (relevant for SEU in electronics)
Both shown for 1 year at L=7.5e34 (ultimate HL-LHC lumi)
HEH fluence <3e16cm^{-2}y^{-1} (LHC threshold for radiation for electronics).

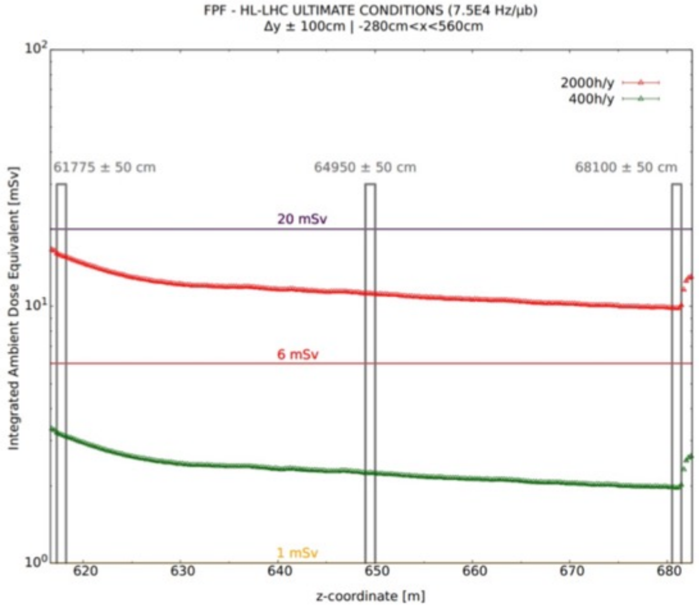


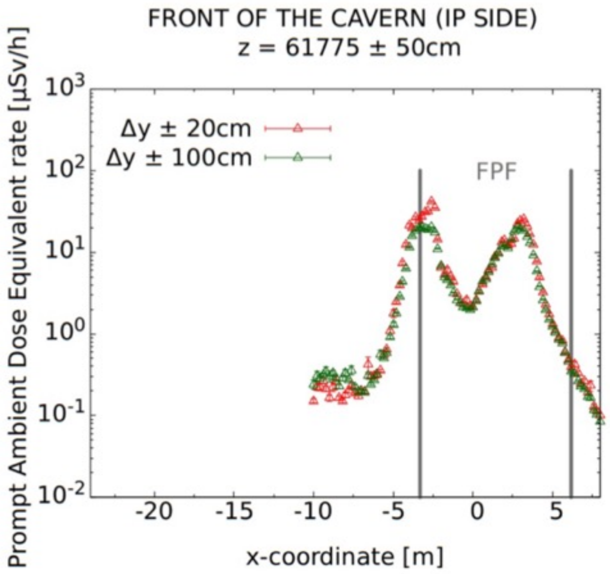


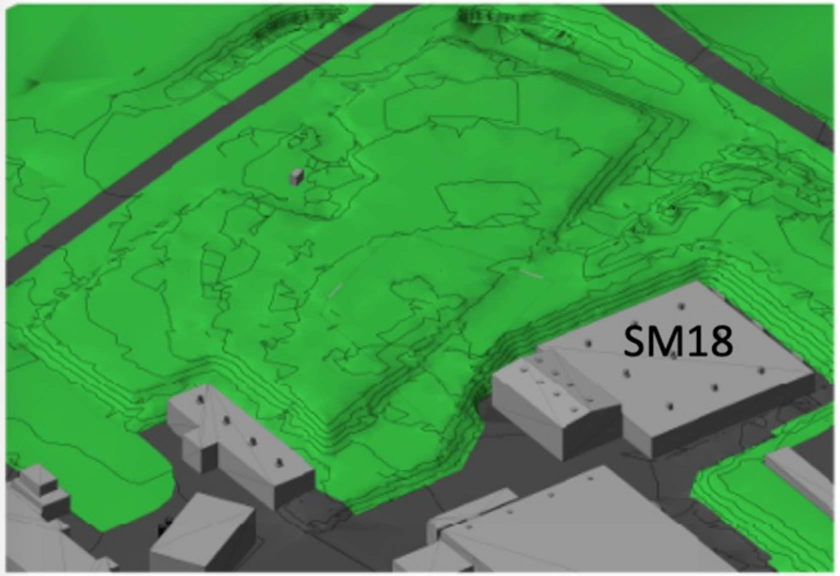
Conclusions: Radio Protection Studies

A. Infantino, L. Elie - RP

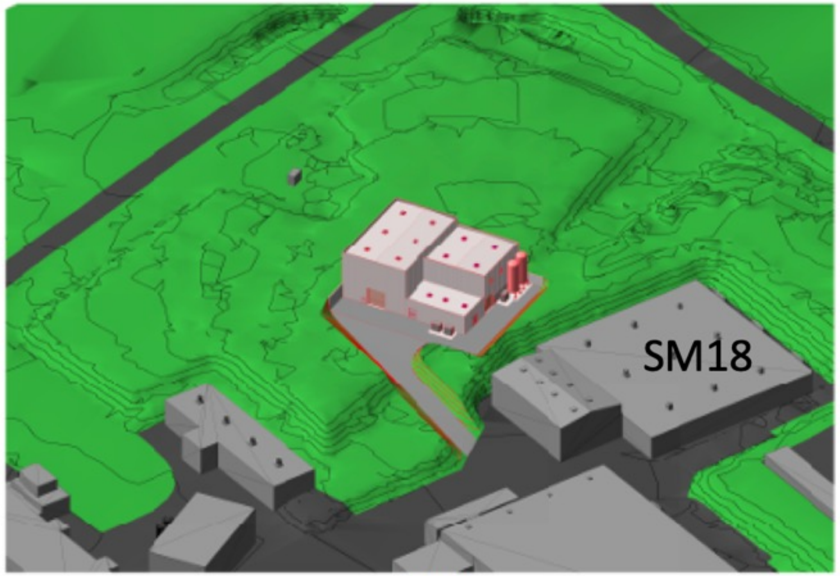
- Direct contribution from muons from IP1/LSS1 can limit the accessibility to the cavern during LHC operation
  - > 6 mSv/year may be achieved locally;
- Classification of the cavern as Simple Controlled/Supervised Radiation Area
  - low occupancy, i.e. < 20% working time seems possible;
- Access to the cavern during LHC beam operation will be limited to Radiation Workers
  - Also relevant for external personnel involved in the excavation (of the cavern and the lower part of the shaft) if done during beam operation
- No permanent control rooms are foreseen underground.
  - During installation and commissioning there may be people in the cavern for an extended period: this time shall be quantified to finalize the RP risk assessment;
- Final study to be done considering a full integration model, i.e. including detectors, service equipment, …



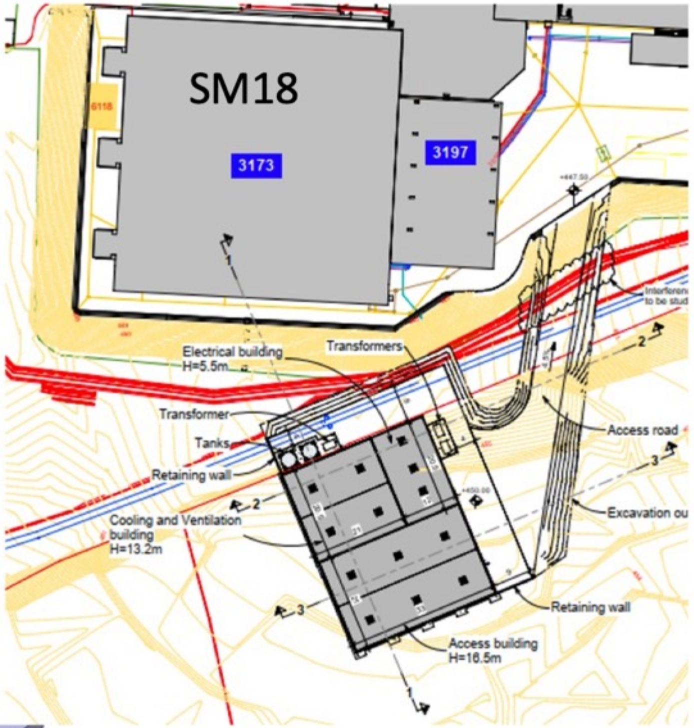


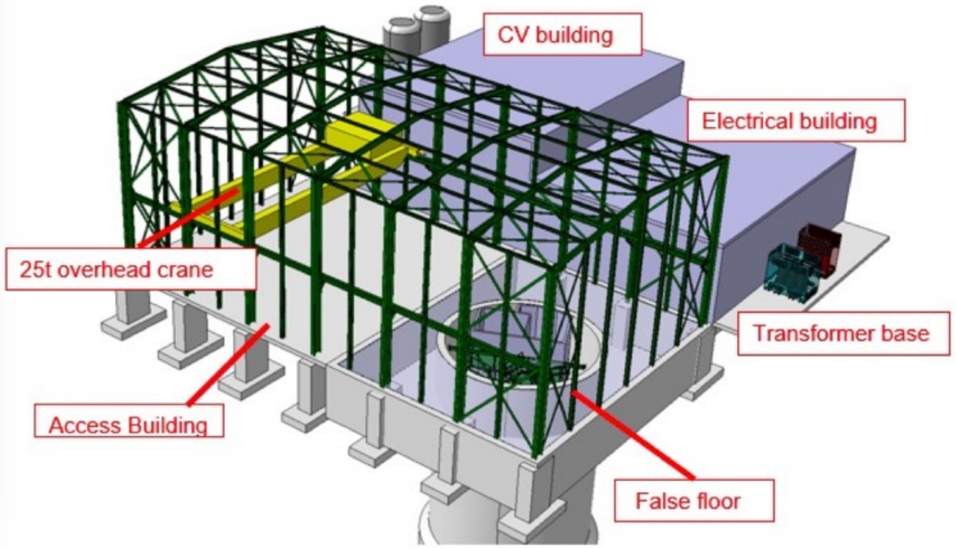


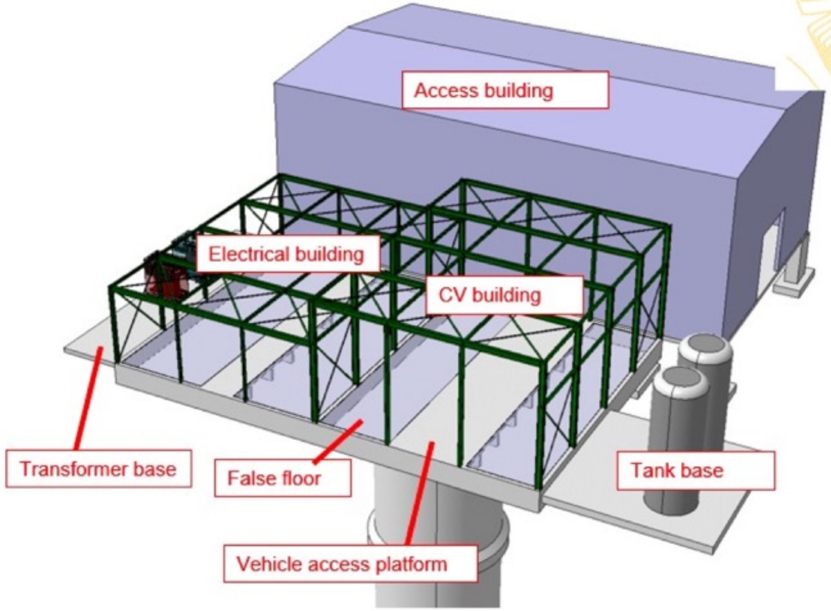
3D EXISTING



3D NEW



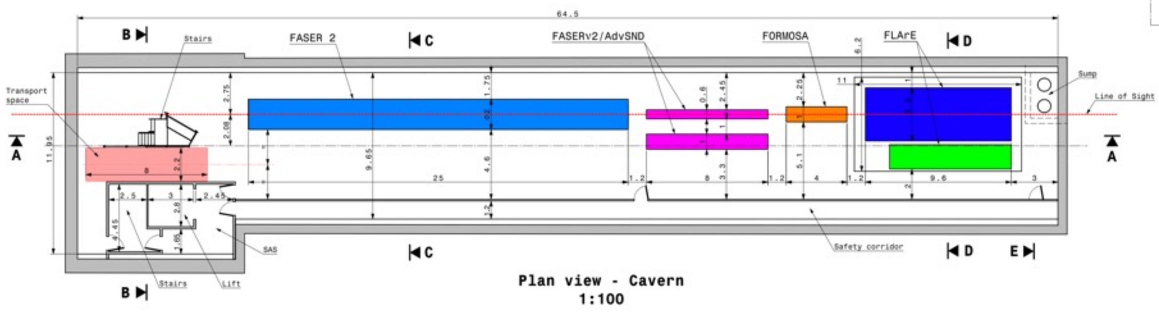




Currently proposed FPF experiments

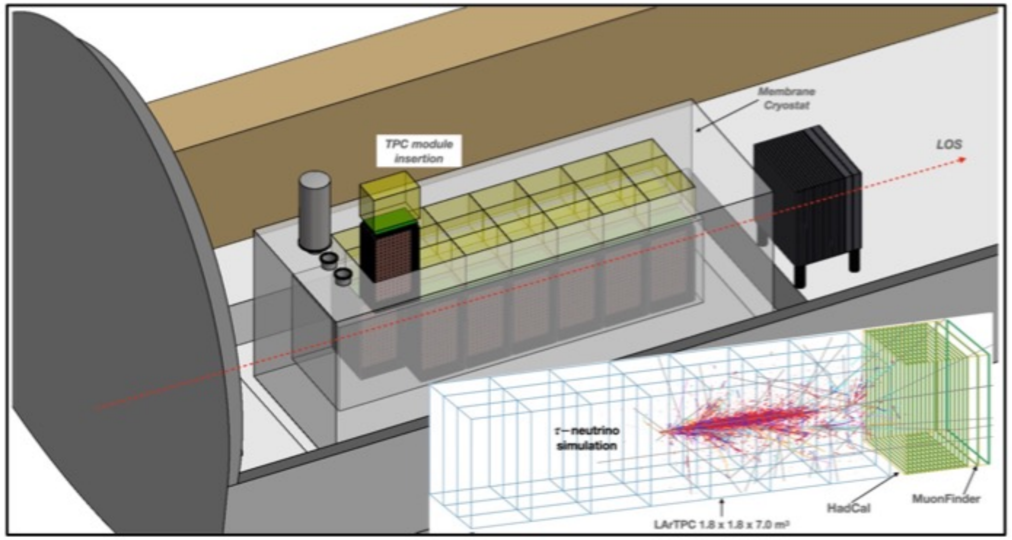
At the moment there are 5 proposed experiments to be situated in the FPF.
With different capabilities and covering different rapiditiy regions:

- FLArE
  - $\mathcal{O}$(10tn) LAr TPC detector
  - DM scattering
  - Neutrino physics (ν_μ/ν_e , capabilitty for ν_τ under study)
    - Full view of neutrino interaction event
- FASERv2
  - $\mathcal{O}$(20tn) emulsion/tungsten detector (FASERv x20)
    - Mostly for tau neutrino physics
  - Interfaced to FASER2 spectrometer for muon charge ID (ν_τ/ $\overline{\nu}_\tau$ separation)
- AdvSND
  - Neutrino detector slightly off-axis
    - Provides complementary sensitvity for PDFs from covering different rapidity to FASERv2
- FASER2
  - Detector for observing decays of light dark-sector particles
  - Similar to scaled up version of FASER (1m radius vs 0.1m)
    - Increases sensitivity to particles produced in heavy flavour decay
  - Larger size requires change in detector and magnet technology: Superconducting magnet
- FORMOSA
  - Milicharged particle detector
  - Scintillator based, similar to current miliQan experiment

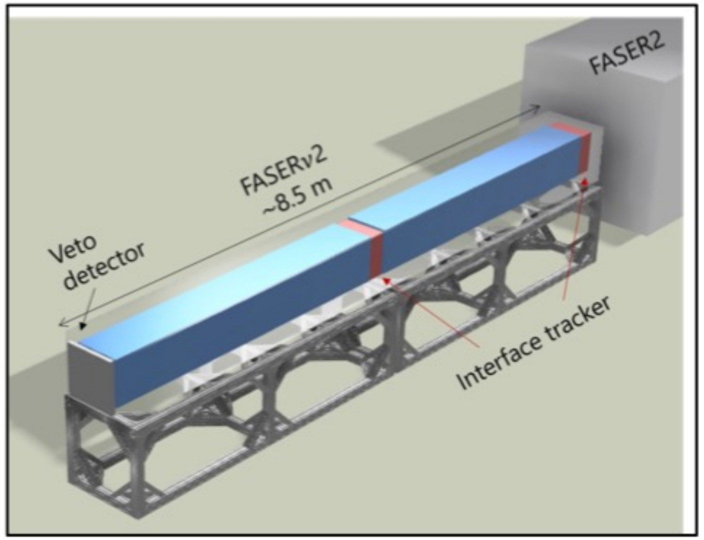


Jamie Boyd

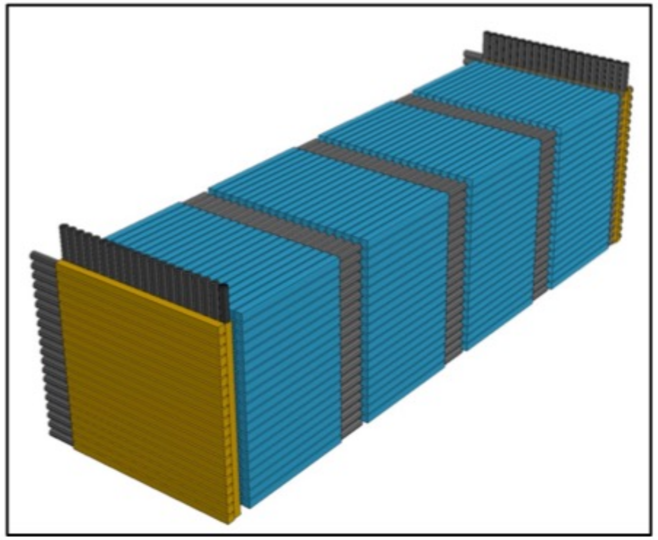
FLArE

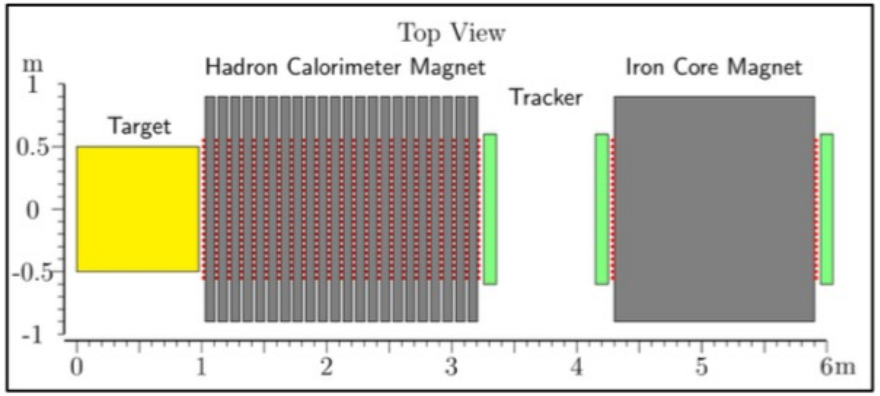


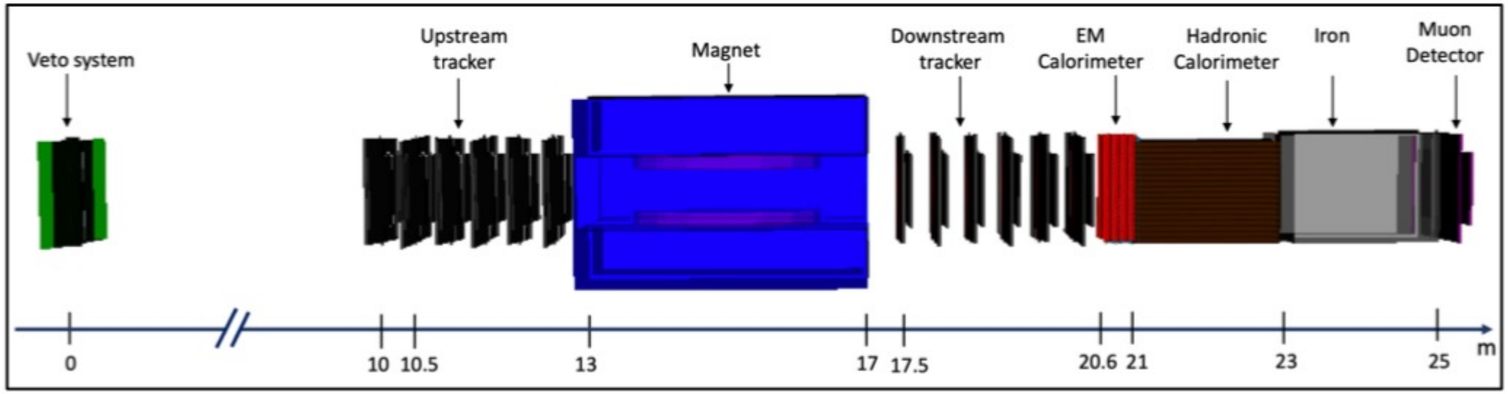
FASERν2



FORMOSA



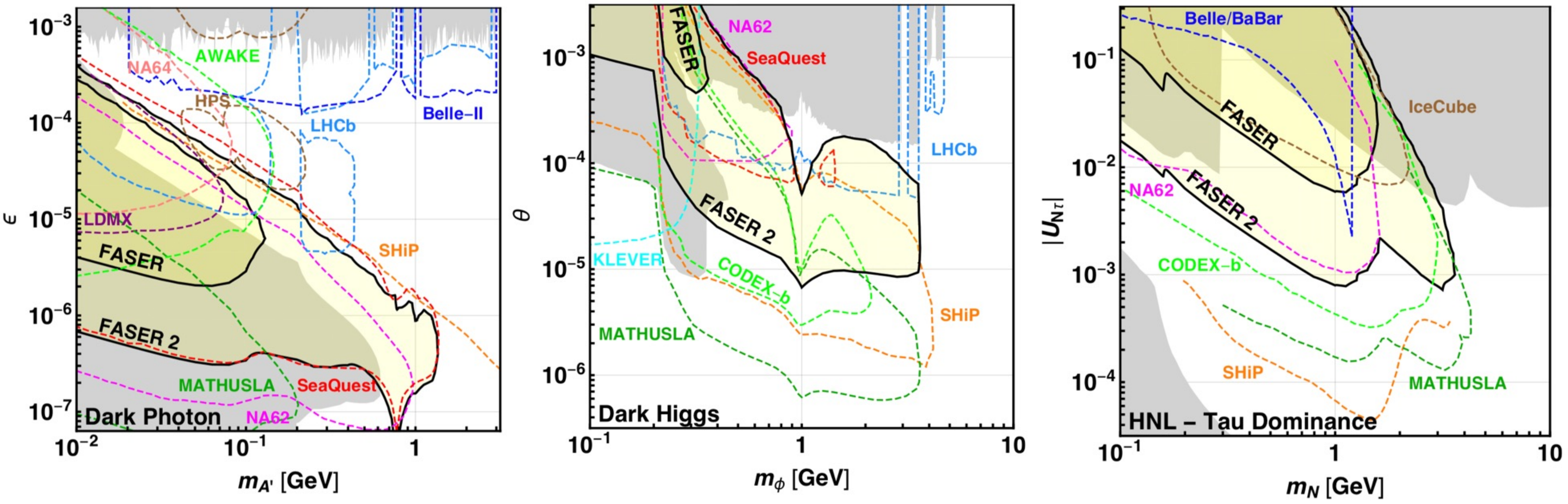




FASER2

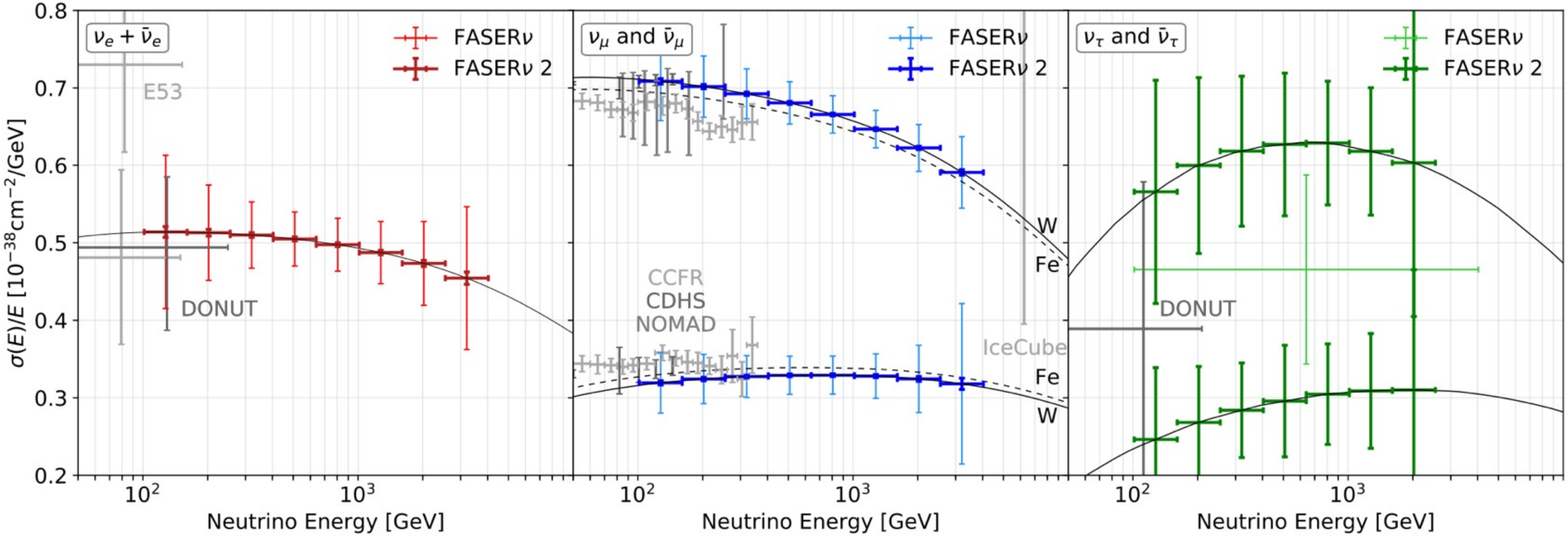
FASER/FASER 2 physics reach for various models

Dark photon **Dark higgs** **Sterile neutrino**



Phys. Rev. D 99, 095011 (2019))

Improvement of the TeV neutrino study

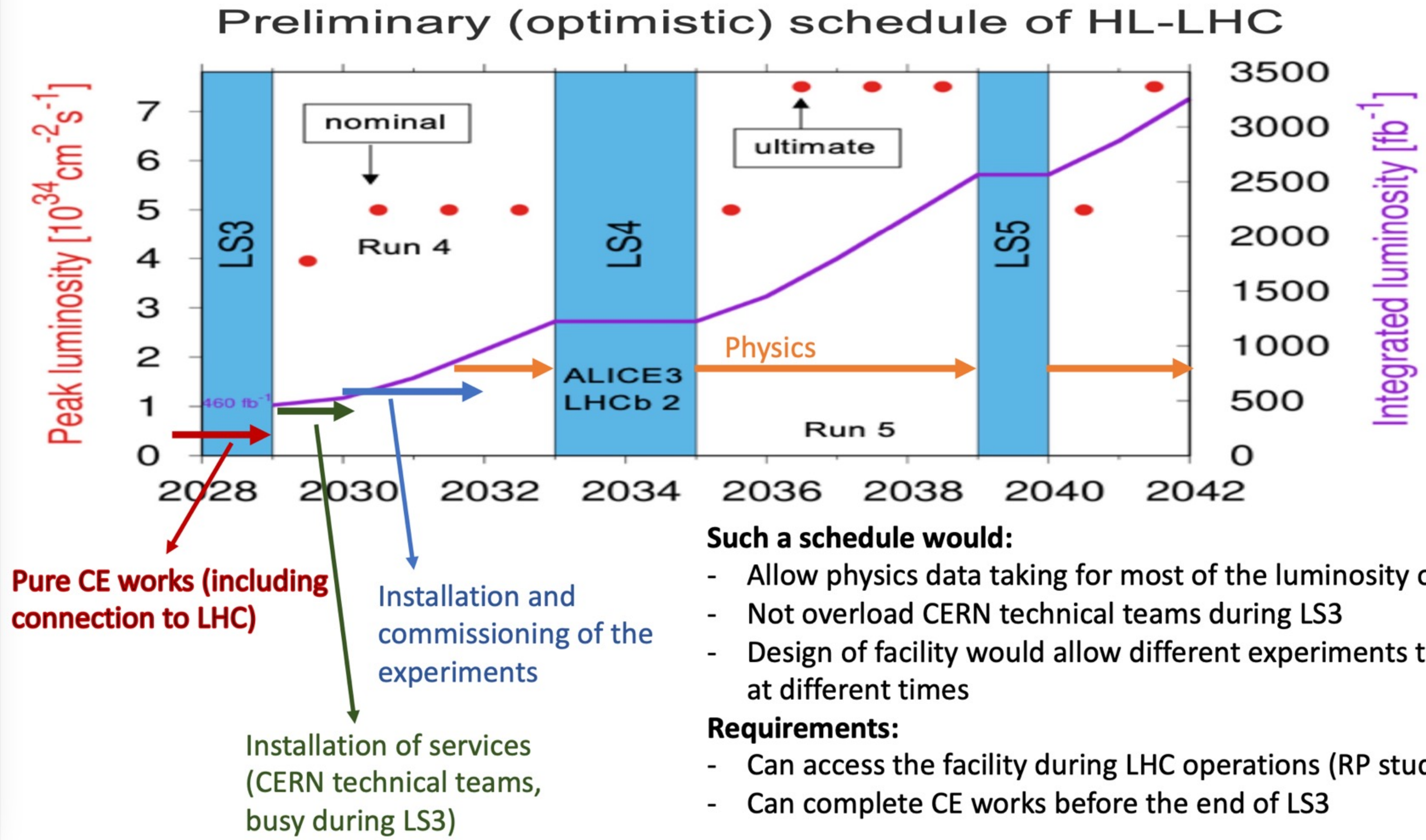


O(10^3-10^4) of Tau neutrino, allowing detailed measurement of final state

- The first Discrimination tau neutrino / anti-tau neutrino
- New information of proton PDF（gluon, charm, strange ..)

Possible FPF schedule

HL-LHC schedule from DG presentation, New-Year (on-line) meeting, 13/1/22

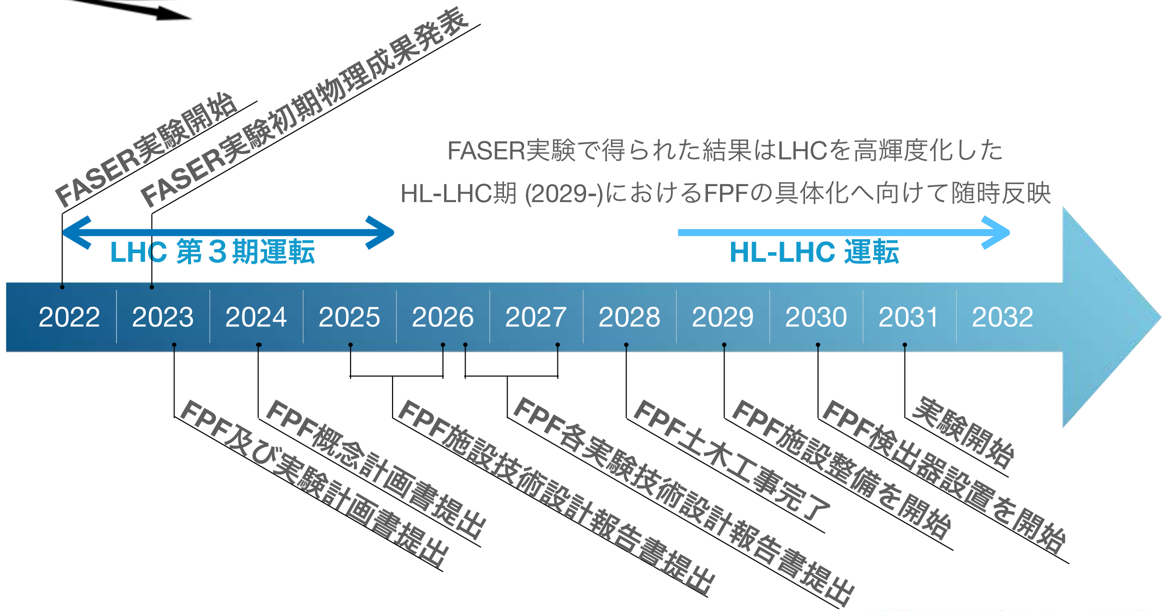


Such a schedule would:

- Allow physics data taking for most of the luminosity of the HL-LHC
- Not overload CERN technical teams during LS3
- Design of facility would allow different experiments to come online at different times

Requirements:

- Can access the facility during LHC operations (RP study ongoing)
- Can complete CE works before the end of LS3



- We -the steering committee- have started some higher level discussions
- PBC can/will sign off after:
  - We conclude on some some outstanding issues on isses on the facility update the document CERN-PBC-Notes-2023-002
  - “Demonstrate the experiments can well mutually fit in the available space”
- This would open the door to sent a LOI to the LHCC for review(*) by end 2023/or beginning 2024
- The LHCC wil then determine the next steps

(*) …if no veto from CERN top management…

FPF Working Group Conveners

Steering Committee Jamie Boyd (CERN), Albert De Roeck (CERN), Milind Diwan (Brookhaven), Jonathan Feng (UC Irvine), Felix Kling (DESY)

WG0 Facility Jamie Boyd (CERN)

WG1 Neutrino Interactions Juan Rojo (Nikhef)

WG2 Charm Production Hallsie Reno (Iowa)

WG3 Light Hadron Production and Astroparticle Connections Luis Anchordoqui (Lehman), Dennis Soldin (Karlsruhe)

WG4 New Physics Brian Batell (Pittsburgh), Sebastian Trojanowski (Warsaw)

WG5 FASER2 Alan Barr (Oxford), Josh McFayden (Sussex), Hide Otono (Kyushu)

WG6 FASERnu2 Aki Ariga (Chiba), Tomoko Ariga (Kyushu)

WG7 FLArE Jianming Bian (UC Irvine), Milind Diwan (Brookhaven)

WG8 Advanced SND Giovanni De Lellis (Napoli)

WG9 FORMOSA Matthew Citron (UC Davis), Chris Hill (Ohio State)

Conclusion

FASER is a new forward experiment at the LHC in the unused tunnel, TI12 for:

- discovery of a light weakly-coupled particle in MeV-GeV range
  - Spectrometer (Tracker and magnets), scintillators and calorimeter installed in March 2021
  - preshower scintillator will be replaced by silicon pixel detector at the end of 2024
- probe all flavors of neutrinos at the TeV-energy frontier
  - Emulsion/Tungsten detector, veto scintillator and interface tracker installed in March 2022
  - Emulsion/Tungsten detector replaced every Technical Shutdown (~3 times in one year)

Successful data taking from the beginning of LHC Run3 in 2022

- the first search of MeV-GeV weakly-interacting particle -- no discovery but more will come soon!
- the first observation of TeV neutrino produced by colliders

Towards HL-LHC, Forward Physics Facility is proposed to host several experiments

- Workshop organized every half year for intensive discussion toward conceptual design
  - The next one (FPF6) will come in June 8-9 https://indico.cern.ch/event/1275380
  - Please register and join !!

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erc

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Physics Beyond Colliders

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- ATLAS for use of ATHENA s/w framework
- ATLAS SCT for spare tracker modules
- LHCb for spare ECAL modules
- CERN FLUKA team for background sim
- CERN PBC and technical infrastructure groups for excellent support during design construction and installation