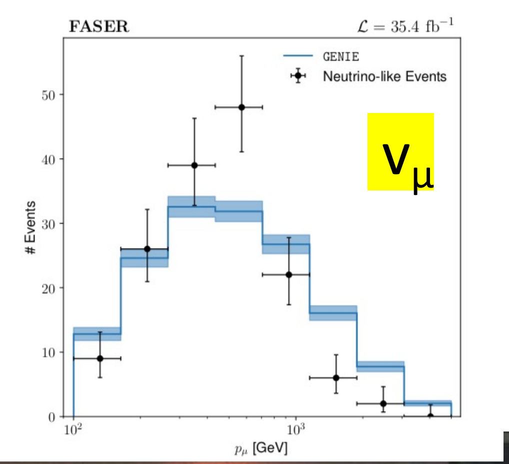

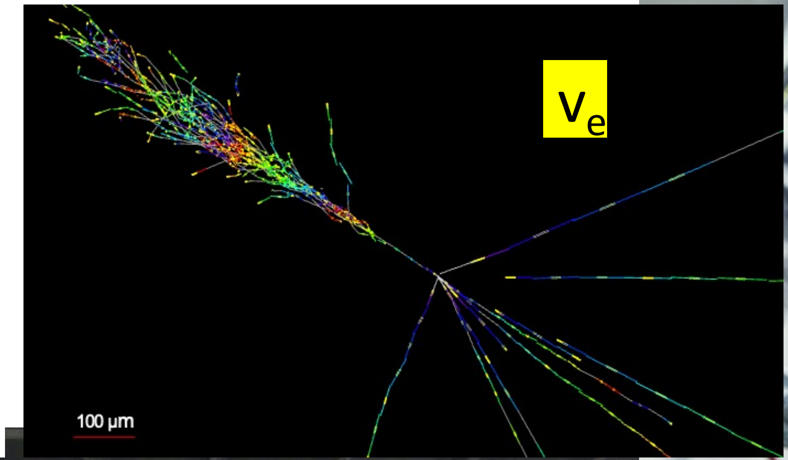

FASER実験によるLHCのビーム軸上でのニュートリノ測定

音野瑛俊　(九州大学)

第21回高エネルギーQCD・核子構造勉強会

PRL published the neutrino paper on 19th July

ν_μ Observation (16 sigma)

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

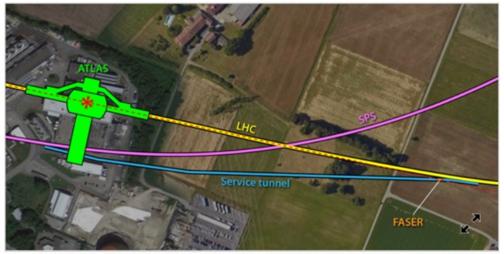
PDF Version

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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Electricity Generated from Coils and

New results from FASERν: statistical significance

ν_e observation (5.1 sigma) reported on 21th Aug

FASERν Preliminary

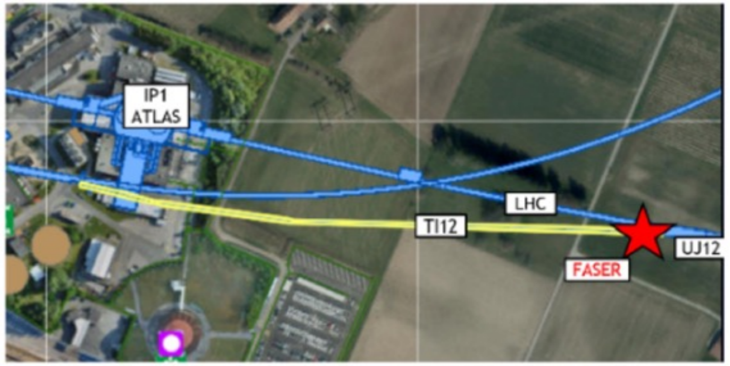
	Expected background		Expected signal	**Observed**	
	Hadron int.	ν NC int.			
ν_e CC	0.002±0.002	-	$1.2\ ^{+4.0}_{-0.6}$	3	$p = 1.6 \times 10^{-7}$ (5.1σ)
ν_μ CC	0.32±0.16	0.19±0.15	$4.4\ ^{+4.2}_{-1.4}$	4	$p = 5.2 \times 10^{-3}$ (2.5σ)

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

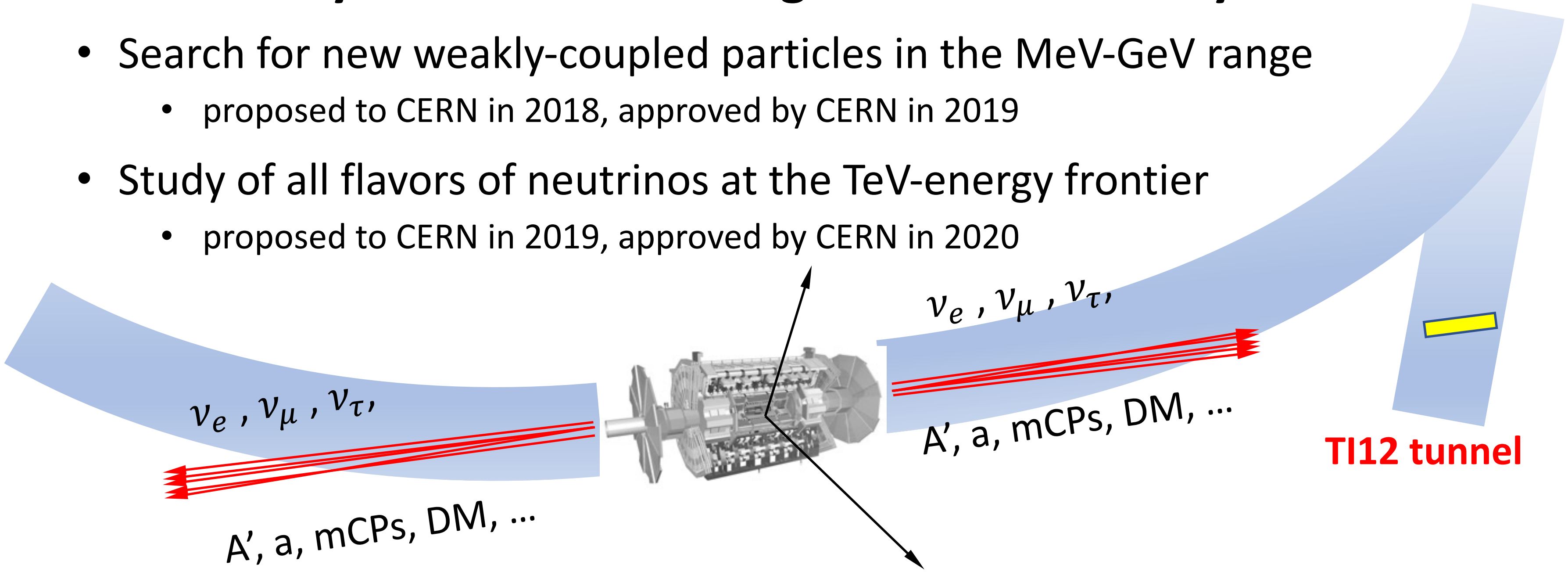
The performance of ν_μ detection will be improved in future analysis using a longer range for μ ID.

FASER experiment



Concept of FASER is proposed in Aug 2017, 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.

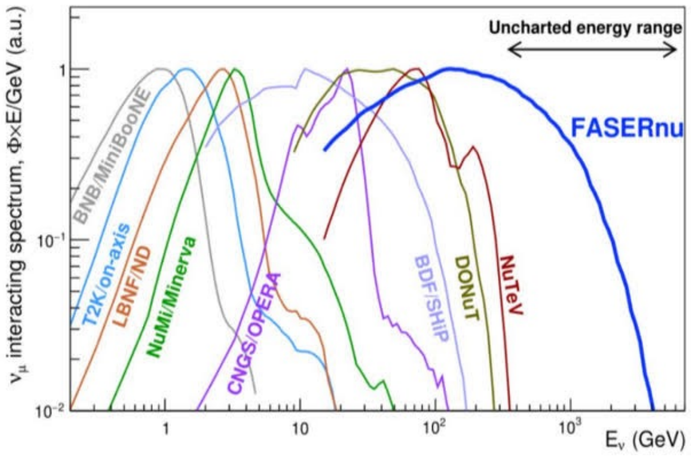
- Background from collision point is only high-energy muon at about 1 /cm^2/sec, thanks to ~100-m rock
- Radiation level from LHC is quite low, around 4×10^{-3} Gy/year (= 4×10^7 *1*-MeV neutron/cm^2/year)

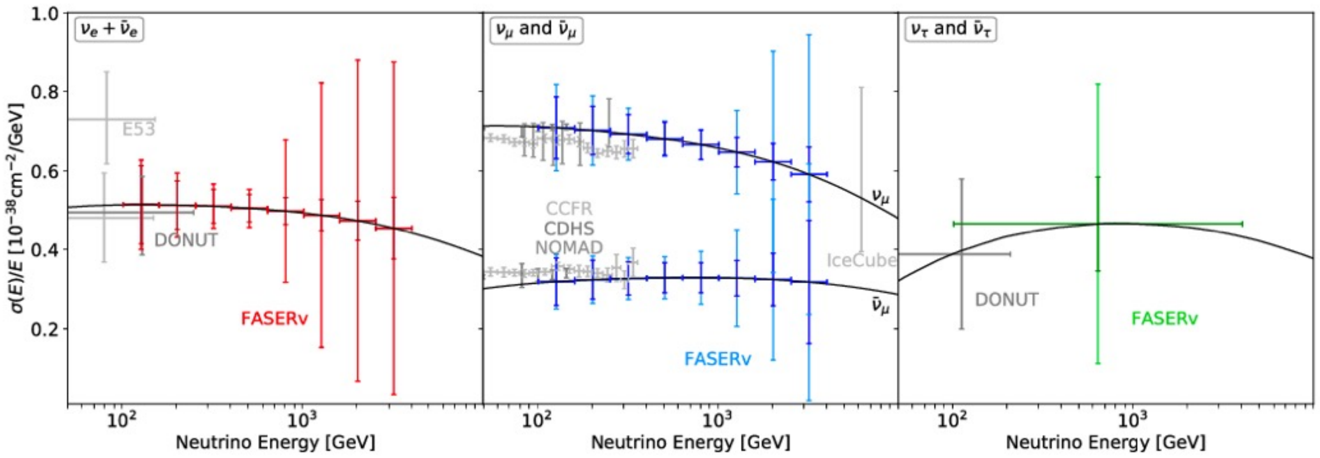
Exploring neutrinos at the TeV-energy frontier

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

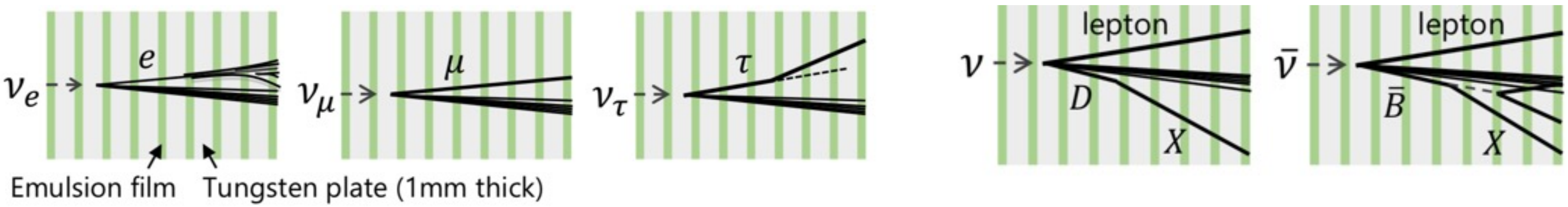
- Expected number of CC neutrino interaction with 250 fb^{-1} in Run 3

based on PhysRevD.104.113008

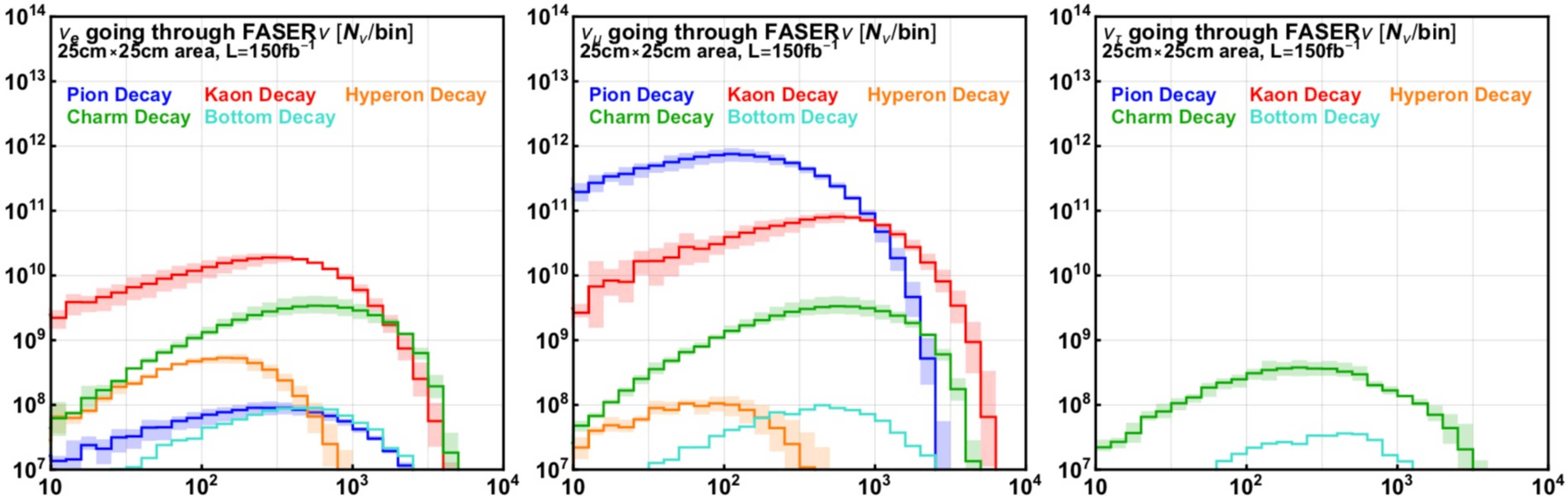




- Emulsion detector provides great ID for all leptons and heavy flavor hadrons from neutrino interaction



Breakdown of the LHC neutrino production



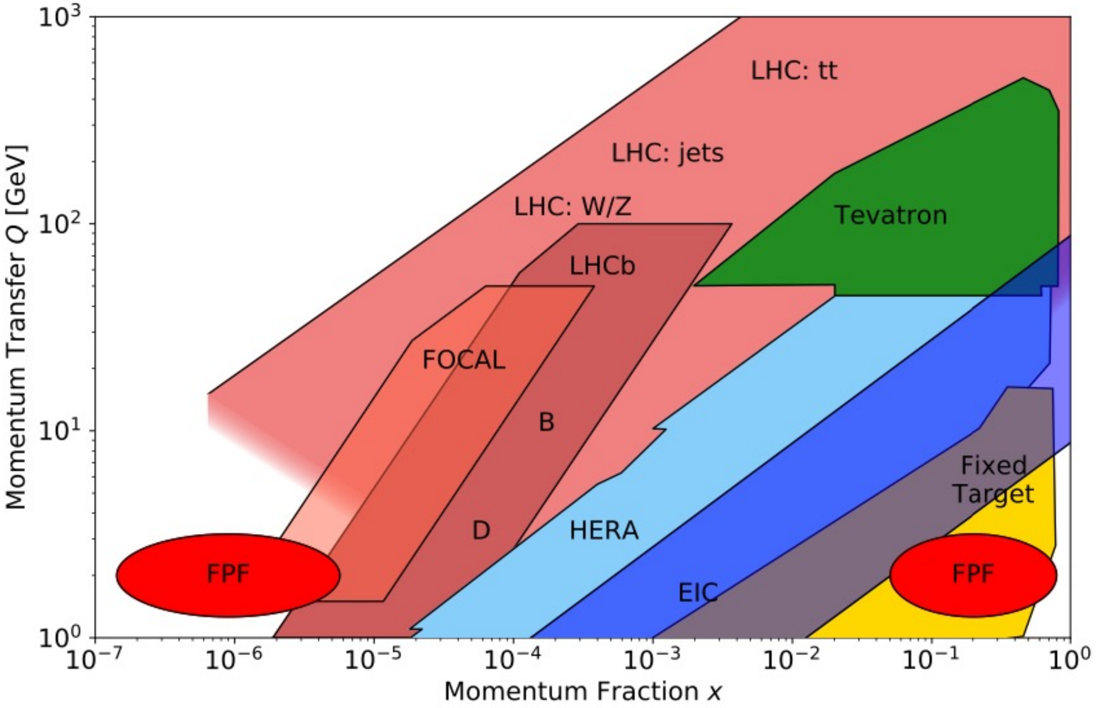
A new approach to measure proton PDFs (Parton Distribution Function)

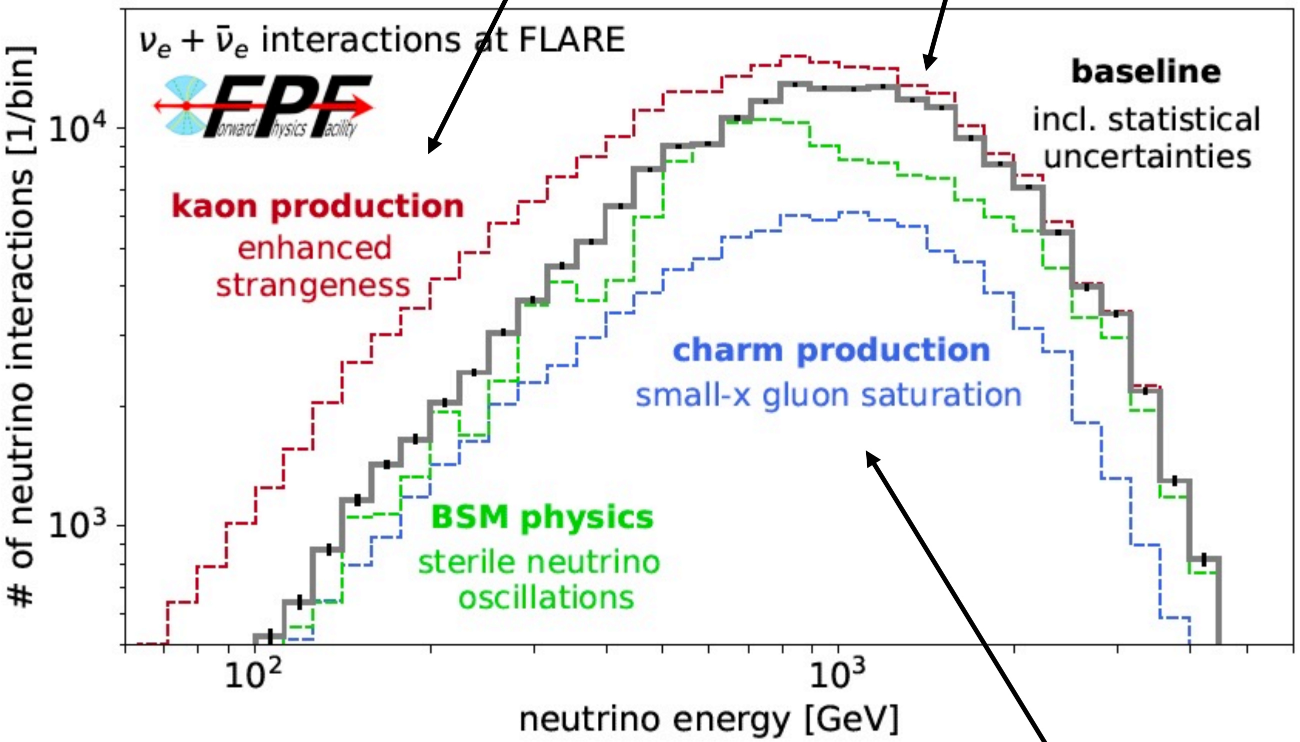
- Gluon saturation
- Strange quark
- Charm quark

Unique inputs to QCD

ν_e energy spectrum

Could be constraind by ν_μ measurement



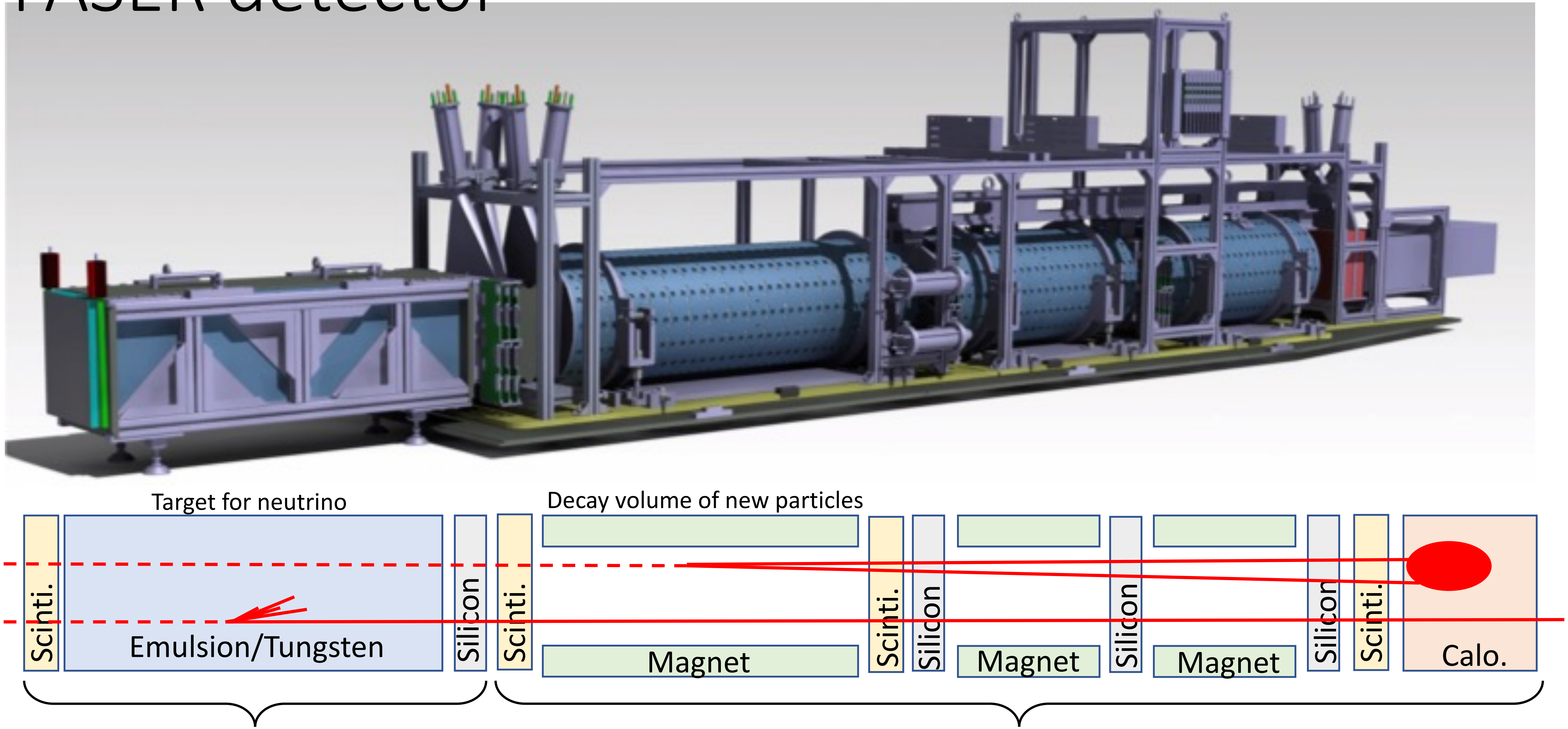


Could be constraind by ν_τ measurement

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

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

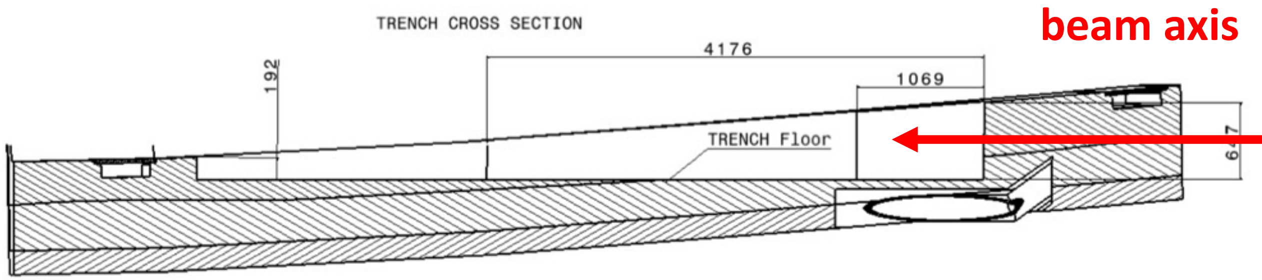
FASER detector



For neutrino physics:
Installation completed 2022 March

For new particle search:
Installation completed 2021 March

Civil engineering work



Aug 2018

Nov 2020

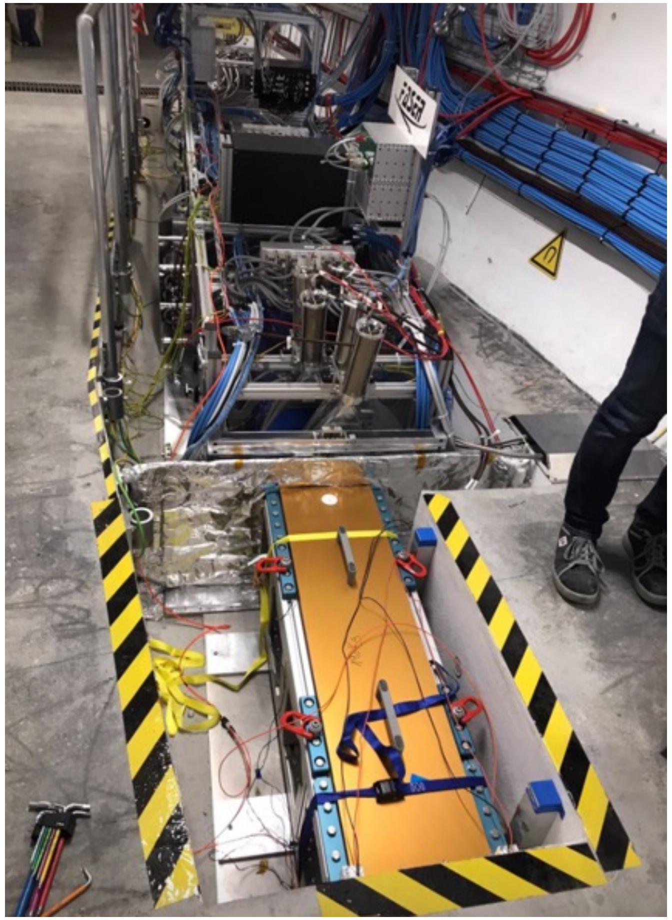
The floor in TI12 excavated by ~50 cm to have the FASER detector on beam axis

FASER detector installation

FASER spectrometer (magnets and tracker), scintillators and calorimter

April 2021

Emusion/Tungsten detector, IFT and scintillator

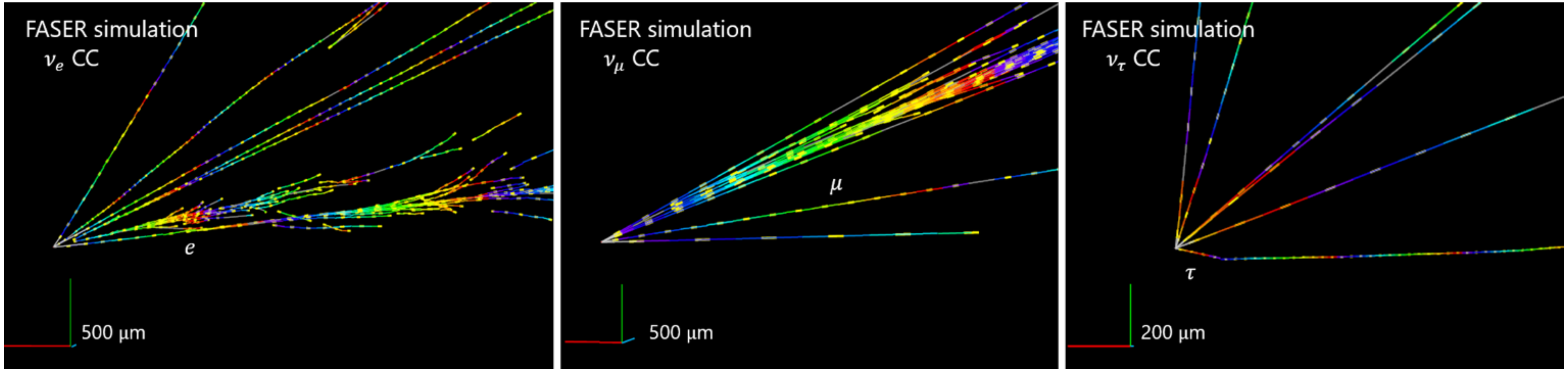


March 2022

Emulsion/Tungsten detector

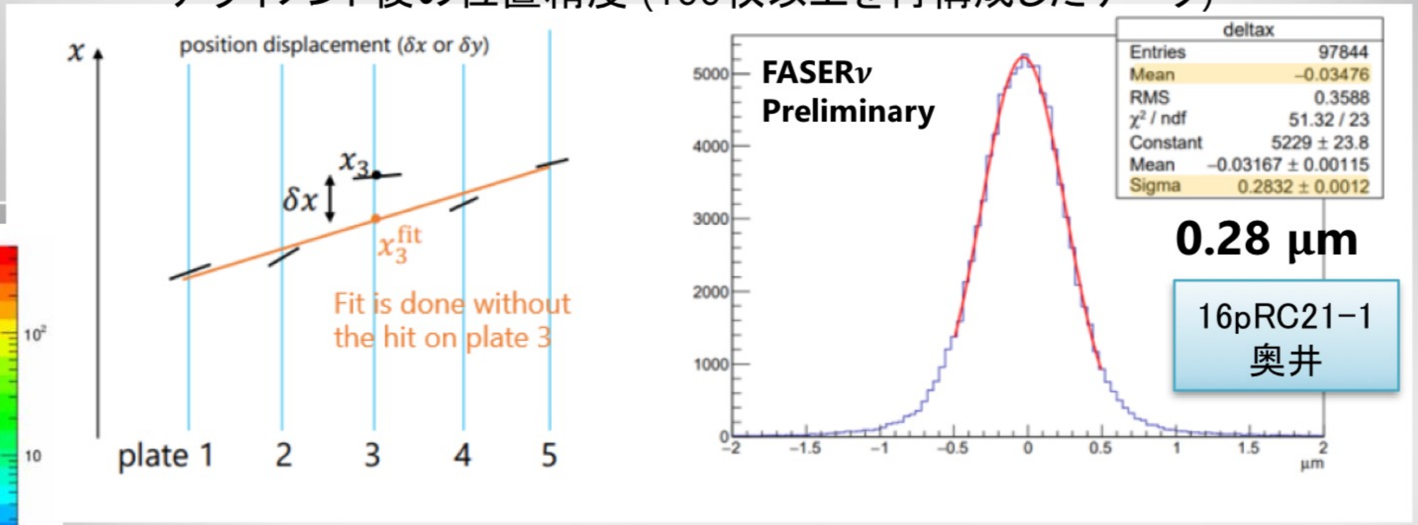
All flavors of neutrino interactions can be identified

- 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

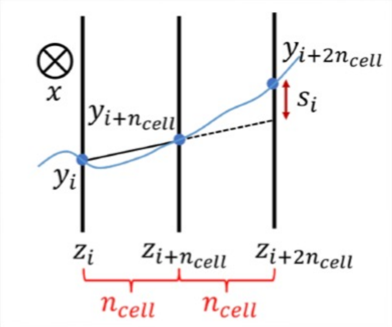


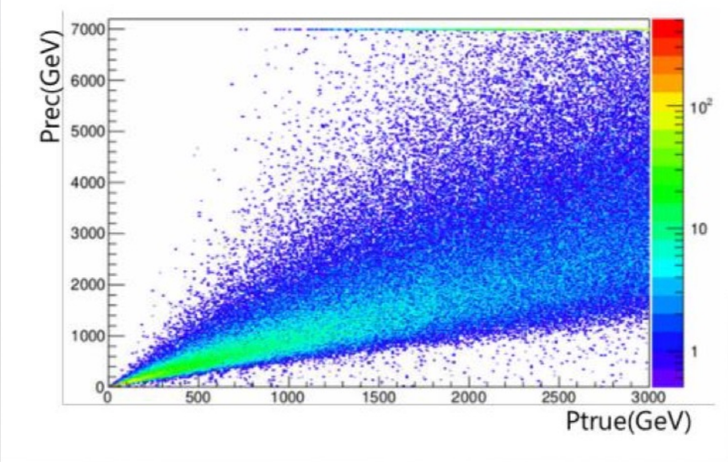
FASERν検出器パフォーマンス

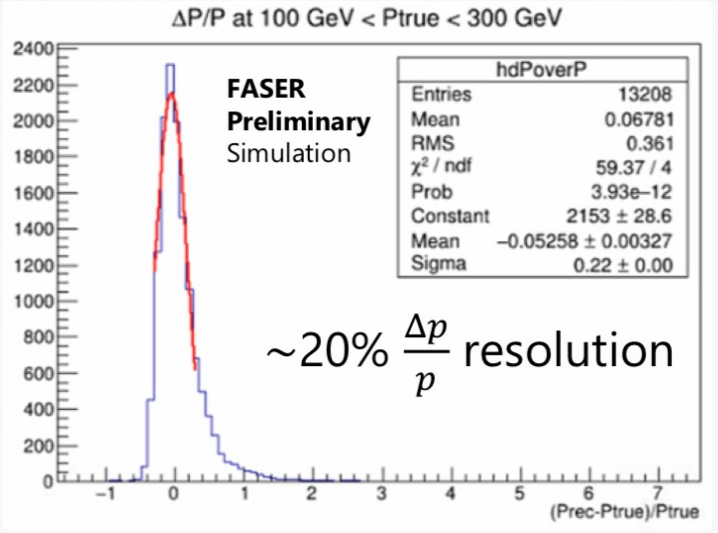
アライメント後の位置精度 (100枚以上を再構成したデータ)



運動量測定



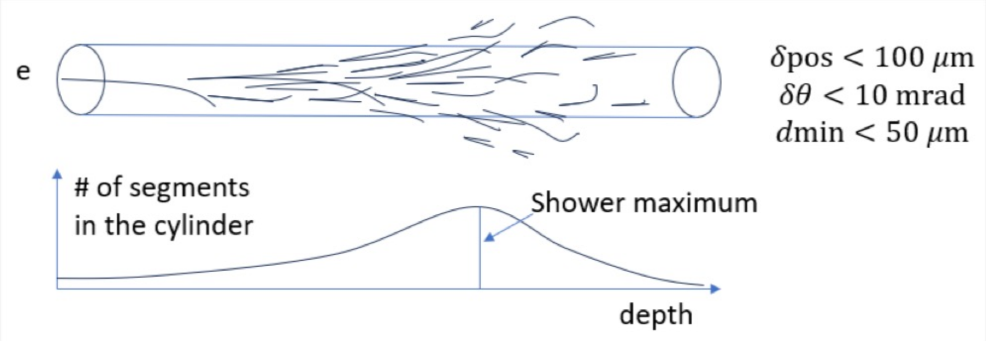


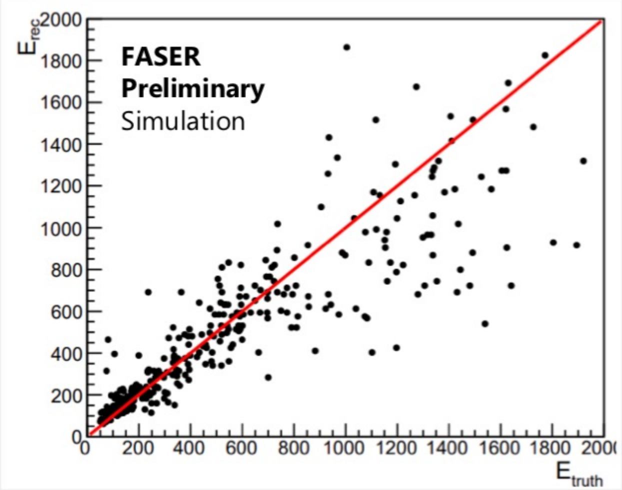


データ中のtrackを上流側と下流側に分けて運動量測定をして比較し、性能を評価

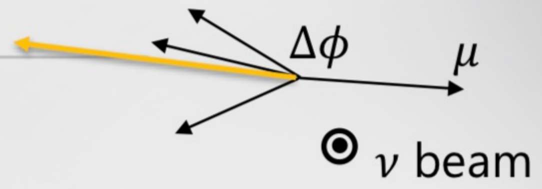
電子のエネルギー測定

Shower maximum辺りの7枚におけるsegment数をエネルギー測定に用いる。$\sim 25\% \frac{\Delta E}{E}$ resolution





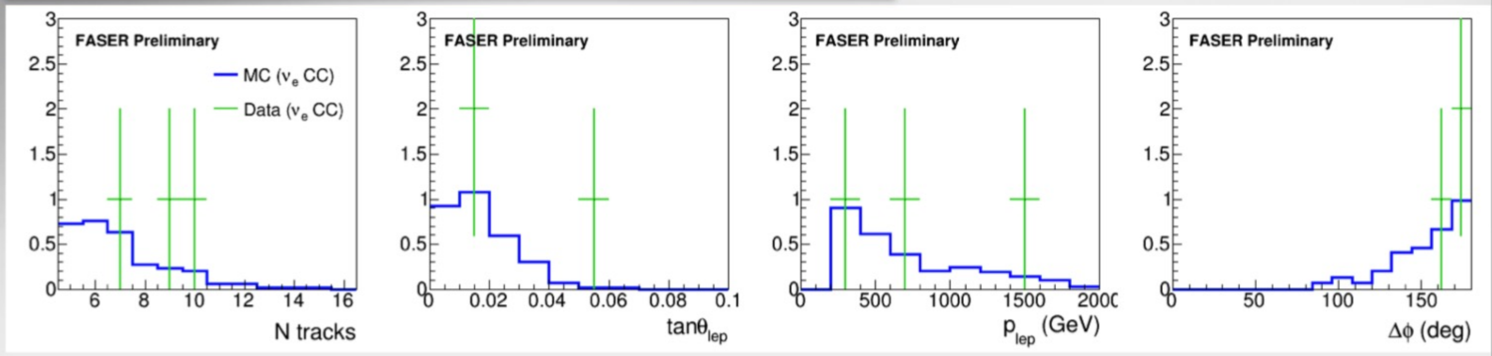
FASERν最新結果：ニュートリノ反応候補の描像



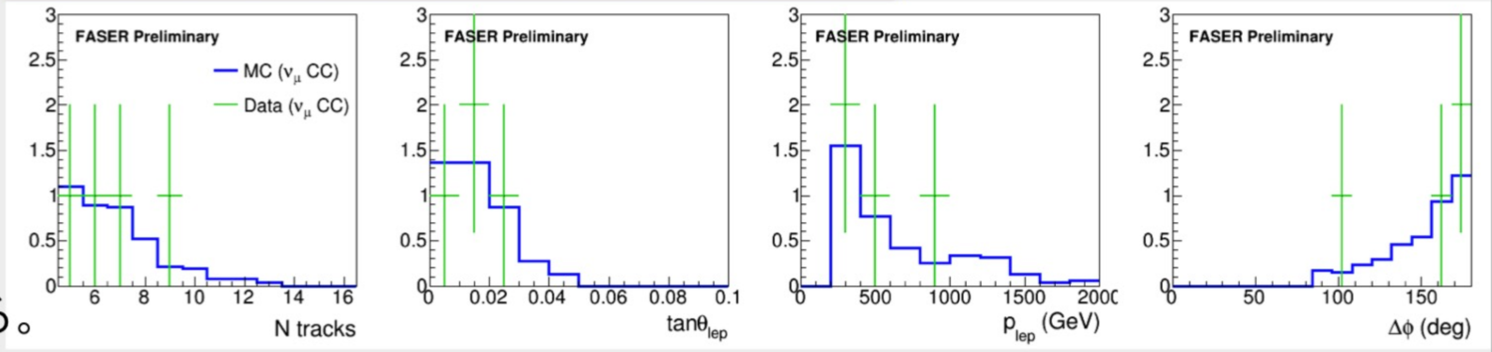
	Expected background		Expected signal	Observed
	Hadron int.	ν NC int.		
ν_e CC	0.002 ±0.002(stat) ±0.002(syst)	-	$1.2^{+4.0}_{-0.6}$	3
ν_μ CC	0.32 ±0.15(stat) ±0.16(syst)	0.19 ±0.15	$4.4^{+4.2}_{-1.4}$	4

- ν_e: $p = 1.6 \times 10^{-7}$ (5.1σ)
  - LHC電子ニュートリノ反応を初めて直接検出
- ν_μ: $p = 5.2 \times 10^{-3}$ (2.5σ)
  - 今回は100層しかmuon IDに使っていないが、読み出しを進め、200-400層使えば改善できる。

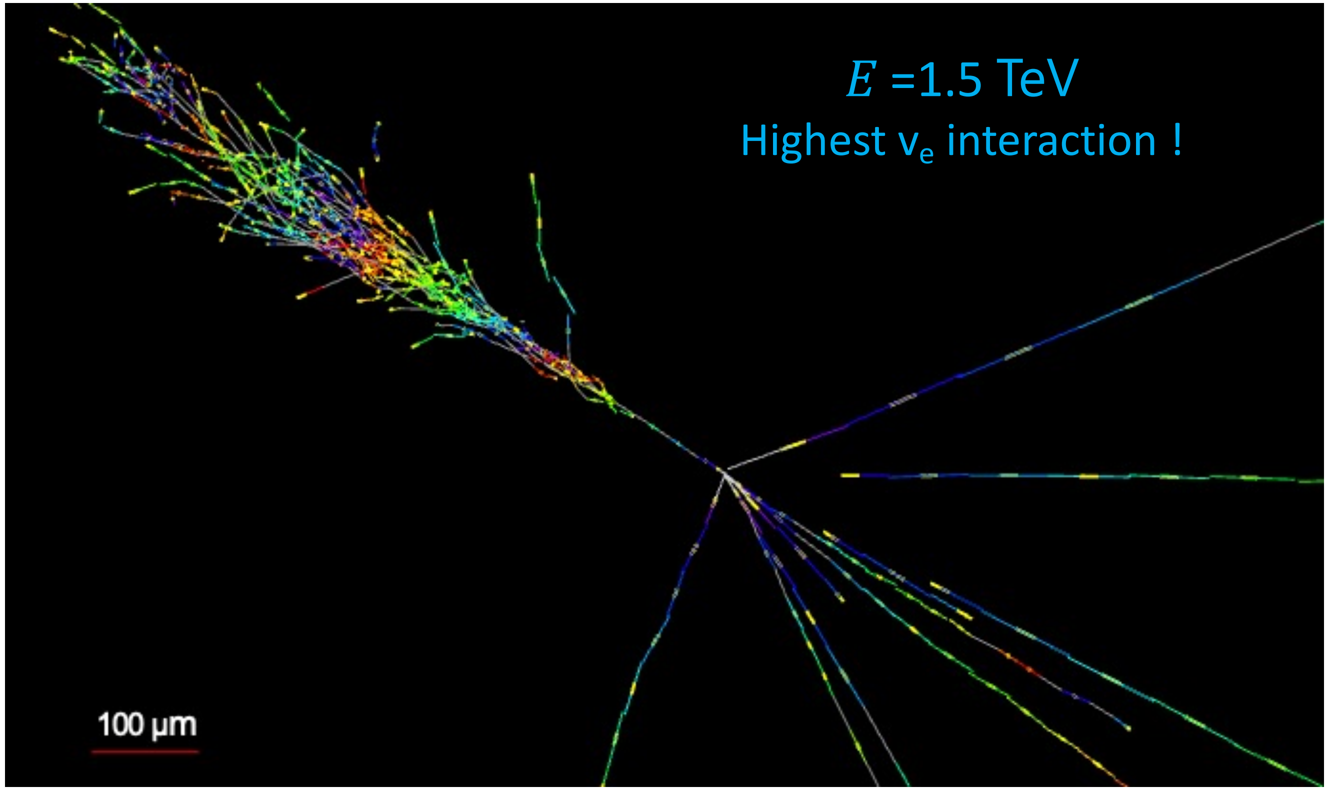
Vertex information of the ν_e CC candidates



Vertex information of the ν_μ CC candidates



Electron Neutrino Event



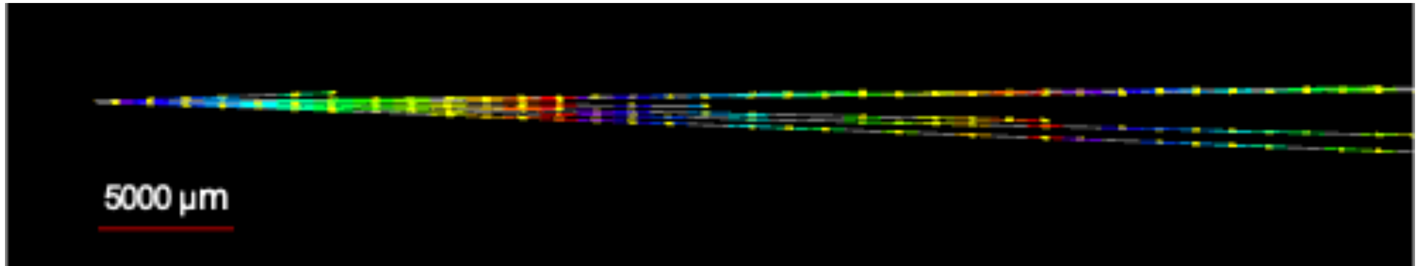
Vertex with 11 tracks

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

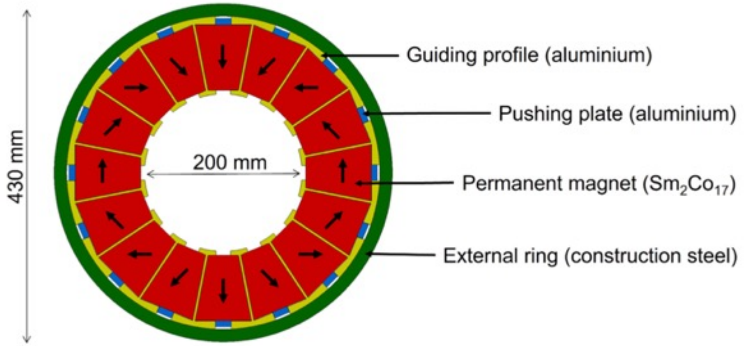


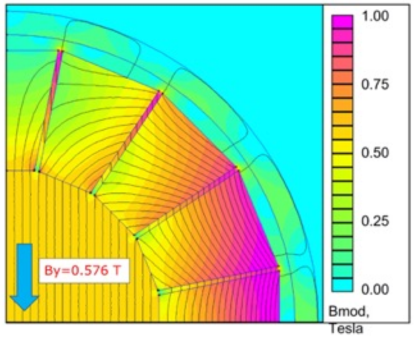
Magnet system

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

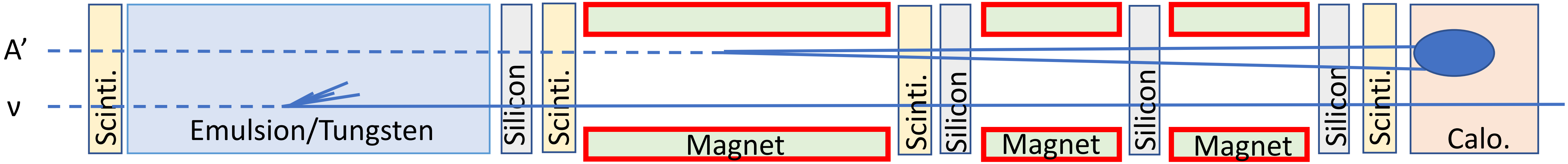
Three 0.57 T permanent dipole magnets (1.5m-long x 1 and 1m-long x 2)

- 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



Target for neutrino

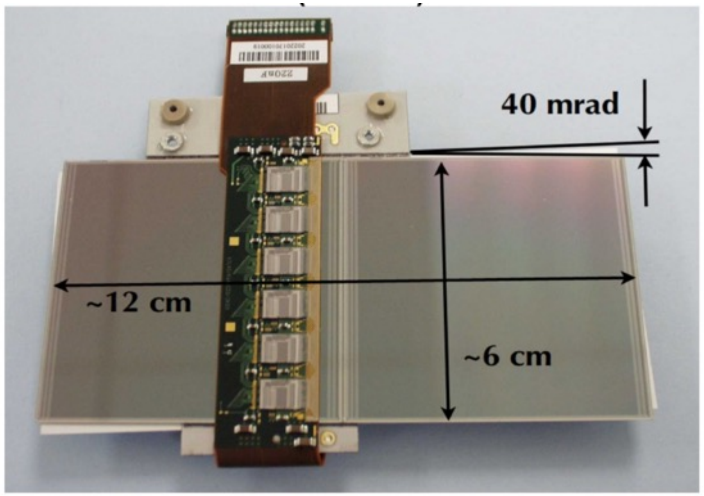
Decay volume of new particles

Tracker station

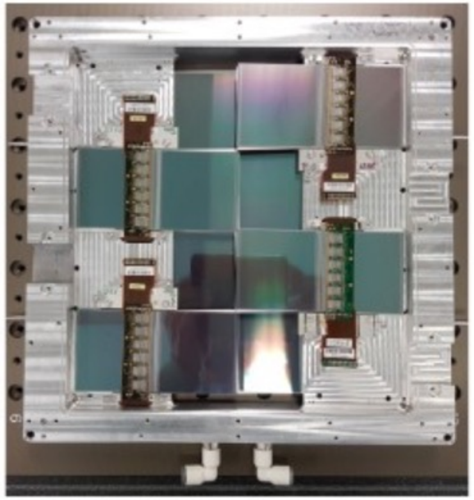
ATLAS SCT module:
- 6cm x 12cm x 2 sides (40 mrad)
- 80 um pitch/ 768 strips per side
- Resolution: 17 um x 580 um
- 6 ASICs per side

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

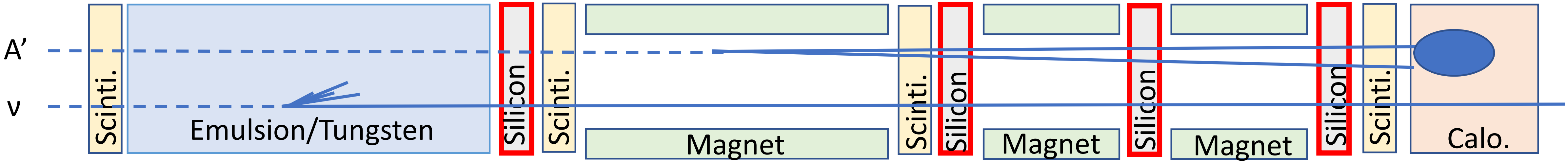
- Based on ATLAS SCT modules - 4 stations x 3 layers x 8 modules = 96 modules



Tracker plane →



Tracker station →



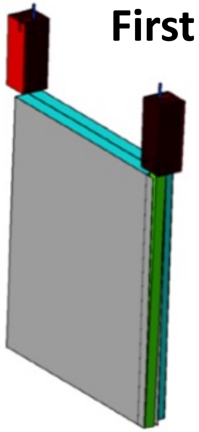
Target for neutrino

Decay volume of new particles

Scintillation detectors

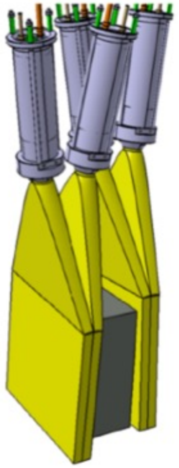
Four scintillator stations are assembled and installed

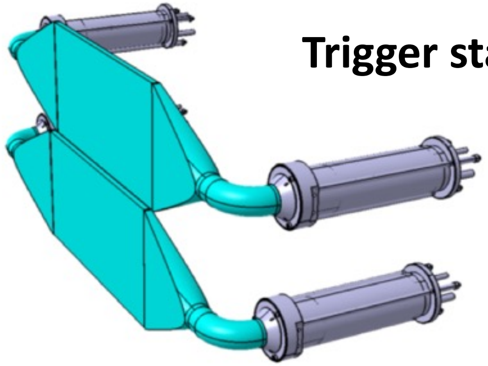
- Veto incoming charged particle, precise timing, and pre-shower for calorimeter
- Scintillators, light guides and PMT housing constructed at CERN scintillator lab (EP-DT)



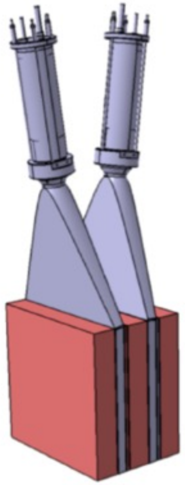
First veto station

Second veto station

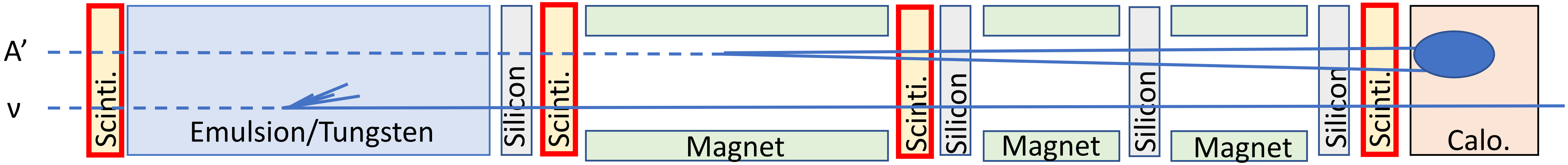




Trigger station



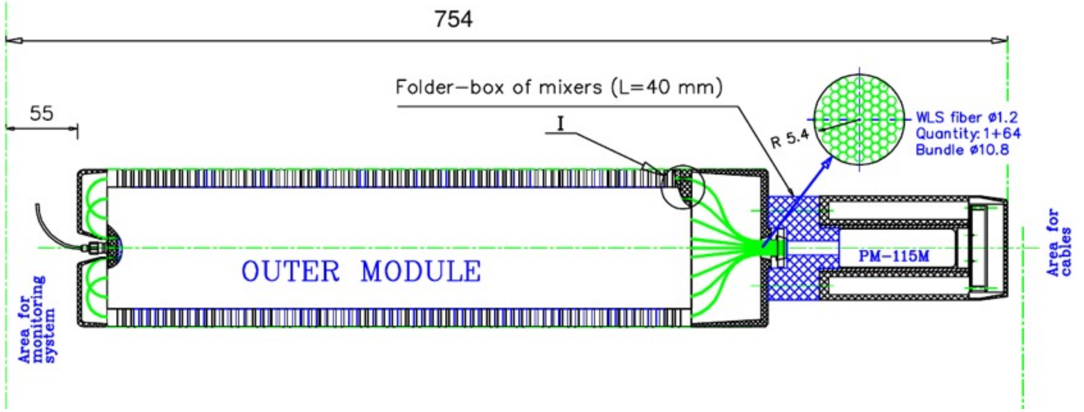
Preshower station

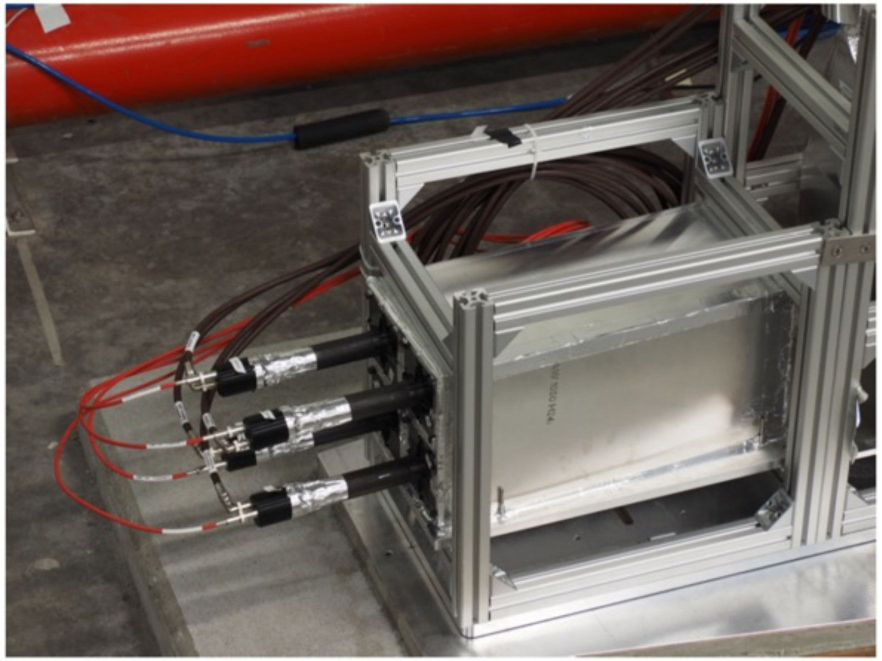


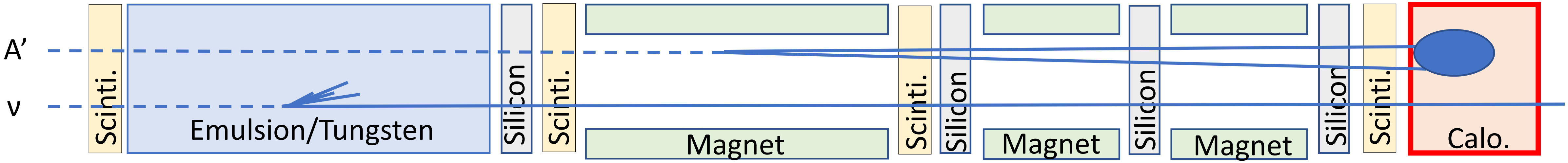
Electromagnetic calorimeter

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)



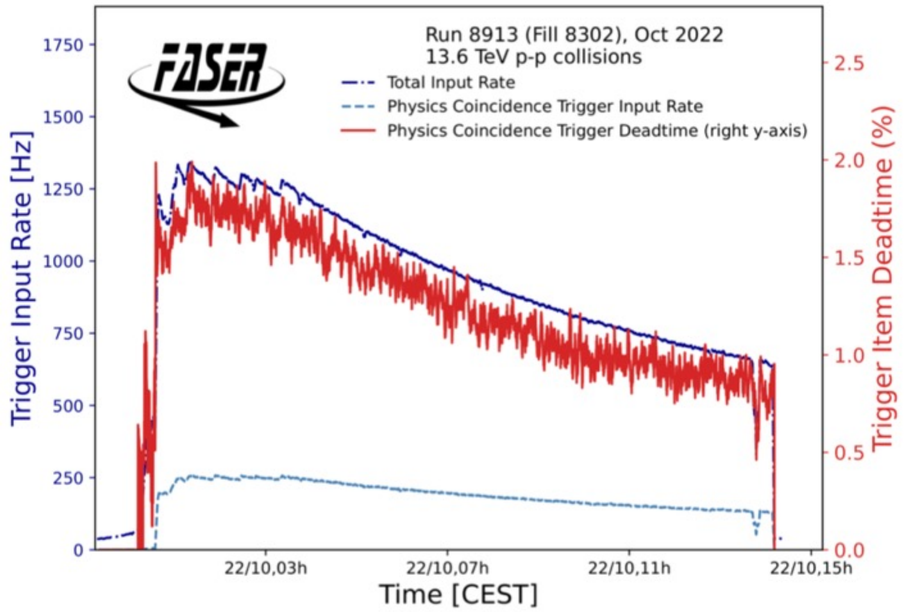




Stable data taking thoughout 2022

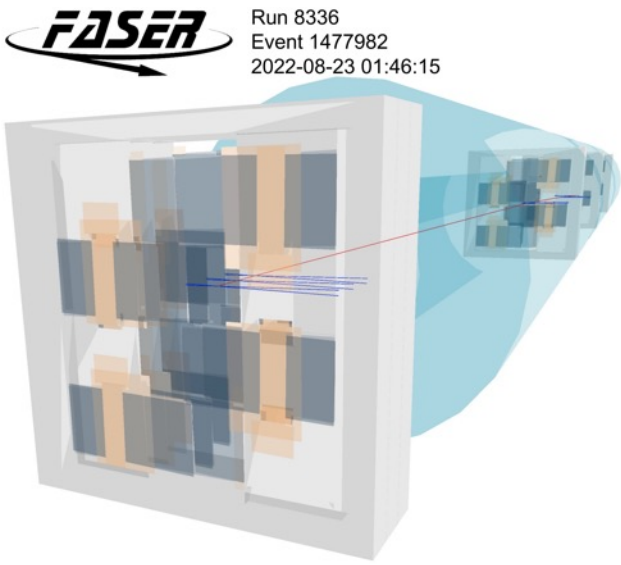
The number of bunches in LHC has reached 2400 since August 2022

- 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



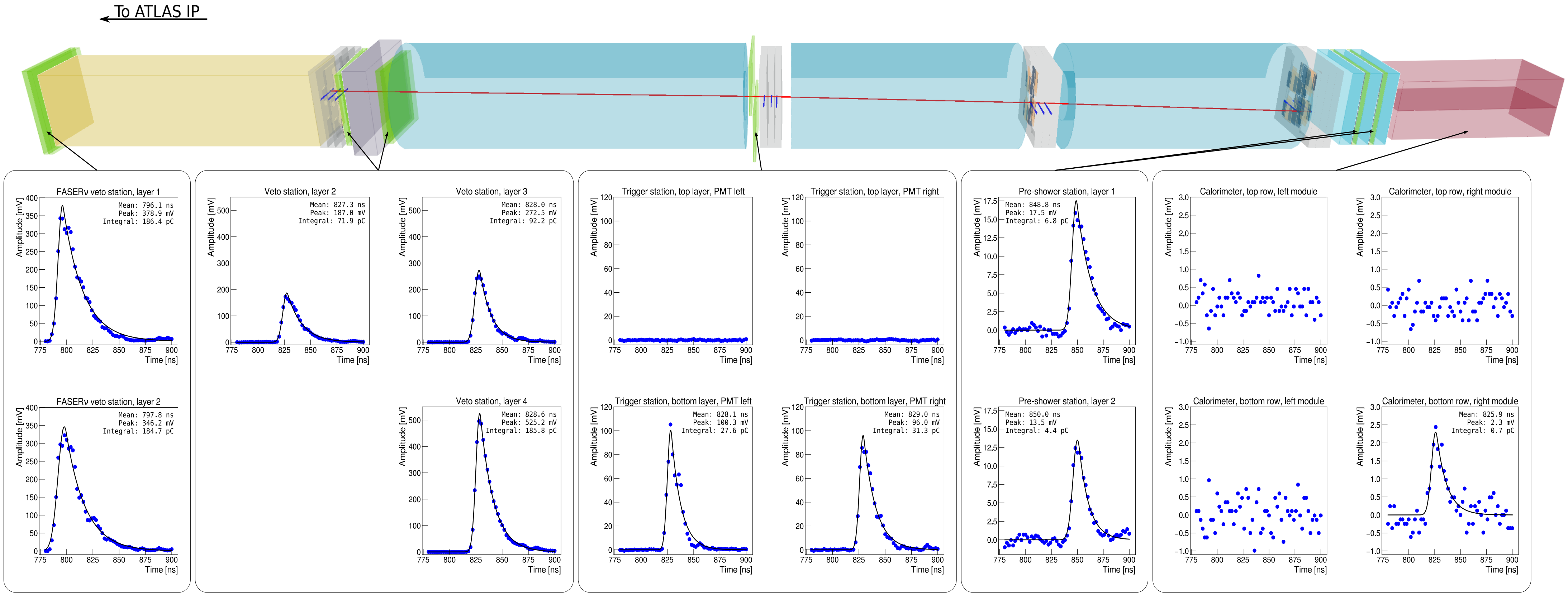
- only 850 pb^{-1} (< 2.5% of full dataset) data lost due to operational issues

Muon event from LHC collission

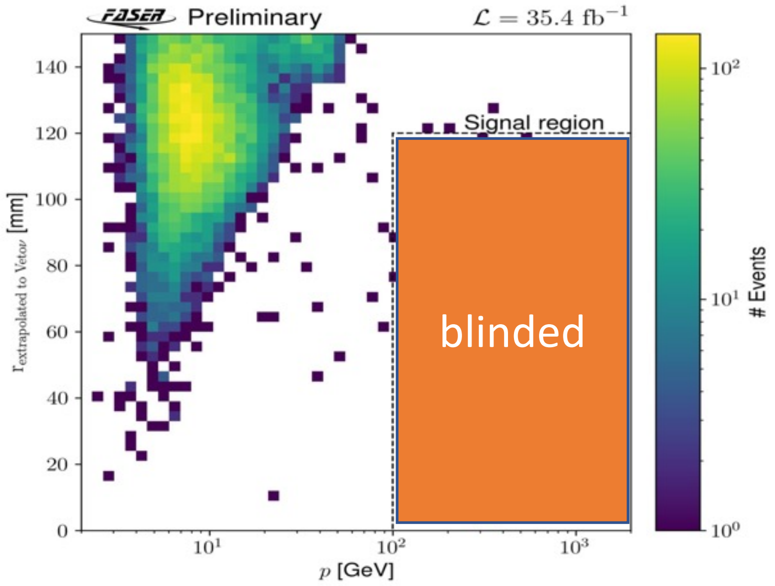


Run 8336
Event 1477982
2022-08-23 01:46:15

Reconstructed momentum 21.9 GeV



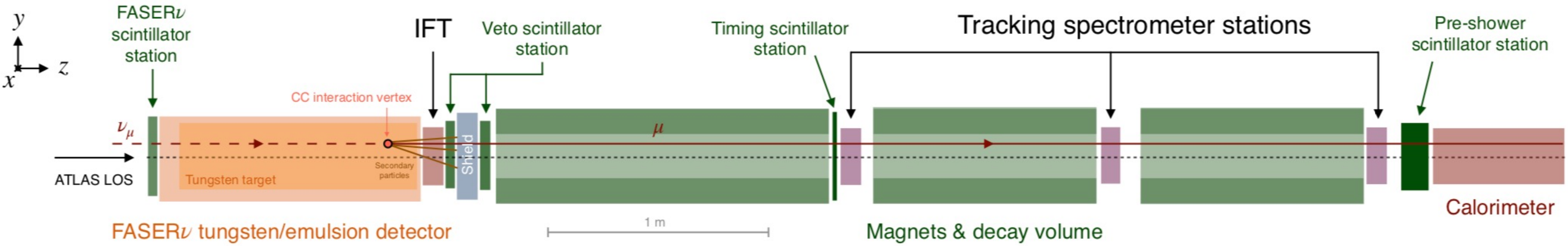
LHC neutrino search



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

1. Good collision events

4. Timing and preshower consistent with ≥1 MIP

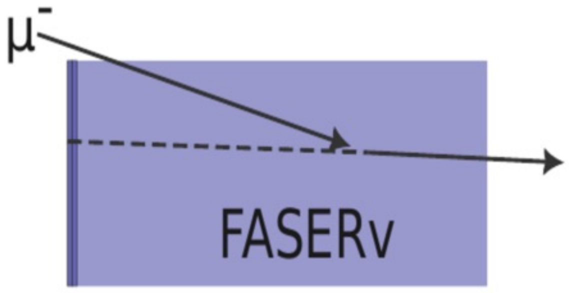


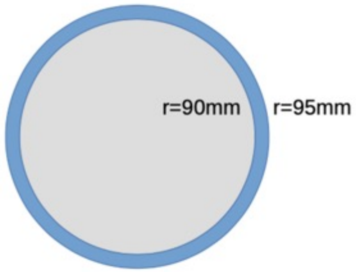
2. No signal (<40 pC) in 2 front vetos
3. Signal (>40 pC) in other 3 vetos

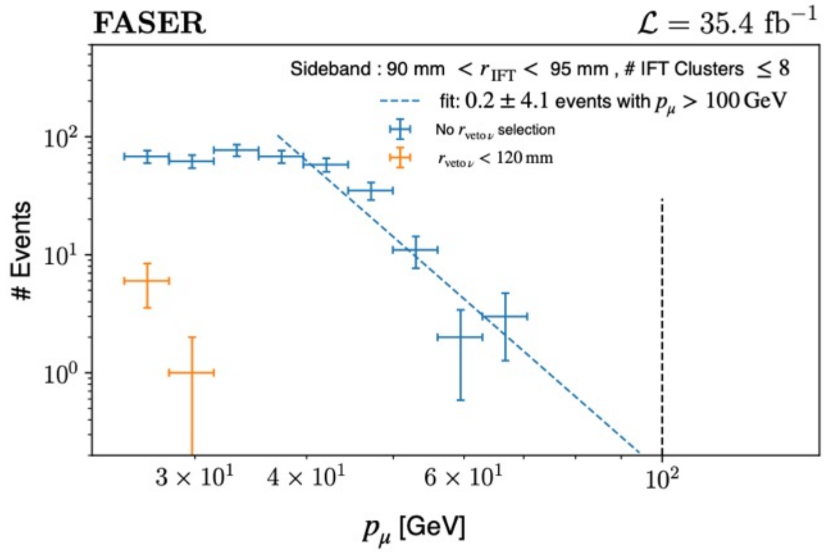
5. Exactly **1 good fiducial** (r < 95 mm) track
- p_T>100 GeV and θ<25 mrad
- Extrapolating to r<120 mm in front veto

Background estimation

Geometric background: 0.08 ± 1.83 events expected

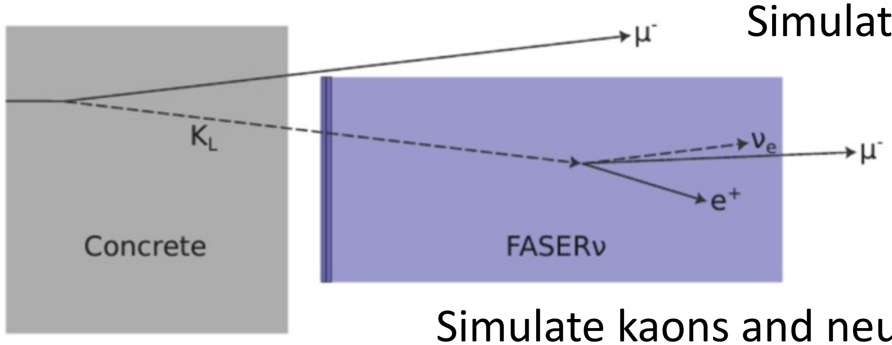






Sideband region determined from r=90-95mm, scaled to full acceptance with muon simulation

Neutral hadron background: 0.11 ± 0.06 events expected

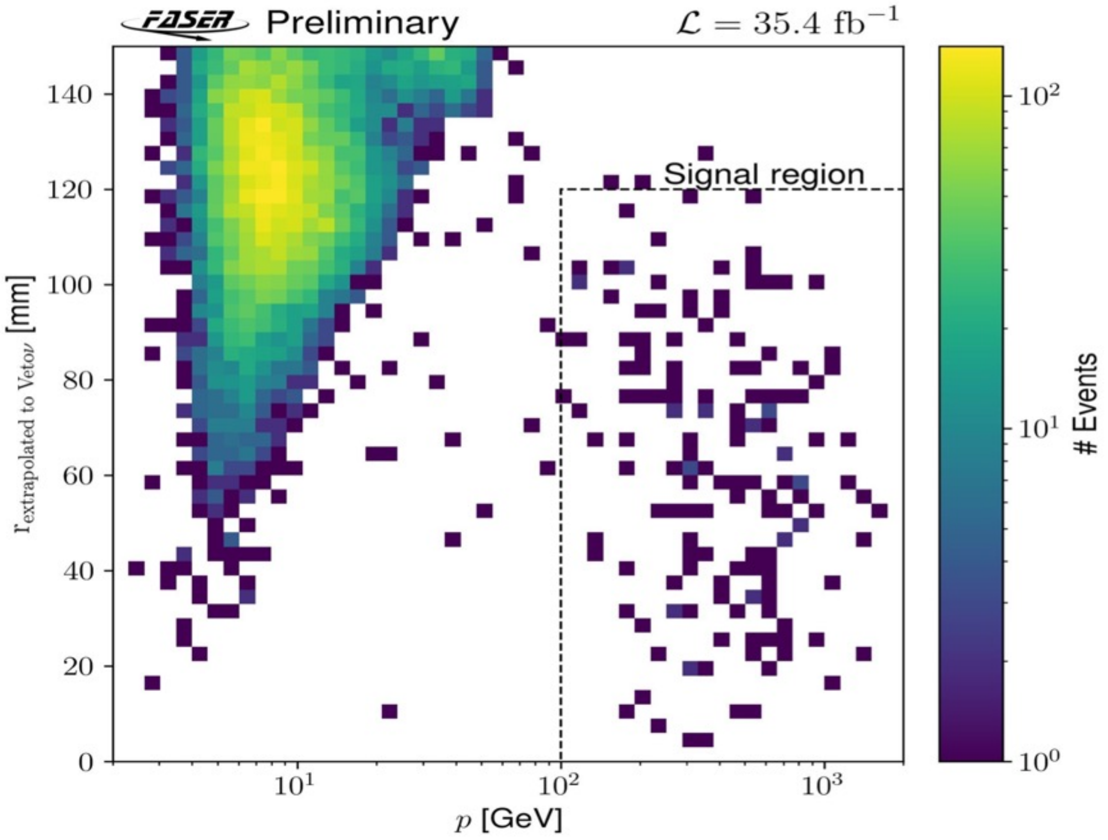


Simulated 10^9 μ+ and μ- events

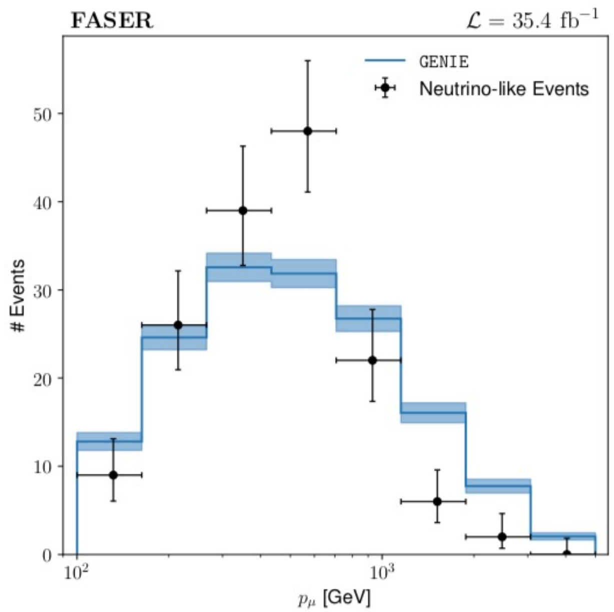
Simulate kaons and neutrons with p > 100 GeV following expected spectra

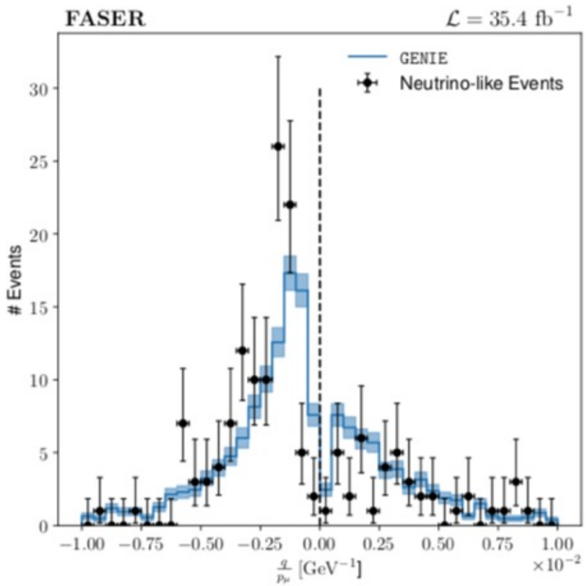
Results – the first observation of LHC neutrino

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



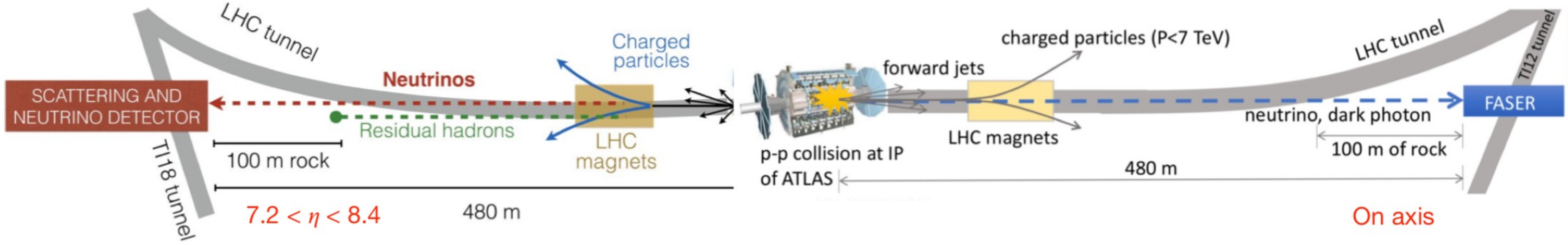
Luminosity-normalized prediction agrees well with data





Opening up a new filed – neutrino physics at collider

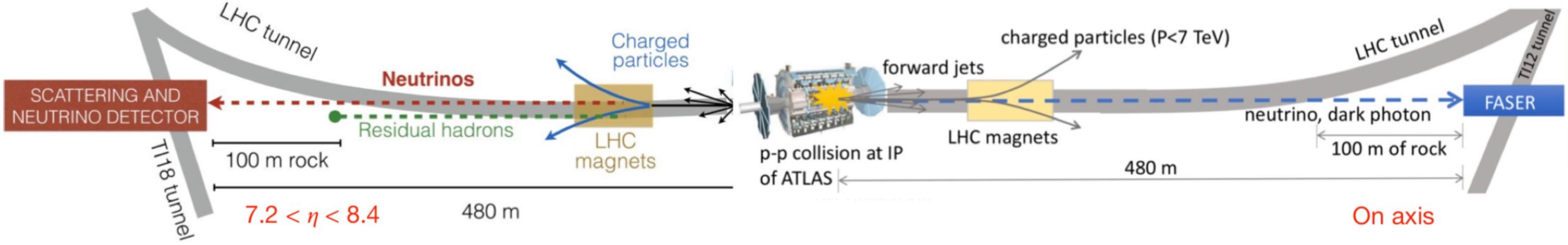
The birth of Collider Neutrinos (at the LHC)



SND

Faser-ν

The birth of Collider Neutrinos (at the LHC)



$7.2 < \eta < 8.4$

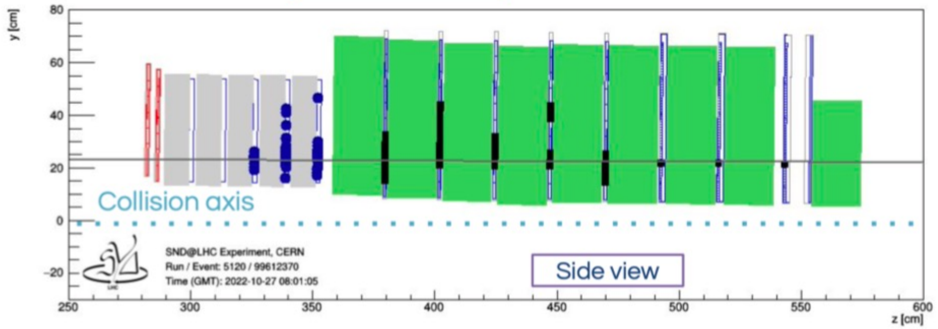
On axis

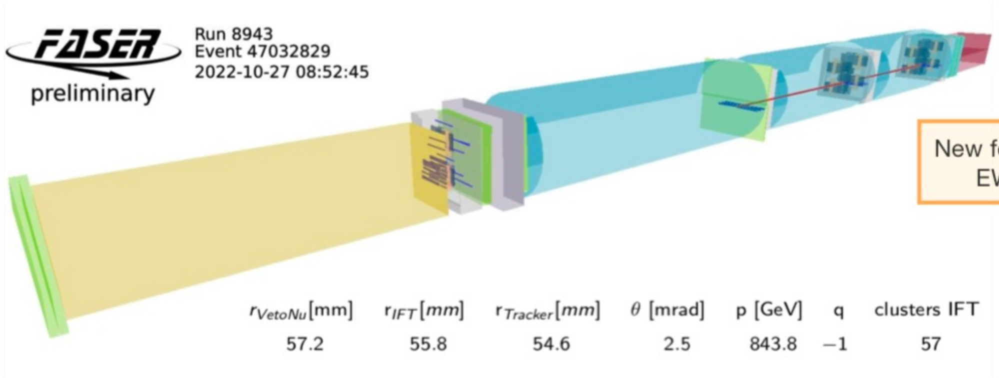
SND

New for Moriond EW 2023

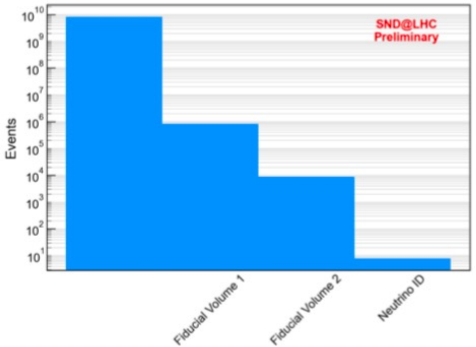
First results from SciFi/Silicon tracking devices

Faser-ν





New for Moriond EW 2023

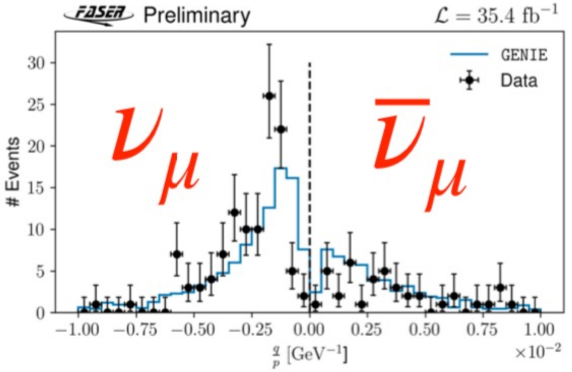


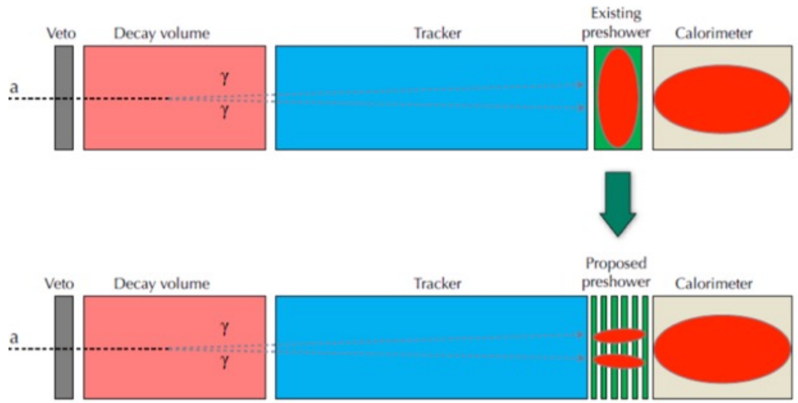
5 events expected and 8 observed (0.2 background)

Approximately 5σ observation!

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

16σ observation!

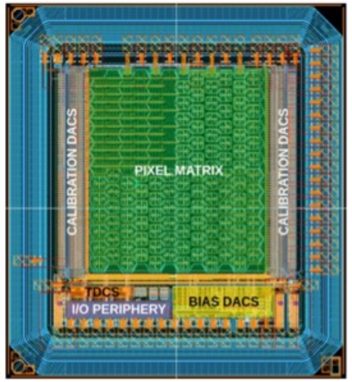




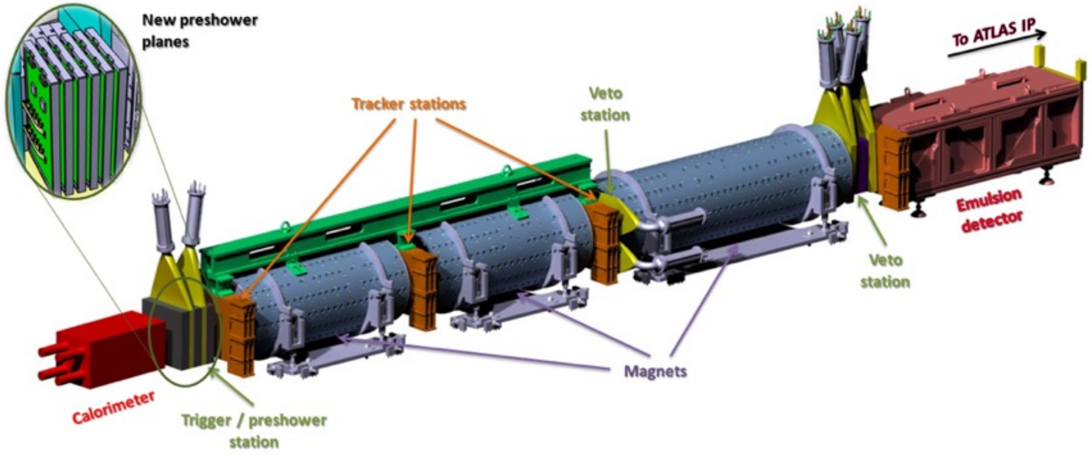
Upgrade planned for 2025

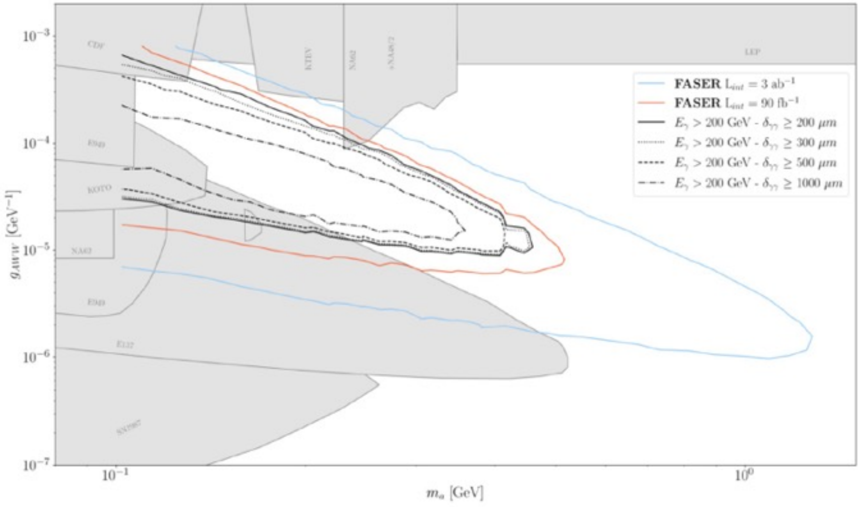
The preshower scintillator will be replaced by silicon pixel detector

- 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/

Reminder: Jan 30th

FASER VIP VISIT

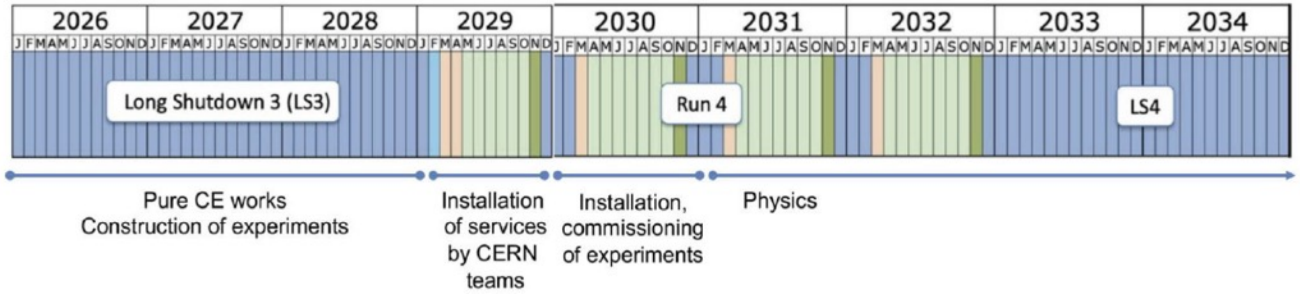
Left to right:
Jamie Boyd, Mike Lamont, Mark Heising, Joachim Mnich, Jim Simons, Jonathan Feng, Greg Gabadadze

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

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

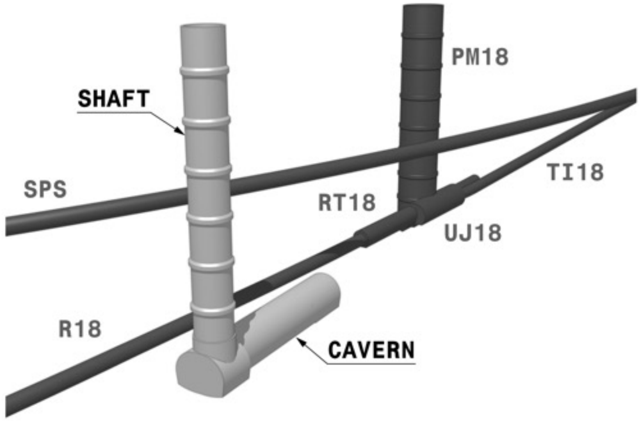
2203.05090 (to appear in J Phys G)

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.

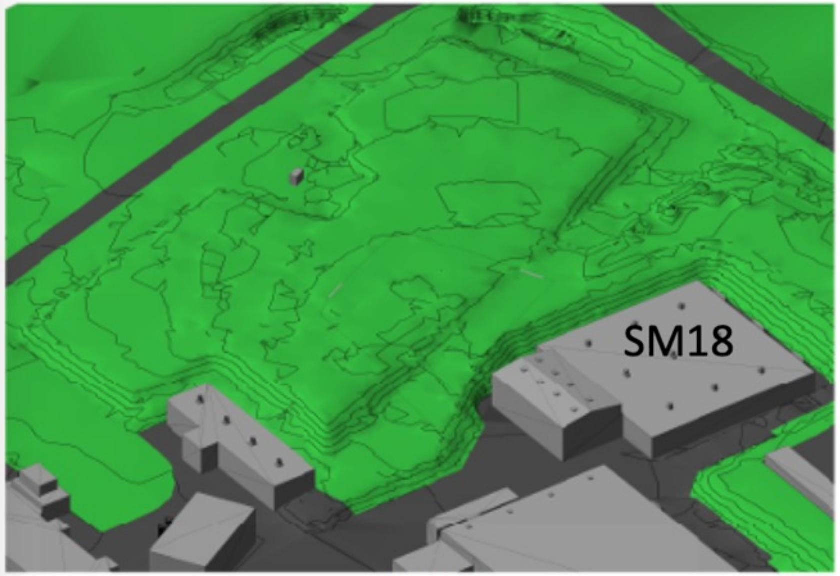
2023 March/April – site investigation work

➢ Drilling machine in place

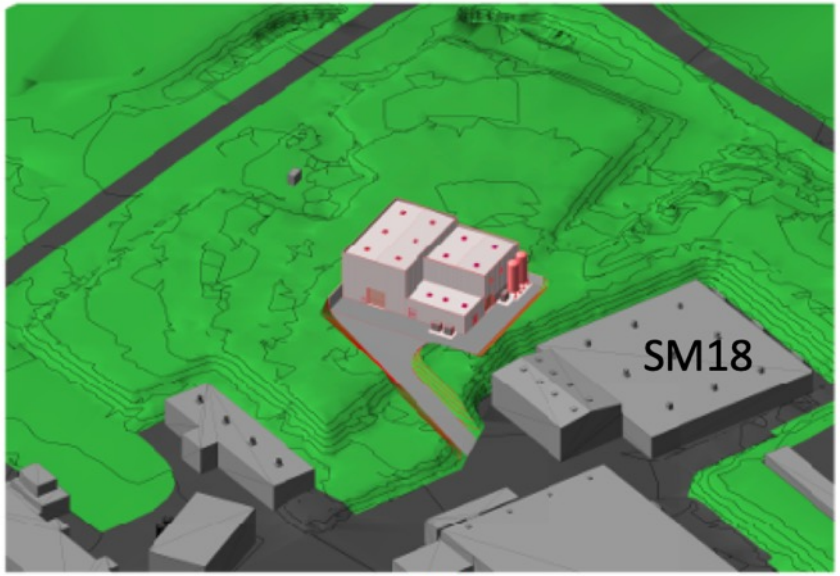
➢ Works started

➢ Core samples

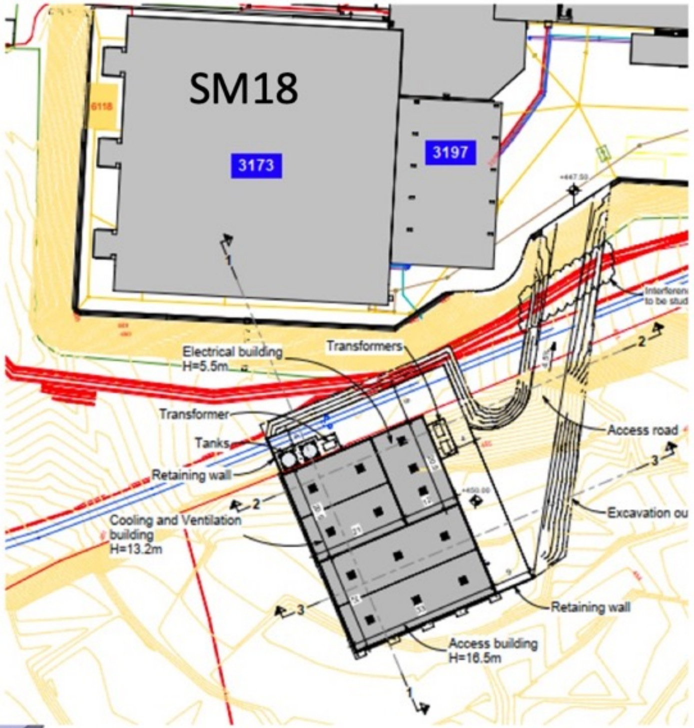
Done by CERN Site and Civil engineering group

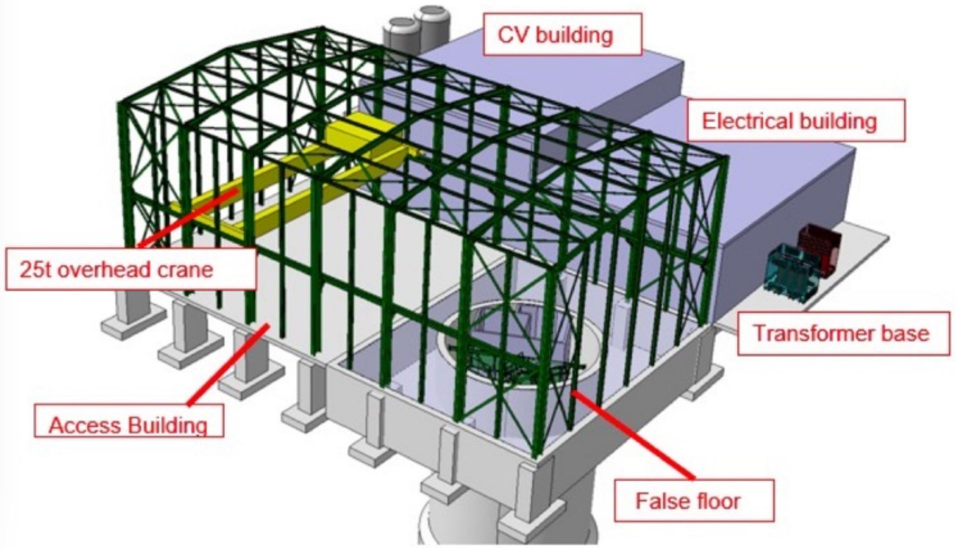


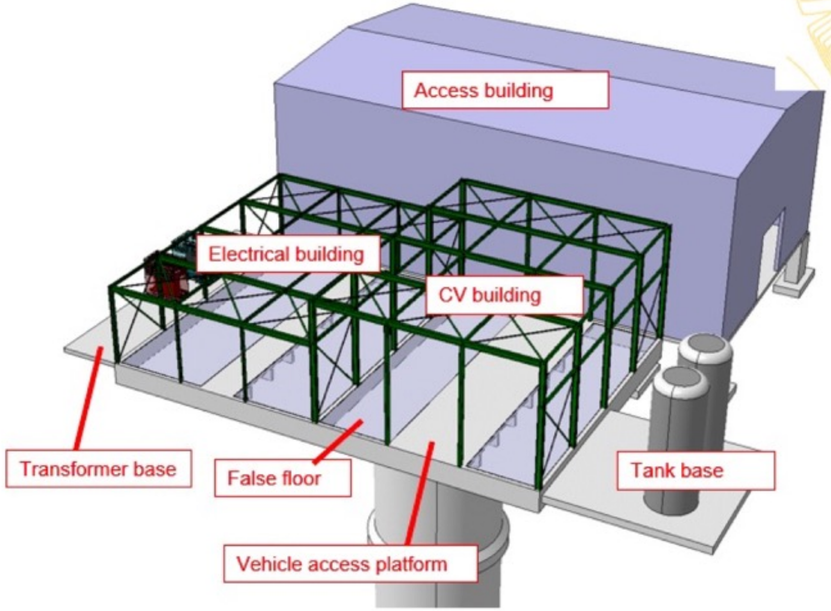
3D EXISTING



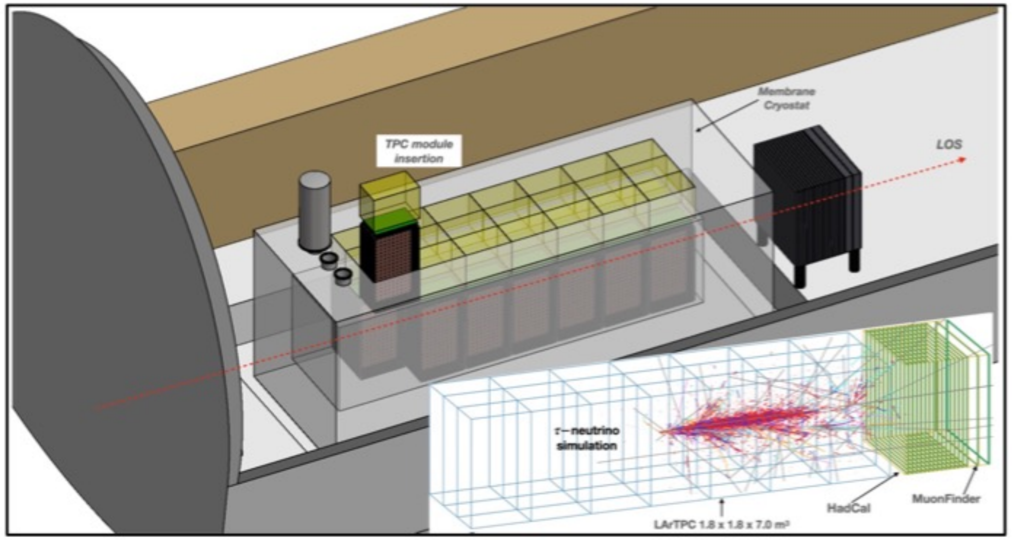
3D NEW



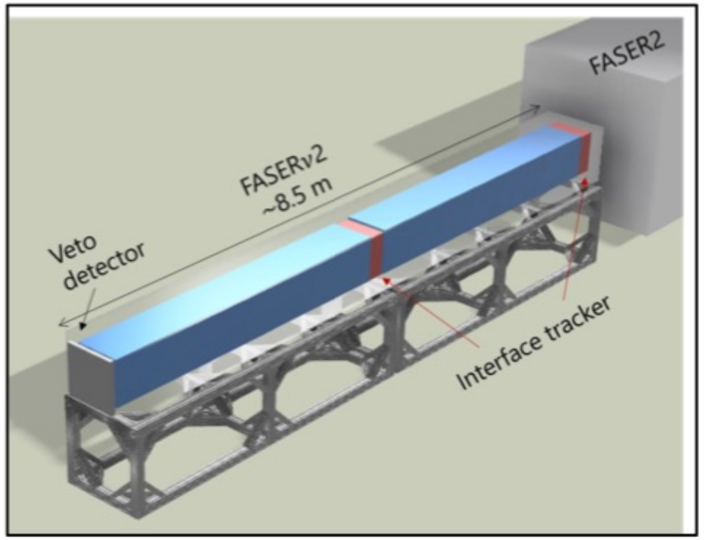




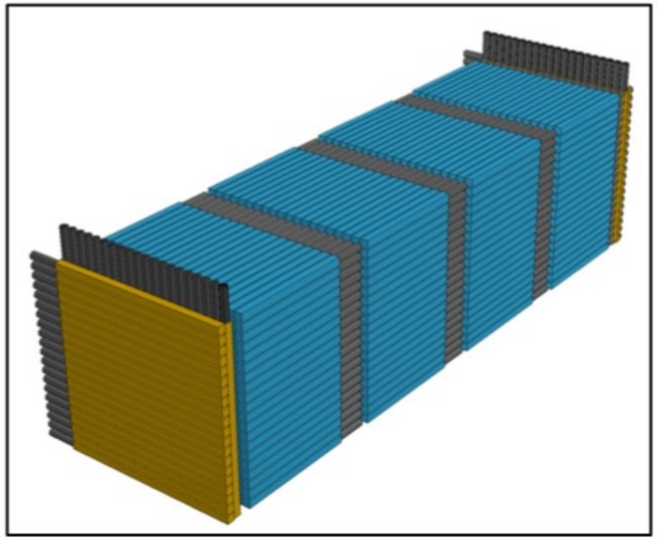
FLArE

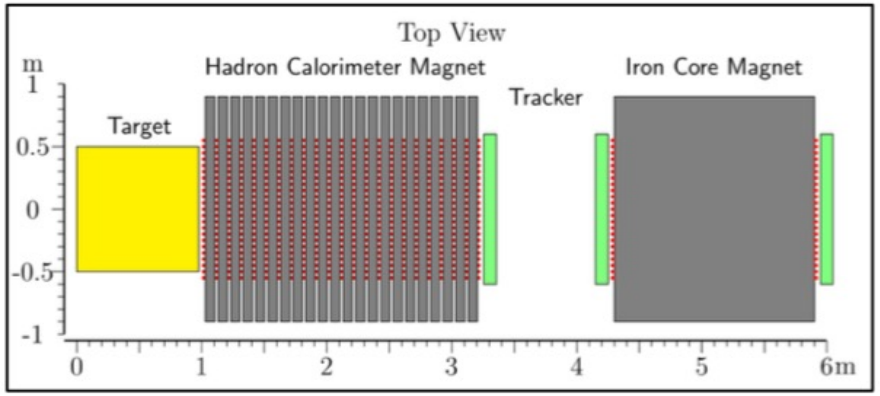


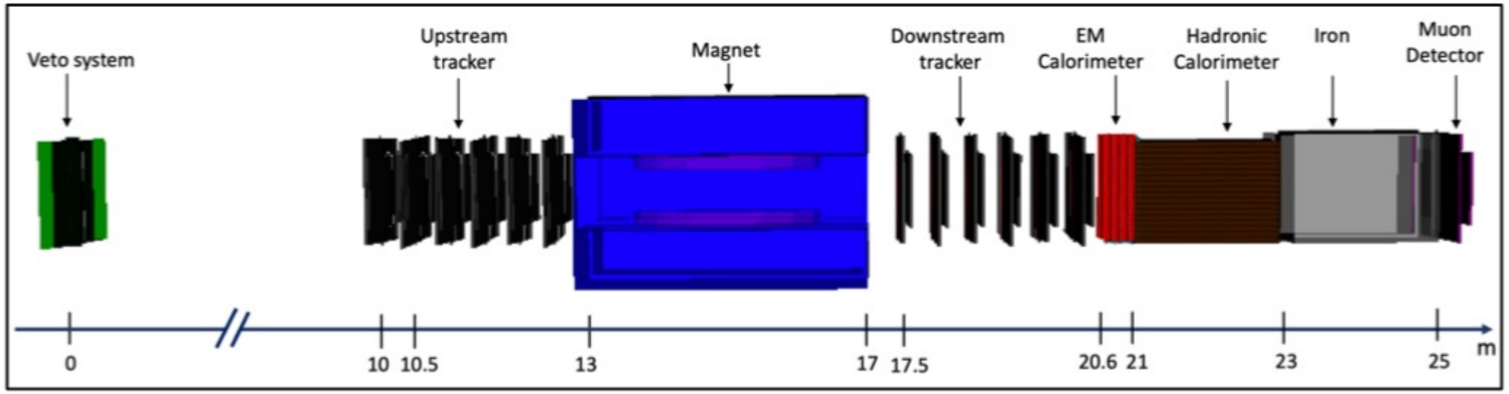
FASERν2



FORMOSA

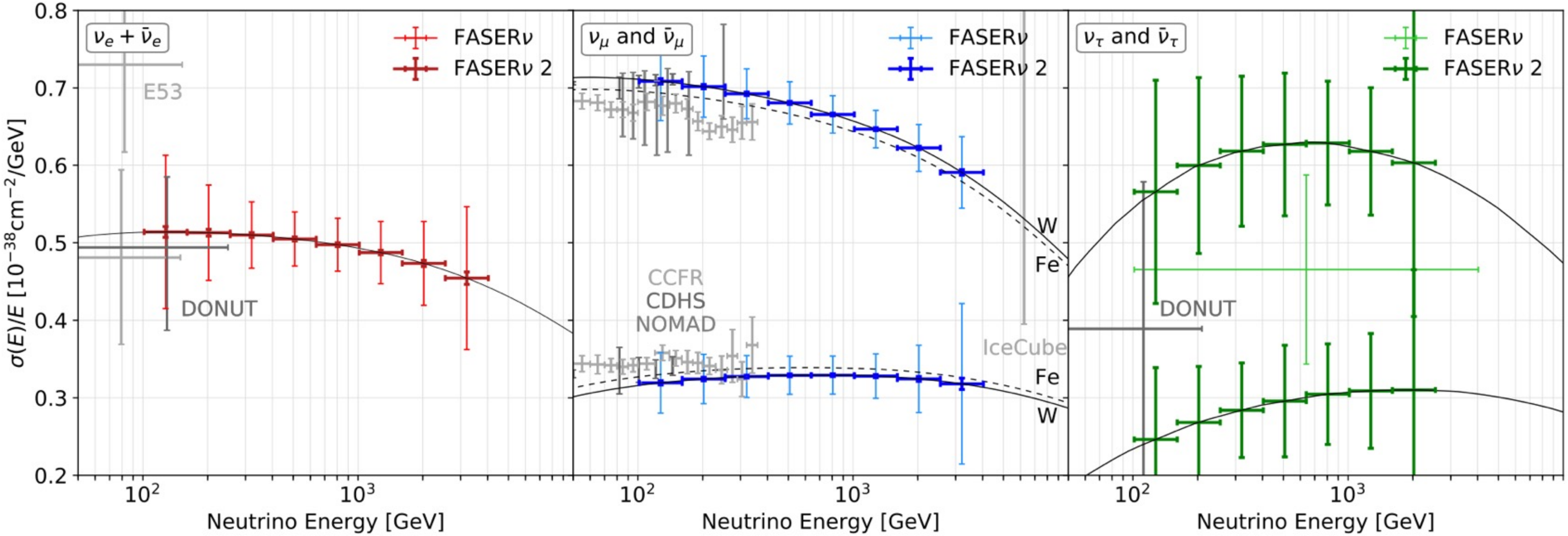






FASER2

Improvement of the TeV neutrino study

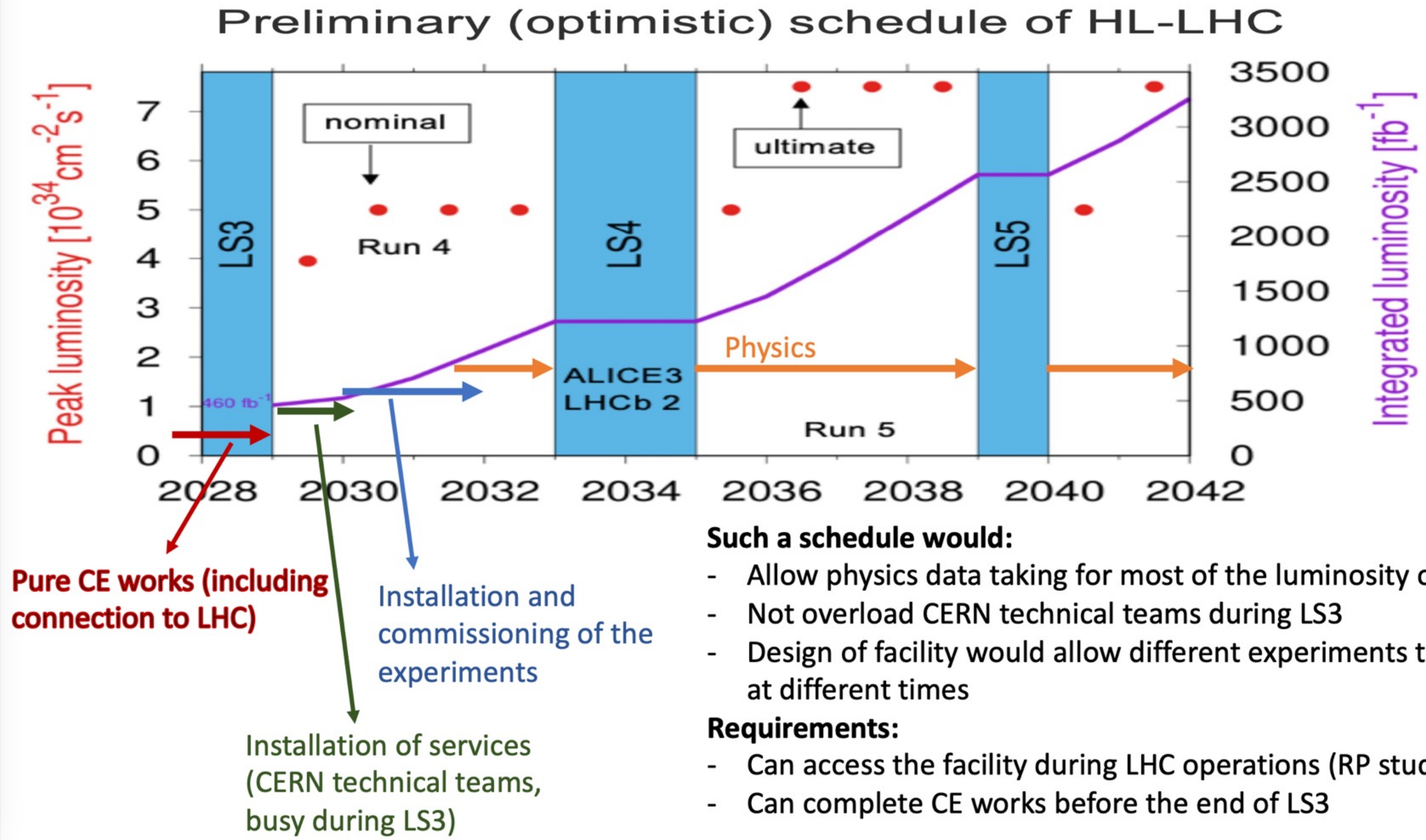


O(10^3-10^4) of Tau neutrino, allowing detailed measurement of final state

- 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

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 last one (FPF6) was held in June 8-9 https://indico.cern.ch/event/1275380
  - The next one (FPF7) will come in Jan/Feb in 2024 (TBD)

FASER Acknowledgements

FASER is supported by:

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In addition, FASERν is supported by:

erc, 科研費 KAKENHI

FPF studies supported by:

Physics Beyond Colliders

And would additionally like to thank

- LHC for the excellent performance in 2022
- ATLAS for providing luminosity information
- 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