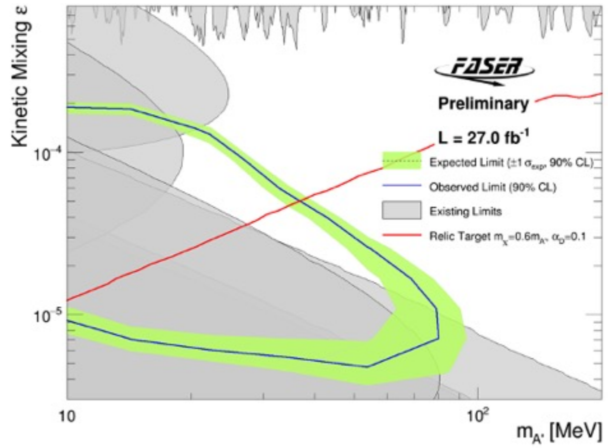
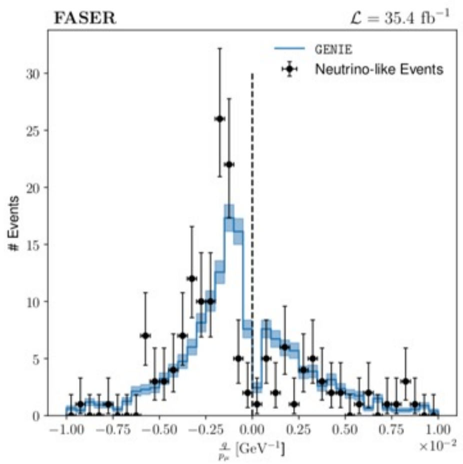
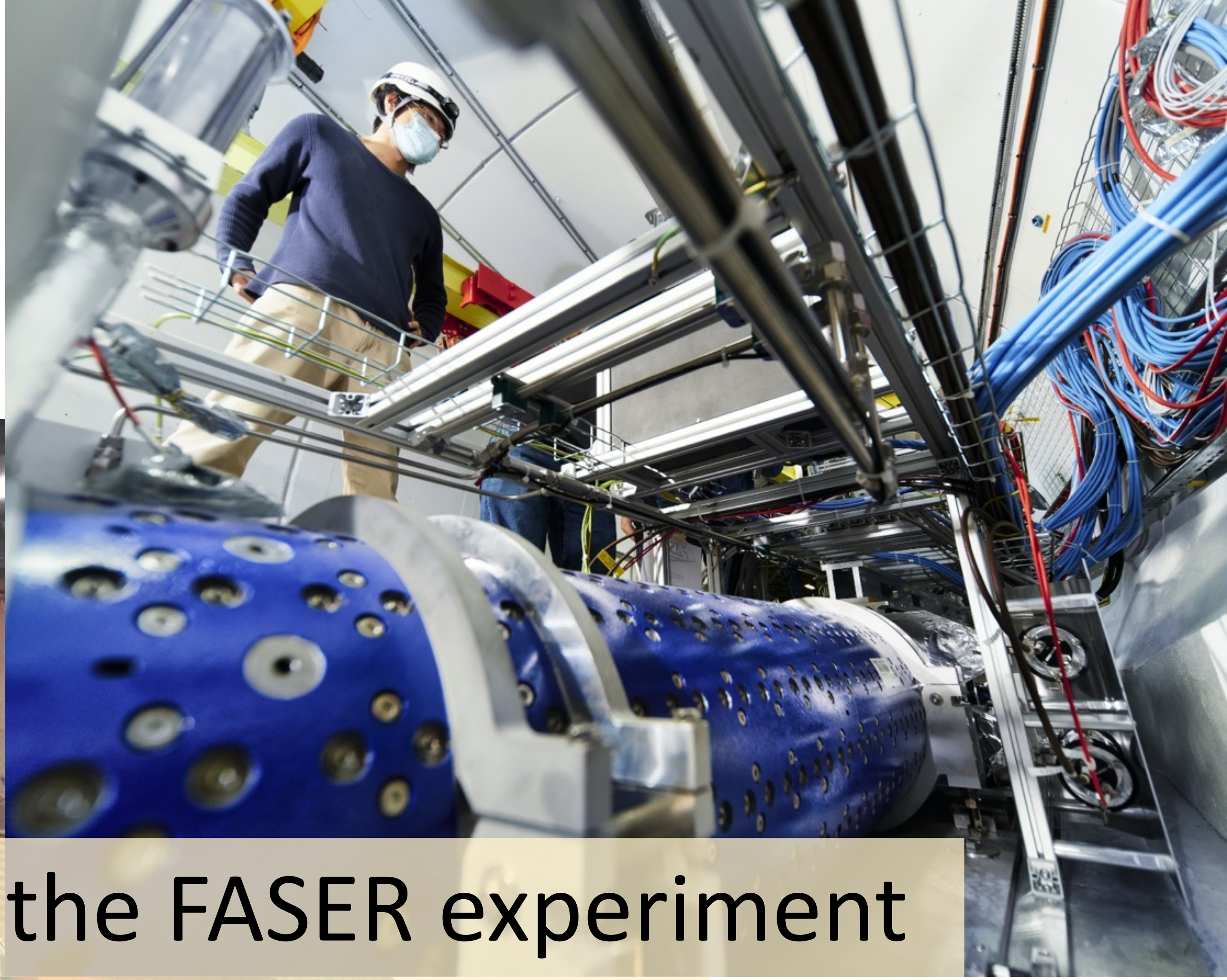




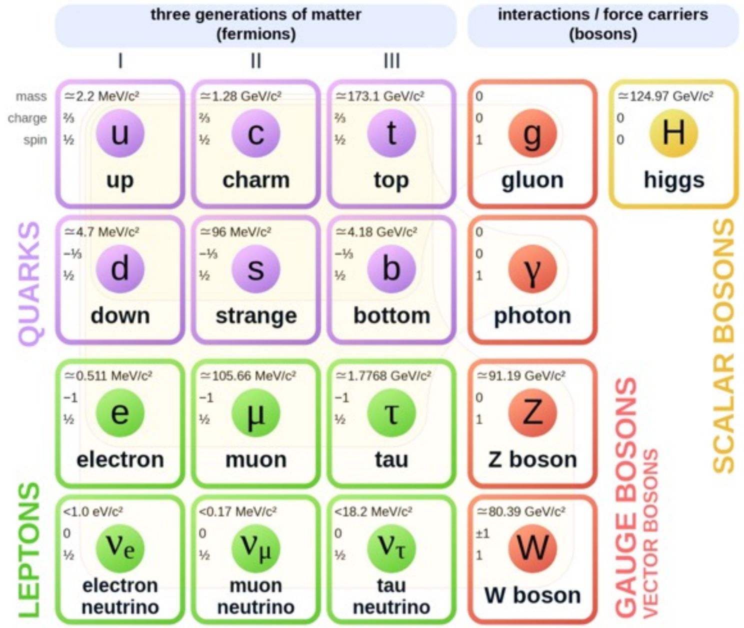


First results from the FASER experiment

Hidetoshi OTONO (Kyushu University)

15th May, 2023
University of Zurich

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…

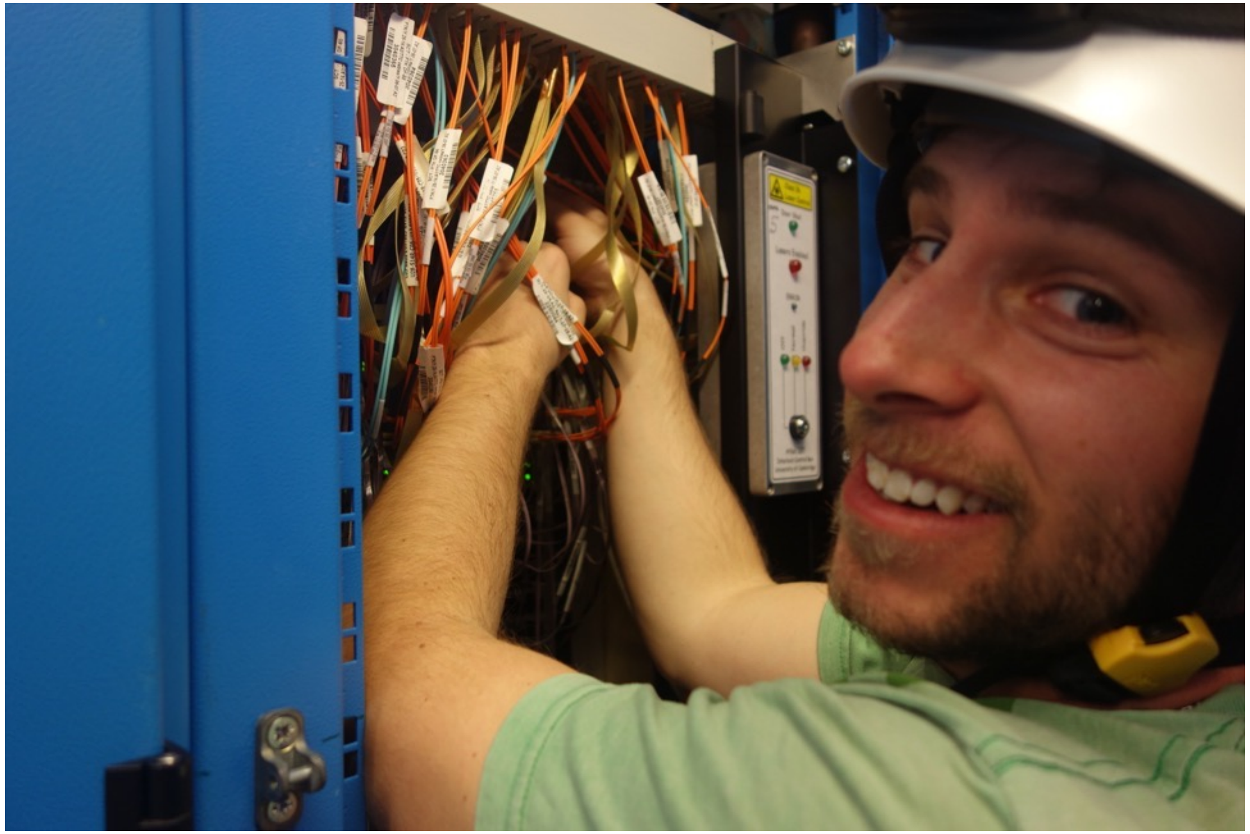
Discovery of a new particle followed by detailed measurement must help this situation

- LHC has been a great energy-frontier collider, which could both produce and detect new particles
- however optimistic scenario used for designing experiments failed
  - e.g, SUSY should have discovered already in Run 1 (2010-)
- I joined ATLAS experiment in 2012, and also started FASER experiment in 2018.

New challenge would be definitely needed !

Busy 2017 with Kyle for SCT operation

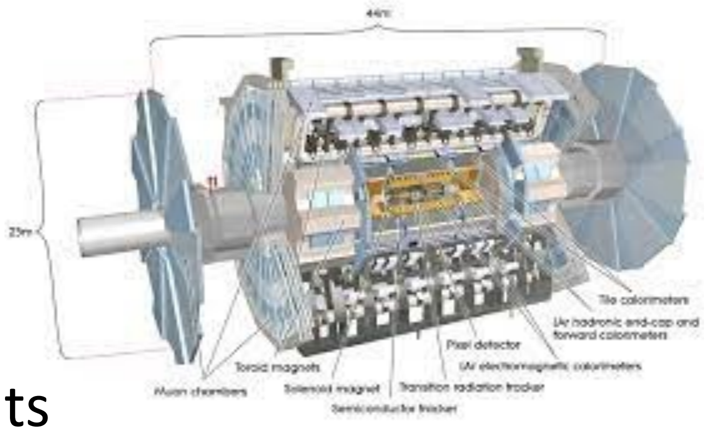
SCT Frontend link swapping to equalize data size to ROD
31.03.2017



My last day as SCT run coordinator
02.11.2017

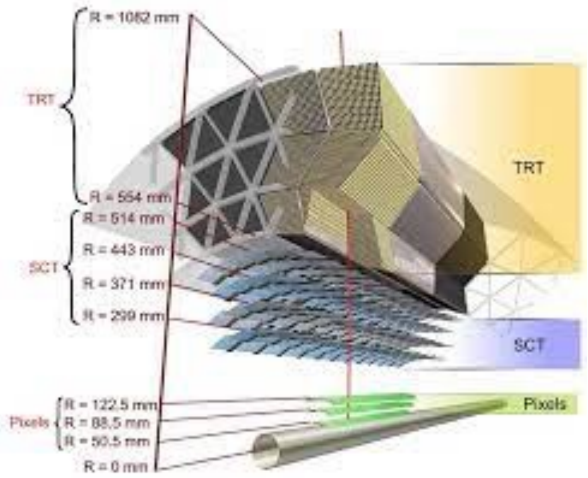
Then I took parental leave until March 2018

ATLAS experiment since 2012



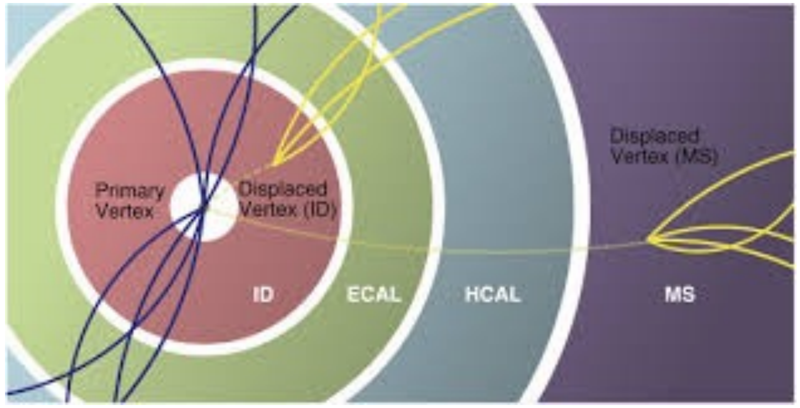
Operation of Silicon strip detector (SCT), serving all physics results

- e.g, Discovery and measurement of the Higgs boson
  - Summary paper published from Nature on July 4th, 2022 (10th anniversary)
- Exploit great performance against 2 times higher inst. lumi. compared to design
  - Throughout Run2 (2015-2018) and steady start in Run3 (2022-2025)
  - SCT run coordinator in 2016-2017
  - Performance paper published from JINST (2109.02591)



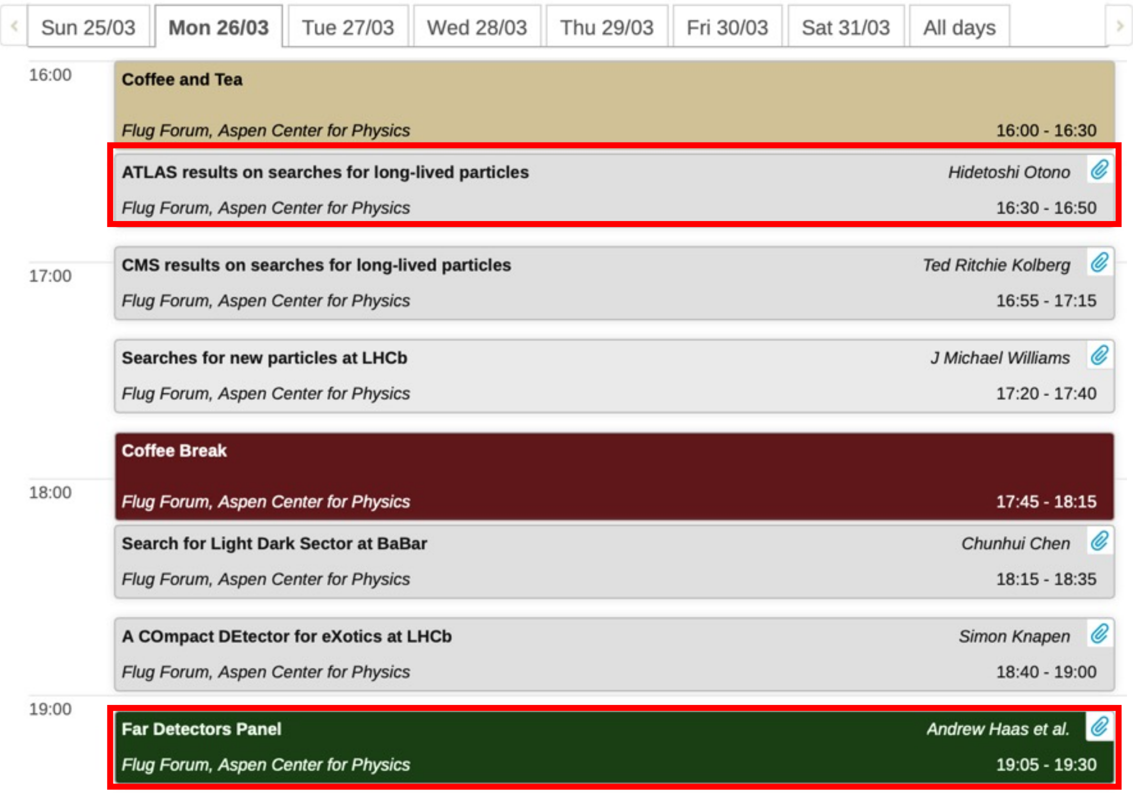
Long-lived particle search since 2014, cornering SUSY scenario

- Displaced vertex search, assuming Bino LSP
  - Pheno papar with theorists (1504.00504, 1506.08206)
  - Run-1 search (1504.05162) and early run-2 search (1710.04901)
- Displaced track search, assuming Higgsino LSP
  - Pheno paper with theorists (1701.07664)
  - Full run-2 search in progress



Encountered FASER in 2018 at Aspen

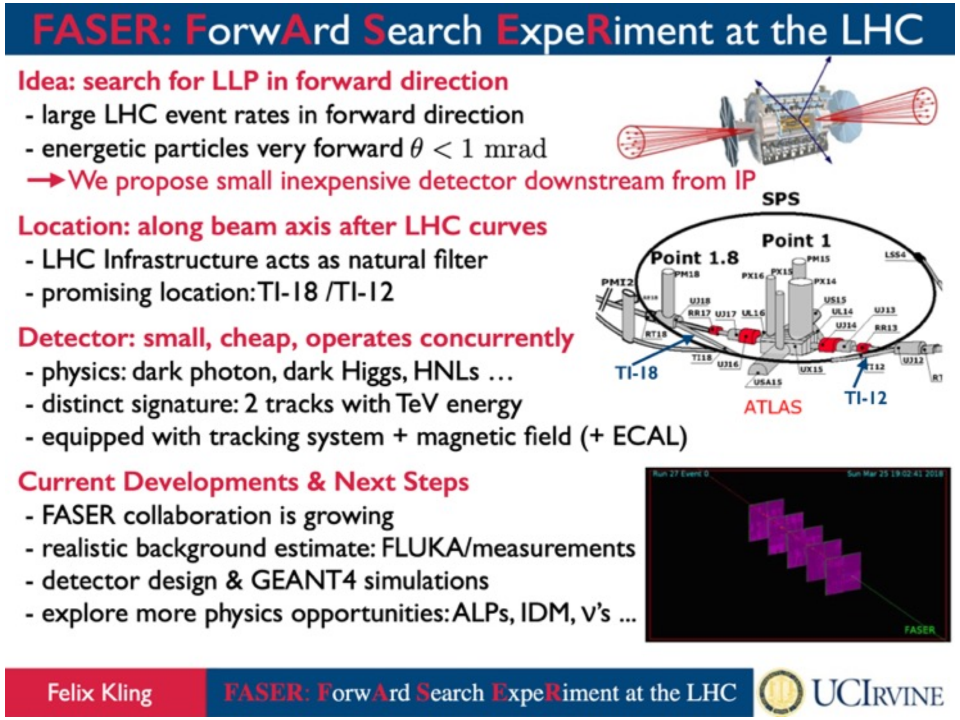
Aspen 2018 - The Particle Frontier



Sun 25/03	Mon 26/03	Tue 27/03	Wed 28/03	Thu 29/03	Fri 30/03	Sat 31/03	All days

Time	Session	Speaker	Location	Time slot
16:00	Coffee and Tea		Flug Forum, Aspen Center for Physics	16:00 - 16:30
	ATLAS results on searches for long-lived particles	Hidetoshi Otono	Flug Forum, Aspen Center for Physics	16:30 - 16:50
17:00	CMS results on searches for long-lived particles	Ted Ritchie Kolberg	Flug Forum, Aspen Center for Physics	16:55 - 17:15
	Searches for new particles at LHCb	J Michael Williams	Flug Forum, Aspen Center for Physics	17:20 - 17:40
18:00	Coffee Break		Flug Forum, Aspen Center for Physics	17:45 - 18:15
	Search for Light Dark Sector at BaBar	Chunhui Chen	Flug Forum, Aspen Center for Physics	18:15 - 18:35
	A COmpact DEtector for eXotics at LHCb	Simon Knapen	Flug Forum, Aspen Center for Physics	18:40 - 19:00
19:00	Far Detectors Panel	Andrew Haas et al.	Flug Forum, Aspen Center for Physics	19:05 - 19:30

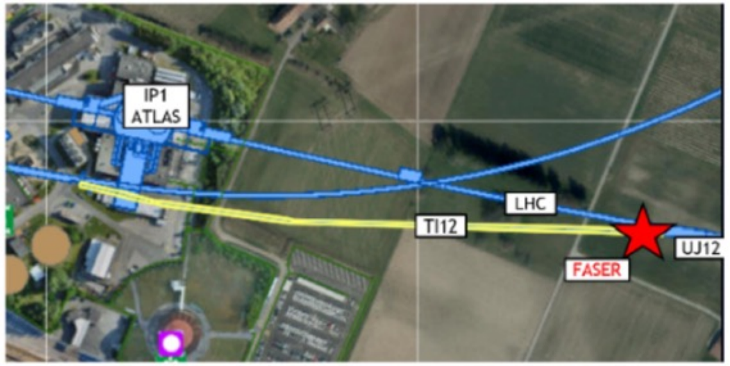
FASER was proposed Aug 2017 (1708.09389) by four theorists in US.



Just 1-page summary for the Far Detectors Panel

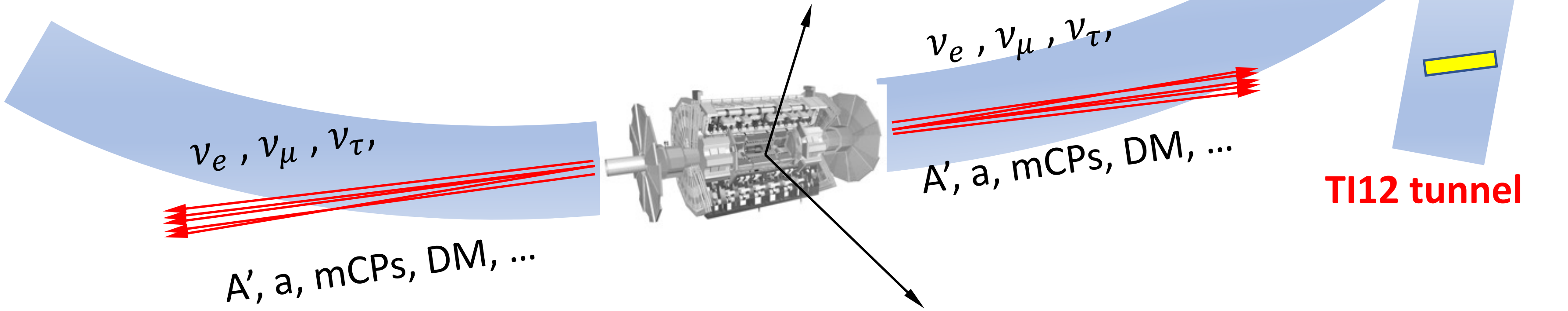
Since April 2018, I'm 9th FASER collaborator (5th experimentalist) with ideas to use **SCT spare module for tracker** and **emulsion detector for background survey**

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



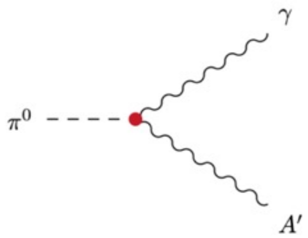
Favorable location, except that refurbishment is needed to be an experimental site.

- 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)

Searching for new particles in MeV-GeV range

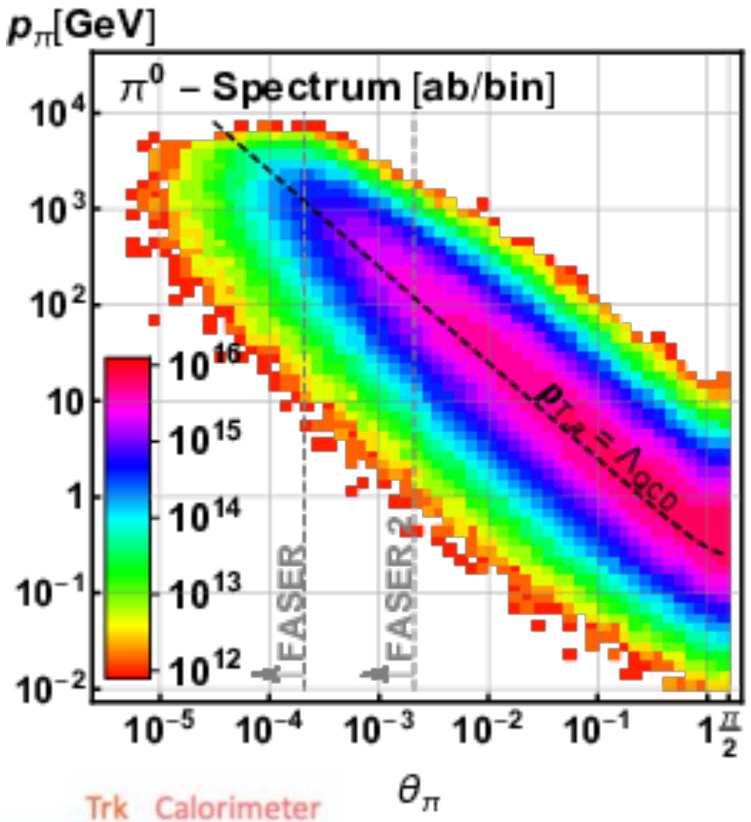
Motivated by dark matter

- 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



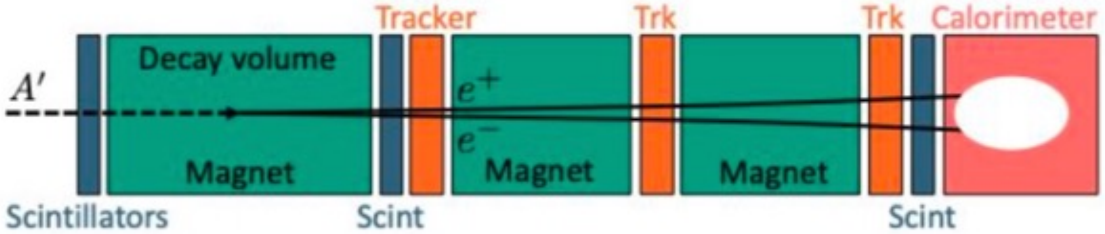
Huge flux of π^0 produced in LHC collision provides strong opptunity

- $O(10^{15})$ 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



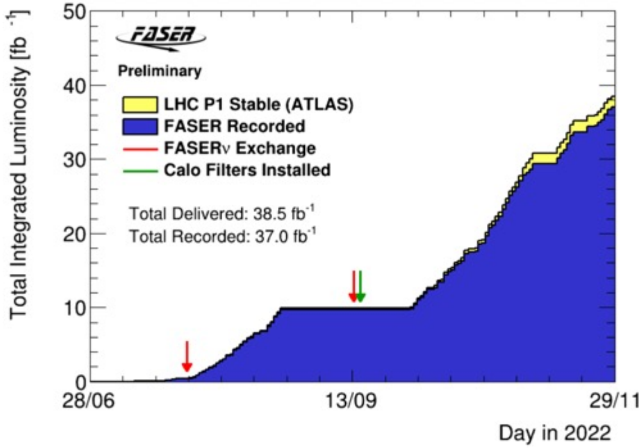
Searching for new particles in MeV-GeV range

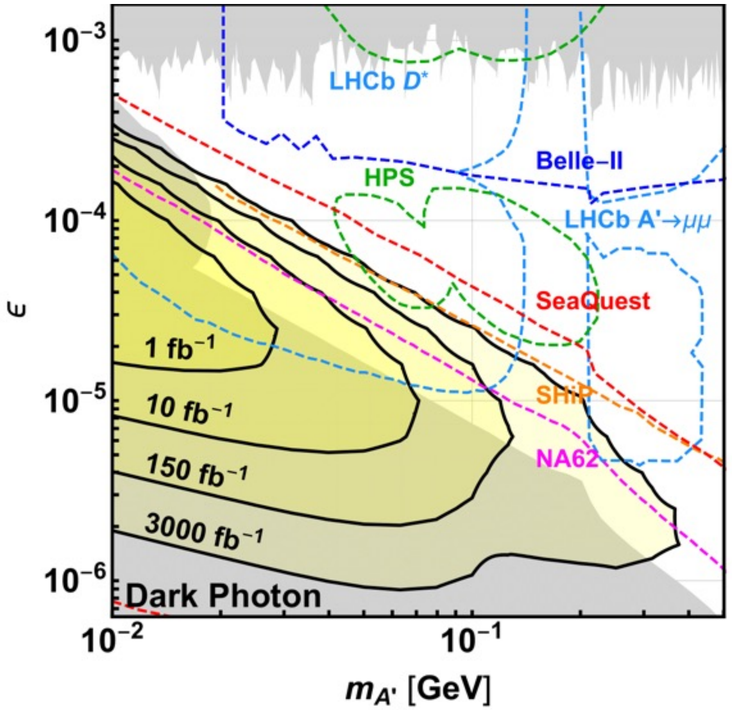
FASER is the first far collider experiment for new particle searches

- 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, the first result presented today
  - 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, …

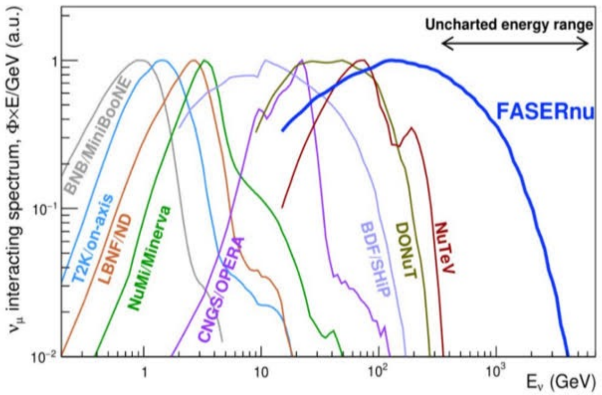
- Comprehensive summary found in Phys. Rev. D 99, 095011 (2019)

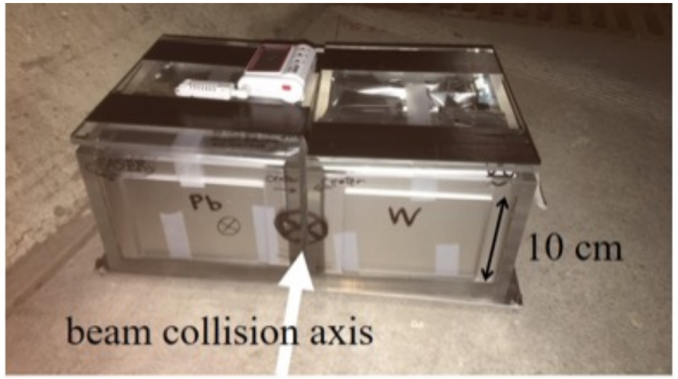
Exploring neutrinos at the TeV-energy frontier

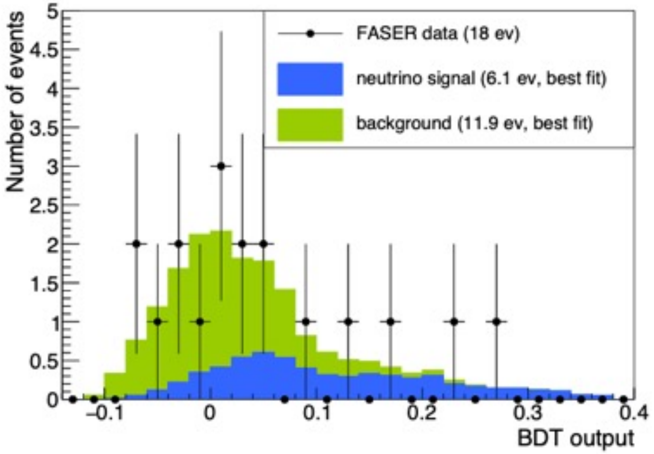
The LHC collisions also produce a copious number of neutrinos at uncharted energies

- FASER is the first experiment to probe collider neutrinos

Phys. Rev. D 104, L091101







In 2018, a 29 kg emulsion detector had been installed

- the fiducial mass used for the pilot analysis was only 12 kg
- exposed to 12.2 fb^{-1} data
- best fit value of 6.1 neutrino interactions (3.3 expected) - 2.7σ

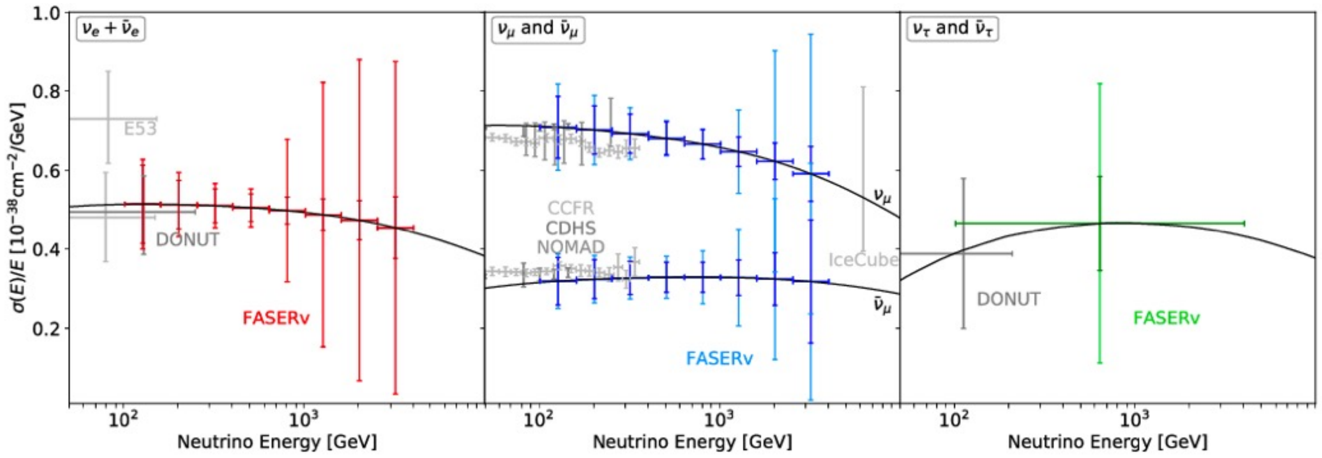
In Run3, the first observation is achieved by electric detectors, i.e, silicon tracker, scintillator and calorimeter

- the first result presented today

Exploring neutrinos at the TeV-energy frontier

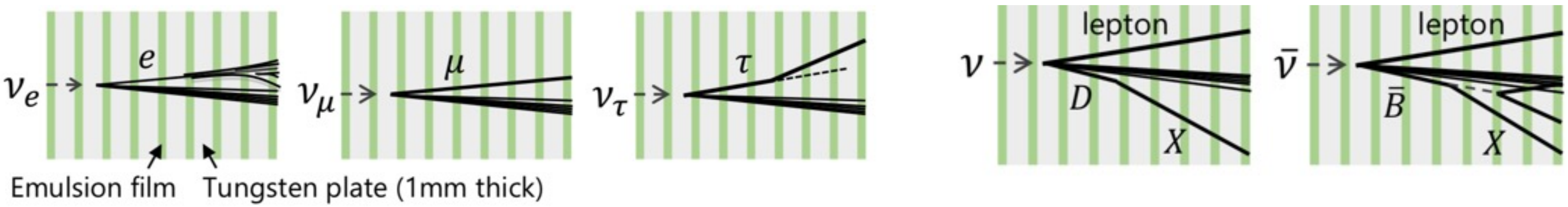
Sensitive to new physics by measuring scattering cross sections and studying the final states

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

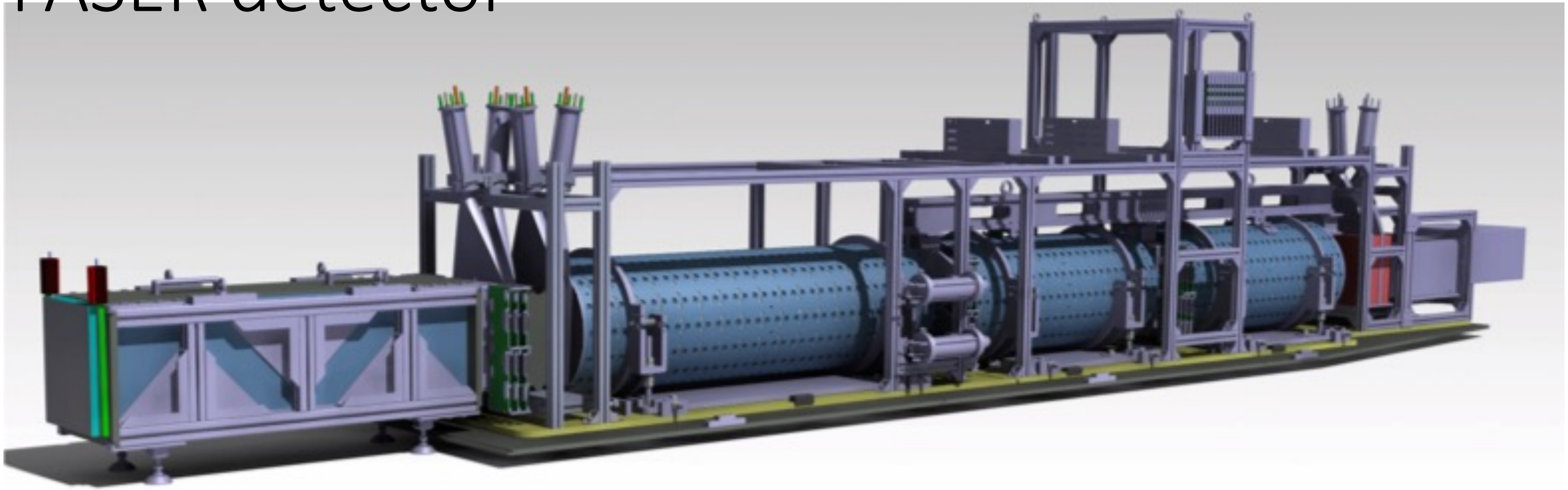


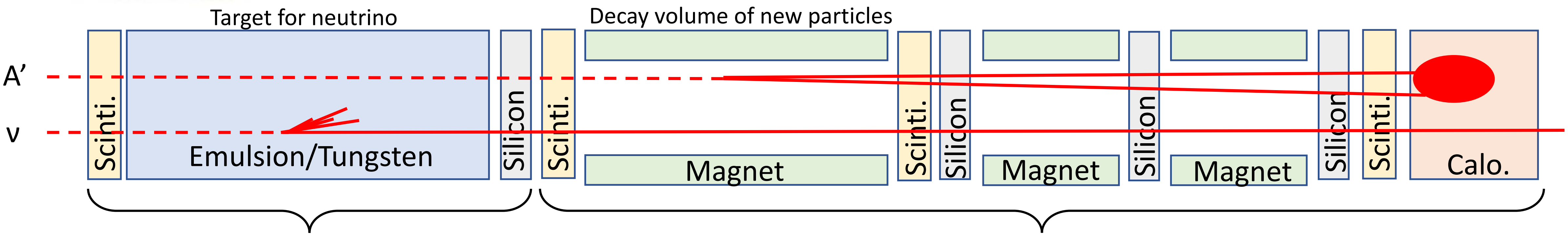
based on PhysRevD.104.113008

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



FASER detector

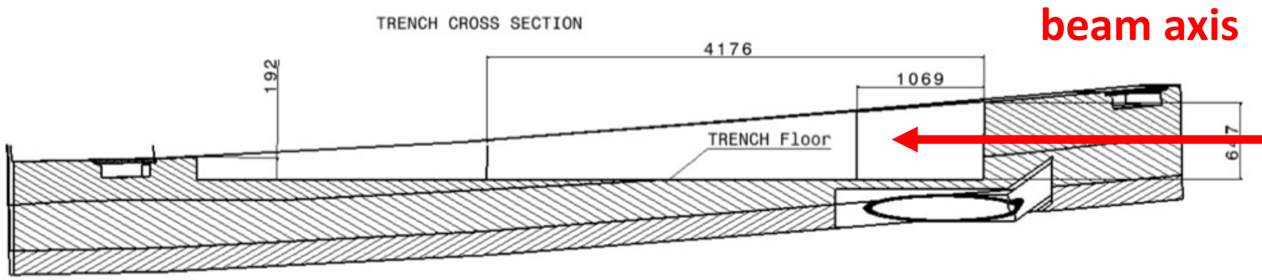




For neutrino physics:
Installation completed 2022 March

For new particle search:
Installation completed 2021 March

Civil engineering work



Aug 2018

Nov 2020

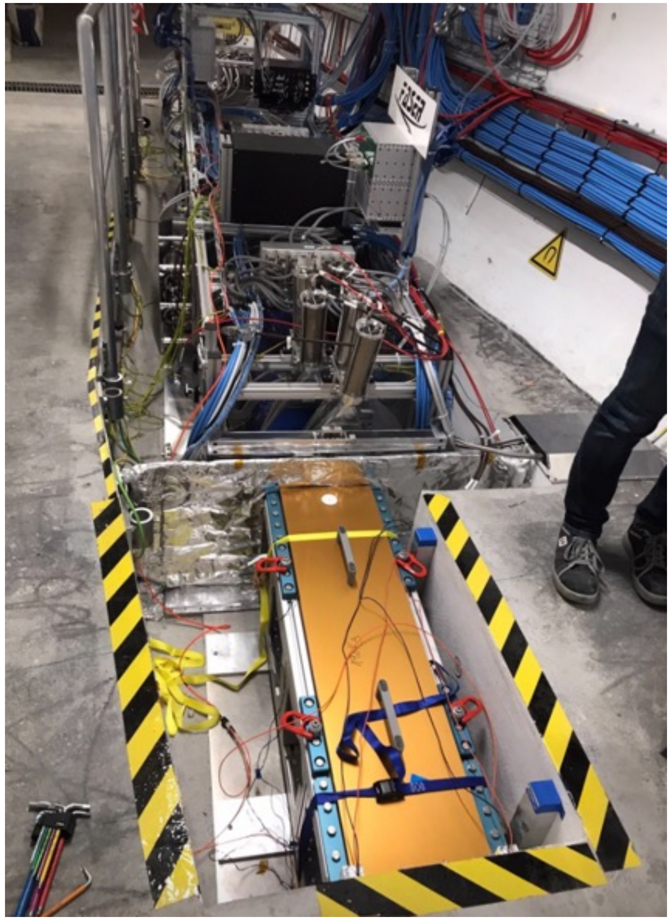
The floor in TI12 excavated by ~50 cm to have the FASER detector on beam axis

FASER detector installation

FASER spectrometer (magnets and tracker), scintillators and calorimter

April 2021

Emusion/Tungsten detector, IFT and scintillator

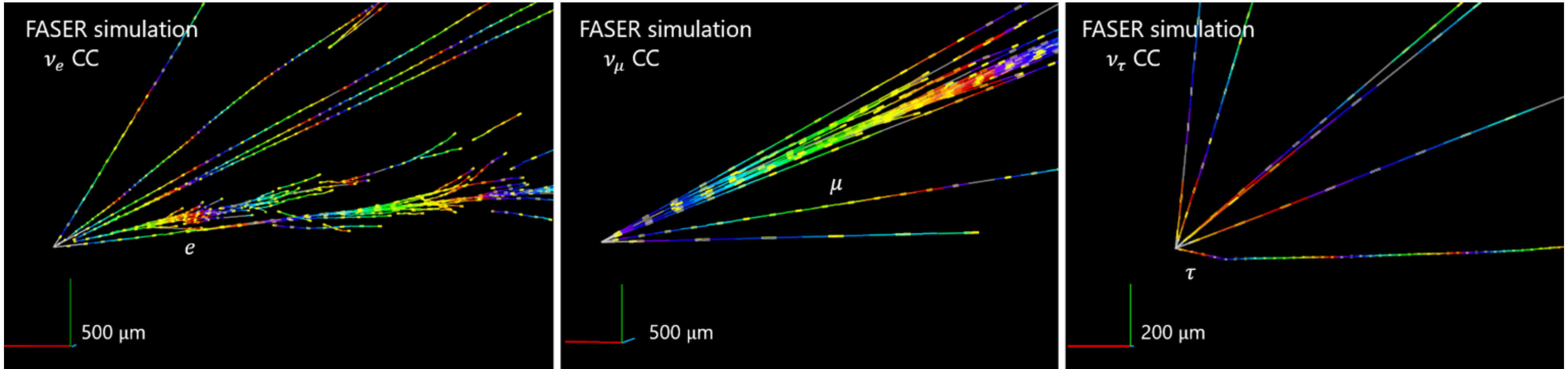


March 2022

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

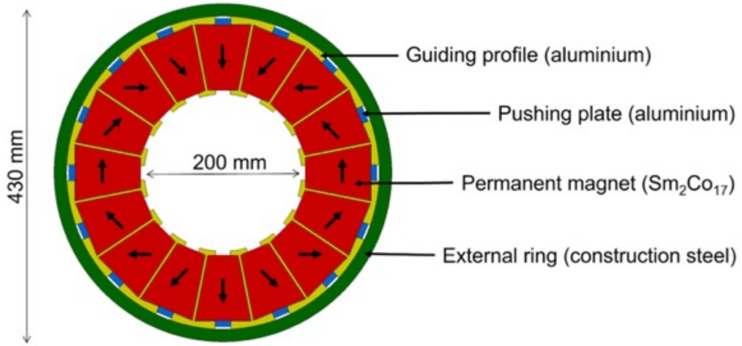


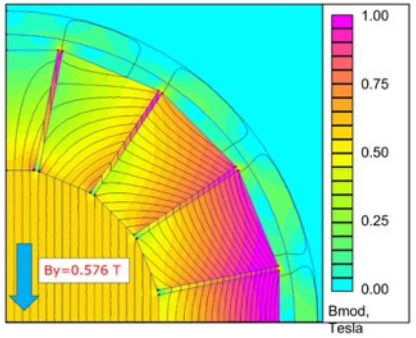
Magnet system

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

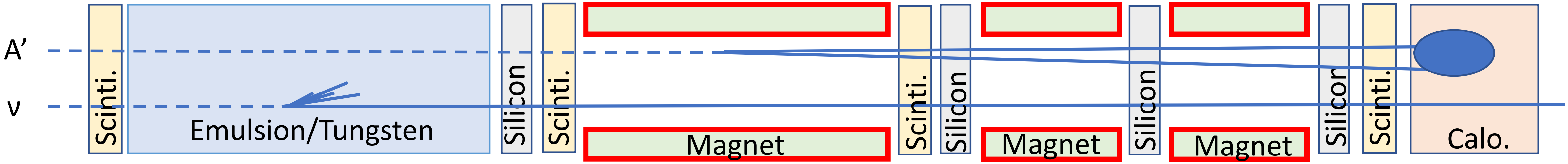
Three 0.57 T permanent dipole magnets (1.5m-long x 1 and 1m-long x 2)

- 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



Target for neutrino

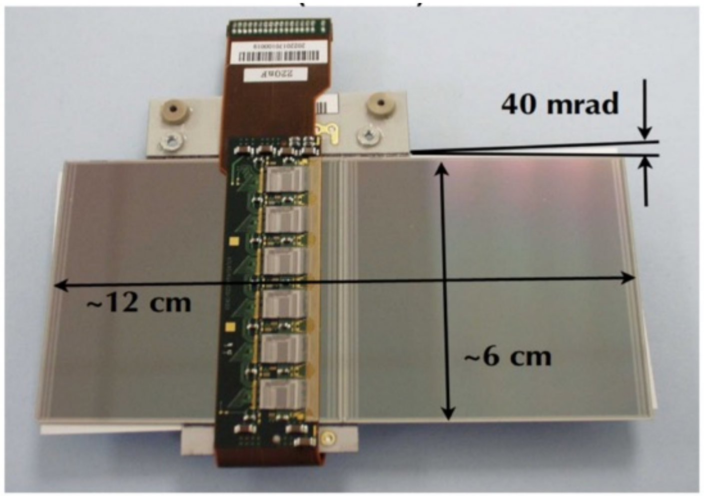
Decay volume of new particles

Tracker station

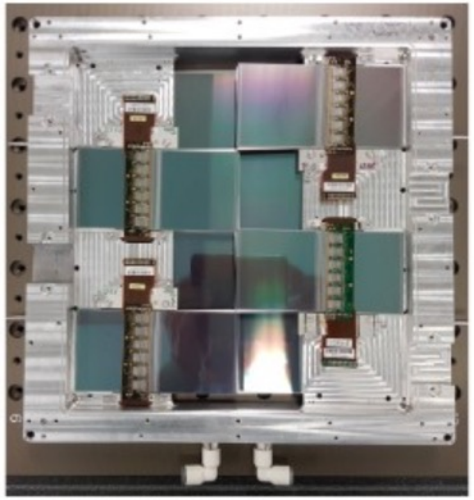
ATLAS SCT module:
- 6cm x 12cm x 2 sides (40 mrad)
- 80 um pitch/ 768 strips per side
- Resolution: 17 um x 580 um
- 6 ASICs per side

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

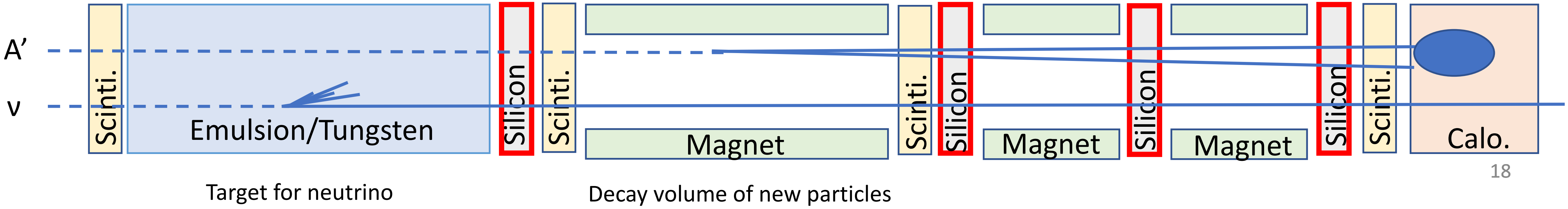
- Based on ATLAS SCT modules - 4 station x 3 layers x 8 modules = 96 modules



Tracker plane →



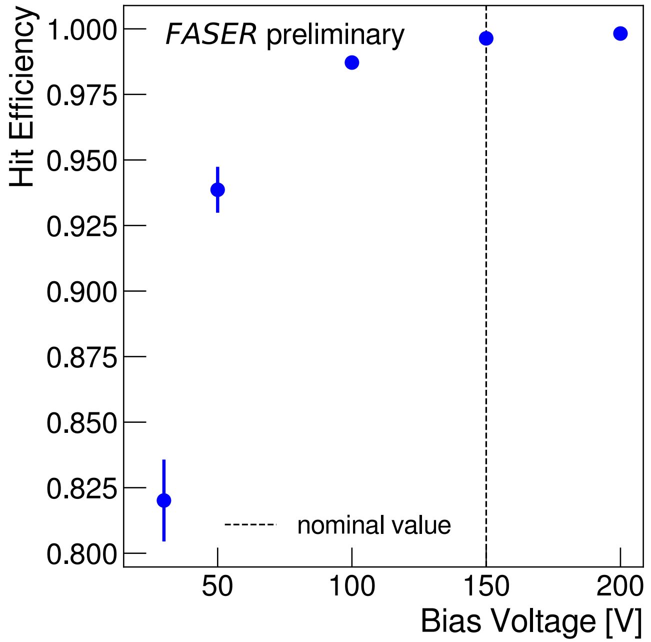
Tracker station →

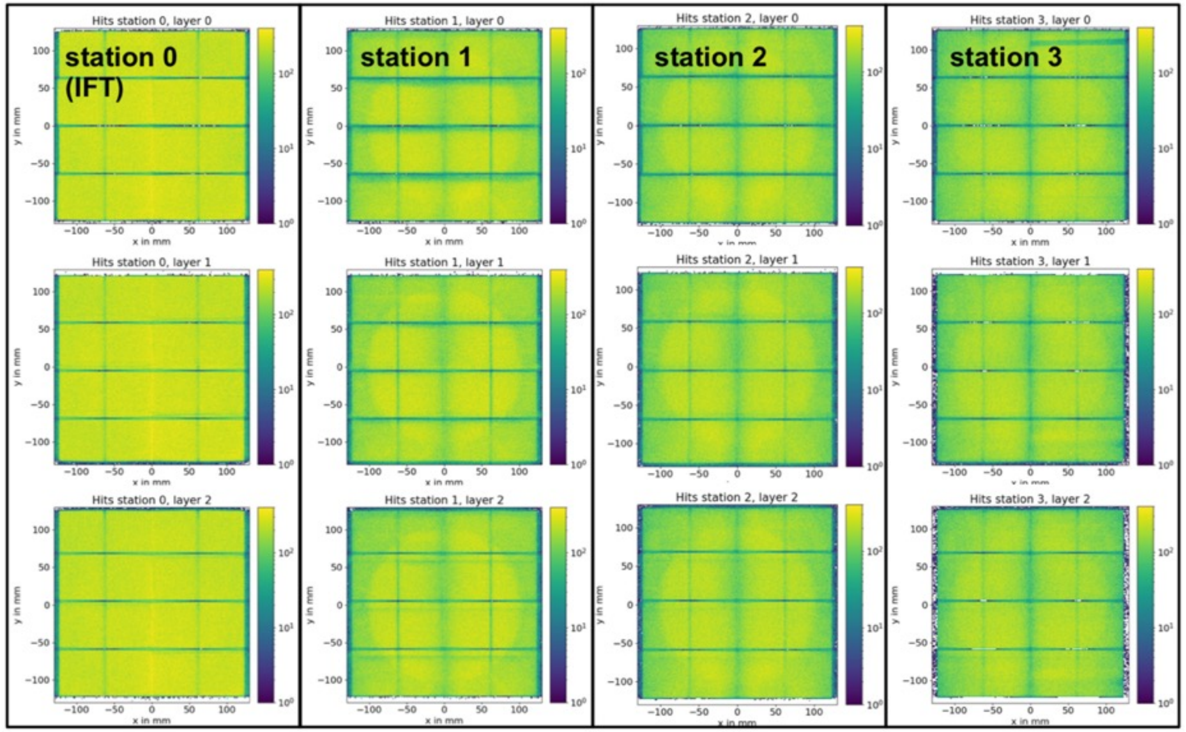


Tracker station performance

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

- 99.7% strips are active
- Uniform distiribution inside magnet aperture except for gaps between SCT modules

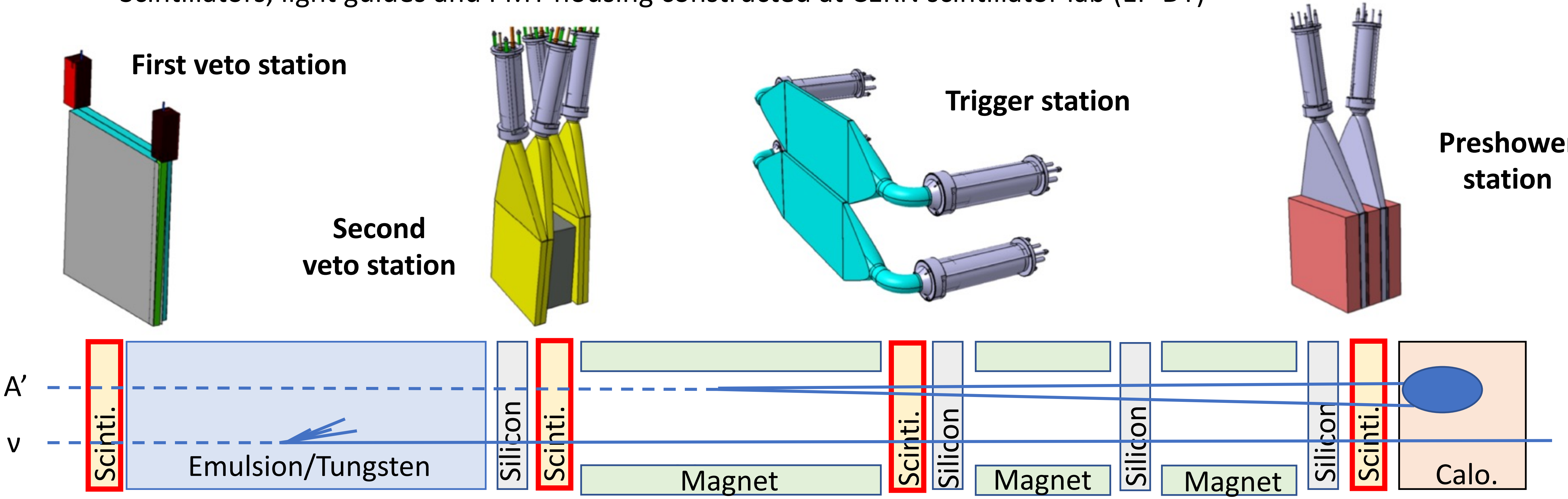




Scintillation detectors

Four scintillator stations are commissioned 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)

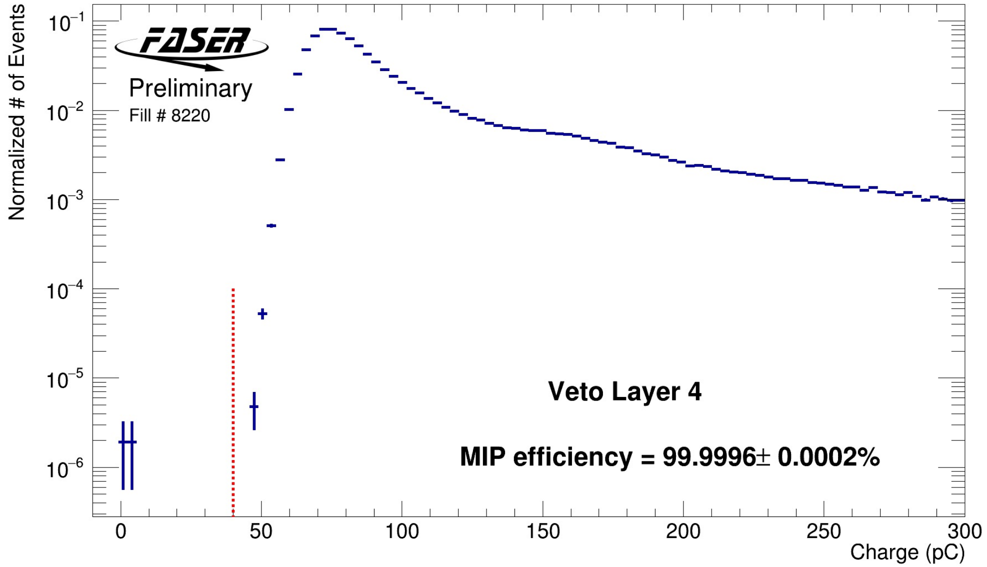


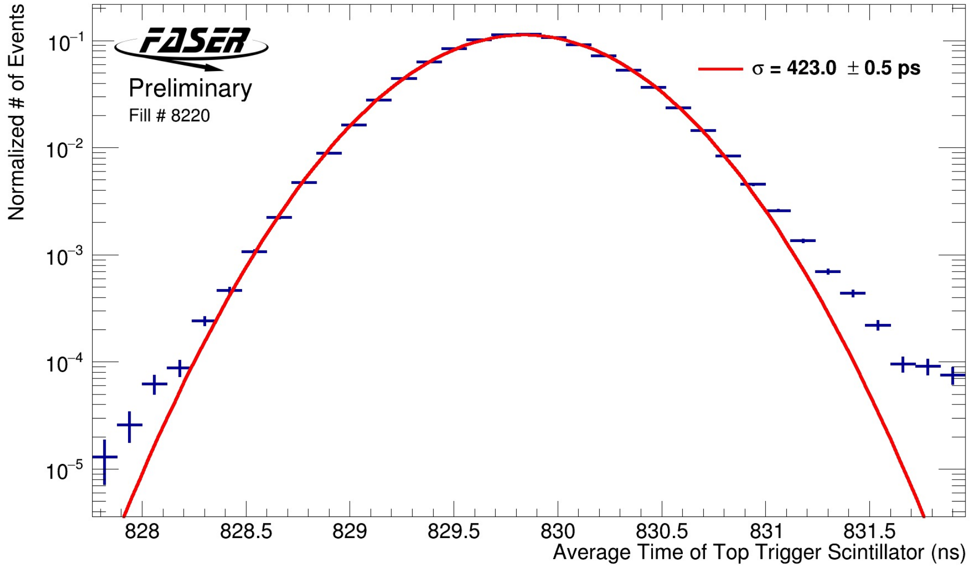
Scintillator performance

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

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





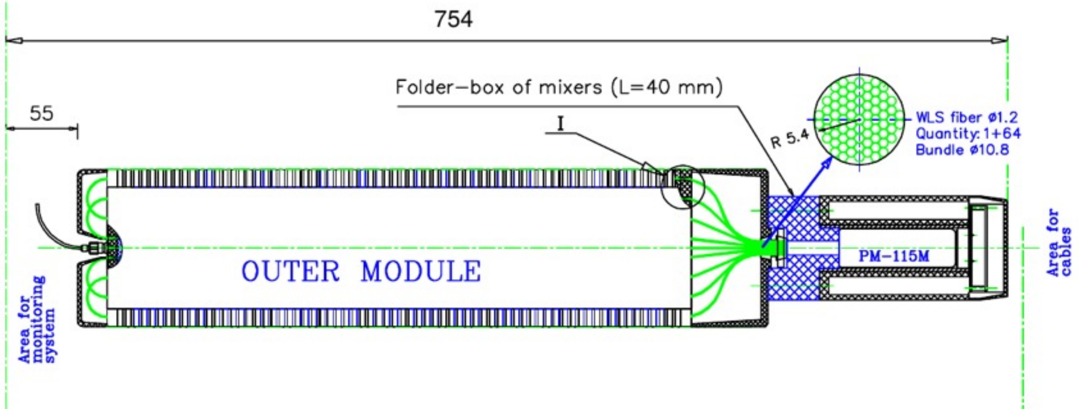
Trigger scintillator provides timing resolution of 423 ps, sufficinet to identify bunch crossing ID of LHC

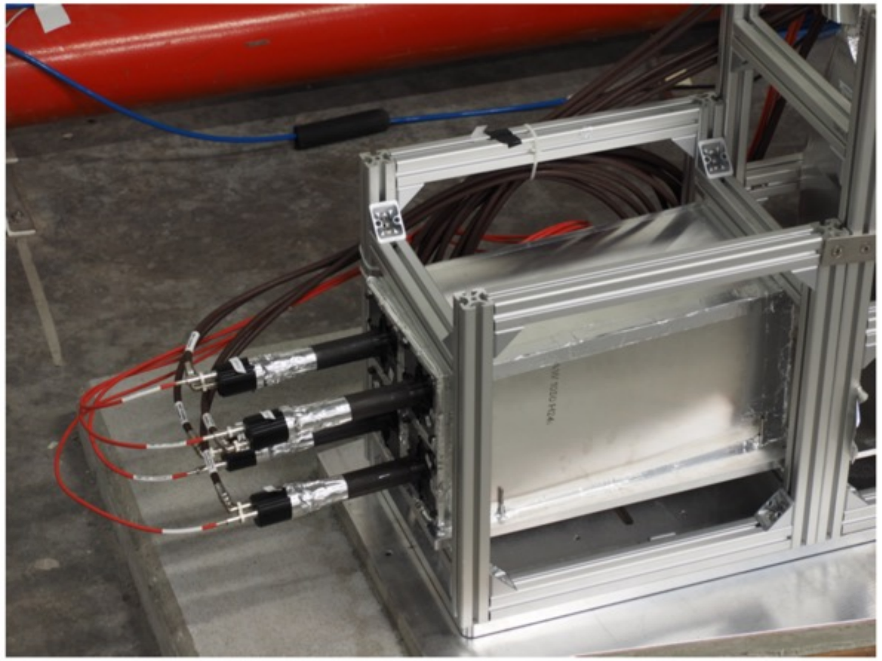
- Average time of two PMTs on both ends of the trigger scintillator to correct for timewalk

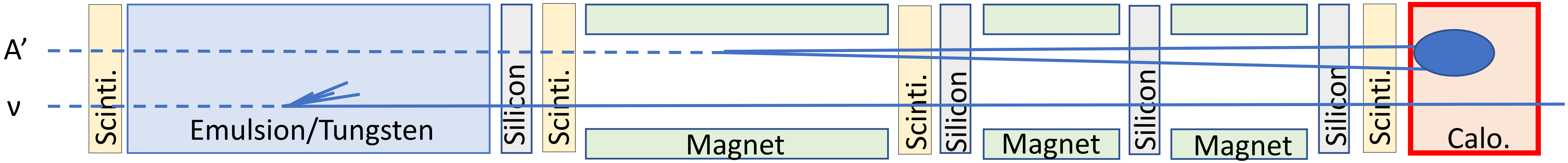
Electromagnetic calorimeter

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)



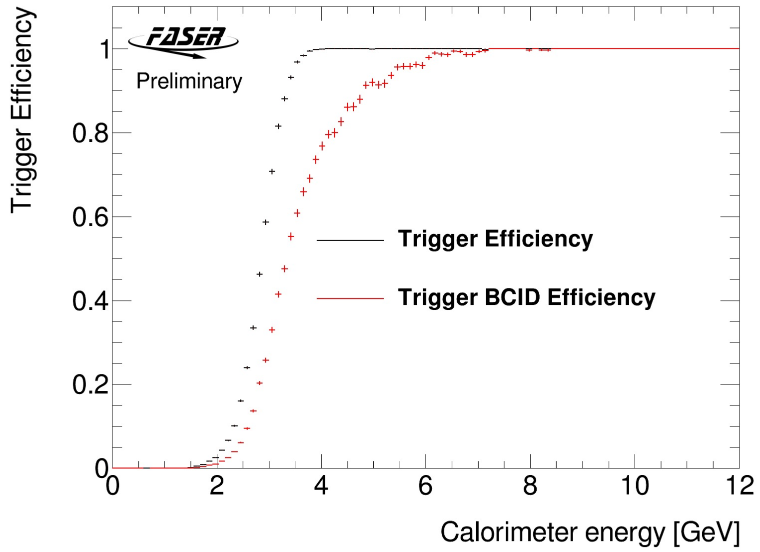




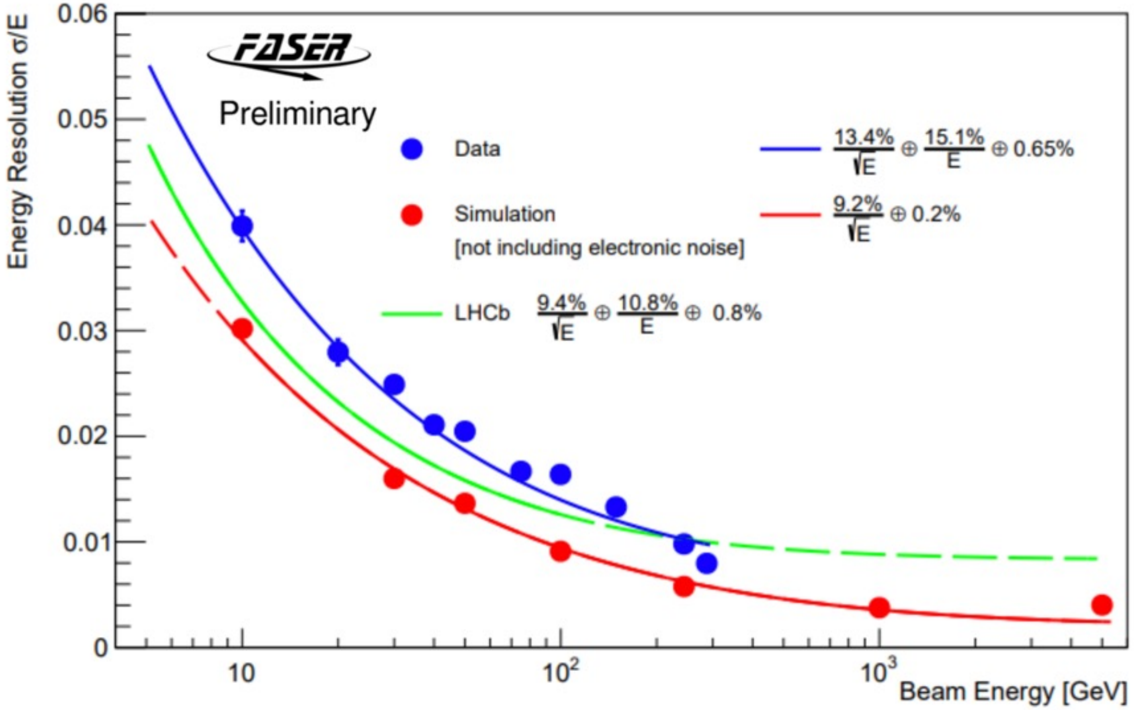
EM Calorimeter – performance

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

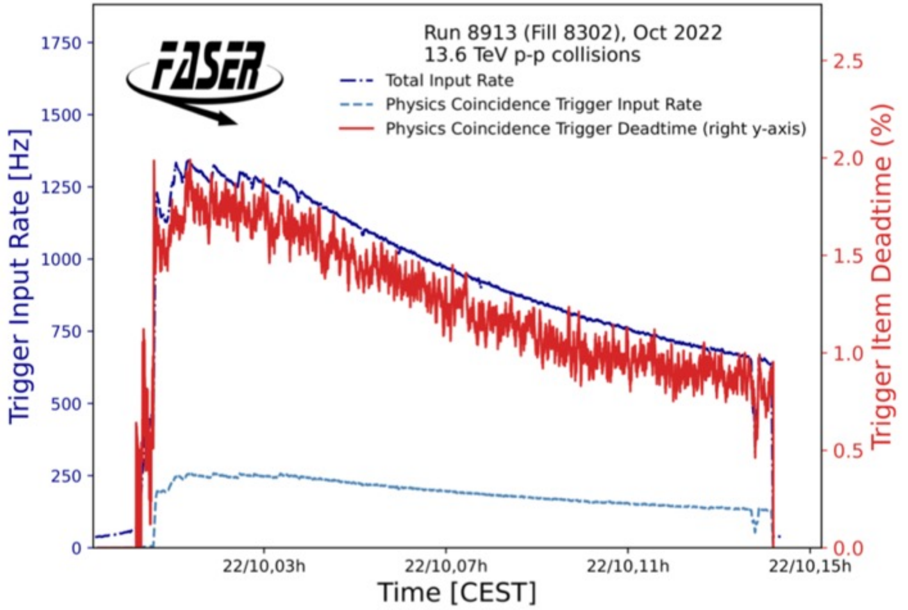


Close to the intrinsic 239 ps timing resolution of the LHC

Stable data taking thoughout 2022

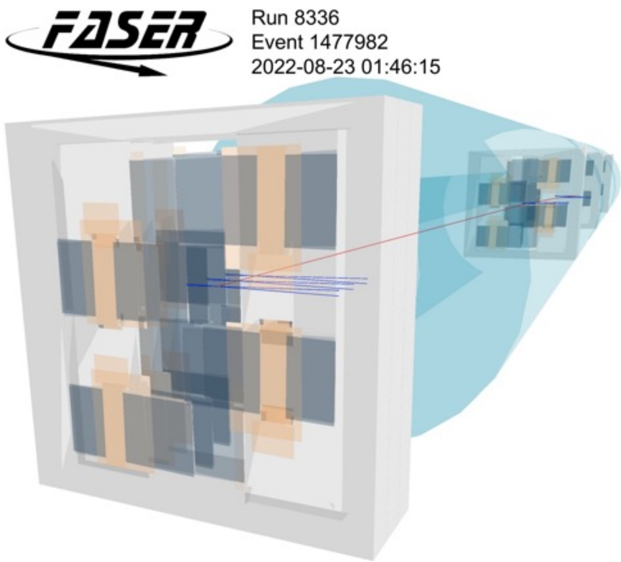
The number of bunches in LHC has reached 2400 since August 2022

- 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



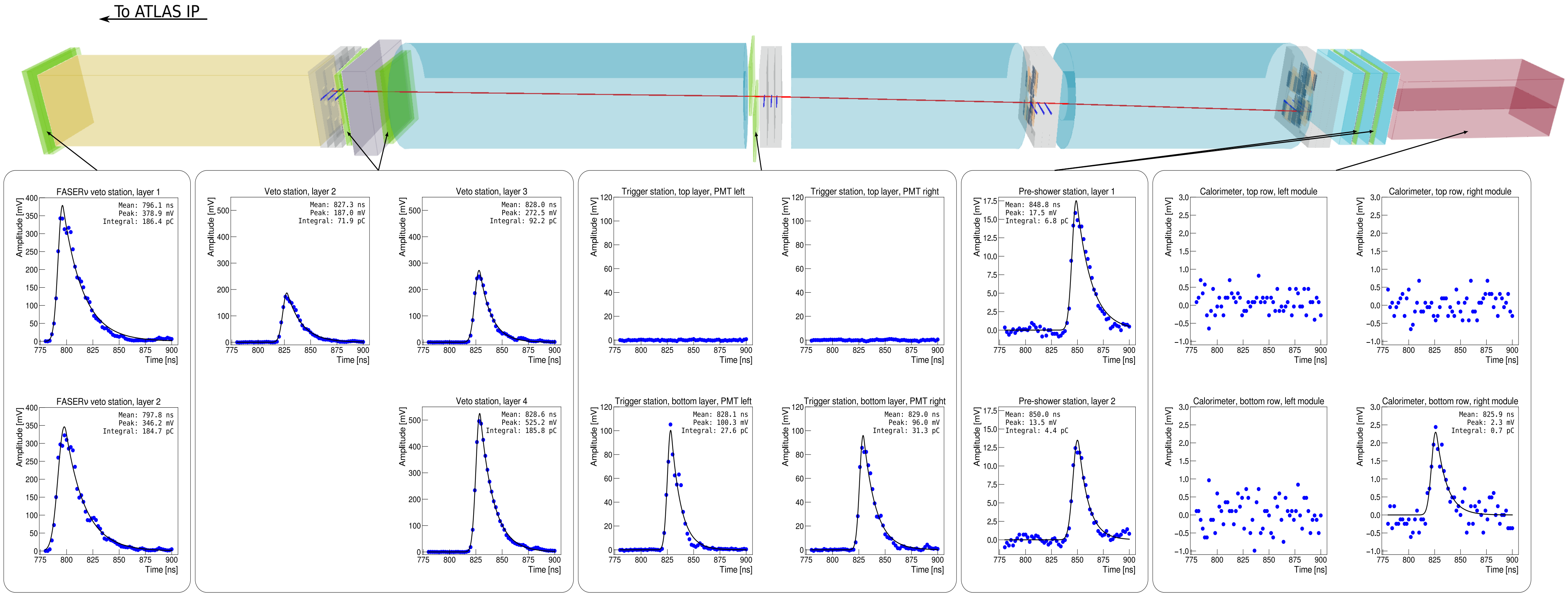
- only 850 pb^{-1} (< 2.5% of full dataset) data lost due to operational issues

Muon event from LHC collission

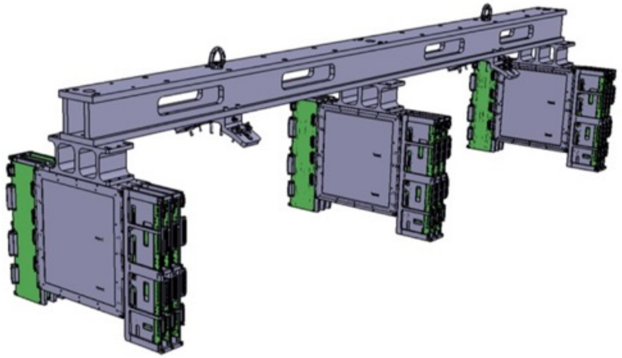


Run 8336
Event 1477982
2022-08-23 01:46:15

Reconstructed momentum 21.9 GeV

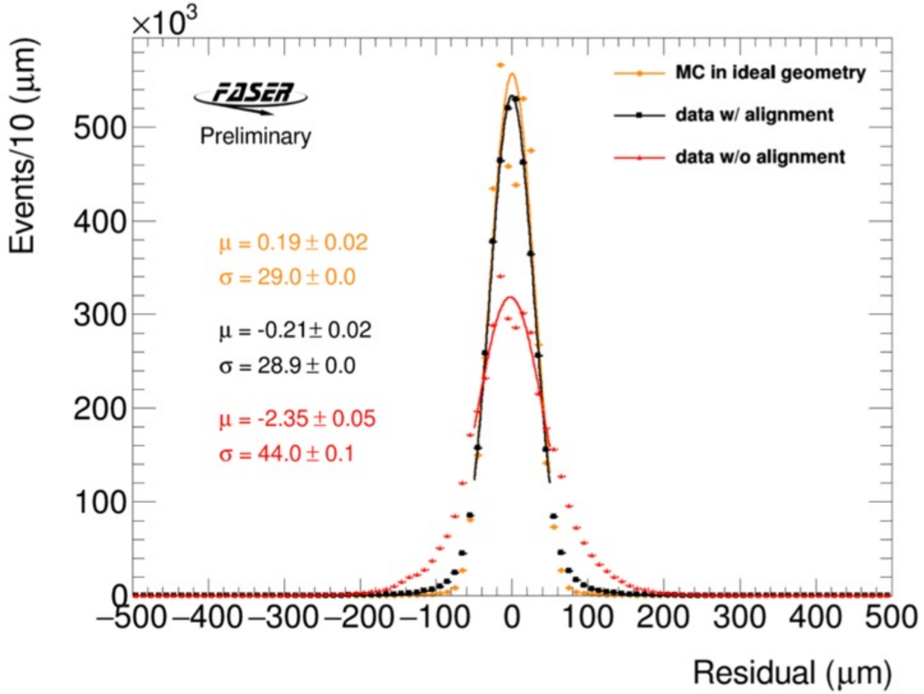


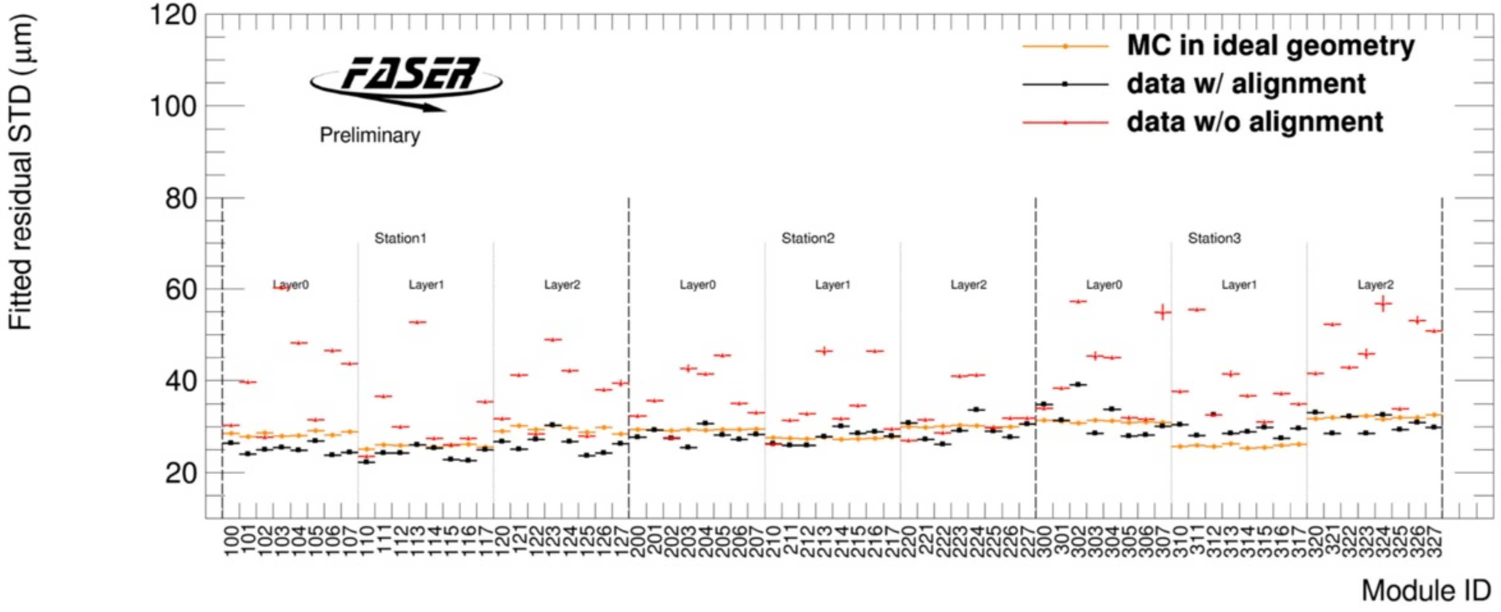
Tracker alignment in progress



Track based alignment clearly improves residual and track chi2 for the three tracker station

- These three tracker stations are connected to the backbone, mechanically decoupled from fourth tracker station (IFT)
- Without alignment (44.0 um) -> With alignment **(28.9 um)** : comparable to MC in ideal geometry (29 um)





Alignment with IFT in progress

Dark photon search

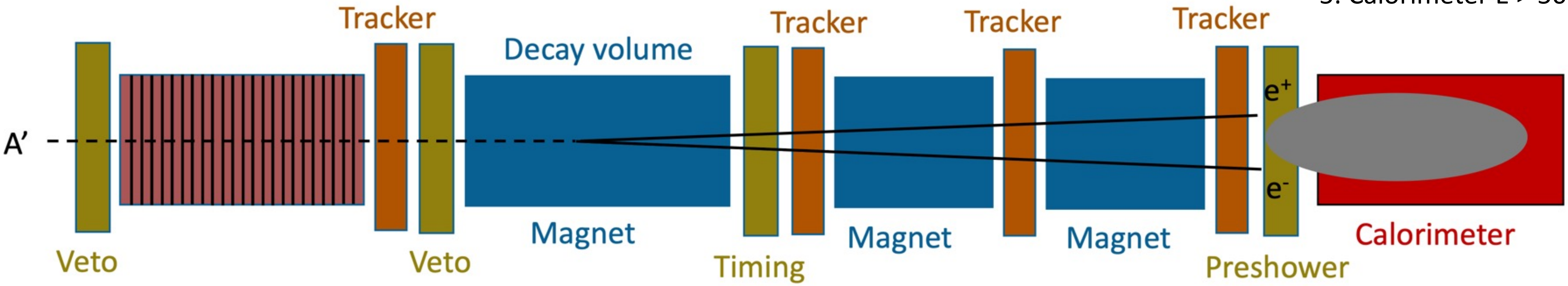
Analysis was **blinded for E>100 GeV** events **without any veto signals**

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

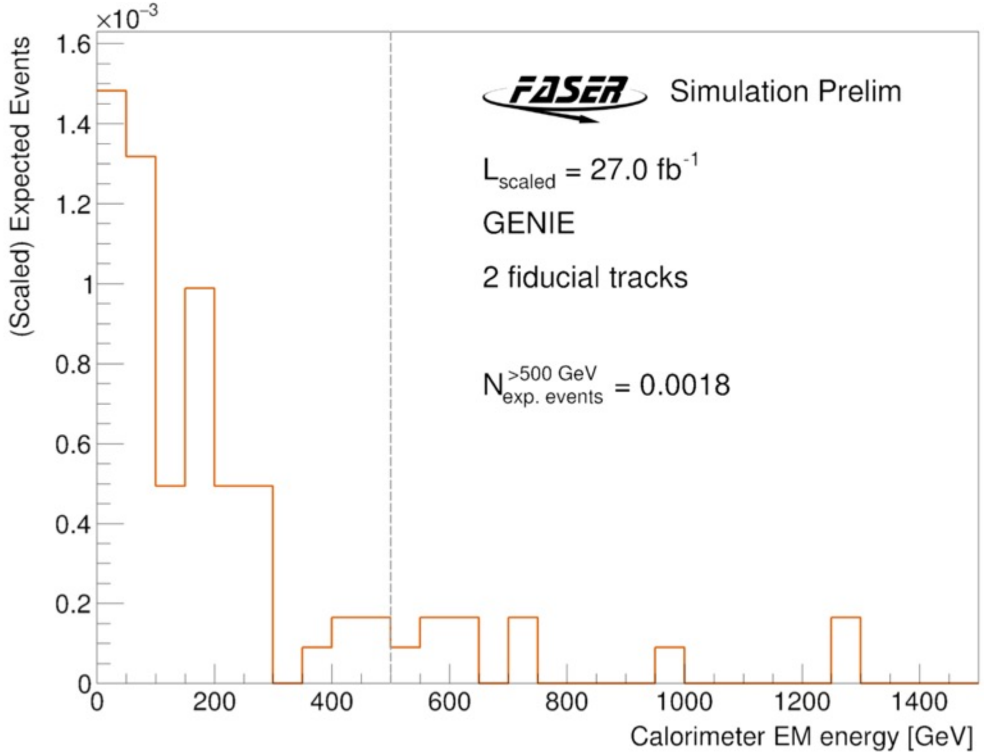
5. Calorimeter E > 500 GeV



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

Minor backgrounds

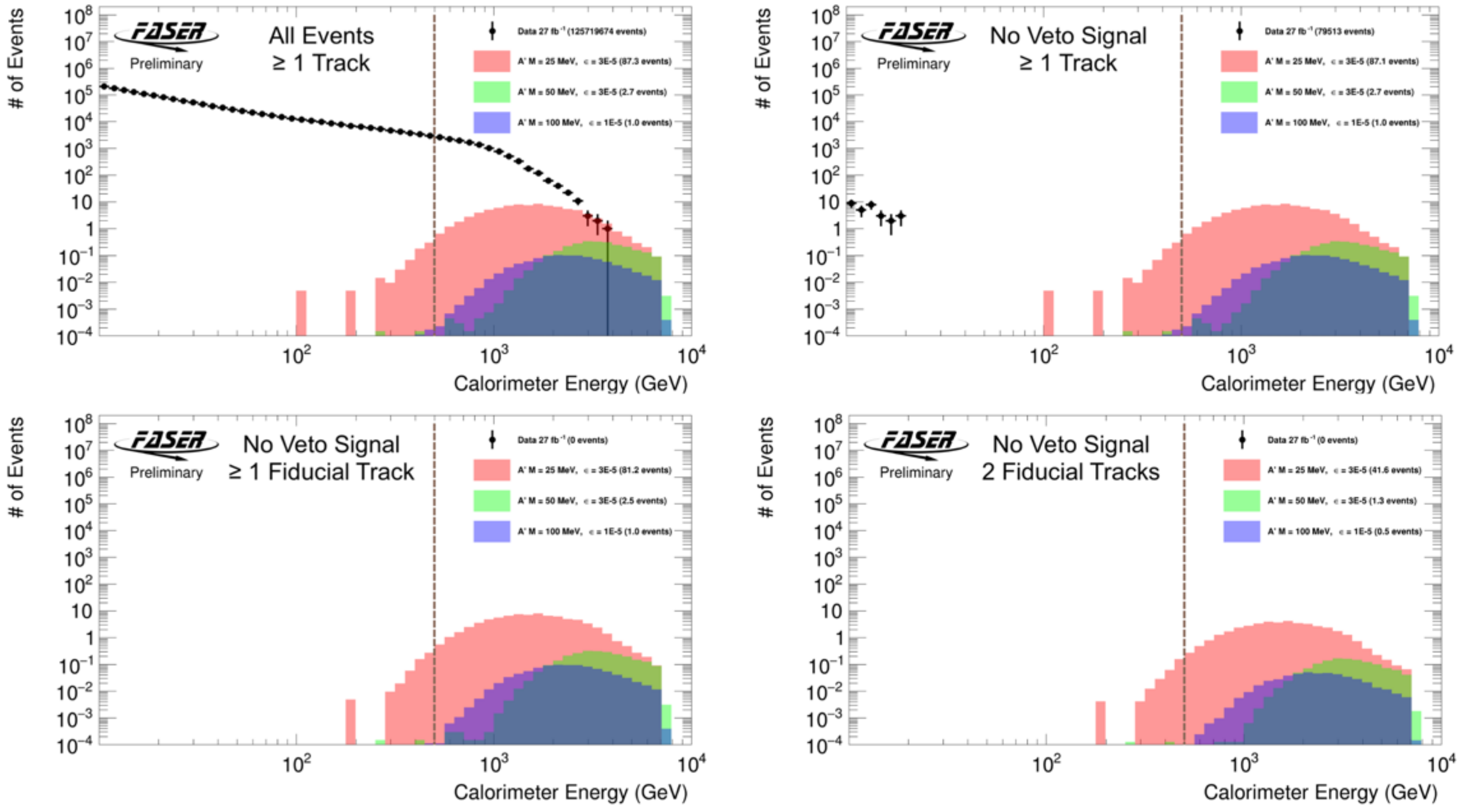
- Neutral hadrons (e.g. Ks) from upstream muons interacting in decay volume : **(2.2±3.1)×10^{-4} events**
- Veto inefficiency: negligible
- Non-collision background: negligible

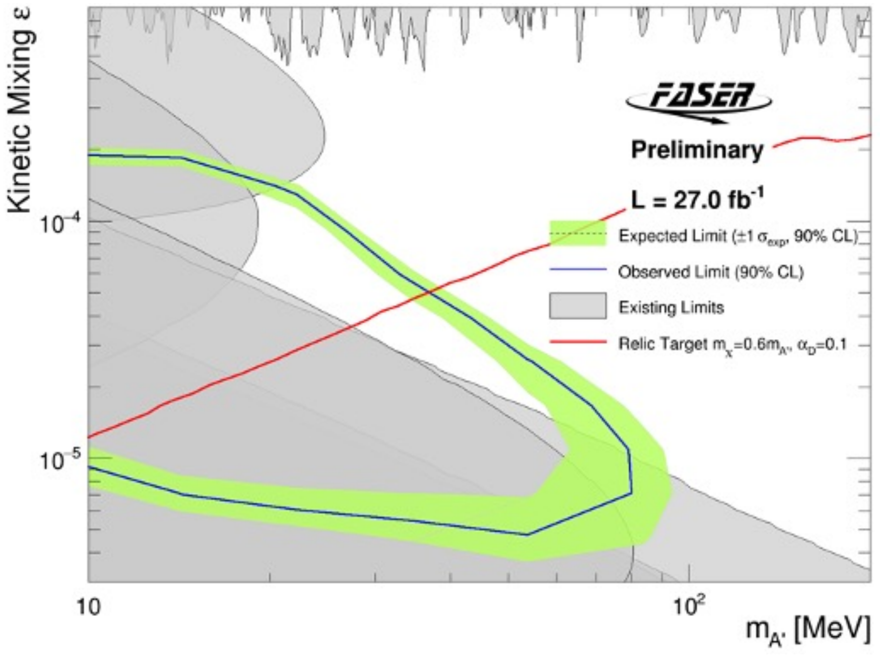
Result

No events seen in unblinded signal region

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

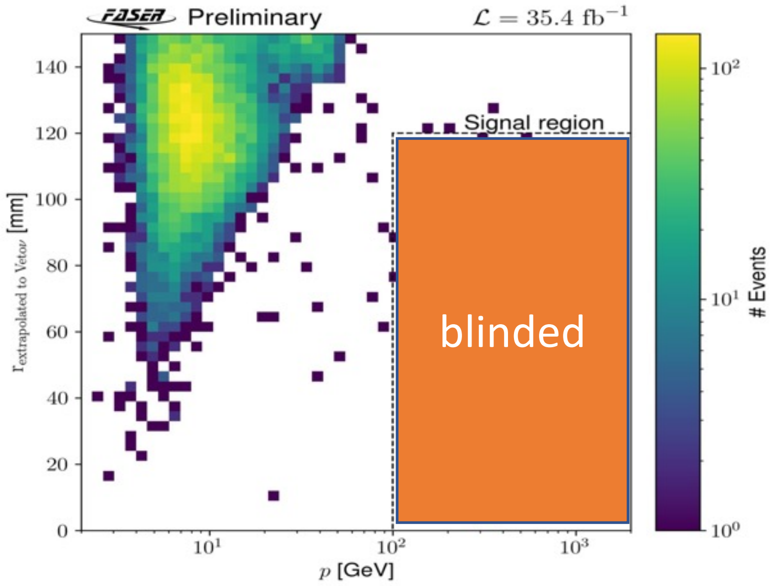
Source	Systematic Uncertainty	Typical Effect on Signal Yield
Theory, Statistics and Luminosity		
A' cross section	$\frac{0.15 + (E_{A'}/4\ \text{TeV})^3}{1 + (E_{A'}/4\ \text{TeV})^3}$	15-45%
Luminosity	2.2%	2.2%
MC statistics	$\sqrt{\sum W^2}$	1-2%
Tracking		
Momentum scale	5%	< 0.5%
Momentum resolution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





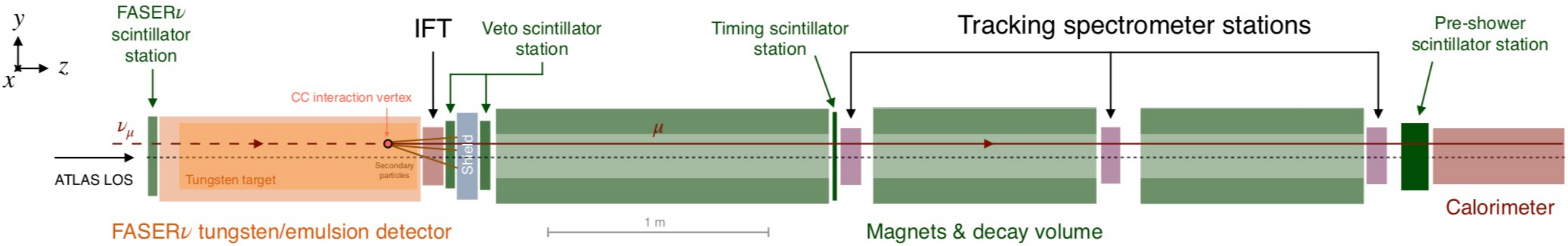
LHC neutrino search

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



1. Good collision events

4. Timing and preshower consistent with ≥1 MIP

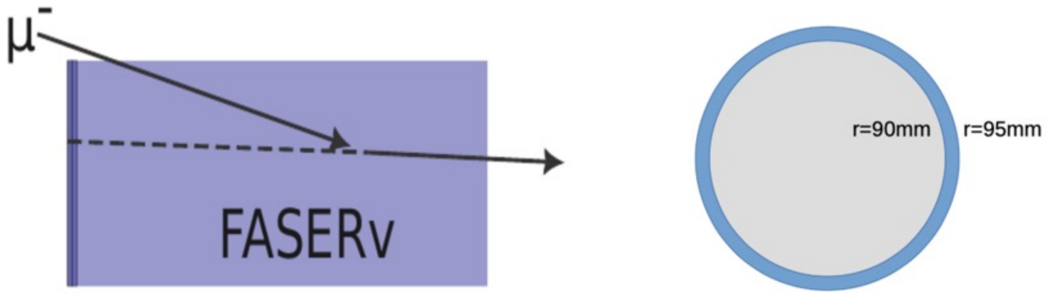


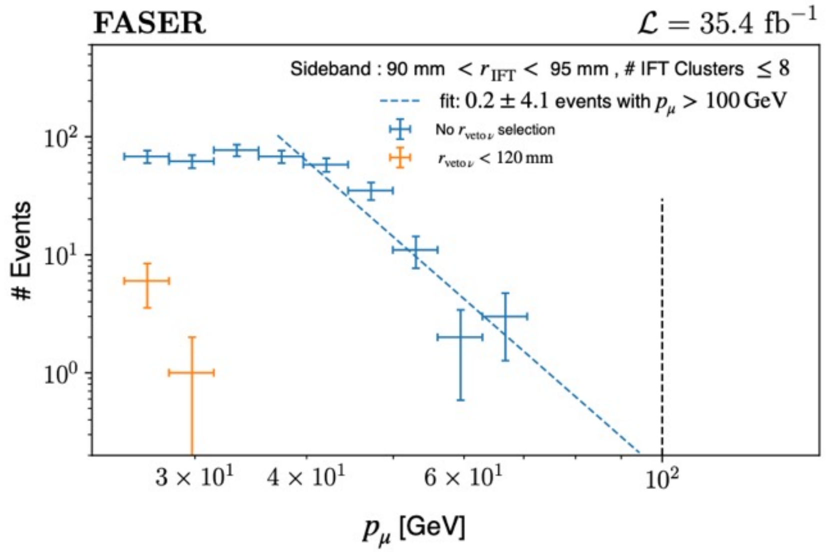
2. No signal (<40 pC) in 2 front vetos
3. Signal (>40 pC) in other 3 vetos

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

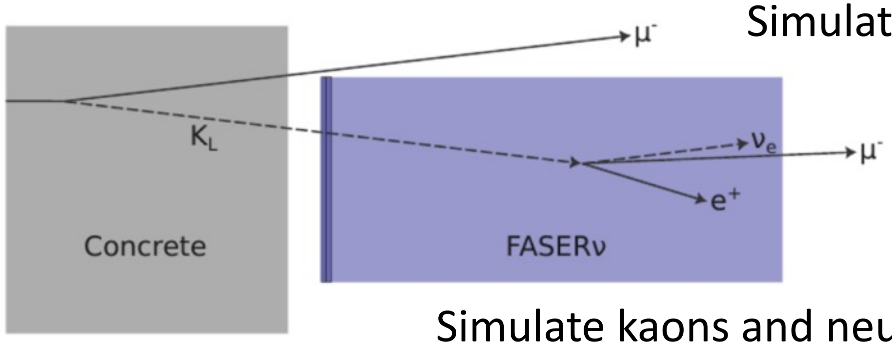
Geometric background: 0.08 ± 1.83 events expected





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

Neutral hadron background: 0.11 ± 0.06 events expected

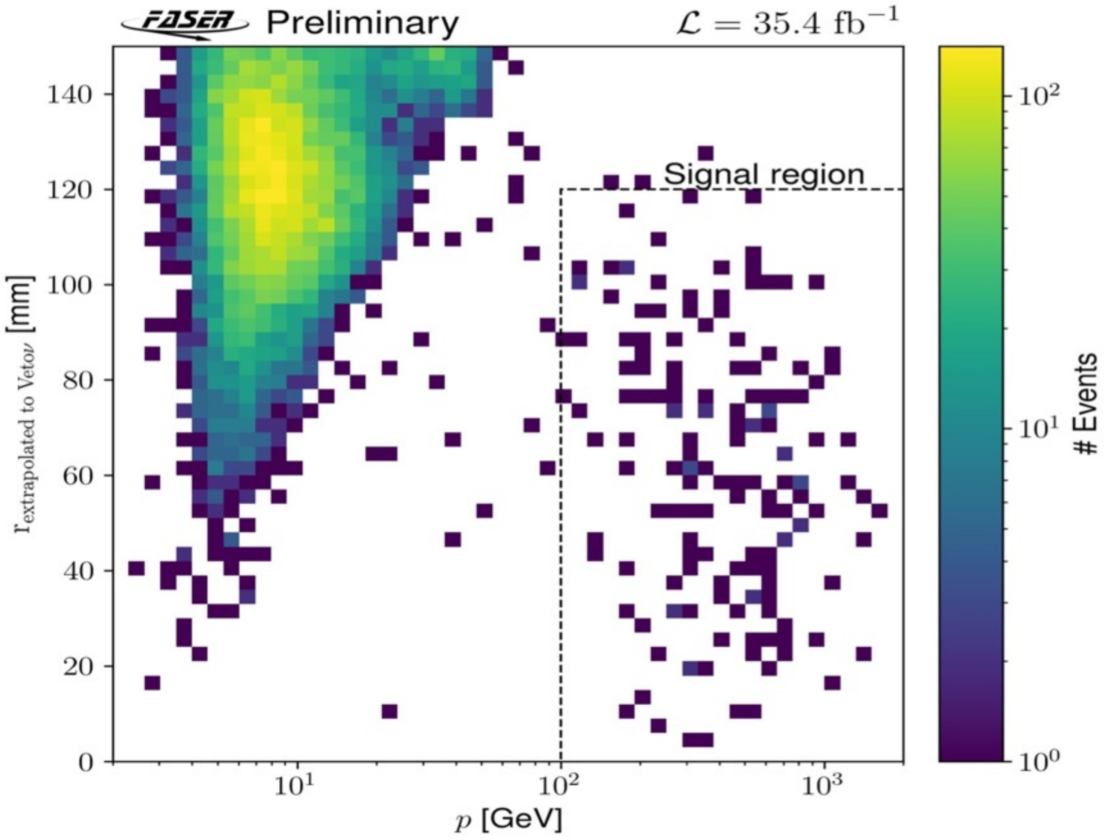


Simulated 10^9 μ+ and μ- events

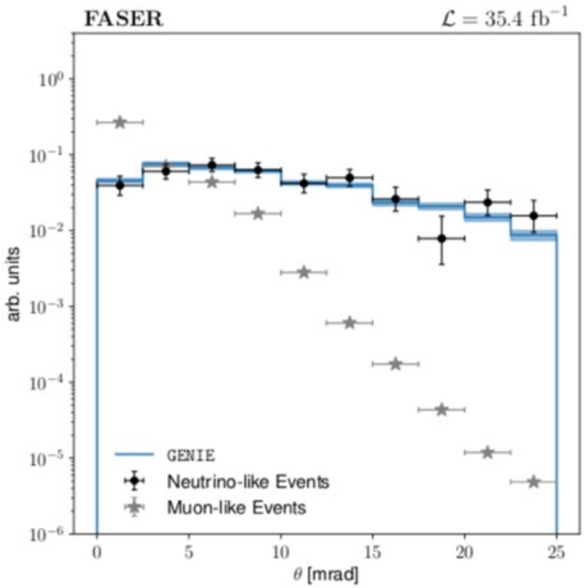
Simulate kaons and neutrons with p > 100 GeV following expected spectra

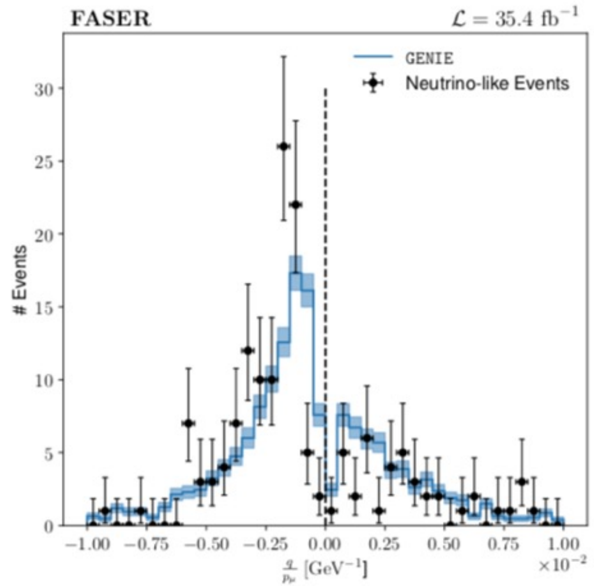
Results – the first observation of LHC neutrino

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



Luminosity-normalized prediction agrees well with data



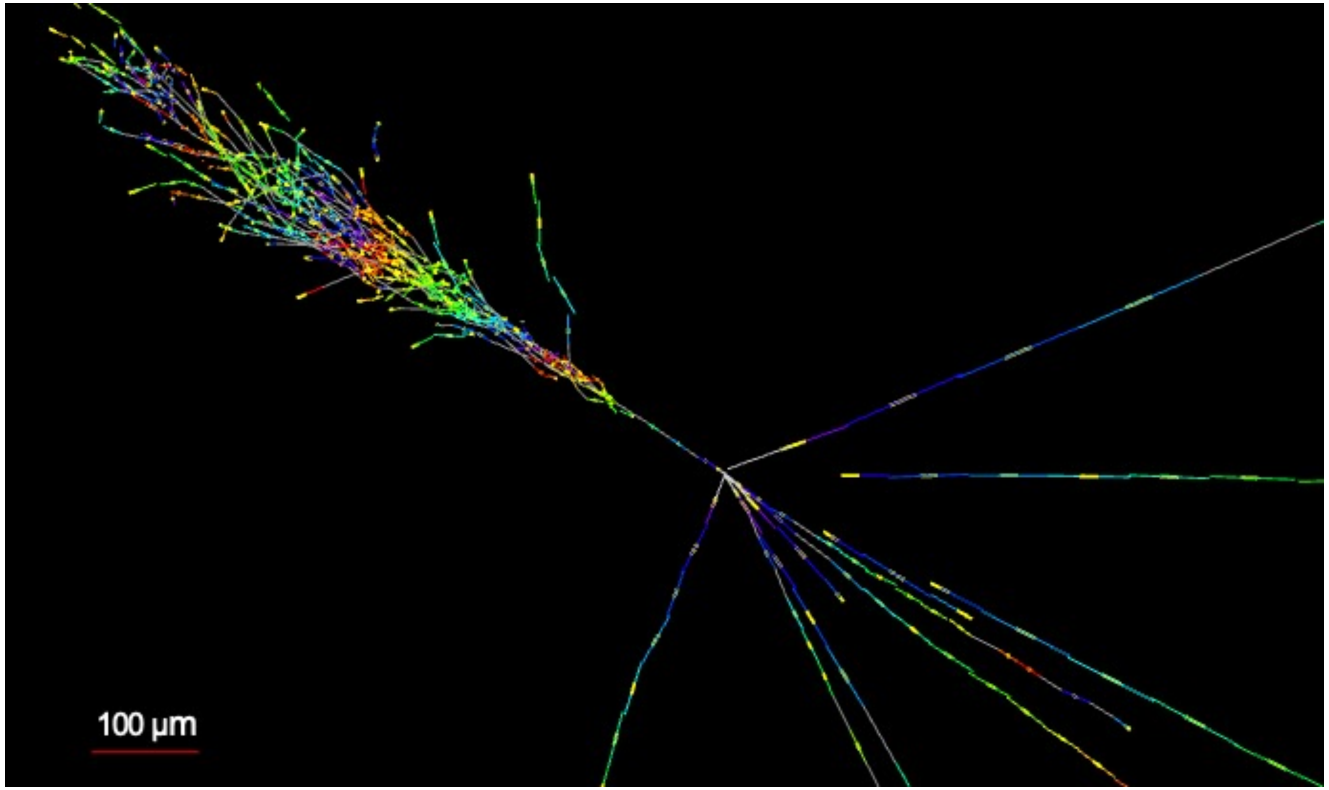


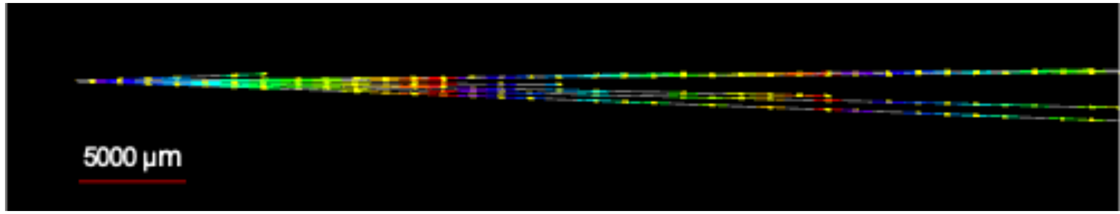
Opening up a new filed – neutrino physics at collider !!

Electron Neutrino Event “Candidate”

Analysis of FASERν emulsion detector underway

- Have multiple candidates including highly ν_e like event





Vertex with 11 tracks

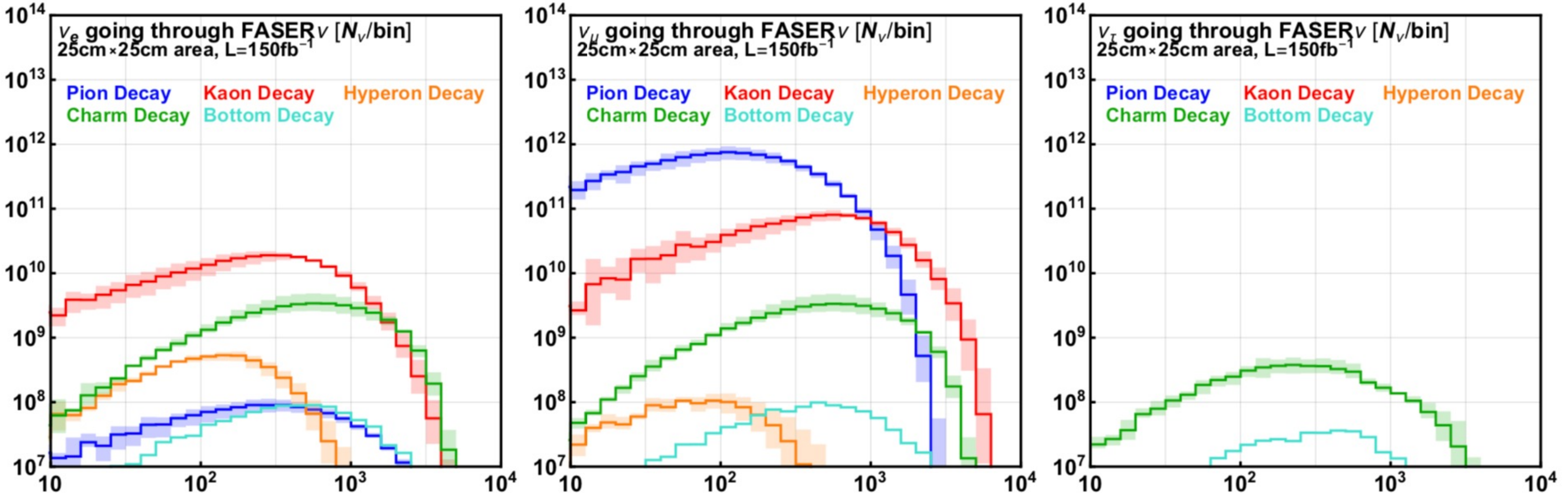
e-like track from vertex

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

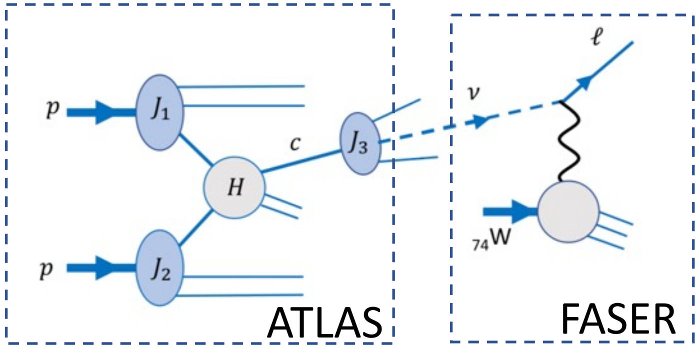
Back-to-back topology

- 175° between e & rest

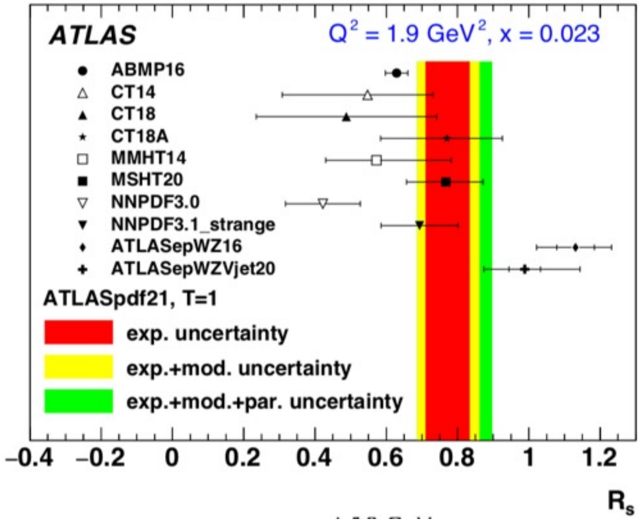
Breakdown of the LHC neutrino production



QCD



$$R_s \equiv \frac{s(x,Q^2)+\bar{s}(x,Q)}{\bar{u}(x,Q)+\bar{d}(x,Q)}$$

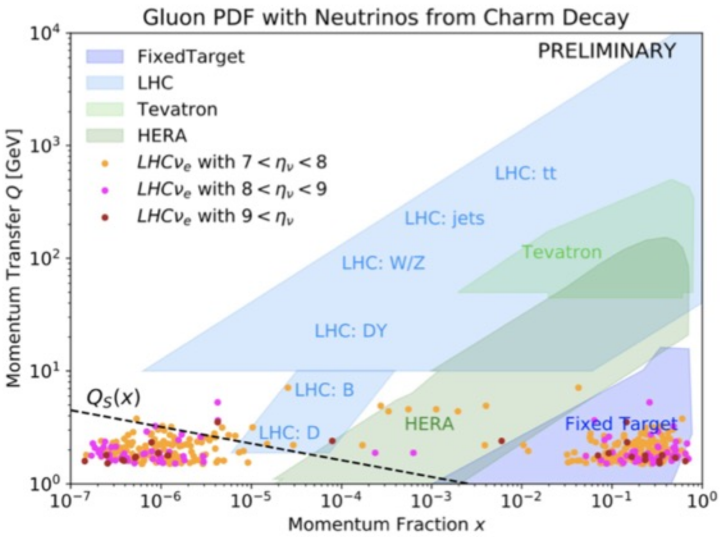


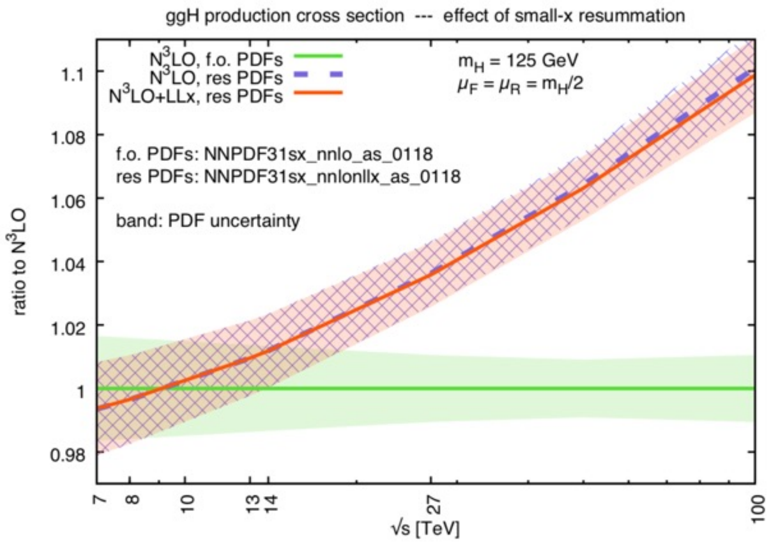
Neutrino-induced DIS could probes strangeness puzzle

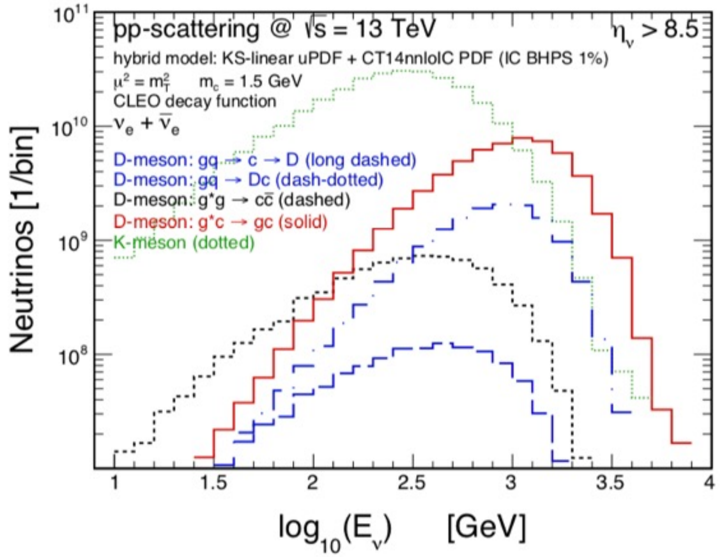
- Provide new information by measuring branch of D -> μ
- Constrain proton PDF, and nuclear PDFs

Neutrino is generated from low x & high x regions of the colliding protons

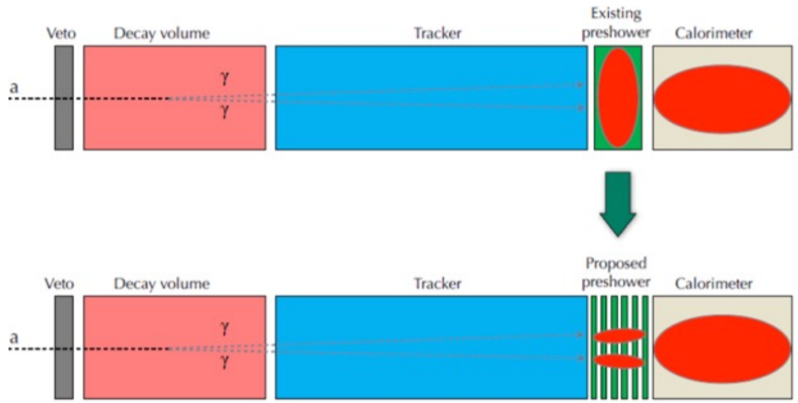
- Low-x Gluon PDF affecting Higgs production x-sec in FCC, intrinsic charm, and so on





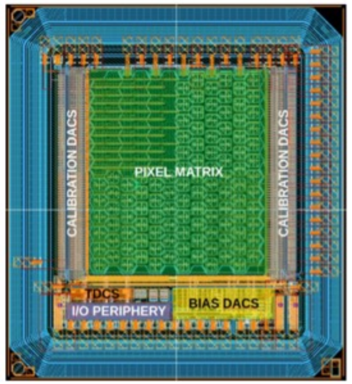


Upgrade planned for 2025

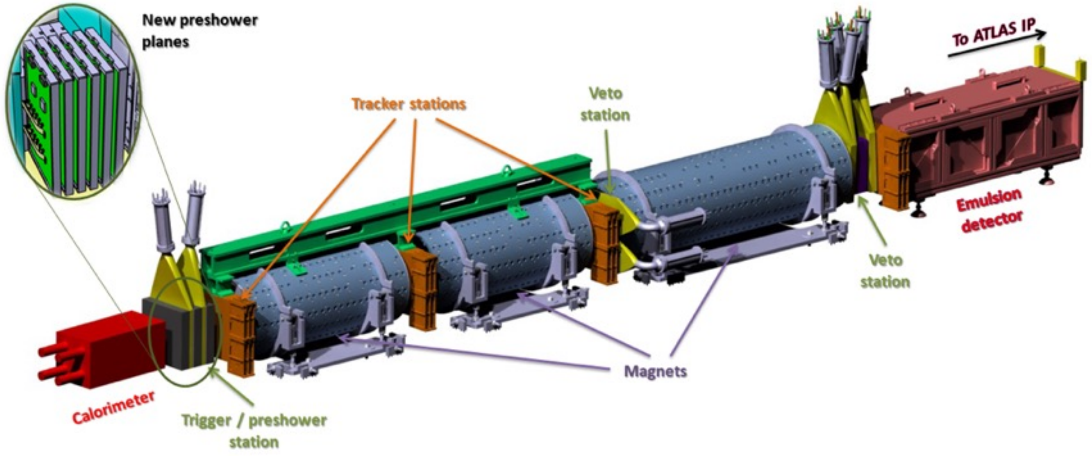


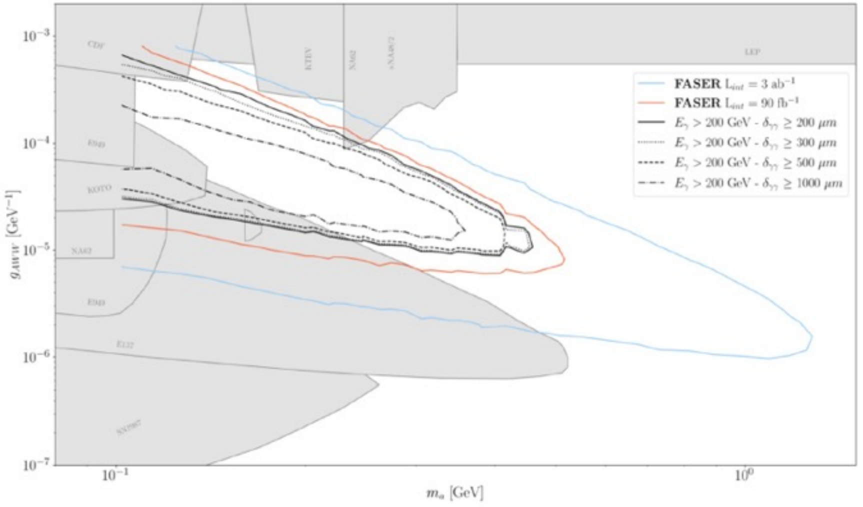
The preshower scintillator will be replaced by silicon pixel detector

- 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



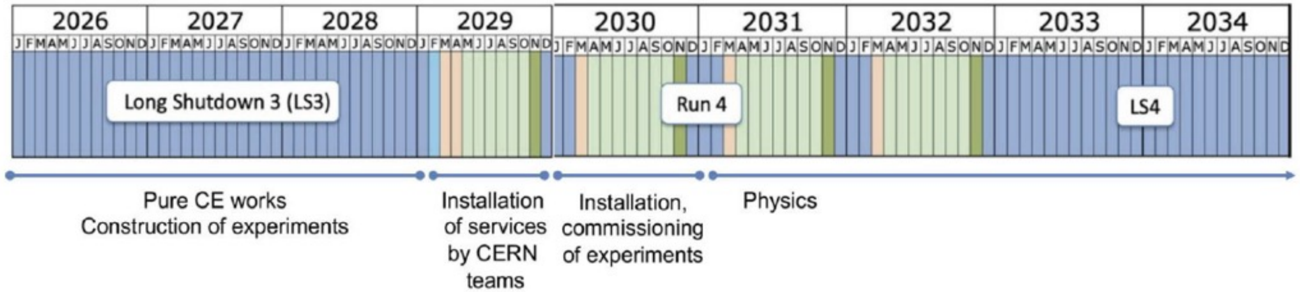


CERN research board formally approved this preshower project in April 2022

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

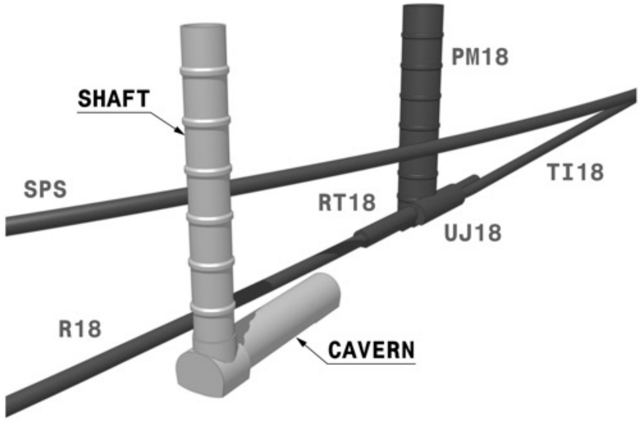
2203.05090 (to appear in J Phys G)

Toward HL-LHC



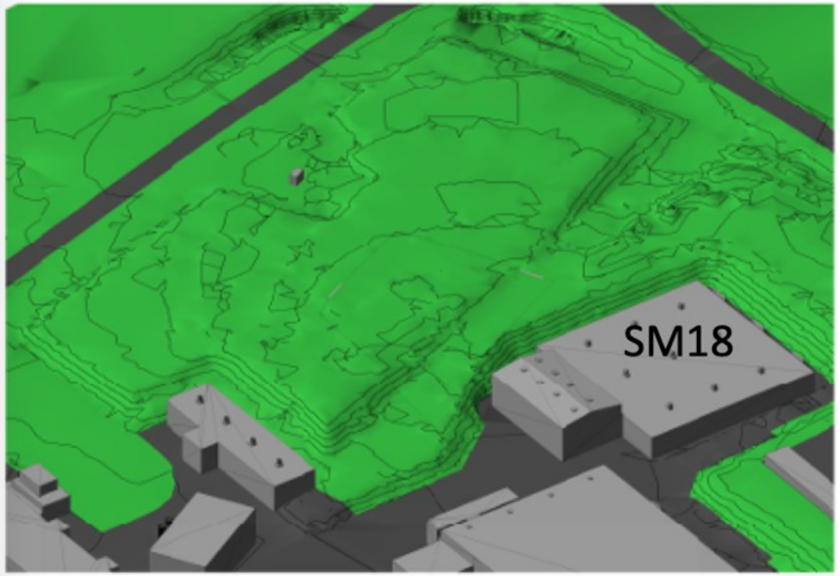
A new facility called the Forward Physics Facility (FPF) under intensive discussion

- 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

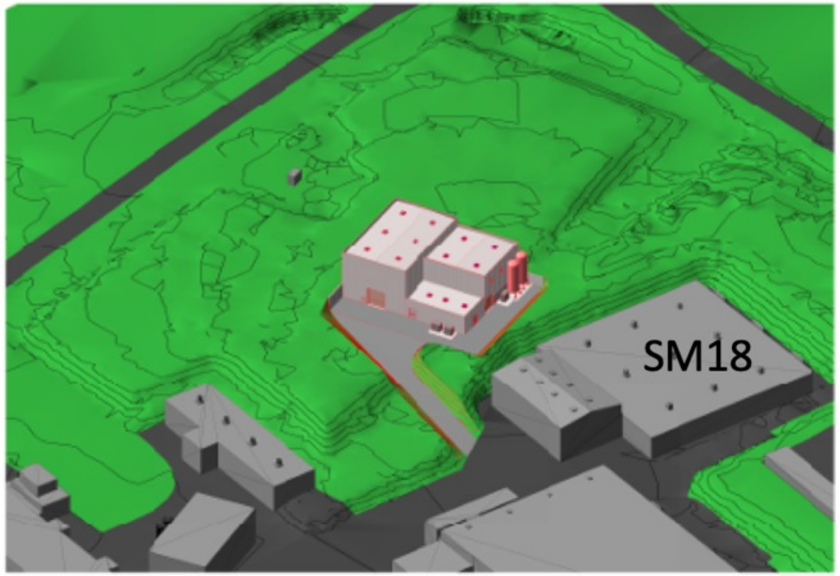


CERN civil engineering team provides a preliminary cost estimation of 40 MCHF including services

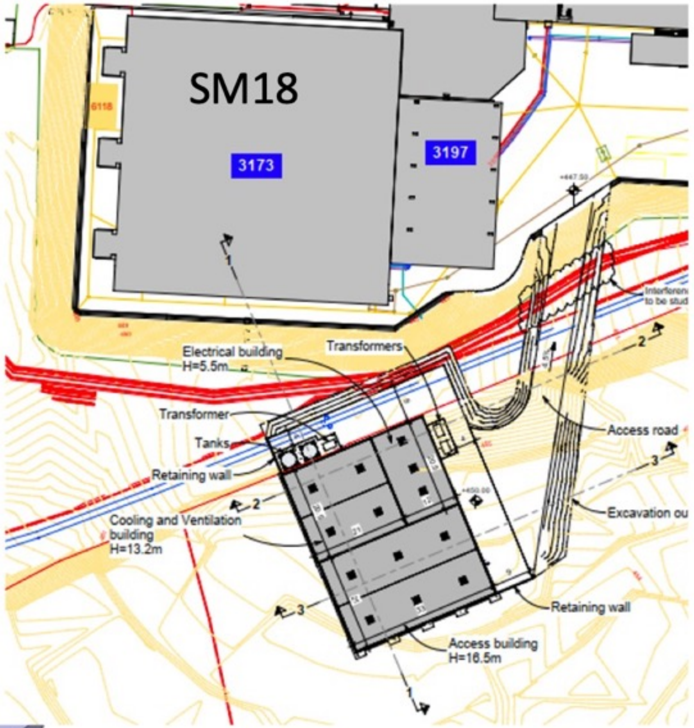
- ongoing drilling of a core at the proposed FPF location to assess the geological conditions.

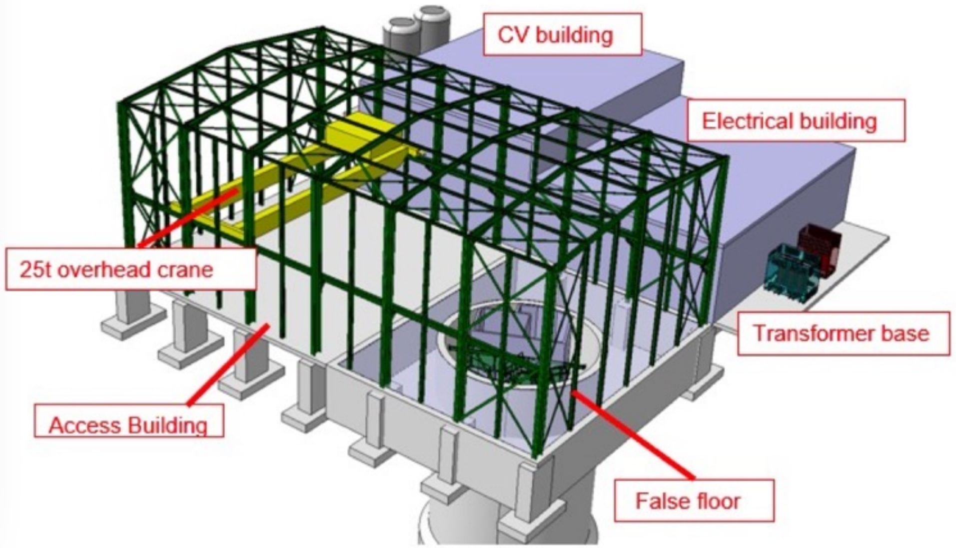


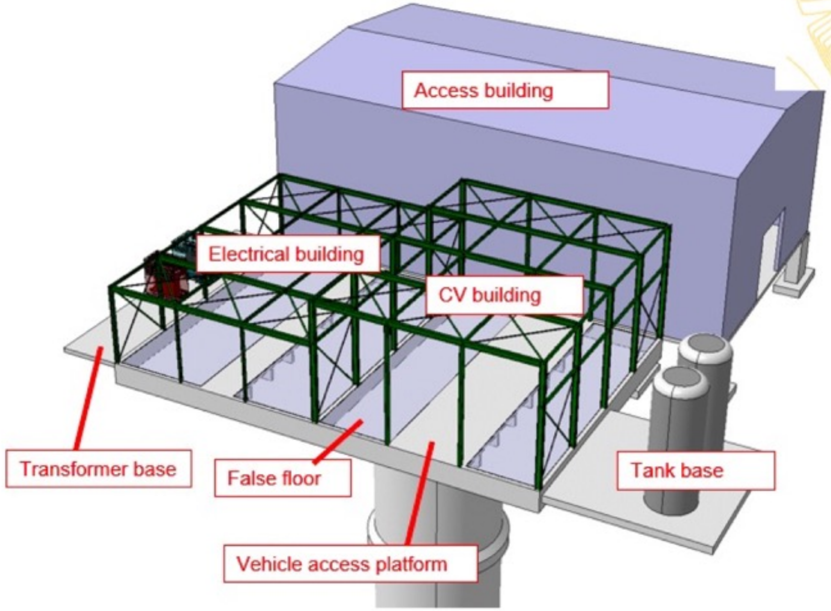
3D EXISTING



3D NEW



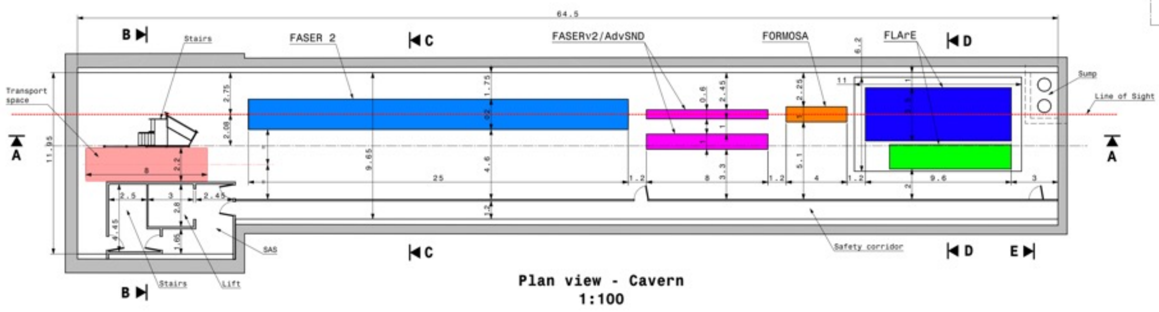




Currently proposed FPF experiments

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

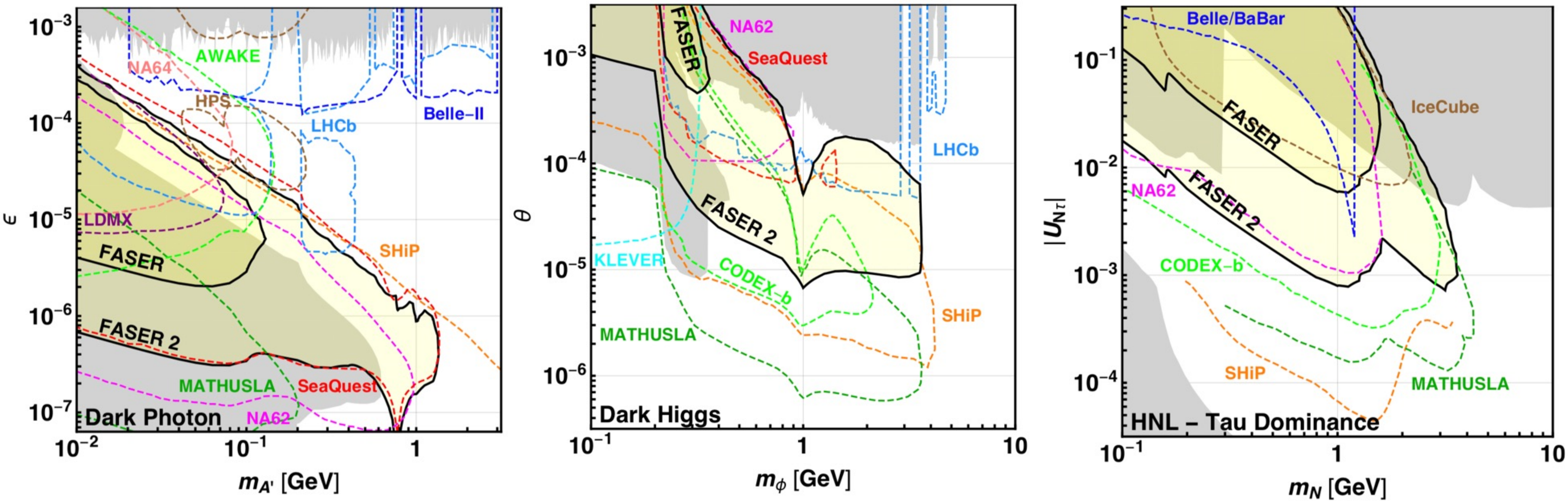
- FLArE
  - $\mathcal{O}$(10tn) LAr TPC detector
  - DM scattering
  - Neutrino physics (ν_μ/ν_e , capabilitty for ν_τ under study)
    - Full view of neutrino interaction event
- FASERv2
  - $\mathcal{O}$(20tn) emulsion/tungsten detector (FASERν x20)
    - Mostly for tau neutrino physics
  - Interfaced to FASER2 spectrometer for muon charge ID ($\nu_\tau/\ \overline{\nu}_\tau$ 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

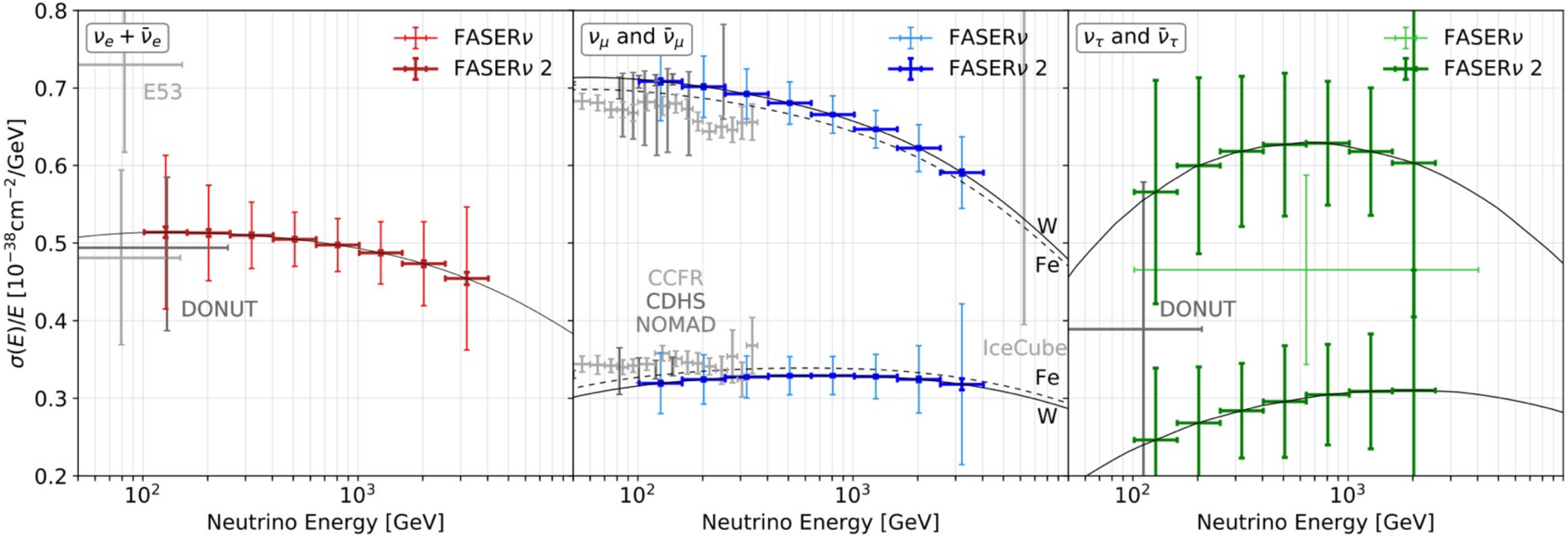
FASER/FASER 2 physics reach for various models

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



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

Improvement of the TeV neutrino study

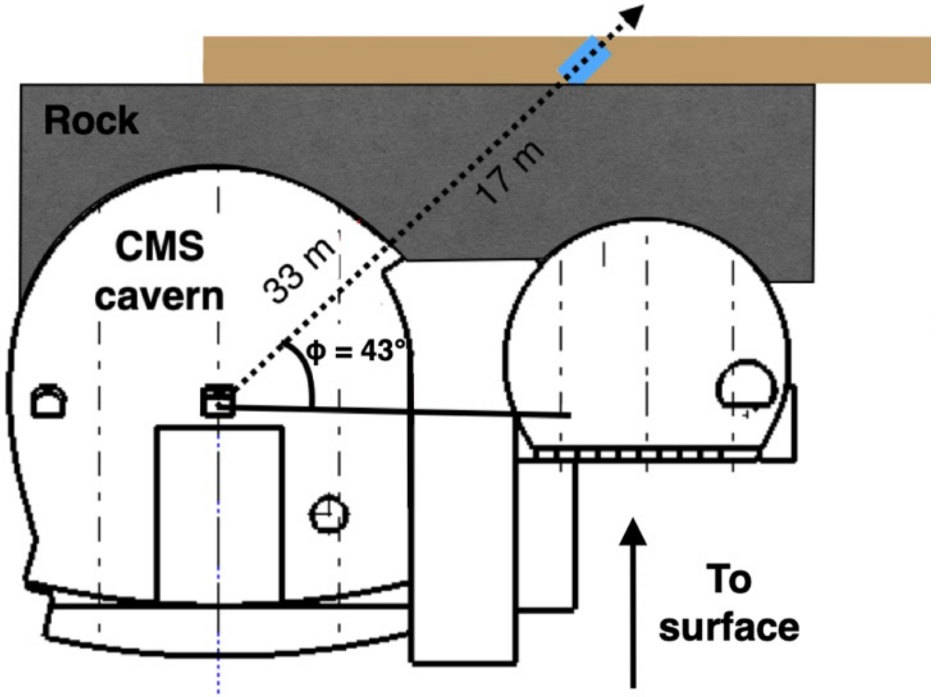


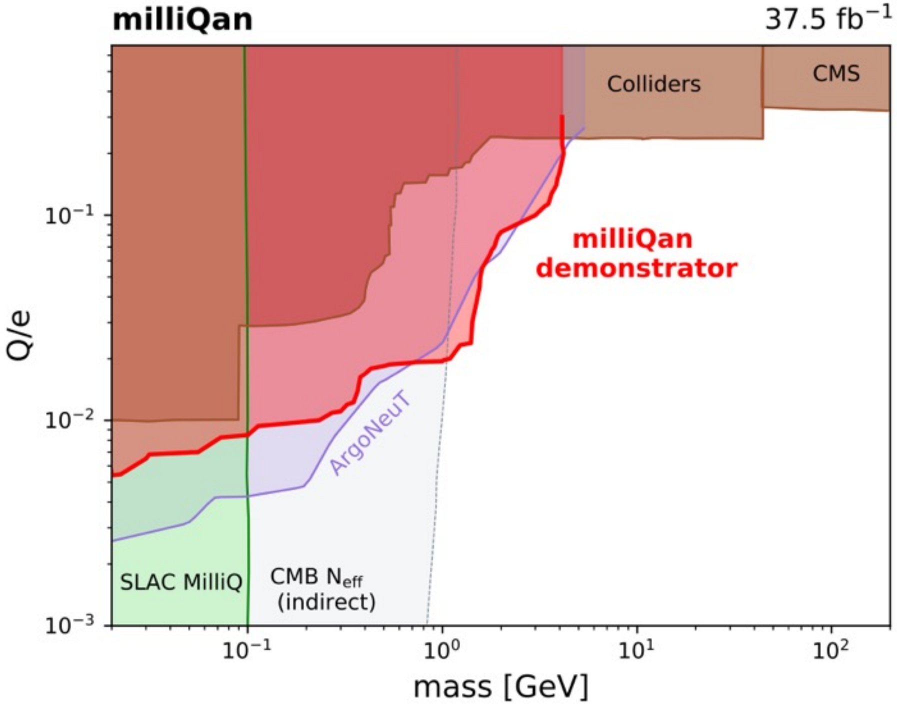
O(10^3-10^4) of Tau neutrino, allowing detailed measurement of final state

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

MilliQan at LHC for millicharged particle search

33m from the CMS interaction point behind 17 m of rock, and

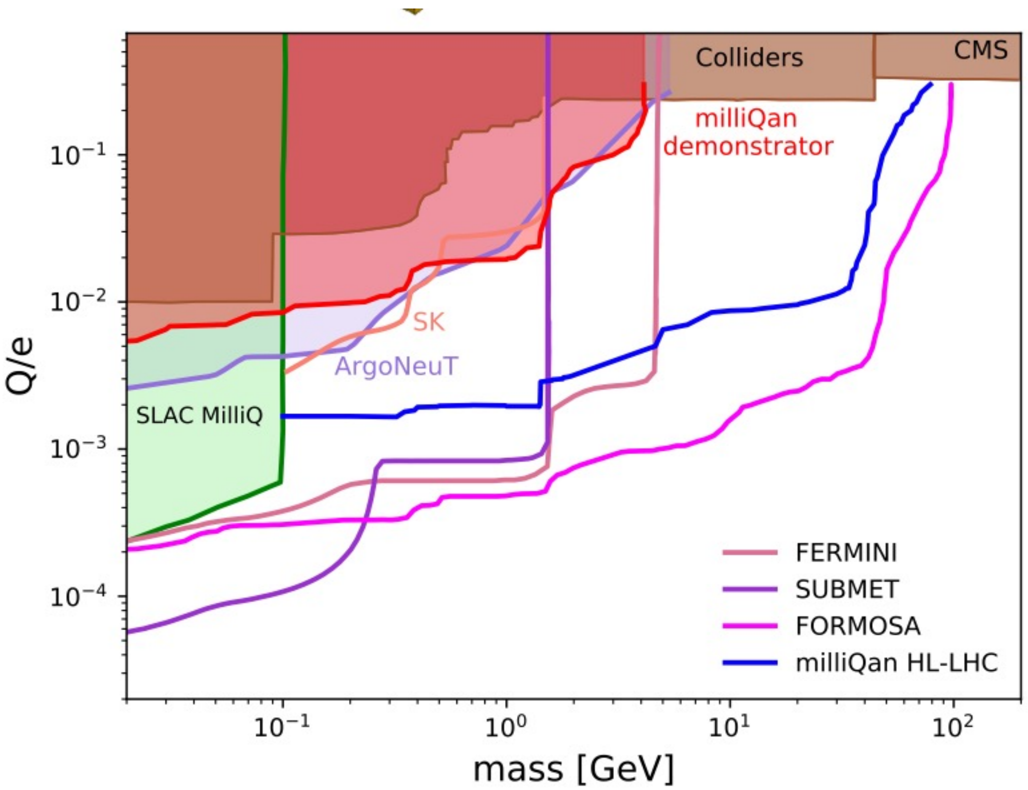


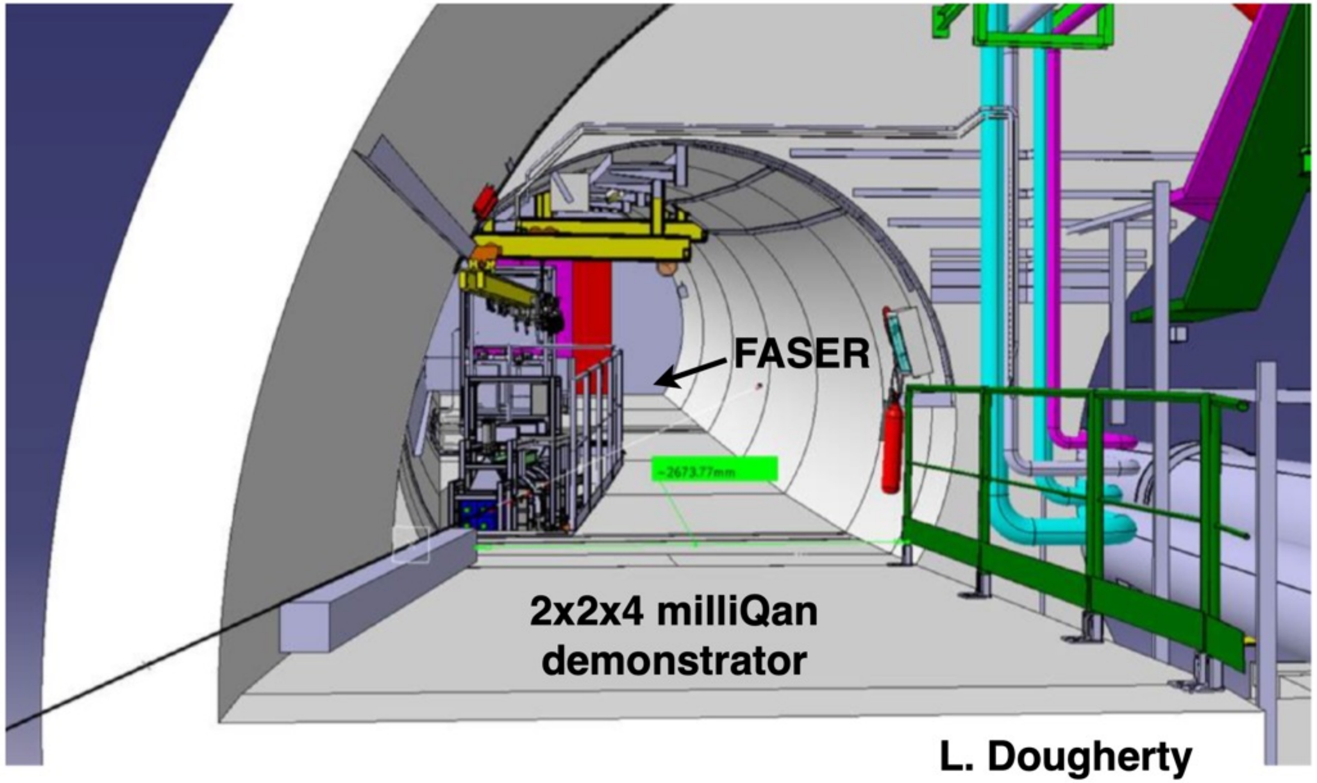


A 1% scale demonstrator was installed and operated in the tunnel above CMS during LHC Run 2.

FORMOSA at FPF

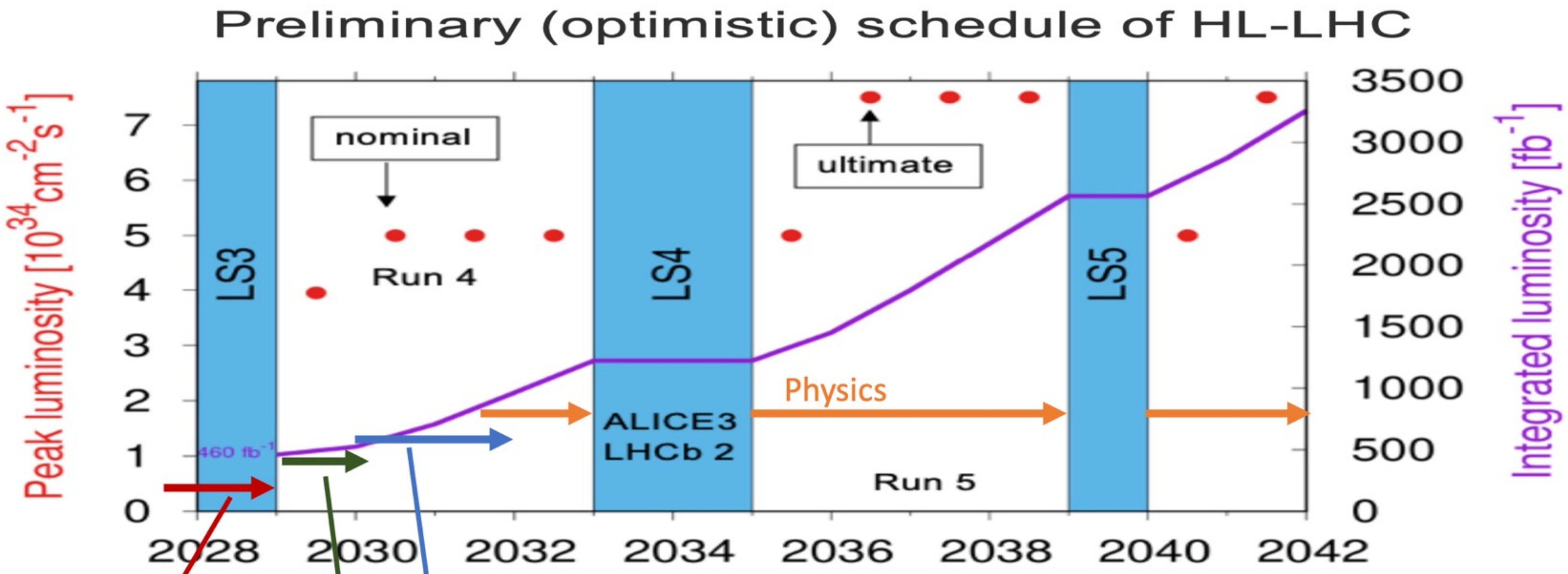
“FORMOSA demonstrator” in FASER cavern would provide critical insights into backgrounds/operation in forward environment





Possible FPF schedule

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



Pure CE works (including connection to LHC)

Installation and commissioning of the experiments

Installation of services (CERN technical teams, busy during LS3)

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

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 !!

FASER Acknowledgements

FASER is supported by:

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

CERN

Swiss National Science Foundation

In addition, FASERν is supported by:

erc

科研費 KAKENHI

FPF studies supported by:

Physics Beyond Colliders

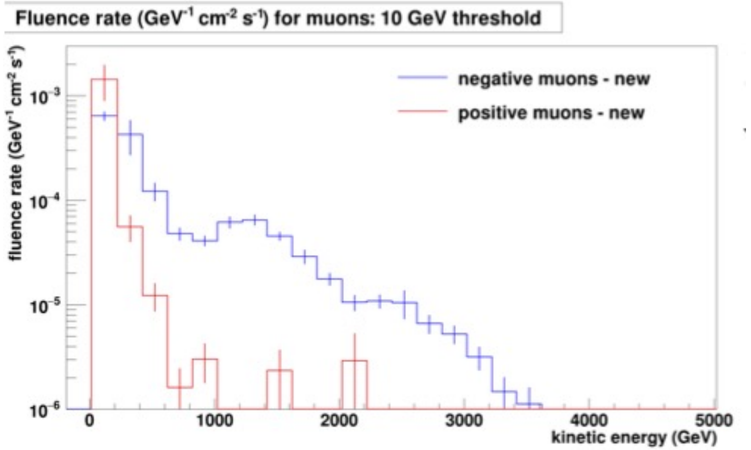
And would additionally like to thank

- 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

Data size

- On /eos/experiment/faser (in directory structure):
  - Raw data - 89.7 TB
  - Reco data - 31.9 TB
  - Simulation - 15.7 TB
  - Physics Ntuples - 1.9 TB

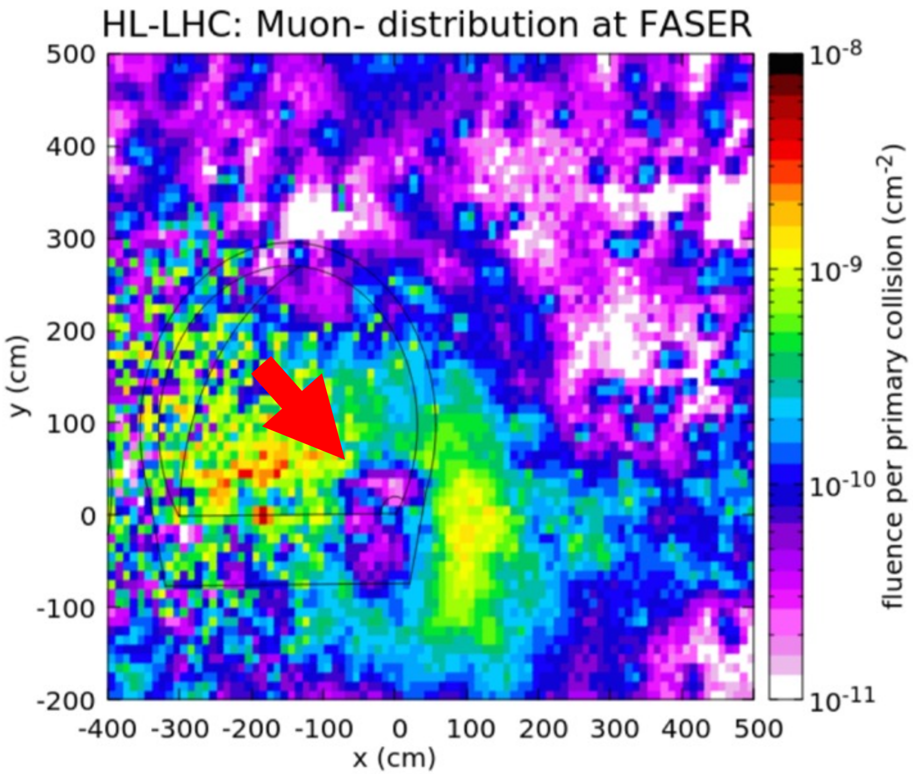
Background simulation

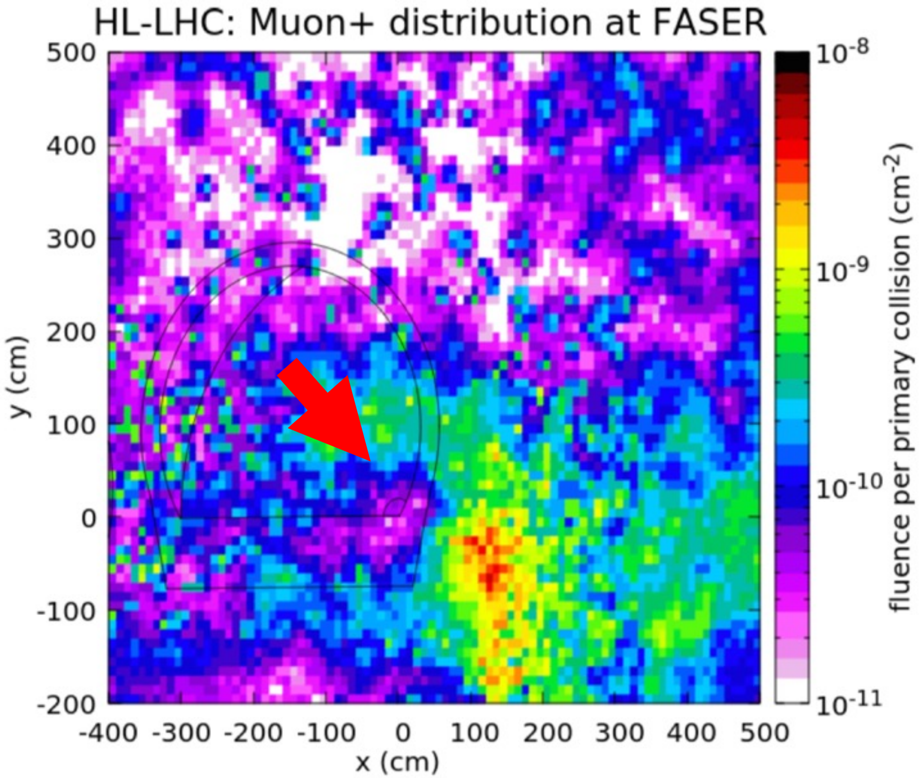


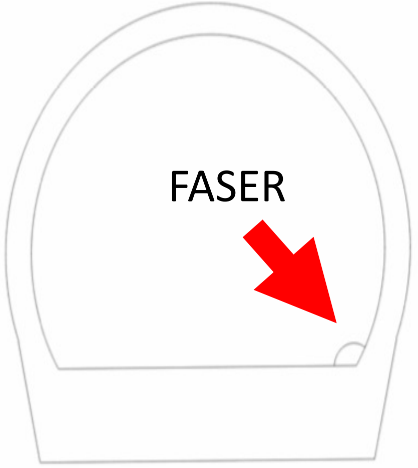
Simulation implied that FASER would be located in very lucky place

- 10^{-3} less flux compared to just 1m away since LHC magnets seems to sweep charged particles
- No neutral particle by 100m thick rock

should be confirmed by measurement



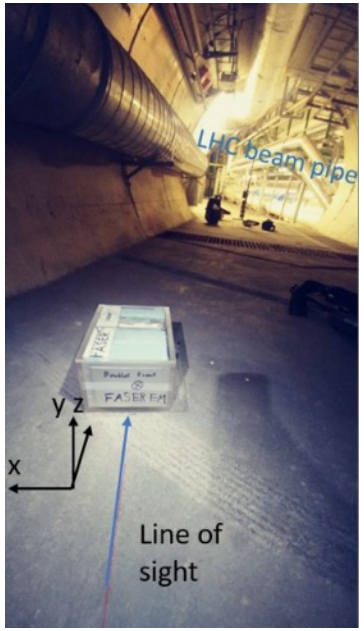


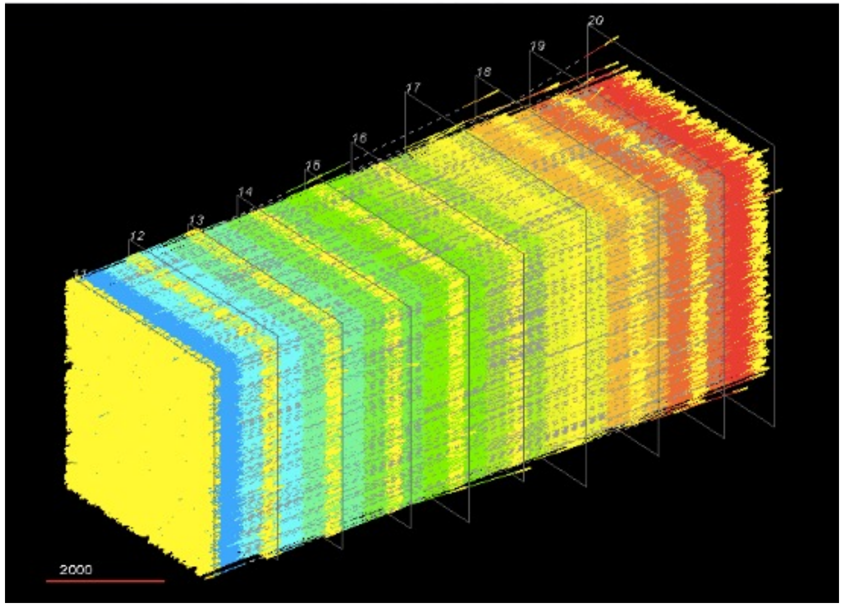


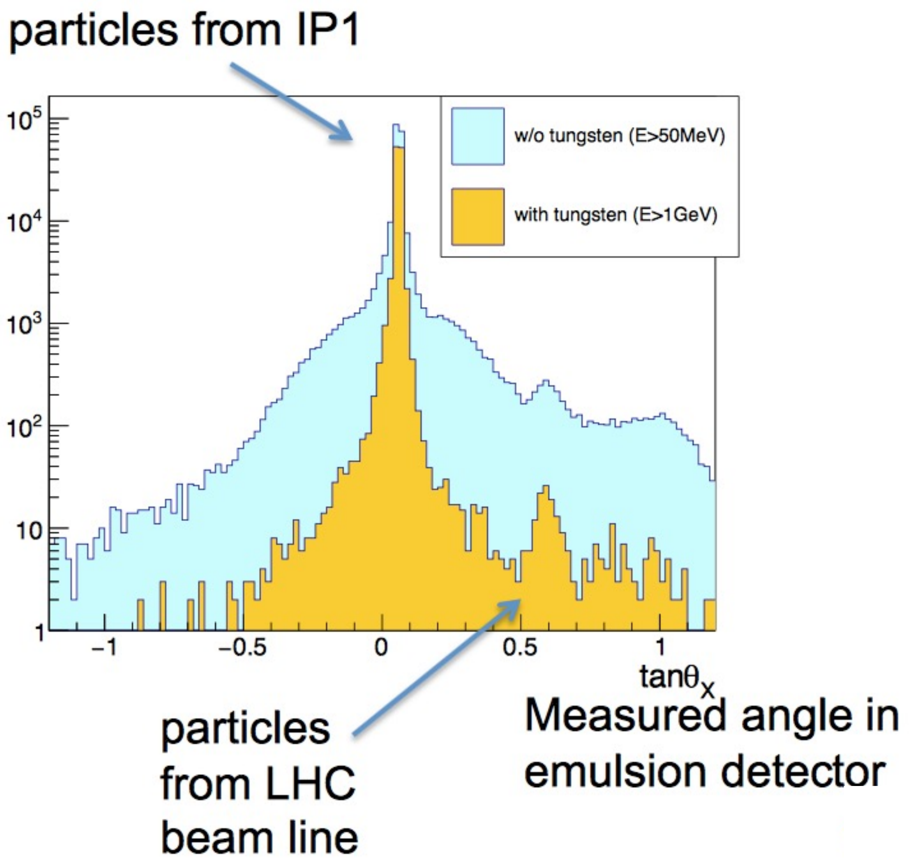
Background measurement in 2018

No infrastructure in 2018 – emulsion detector provided quick/reliable measurement

- Good agreement with FLUKA simulation, accelerating designing the FASER experiment

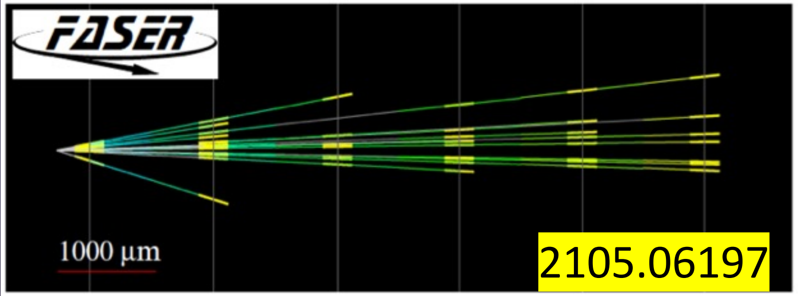






	beam $[\text{fb}^{-1}]$	observed tracks $[\text{cm}^{-2}]$	efficiency	normalized flux, all $[\text{fb cm}^{-2}]$	normalized flux, main peak $[\text{fb cm}^{-2}]$
TI18	2.86	18407	0.25	$(2.6 \pm 0.7) \times 10^4$	$(1.2 \pm 0.4) \times 10^4$
TI12	7.07	174208	0.80	$(3.0 \pm 0.3) \times 10^4$	$(1.9 \pm 0.2) \times 10^4$
FLUKA simulation, E>100 GeV				1×10^4	

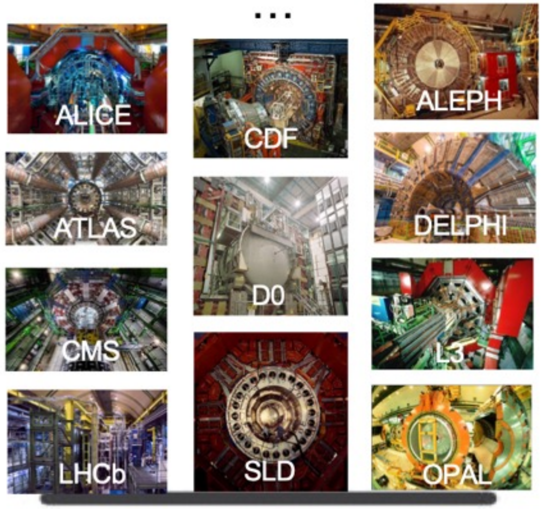
First collider neutrino candidate



FASER Pilot Detector

Suitcase-size, 4 weeks
$0 (recycled parts)

6 candidate neutrinos



All previous
collider detectors

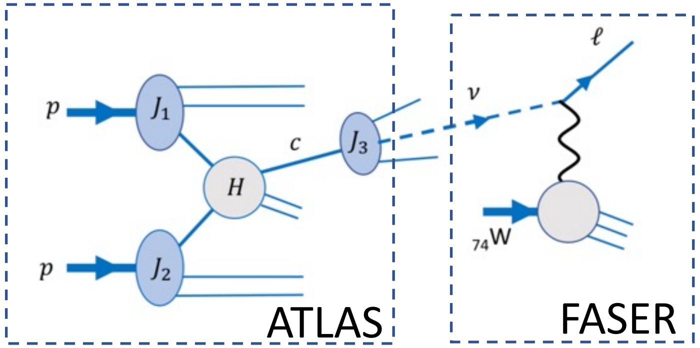
Building-size, decades
~$$10^9$

0 candidate neutrinos

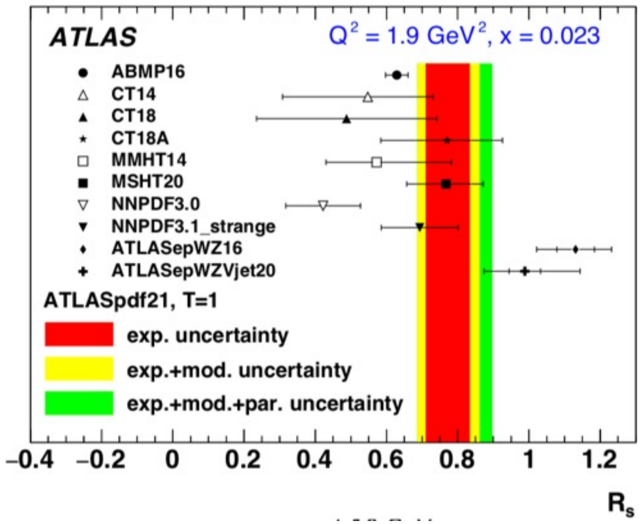
This opens up a new field:
neutrino physics at colliders

Jonathan Feng

QCD



$$R_s \equiv \frac{s(x,Q^2)+\bar{s}(x,Q)}{\bar{u}(x,Q)+\bar{d}(x,Q)}$$

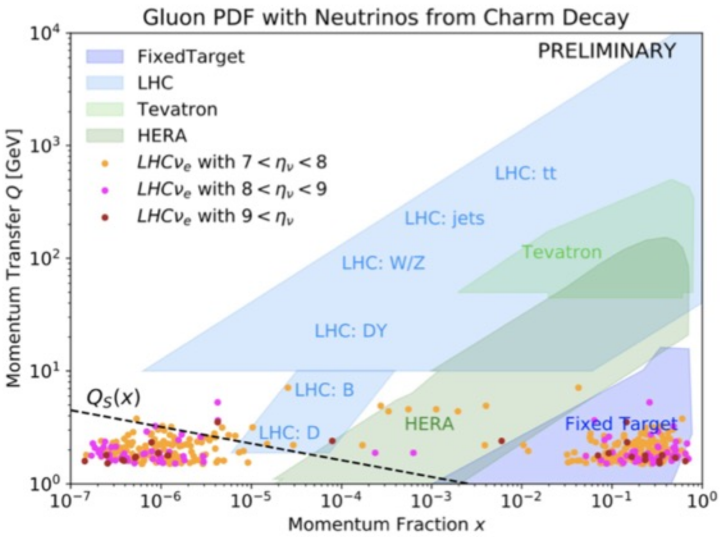


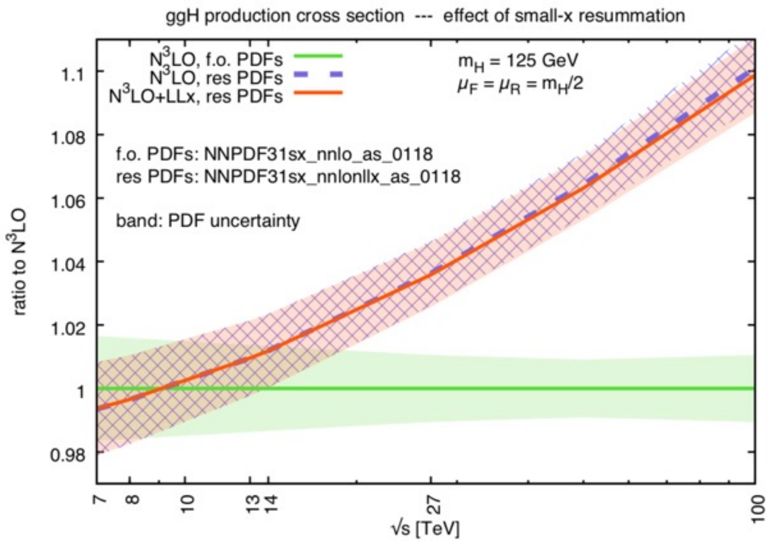
Neutrino-induced DIS could probes strangeness puzzle

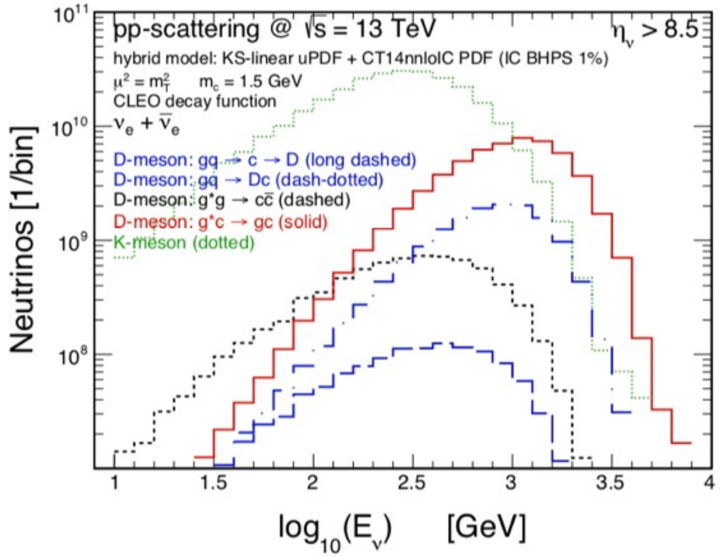
- Provide new information by measuring branch of D -> μ
- Constrain proton PDF, and nuclear PDFs

Neutrino is generated from low x & high x regions of the colliding protons

- Low-x Gluon PDF affecting Higgs production x-sec in FCC, intrinsic charm, and so on

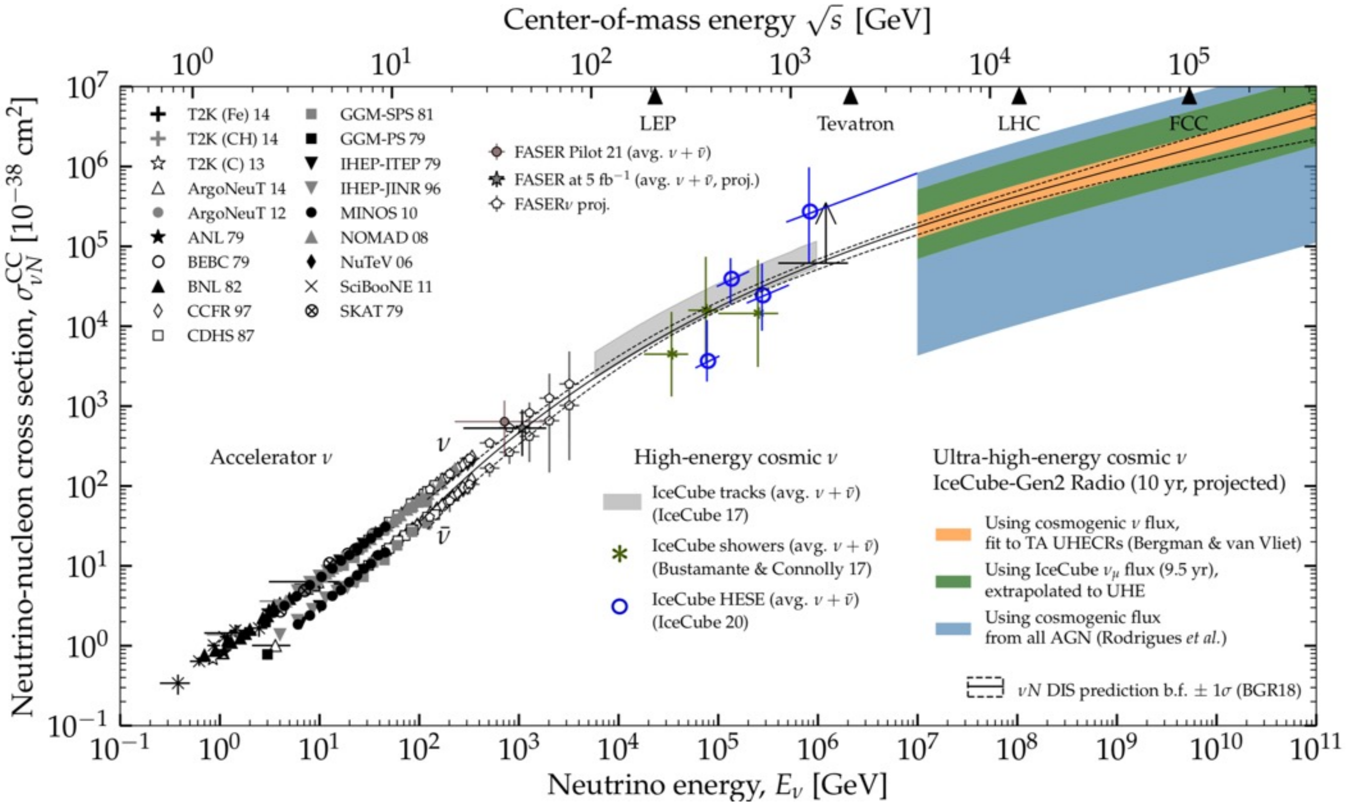


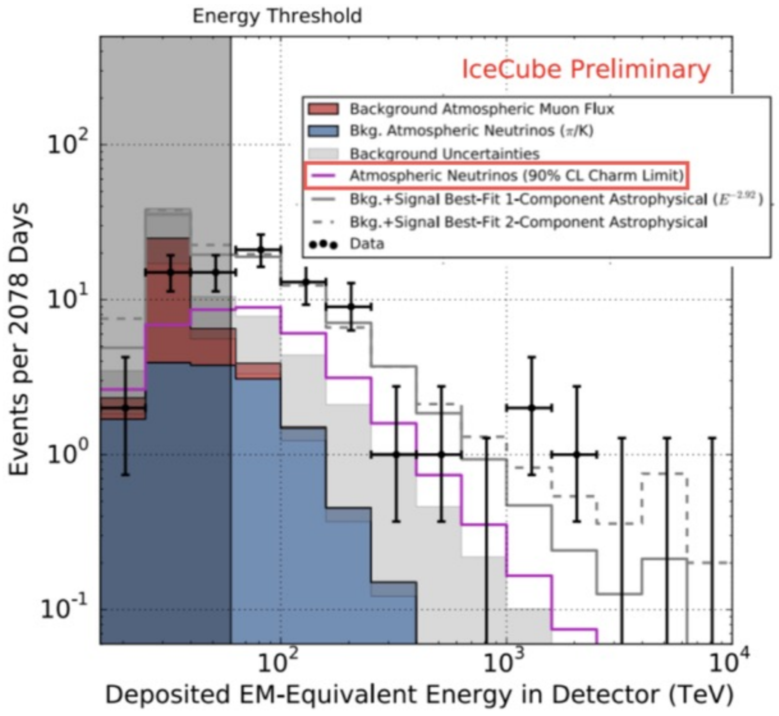




Astoroparticle physics

13 TeV center-of-mass pp collision corresponds to 100 PeV proton in lab frame





Better understanding of atomospheric neutrino could improve the IceCube experiment

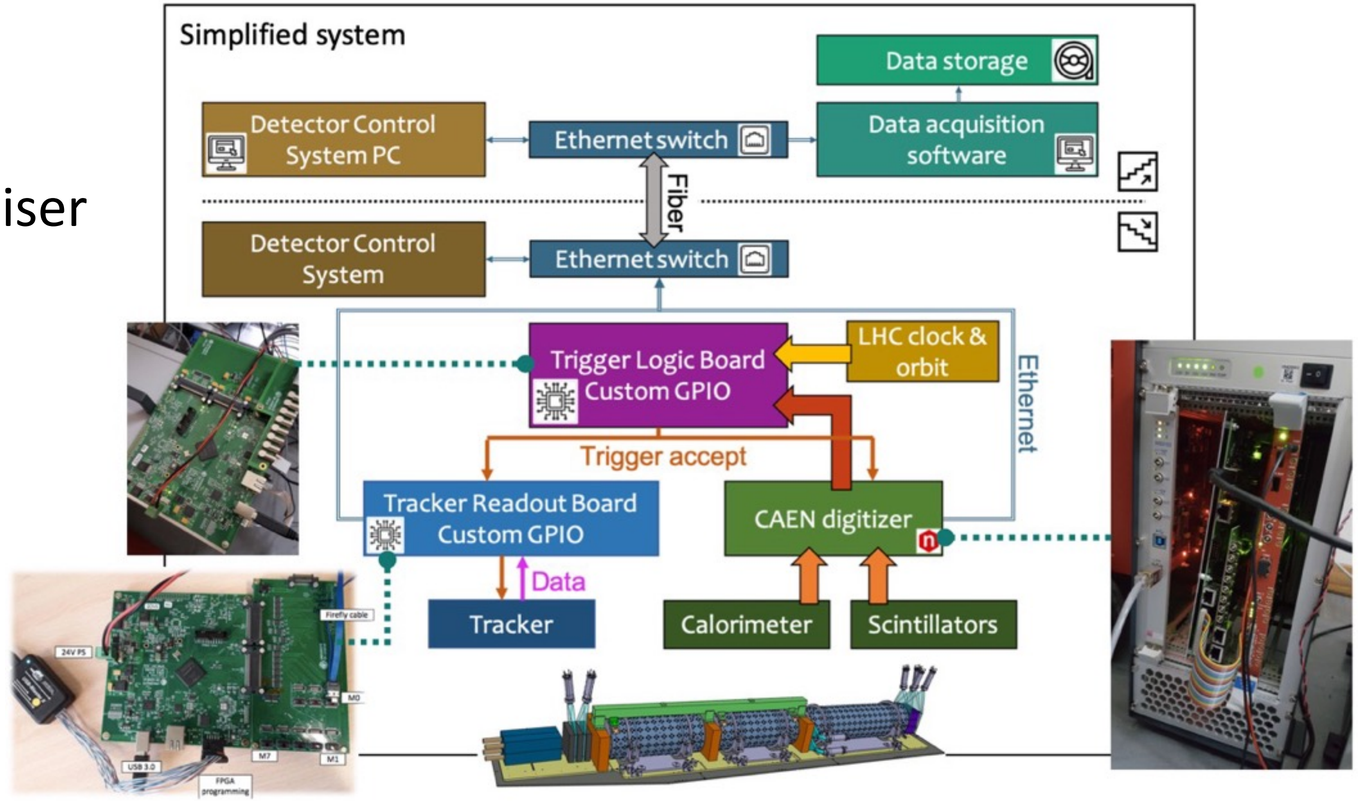
Trigger and Data acquisition

Readout electronics in TI12

- Tracker: Custom GPIO board
- Scintillator and Calorimeter: CAEN digitiser
- Trigger: Custom GPIO board
  - 500 Hz expected rate
  - Clock and bunch taken from LHC
- Ethernet switch -> Servers on surface

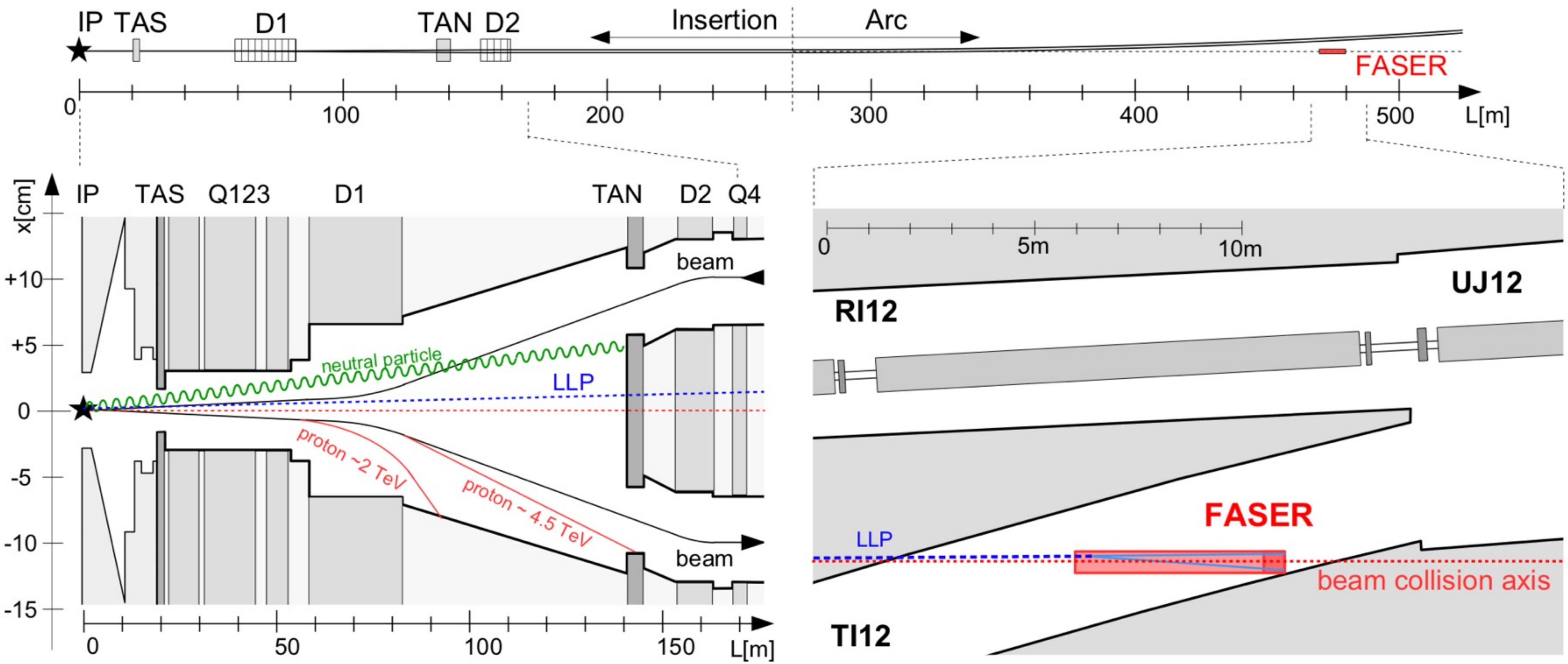
All components are installed

- High rate test at 1 kHz successful
- Monitoring tool in place
  - Status of the detector and data taking



Paper is published: 2021 JINST 16 P12028

More detail about FASER location

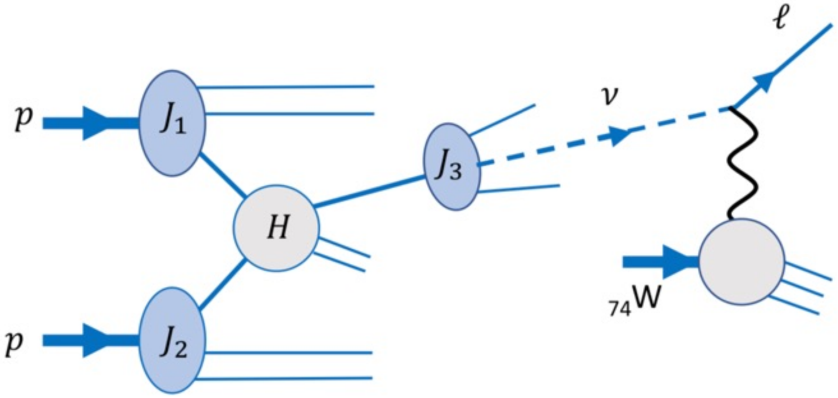


QCD in the forward region

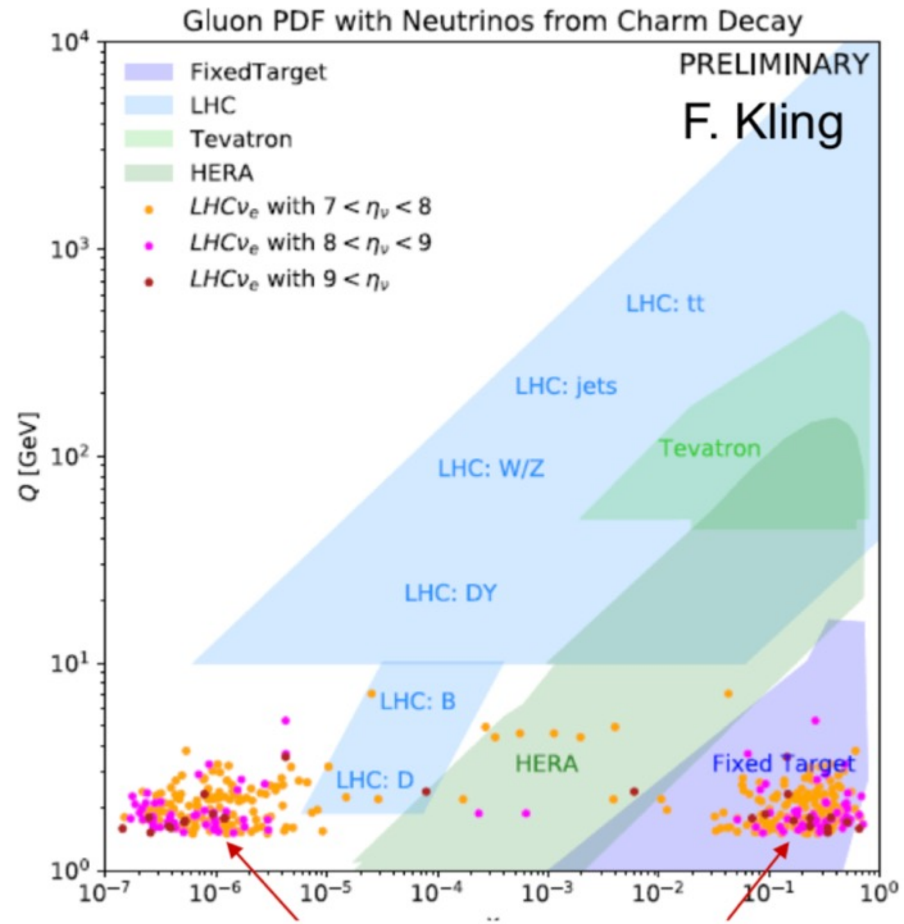
QCD@FPF

- Wide range of QCD studies relating to:

★ **Forward particle production** mechanisms in the central detector. and/or ★ **Neutrino induced DIS** scattering at FPF.



- Both aspects can provide new understanding of QCD physics, complementary to ongoing LHC (...) programme.



Lucian Harland-Lang, 4th FPF workshop: https://indico.cern.ch/event/1110746/contributions/4701724/attachments/2382412/4071581/lhl_FPF_QCD.pdf

My major cotributions to FASER would be:

Tracking detector for a pair of charged particle from long-lived particle, e.g dark photon

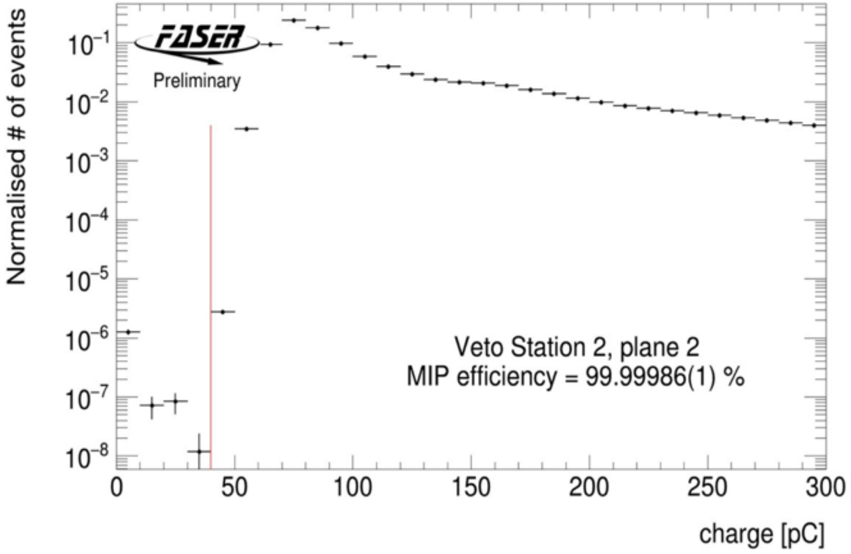
- Brought idea 2018 April to make use of spare modules from ATLAS silicon micro-strip detector (SCT)
    - I did SCT data quality coordinator (2013-2016) and SCT run coodinator (2016-2017)
- Taken a lead as a Project leader after getting approval from CERN in 2019
    - from design, development, integration, installation, and operation
    - dealing with the COVID situation

In-situ measurement of background in spring/summer 2018 (before finishing Run2)

- Brought idea 2018 April to install emulsion detector, which was placed 2018 July
    - succssful measuement, confiming good agreement with estimation
- Derived Neutrino program in the FASER experiment with emulsion experts
    - Build and install additional tracking detector to integrate the emulsion detector with other detectors

Exective board member since 2019 to grow the FASER experiment

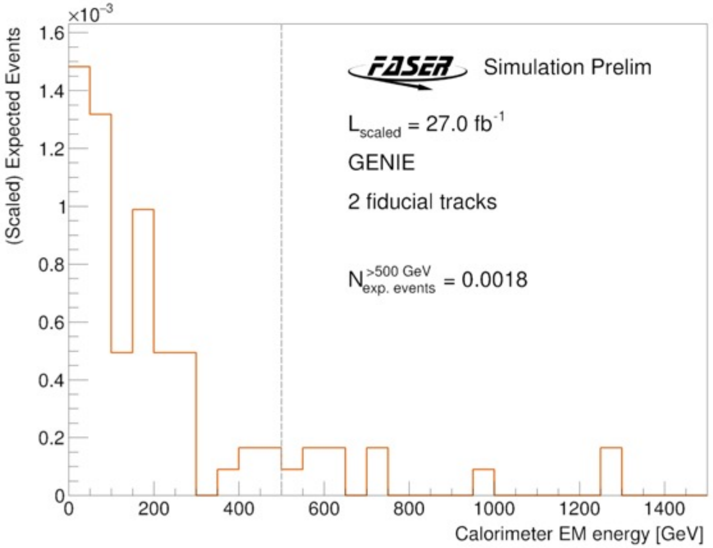
Background estimation



Veto inefficiency

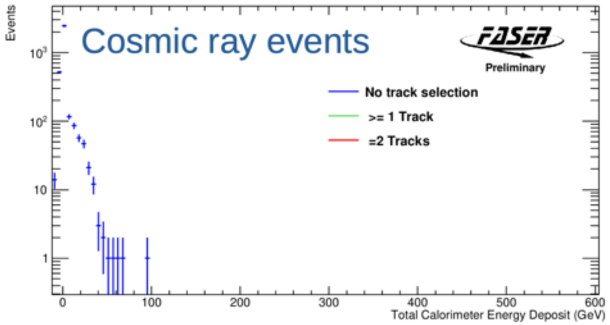
- Veto layer scintillators efficiency >99.998%
  - Measured layer-by-layer using muon tracks in trackers pointing back
- With all layers, even 10^8 muons going through veto produces negligible background even before any other selections applied

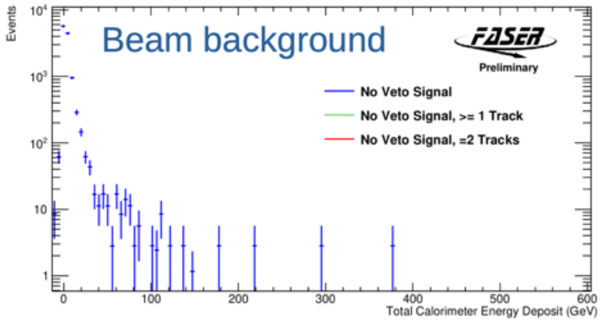
Neutrino background



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

Background estimation





Non-collision background

- Cosmics measured in runs with no beam
- Near-by beam debris measured in non-colliding bunches
- No events observed with≥1track or E(calo) > 500 GeV individually

Neutral hadrons (e.g. Ks) from upstream muons interacting in decay volume

- Heavily suppressed since
  - Muon nearly always continues after interaction
  - Has to pass though 8 interaction lengths
  - Decay products have to leave E(calo)>500GeV
- Estimated from lower E events with 2 and 3 tracks and different veto conditions: **(2.2±3.1)×10^{-4} events**