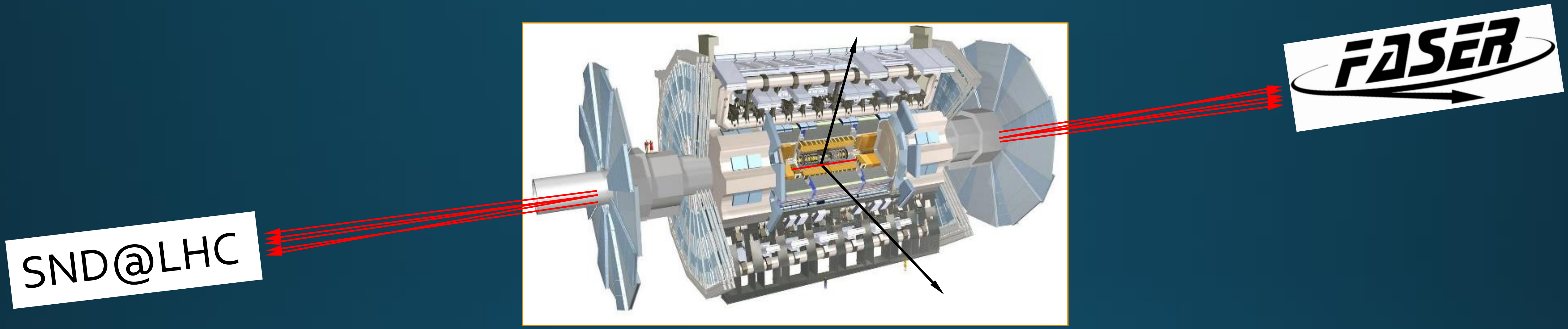


Akitaka Ariga, UniBe
On behalf of FASER and SND@LHC collaboration

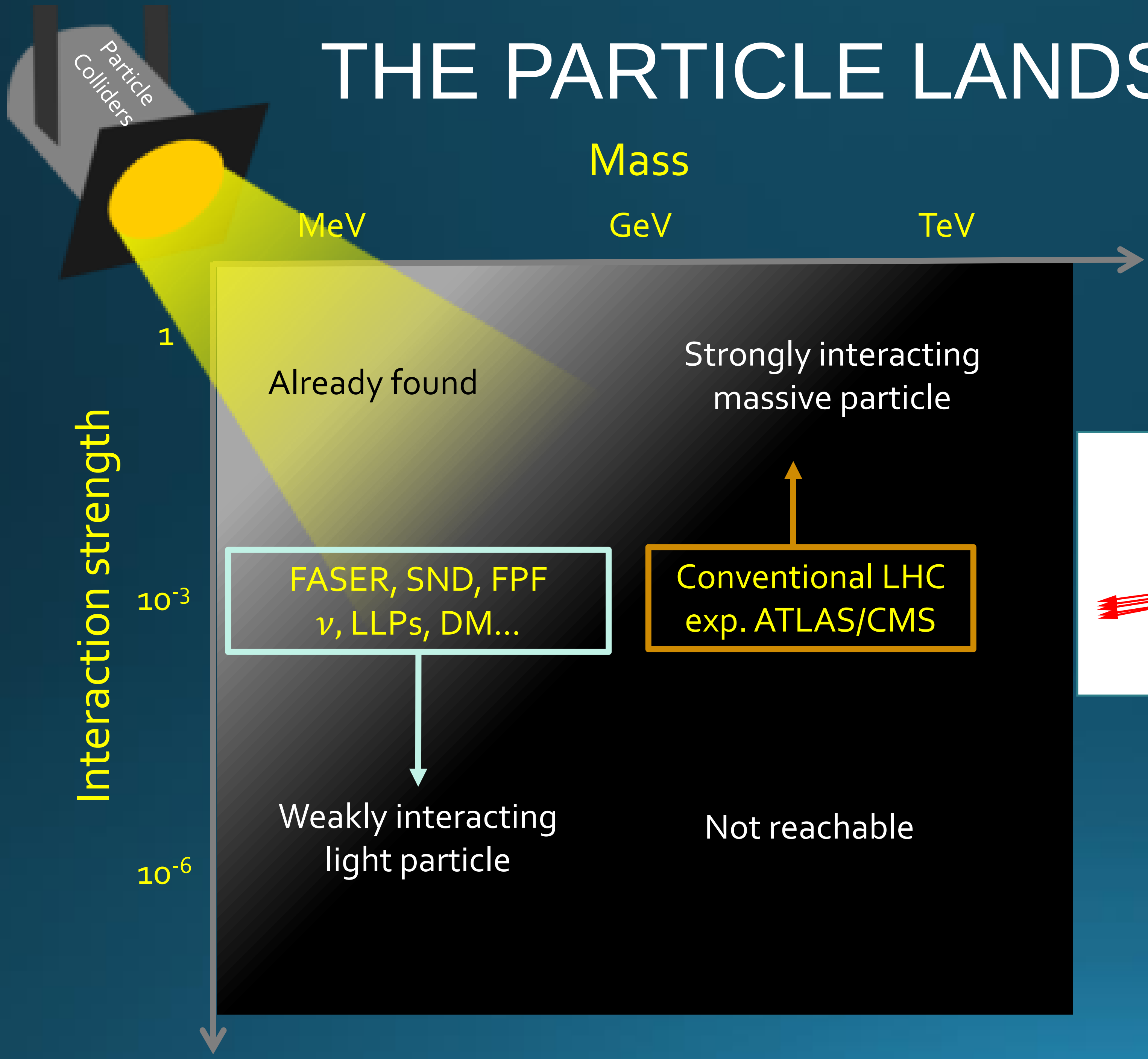
FASER / FASERν / SND@LHC

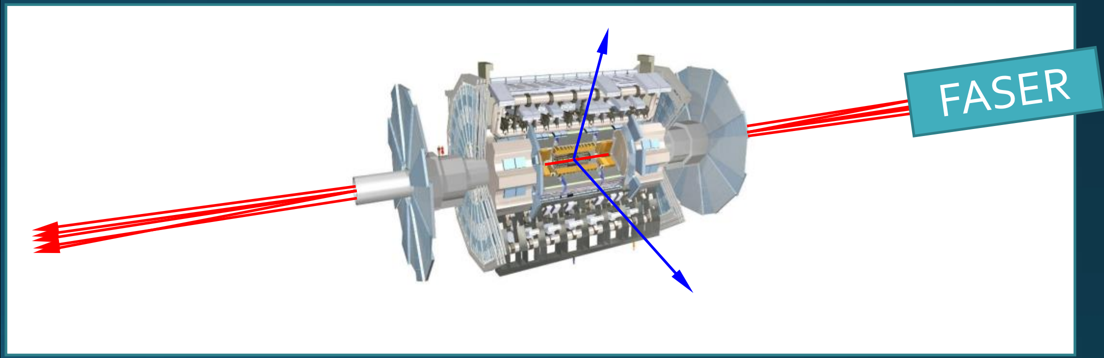
ForwArd Search ExpeRiment
Scattering and Neutrino Detector at the LHC

New experiments at the LHC

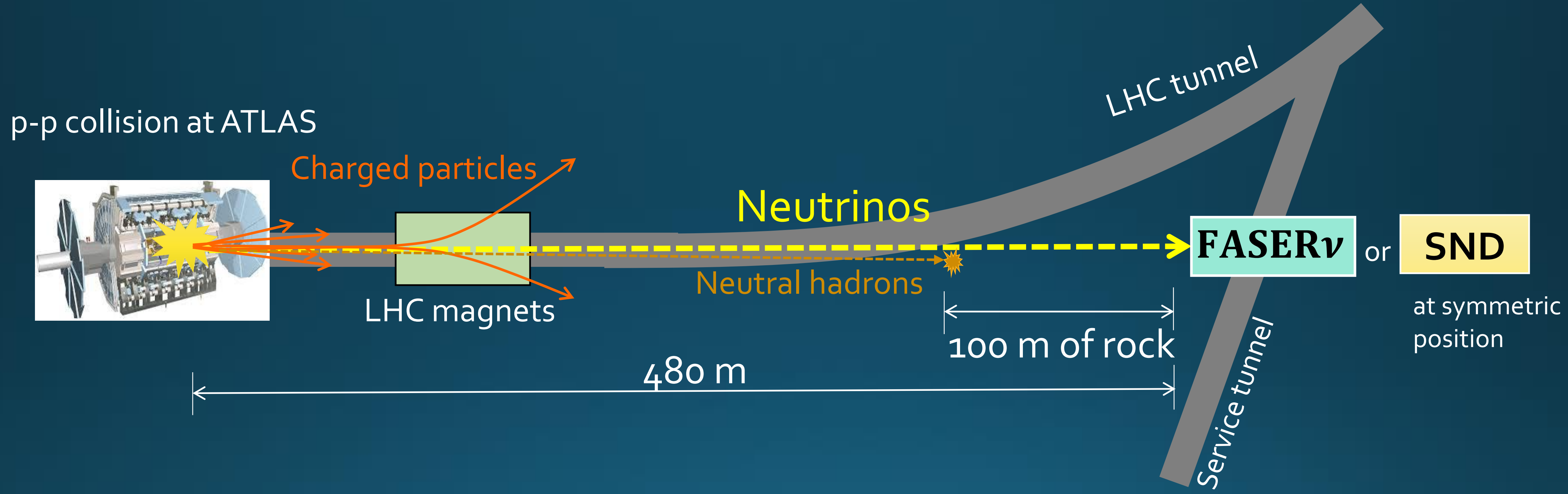
- LHC = Great investment of particle physics community
- Its focus had been on the "strongly-interacting massive particles" → So far, no evidence of NP, except for Higgs
- Maximum use of the LHC, extending physics programs to the "weakly-interacting light particle"
  - Neutrinos
  - Dark photon, ALPs
- FASER, FASERν and SND have recently approve approved
  - FASER, new particle searches, TP 1812.09139, approved in Mar 2019
  - FASERν, neutrinos, TP 2001.03073, approved in Dec 2019
  - SND@LHC, neutrinos, cds.cern.ch/record/2750060, approved in Mar 2021
  - These are relatively small and cost-effective, thanks to existing infrastructures

THE PARTICLE LANDSCAPE





Neutrinos at the LHC



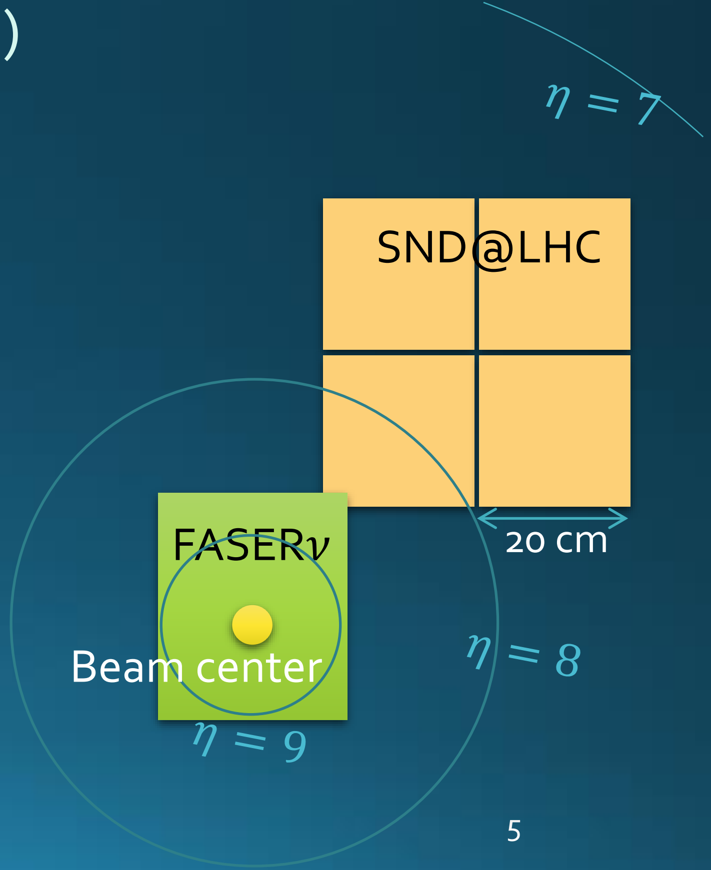
Neutrino physics

- Neutrino spectra at unexplored energy range
  - Study production / propagation / interaction
  - Cross section measurements of ν_e, ν_μ, ν_τ
  - Heavy flavor physics, NC, QCD, NSI, oscillations → see backup p18, 19
  - Complementarity between FASERν (on axis) and SND (off axis)

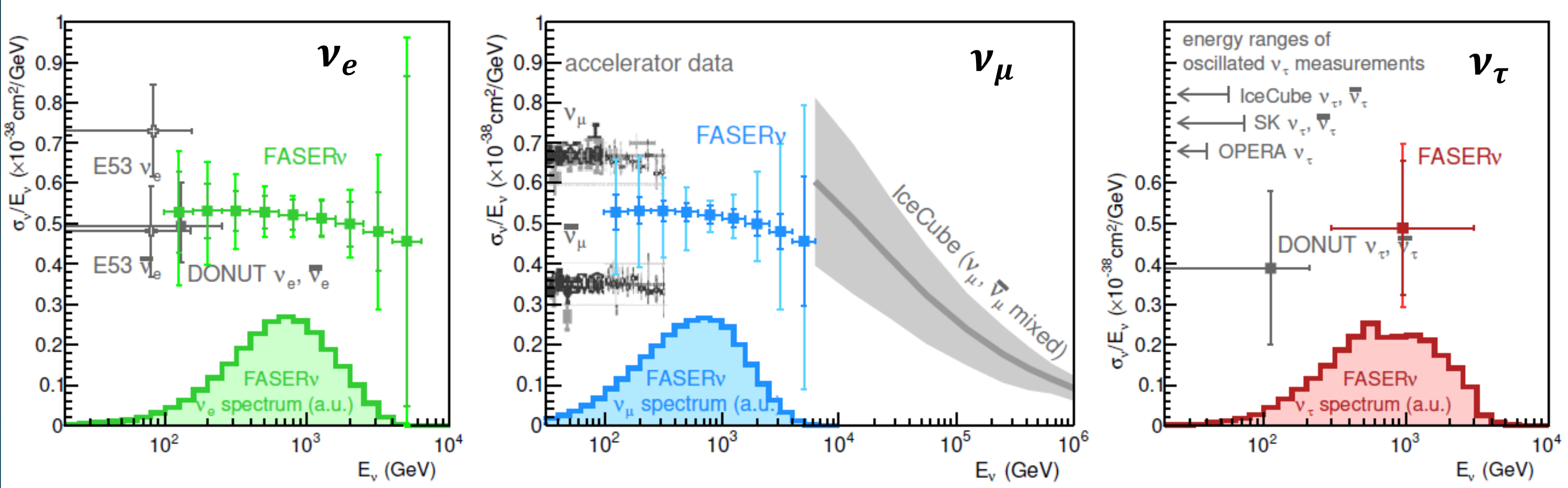
Expected CC event statistics

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	1343	6072	21.2	184	965	10.1
DPMJET	DPMJET	4614	9198	131	547	1345	22.4
EPOSLHC	Pythia8 (Hard)	2109	7763	48.9	367	1459	16.1
QGSJET	Pythia8 (Soft)	1437	7162	24.5	259	1328	10.7
Combination (all)		2376^{+2238}_{-1032}	7549^{+1649}_{-1476}	$56.4^{+74.5}_{-35.1}$	339^{+208}_{-155}	1274^{+184}_{-308}	$14.8^{+7.5}_{-4.7}$
Combination (w/o DPMJET)		1630^{+479}_{-286}	7000^{+763}_{-926}	$31.5^{+17.3}_{-10.3}$	270^{+96}_{-85}	1251^{+208}_{-285}	$12.3^{+3.8}_{-2.1}$

F. Kling, arXiv:2105.08270



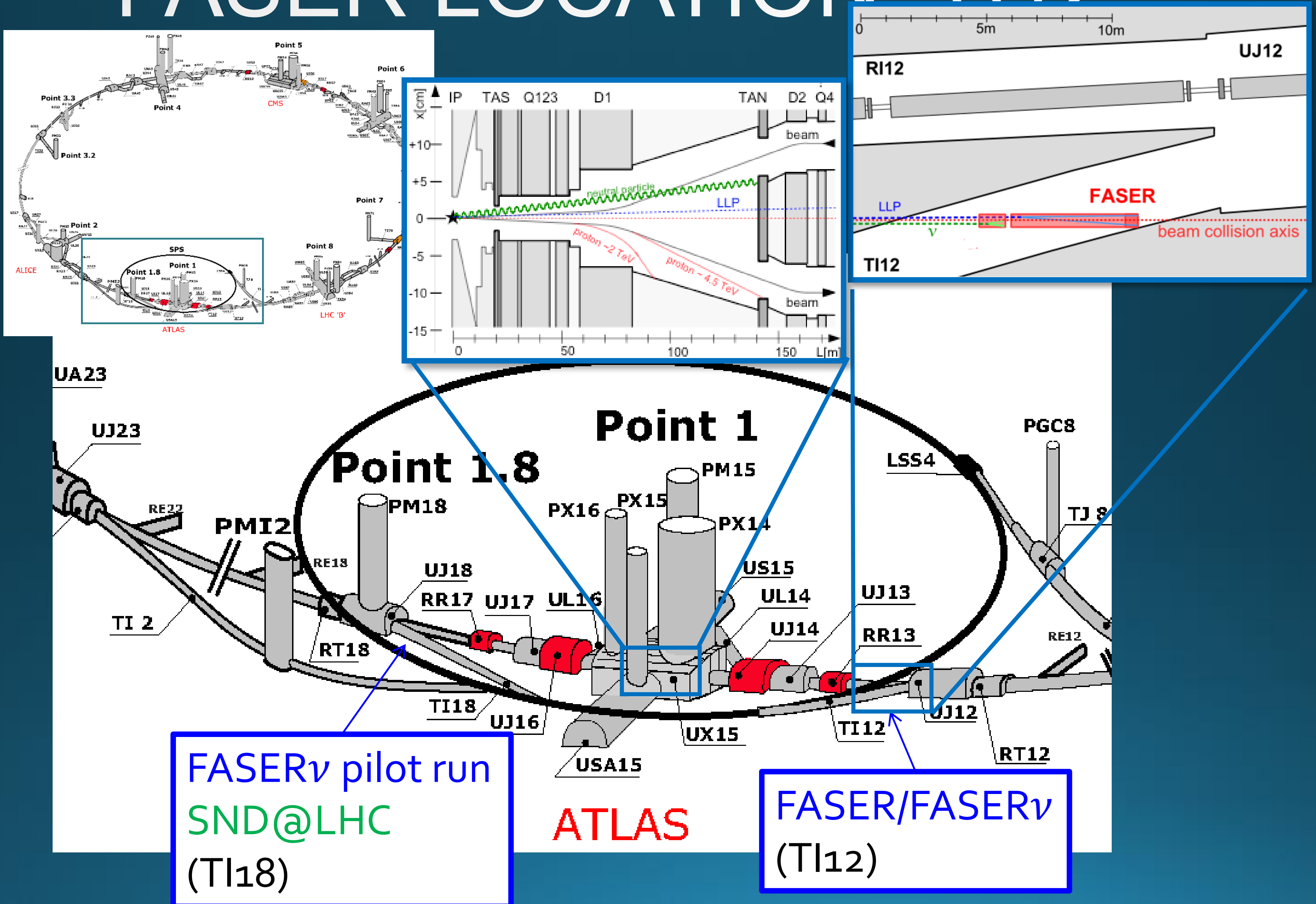
Projected precision of FASERν measurement at 14-TeV LHC (150 fb^{-1})



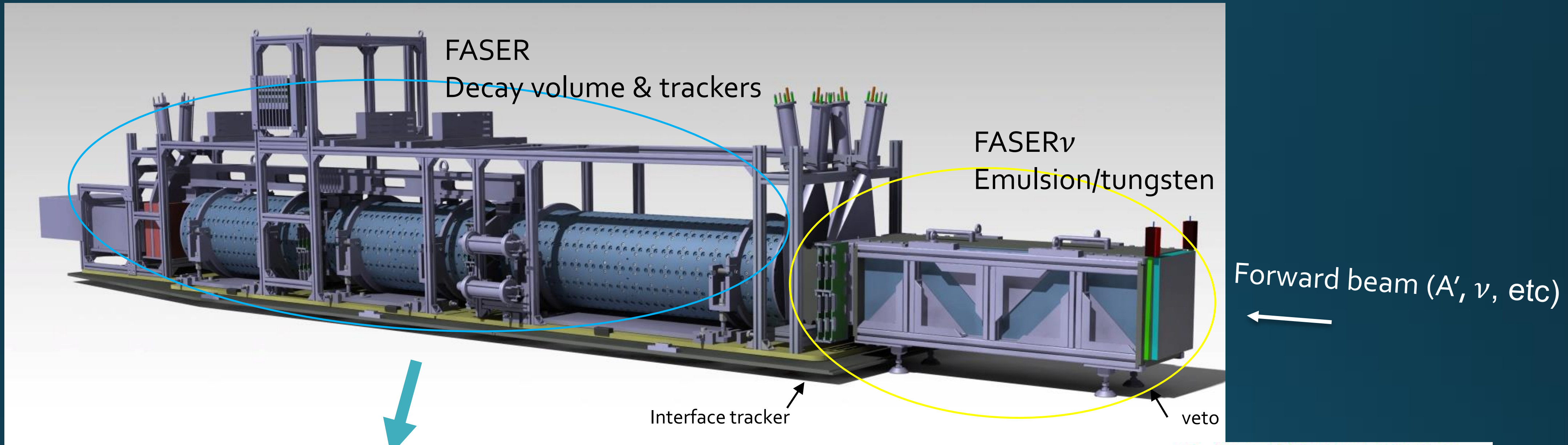
inner error bars: statistical uncertainties, outer error bars: uncertainties from neutrino production rate corresponding to the range of predictions obtained from different MC generators.

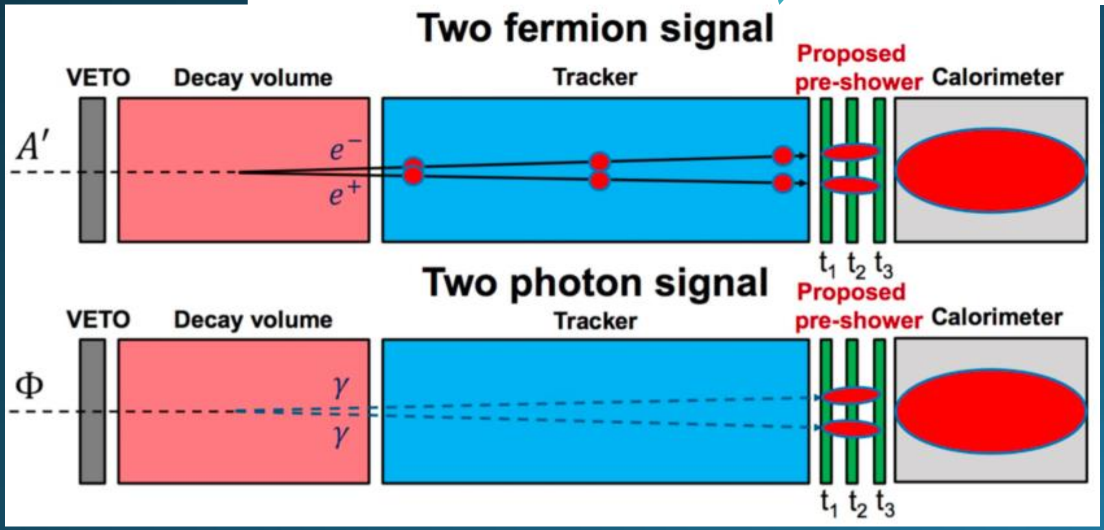
FASER Collaboration, Eur. Phys. J. C 80 (2020) 61, arXiv:1908.02310

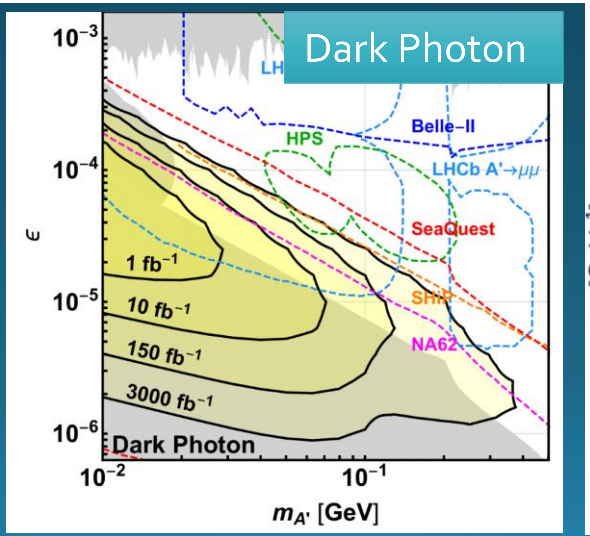
FASER LOCATION: TI12

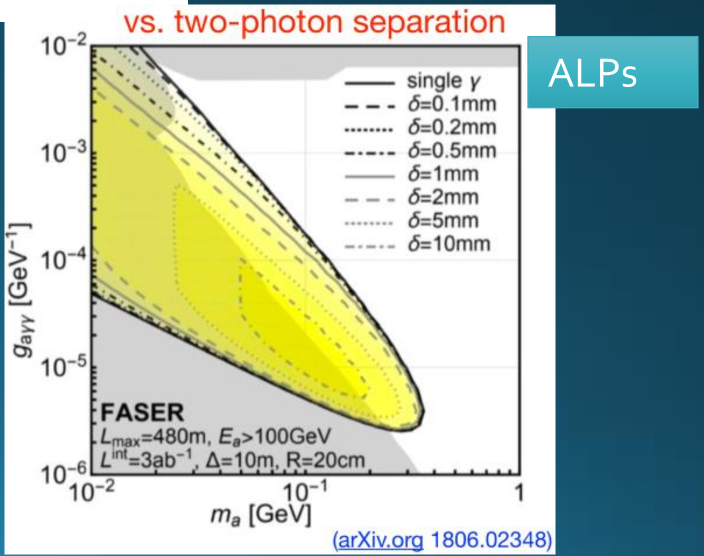


FASER/FASERν detector

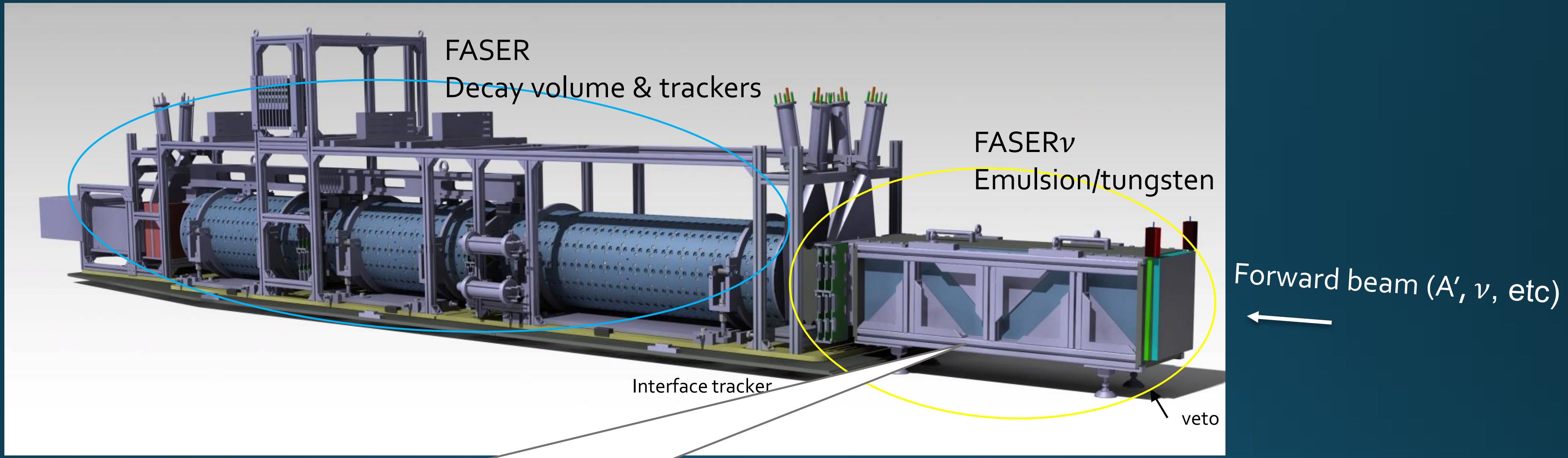


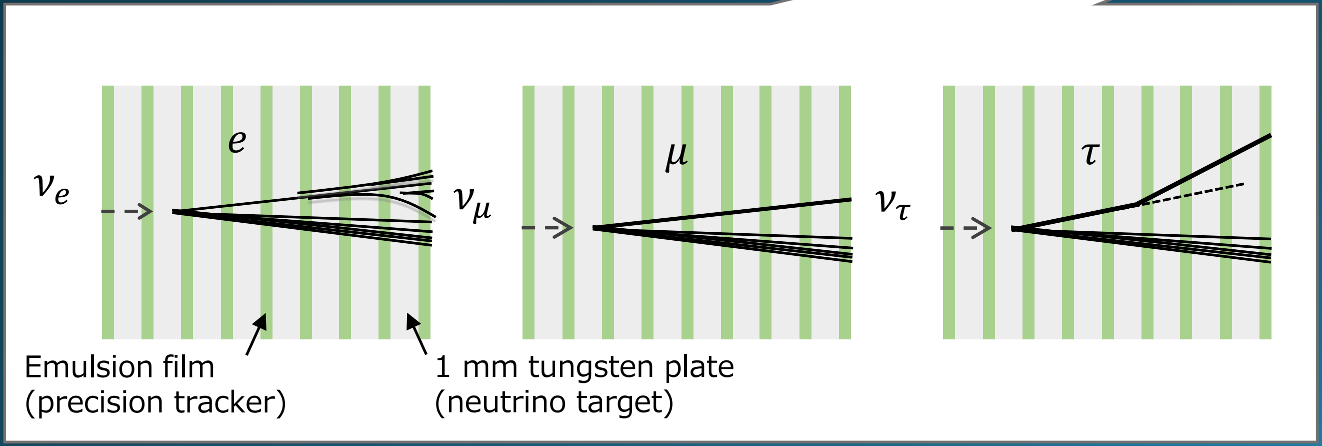






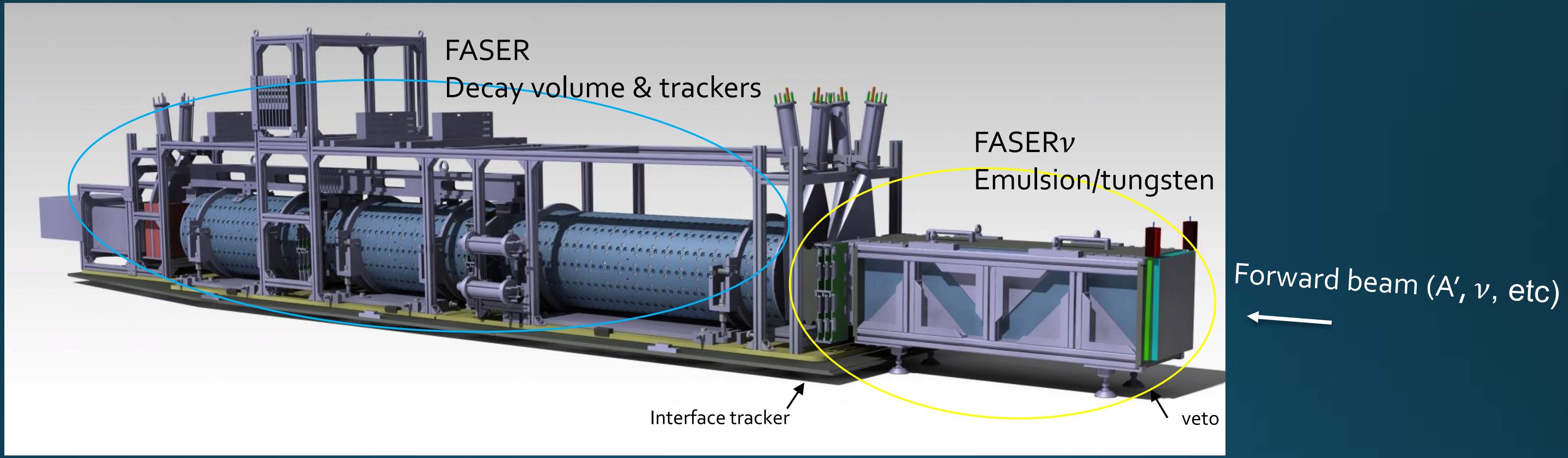
FASER/FASERν detector





- 770 1-mm-thick tungsten target and emulsion films
- 25x30 cm², 1.1 m, 1.1 tons (8 λ_{int}, 220X_0)
- Muon ID in track length in tungsten
- 3 flavor neutrinos
- Global reconstruction with FASER spectrometer → $\nu_\mu/\bar{\nu}_\mu$ separation

Swiss contributions to FASER



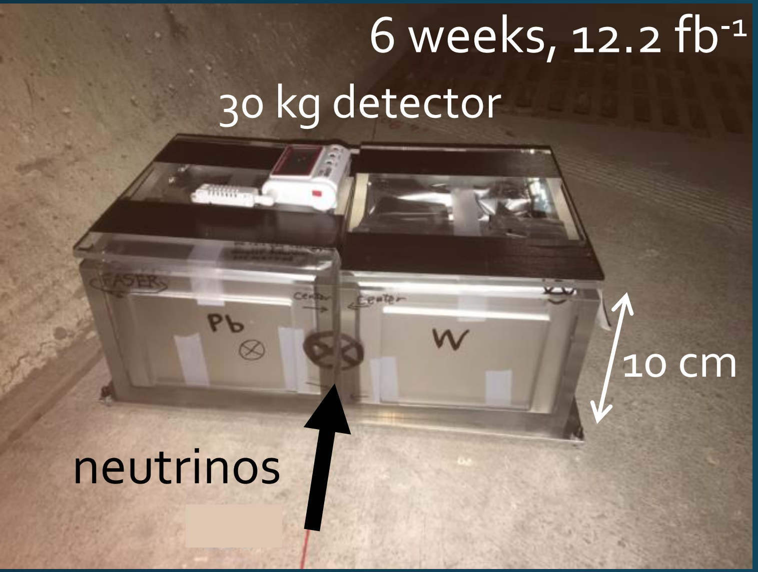
FASER

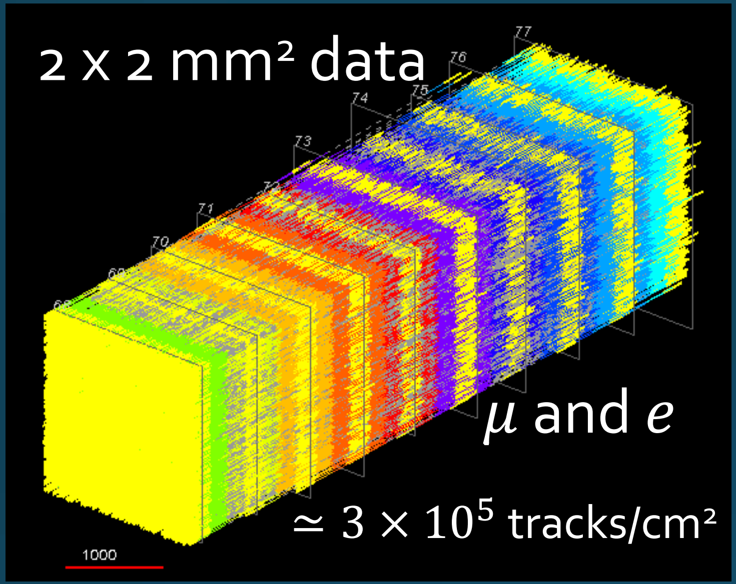
- Tracker mechanics
- Pre-shower detector upgrade
- TDAQ electronics
- Detector & TDAQ operation
- CB chair (Peppe Iacobucci, Geneva)
- TDAQ project leader (Anna Sfyrla, Geneva)
- Detector Support project leader (Franck Cadoux, Geneva)

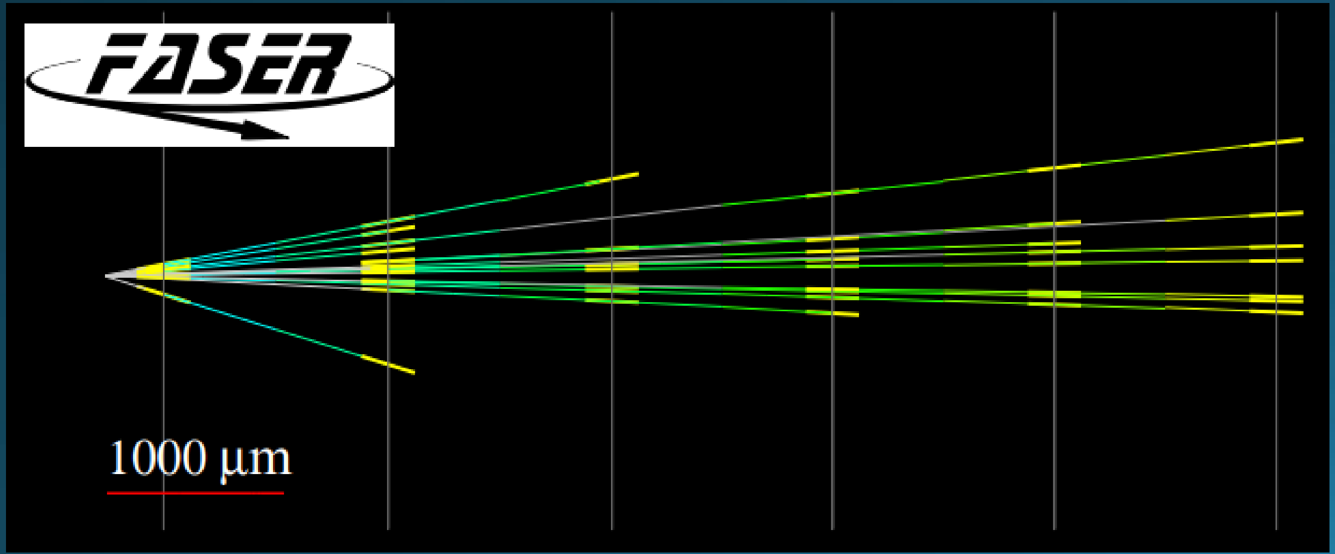
FASERν

- Detector structure, assembling
- Chemical processing
- Emulsion analysis
- FASERν co-project leader (Akitaka Ariga, Bern)

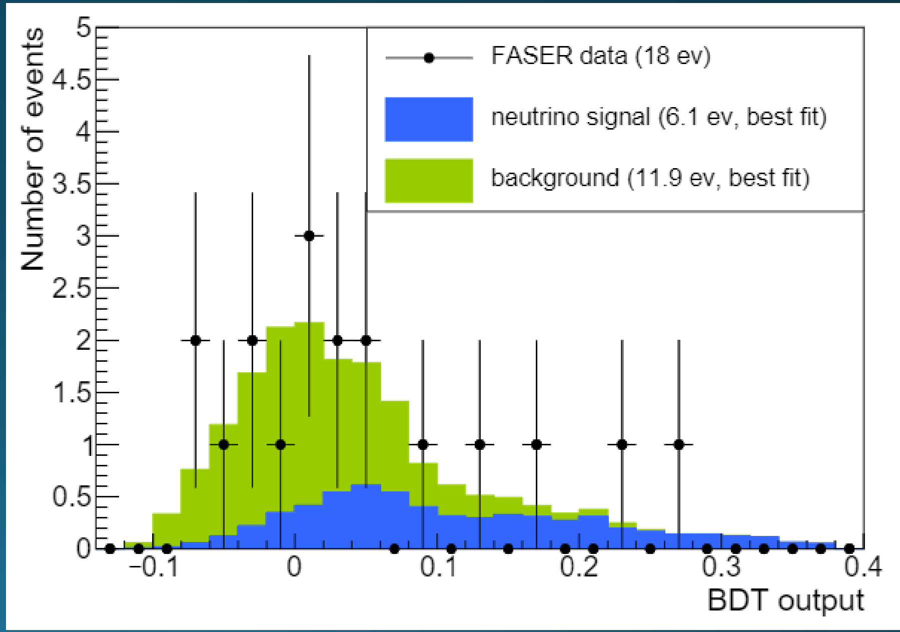
FASERν pilot run in 2018





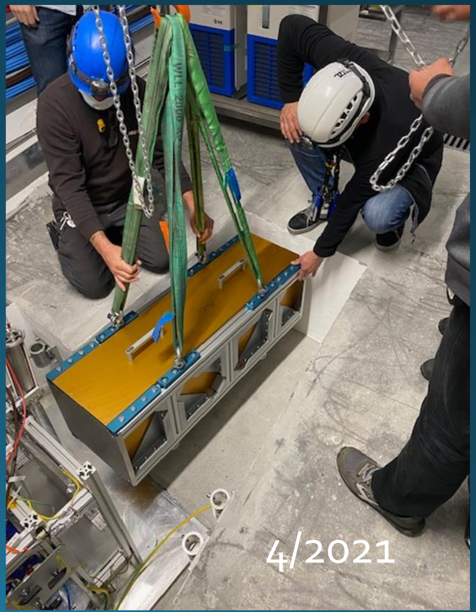


- Analyzed target mass of 11 kg and 12.2 fb^{-1}
- Pilot neutrino detector doesn't have lepton ID
- Expected signal = $3.3^{+1.7}_{-0.95}$ events, BG = 11.0 events
- In BDT analysis, an excess of neutrino signal is observed. Statistical significance = 2.7 sigma from null hypothesis



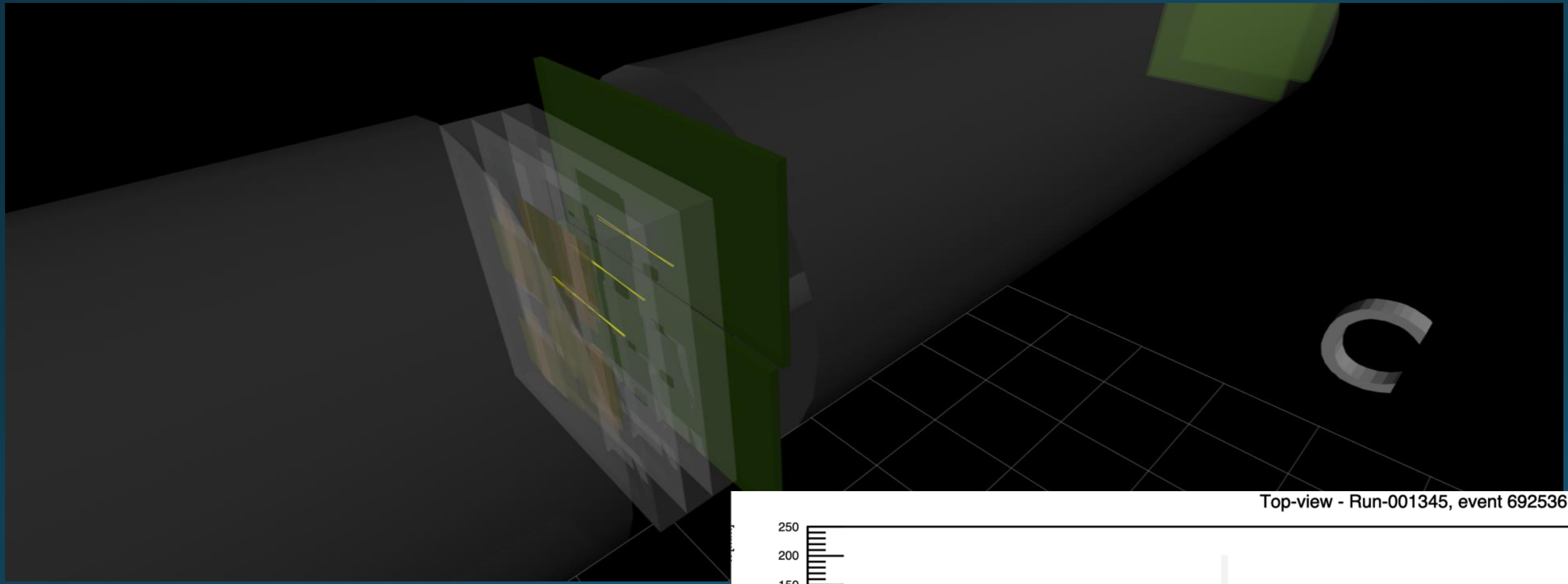
"First neutrino interaction candidates at the LHC, arXiv:2105.06197"

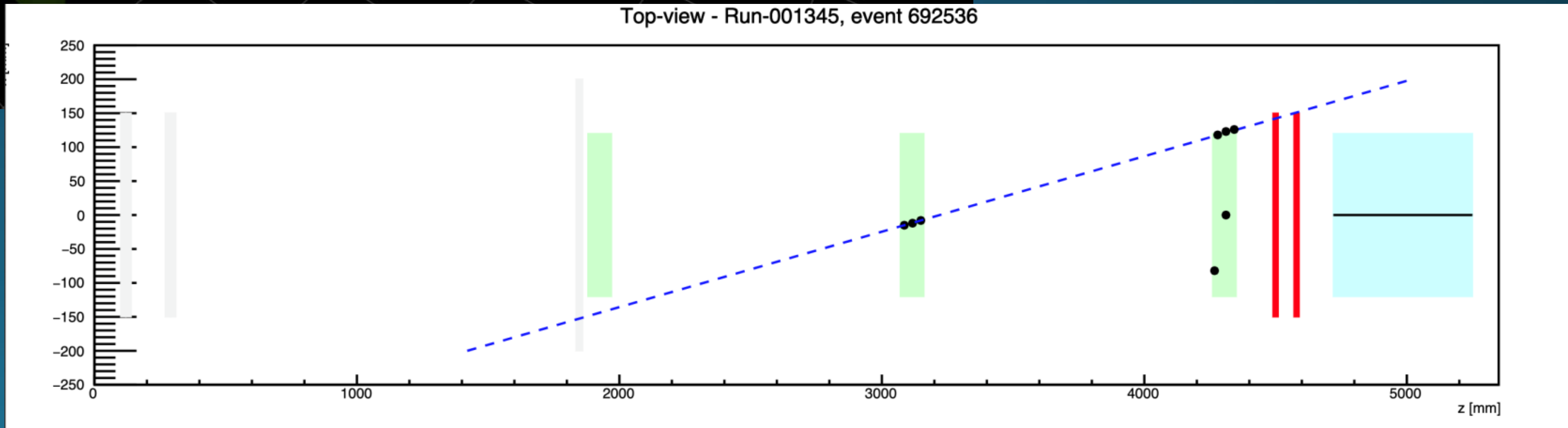
Evolution of TI12 tunnel for FASER installation



Commissioning of FASER trackers

Cosmic-ray tracks at the experimental site (TI12 tunnel).
Rate of such tracks is 1 every 2 minutes.





SND detector

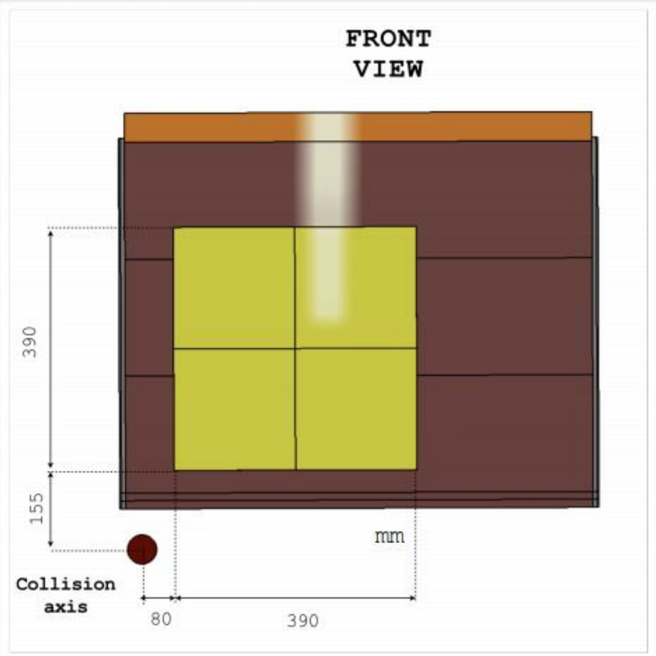
Swiss involvement:
- EPFL builds SciFi and DAQ;
- UZH builds muon system.

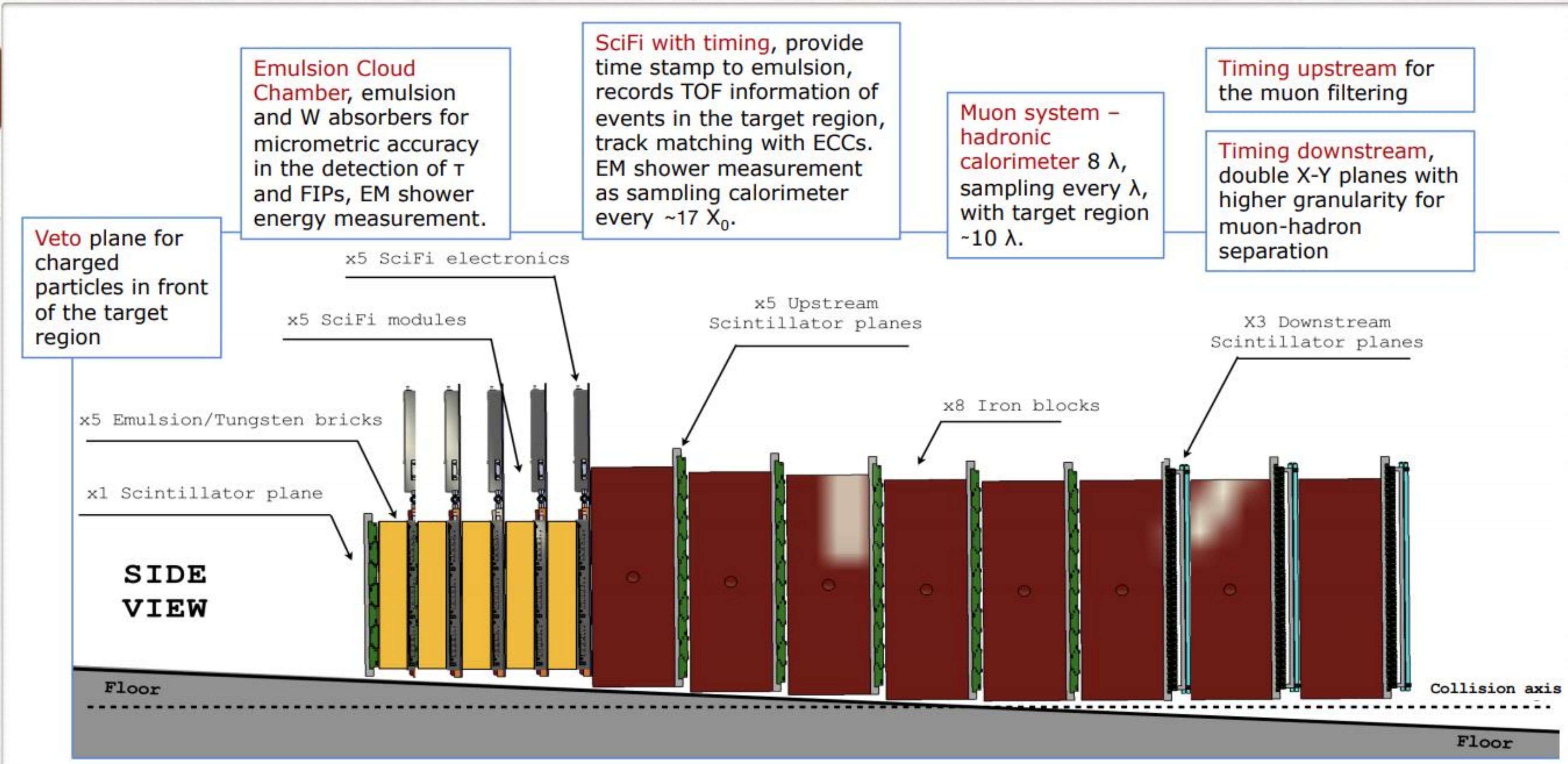
- Angular acceptance: $7.2 < \eta < 8.6$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm²

Electromagnetic calorimeter
~40 X_0

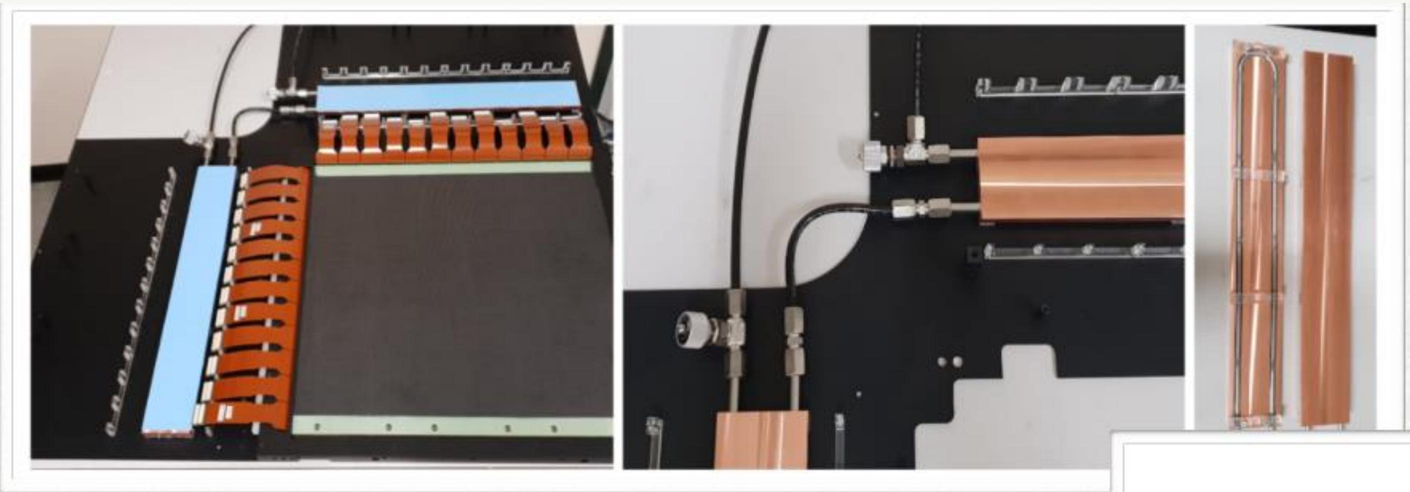
Hadronic calorimeter
~10 λ

Off axis location



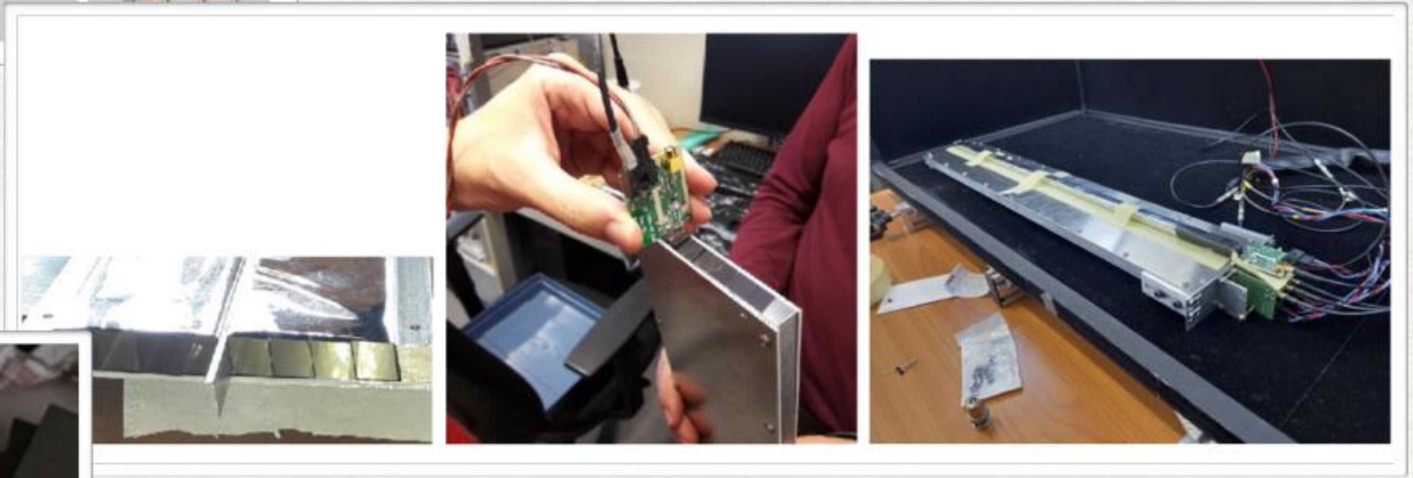


SND detector construction



- Construction of SciFi planes @EPFL

- Test of scintillator bars @Bologna



- Tungsten plates delivered @CERN

Forward Physics Facility at the HL-LHC

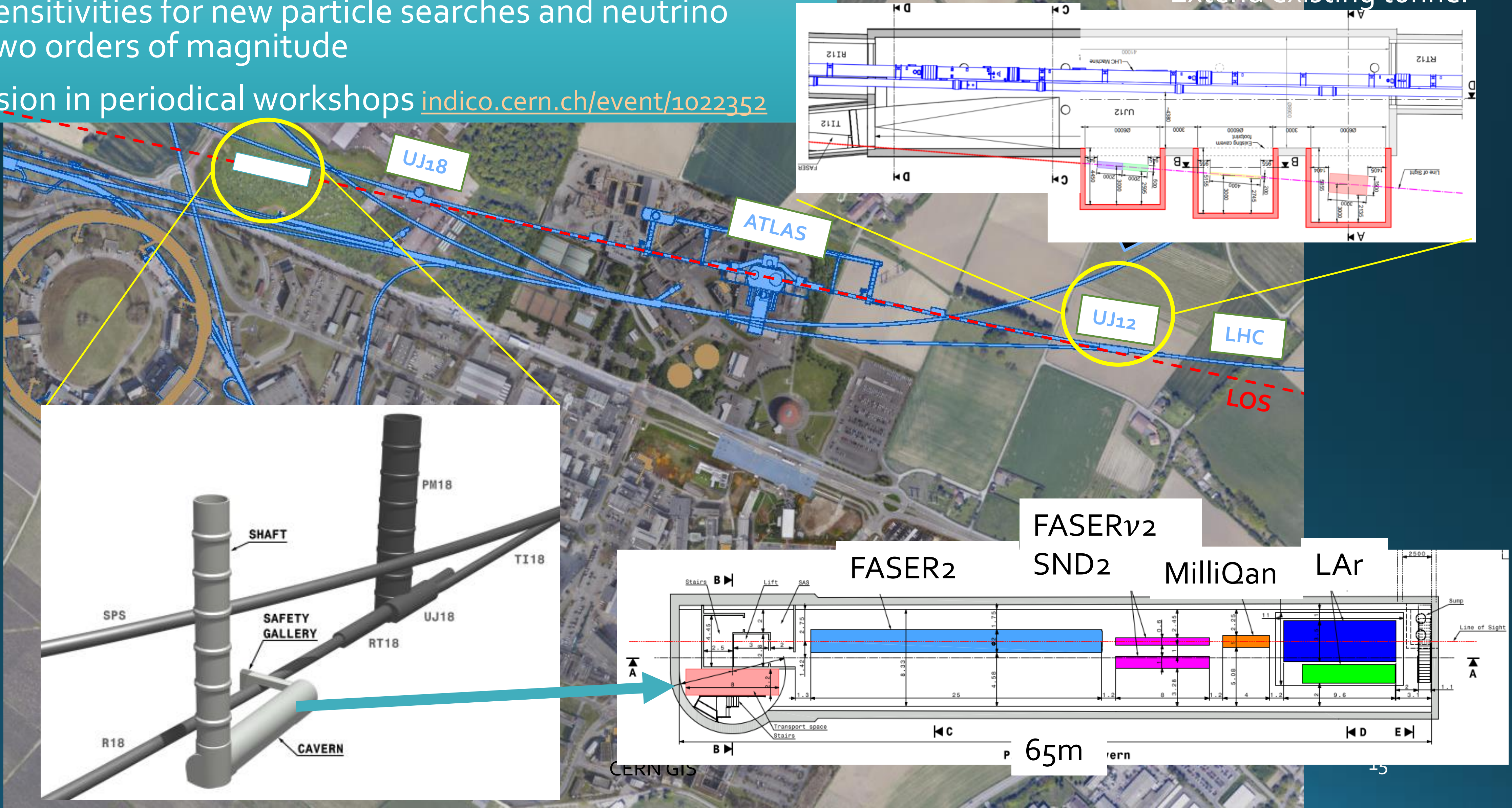
HL-LHC provides x20 proton collisions

Extending sensitivities for new particle searches and neutrino physics by two orders of magnitude

Wide discussion in periodical workshops indico.cern.ch/event/1022352

Option 1:
Extend existing tunnel

Option 2:
New shaft
and hall



CERN GIS

Summary

- New domain of research is opening at the far forward region of the LHC
- Three approved experiments/projects: FASER/FASERν/SND@LHC
- All three will start data taking in 2022
- Swiss contribution to this new field is fundamental
- Discussion on the next stage experiments at the HL-LHC is ongoing

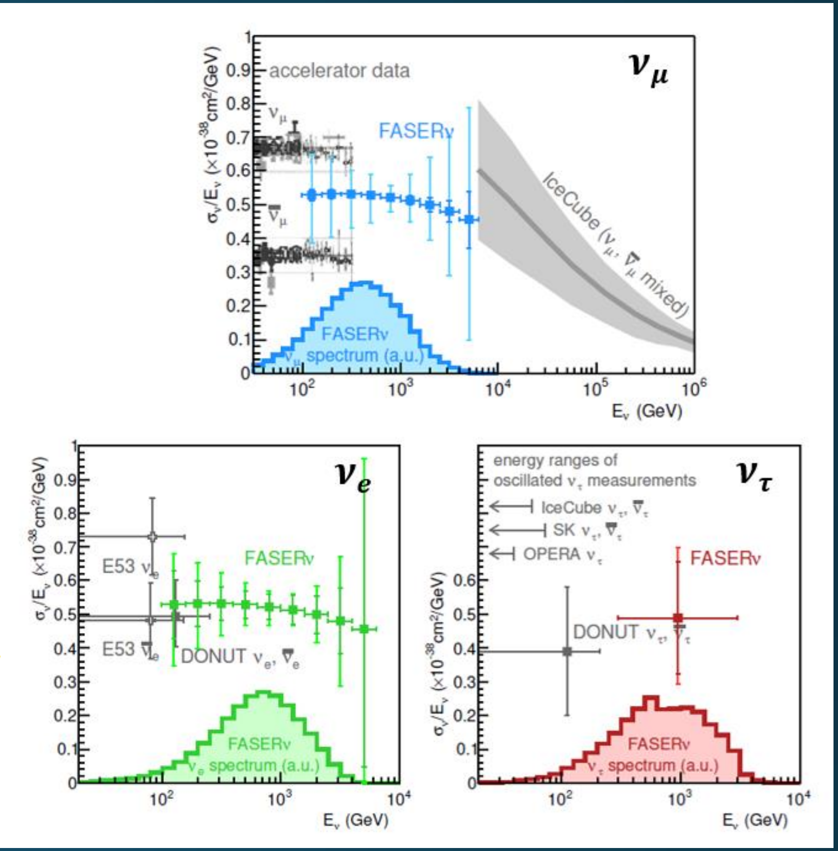
Neutrino physics

Physics potential:

high-energy neutrino interactions

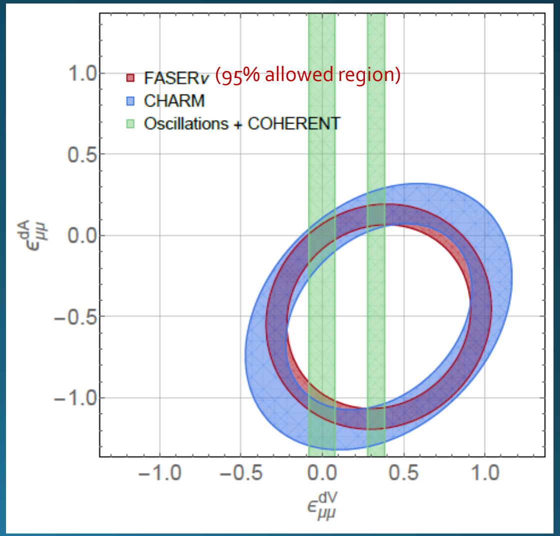
- Primary goal: cross section measurements of different flavors at TeV energies
    - where no such measurements currently exist.

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



- NC measurements
    - Could constrain neutrino non-standard interactions (NSI).

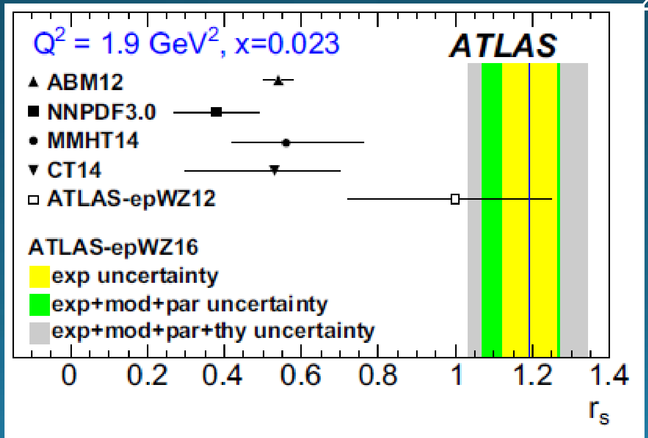
A. Ismail, R.M. Abraham, F. Kling, Phys. Rev. D 103, 056014 (2021), arXiv:2012.10500



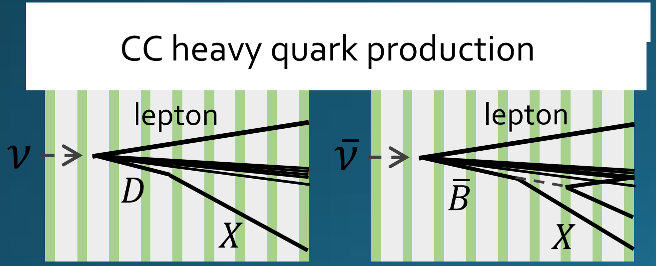
- Neutrino CC interaction with charm production ($\nu s \rightarrow lc$)
    - Study the strange quark content.
    - Probe inconsistency between the predictions and the LHC data [Eur. Phys. J. C77 (2017) 367].

Eur. Phys. J. C77 (2017) 367

$$r_s = \frac{s + \bar{s}}{2\bar{d}}$$



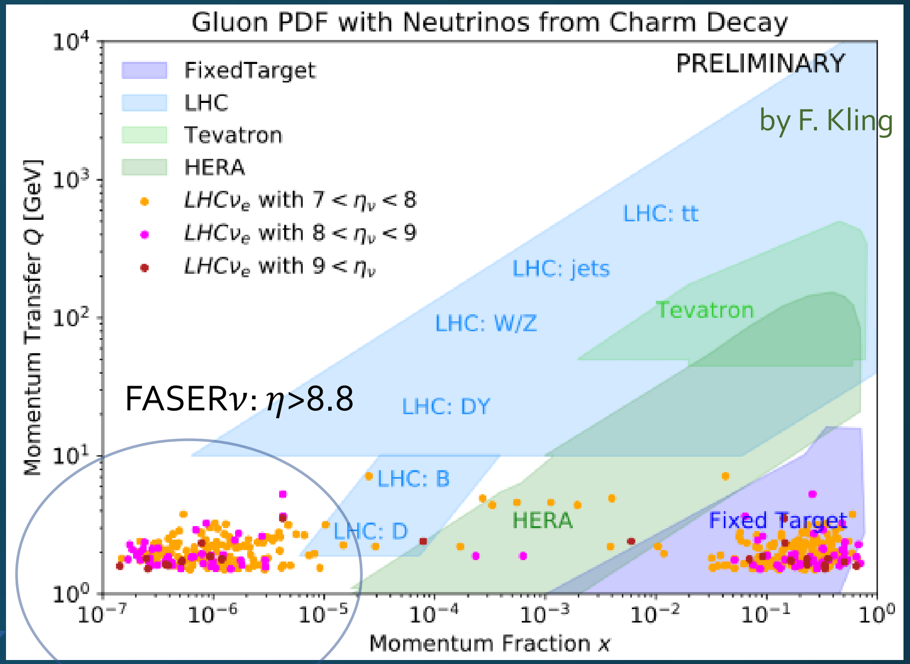
- Neutrino CC interaction with beauty production
    - Has never been detected.



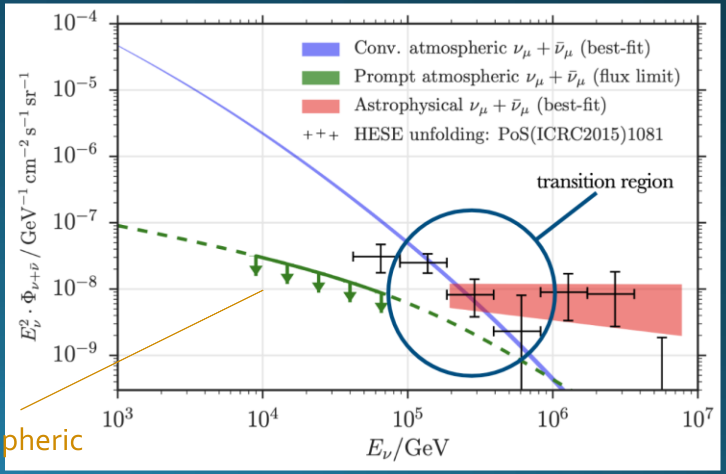
Physics potential:

forward particle production

- Neutrinos produced in the forward direction at the LHC originate from the decay of hadrons, mainly pions, kaons, and charm particles.
- Forward particle production is poorly constrained by other LHC experiments.
- FASERν's measurements provide novel input to validate/improve generators.
  - First data on forward kaon, hyperon, charm
- Neutrinos from charm decay could allow to
  - test transition to small-x factorization, see effects of gluon saturation, constrain low-x gluon PDF, probe intrinsic charm.
- Relevant for neutrino telescopes (such as IceCube).
  - 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 would provide important basic data for current and future high-energy neutrino telescopes.



IceCube Collaboration, Astrophys. J. 833 (2016)



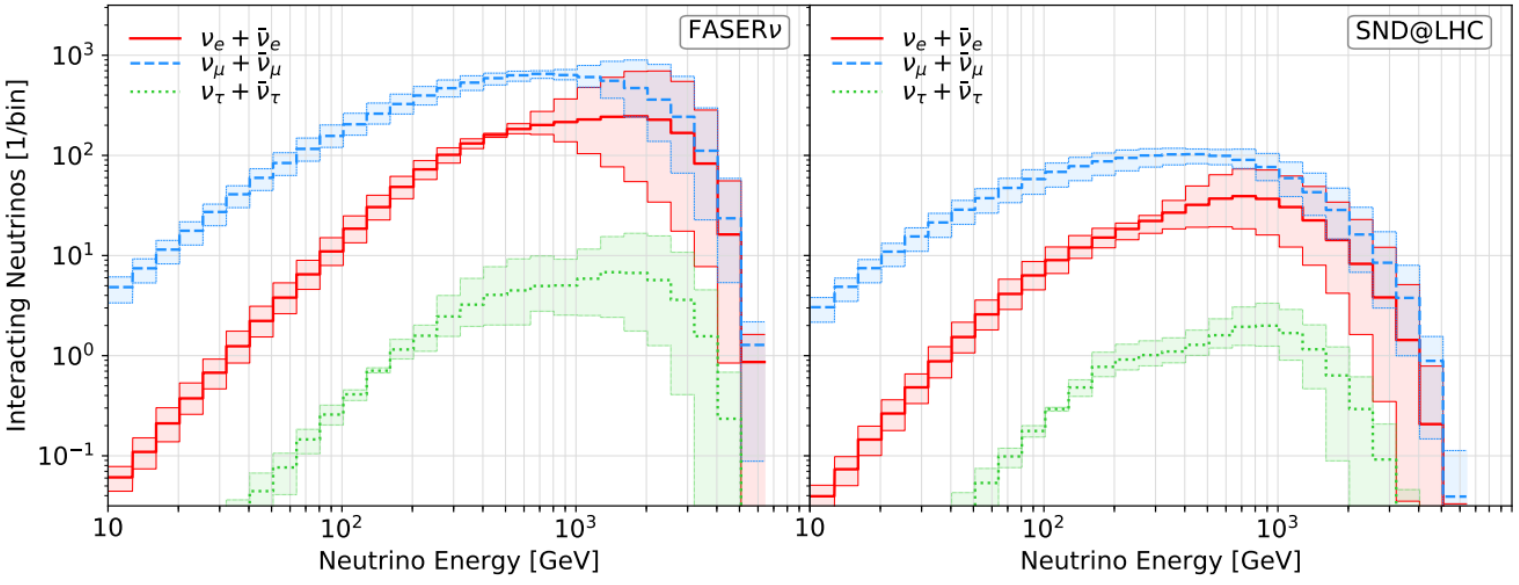
prompt atmospheric neutrinos

Backup

FASERν / SND

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	1343	6072	21.2	184	965	10.1
DPMJET	DPMJET	4614	9198	131	547	1345	22.4
EPOSLHC	Pythia8 (Hard)	2109	7763	48.9	367	1459	16.1
QGSJET	Pythia8 (Soft)	1437	7162	24.5	259	1328	10.7
Combination (all)		2376^{+2238}_{-1032}	7549^{+1649}_{-1476}	$56.4^{+74.5}_{-35.1}$	339^{+208}_{-155}	1274^{+184}_{-308}	$14.8^{+7.5}_{-4.7}$
Combination (w/o DPMJET)		1630^{+479}_{-286}	7000^{+763}_{-926}	$31.5^{+17.3}_{-10.3}$	270^{+96}_{-85}	1251^{+208}_{-285}	$12.3^{+3.8}_{-2.1}$

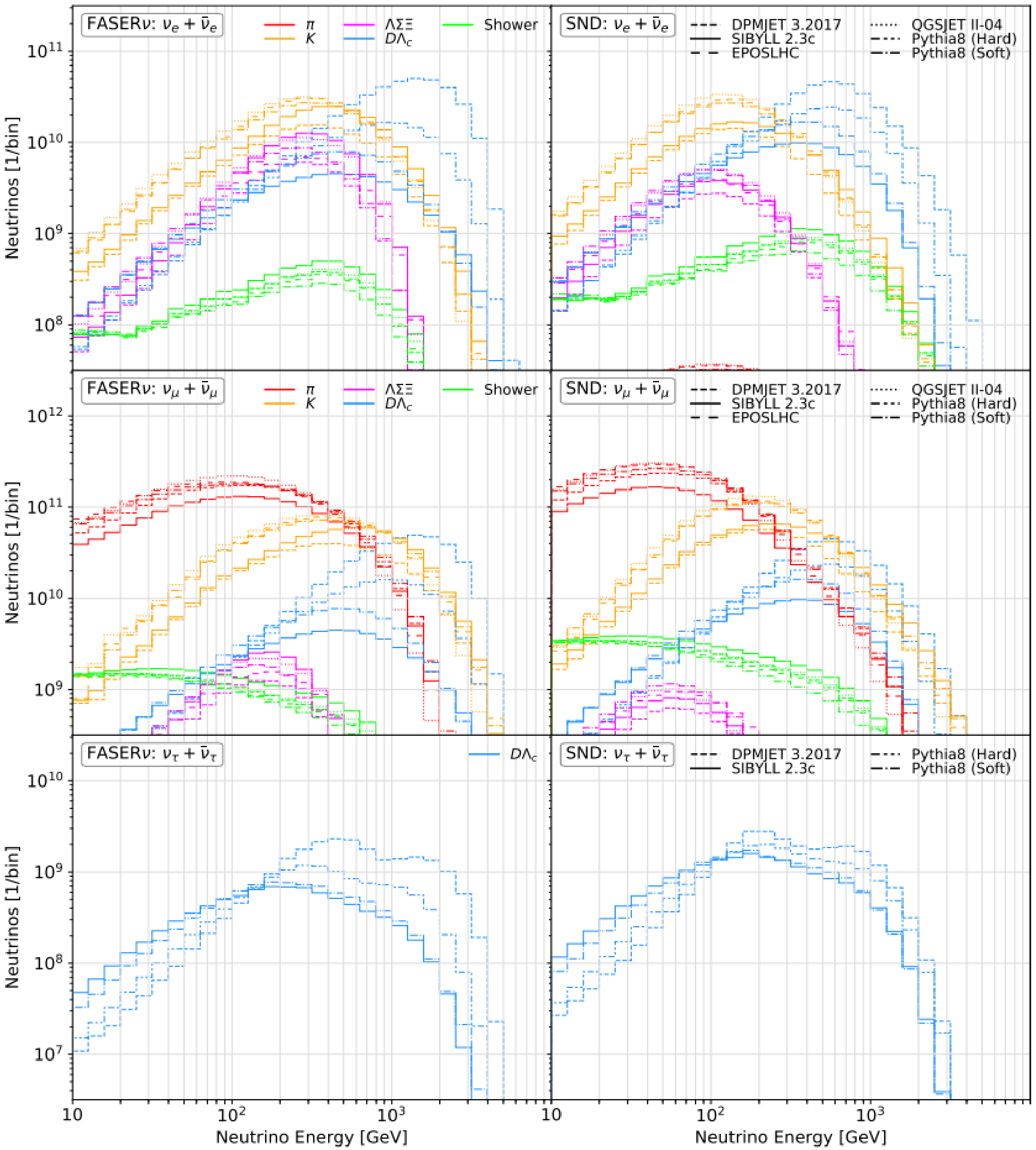
TABLE I. Expected number of neutrino interaction events occurring in FASERν and SND@LHC during LHC Run 3 with 150 fb^{-1} integrated luminosity. We provide predictions for SIBYLL 2.3c, DPMJET III.2017.1, EPOSLHC/Pythia 8.2 with HardQCD, and QGSJET II-04/Pythia 8.2 with SoftQCD. The two bottom rows provide a combined average, both including and excluding the DPMJET prediction, where the uncertainties correspond to the range of predictions obtained from different MC generators.



F. Kling, Forward Neutrino Fluxes at the LHC, arXiv:2105.08270

Neutrino flux

- Contributions from difference hadrons
- Currently large uncertainty exists
- Improving by creating a dedicated tune of hadron physics for forward region



Angular profile and acceptance of FASERnu and SND

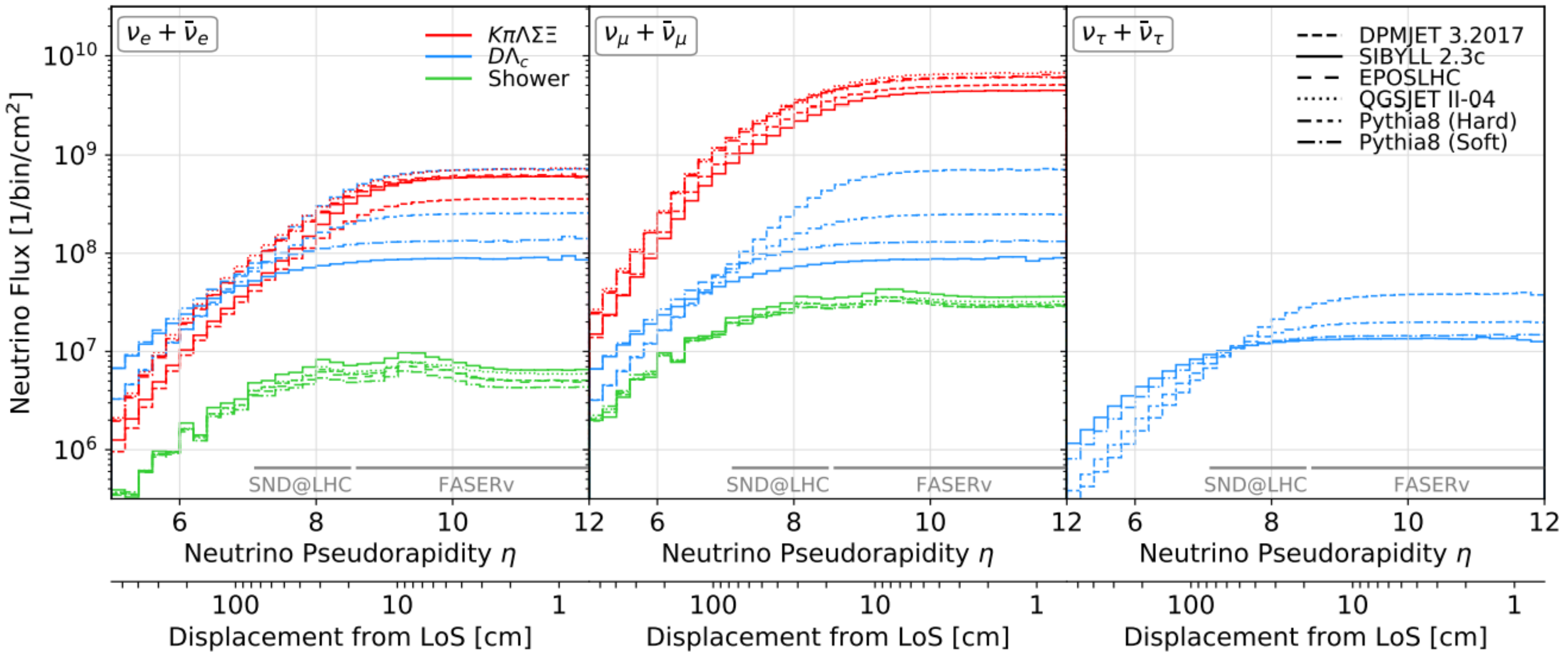


FIG. 3. **Neutrino Angular Distribution:** The panels show the flux for electron (left), muon (center) and tau (right) neutrinos, in units of particles per area per bin, as function of pseudorapidity η, or equivalently the radial displacement from the line of sight (LoS) at $z = 480$ m. The flux components from light hadron decays, charmed hadron decays and downstream hadronic showers are shown in red, blue and green, respectively. The line-styles denote the different event generators. All energies $E_\nu > 10$ GeV are included. Shown at the bottom of each panel is the angular coverage of FASERν and SND@LHC.