Neutrino physics with FASER

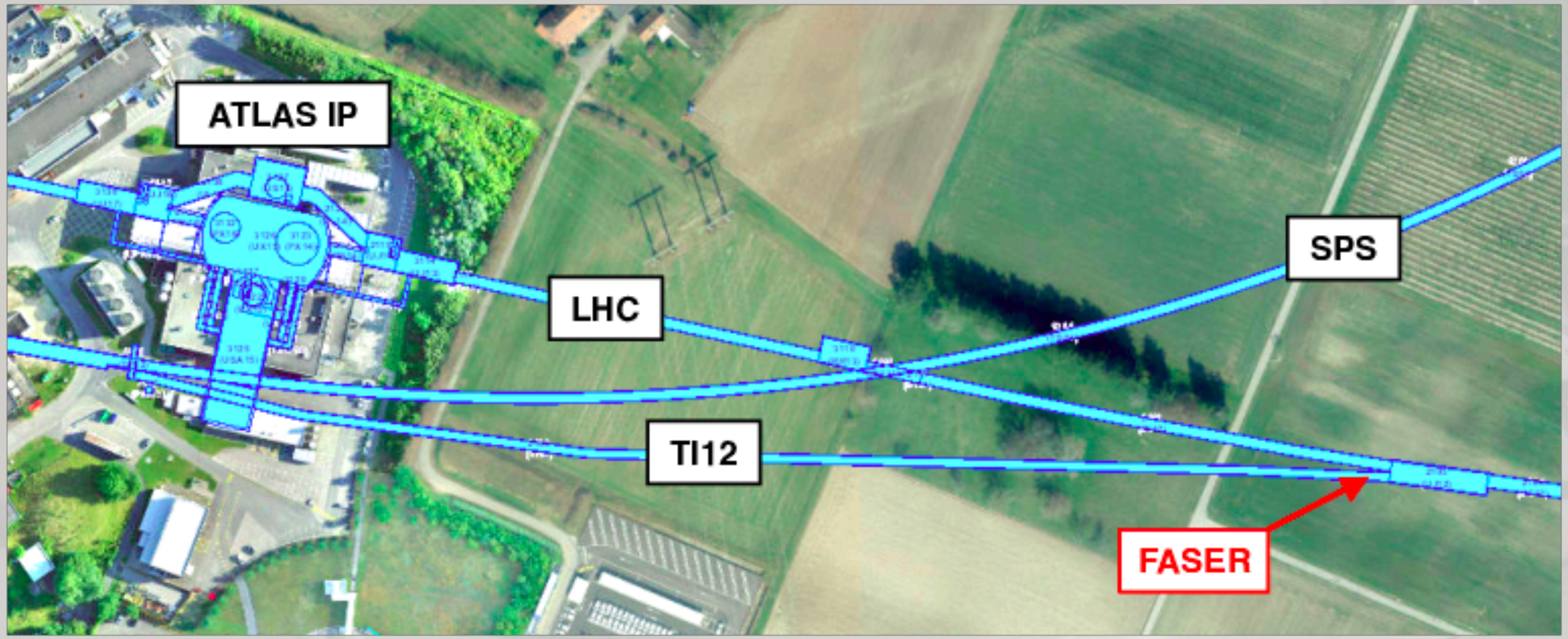
LHCP2024

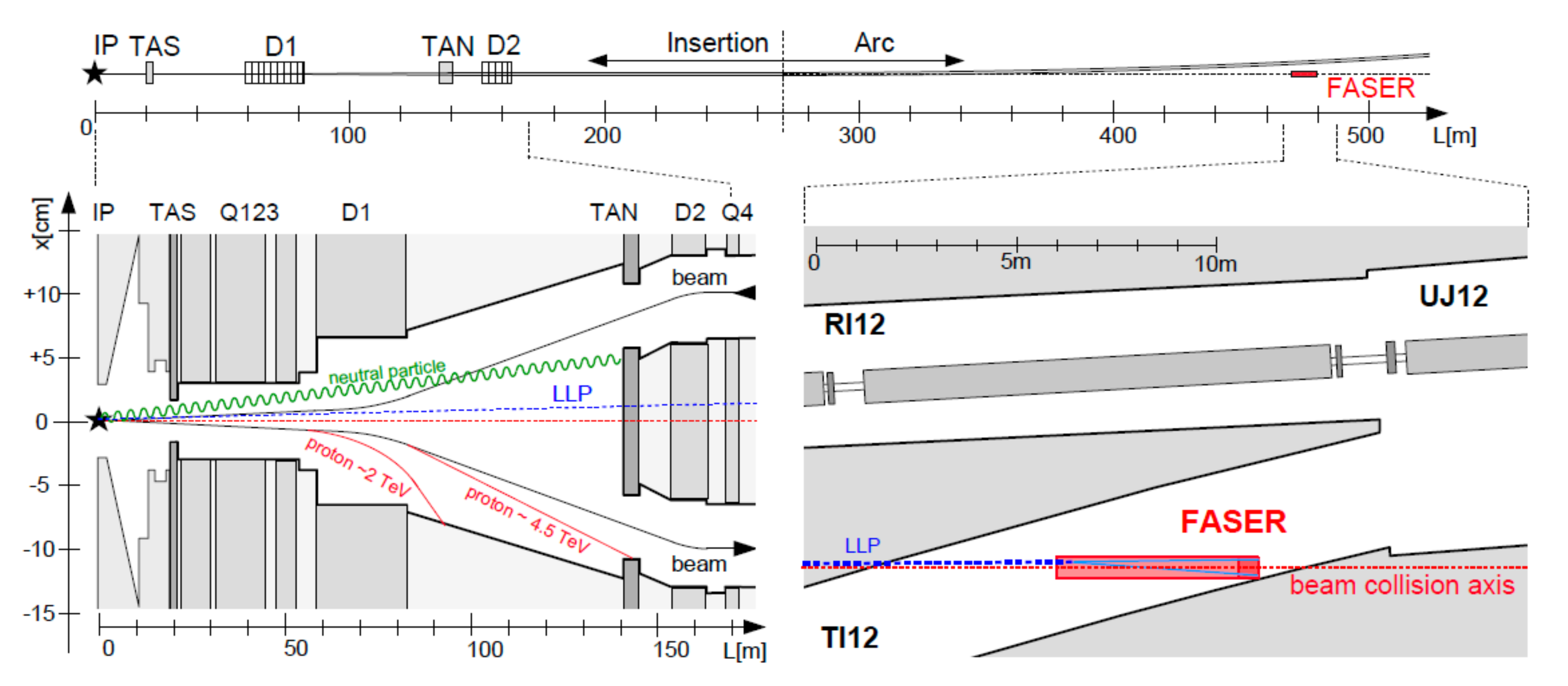
Daniela Koeck
(dkoeck@cern.ch)

FASER

UNIVERSITY OF OREGON

NSF HEISING-SIMONS FOUNDATION CERN SIMONS FOUNDATION Swiss National Science Foundation erc 科研費 KAKENHI





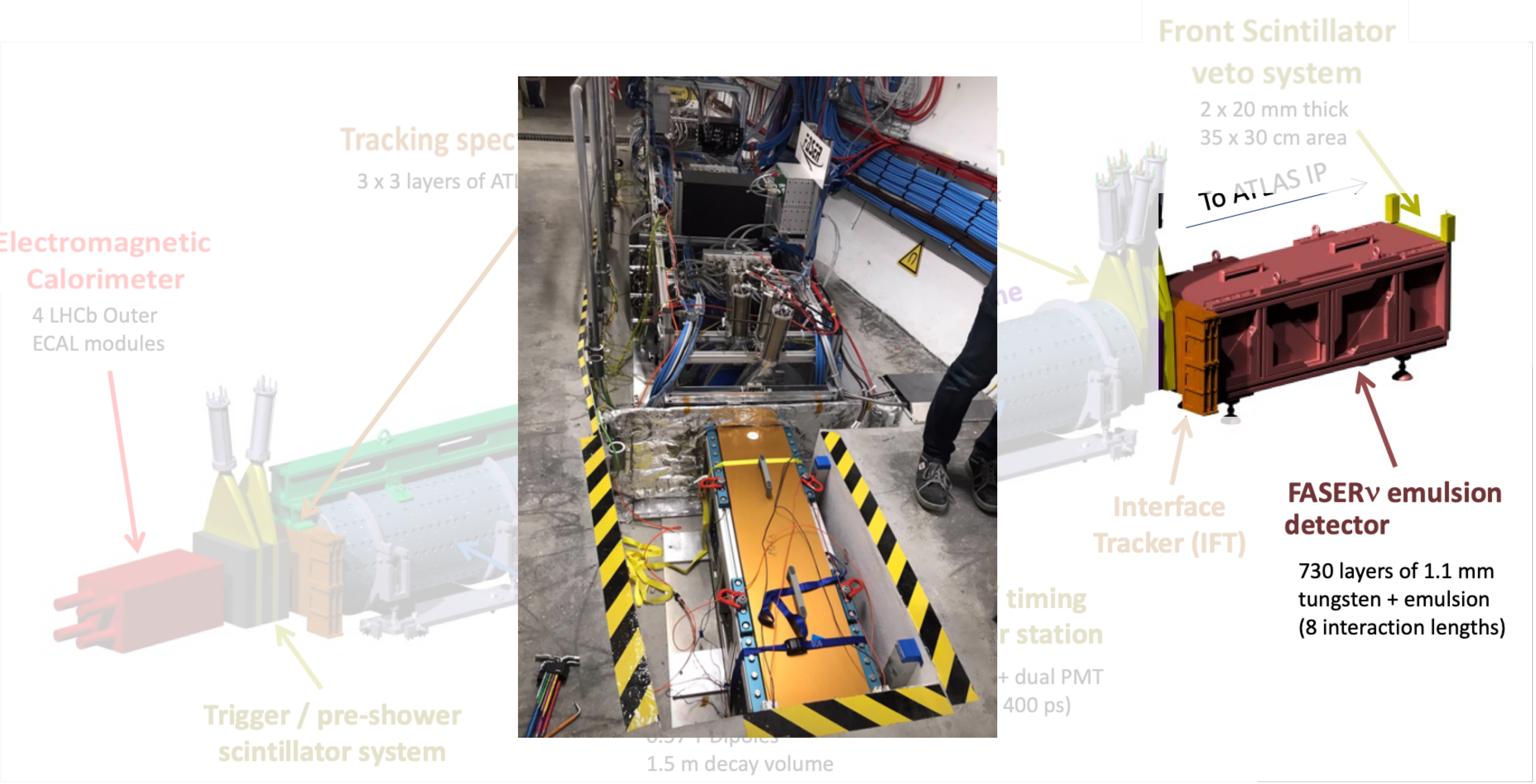
~ 480m from IP1

- detector aligned with collision axis line of sight

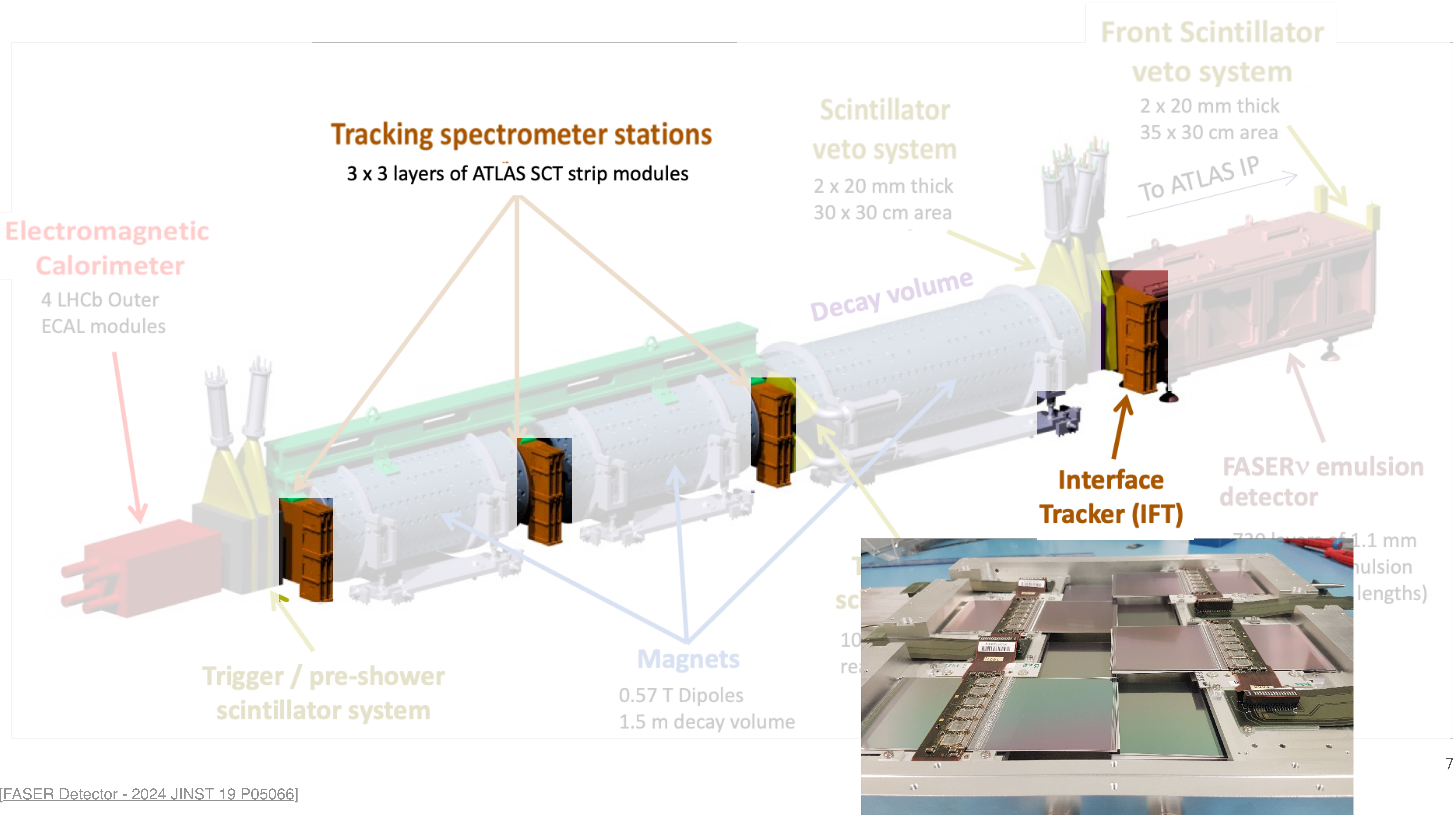

CMU 2t


CMU 2t
CMU 2t
FASER

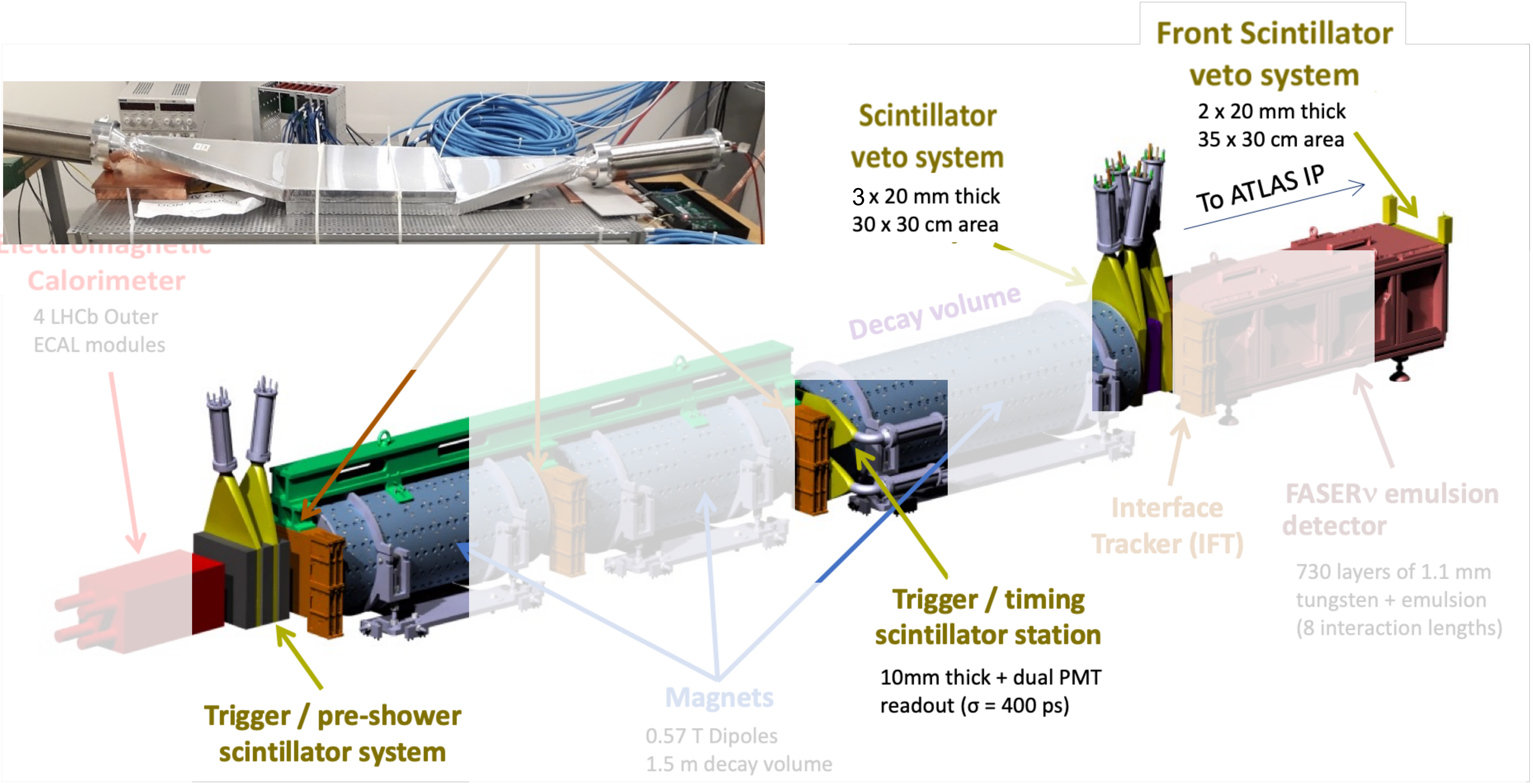
https://arxiv.org/abs/2207.11427



[FASER Detector - 2024 JINST 19 P05066]



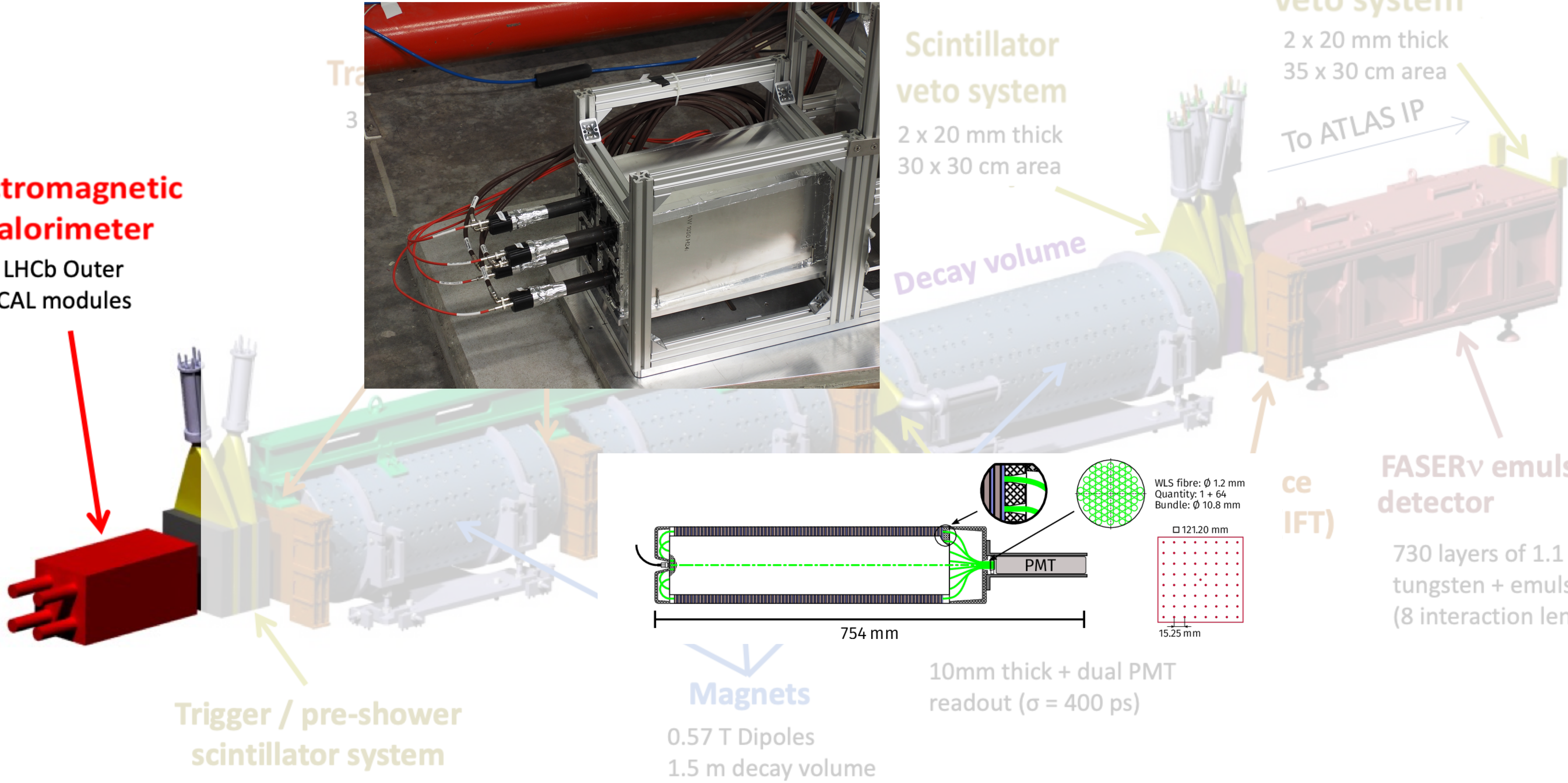
[FASER Detector - 2024 JINST 19 P05066]



[FASER Detector - 2024 JINST 19 P05066]

Electromagnetic Calorimeter

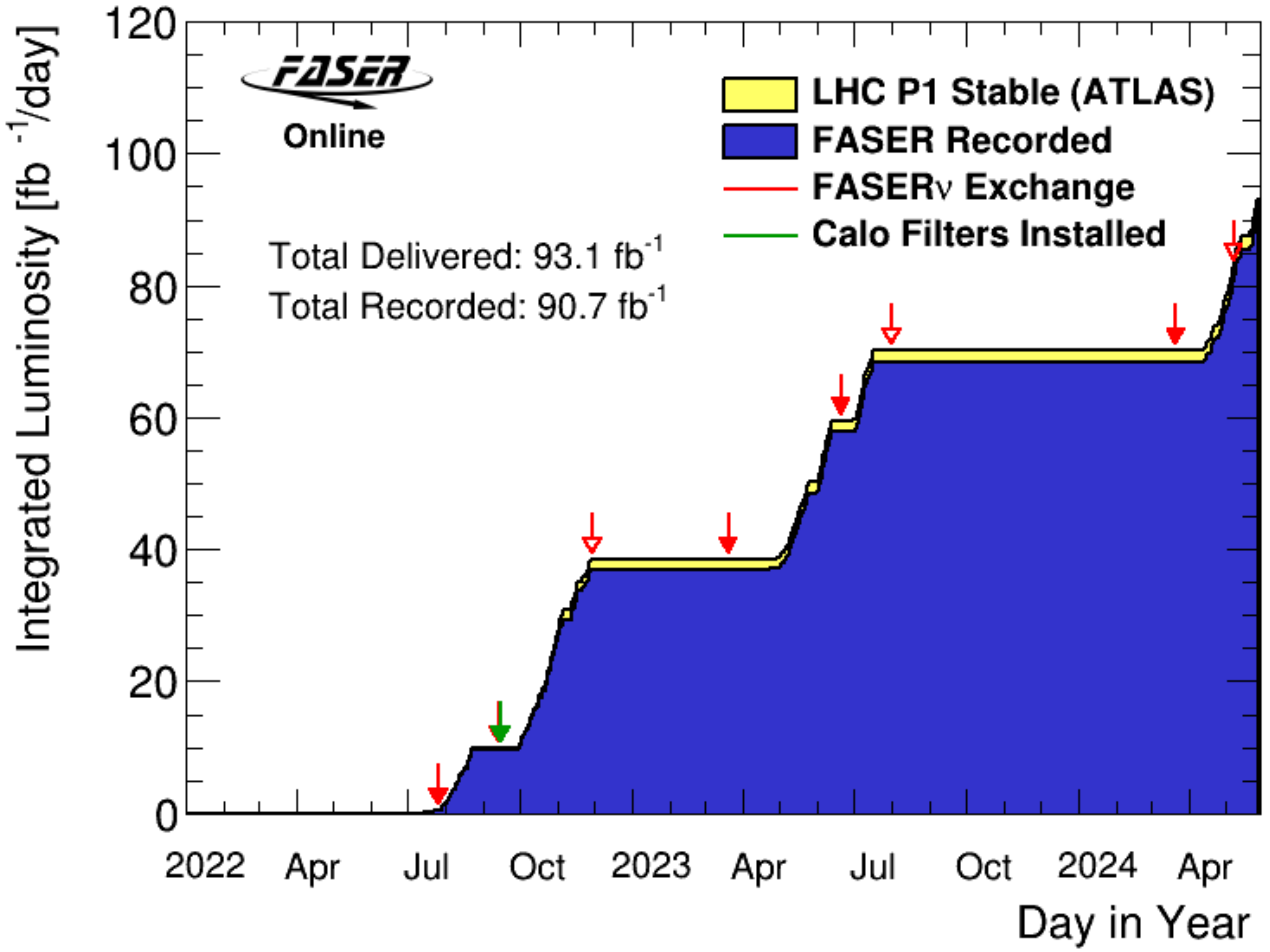
4 LHCb Outer
ECAL modules



[FASER Detector - 2024 JINST 19 P05066]

FASER during LHC Run-3

- Start of data taking in July 2022
- 35.4 fb^{-1} of Luminosity in 2022
- Exchanges of FASERnu emulsion boxes 5 times so far
- Very high (~98%) data-taking efficiency and excellent detector performance



FASER upgrades

Théo Moretti (Universite de Geneve (CH))
05 June 2024 14:00
ISEC Room 138
12th Edition of the Large Hadron Collider Physics Conference

FASER results on BSM physics

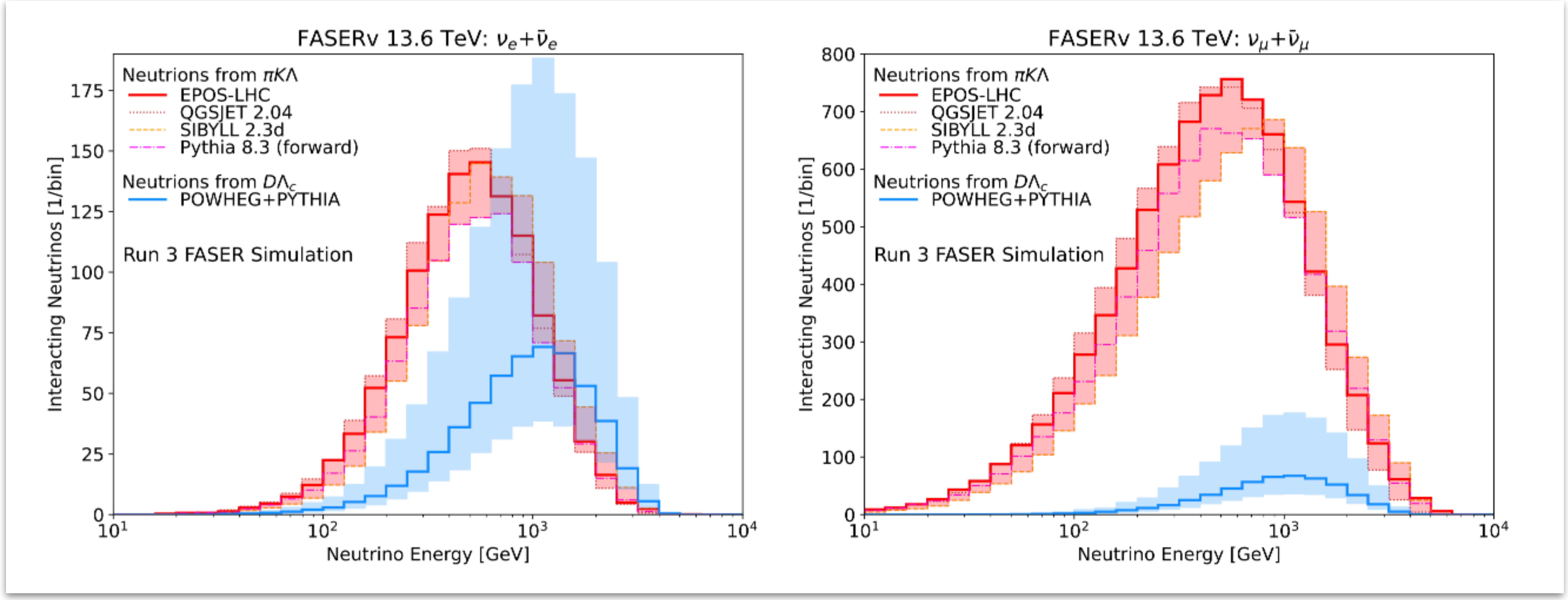
Charlotte Cavanagh (University of Liverpool (GB))
06 June 2024 14:18
ISEC Room 142
12th Edition of the Large Hadron Collider Physics Conference

Performance overview of SND@LHC and Faser

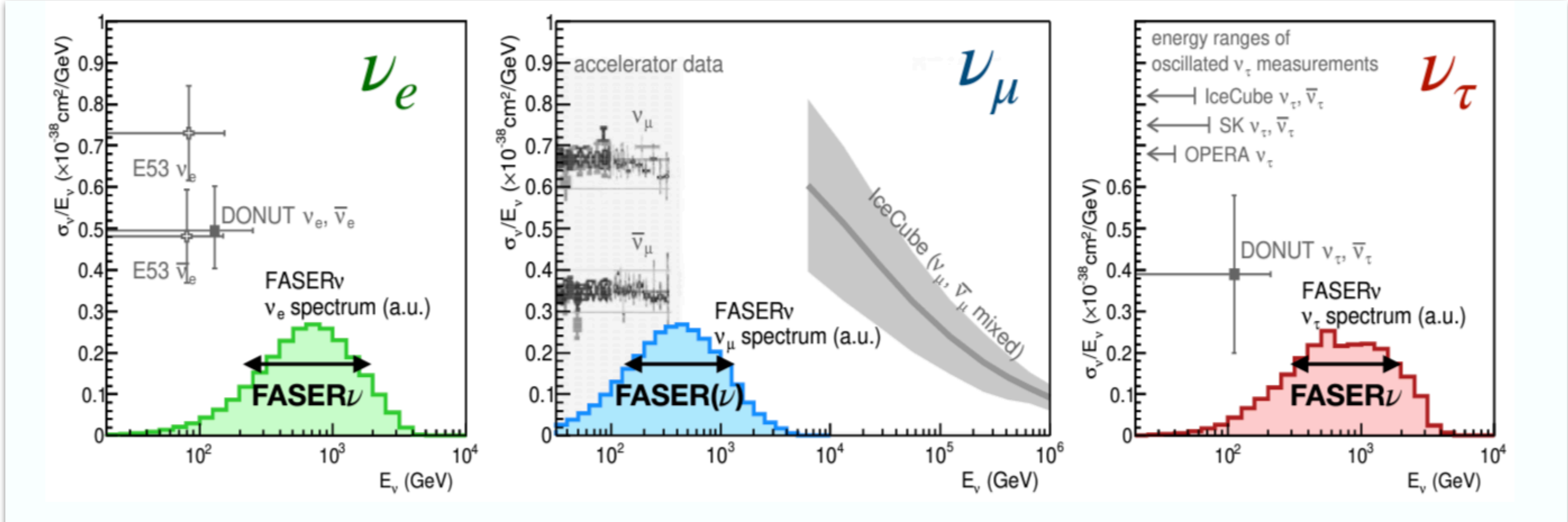
Ettore Zaffaroni (EPFL - Ecole Polytechnique Federale Lausanne (CH)), Anni Kauniskangas (EPFL)
04 June 2024 15:12
ISEC Room 140
12th Edition of the Large Hadron Collider Physics Conference

Collider neutrinos…

- TeV energy neutrino cross sections unexplored
- Probing of forward hadron productions - novel QCD inputs



[Neutrino predictions for FASER]



[Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC]

Generators		FASERν at Run 3		
light hadrons	charm hadrons	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
EPOS-LHC	–	1149	7996	–
SIBYLL 2.3d	–	1126	7261	–
QGSJET 2.04	–	1181	8126	–
PYTHIAforward	–	1008	7418	–
–	POWHEG Max	1405	1373	76
–	POWHEG	527	511	28
–	POWHEG Min	294	284	16
Combination		1675^{+911}_{-372}	8507^{+992}_{-962}	28^{+48}_{-12}

Neutrino measurements with FASER

- Analysing FASERnu emulsion films
- Sensitive to all neutrino flavours
- Very good spatial resolution
- Due to scanning and processing of films time intensive

- FASERnu as target (1.1 t) - using electronic components to detect muon from charged current interaction
- Can separate neutrino and anti-neutrino
- Fast analysis of data possible
- Only sensitive to muon neutrinos

First collider neutrino observation

PHYSICAL REVIEW LETTERS

Featured in Physics | Editors' Suggestion | Open Access

First Direct Observation of Collider Neutrinos with FASER at the LHC

Henso Abreu *et al.* (FASER Collaboration)
Phys. Rev. Lett. **131**, 031801 – Published 19 July 2023

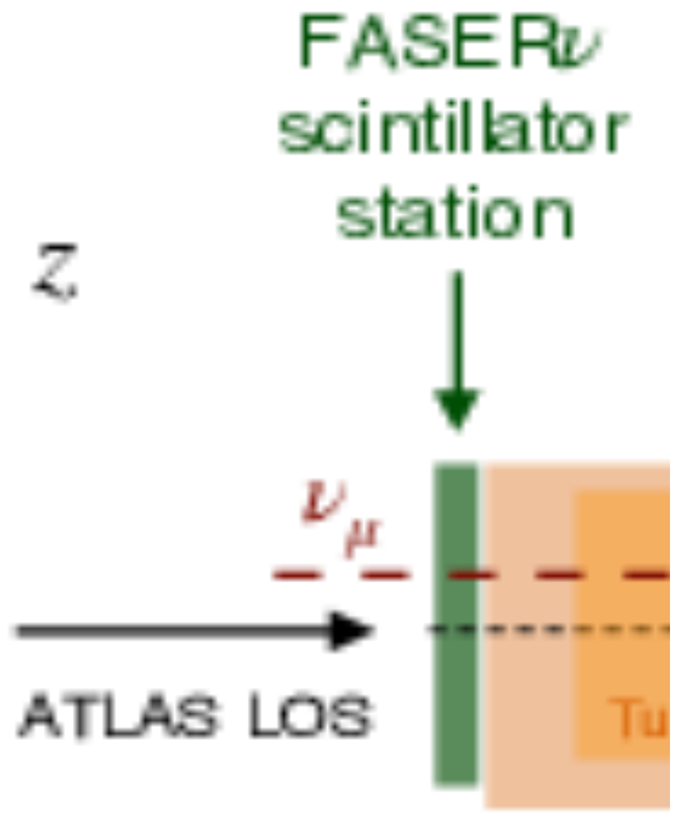
Physics See Viewpoint: The Dawn of Collider Neutrino Physics

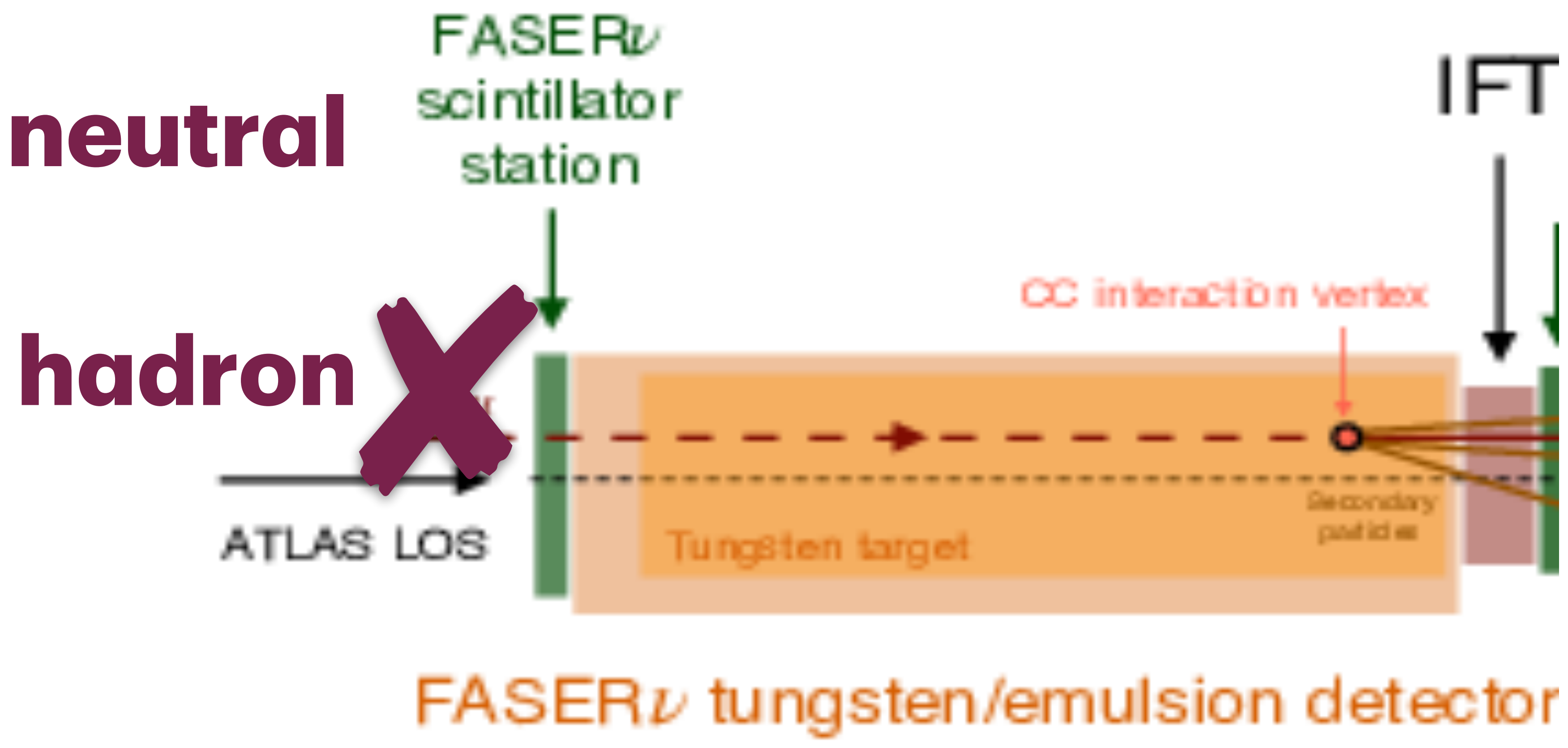
Electronic Neutrino analysis

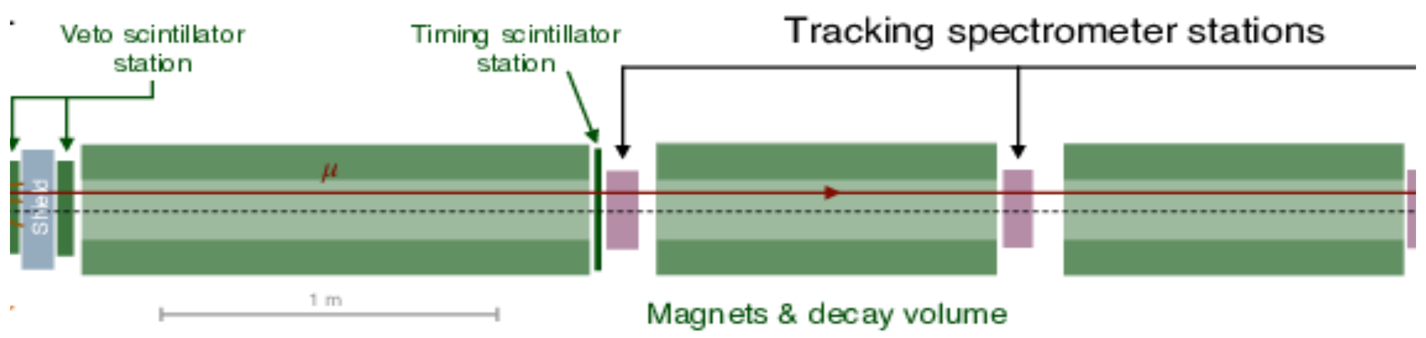
- FASERnu as target
- Muon track, extrapolated back to the veto station
- Increased activity in IFT, veto and timing scintillator

- Data collected between July and November 2022
- $n_{\nu}^{exp} = 151 \pm 41$; uncertainty dominated by forward hadron production models)

Expected backgrounds







- **Front-veto inefficiency**

Negligible

- **Neutral hadrons**
- Estimated through simulation
- Most neutral hadrons absorbed in tungsten

0.11 ± 0.06

- **Geometric muons**
- control region estimate

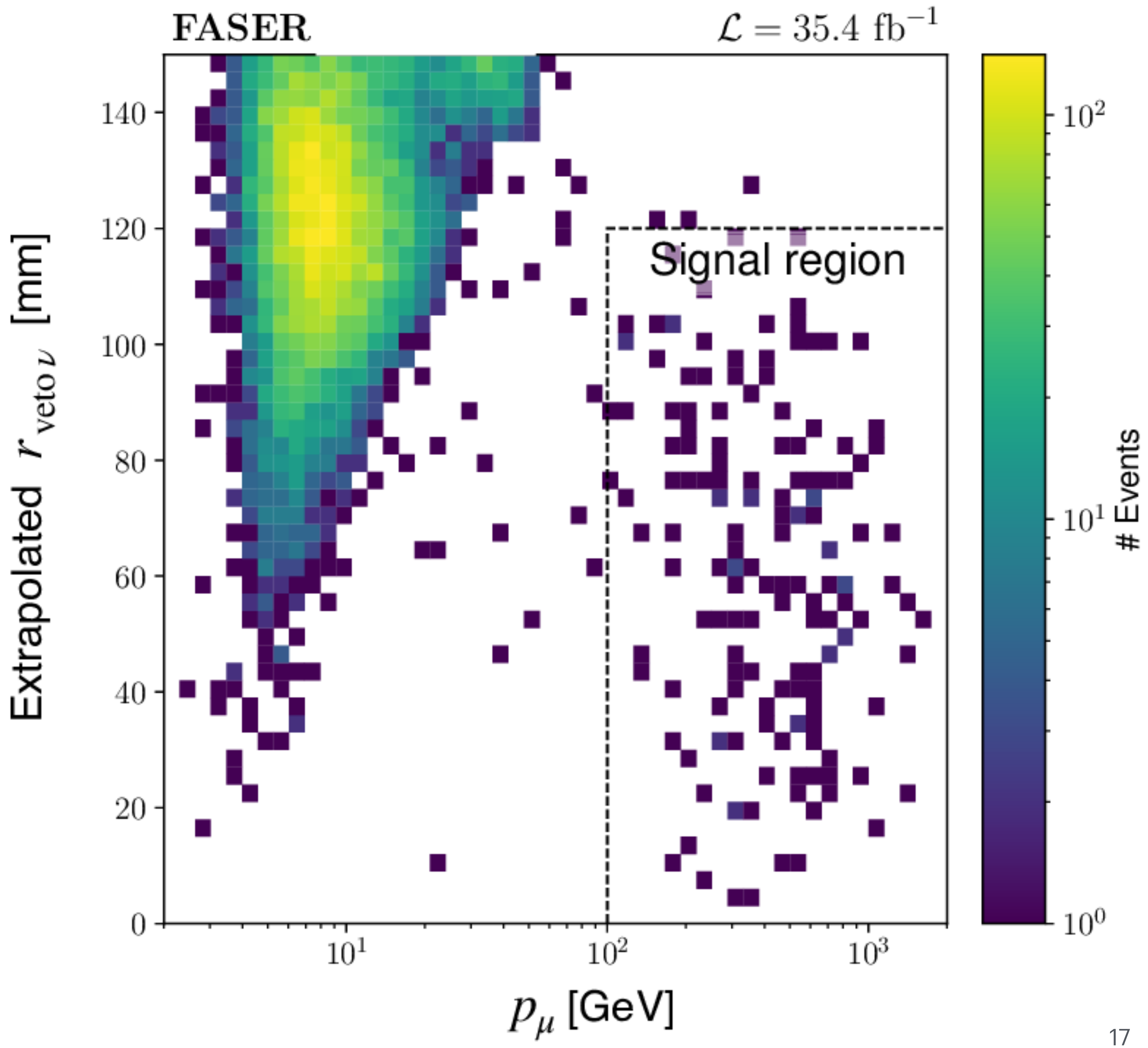
0.08 ± 1.83

Signal region

- Observed events analysed with maximum likelihood fit
- Events categorised into background and signal

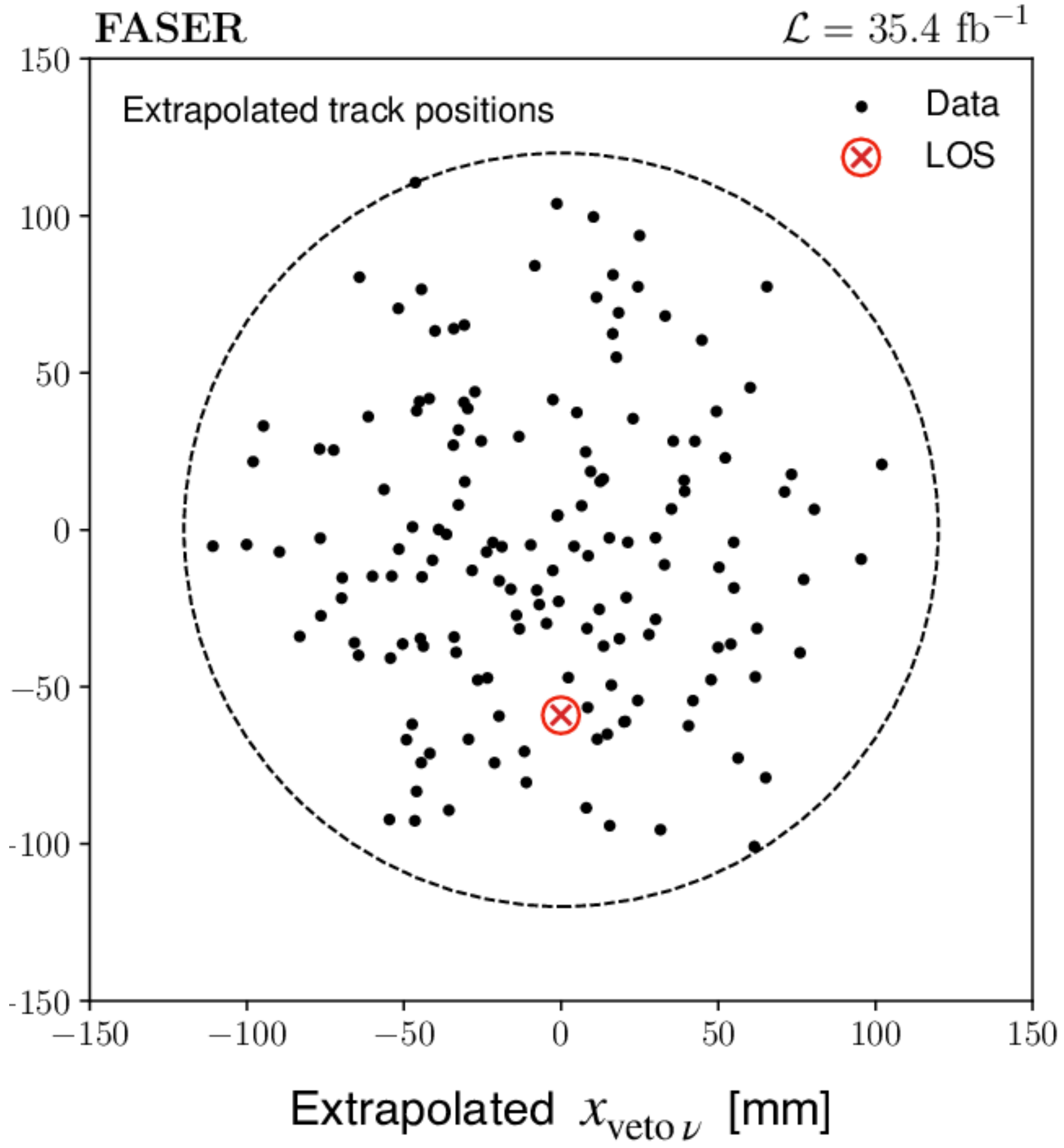
$$n_\nu = 153^{+12}_{-13} \text{ (tot)}$$

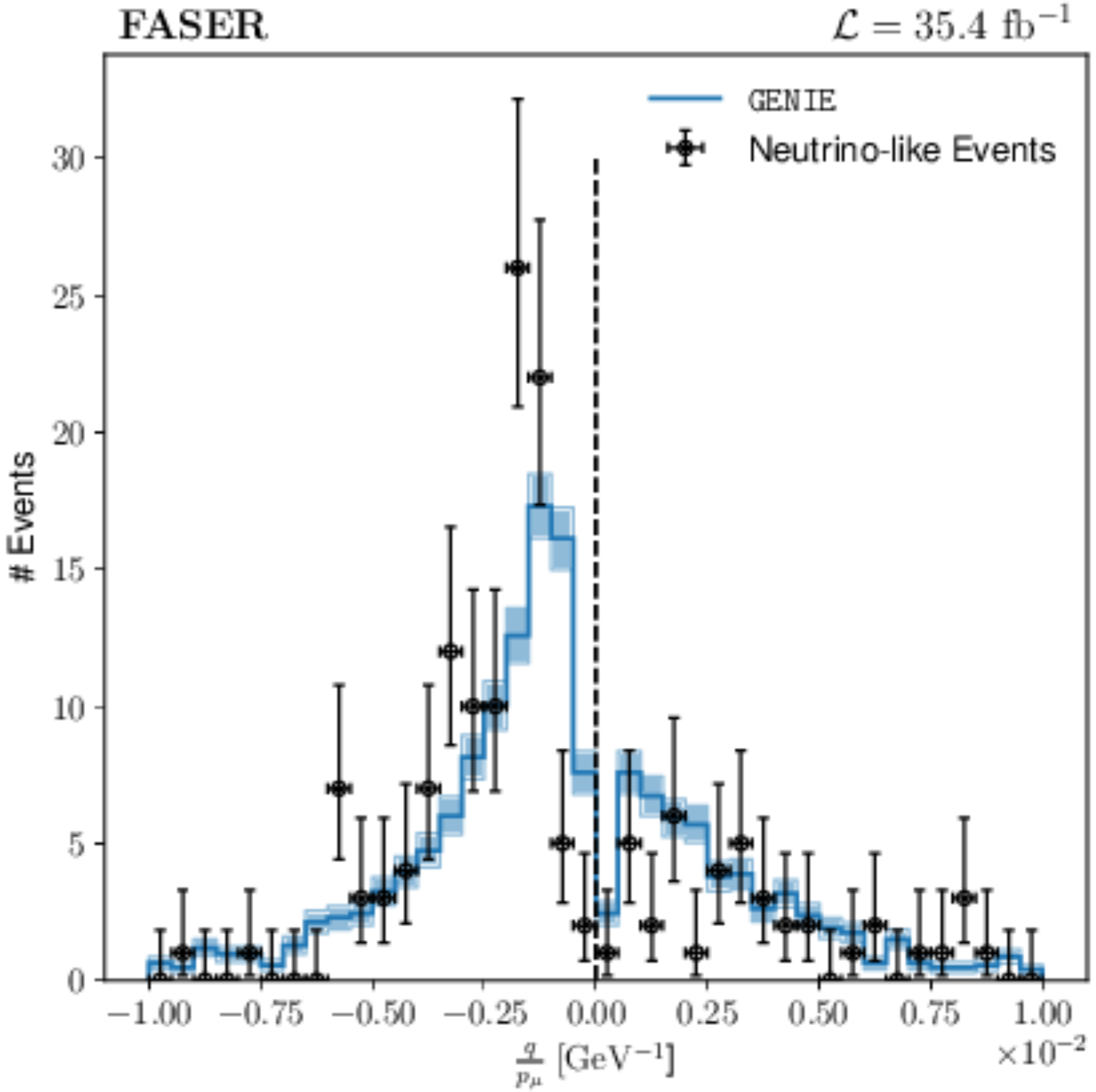
- 16 σ over background-only hypothesis
- **First observation of neutrinos from colliders**



Properties of the neutrinos

- Expect neutrinos all across FASER surface





- q: assigned track charge
- 40 events with positive charge - antineutrinos


LHC Fill 8315, Event 47032829,
2022-10-27 08:52:45
Tracking stations
Decay Volume
FASERnu

First collider electron neutrino observation

To appear in PRL

arXiv > hep-ex > arXiv:2403.12520

Help

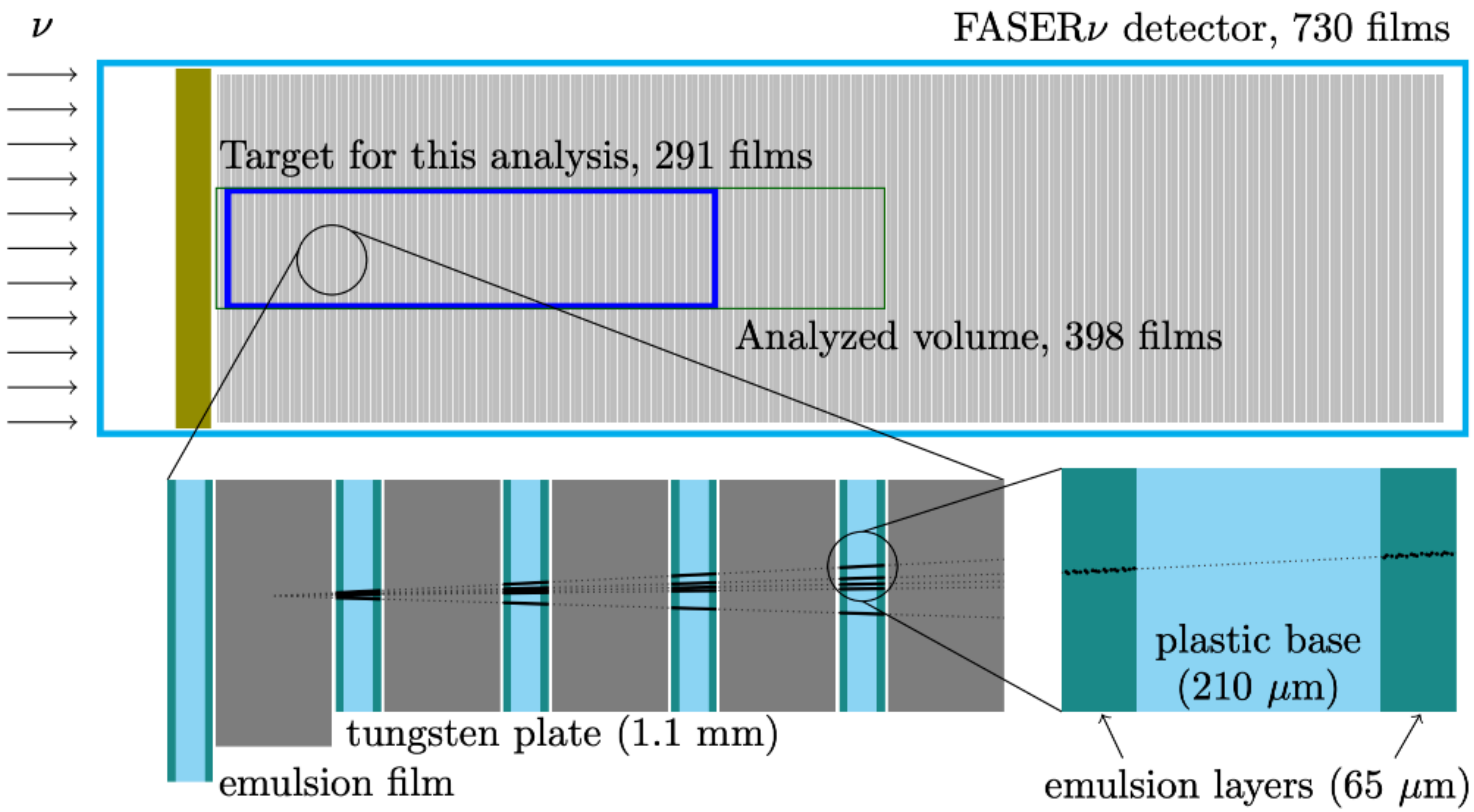
High Energy Physics – Experiment

[Submitted on 19 Mar 2024]

First Measurement of the ν_e and ν_μ Interaction Cross Sections at the LHC with FASER's Emulsion Detector

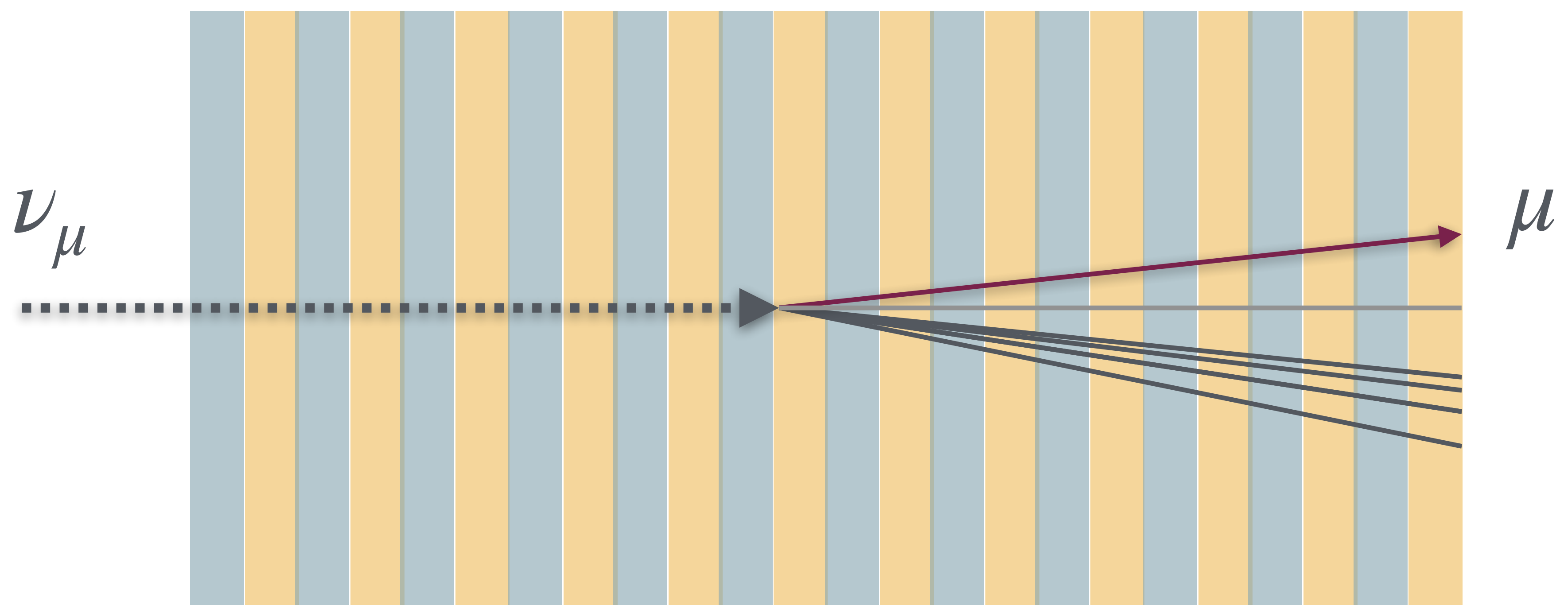
FASER nu Emulsion analysis

- up of 730 layers of interleaved tungsten plates and emulsion films, with a total target mass of 1.1 tonnes
- Each emulsion film with 0.34 mm thickness
- Position resolution $0.30\mu m$
- Data collected between July 26th and September 13th 2022 ($9.5\ fb^{-1}$ delivered)
- Analysed target mass of 128.6 kg

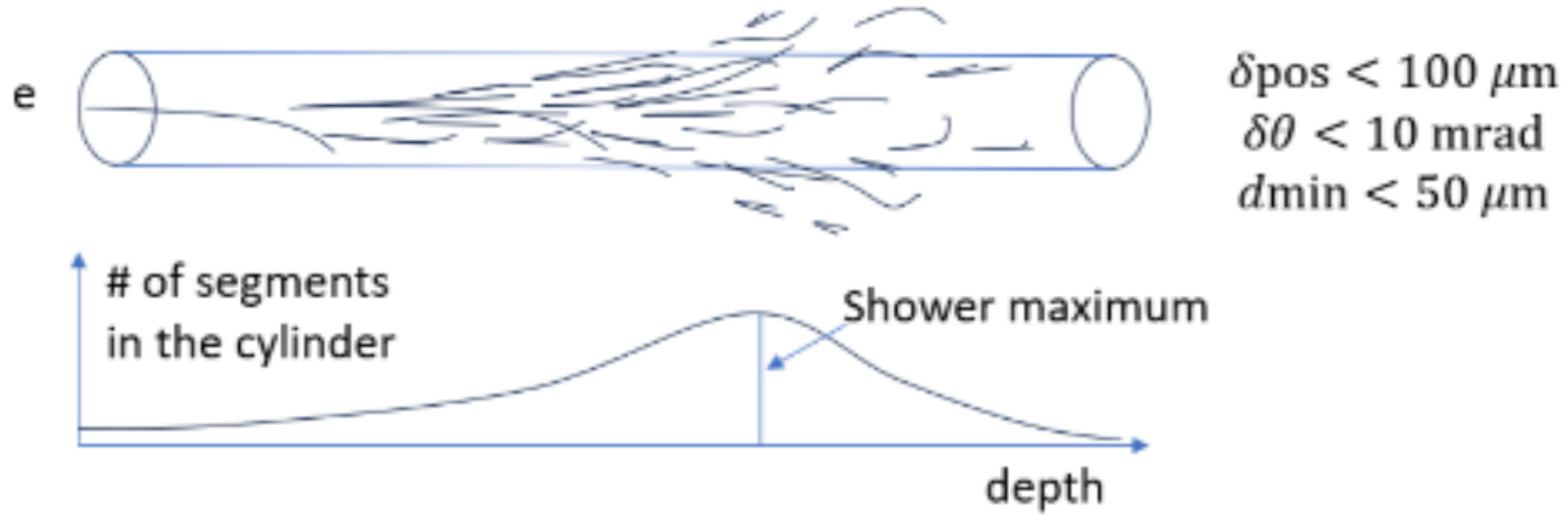


Signal signature

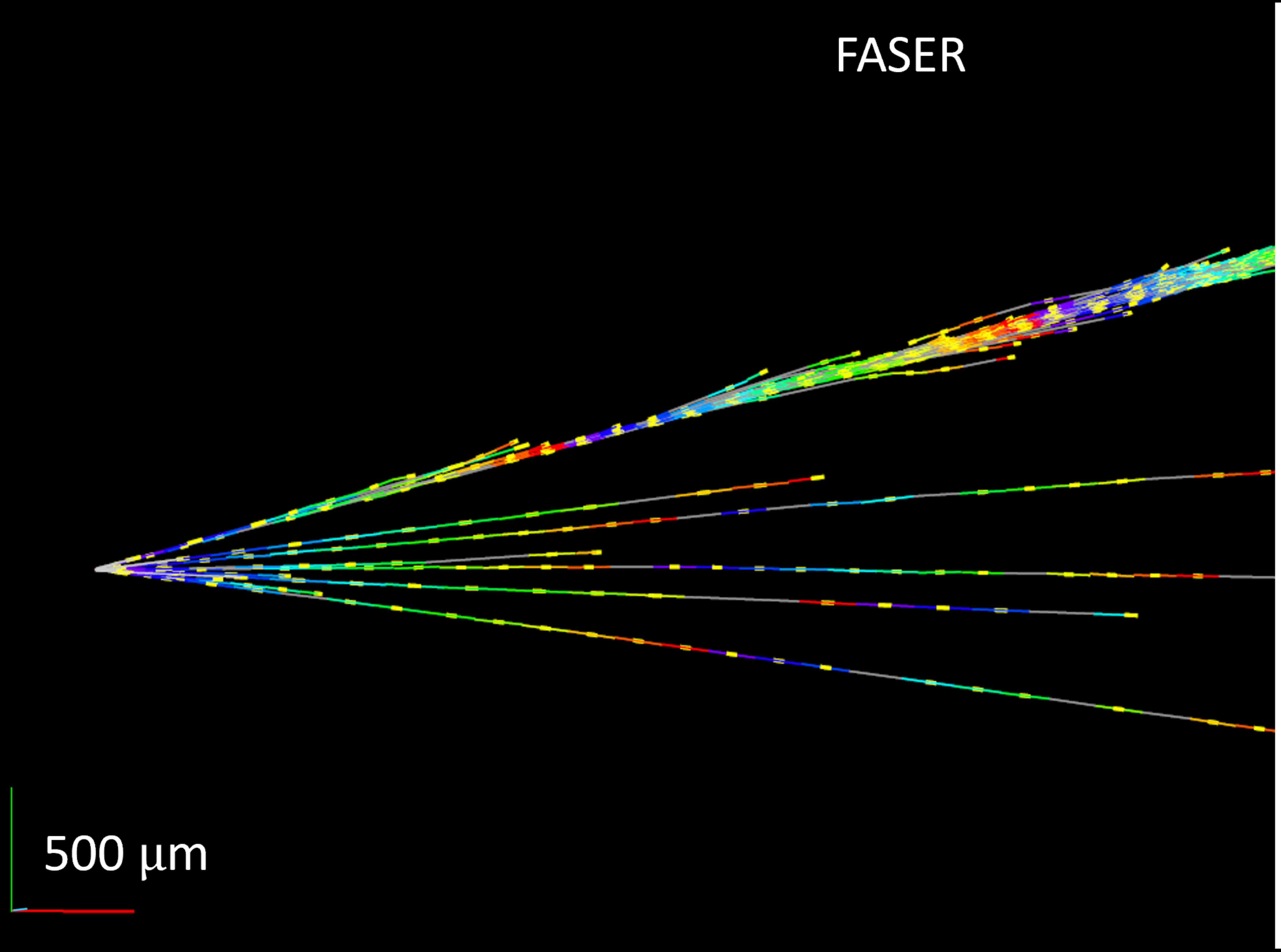
- **Vertex selection**
  - Neutral vertex in the emulsion - no incoming track
  - boosted outgoing tracks, lepton well separated from other tracks, muon penetrating > 100 tungsten plates
  - Associated high-energy EM shower > 200 GeV or muon with p>200 GeV

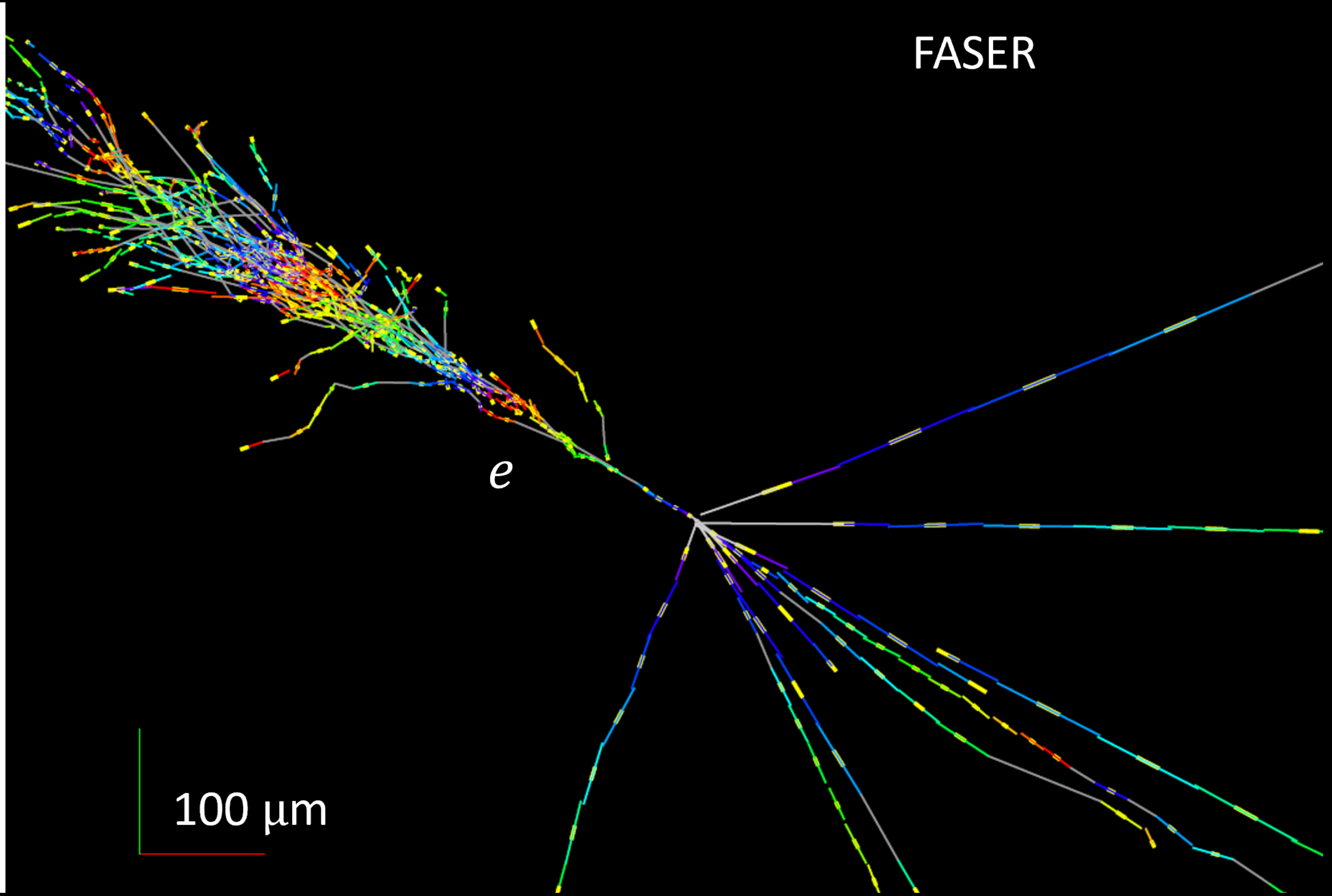


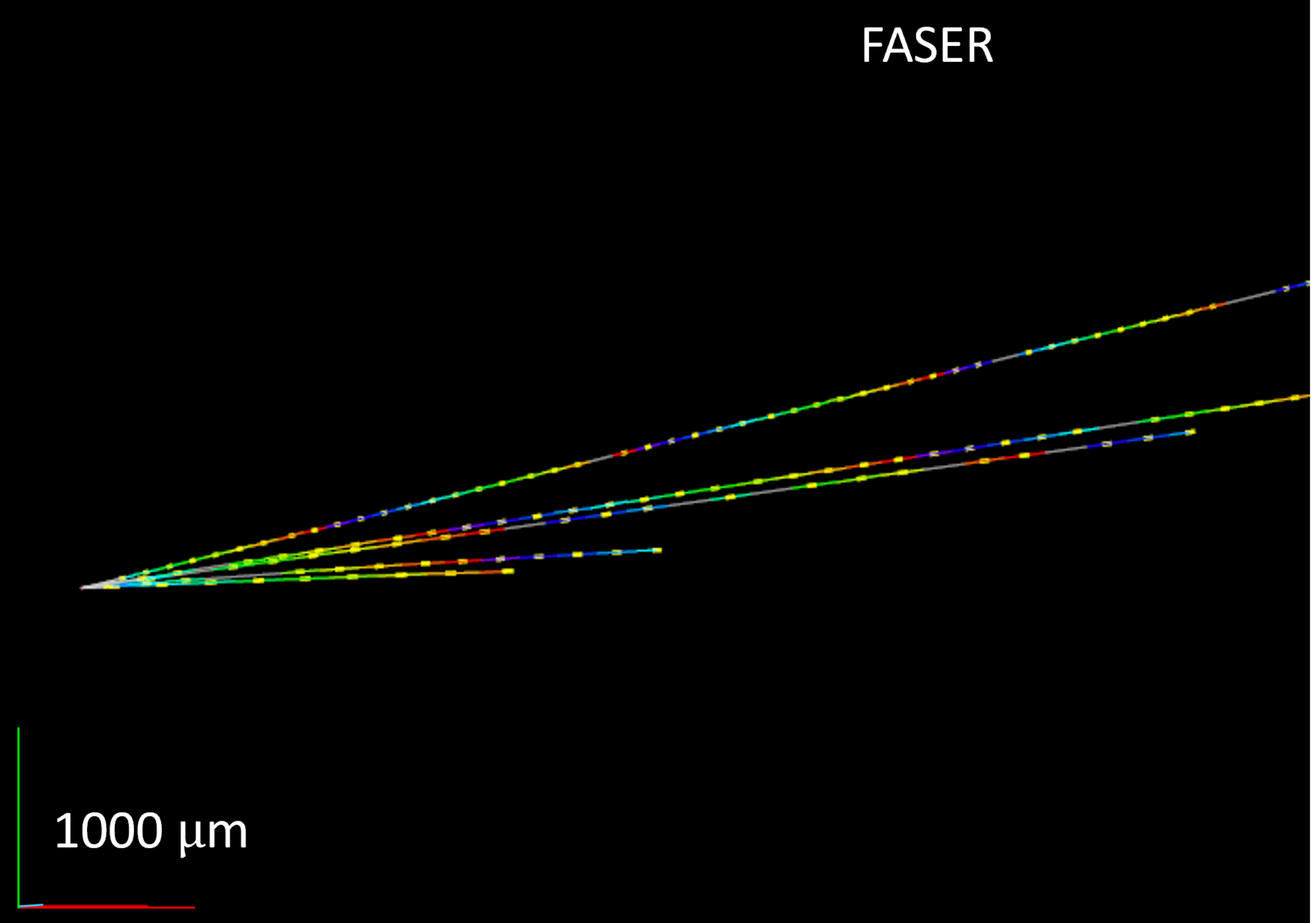
- **Energy and momentum measurement**
  - shower formed from reconstructed segments in the emulsion (e+/e- pair prod.)
  - EM shower reconstruction based on cylinder around shower axis

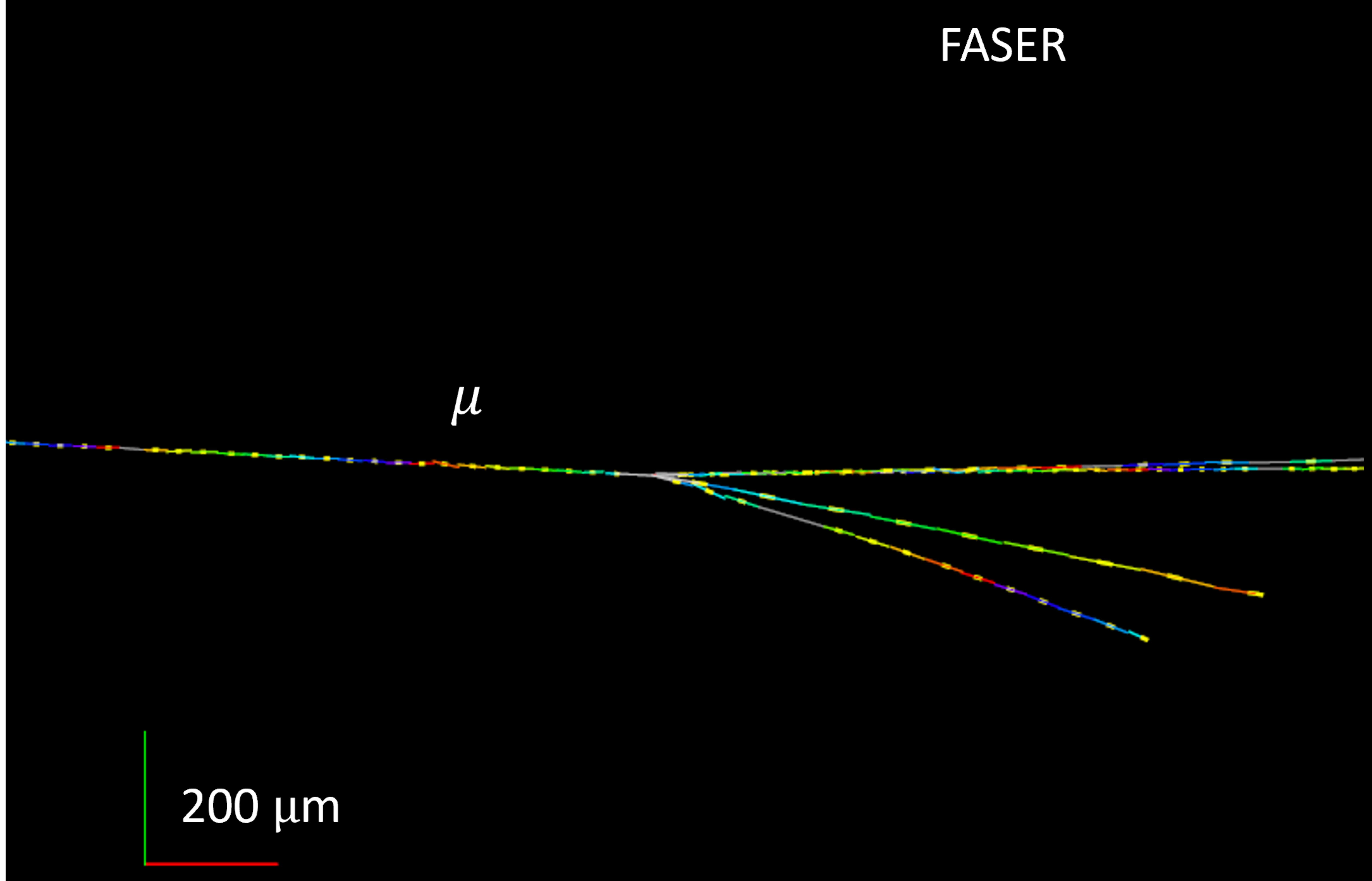


  - (Muon) momentum measured through multiple coulomb scattering


FASER
500 μm

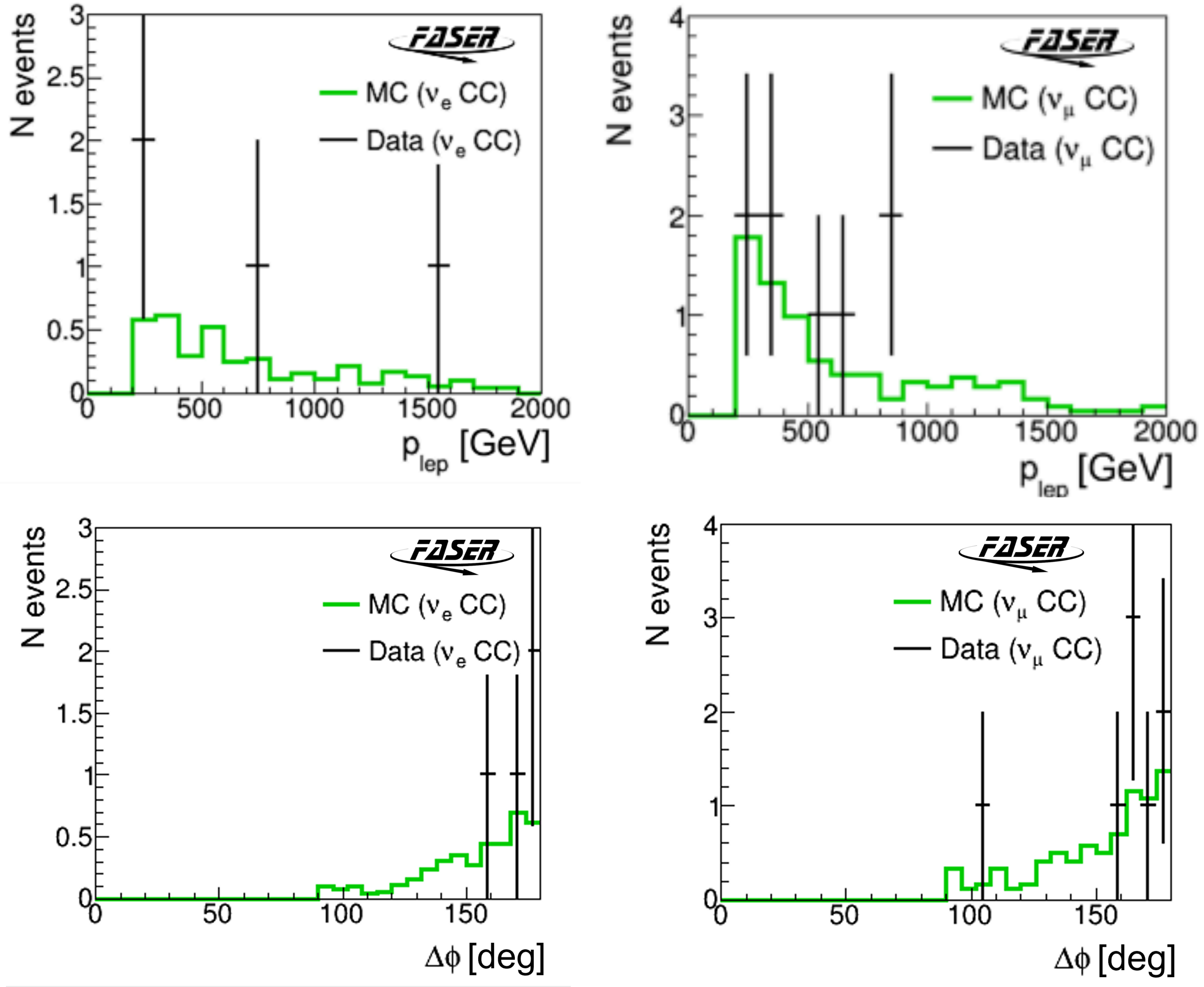

FASER
e
100 μm


FASER
1000 μm

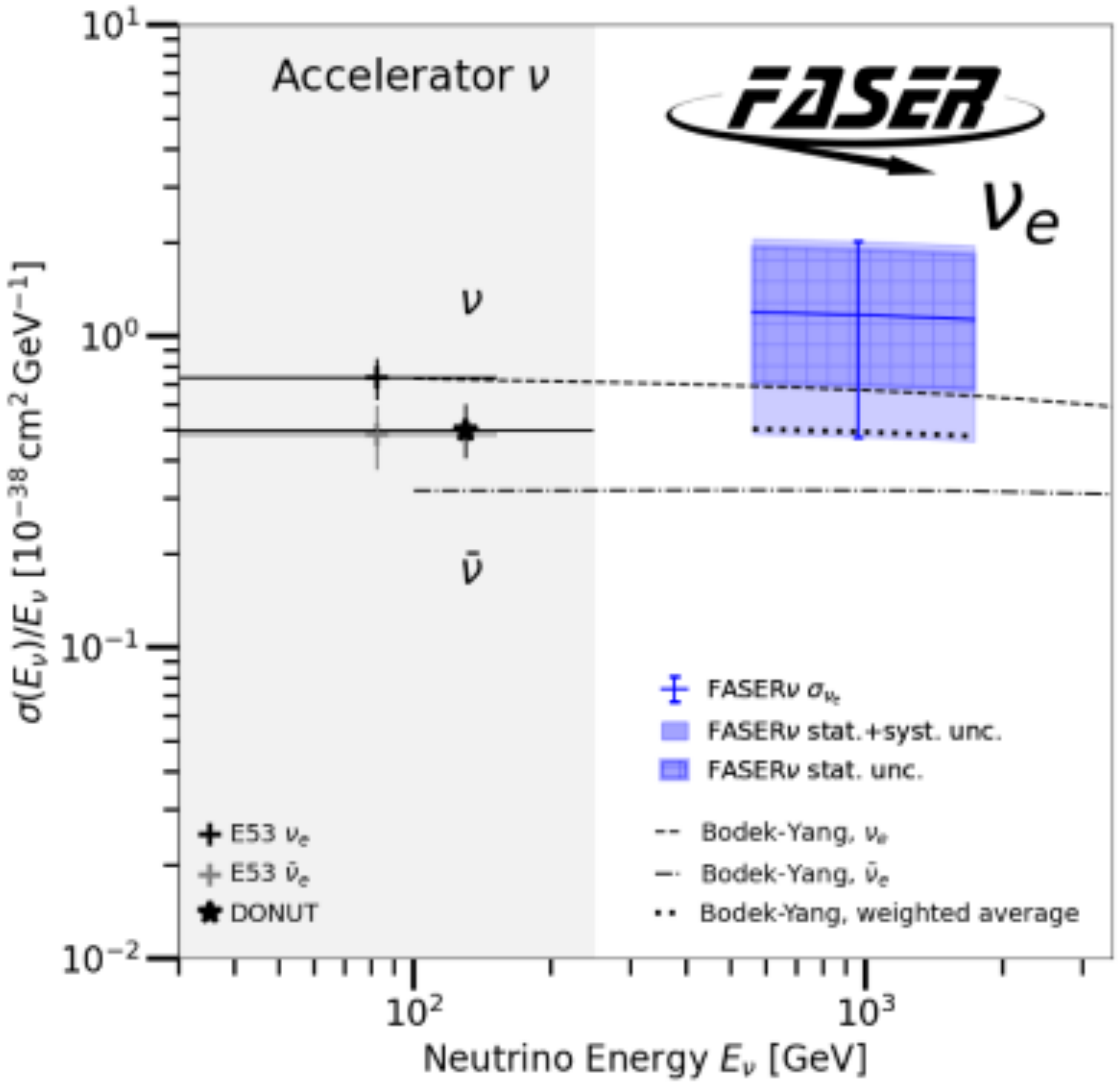

FASER
μ
200 μm

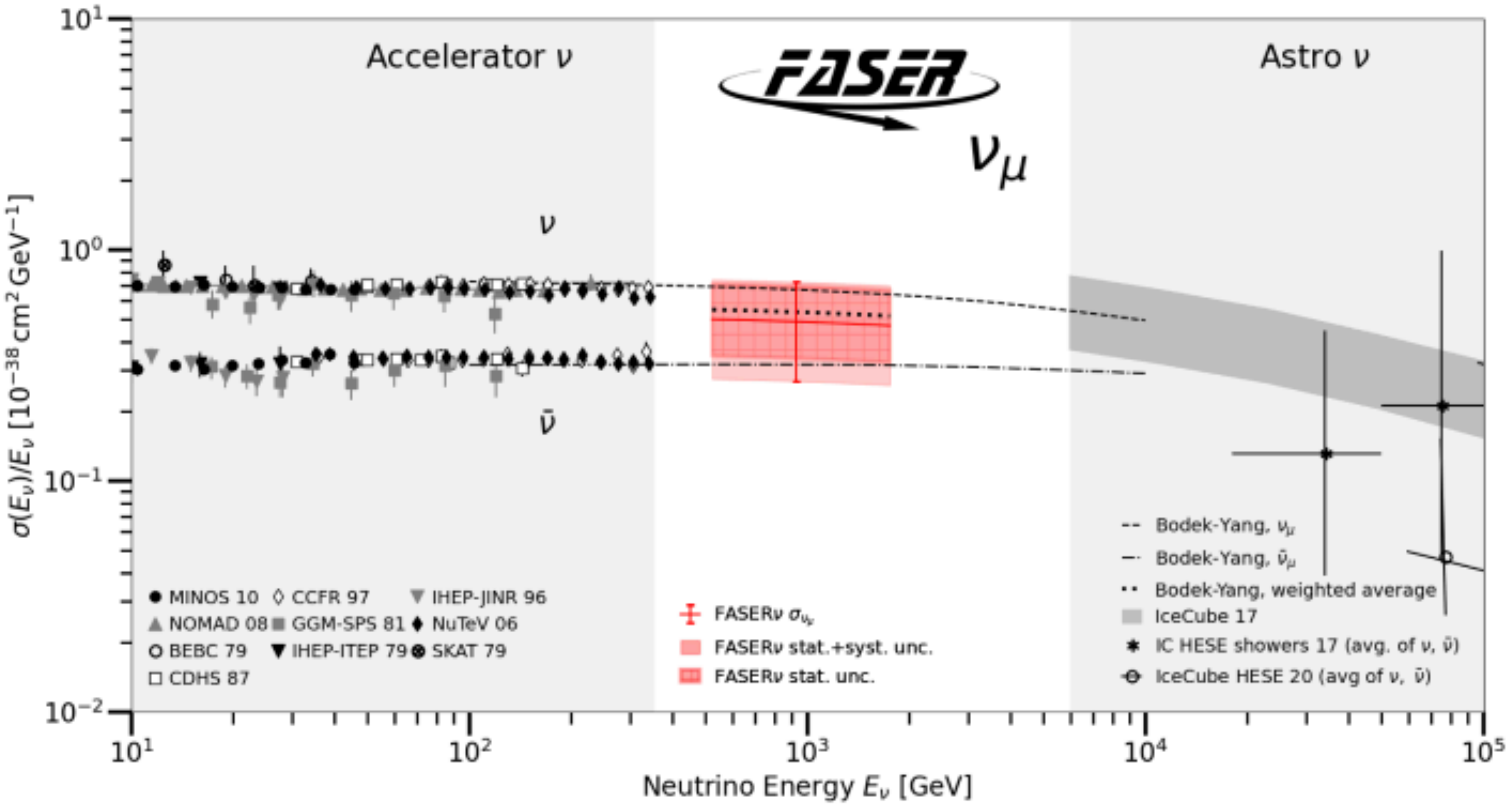
Analysing emulsion films

- Electron neutrino events observed: 4 (5.2σ)
- Muon neutrino events observed: 8 (5.7σ)
- **first direct observation of electron neutrinos produced at a particle collider**
- Expected background:
  - Elec. 0.025 +/- 0015 (neutral hadrons)
  - Muon 0.22 +/0.09 (Neutral hadrons, NC)



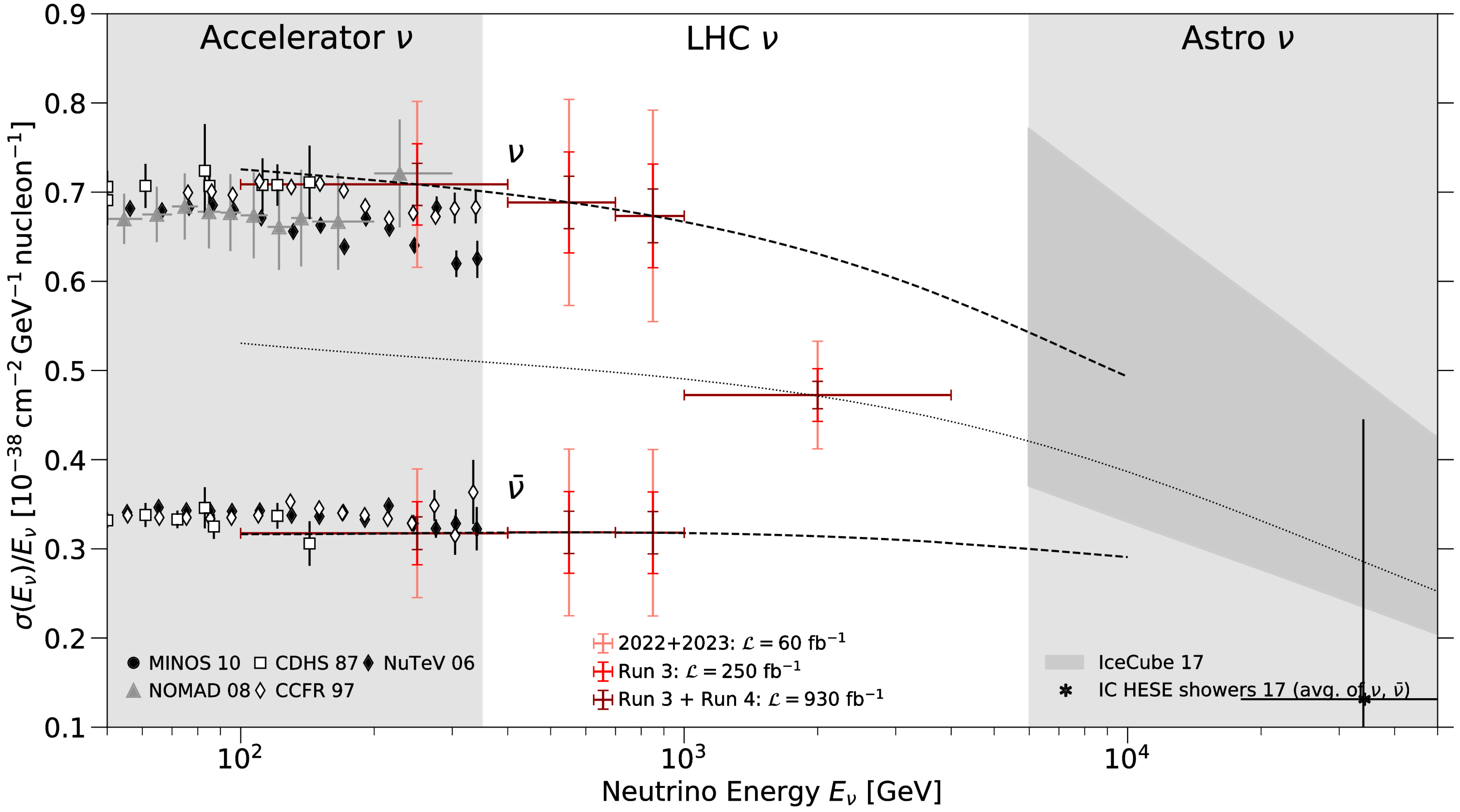
Cross section measurements



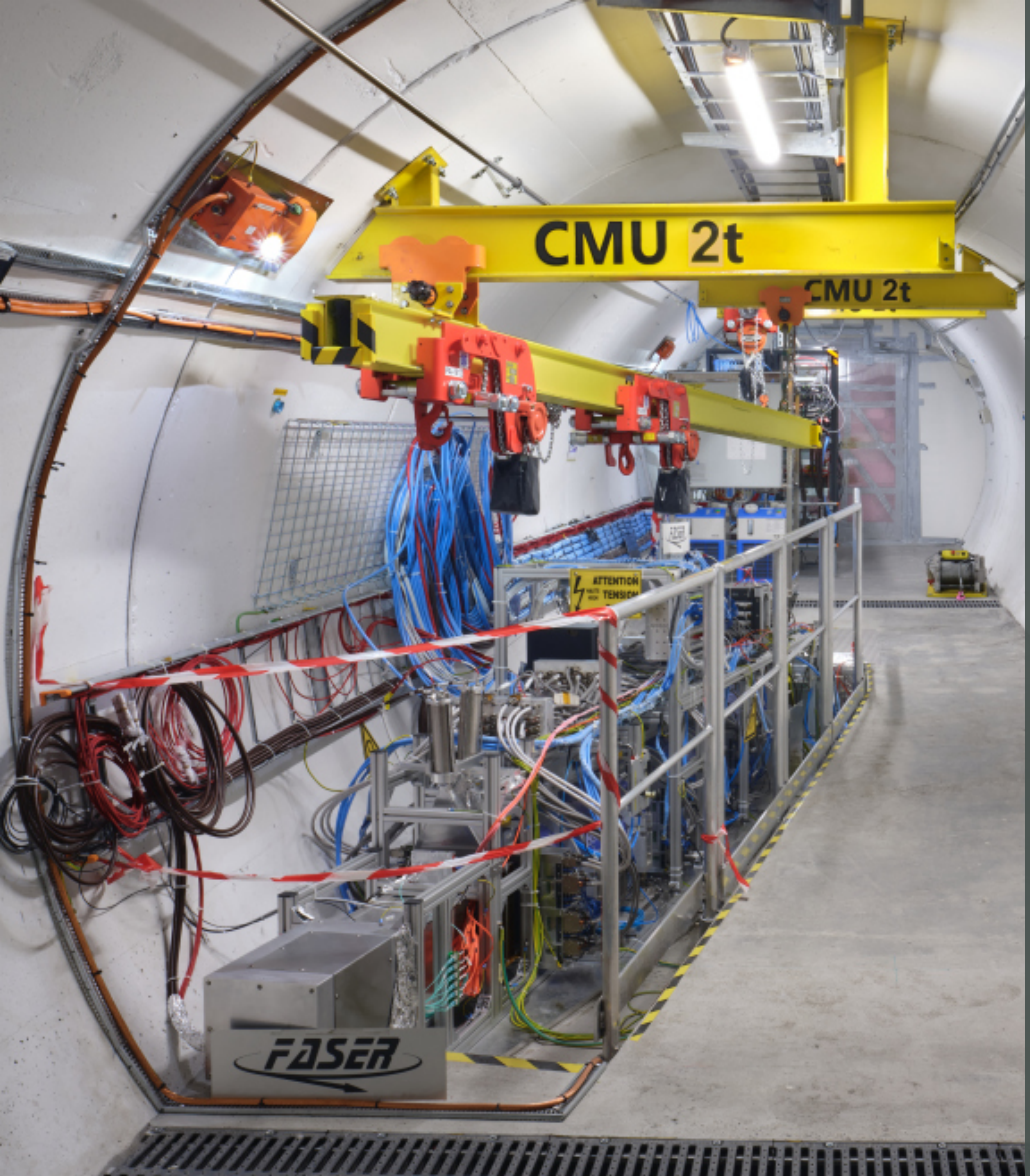


Further prospects of FASER

- Only small percentage of 2022 data analysed for emulsion-based neutrino measurements yet!
- FASER run approved for Run-4 (HL-LHC)
  [FASER Run 4 LOI]
  - Tungsten only Fasernu configuration
  - Large statistics for neutrino measurements
- FPF & FASER(nu)2 would offer many more opportunities!



[FASER in Run-4 LHCC]



Conclusions

- Exciting first neutrino results with 2022 FASER data

- First collider neutrino observation
- First electron neutrinos from colliders

- Neutrino cross section measurements in previously uncovered energy ranges

Collaboration meeting #5

The FASER collaboration

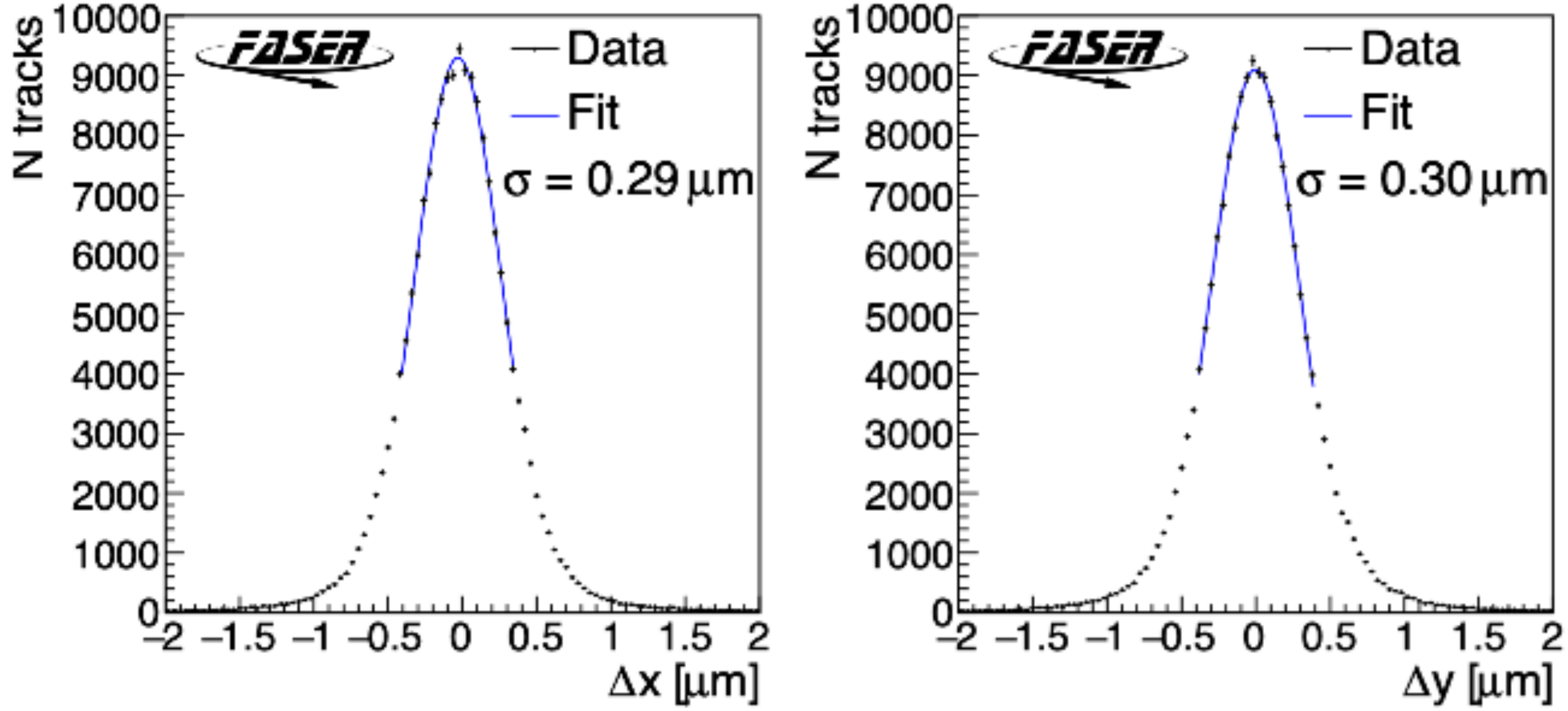
99 collaborators, 27 institutions, 11 countries

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
DESY.
INFN
ISS
International laboratory covered by a cooperation agreement with CERN
清華大學
Tsinghua University
ROYAL HOLLOWAY UNIVERSITY OF LONDON
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
UNIVERSITY OF LIVERPOOL
ZHENGZHOU UNIVERSITY
CHIBA UNIVERSITY
UNIVERSITY OF SUSSEX
Nikhef
UNIVERSITÄT BONN
ETH zürich
MANCHESTER 1824
The University of Manchester

- There is a flux of around 0.5 Hz/cm2 of high-energy muons passing through FASER during nominal LHC running

Category	Events	Expectation
Signal	153	$n_\nu + n_b \cdot p_1 \cdot p_2 + n_{\text{had}} + n_{\text{geo}} \cdot f_{\text{geo}}$
n_{10}	4	$n_b \cdot (1 - p_1) \cdot p_2$
n_{01}	6	$n_b \cdot p_1 \cdot (1 - p_2)$
n_2	64 014 695	$n_b \cdot (1 - p_1) \cdot (1 - p_2)$

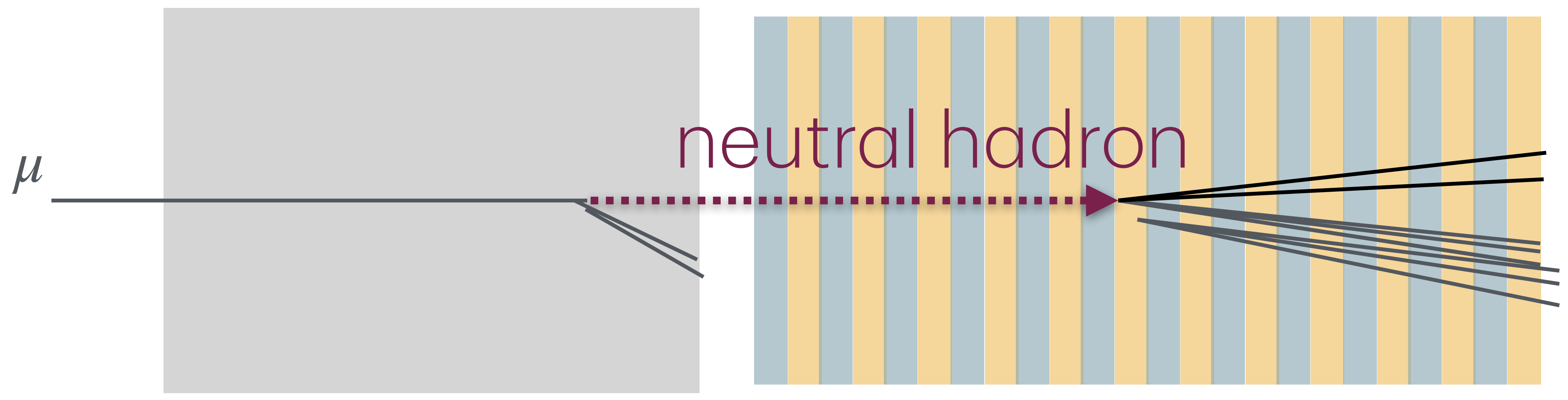
Emulsion analysis

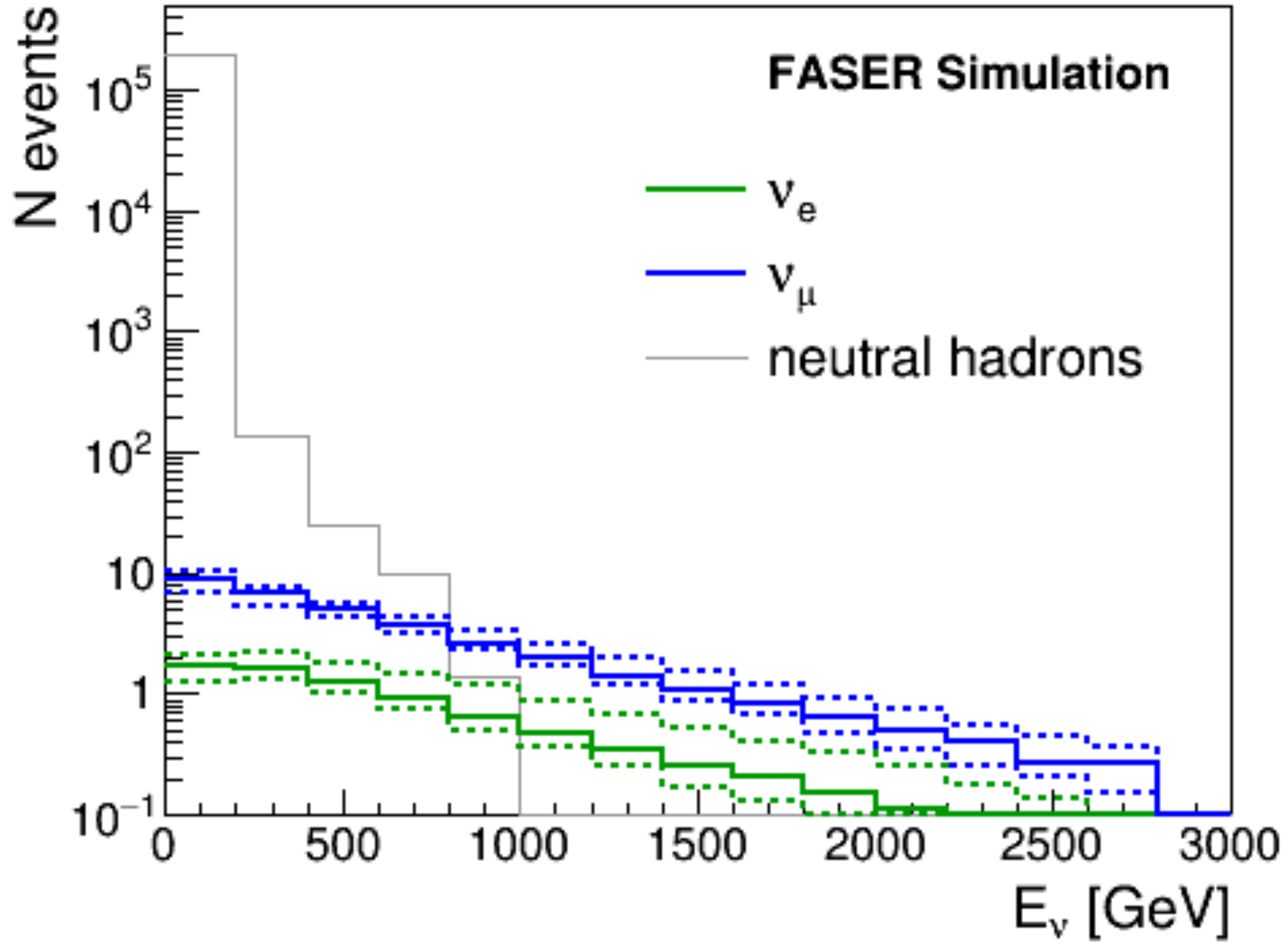


$\nu_e + \bar{\nu}_e$ CC	$\nu_\mu + \bar{\nu}_\mu$ CC	$\nu_\tau + \bar{\nu}_\tau$ CC	NC
$8.5^{+4.3}_{-1.8}$	$43.6^{+4.7}_{-5.2}$	$0.12^{+0.22}_{-0.05}$	$16.5^{+3.0}_{-2.1}$

Backgrounds

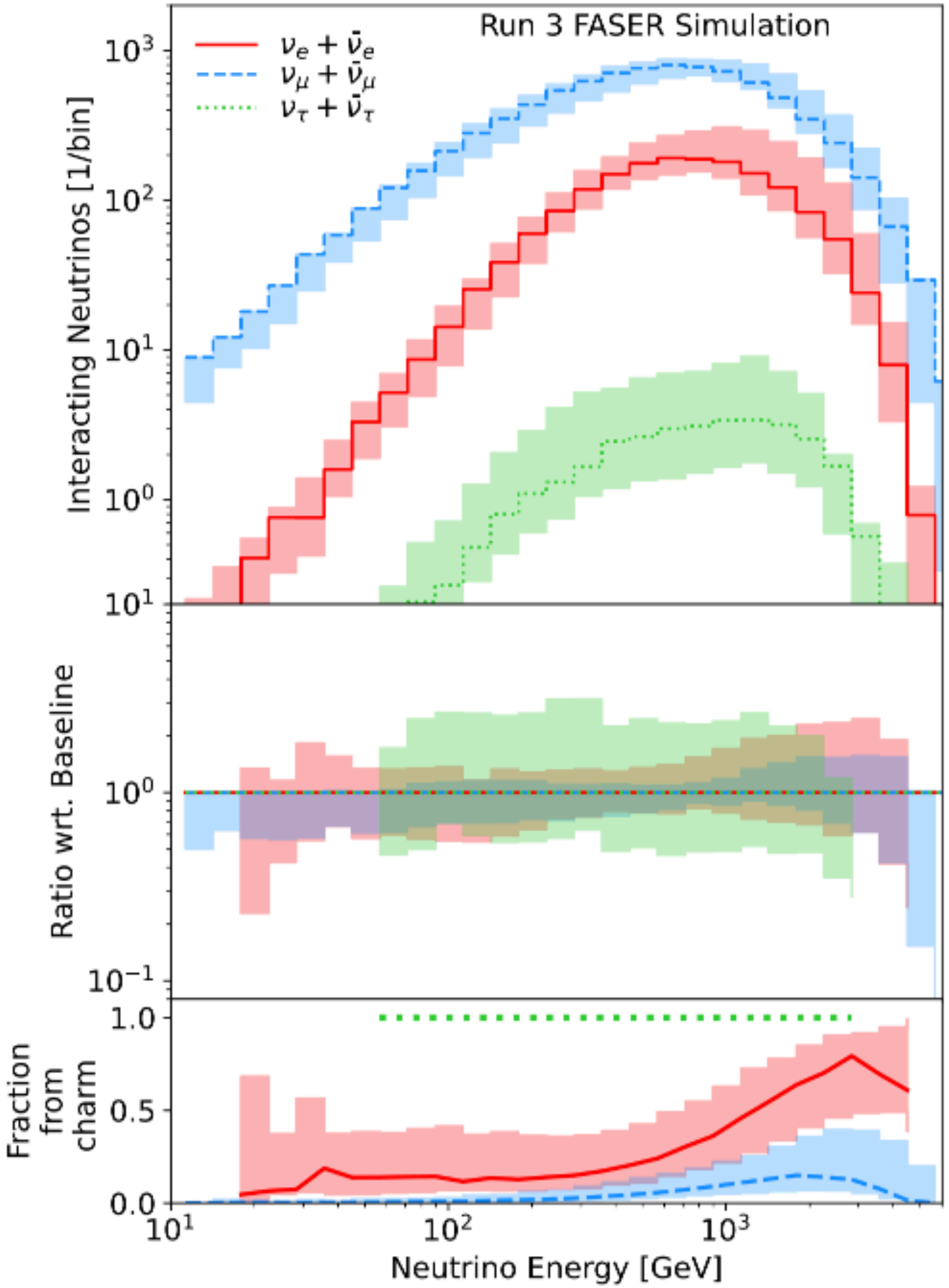
- **Main background: neutral hadrons** produced infront of FASER or in FASERnu material
  - Estimated through simulation
  - Suppressed by vertex and energy selections





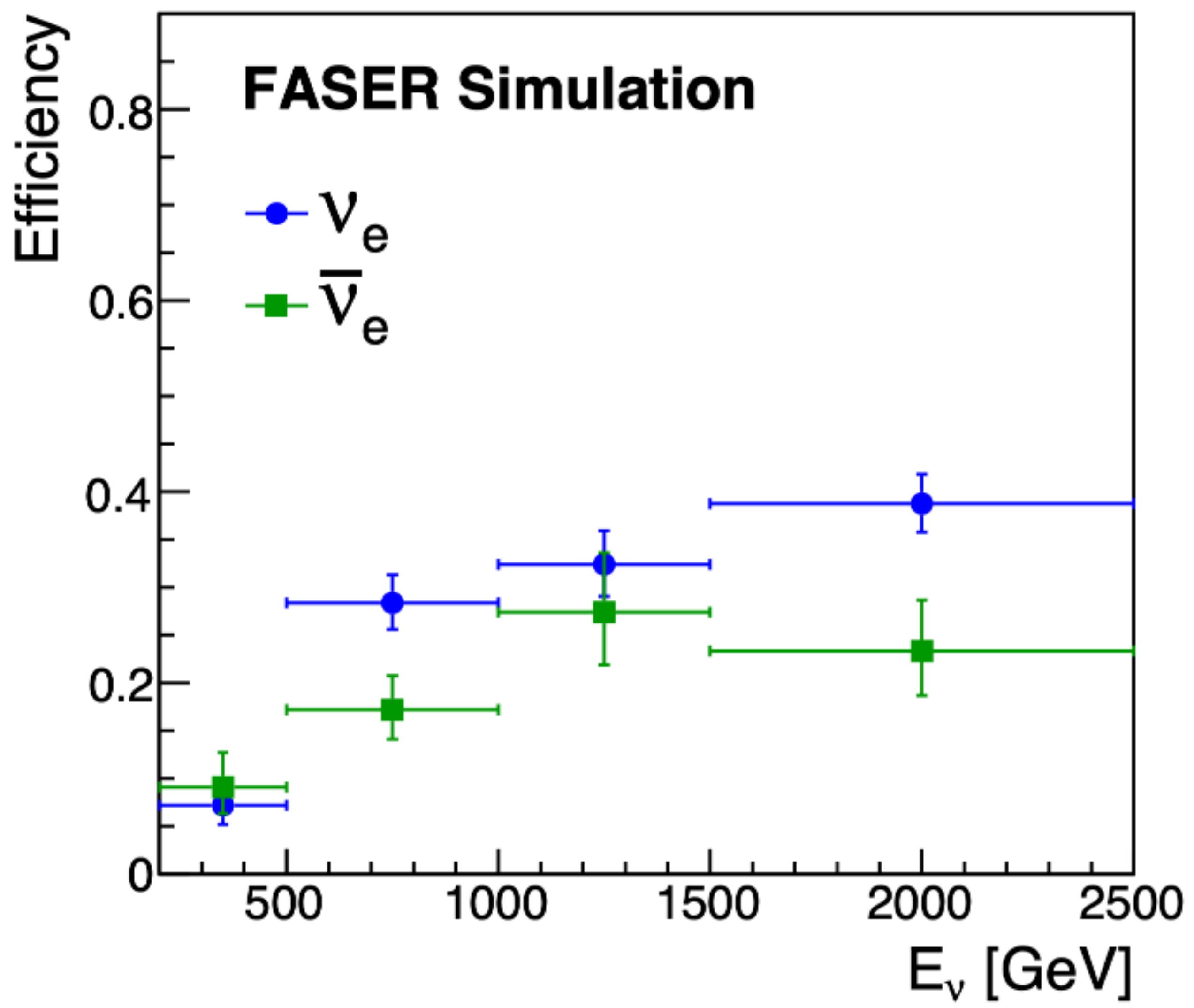
Charm fraction

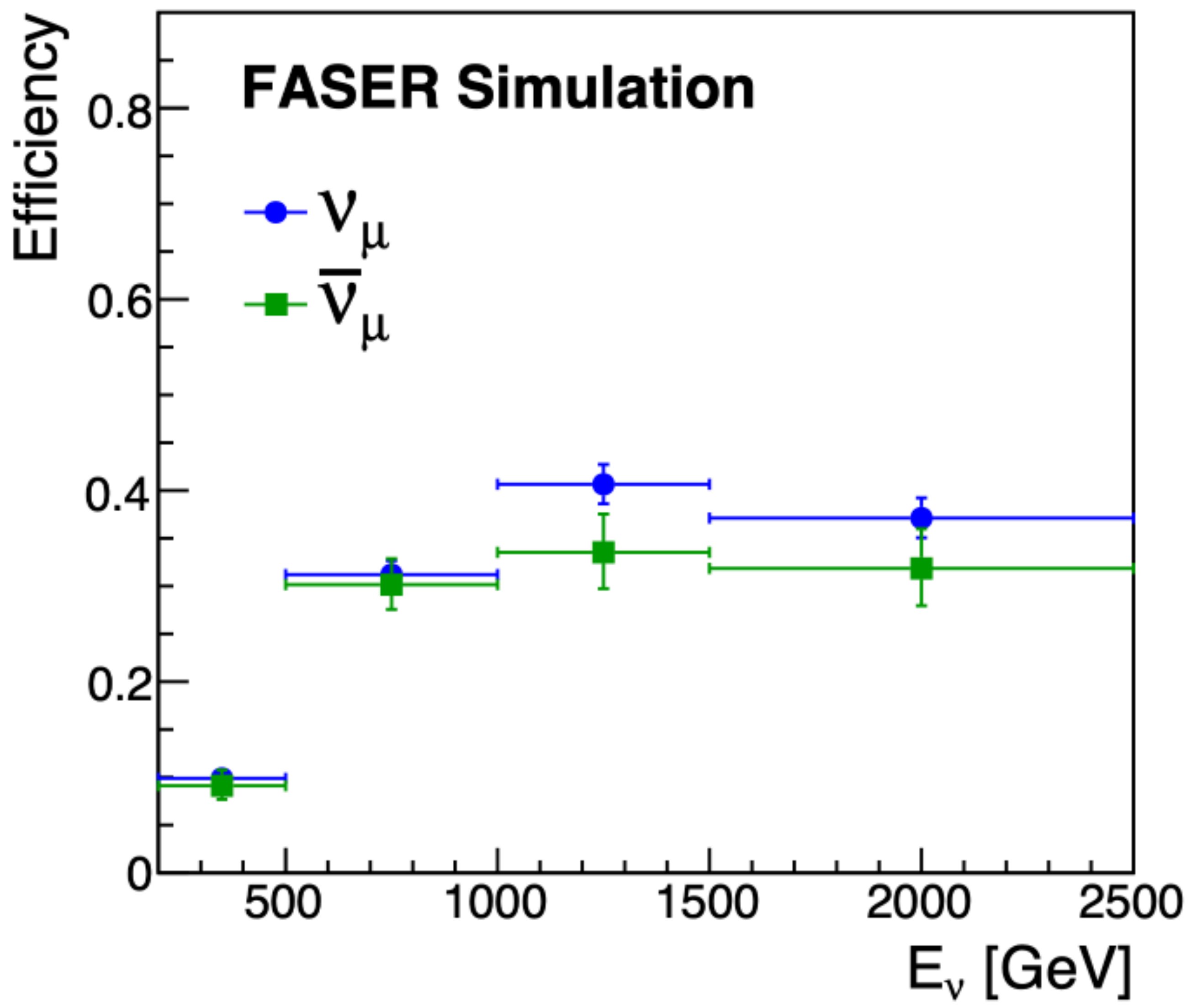
• Signal efficiency ~50% for A′ deca

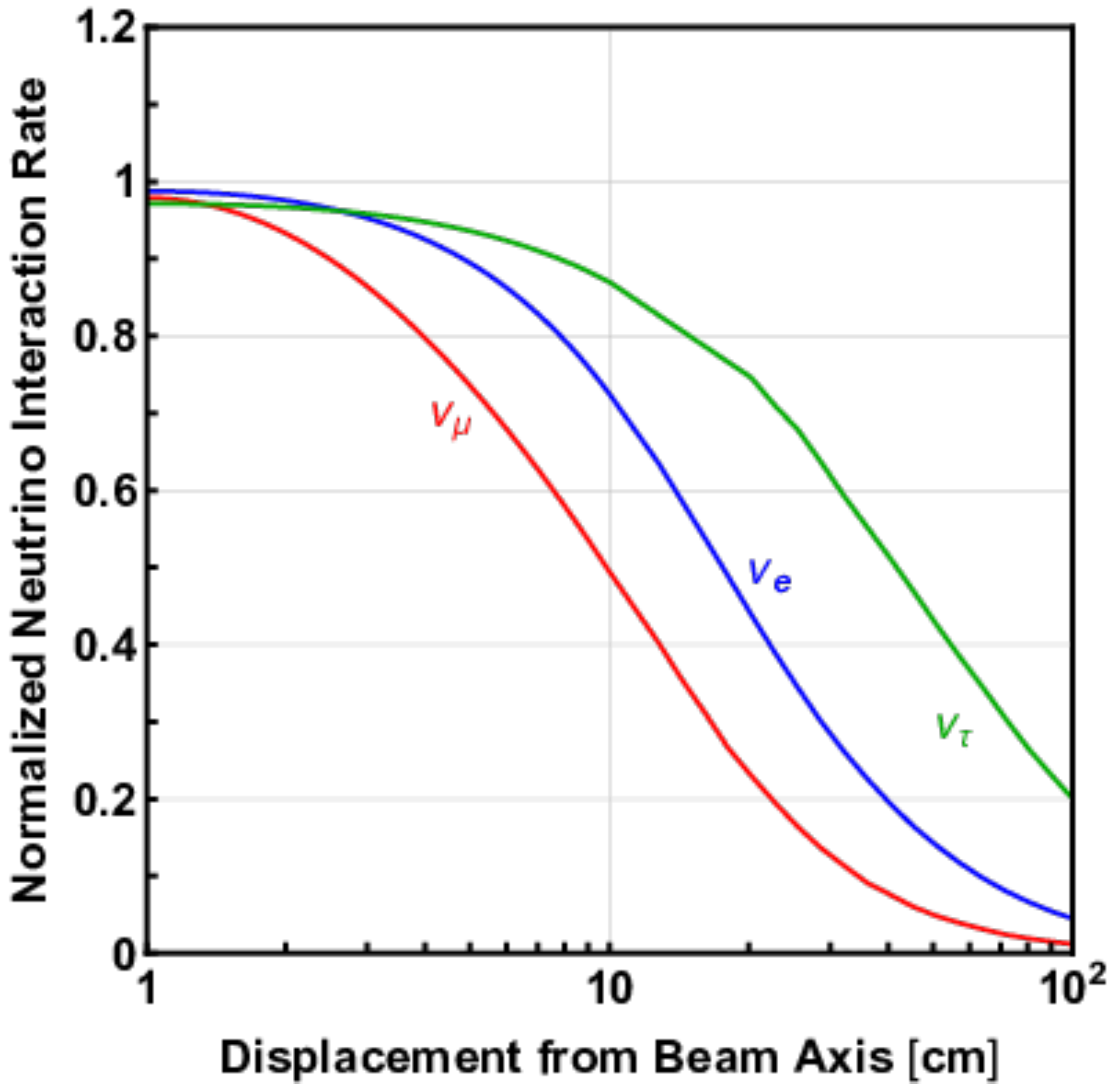


Efficiency and backgrounds

- Slightly smaller efficiency for anti-neutrinos
- Neutral hadron background estimation







Workflow

In Japan

Emulsion film production →

At CERN

Detector assembling → **Exposure** → **Disassembling** → **Development** →

In Japan

Full area readout

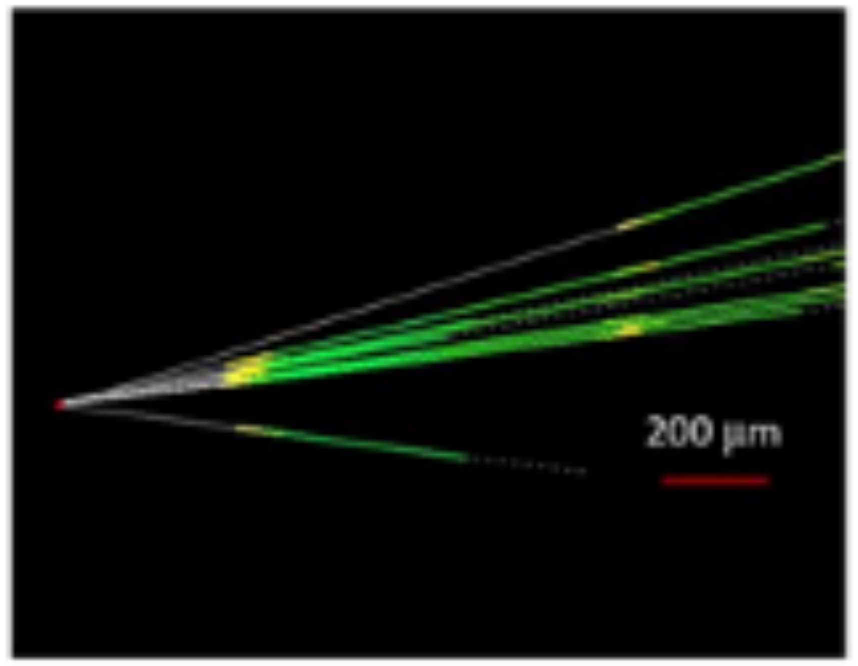
↓

Off-line analysis

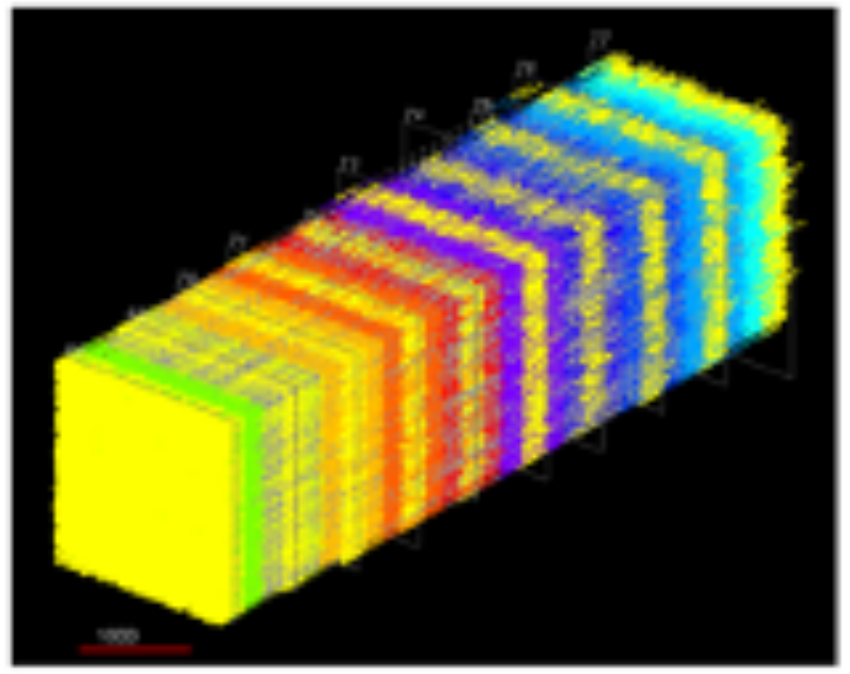
Alignment → Track reconstruction → Vertex reconstruction → μ / e ID → Search for tau/charm decays → Kinematical analysis

Interface tracker data

Spectrometer data



500-1000 TB/Run3



~500 TB/Run3