Neutrinos at the LHC:
FASERν and SND@LHC

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On behalf of the FASER & SND@LHC Collaboration

FASERν is supported by
erc
HEISING-SIMONS FOUNDATION
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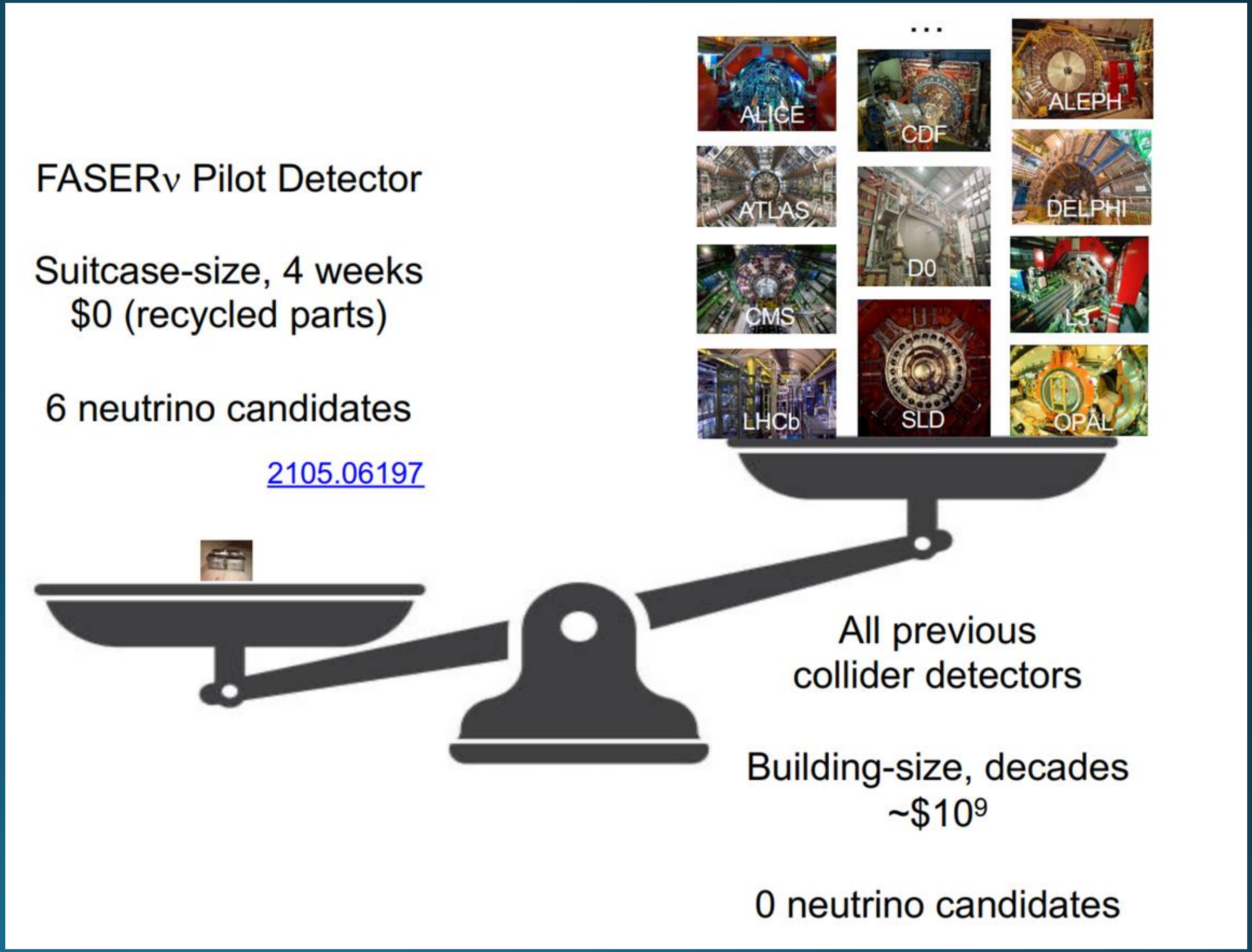
科研費 KAKENHI
CERN

Collider neutrinos

- New opportunities for neutrino researches
- Neutrino at the LHC were considered in 80s-90s, however, never realized, e.g. A. De Rujula, et al.
  - Cost was considered too expensive w.r.t. physics
- No neutrino detected by any collider experiments by 2018
- In 2018, new initiatives have started



FASERν Pilot Detector

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

6 neutrino candidates

2105.06197

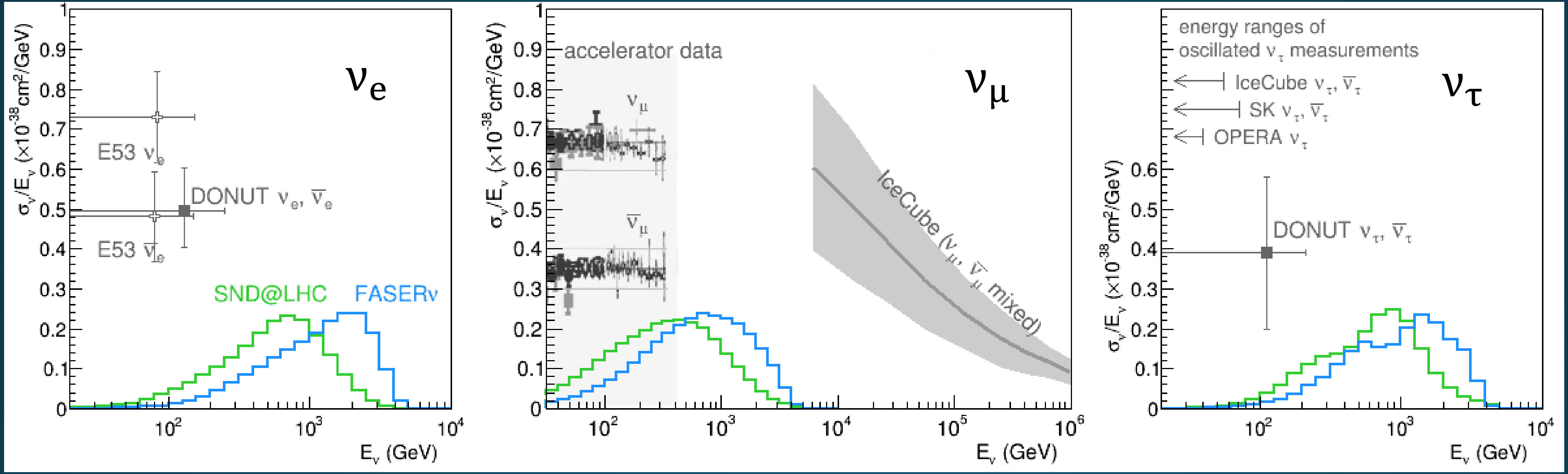
All previous
collider detectors

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

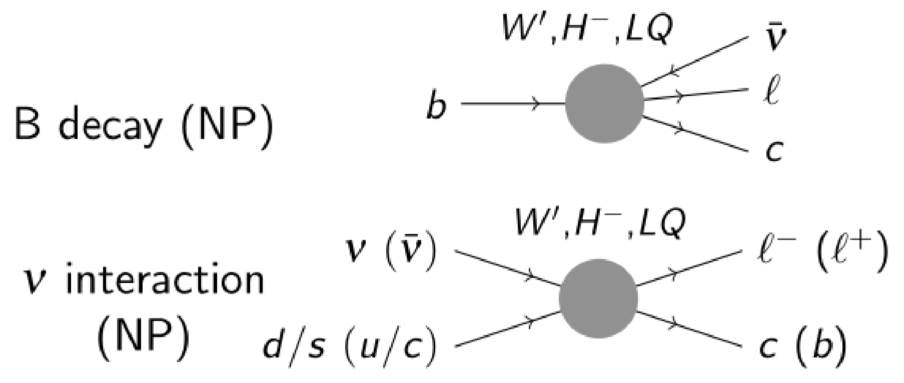
0 neutrino candidates

Slide from J. Feng

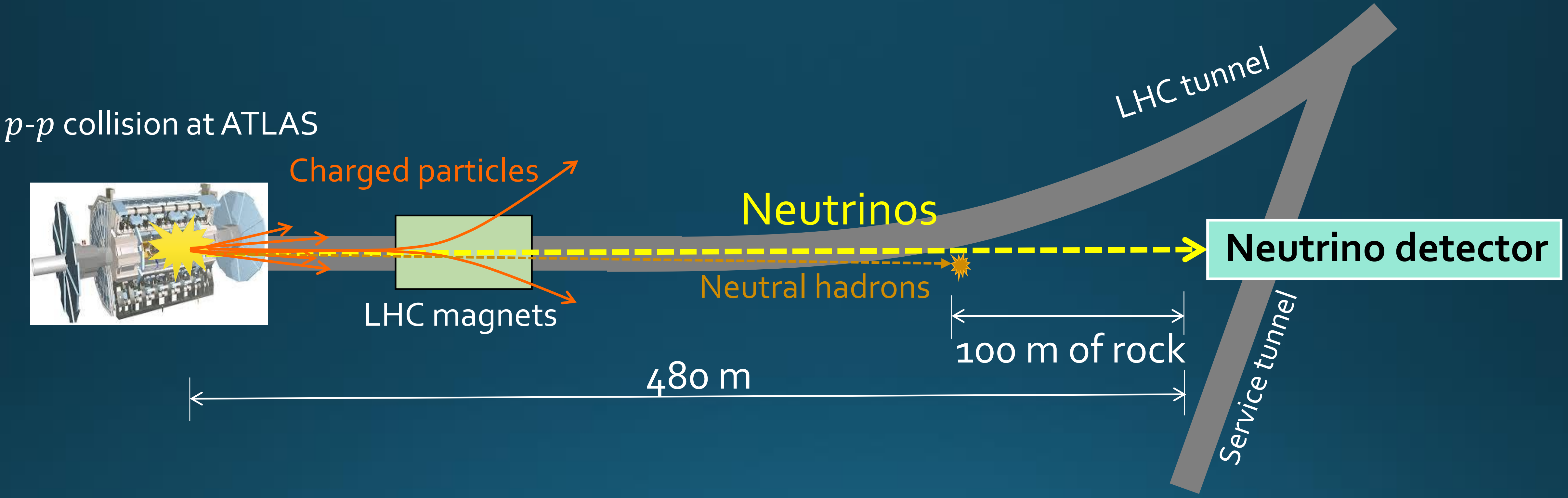
Motivation for TeV energy neutrinos



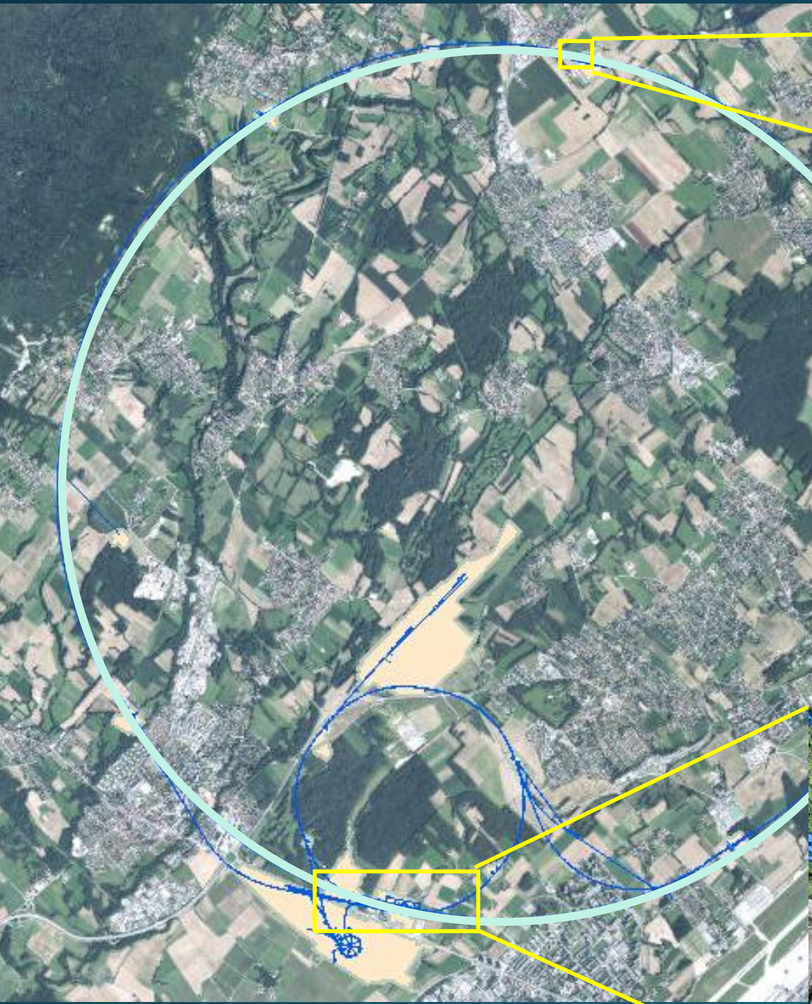
- Highest neutrino energy made by man-kind
- Behavior of neutrinos at TeV energies?
- Lepton Universality in neutrino scattering?
  - ν_τ and heavy quarks → Flavor anomaly e.g. R_D
- Any new physics effects at high energy?



LHC's "neutrino beamline"

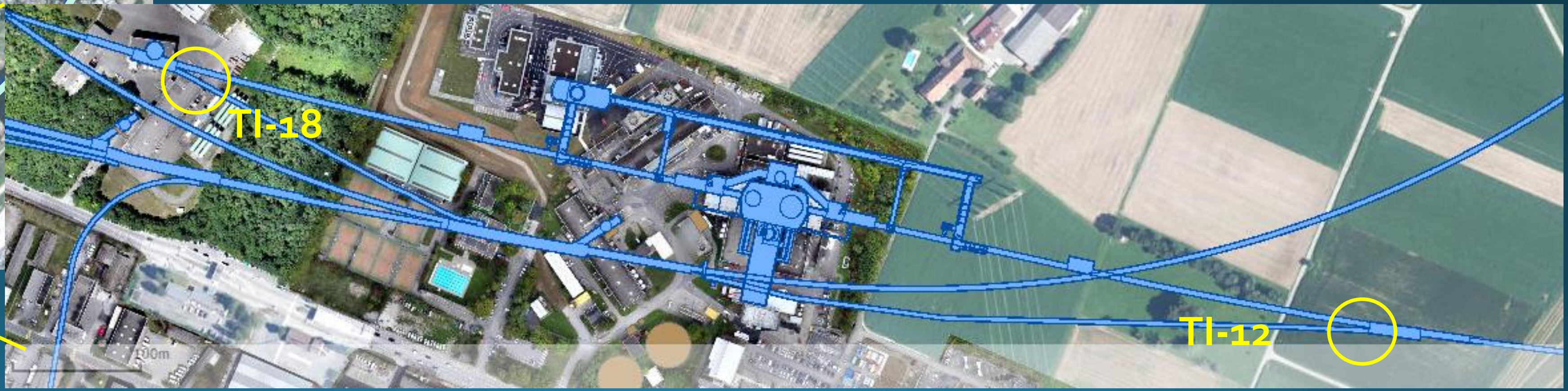


Site studies in 2018

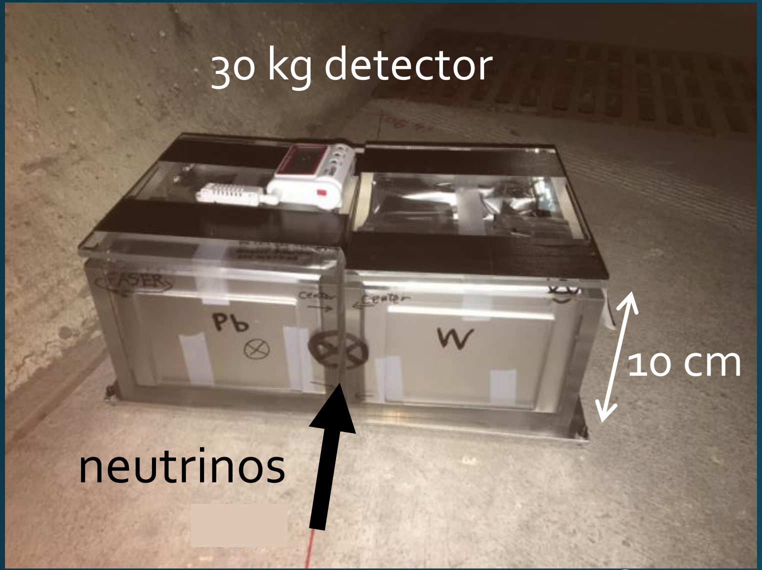


XSEN group investigated locations around CMS
10.1088/1361-6471/ab3f7c
Background levels were too high for emulsion detectors

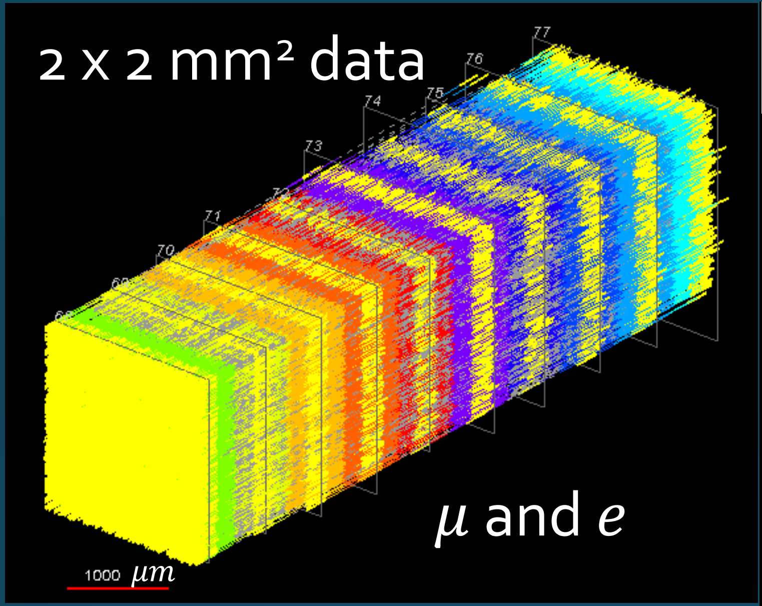
FASER group investigated those at very forward of ATLAS, TI-18 and TI-12
10.1140/epjc/s10052-020-7631-5
Background levels were reasonably low!



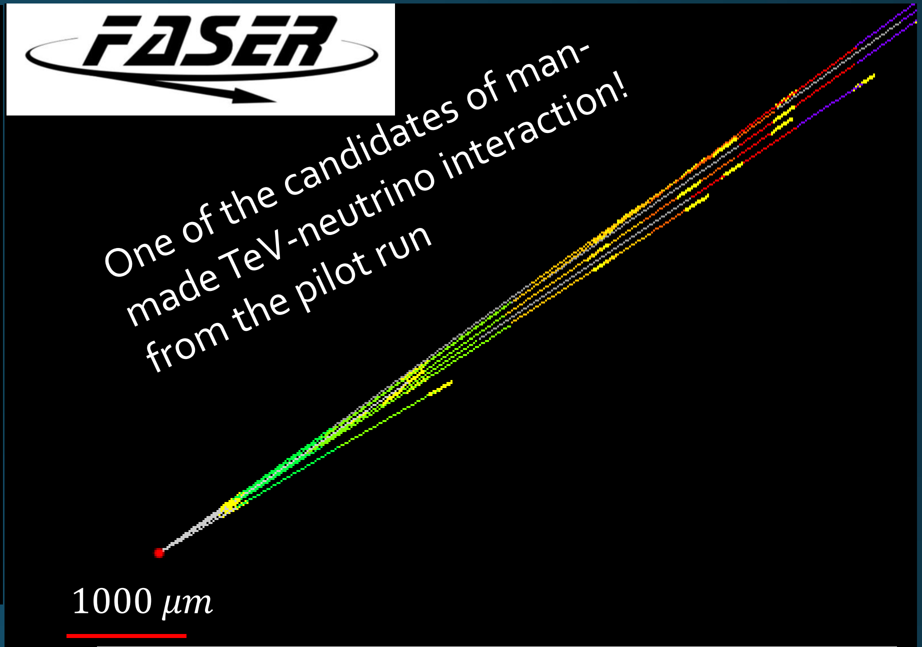
FASERν pilot run in 2018 at TI-18



6 weeks, 12.2 fb^{-1}



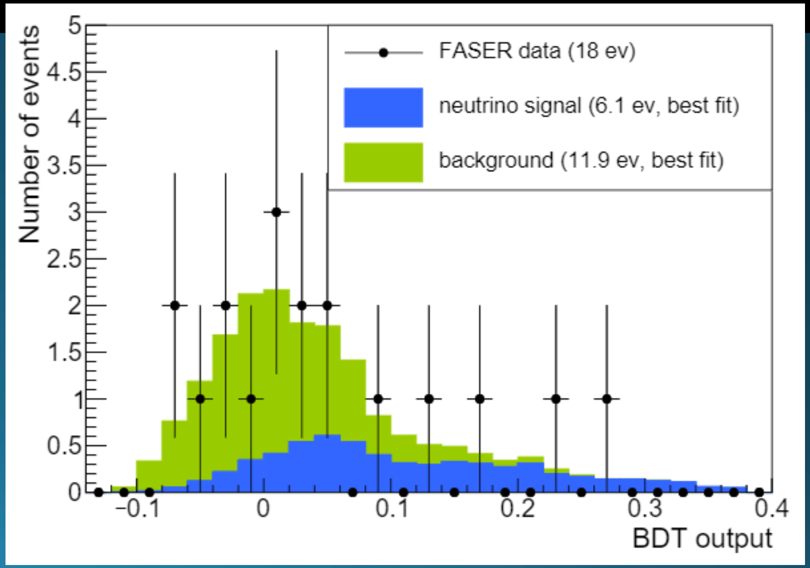
$\simeq 3 \times 10^5$ tracks/cm²



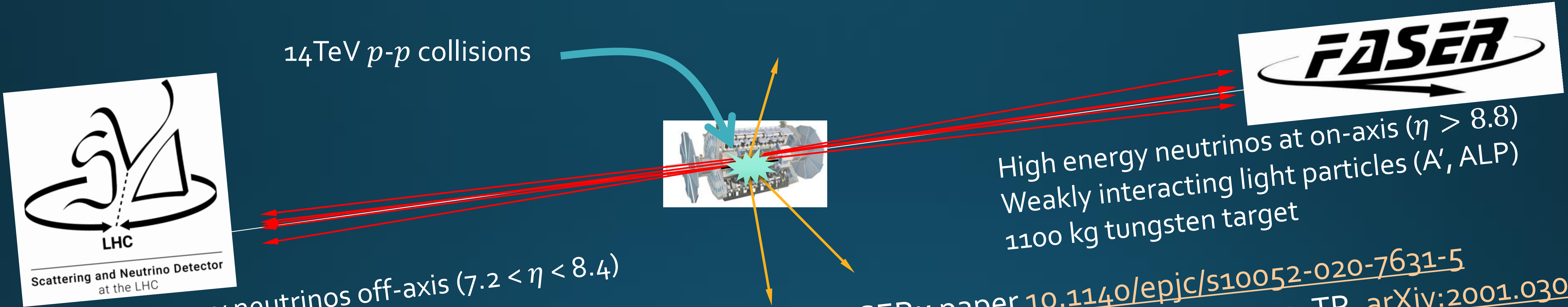
One of the candidates of man-made TeV-neutrino interaction from the pilot run

- A 30 kg emulsion based detector, on axis, collected 12.2 fb^{-1} of data in Sep-Oct 2018
- First neutrino candidates at 2.7 σ

Phys. Rev. D 104, L091101 (2021)



Neutrino experiments at the LHC

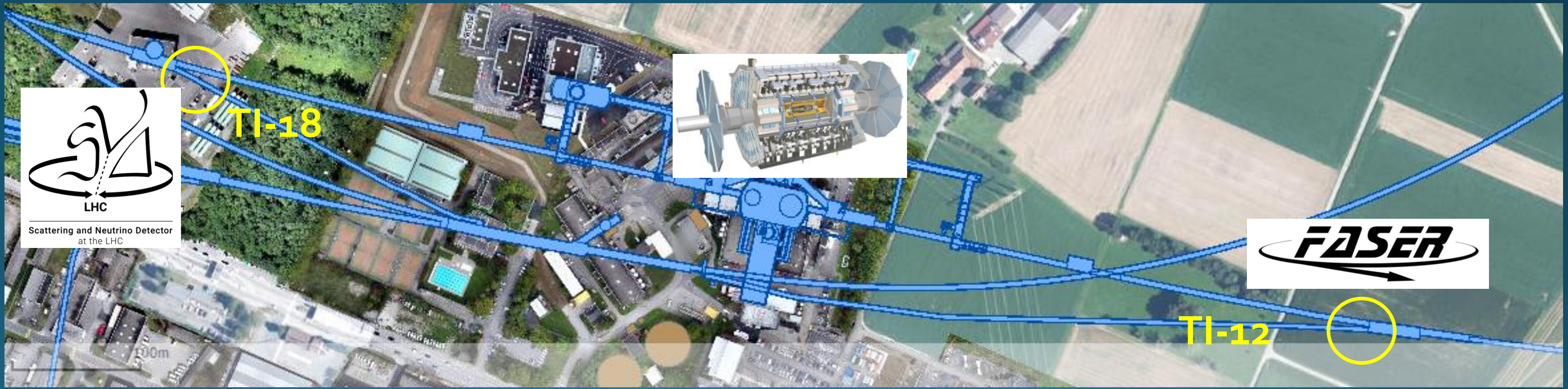


High energy neutrinos at on-axis ($\eta > 8.8$)
Weakly interacting light particles (A′, ALP)
1100 kg tungsten target

Mid-high energy neutrinos off-axis ($7.2 < \eta < 8.4$)
800 kg tungsten target

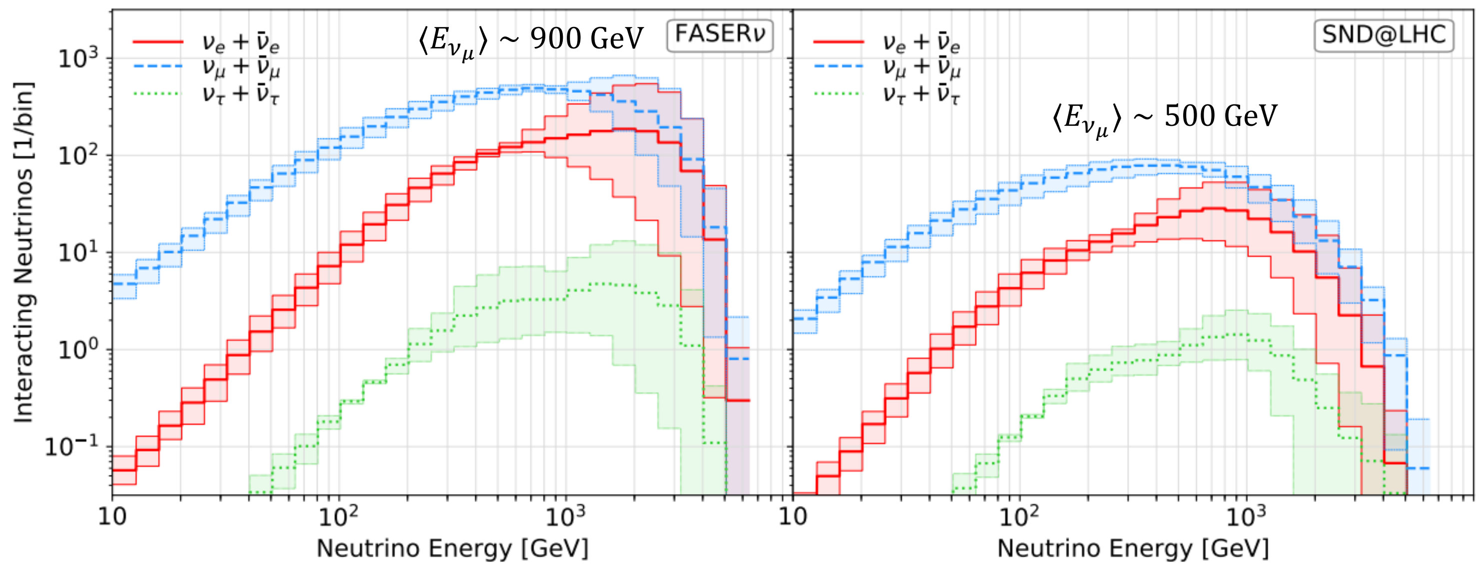
SND@LHC was approved in Mar 2021,
TP arXiv:2002.08722

FASERν paper 10.1140/epjc/s10052-020-7631-5
FASERν was approved in Dec 2019, TP arXiv:2001.03073



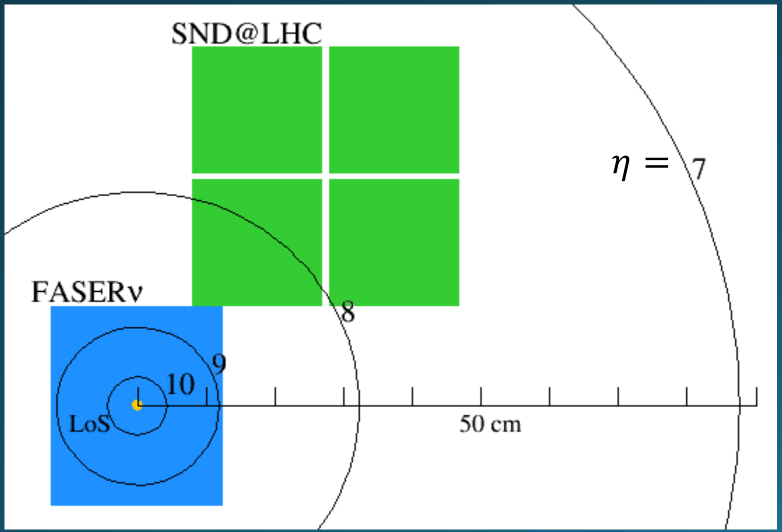
Expected neutrino spectra

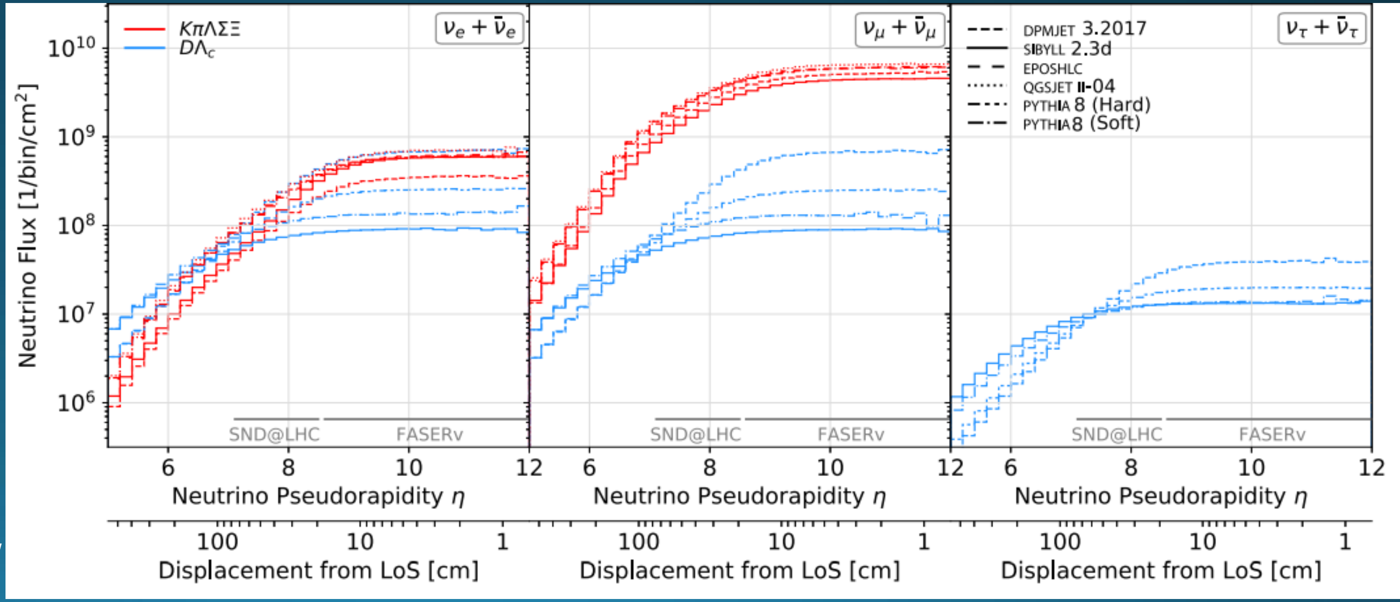
Expected CC interactions with 150 fb^{-1}



	FASERν	**SND@LHC**
Target mass	1100 kg	800 kg
Location	On axis	Off axis
Features	High energy & high statistics	More neutrinos from charm decay

10.1103/PhysRevD.104.113008





Expected number of CC interactions

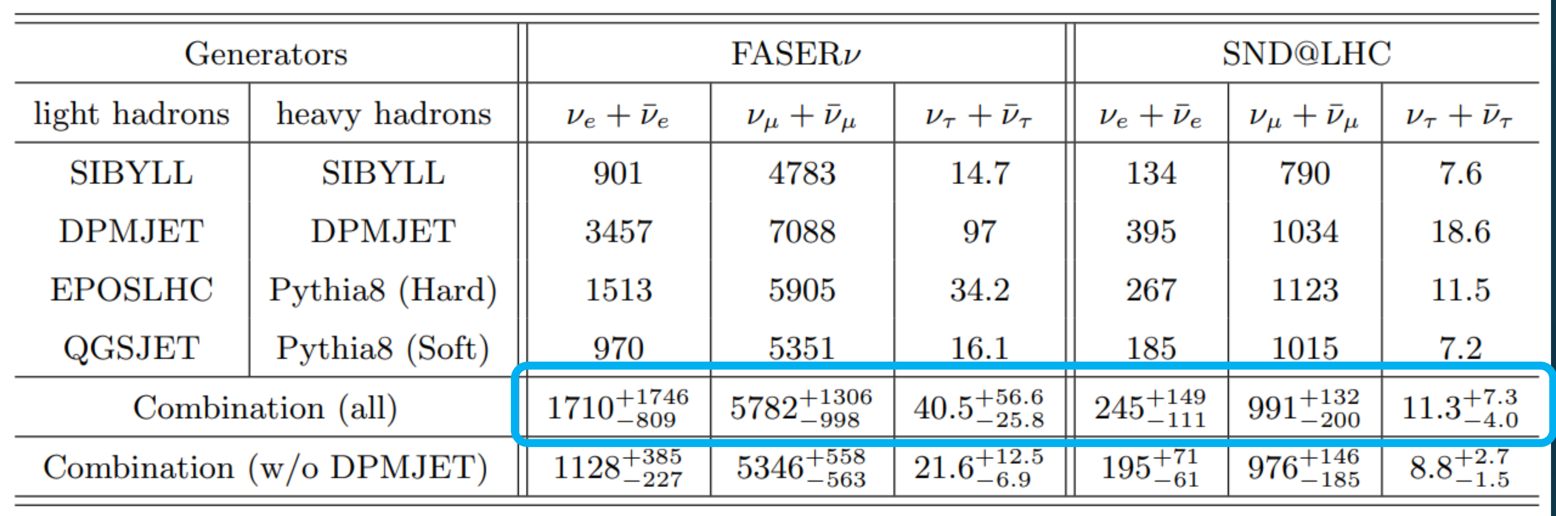
10.1103/PhysRevD.104.113008

Three flavors neutrino cross section measurements at unexplored energies

O(10,000) ν interactions expected in LHC Run 3

Test Lepton Universality in CC-int

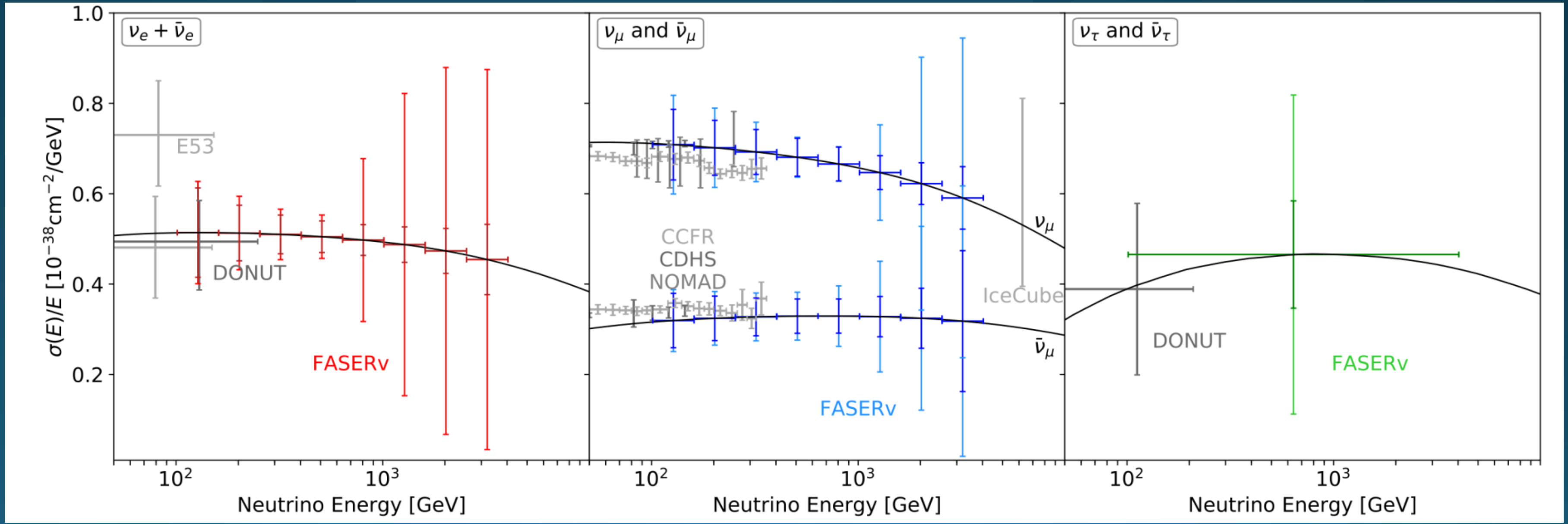
Also NC interaction studies



Generators		FASERν			SND@LHC		
light hadrons	heavy hadrons	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$
SIBYLL	SIBYLL	901	4783	14.7	134	790	7.6
DPMJET	DPMJET	3457	7088	97	395	1034	18.6
EPOSLHC	Pythia8 (Hard)	1513	5905	34.2	267	1123	11.5
QGSJET	Pythia8 (Soft)	970	5351	16.1	185	1015	7.2
Combination (all)		1710^{+1746}_{-809}	5782^{+1306}_{-998}	$40.5^{+56.6}_{-25.8}$	245^{+149}_{-111}	991^{+132}_{-200}	$11.3^{+7.3}_{-4.0}$
Combination (w/o DPMJET)		1128^{+385}_{-227}	5346^{+558}_{-563}	$21.6^{+12.5}_{-6.9}$	195^{+71}_{-61}	976^{+146}_{-185}	$8.8^{+2.7}_{-1.5}$

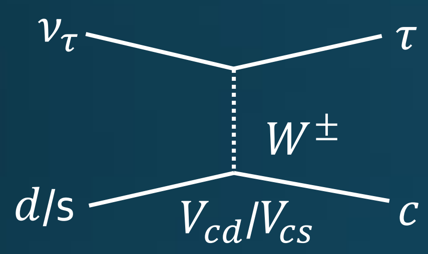
Expected CC interactions with 150 fb^{-1}

Projected cross section sensitivities (FASERν)

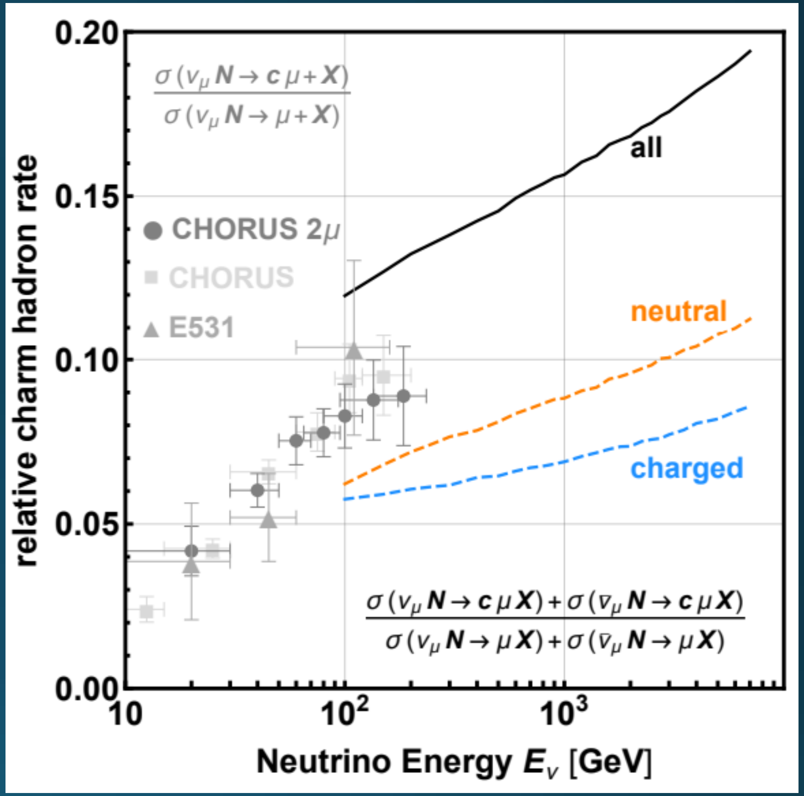


neutrino-induced heavy-flavor production

- Measure charm production channels
  - Large rate ~ 15% ν CC events. Charm factory!
  - First measurement of ν_e induced charm prod.

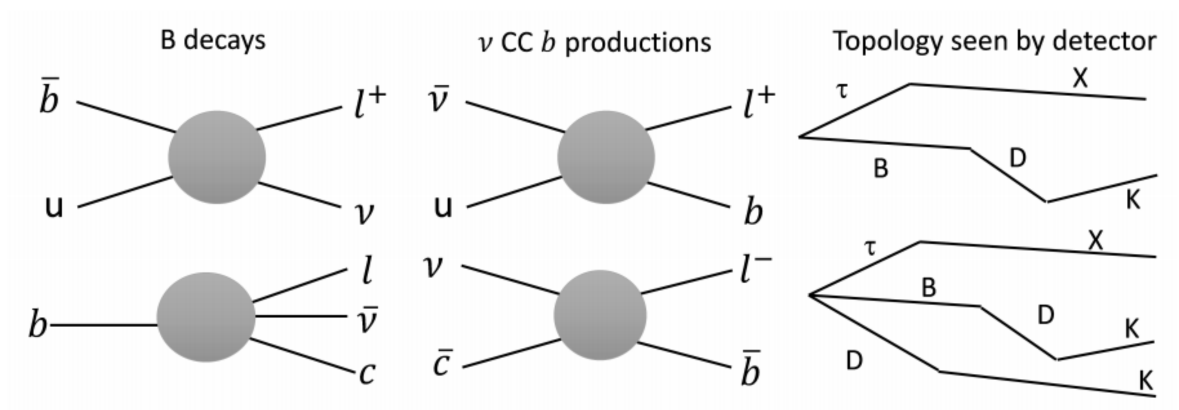


$$\frac{\sigma(\nu_\ell N \to \ell\, X_c + X)}{\sigma(\nu_\ell N \to \ell + X)} \quad \ell = e, \mu, \tau$$



Eur. Phys. J. C (2020) **80**: 61

- Search for Beauty production channels
  - Expected SM events (ν_μ CC b production) are $\mathcal{O}(0.1)$ events due to CKM suppression, $V_{ub}^2 \simeq 10^{-5}$



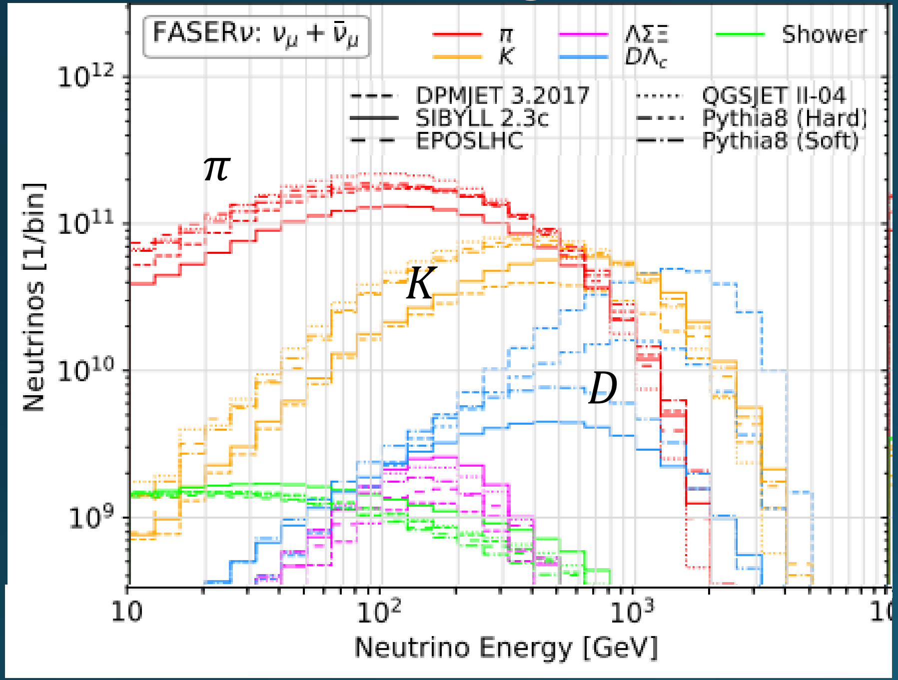
$$\bar\nu N \to \ell \bar{B} X$$

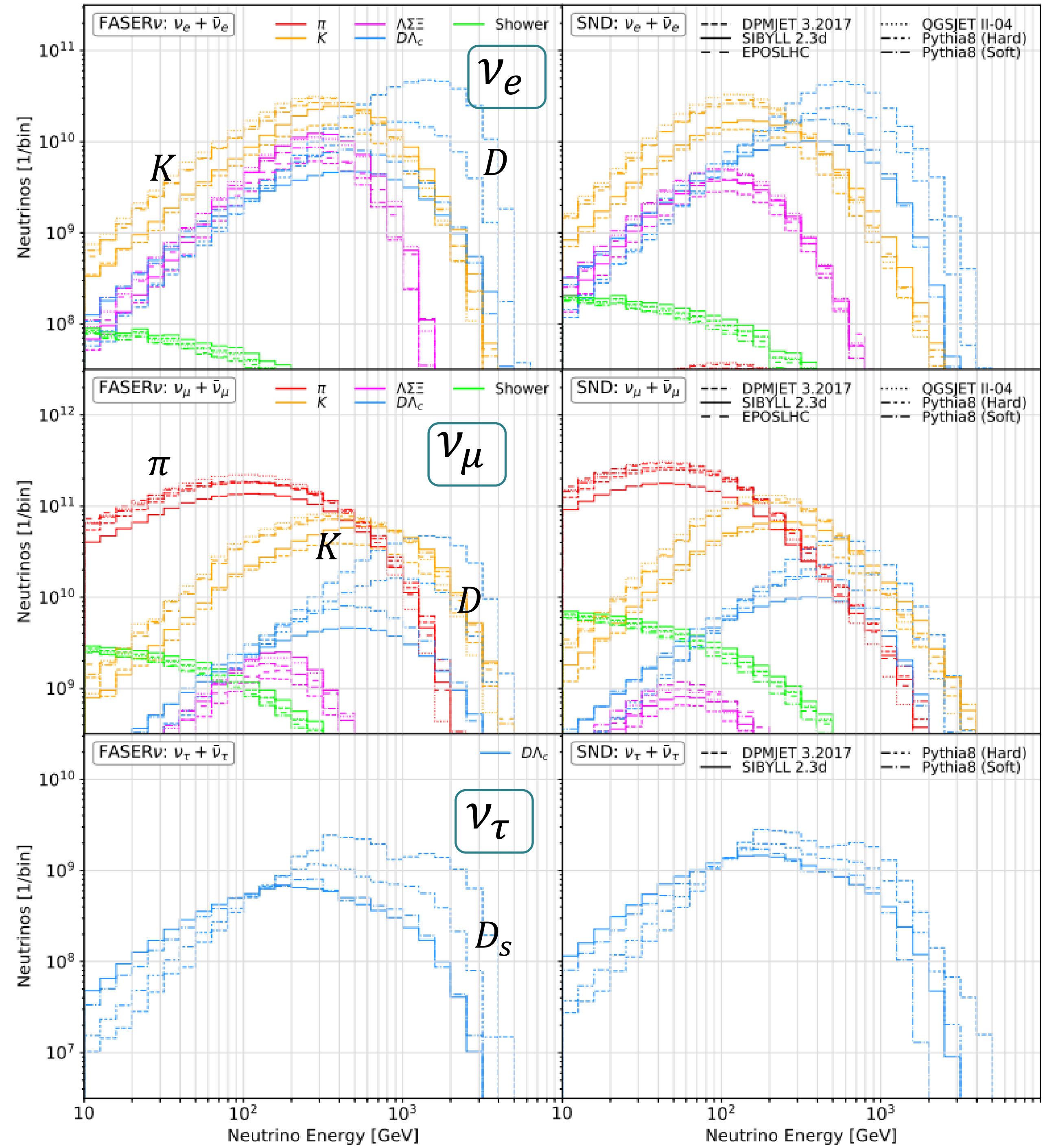
$$\nu N \to \ell B D X$$

Neutrinos = proxy of forward hadron production

- Pion, Kaon, charm contribute to different part of rapidity and energy spectra and flavor

ν_μ

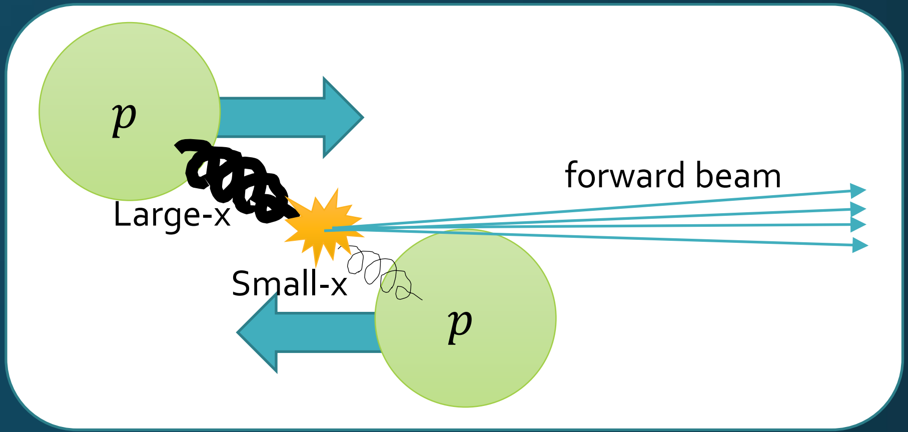


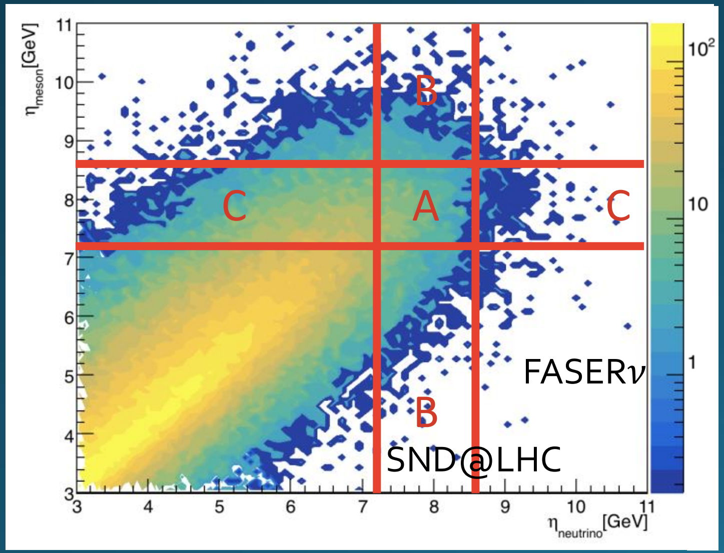


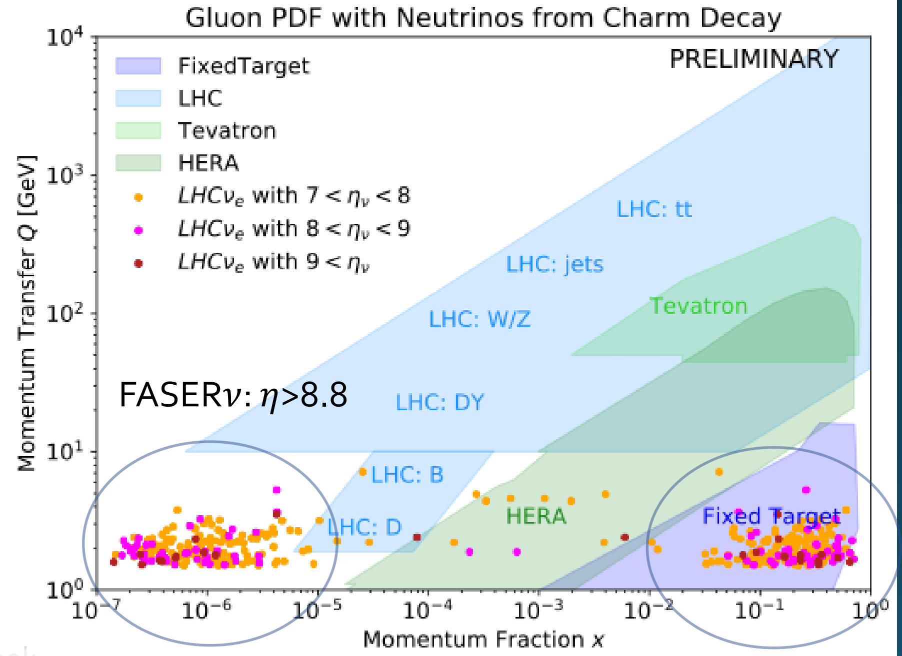
- FASERν and SND@LHC provides important inputs to validate/improve generators → Muon excess, prompt neutrinos

Further insights on QCD

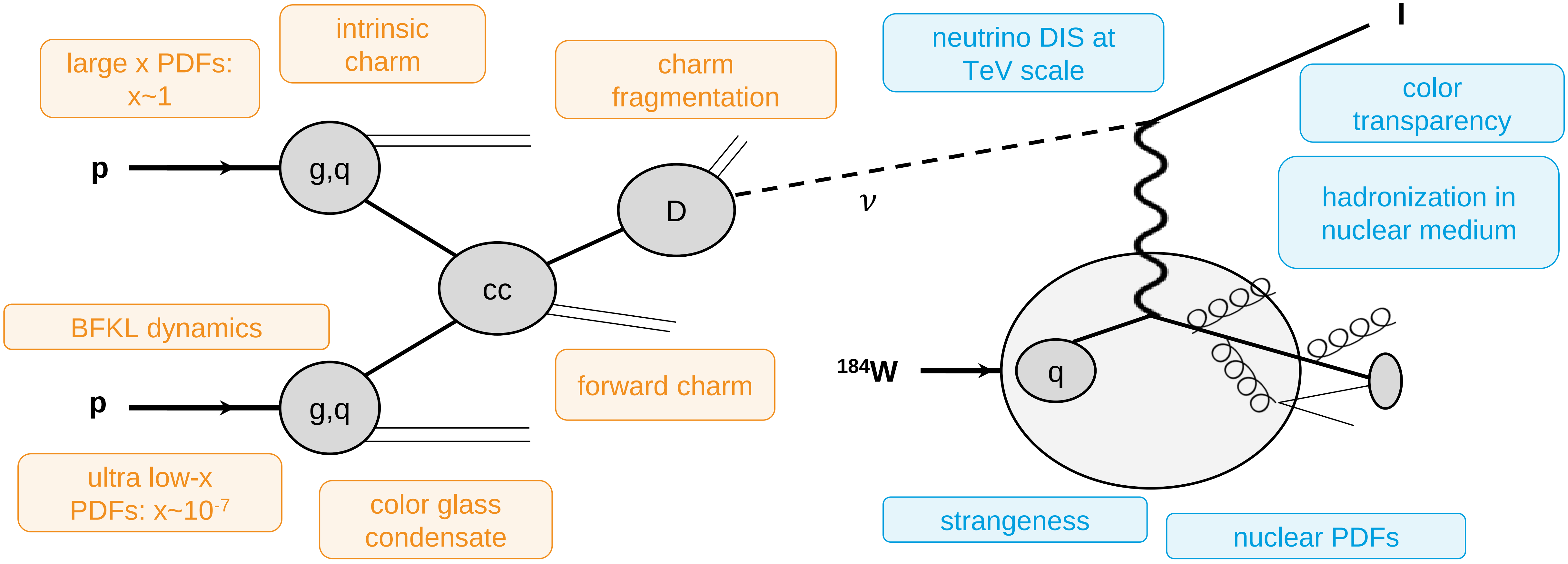
- Asymmetric collisions → Forward beam
- New kinematical regime at $x < 10^{-5}$
- Neutrinos from charm decay in FASERν and SND@LHC could allow to test transition to small-x factorization, probe intrinsic charm







QCD using LHC Neutrinos



large x PDFs: x~1

intrinsic charm

charm fragmentation

BFKL dynamics

forward charm

ultra low-x PDFs: x~10^{-7}

color glass condensate

Forward Particle Production

TeV Energy Neutrino Interaction

neutrino DIS at TeV scale

color transparency

hadronization in nuclear medium

strangeness

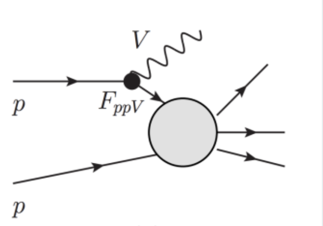
nuclear PDFs

shadowing

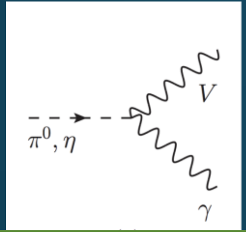
EMC effect

Feebly interacting particles

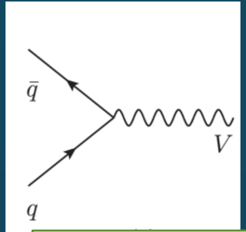
- SND@LHC, FASER is sensitive to new **dark sector** particles



p bremmstrahlung

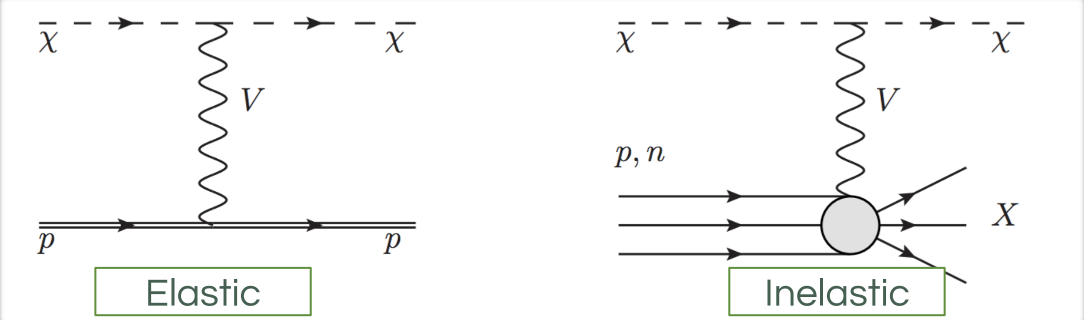


Meson decay



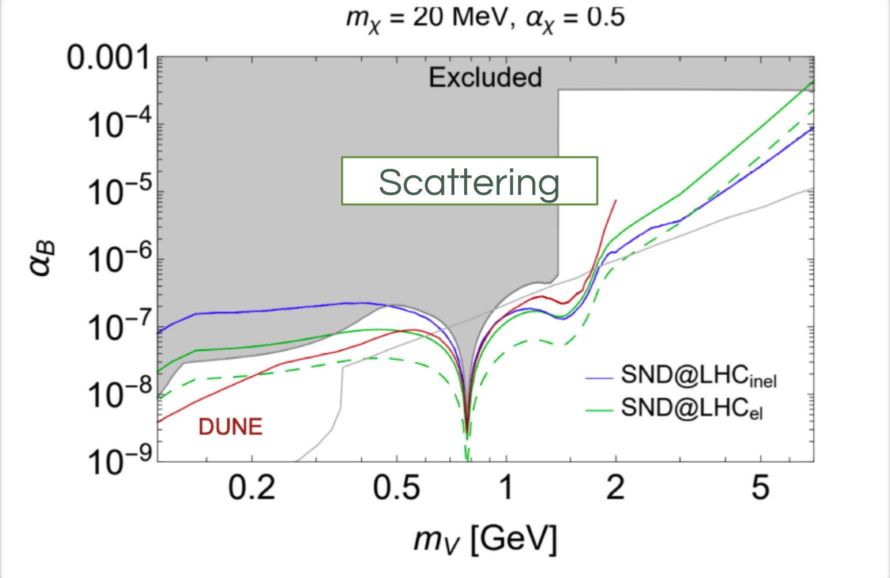
Drell-yan

  - **Scattering** in SND@LHC
    - E.g., scalars interacting with nucleons via a leptophobic portal



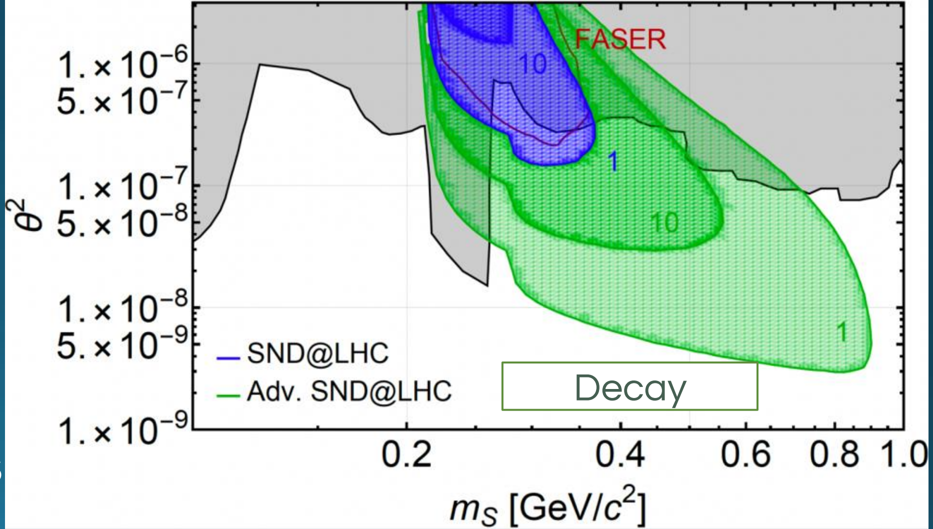
Elastic

Inelastic



Scattering

  - **Decaying** in SND@LHC, FASER
    - Dark scalars, heavy neutral leptons or dark photons decaying into a pair of charged tracks



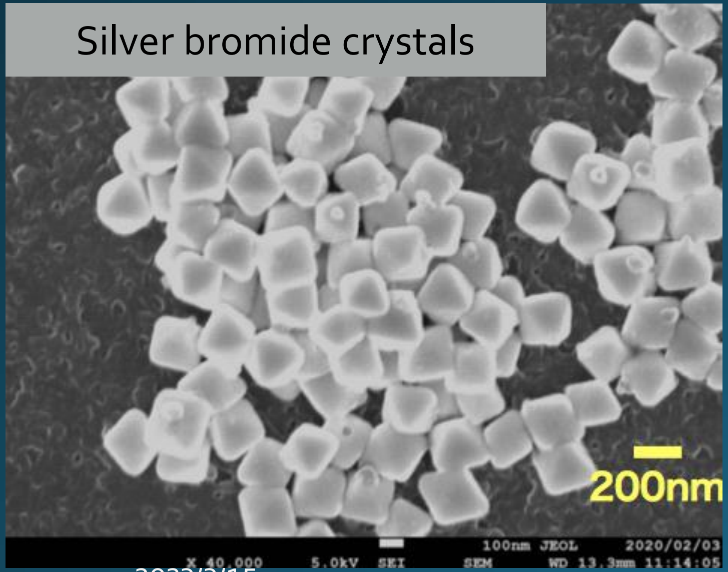
Decay

10.1007/JHEP03(2022)006

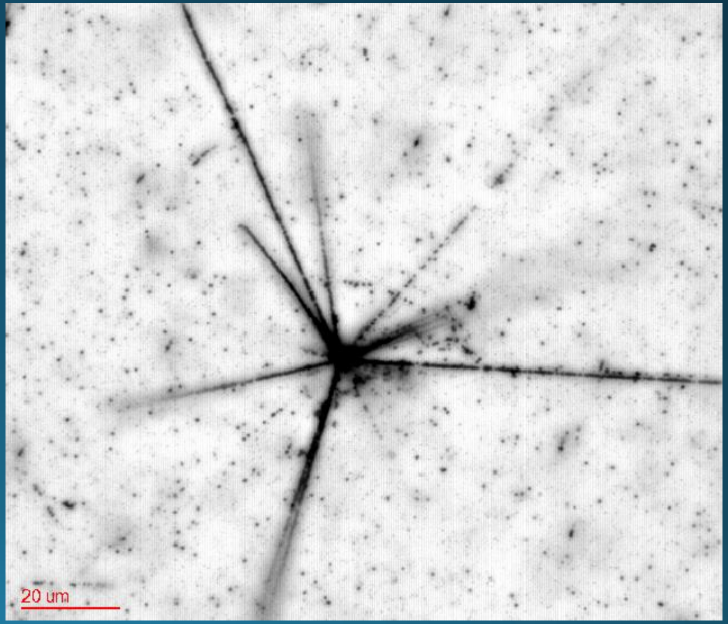
Experimental status

Emulsion-based neutrino target

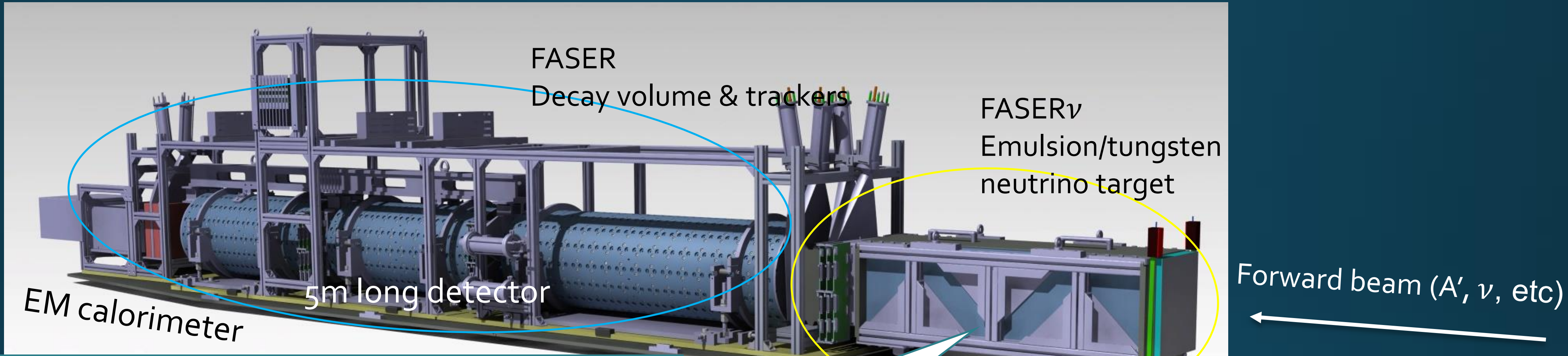
- Employed by both FASERν and SND@LHC
- Super large number of detection channels ~ 8×10^{14} detection channels / film (30 x 25 cm^2 in FASERν). (39 x 39 cm2 in SND@LHC)
- 3D tracking device with 50 nm intrinsic resolution
- Coupled with tungsten target

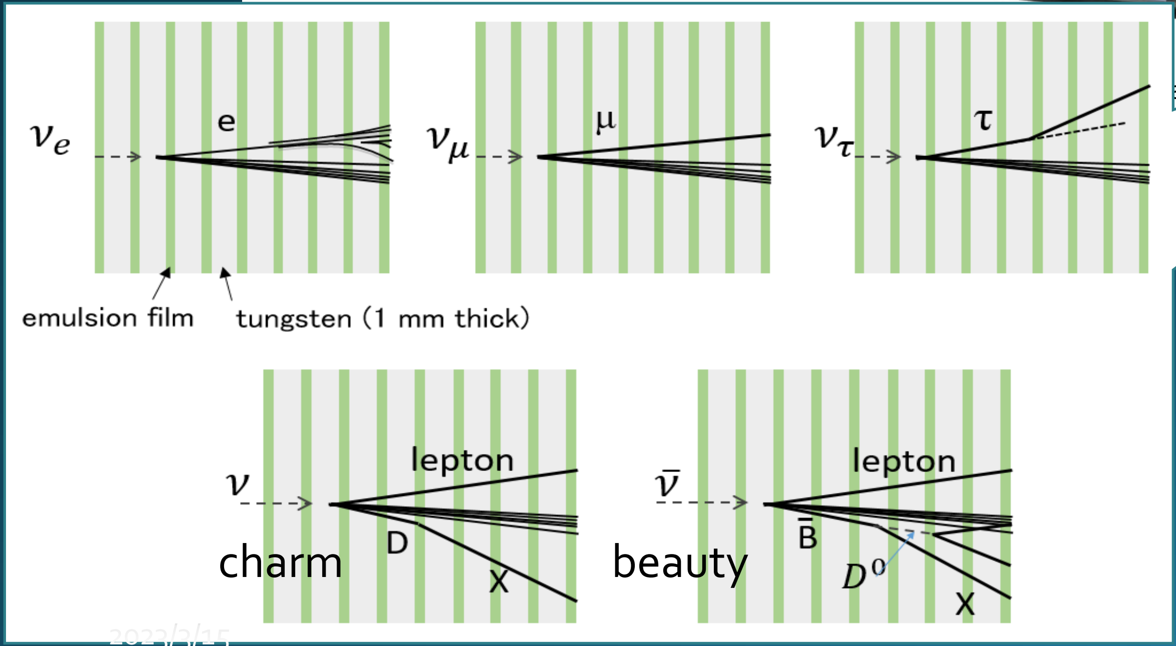

Silver bromide crystals


Emulsion films produced in Japan



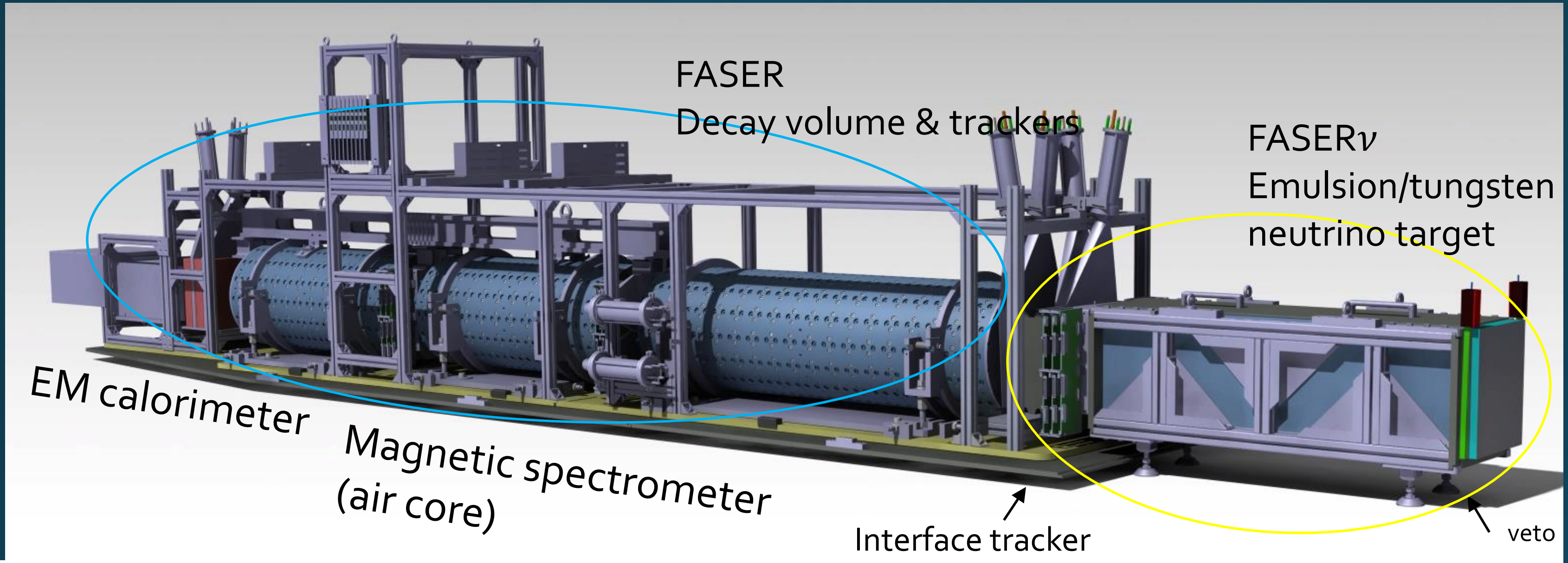
FASER+FASERν detector in Run3 (2022-2025)



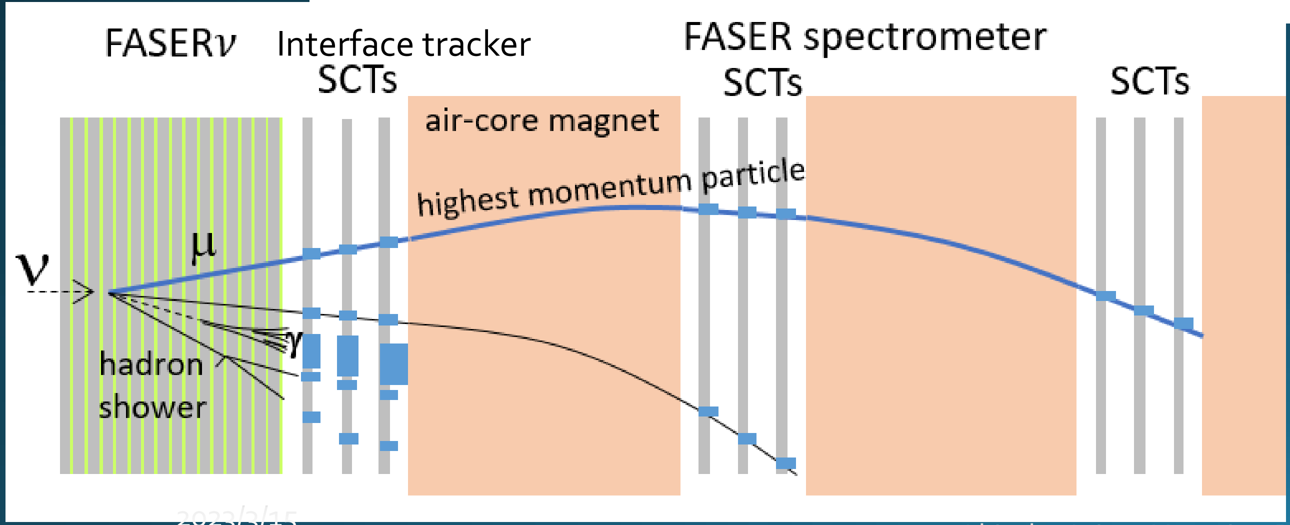


- Emulsion films = trackers with sub-micron spatial resolution, $\sigma_{intrinsic} \simeq 50\ nm$, $\sigma_{practical} \simeq 0.3\ \mu m$
- 730 1.1-mm-thick tungsten target and emulsion films
- 25x30 cm^2, 1.1 m, 1.1 tons (8 λ_{int}, 220X_0)
- Sensitive to 3 flavor neutrinos
- Muon ID in track length in tungsten
- Replace emulsions 3 times a year

FASER+FASERν detector in Run3 (2022-2025)



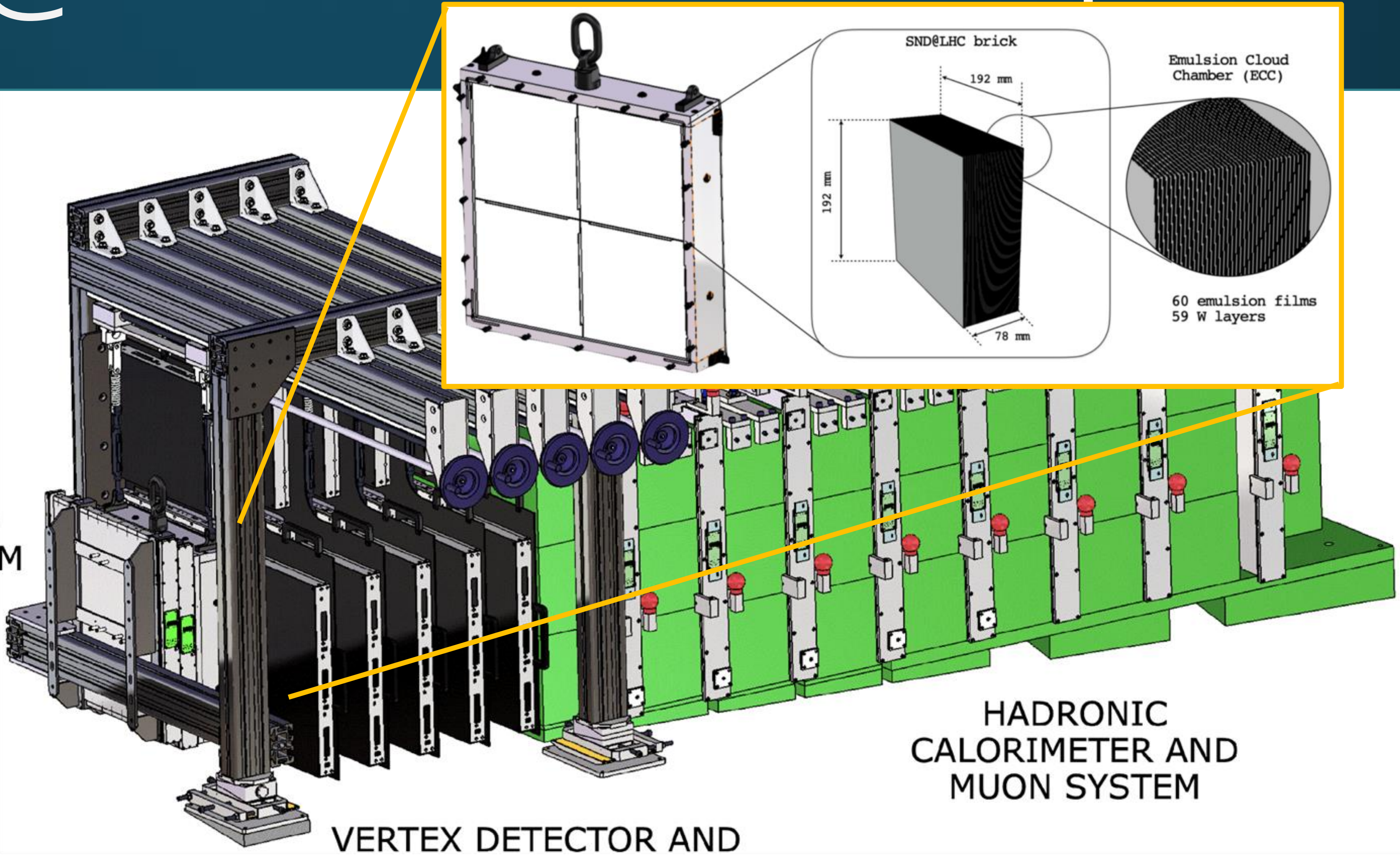
Forward beam (A′, ν, etc)



- Global reconstruction with FASER spectrometer
  → muon charge identification
  → $\nu_\mu/\bar{\nu}_\mu$ separation
- Improve energy resolution

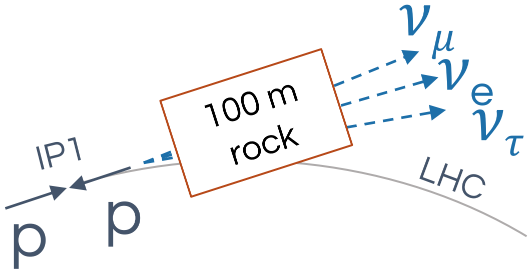
The SND@LHC detector concept

- Hybrid detector design.
- Optimized for the identification of three neutrino flavours and feebly interacting particles.



Scintillator strips + iron

Emulsion/W target and SciFi planes

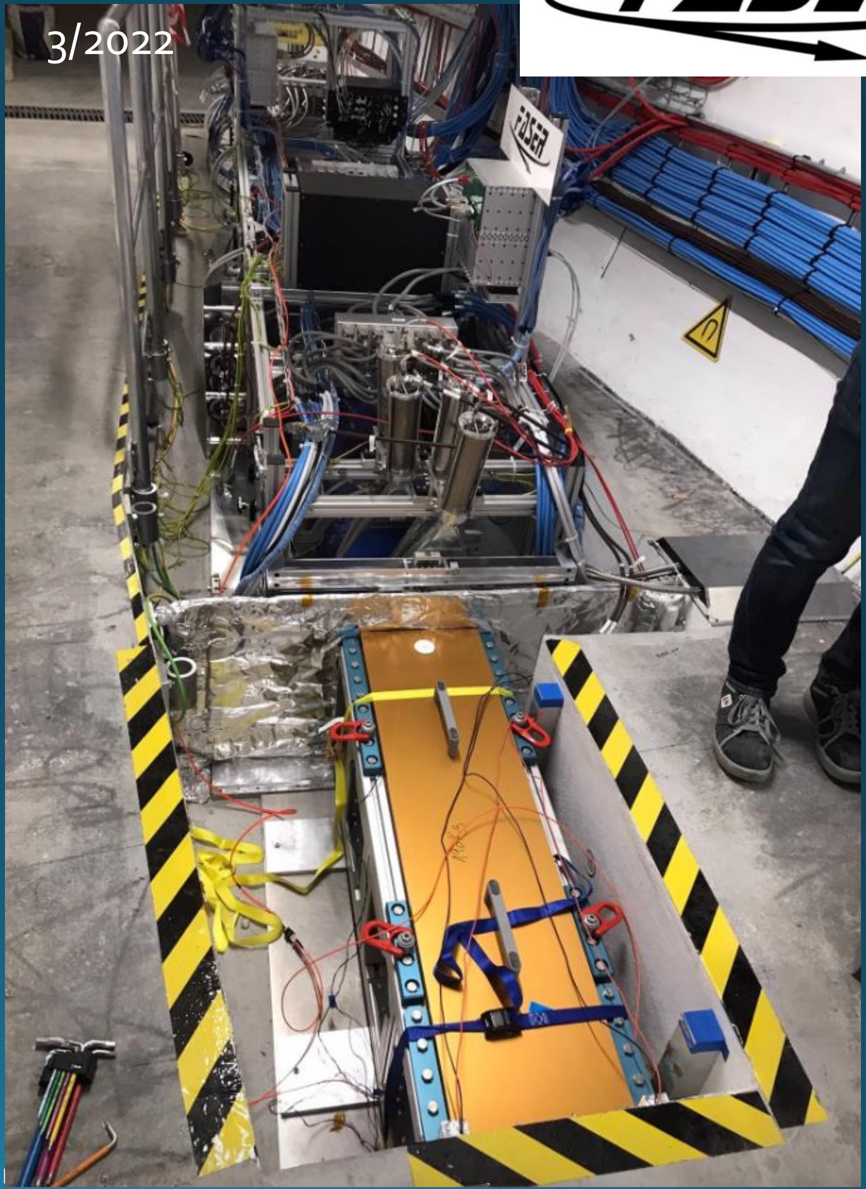


Construction

- Despite the difficult period, both neutrino experiments were constructed in time for Run3!
- Amazingly quick works!

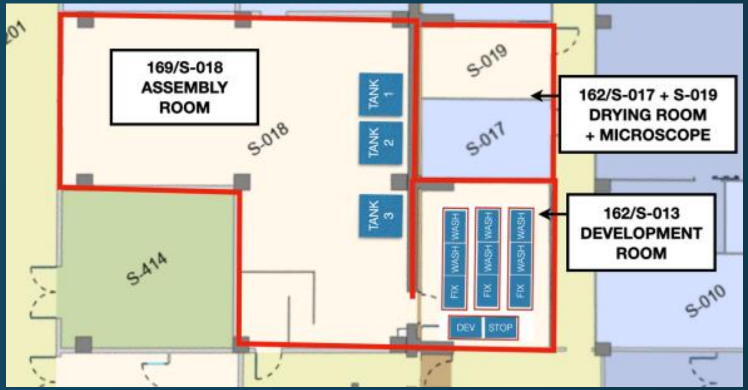
LHC

Scattering and Neutrino Detector at the LHC



3/2022

CERN Emulsion Facility



- Dark room at CERN established in 80s → Obsolete
- Emulsion experiments are increasing: NA65/DsTau, FASERν, SND@LHC, SHiP, test beams…
- Refurbished recently, big thanks for supports from CERN!
- Experiments share installation and equipment


Dark room operation
Assembling of FASERν and SND@LHC


Temperature controlled developer bath

Development timer

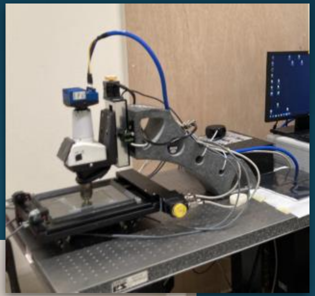

1 04:39:09 01:09:09 passed since finished
2 04:33:09 01:03:09 passed since finished
3 03:06:25 00:36:25 wash2 00:23:35 to finish
4 02:01:21 00:31:21 wash1 00:28:39 to wash2
5 00:59:08 00:29:08 fix 00:30:52 to wash1
6 00:24:33 00:04:33 stop 00:05:27 to fix
7 00:10:50 00:10:50 develop 00:09:10 to stop
8
9
10
11
12

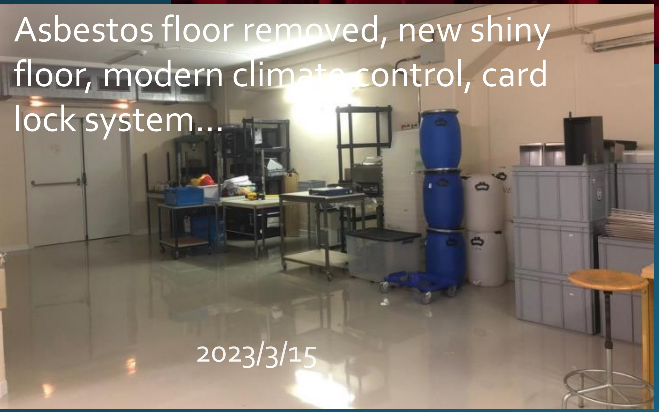
18:52 22
14 02 2023 Tuesday

Task List
1. Chain6 stop->fix 00:05:28
2. Chain 7 develop -> stop 00:09:11
3. Chain 3 wash2 -> finish 00:23:36

Film drying

Microscope




Asbestos floor removed, new shiny floor, modern climate control, card lock system…

2023/3/15

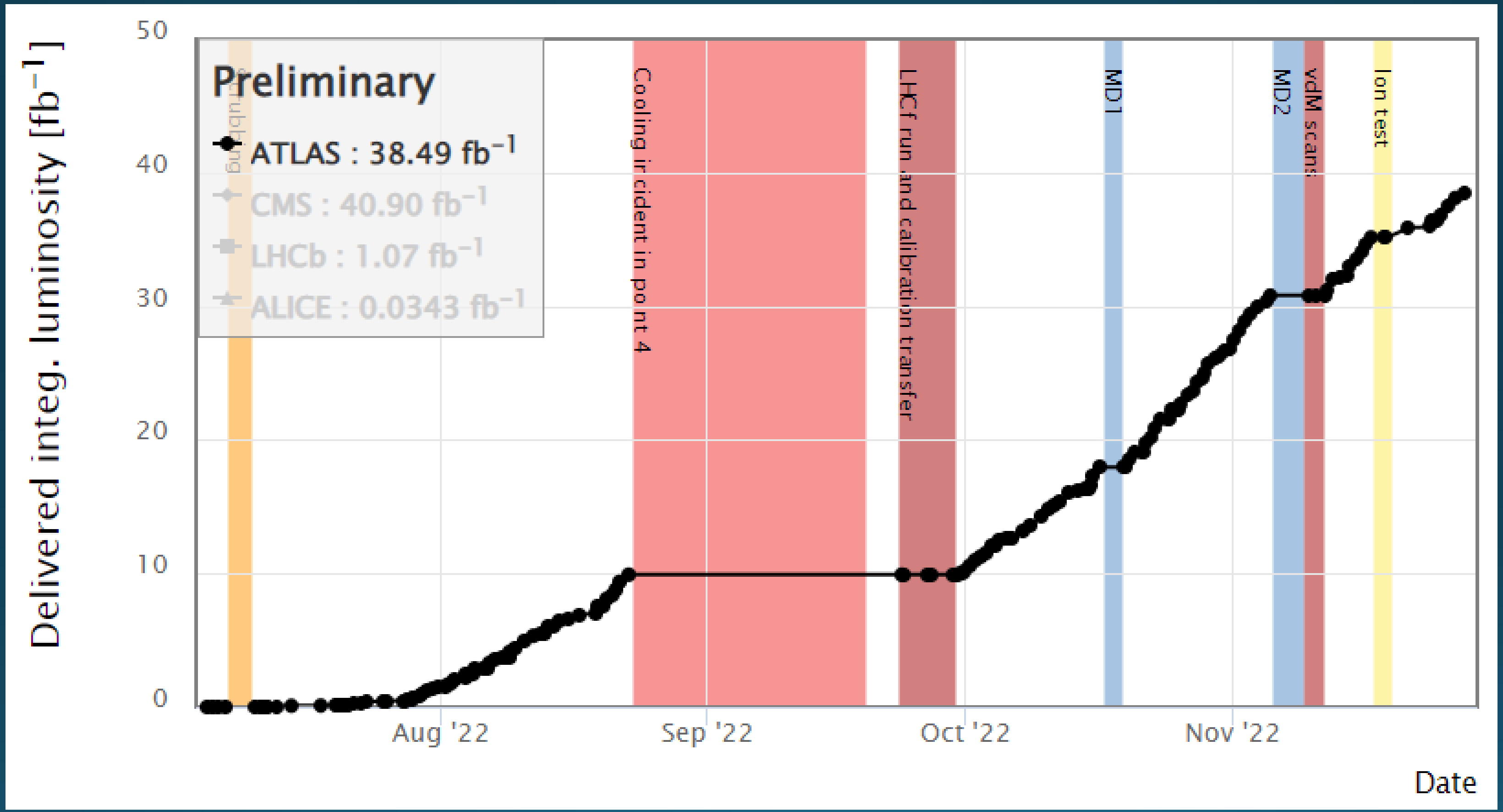

Development room
13 x 100L tanks
Easy disposal system

Disposal

Data taking in 2022

38.5 fb^{-1} of data delivered

Run 3 total expected (2022-2025) = 250 fb^{-1}

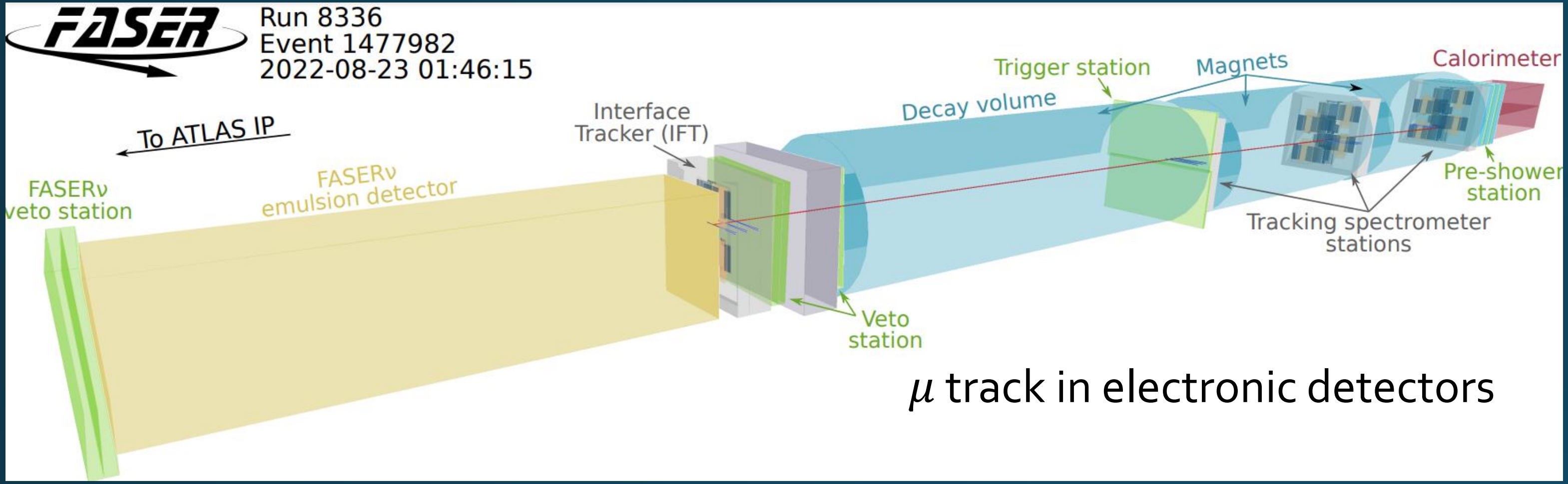


FASER: 0.5 fb^{-1} | 10.6 fb^{-1} | 30.2 fb^{-1}

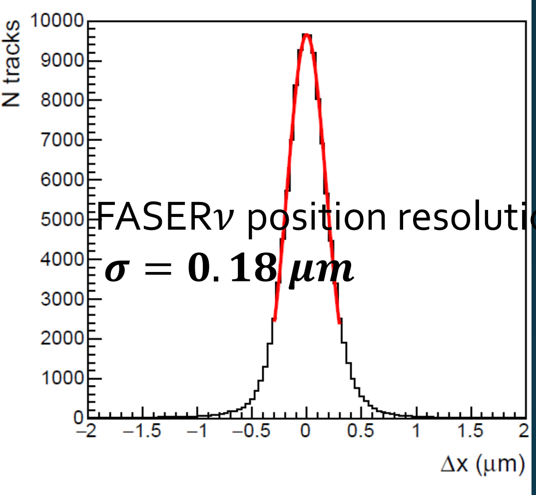
SND@LHC: 0.5 fb^{-1} | 10.6 fb^{-1} | 21.1 fb^{-1} | 9.2 fb^{-1}

Emulsion films were exchanged 3-4 times

Muon tracks in FASER

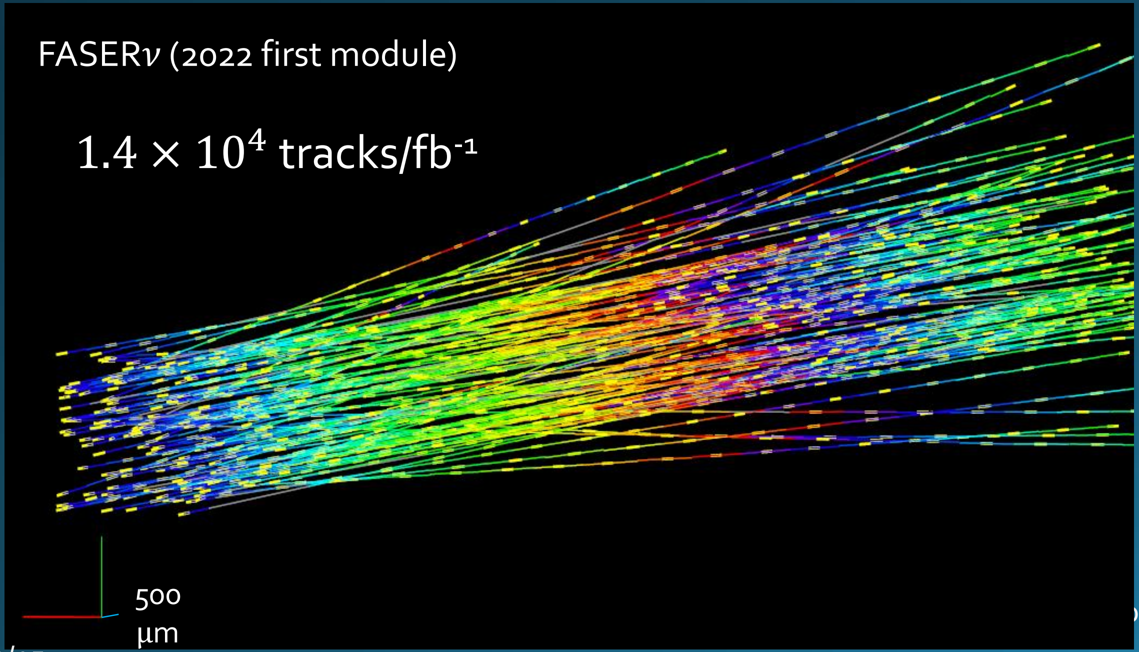


μ track in electronic detectors



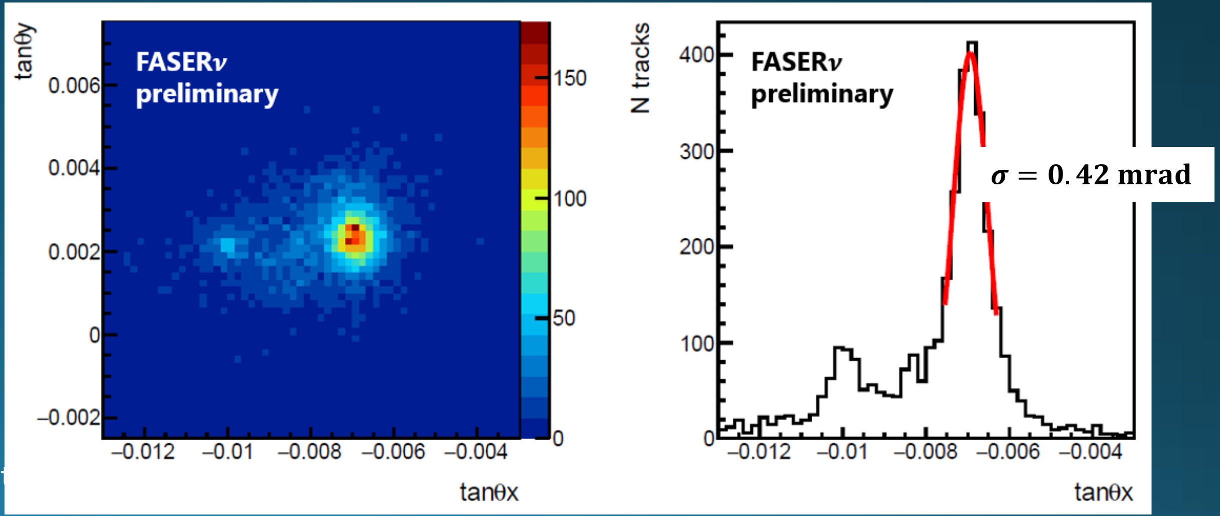
FASERν position resolution

$\boldsymbol{\sigma = 0.18\ \mu m}$



FASERν (2022 first module)

1.4×10^4 tracks/fb-1

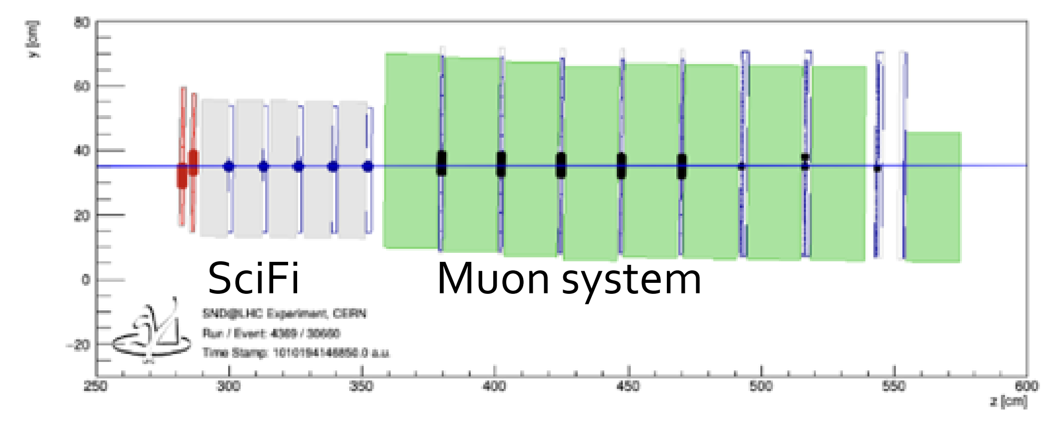


$\sigma = 0.42$ mrad

Muon angular distributions in SND@LHC

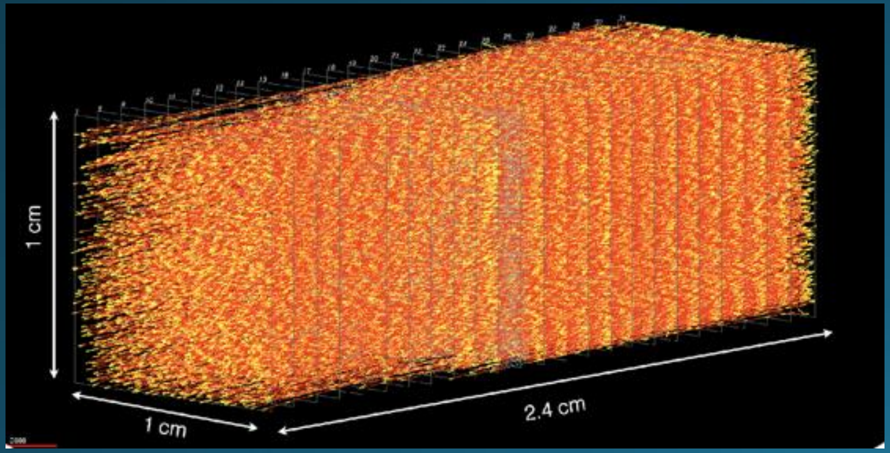
SciFi

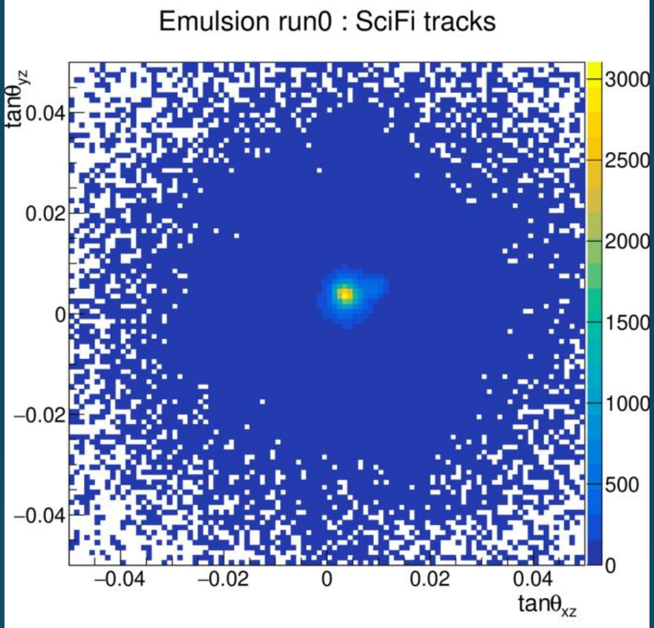
Measured rates on BRICK1 surface
1.4×10^4 fb/cm^2

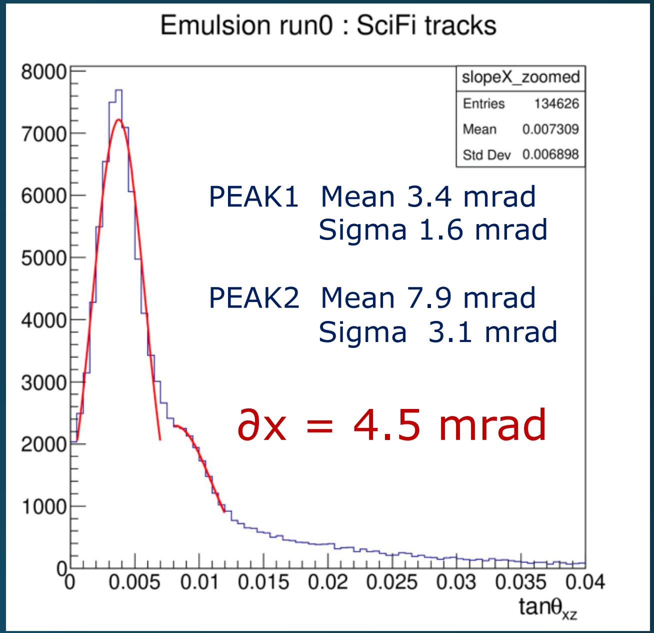


EMULSIONS

Measured rates in BRICK1
1.5×10^4 fb/cm^2



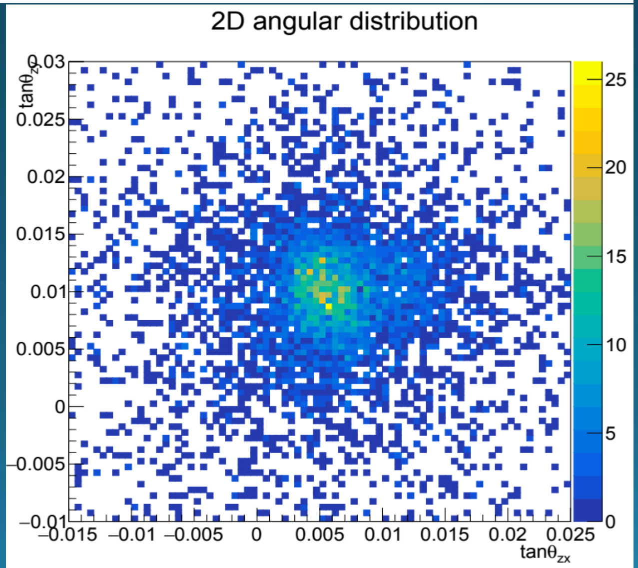

Emulsion run0 : SciFi tracks

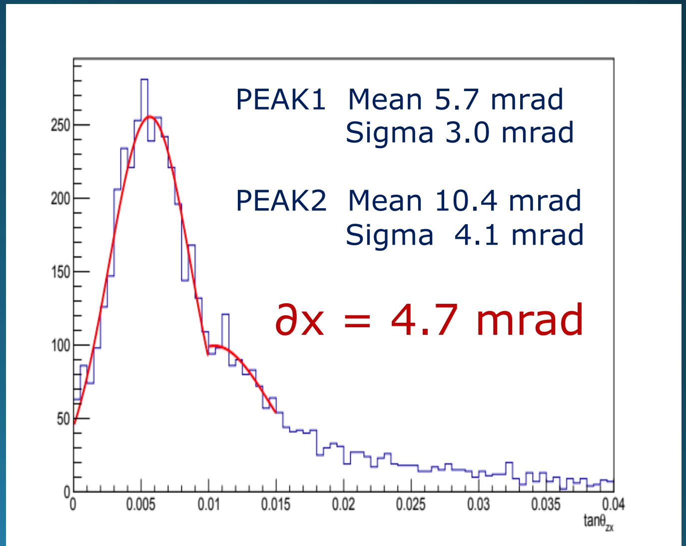

Emulsion run0 : SciFi tracks

PEAK1 Mean 3.4 mrad
Sigma 1.6 mrad

PEAK2 Mean 7.9 mrad
Sigma 3.1 mrad

$\partial x = 4.5$ mrad


2D angular distribution



PEAK1 Mean 5.7 mrad
Sigma 3.0 mrad

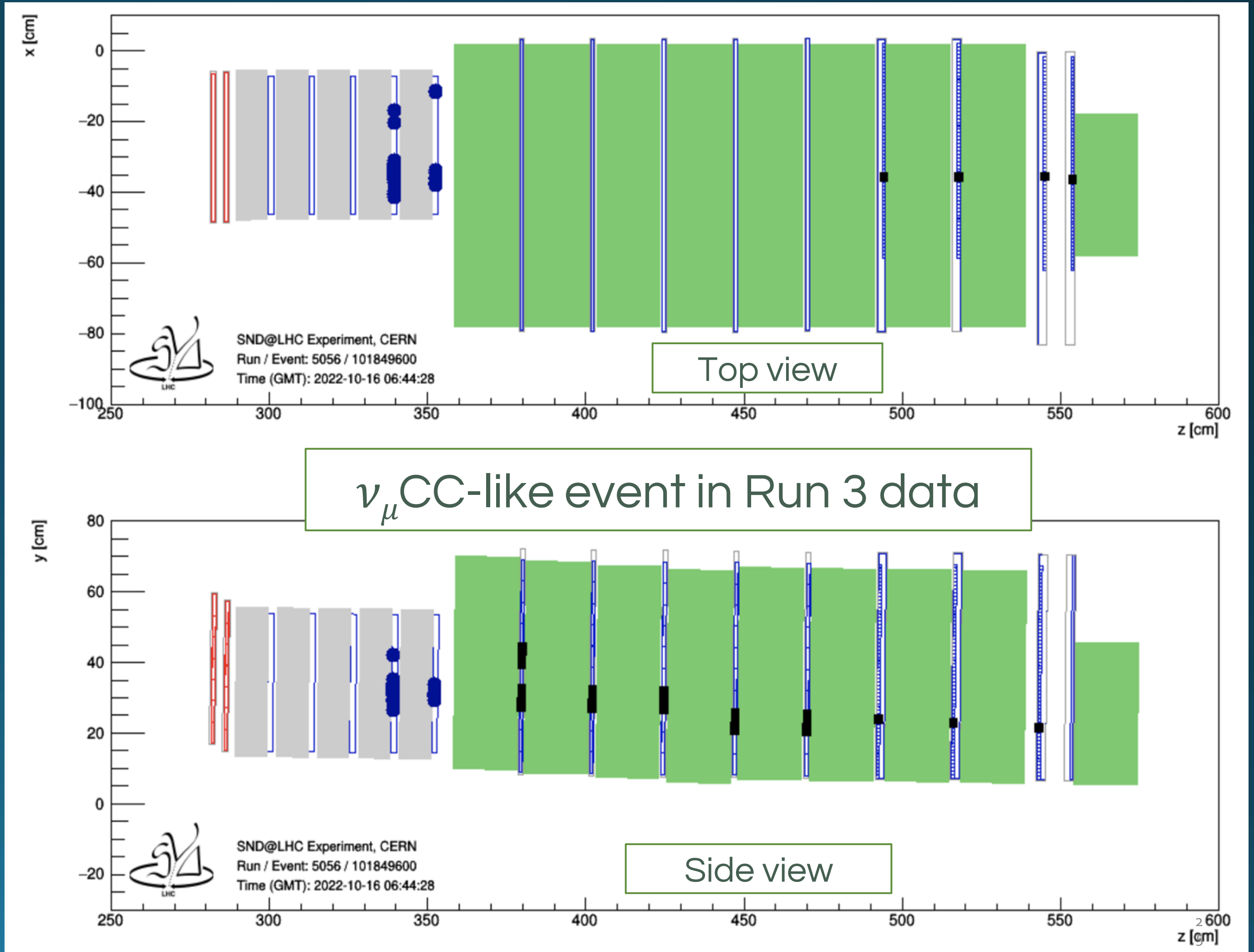
PEAK2 Mean 10.4 mrad
Sigma 4.1 mrad

$\partial x = 4.7$ mrad

NEUTRINO IDENTIFICATION WITH ELECTRONIC DETECTORS

SND@LHC PRELIMINARY

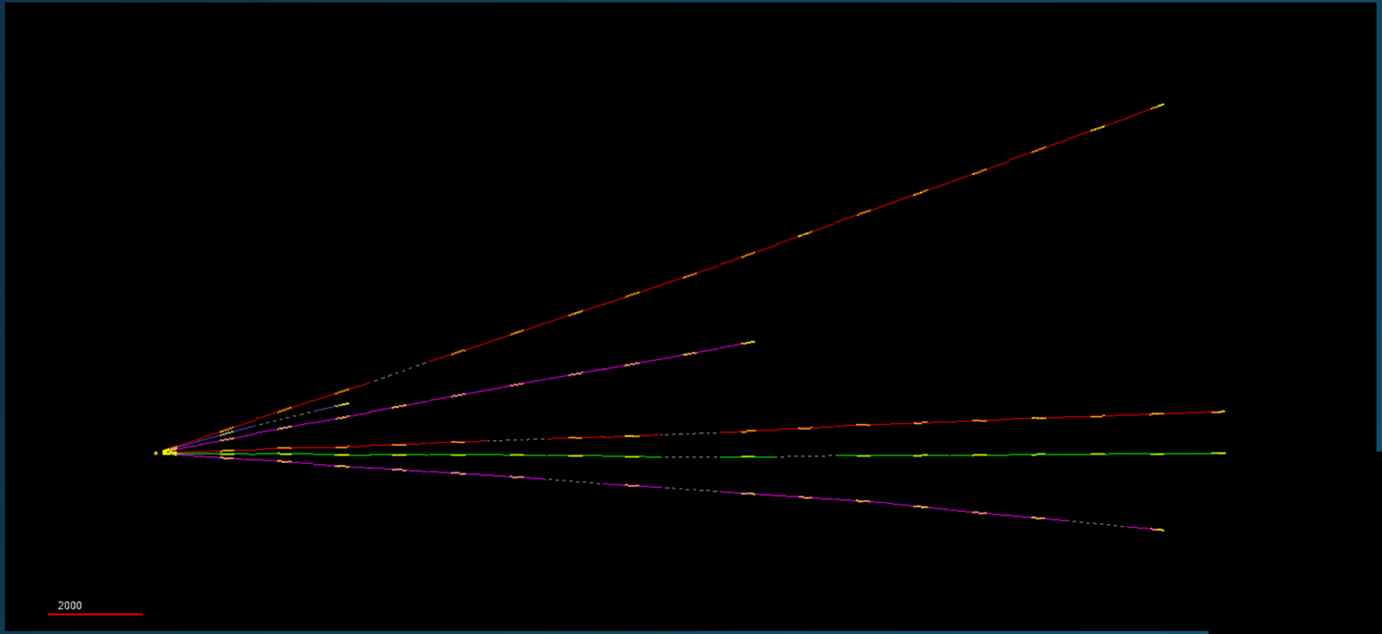
- Analysis of full 2022 data set (~40 fb^{-1})
  - ~10^{10} events
- Signal selection based on topological and calorimetric information
  - No activity in veto or first SciFi station
  - Event does not start in last SciFi station
  - Large activity in calorimeters
  - Tight fiducial volume in target center
  - Event corresponds to IP1 colliding bunch
  - Event is isolated in time from previous and following event
- Identification a few ν_μCC-like
- Detailed estimation of background performed



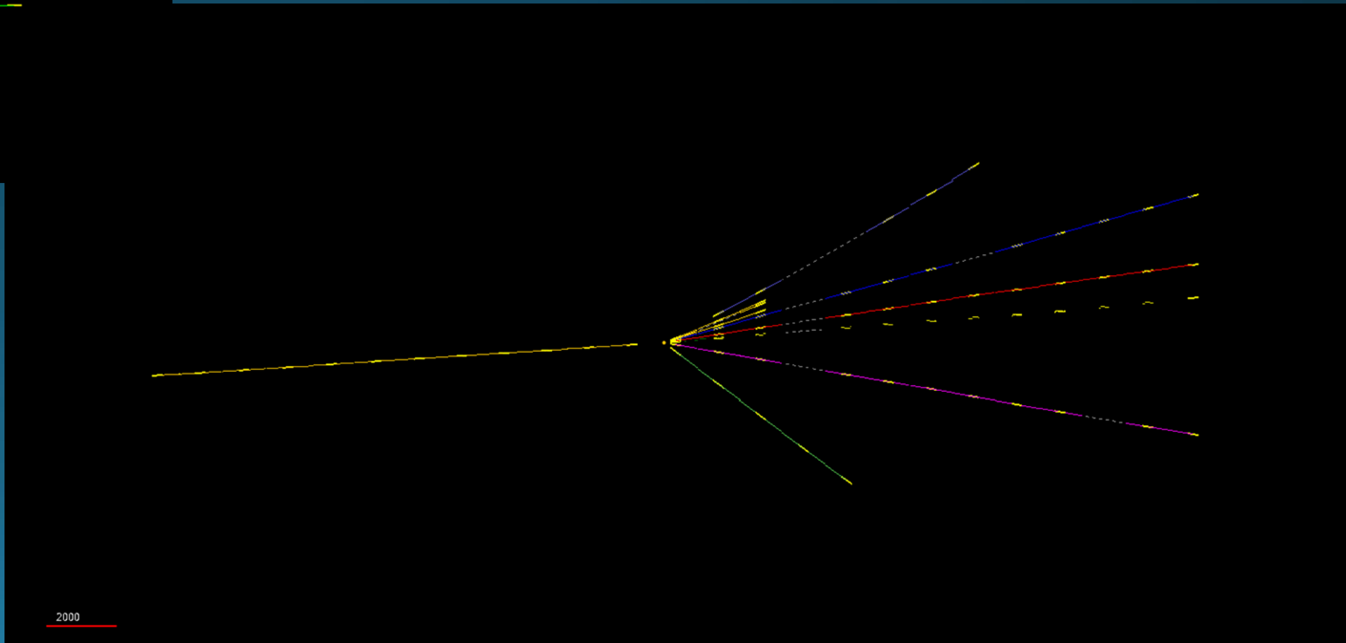
ν_μCC-like event in Run 3 data

VERTEX SEARCH IN EMULSION DATA

- Neutral vertex

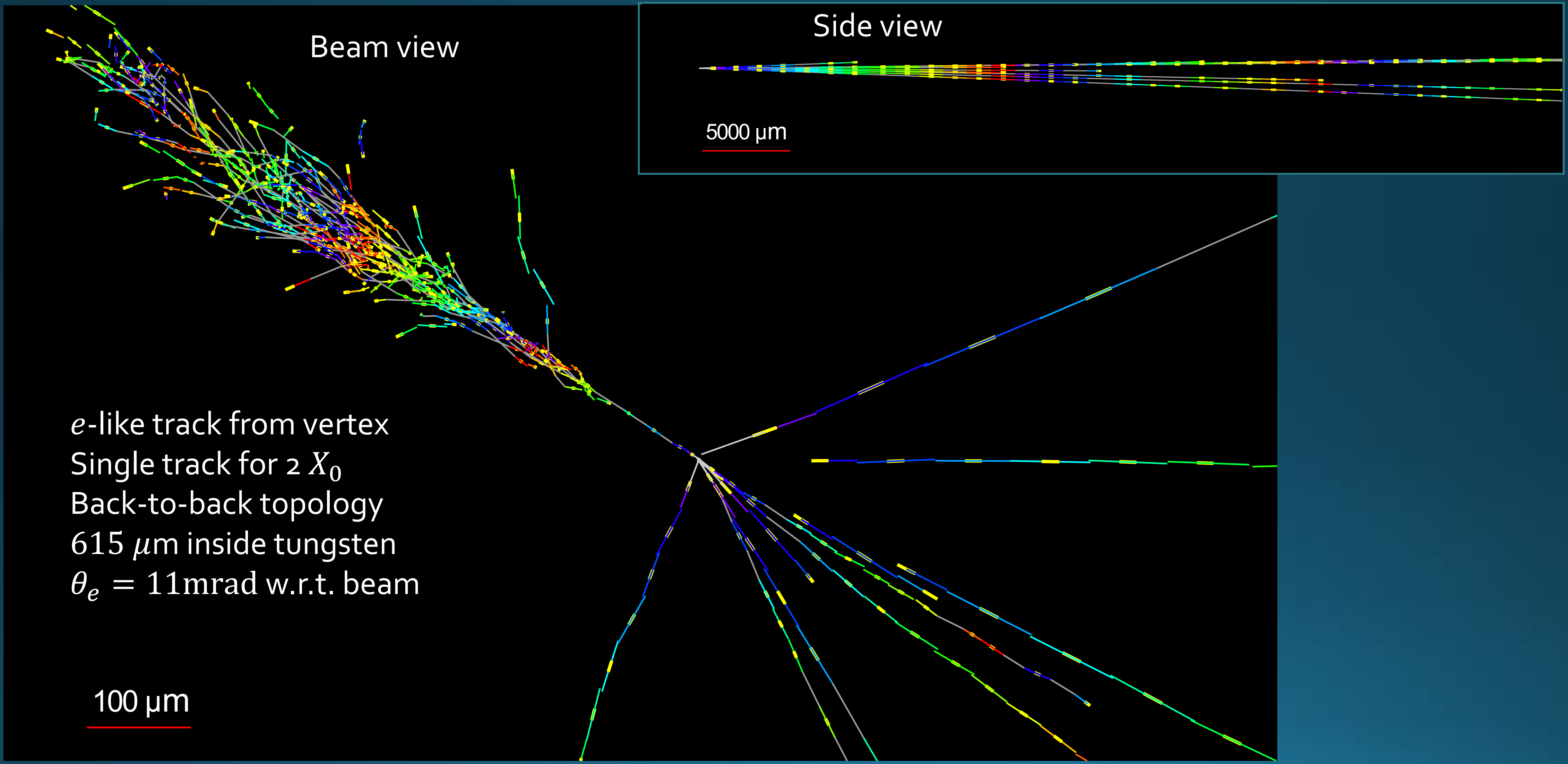


- Charged vertex



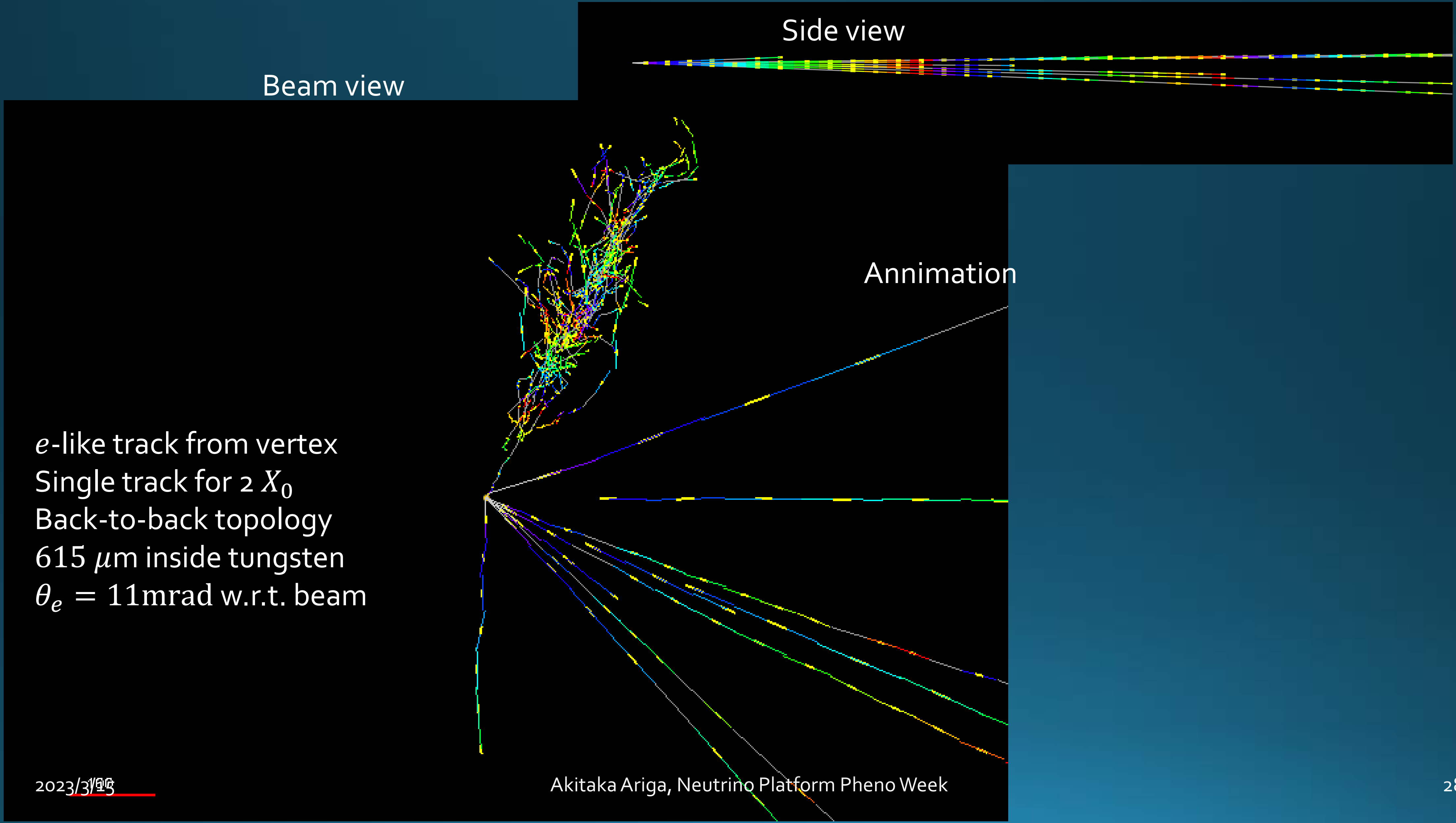
Note: there are more hadron interactions than neutrino interactions

Observed ν_e candidate in FASERν



e-like track from vertex
Single track for 2 X_0
Back-to-back topology
615 μm inside tungsten
$\theta_e = 11$mrad w.r.t. beam

Observed ν_e candidate in FASERν



e-like track from vertex
Single track for 2 X_0
Back-to-back topology
615 μm inside tungsten
$\theta_e = 11$mrad w.r.t. beam

Forward Physics Facility (*FPF*) at the HL-LHC

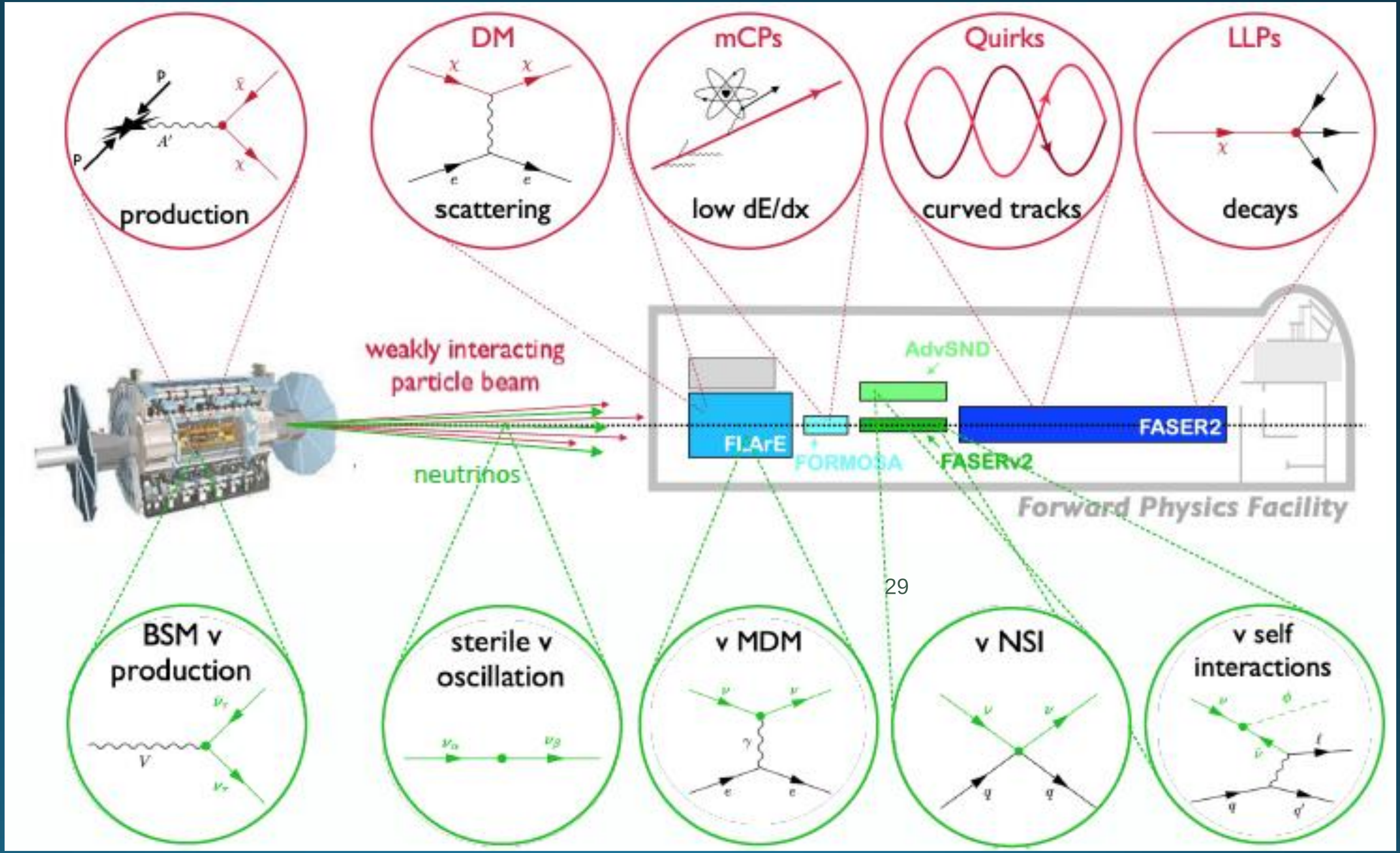
FPF White Paper (2022/3)
http://arxiv.org/abs/2203.05090
FPF 5th workshop (2022/11)
https://indico.cern.ch/event/1196506/
FPF Facility studies (2023/3)
https://cds.cern.ch/record/2851822

BSM particles can be detected in various ways

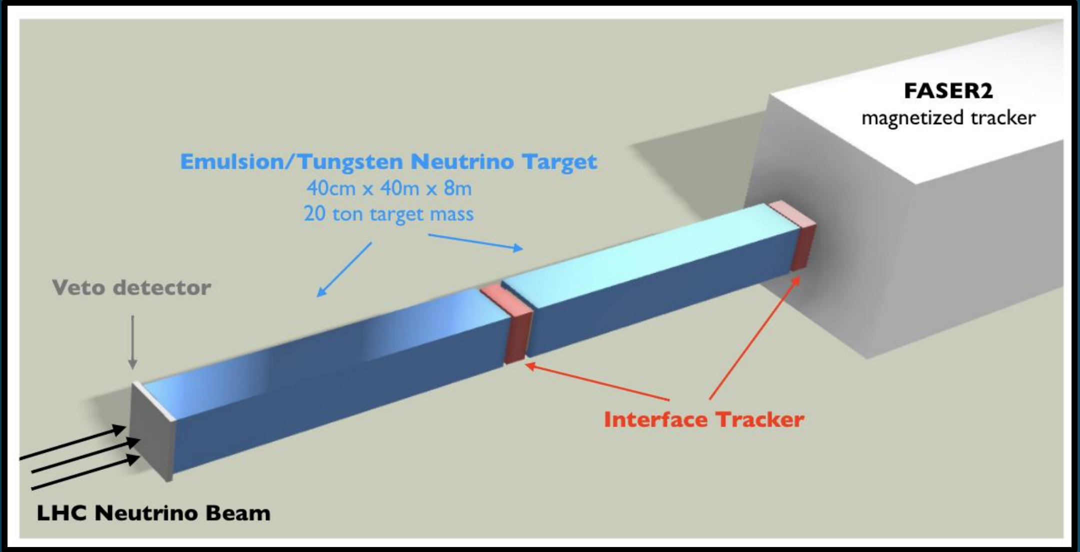
- Giving access to wide range of models

Neutrinos can be used to search for BSM effects

- Production
- Propagation
- Interaction

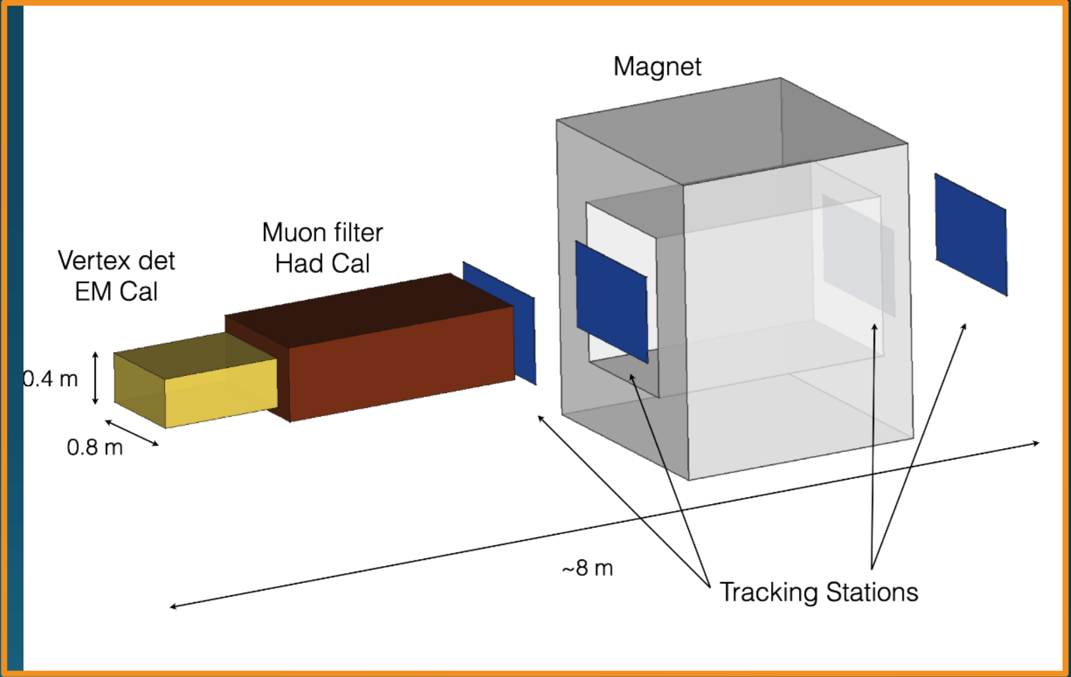


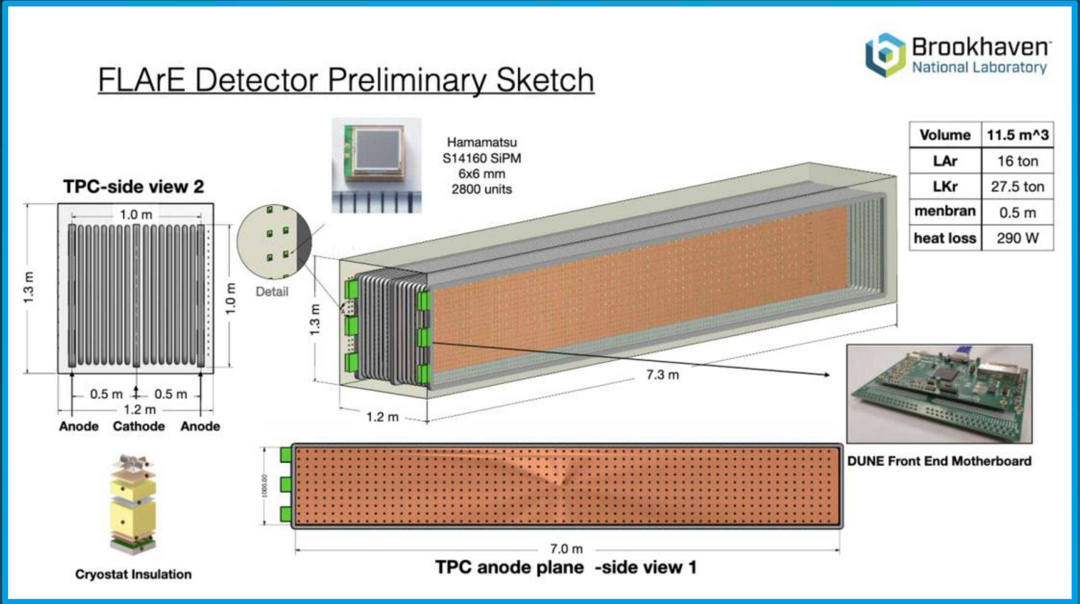
Neutrino Detector at the FPF



FASERv2

20 tons emulsion neutrino detector
followed by FASER spectrometer




FLArE Detector Preliminary Sketch

Volume	11.5 m^3
LAr	16 ton
LKr	27.5 ton
menbran	0.5 m
heat loss	290 W

FLArE

liquid noble gas detector

AdvSND

electronic detector
near detector at η~5
far detector at FPF

Summary

- Neutrinos at the LHC, a new domain of particle physics research!
- The FASER and SND@LHC experiments: neutrinos and LLPs
  - First experiments to use "collider neutrinos"
  - Beam at new kinematical regime, including 3 flavors
  - Unique playground for neutrino, flavor, QCD, cosmic-ray physics
- Detection of neutrinos was demonstrated with FASERν pilot run in 2018
- 2 experiments are taking data! First results show an excellent performance of detector. Neutrino observation will be firmly established soon!
  - 40 fb^{-1} collected in 2022, expected to correct 250 fb^{-1}
- Future projects (FPF) at the HL-LHC are under discussion
  - Strong and broad physics motivation with significant interest from the community
  - We invite people from neutrino and wider fields!

Backup

FASER

FASER Collaboration

74 collaborators, 21 institutions, 9 countries (as of Jan. 2022)

- CERN
- UNIVERSITÉ DE GENÈVE
- KYUSHU UNIVERSITY
- UC IRVINE
- UNIVERSITÄT BERN
- Technion Israel Institute of Technology
- NAGOYA UNIVERSITY
- UNIVERSITY of WASHINGTON
- JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U
- מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
- KEK
- UNIVERSITY OF OREGON
- UNIVERSITÄT BONN
- INFN
- 清華大学 Tsinghua University
- SLAC NATIONAL ACCELERATOR LABORATORY
- ROYAL HOLLOWAY UNIVERSITY OF LONDON
- UNIVERSITY OF LIVERPOOL
- CHIBA UNIVERSITY
- UNIVERSITY OF SUSSEX
- JINR

Publications on FASER/FASERnu

- Publications of the FASER Collaboration
  - FASER Letter of Intent at CERN document server and in arXiv
  - FASER Technical Proposal at CERN document server and in arXiv
  - FASER's Physics Reach for Long-Lived Particles in Physical Review D and in arXiv
  - Input to the European Strategy for Particle Physics Update in arXiv
  - Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC in European Physical Journal C and in arXiv
  - Technical Proposal of FASERν neutrino detector at CERN document server and in arXiv
  - First neutrino interaction candidates at the LHC in arXiv

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BSM particles can be detected in various ways

- Giving access to wide range of models

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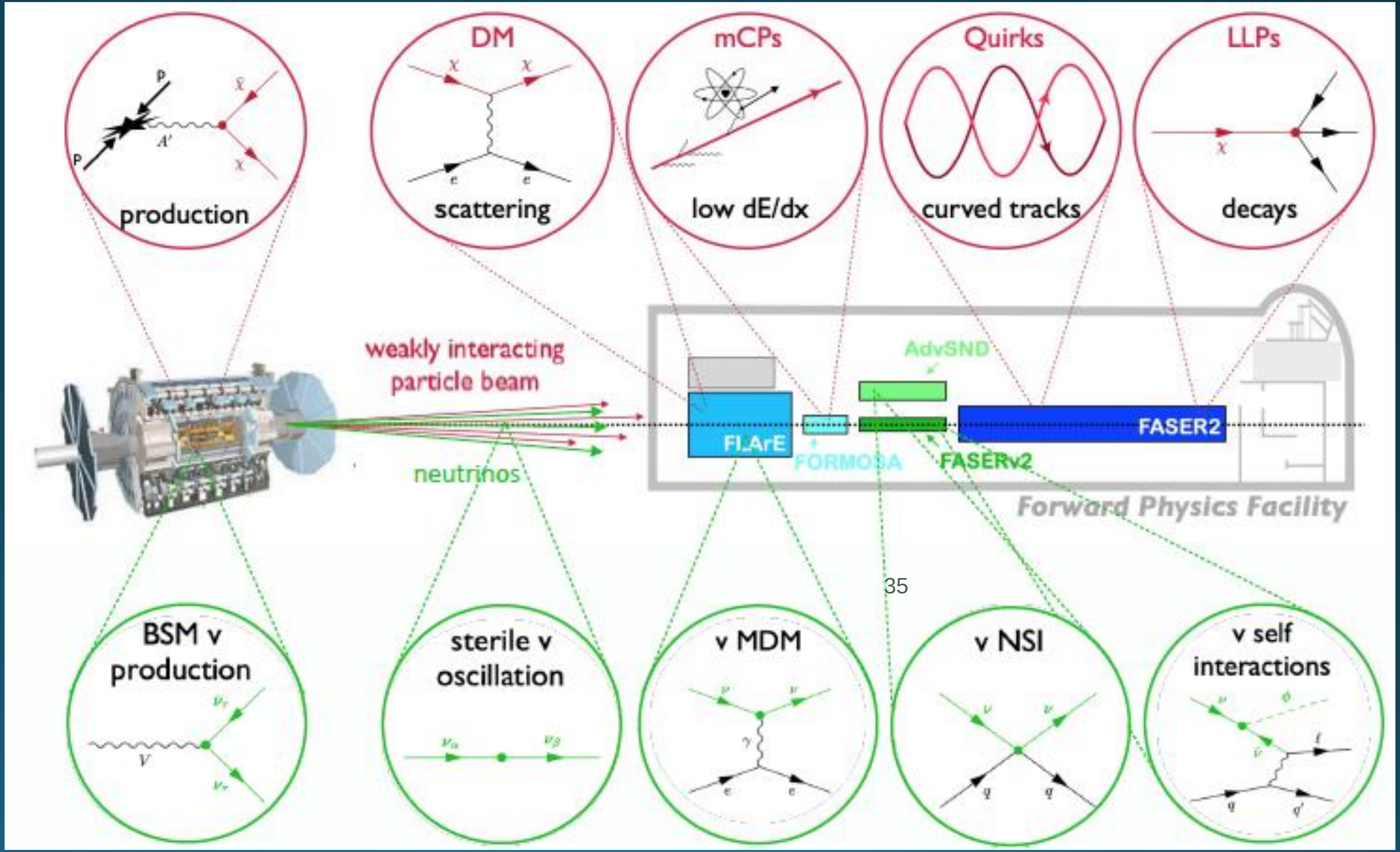
- Production
- Propagation
- Interaction



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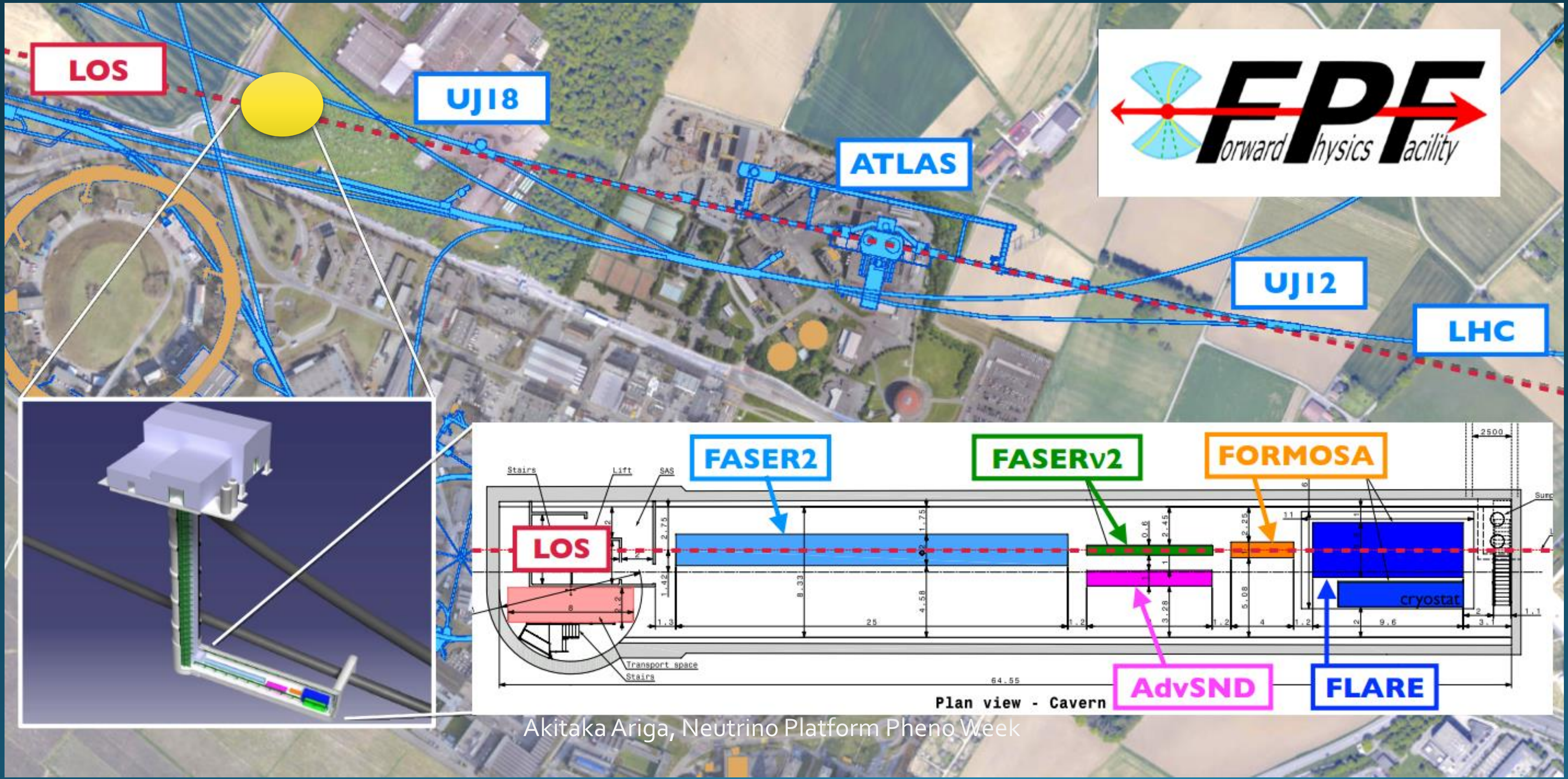
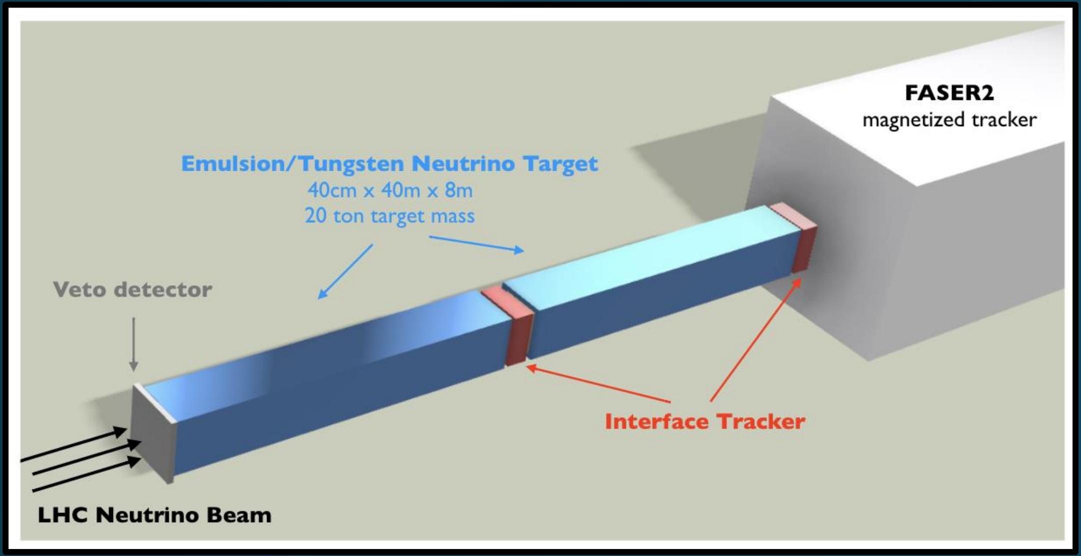
- FPF 5th workshop (2022/11) https://indico.cern.ch/event/1196506/
- FPF Facility technical studies (2023/3): https://cds.cern.ch/record/2851822

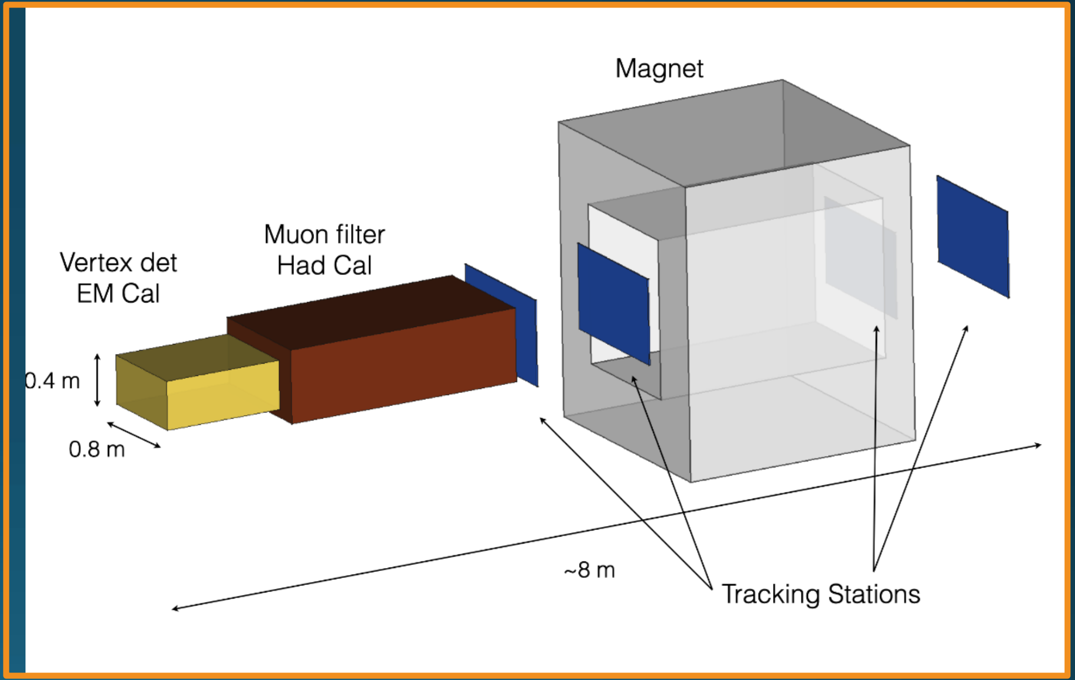


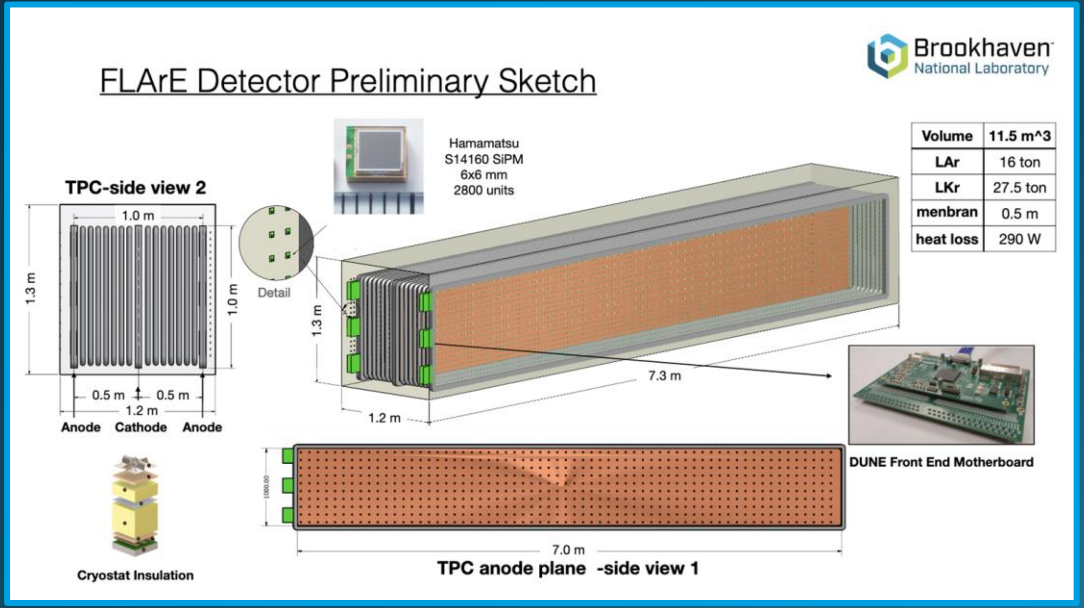
Neutrino Detector at the FPF



FASERv2

emulsion neutrino detector
followed by FASER spectrometer





FLArE Detector Preliminary Sketch

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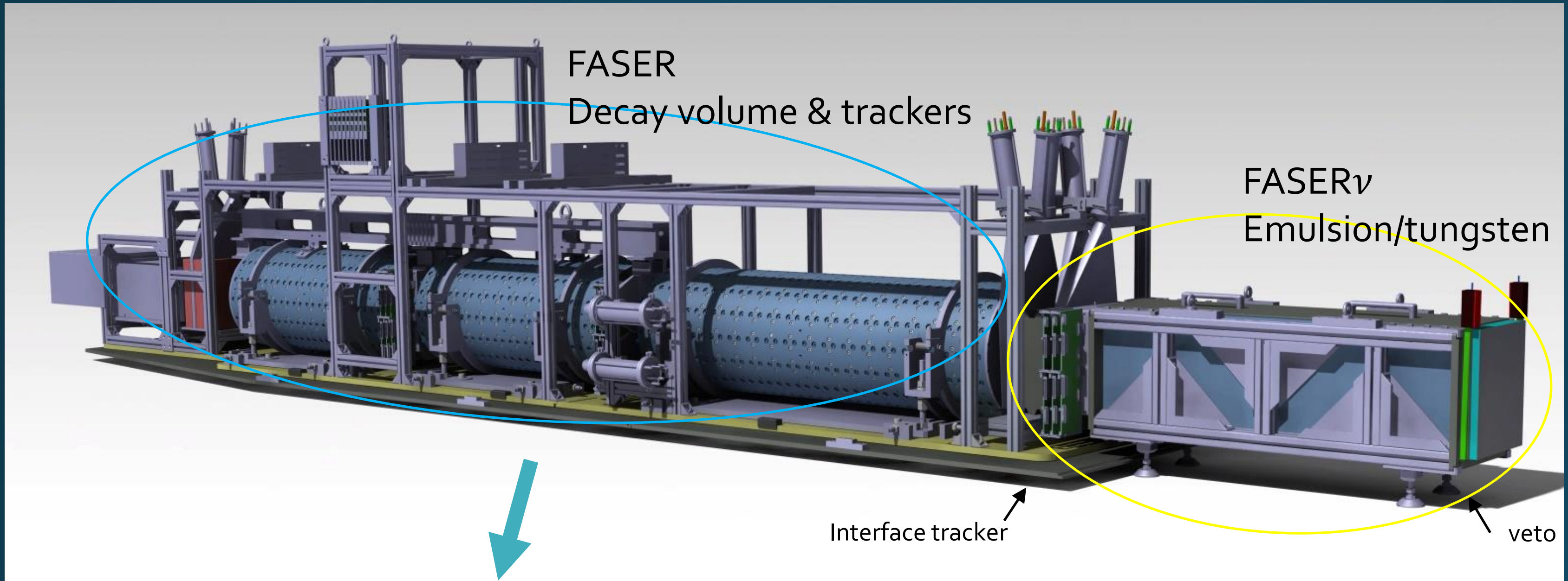
FLArE

liquid noble gas detector

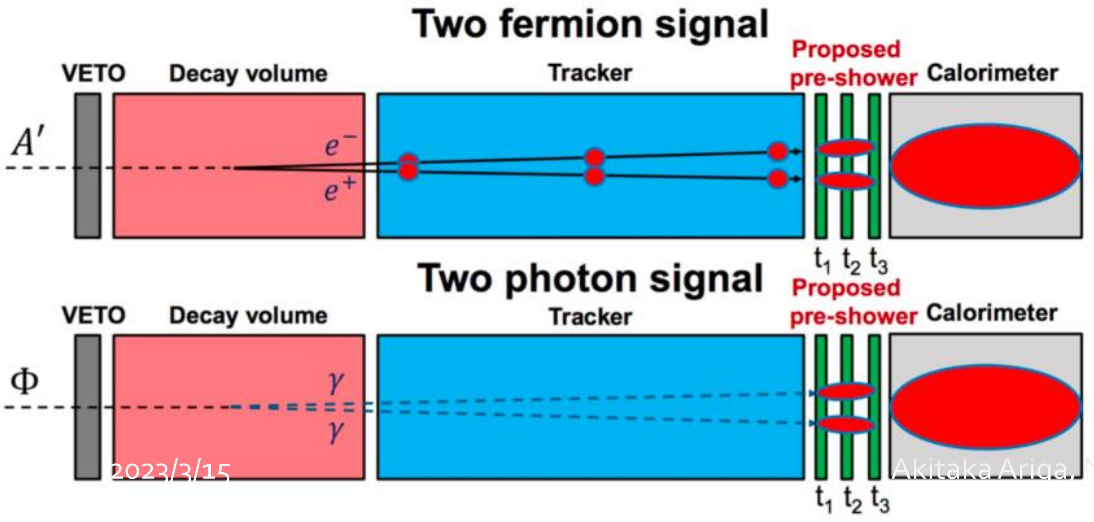
AdvSND

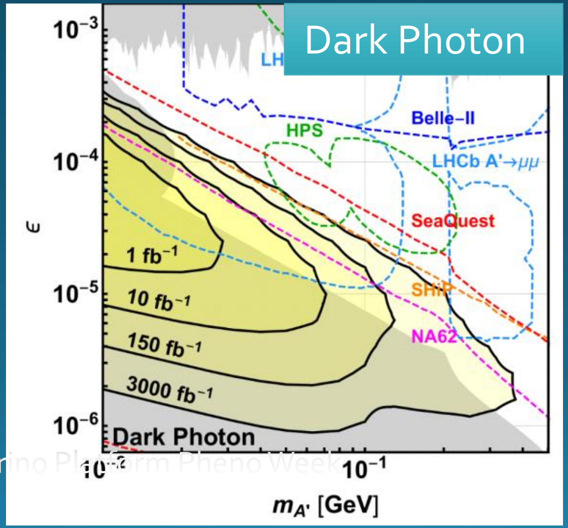
electronic detector
near detector at η~5
far detector at FPF

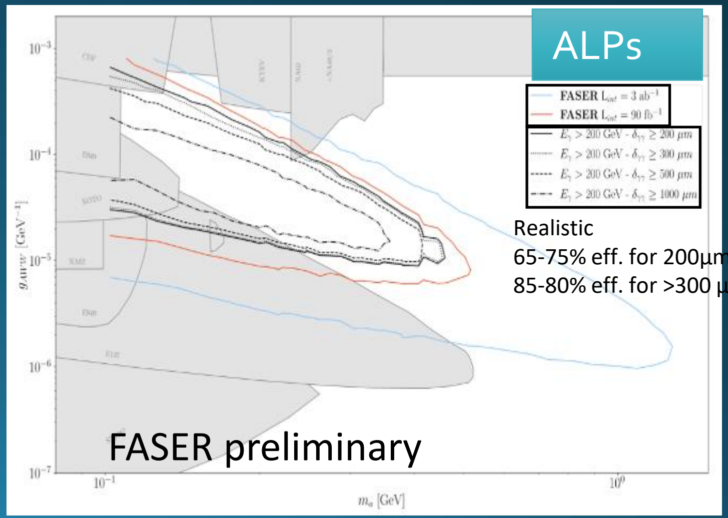
FASER/FASERν detector



Forward beam (A′, ν, etc)







Realistic
65-75% eff. for 200µm
85-80% eff. for >300 µm

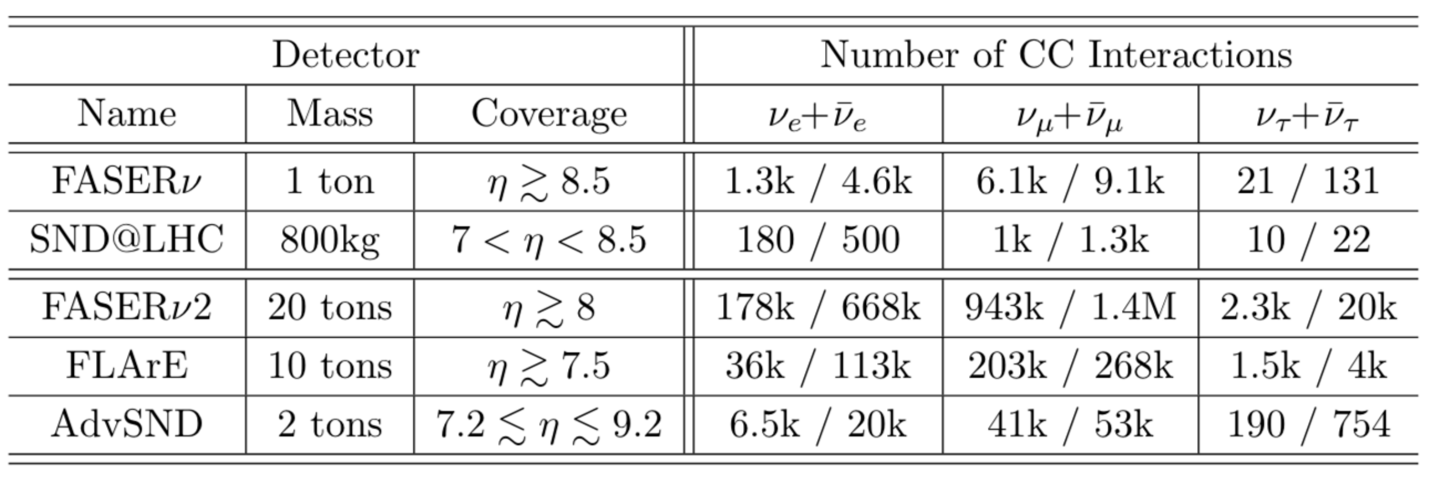
FASER preliminary

Neutrino Fluxes and Rates

Event rates at LHC neutrino experiments
estimated with two LO MC generators: SIBYLL / DPMJET

LHC Run3

HL-LHC



Detector			Number of CC Interactions		
Name	Mass	Coverage	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
FASERν	1 ton	$\eta \gtrsim 8.5$	1.3k / 4.6k	6.1k / 9.1k	21 / 131
SND@LHC	800kg	$7 < \eta < 8.5$	180 / 500	1k / 1.3k	10 / 22
FASERν2	20 tons	$\eta \gtrsim 8$	178k / 668k	943k / 1.4M	2.3k / 20k
FLArE	10 tons	$\eta \gtrsim 7.5$	36k / 113k	203k / 268k	1.5k / 4k
AdvSND	2 tons	$7.2 \lesssim \eta \lesssim 9.2$	6.5k / 20k	41k / 53k	190 / 754

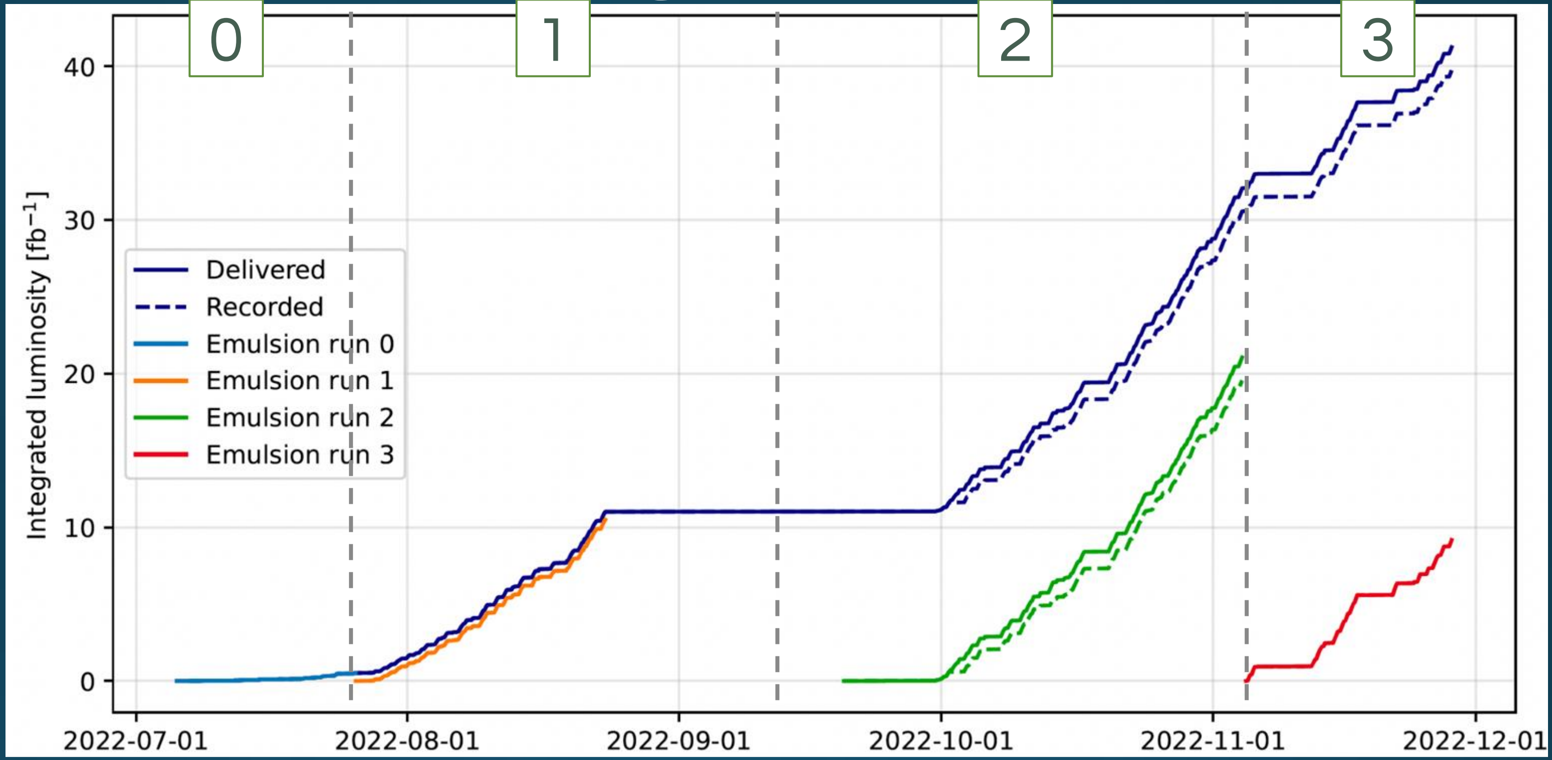
Large spread in current generator predictions

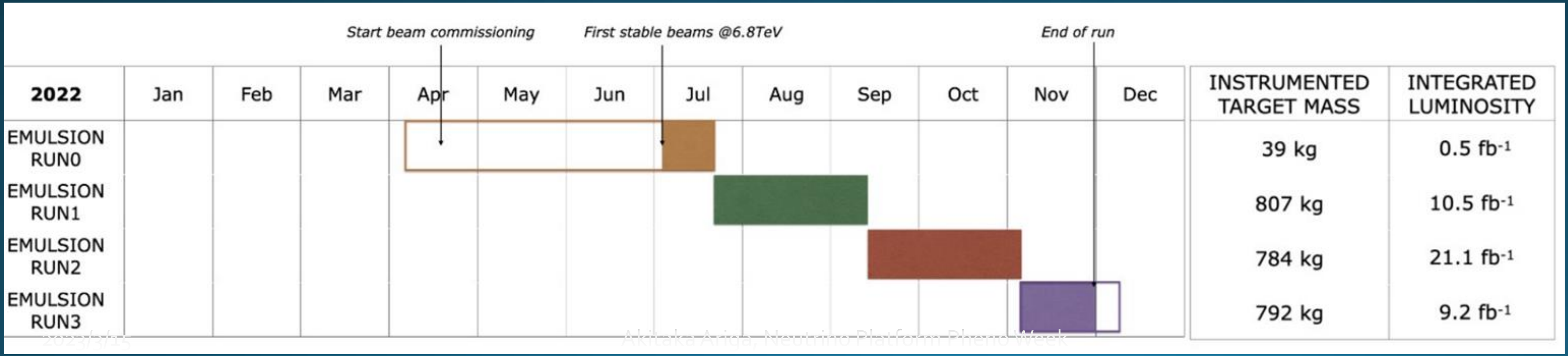
Challenge:
For neutrino physics measurement we need to quantify and reduce neutrino flux uncertainties

Opportunity:
Forward neutrino flux measurement can help to improve our understanding of underlying physics.

Data taken in Run 3

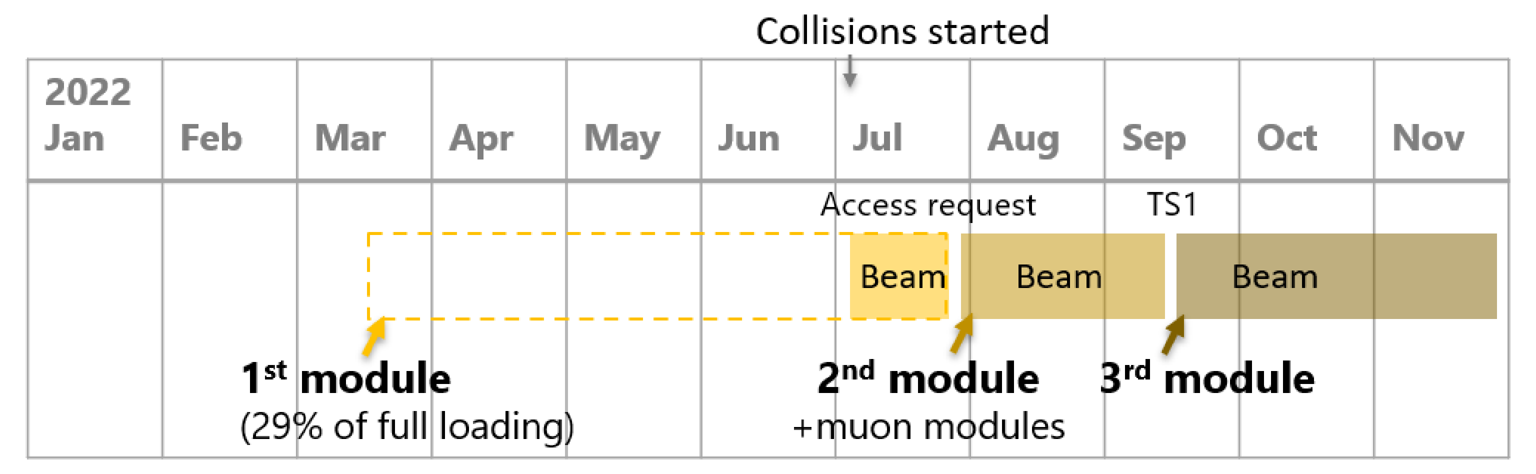
Run 3
Delivered:
41.25 fb^{-1}
Recorded:
39.74 fb^{-1} (96%)





2022	INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
EMULSION RUN0	39 kg	0.5 fb^{-1}
EMULSION RUN1	807 kg	10.5 fb^{-1}
EMULSION RUN2	784 kg	21.1 fb^{-1}
EMULSION RUN3	792 kg	9.2 fb^{-1}

FASERν 2022 runs



Collisions started

2022 Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov

Access request

TS1

Beam

Beam

Beam

1st module
(29% of full loading)

2nd module
+muon modules

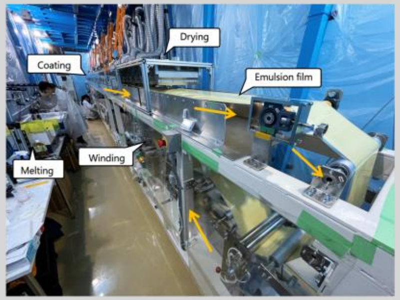
3rd module

		Integrated luminosity per module (fb^{-1})	N ν int. expected
2022 1st module	**Mar 15 – Jul 26**	**0.5**	**~7**
2022 2nd module	Jul 26 – Sep 13	10.6	~530
2022 3rd module	Sep 13 – Nov 29	(~30)	(~1500)

based on "F. Kling and L.J. Nevay, Forward Neutrino Fluxes at the LHC, Phys. Rev. D 104, 113008"

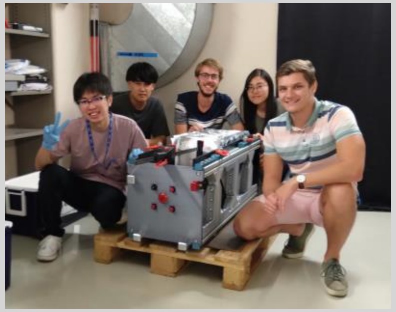
FASERν steps

Japan



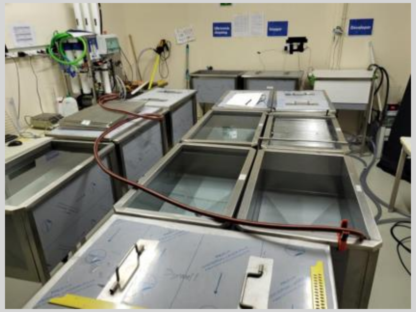
Film production

CERN



Assembly

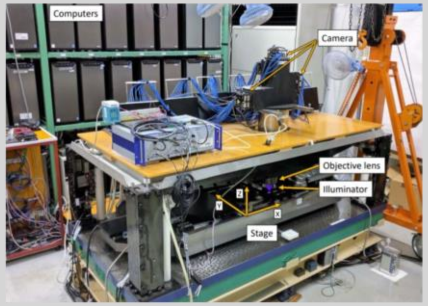
Exposure



Disassembling

Development

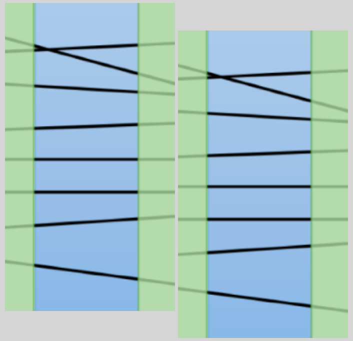
Japan



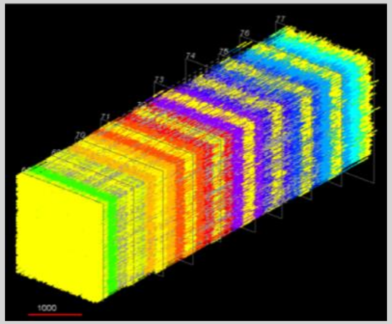
Readout

Offline analysis

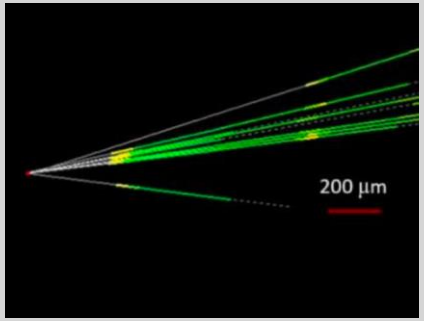
Alignment



Track reconstruction

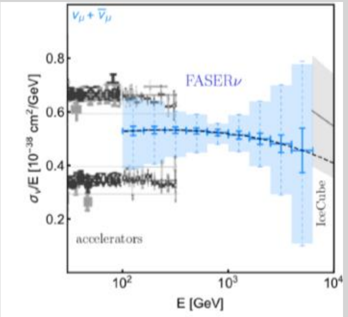


Vertex reconstruction



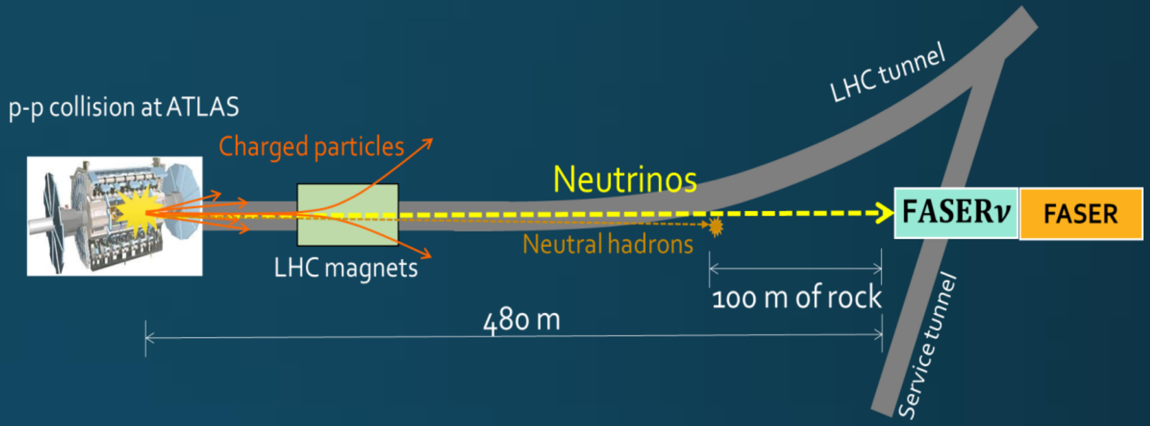
e, μ ID
τ decay search
charge ID
Eν reco
charm/beauty
etc.

Physics analysis

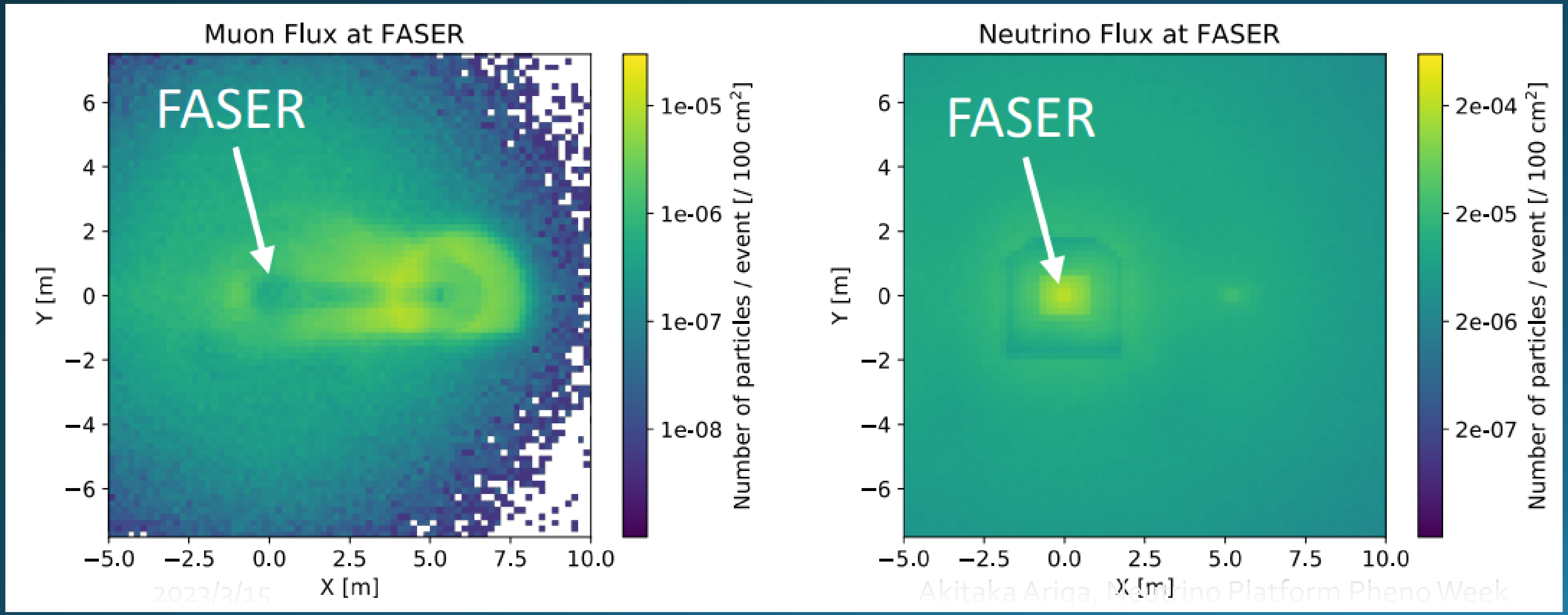


Particle fluence at the site

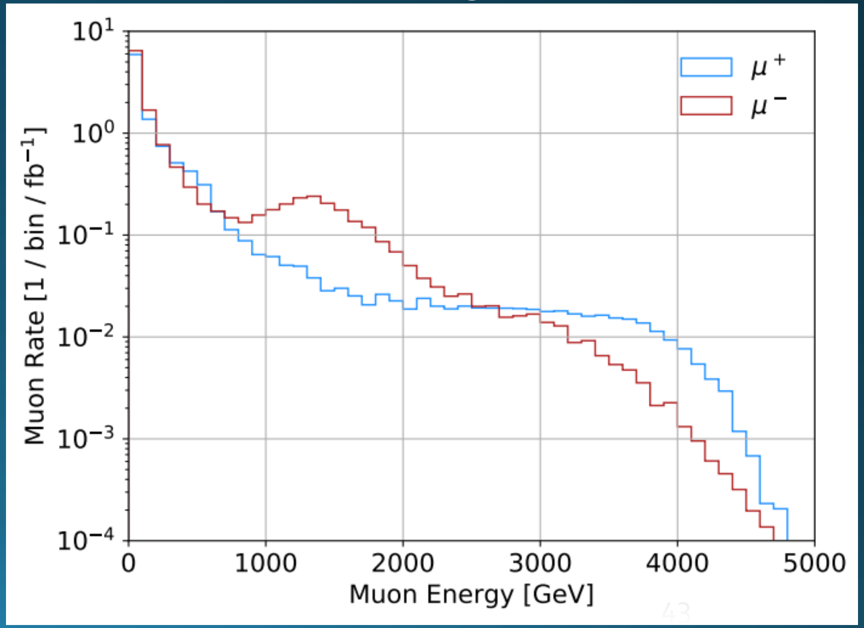
- Crucial for both neutrinos and LLP searches
- Simulation through the LHC infrastructures by FLUKA and BDSim
- Minimum muons, maximum neutrinos

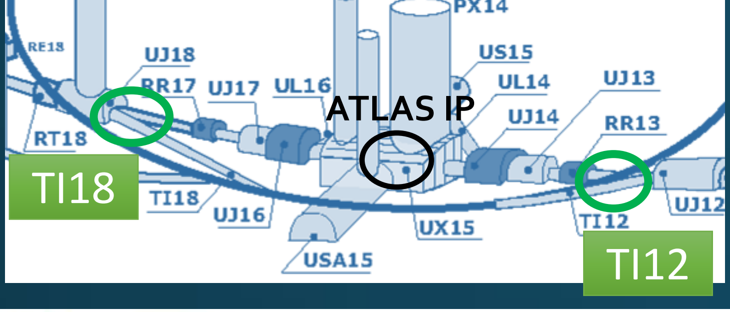


BDSim result for TI12, Lefebvre ICHEP2020



Muon energy (at 409m from IP, pilot run)
Simulated by CERN-STI group with FLUKA

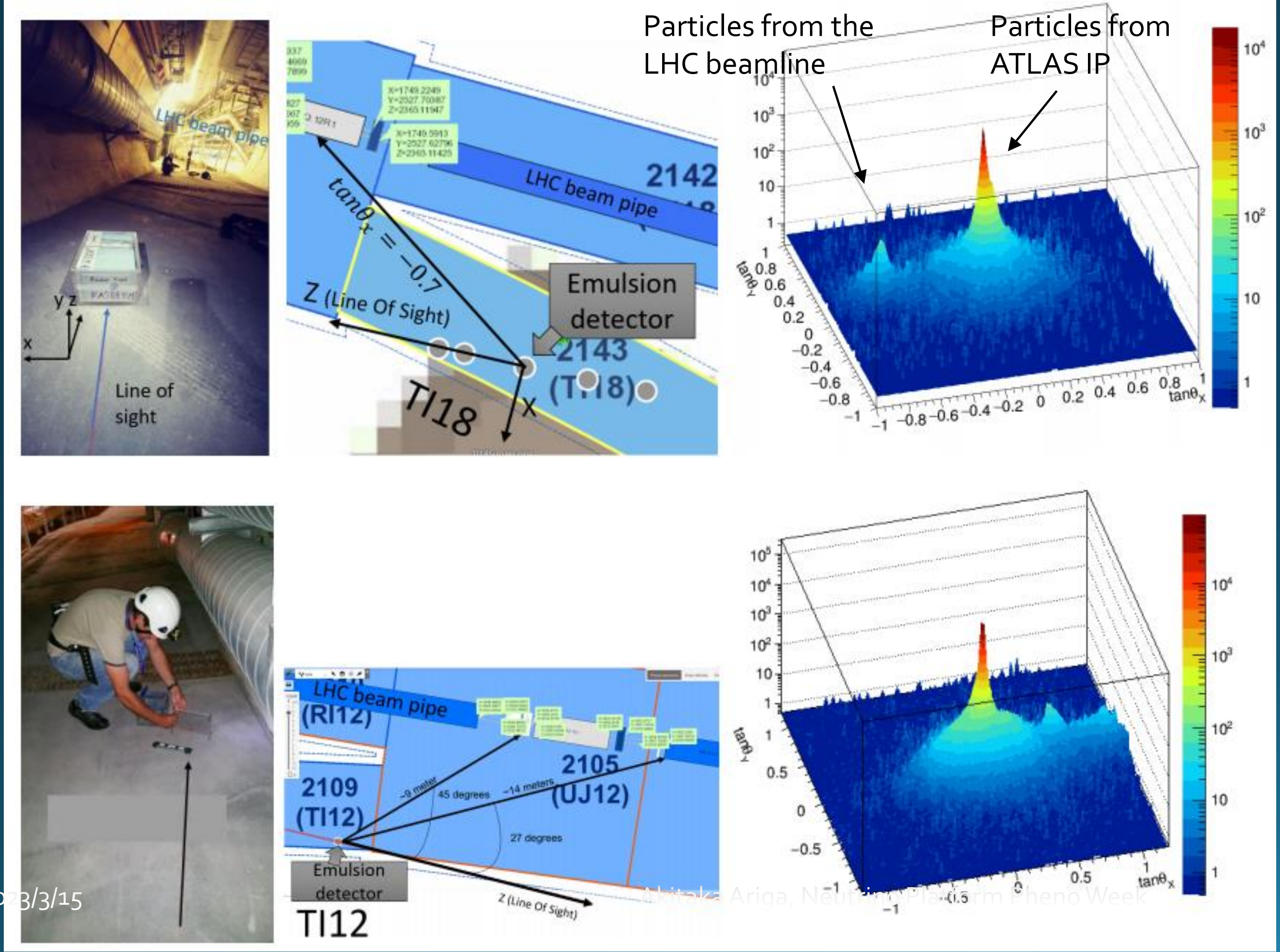




In situ measurements in 2018: Charged particle background

TI18

TI12



Particles from the LHC beamline

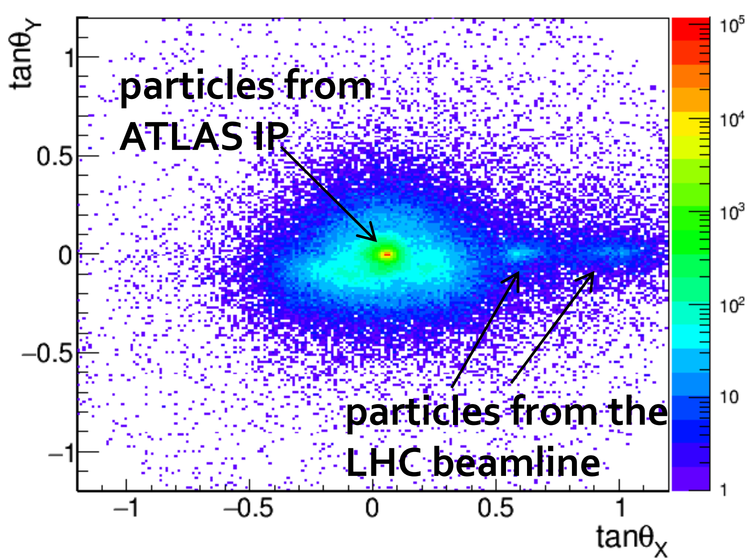
Particles from ATLAS IP

- Emulsion detectors were installed to investigate TI18 and TI12.
- **Low background was confirmed.**
- Few hadron tracks
- Consistent with the FLUKA prediction.

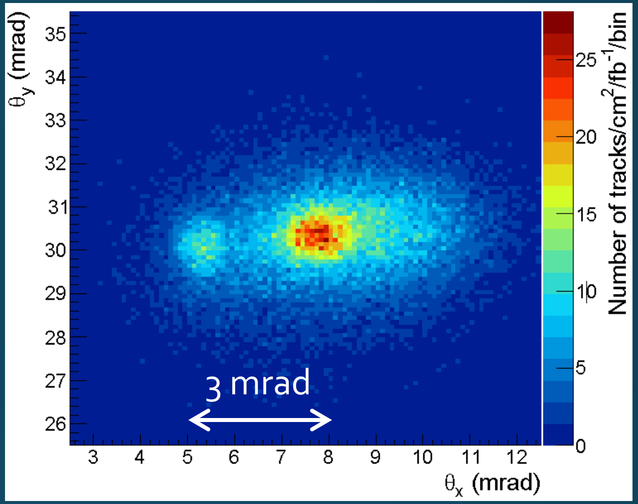
	Normalized flux (tracks/fb^{-1}/cm^2)
TI18	$(2.6 \pm 0.7) \times 10^4$
TI12	$(3.0 \pm 0.3) \times 10^4$

Emulsion detector can work at the actual environment!
(up to ~10^6/cm^2 $\simeq$ 30 fb^{-1} of data)

Angular distributions of beam backgrounds



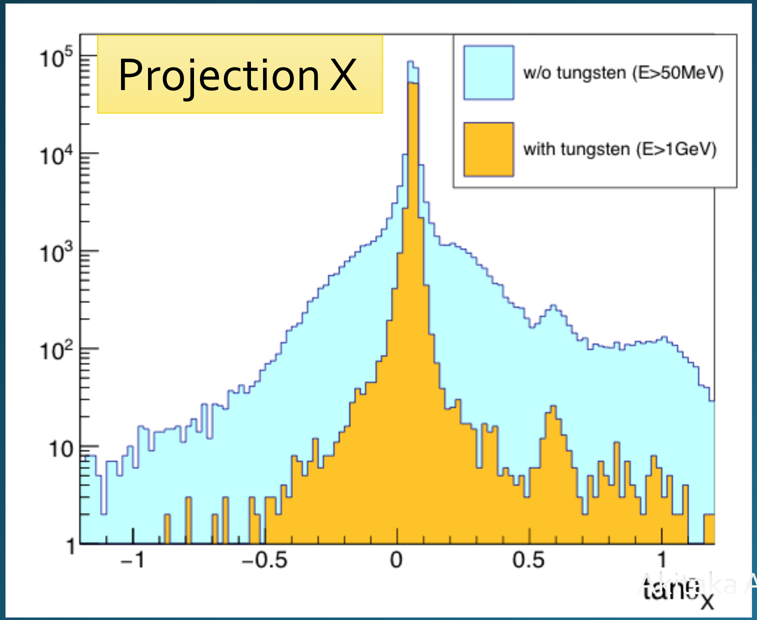
Close up to the main peak (TI-18)



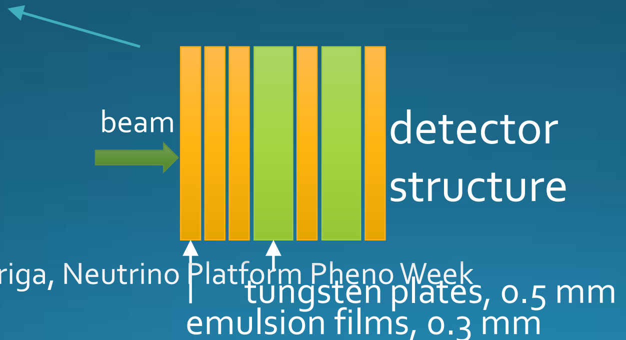
2 peak structure

$\sigma = 0.6\ mrad$

After 100 m of rock, it scatters only 0.6 mrad.
→ ~700 GeV



	Flux in main peak [fb/cm²]
TI18 data	$1.7 \pm 0.1 \times 10^4$
TI12 data	$1.9 \pm 0.2\ \times 10^4$
FLUKA MC	$2.5\ \times 10^4$ (uncertainty 50%)

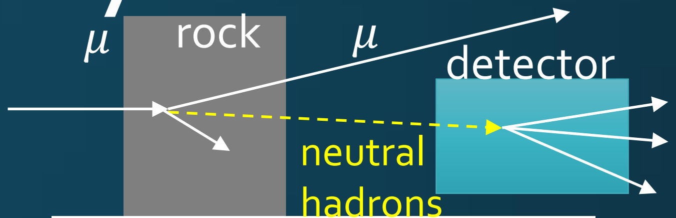


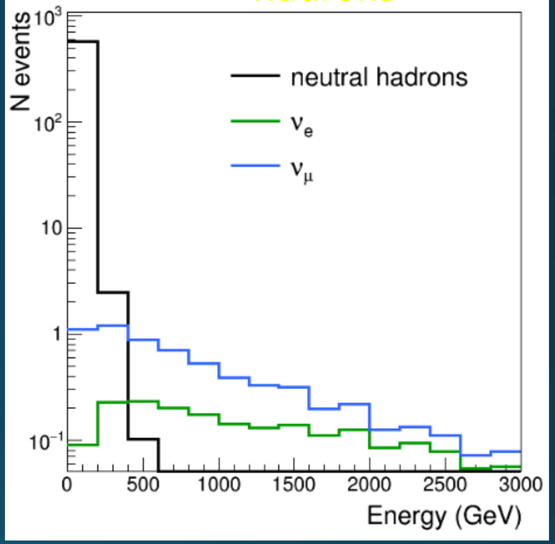
Data and the FLUKA prediction agrees within their uncertainties.

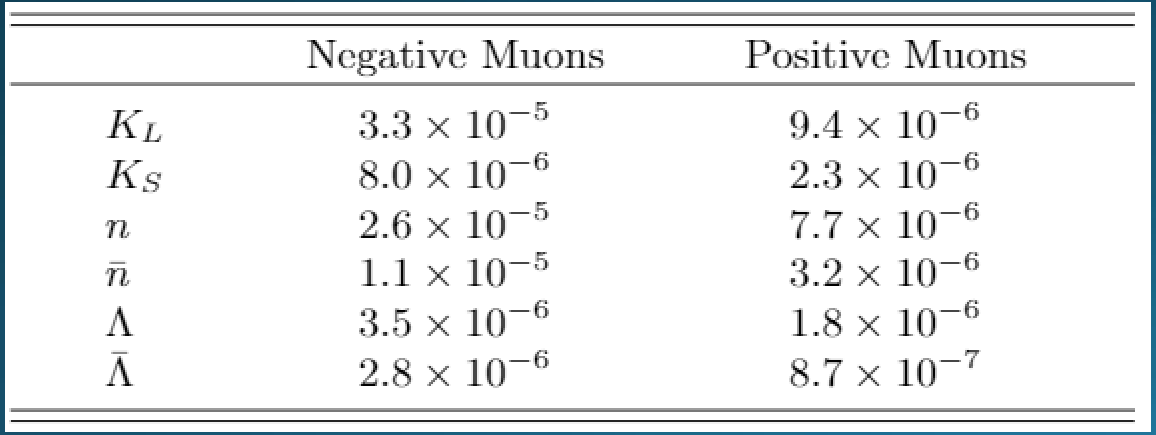
Phys. Rev. D 104, L091101 (2021)

Background for neutrino analysis

- Muons rarely produce neutral hadrons in upstream rock or in detector, which can mimic neutrino interaction vertices
  - Probability of O(10^{-5})
- Pilot neutrino detector doesn’t have lepton ID
  - → Separation from neutral hadron BG (produced by muons) is challenging → tighter cuts
- The produced neutral hadrons are low energy → Discriminate by event topology



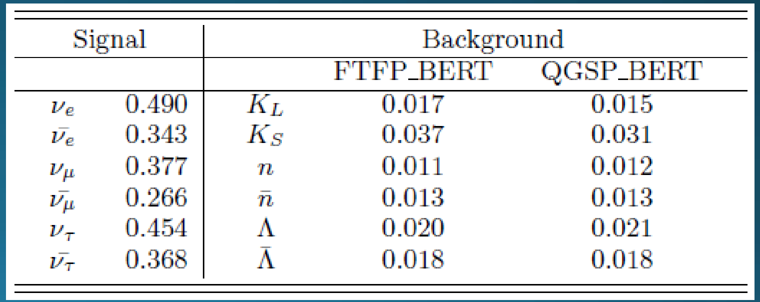




	Negative Muons	Positive Muons
K_L	3.3×10^{-5}	9.4×10^{-6}
K_S	8.0×10^{-6}	2.3×10^{-6}
n	2.6×10^{-5}	7.7×10^{-6}
$\bar{n}$	1.1×10^{-5}	3.2×10^{-6}
Λ	3.5×10^{-6}	1.8×10^{-6}
$\bar{\Lambda}$	2.8×10^{-6}	8.7×10^{-7}

Production rate per muon (E_{had}>10 GeV)

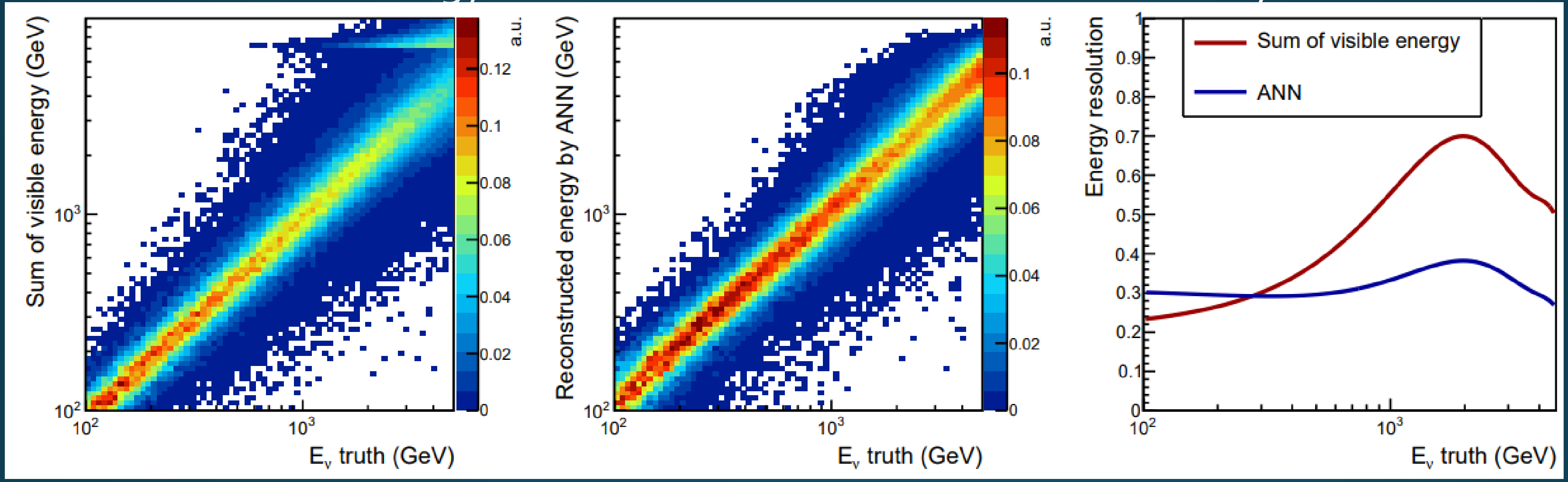
Vertex detection efficiency



Signal		Background		
			FTFP_BERT	QGSP_BERT
ν_e	0.490	K_L	0.017	0.015
$\bar{\nu_e}$	0.343	K_S	0.037	0.031
ν_μ	0.377	n	0.011	0.012
$\bar{\nu_\mu}$	0.266	$\bar{n}$	0.013	0.013
ν_τ	0.454	Λ	0.020	0.021
$\bar{\nu_\tau}$	0.368	$\bar{\Lambda}$	0.018	0.018

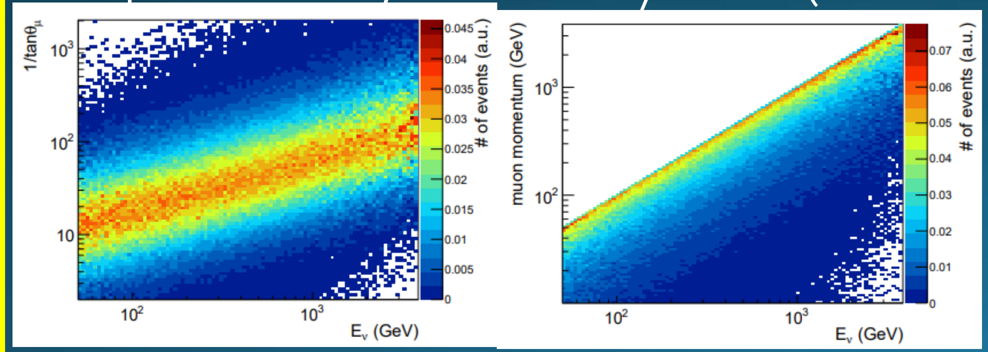
Energy reconstruction (ν_μ CC)

Sum of visible energy ANN method $\Delta E/E$



(smeared)

inputs for ANN, simulated by GENIE (MC truth)



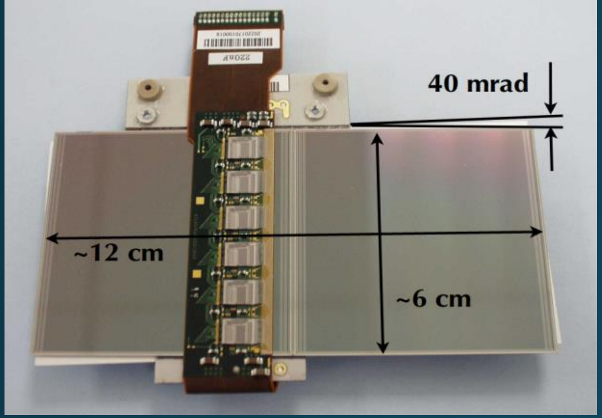
…

Angular info

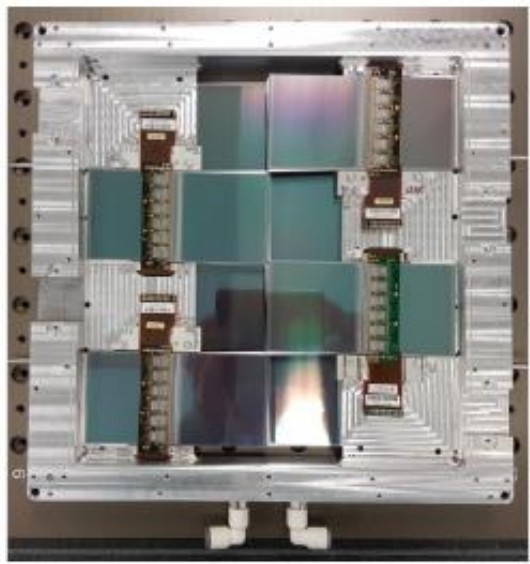
Momentum

- Sum of visible energy (model independent) already gives a reasonable resolution
- ANN can solve problem at high energy and gives about 30% resolution at relevant energy range.

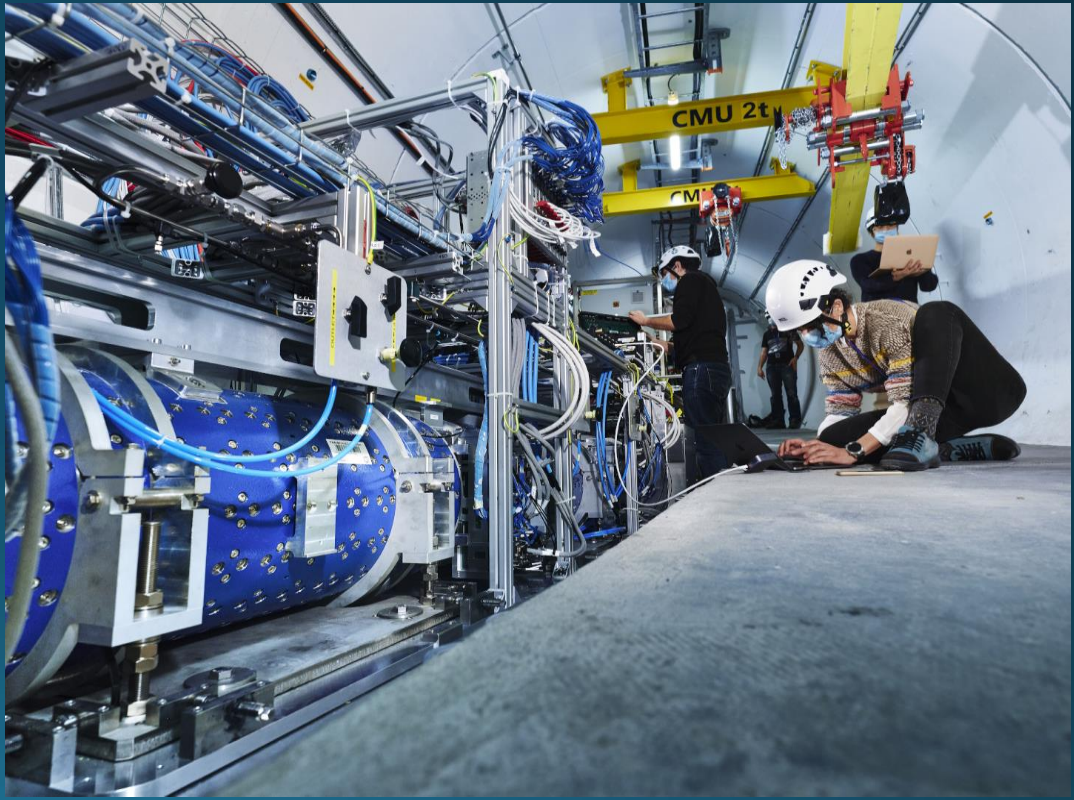
FASER detector components

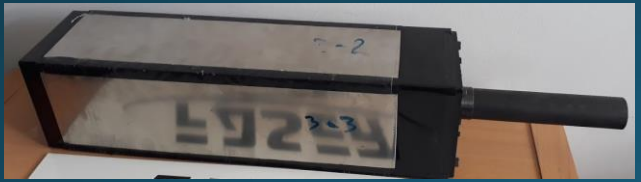


SCT module from ATLAS, 80 um silicon strip detector



Tracking layer = 8 SCT modules





Calorimeter module from LHCb

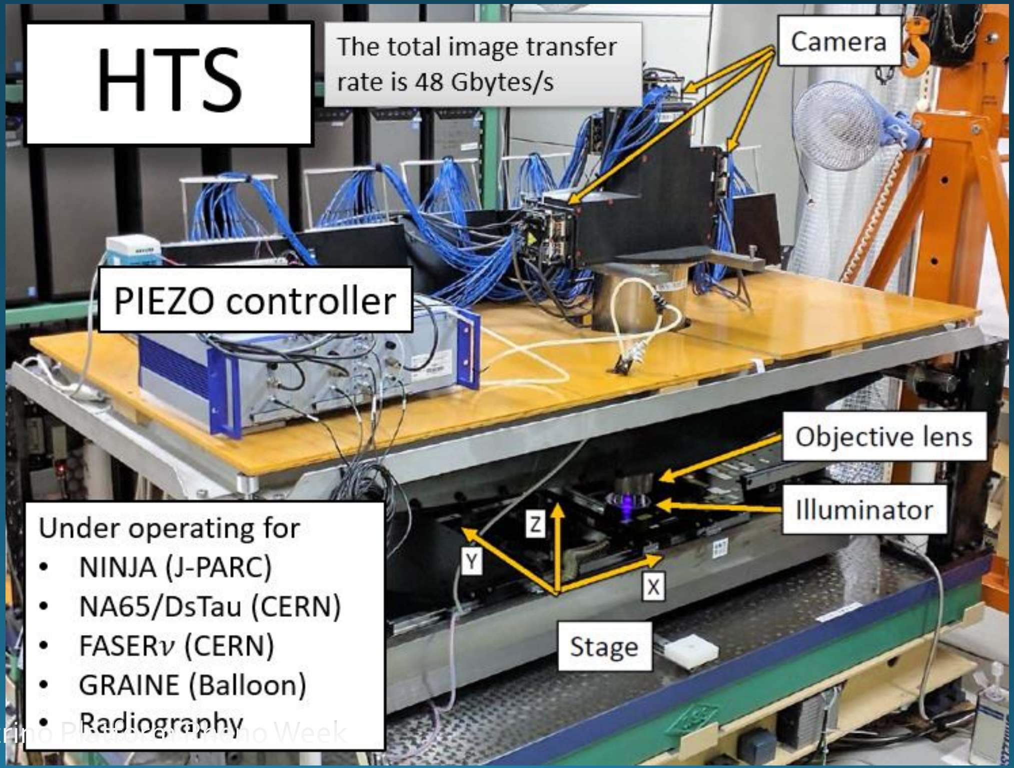
Scintillators

Emulsion detector technology

- **Fast readout of emulsion films**
  - Great progress in the readout speed, throughput of 48 GBytes/sec
  - ~100 times faster than OPERA
- Data readout for FASER will catch up with the irradiation at the LHC
  - 3 months irradiation at the LHC, followed by 3 months scanning for each module
  - 3 modules per year

	Start year	Field of view (mm²)	Readout speed (cm²/h/layer)
S-UTS	2006	0.05	72
HTS-1	**2015**	**25**	**4700**
HTS-2	2021	50	25000

HTS paper: M. Yoshimoto, T. Nakano, R. Komatani, H. Kawahara, PTEP 10 (2017) 103H01.

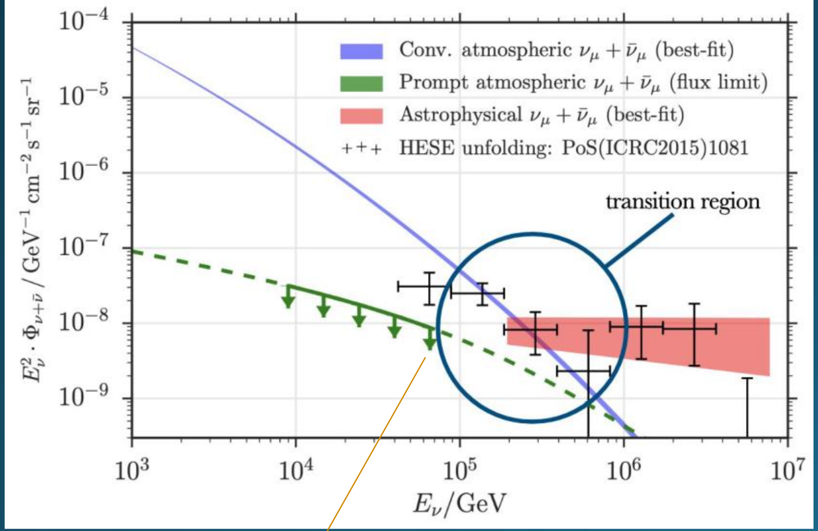


The total image transfer rate is 48 Gbytes/s

Under operating for
- NINJA (J-PARC)
- NA65/DsTau (CERN)
- FASERν (CERN)
- GRAINE (Balloon)
- Radiography

Physics studies in the LHC Run 3 (4):
Cosmic rays and neutrino

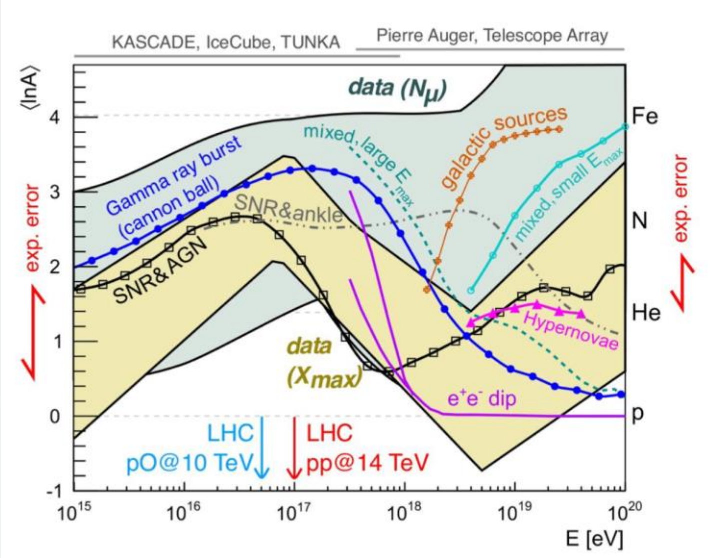
- In order for IceCube **to make precise measurements of the cosmic neutrino flux**, accelerator measurements of high energy and large rapidity charm production are needed.
- As 7+7 TeV p-p collision corresponds to 100 PeV proton interaction in fixed target mode, a direct **measurement of the prompt neutrino production at FASERν** would provide important basic data for current and future high-energy neutrino telescopes.



prompt atmospheric neutrinos

IceCube Collaboration, Astrophys. J. 833 (2016)

- Muon problem in CR physics: cosmic ray experiments have reported an excess in the number of muons over expectations computed using extrapolations of hadronic interaction models tuned to LHC data at the few σ level. New input from LHC is crucial to reproduce CR data consistently.

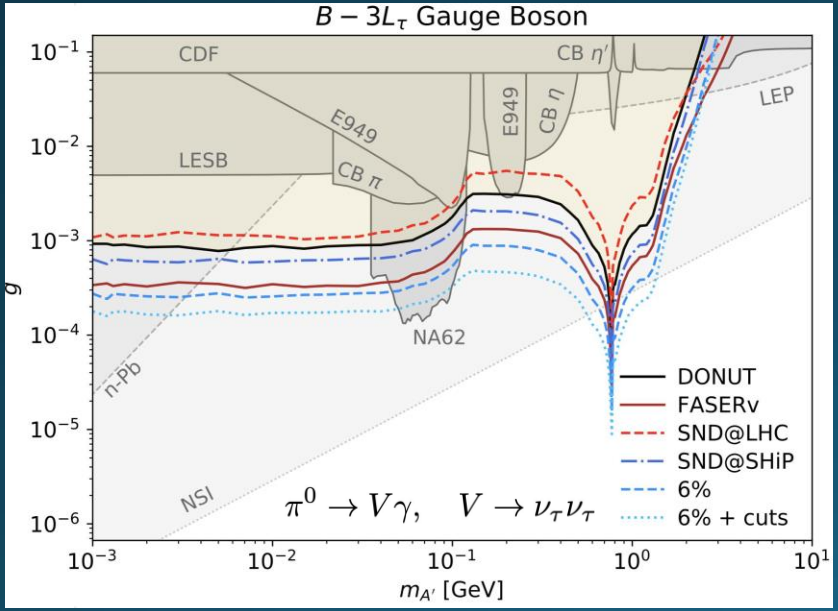


K.H. Kampert, M. Unger, Astropart. Phys. 35, 660 (2012),
H.P. Dembinski et al., EPJ Web Conf. 210, 02004 (2019)

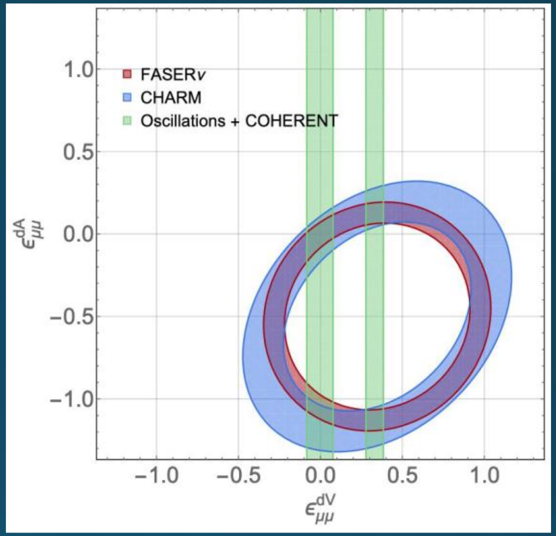
Physics studies in the LHC Run 3 (5):
BSM Physics

- The tau neutrino flux is small in SM. A **new light weakly coupled gauge bosons** decaying into tau neutrinos could significantly enhance the tau neutrino flux.

F. Kling, Phys. Rev. D 102, 015007 (2020), arXiv:2005.03594



- NC measurements at FASERν could constrain **neutrino non-standard interactions** (NSI).



A. Ismail, R.M. Abraham, F. Kling, arXiv: 2012.10500

- **Sterile neutrinos** with mass ~40 eV can cause oscillations at FASERν and the spectrum deformation may be seen.

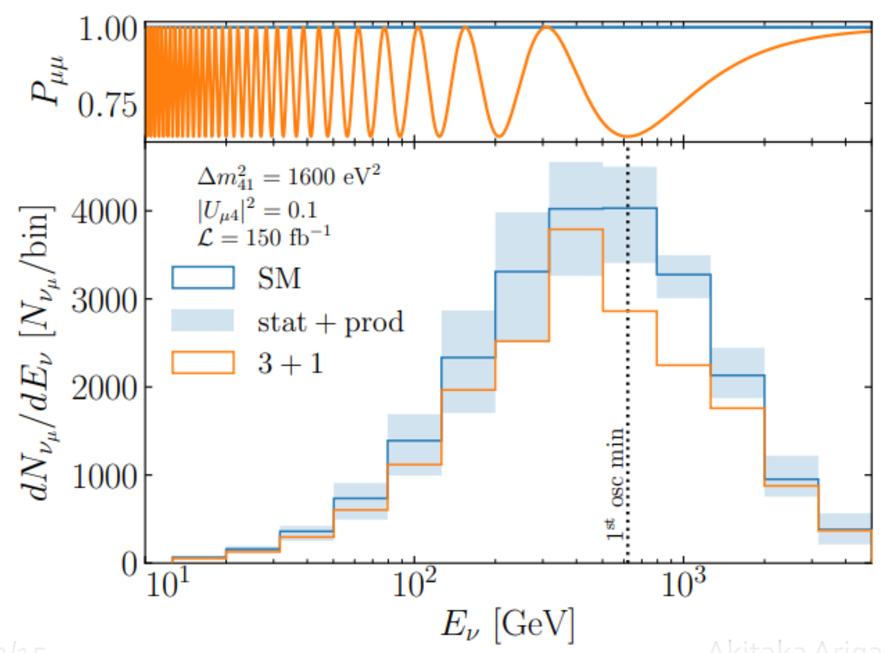
FASER Collaboration, Eur. Phys. J. C 80 (2020) 61, arXiv:1908.02310

- If DM is light, the LHC can produce an energetic and collimated DM beam towards FASERν. FASERν could also search for **DM scattering**.

B. Batell, J. Feng, S. Trojanowski, 2020, in preparation

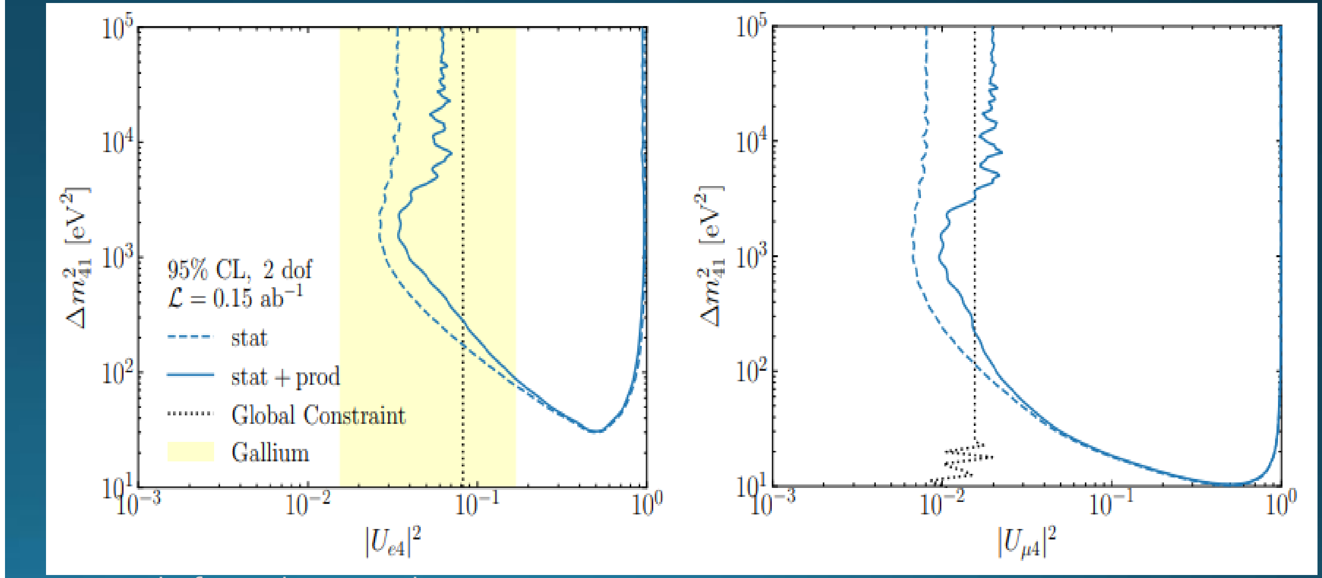
Sterile neutrino oscillation

- Due to unique energy and baseline ($L/E \sim 10^{-3}$ m/MeV), FASERν is sensitive to large $\Delta m^2 \sim 10^3$ eV².
- Neutrino spectrum deformation
- Competitive in disappearance channels.

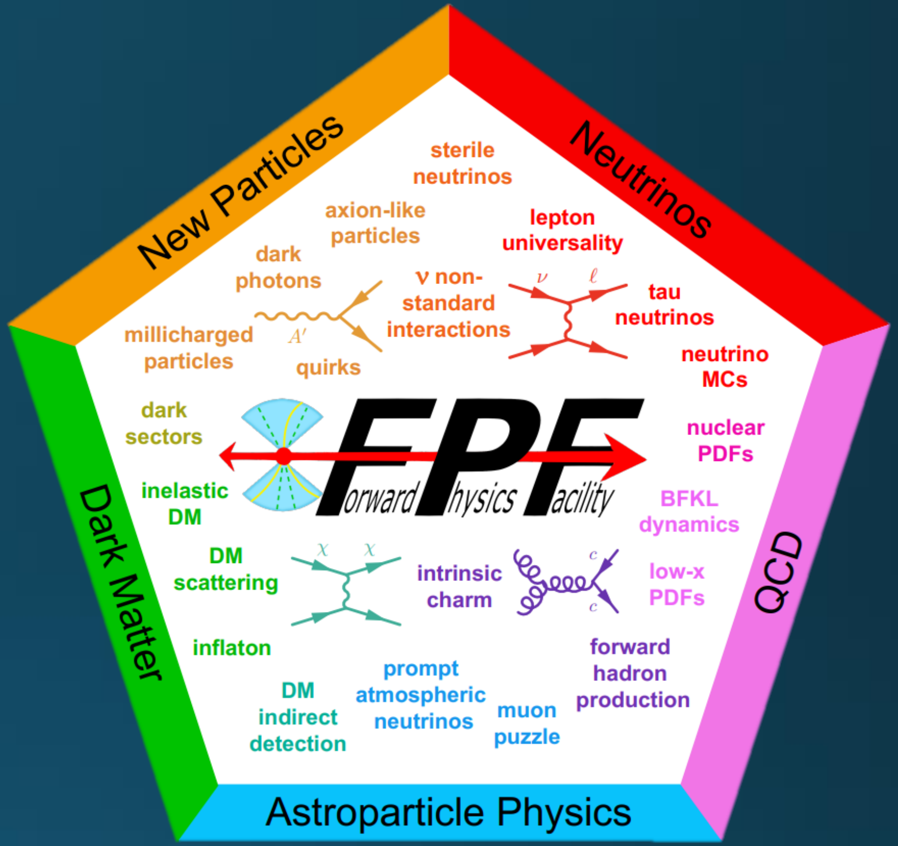


ν_e disappearance

ν_μ disappearance



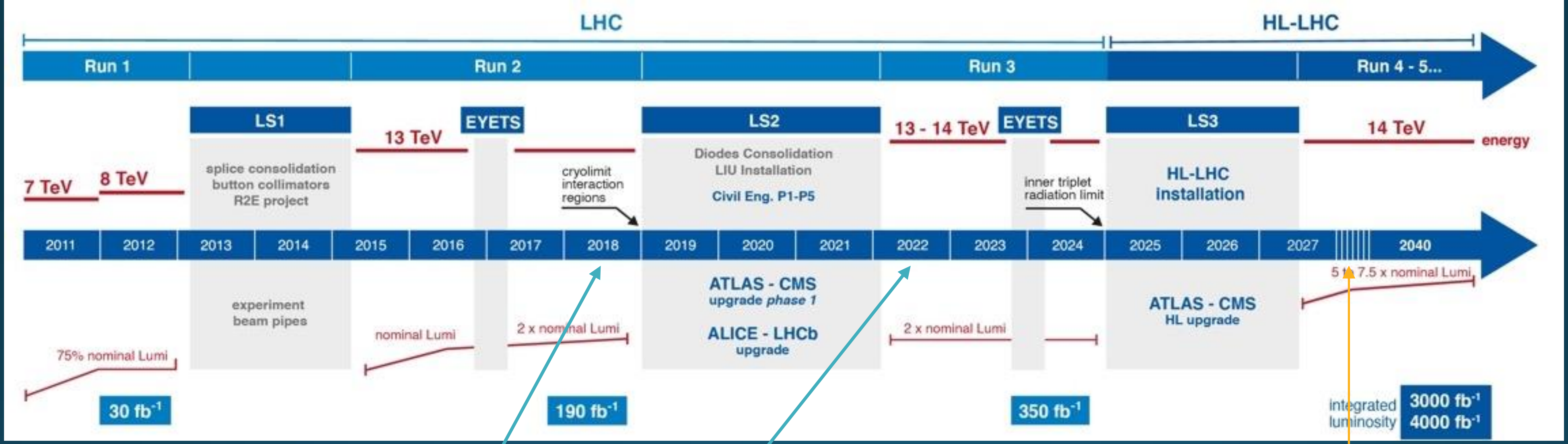
Physics Motivation



- The FPF has a rich and broad physics programme
- Three main physics motivations
  - Beyond Standard Model (BSM) "dark sector" searches
  - Neutrino physics
  - QCD physics
- In order to fully benefit from the increase in luminosity from the HL-LHC, the FPF will allow:
  - Longer detectors to increase target/decay volume
  - Wider detectors to increase sensitivity to heavy flavour produced particles
  - Space for new detectors with complementary physics capabilities

FASERν/FASERν2 schedule

- LHC Run-3 will start in 2022, FASERν.
- HL-LHC, starting in 2028, will deliver 10 times more integrated luminosity → FASERν2



Pilot run & background measurements in 2018

FASER's physics run (~150 fb^{-1} or more)

Forward experiment in HL-LHC

2022-25 physics run in LHC RUN3, 1.1 tons, a total area of film 720 m^2

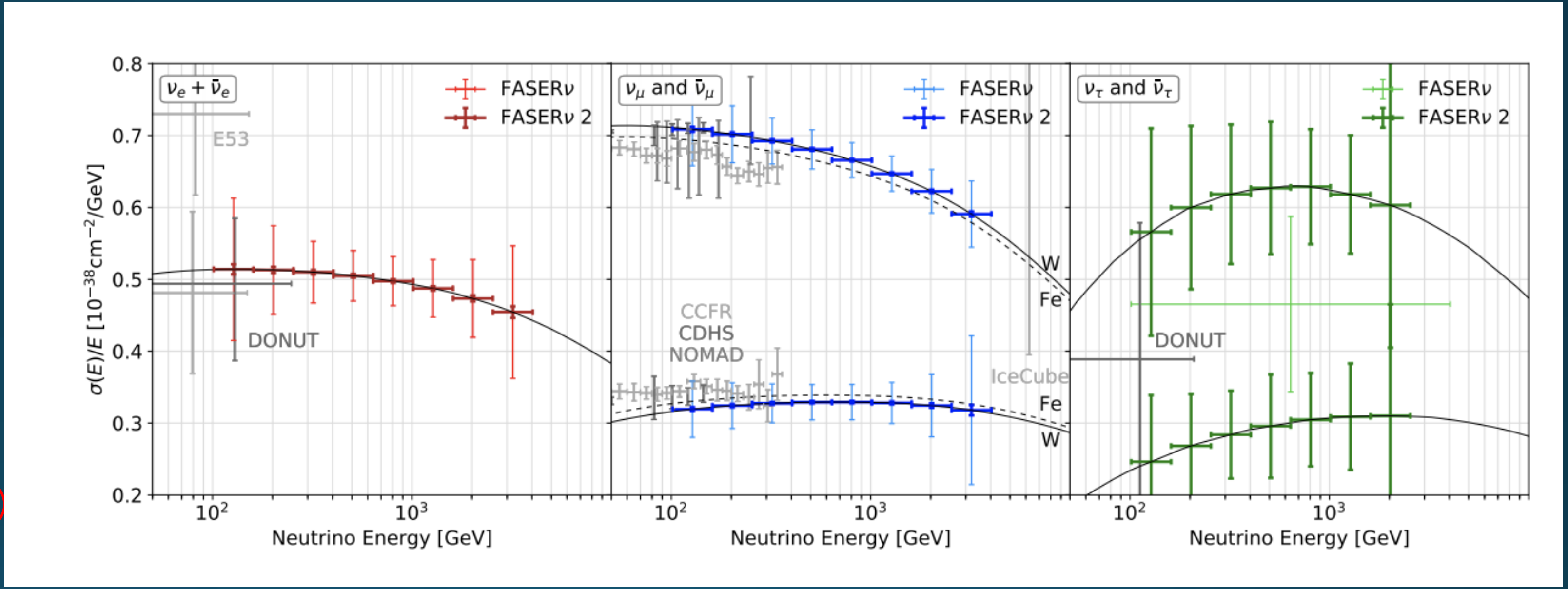
2031- FASERν2@FPF in HL-LHC, 10-20 tons

Neutrinos at the FPF

A huge number of high-energy neutrinos of all flavours will be detected by experiments at the FPF

https://arxiv.org/pdf/2105.08270.pdf (F. Kling)

Species	#evts (20tn, 3/ab)	
ν_e	64k	~100k
$\bar{\nu}_e$	36k	
ν_μ	430k	~500k
$\bar{\nu}_\mu$	120k	
ν_τ	2k	~3k
$\bar{\nu}_\tau$	0.8k	



Tau neutrino:

- FPF experiments will **increase this number by over two orders of magnitude**, enabling precision ν_τ studies:
- Measure high energy ν_τ/ ν_τ charge-current cross sections
- Study ν_τ → heavy flavour – towards probing same diagrams as LHCb lepton-flavour violation anomalies

Large sample of ν_e, ν_μ:

- Sterile neutrino, NSI, constrain SM EFT, s-channel resonance,,,

QCD studies → Cosmic-ray

Forward Physics Facility

FPF workshop series:
FPF1, FPF2, FPF3, FPF4

FPF Paper:
2109.10905
~75 pages, ~80 authors

Snowmass Whitepaper:
2203.05090
~450 pages, ~250 authors

4th Forward Physics Facility Meeting

31 January 2022 to 1 February 2022
Europe/Zurich timezone

Starts 31 Jan 2022, 16:00
Ends 1 Feb 2022, 21:00
Europe/Zurich

There are no materials yet.

The Forward Physics Facility (FPF) project is moving forward!

At the 4th Forward Physics Facility Meeting we will discuss the facility, experiments, and physics goals of the proposed FPF at the HL-LHC. The meeting takes place just before the completion of the FPF Snowmass White Paper and will provide an opportunity to summarize the current status of the White Paper and the final steps in its preparation. The whole event will be held online.

The Zoom links are:
Plenary sessions (both Monday and Tuesday): https://uci.zoom.us/j/91591021575
//vu-live.zoom.us
J9RQnRzTjlpdz09
tps://uiowa.zoom.us/j/94645515841
//zoom.us/j/97280888150

The Forward Physics Facility:
Sites, Experiments, and Physics Potential

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Maria Vittoria Garzelli,[33,‡] Francesco Giuli,[34] Victor P. Goncalves,[35] Marco Guzzi,
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Adam Ritz,[28] Juan Rojo,[55] Ina Sarcevic,[56,*] Christiane Scherb,[57] Pedro Schwaller,
Holger Schulz,[59] Dipan Sengupta,[60] Torbjörn Sjöstrand,[61,*] Tyler B. Smith,[26] Dennis Sol
Anna Stasto,[62] Antoni Szczurek,[48] Zahra Tabrizi,[63] Sebastian Trojanowski,[64,65]
Yu-Dai Tsai,[26,46] Douglas Tuckler,[66] Martin W. Winkler,[67] Keping Xie,[7] and Yue Zha

The Forward Physics Facility (FPF) is a proposal to create a cavern with the sp
infrastructure to support a suite of far-forward experiments at the Large Hadron
during the High Luminosity era. Located along the beam collision axis and shield
the interaction point by at least 100 m of concrete and rock, the FPF will house expe
that will detect particles outside the acceptance of the existing large LHC experime
will observe rare and exotic processes in an extremely low-background environment.
work, we summarize the current status of plans for the FPF, including recent pro
civil engineering in identifying promising sites for the FPF; the FPF experiments c
envisioned to realize the FPF's physics potential; and the many Standard Model a
physics topics that will be advanced by the FPF, including searches for long-lived p
probes of dark matter and dark sectors, high-statistics studies of TeV neutrinos of a
flavors, aspects of perturbative and non-perturbative QCD, and high-energy astro
physics.

Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

The Forward Physics Facility
at the High-Luminosity LHC

High energy collisions at the High-Luminosity Large Hadron Collider (LHC) produce a large number of particles along the beam collision axis, outside of the acceptance of existing LHC experiments. The proposed Forward Physics Facility (FPF), to be located several hundred meters from an LHC interaction point and shielded by concrete and rock, will host a suite of experiments to probe standard model processes and search for physics beyond the standard model (BSM). In this report, we review the status of the civil engineering plans and the experiments to explore the diverse physics signals that can be uniquely probed in the forward region. FPF experiments will be sensitive to a broad range of BSM physics through searches for new particle scattering or decay signatures and deviations from standard model expectations in high statistics analyses with TeV neutrinos in this low-background environment. High statistics neutrino detection will trace back to fundamental topics in perturbative and non-perturbative QCD and in weak interactions. Experiments at the FPF will enable synergies between forward particle production at the LHC and astroparticle physics to be exploited. We report here on these physics topics, on infrastructure, detector and simulation studies, and on future directions to realize the FPF's physics potential.