Measuring high-energy neutrinos with FASERν at the LHC

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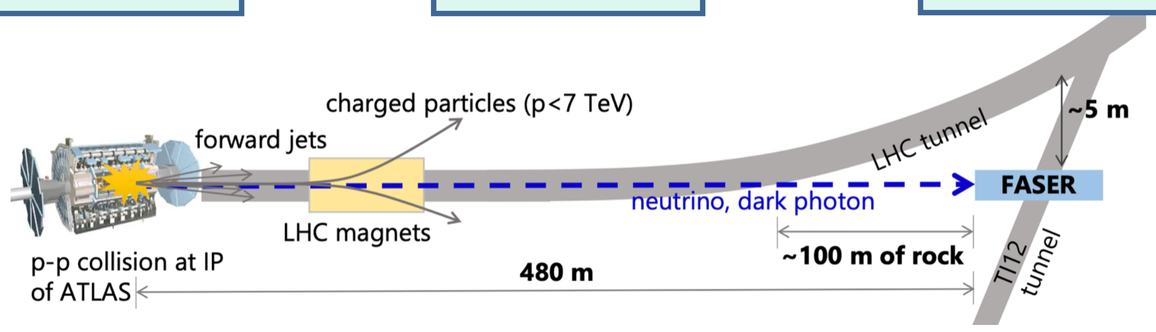
1. Forward physics at LHC with FASER

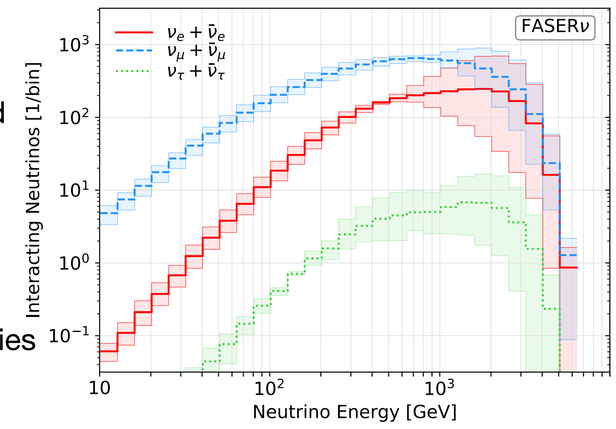
- **FASER is a small experiment to be installed in the LHC to take data in LHC Run3**
- **FASER (new particle searches) approved by CERN in Mar. 2019**
  - Targeting light, weakly-coupled new particles at low p_T
- **FASERν (neutrino measurements) approved by CERN in Dec. 2019**
  - Will perform first measurements of neutrinos from a collider
  - Enable to study neutrino production. propagation and interaction in an unexplored energy

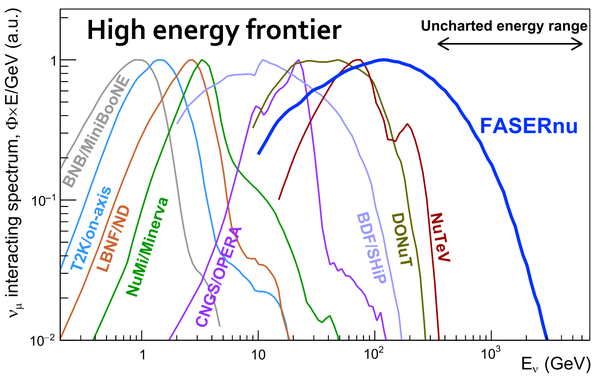
Production | **Propagation** | **Interaction**



2. Physics motivation

Production:
・Prompt neutrino production at 100 PeV fixed target ($\sqrt{s}$ = 10 TeV) → neutrino astronomy
・QCD (charm/gluon PDF, intrinsic charm
Propagation:
・Neutrino oscillation at $\Delta m^2 \sim 100\mathrm{eV}^2$
Interaction:
・3 flavor ν cross-section in unexplored Energies
・Neutrino induced heavy quark productions





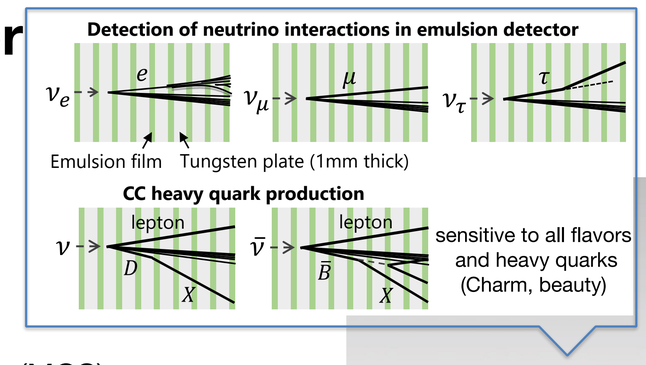
Differences between the generators

Generators		FASERν		
light hadrons	heavy hadrons	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$
SIBYLL	SIBYLL	1343	6072	21.2
DPMJET	DPMJET	4614	9198	131
EPOSLHC	Pythia8 (Hard)	2109	7763	48.9
QGSJET	Pythia8 (Soft)	1437	7162	24.5
Combination (all)		2376^{+2238}_{-1032}	7549^{+1649}_{-1476}	$56.4^{+74.5}_{-35.1}$
Combination (w/o DPMJET)		1630^{+479}_{-286}	7000^{+763}_{-926}	$31.5^{+17.3}_{-10.3}$

3. FASERν + FASER hybrid detector

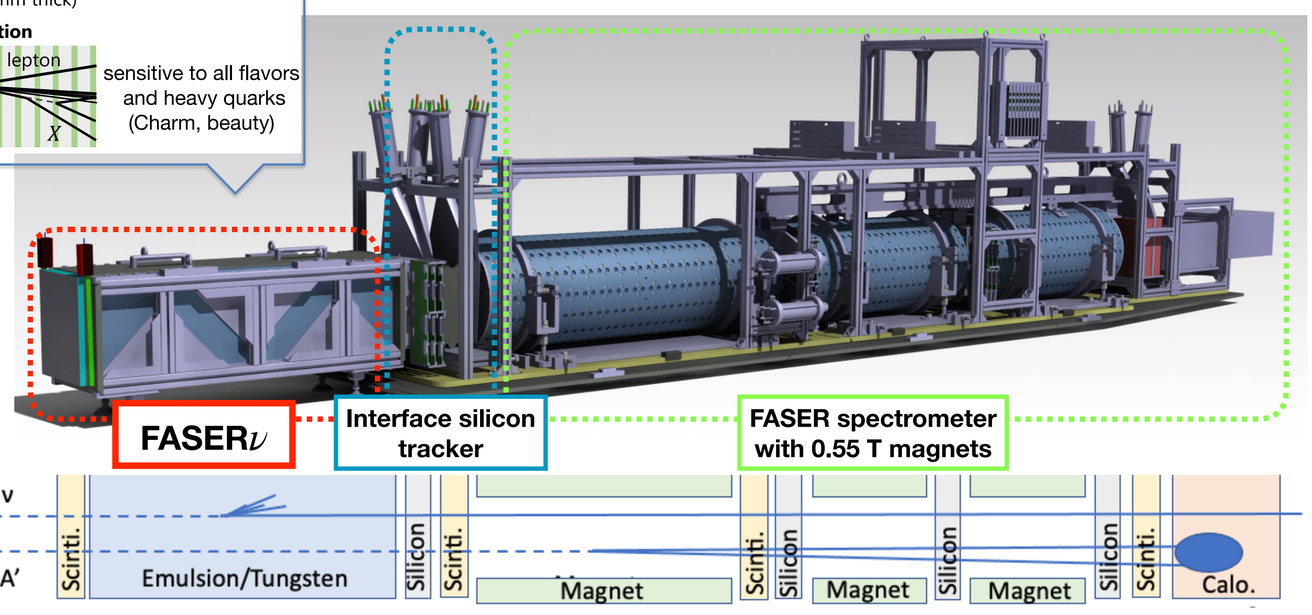
(Neutrino)

- **Emulsion/tungsten detector and interface silicon tracker will be installed in front of the FASER spectrometer**
  - 770 (1-mm-thick) tungsten plates, interleaved with emulsion films
  - 25 × 30 cm², 1.1 m length, 1.2 tons detector (220 X_0)
    - EM shower reconstruction
    - Momentum reconstruction by multiple Coulomb scattering (MCS)
  - Spatial resolution : 0.4 μm
  - Angular resolution : ~ 0.1mrad
  - Energy resolution : ΔE / E ~30%
  - Emulsion films will be replaced every 30 - 50 fb^{-1} (3 times per year)
- **Enable to distinguish all favor of neutrino interaction**
  - Muon identification by their track length in the detector (8 λ_{int})
  - Muon charge identification with hybrid configuration → distinguishing ν_μ and $\bar{\nu}_\mu$
  - Neutrino energy measurement with ANN by combining topological and kinematical variables.



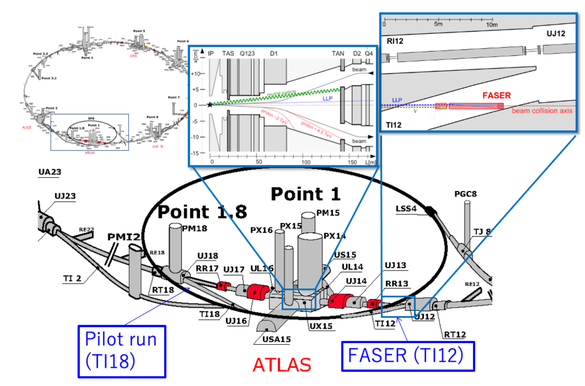
(New particle Search)

- **Sensitive to light, weakly-coupled new particles (A') and neutrinos**
  - Search for a rare decay from new particles such as dark photon or Axion with the FASER spectrometer

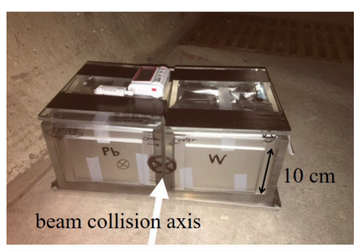


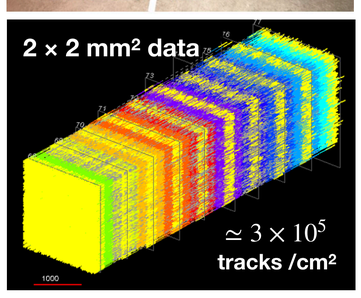
4. First neutrino interaction candidates at the LHC

- **Pilot run in 2018**
  - Aims: charged particle flux measurement and neutrino detection
  - Detector : ~30 kg mass emulsion
    - Lead (1-mm-thick, 100 layers) and Tungsten (0.5-mm-thick, 120 layers)
    - Installed in TI18
  - Exposure : 12.2 fb^{-1} (~1.5 months)

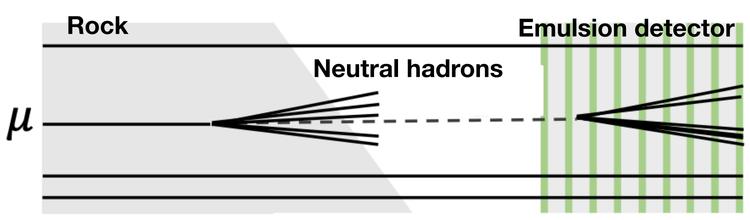


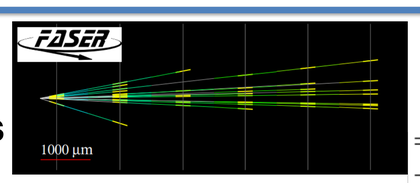
T18 and TI12





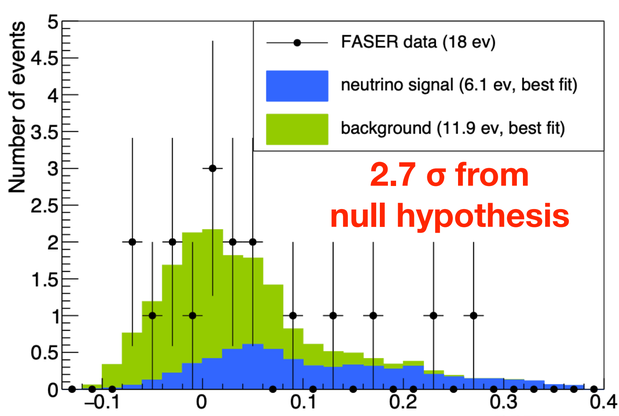
- **Pilot Run Data Analysis**
  - Analyzed mass target : 11 kg
  - Main background (BG) : neutral hadron produced by μ
    - Probability of $O(10^{-5})$
  - Physics run : lepton ID can kill background efficiently
  - Pilot run : lepton ID is challenging by lack of detector length
    - Expected signal =3.3$^{+1.7}_{-0.95}$, BG = 11.0 events
  - 18 neutral vertices were selected
    - by applying # of charged particle ≥ 5, etc.
  - In BDT analysis, an excess of neutrino signal is observed.
    - Statistical significance = 2.7 σ from null hypothesis





Vertex detection efficiency
The background efficiencies are estimated with energy >10 GeV by Geant4.

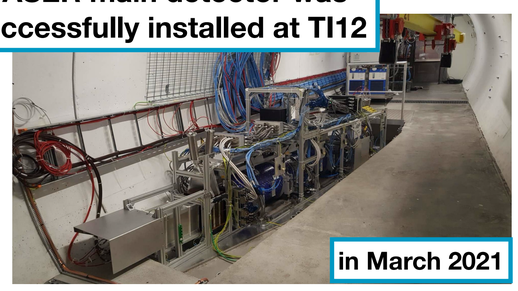
Signal		Background		
			FTFP_BERT	QGSP_BERT
ν_e	0.490	K_L	0.017	0.015
$\bar{\nu}_e$	0.343	K_S	0.037	0.031
ν_μ	0.377	n	0.011	0.012
$\bar{\nu}_\mu$	0.266	$\bar{n}$	0.013	0.013
ν_τ	0.454	Λ	0.020	0.021
$\bar{\nu}_\tau$	0.368	$\bar{\Lambda}$	0.018	0.018



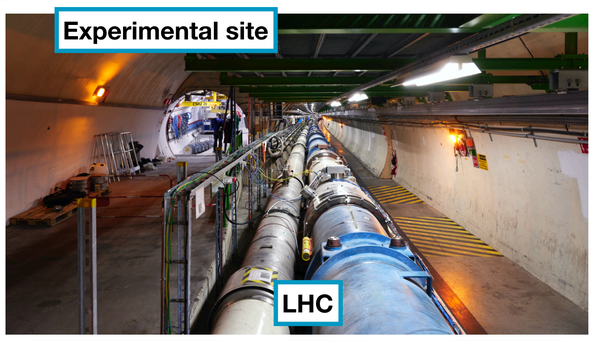
5. Commissioning is ongoing !!!

Surface run 2020 October

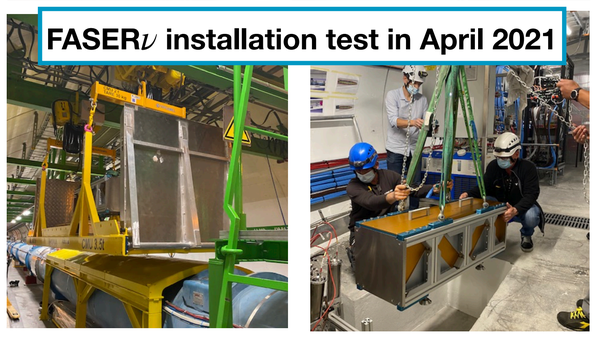
FASER main detector was successfully installed at TI12



Experimental site



FASERν installation test in April 2021



6. Outlook & Summary

- The FASER experiment is a new experiment at the LHC
  - FASER : new particle search
  - FASERν : High-energy neutrinos
- FASERv is the first collider neutrino experiment
  - Detector with flavor sensitivity
  - Physics run start in 2022 - 2024 (~150 fb^{-1})
  - Detection of neutrinos from the LHC was demonstrated with the pilot detector in 2018

Reference

- FASER Letter of Intent: arXiv:1811.10243
- FASER Technical Proposal: arXiv:1812.09139
- FASER's Physics Reach for Long-Lived Particles: Phys. Rev. D 99 (2019) 095011
- Input to the European Strategy for Particle Physics Update: arXiv:1811.12522
- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC: Eur. Phys. J. C 80 (2020) 61
- Technical Proposal of FASERv neutrino detector: arXiv:2001.03073
- First neutrino interaction candidates at the LHC: arXiv:2105.06197
- Forward Neutrino Fluxes at the LHC: arXiv:2105.08270