南京大学
NANJING UNIVERSITY

对撞机上新物理寻找

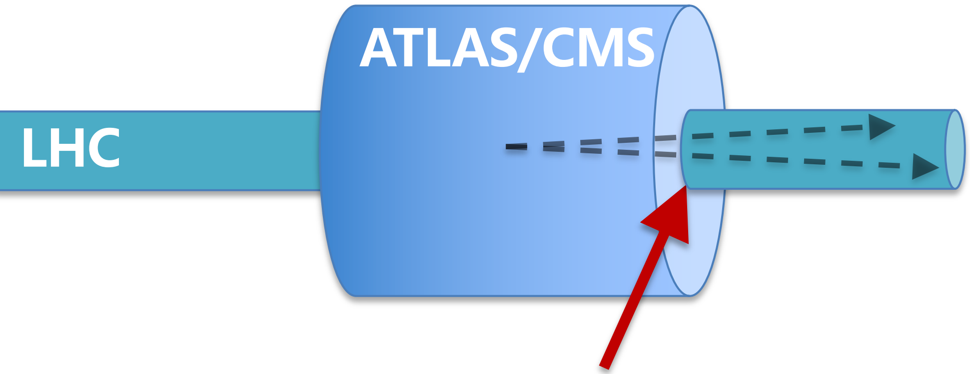
SEARCH FOR NEW PHYSICS AT COLLIDERS

New results from LHC forward experiments

清華大學
Tsinghua University

胡震

Physics potential in forward region



Forward region ocupied by beam pipe

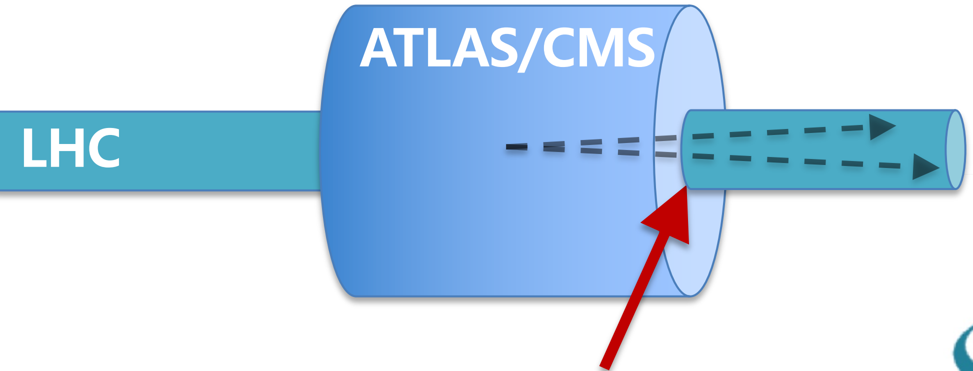
"a hole without detector"

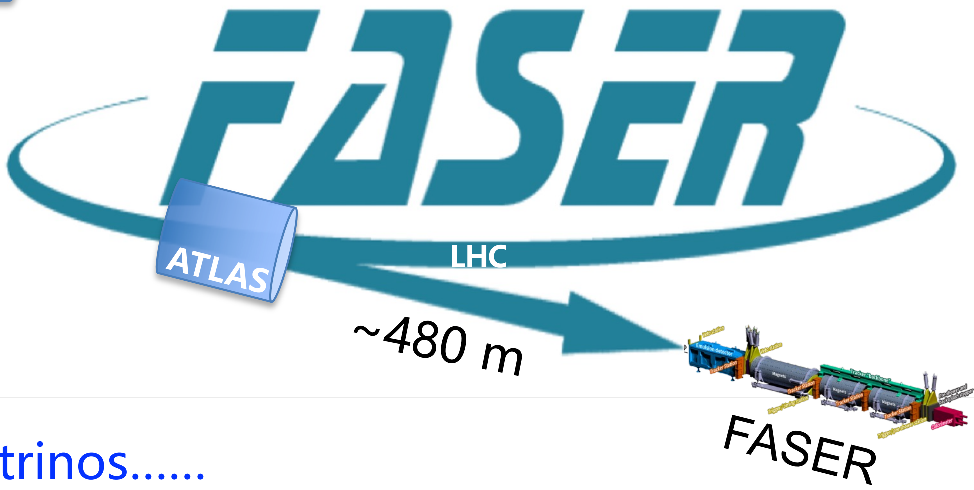
Light and weakly-interacting particles:

Dark photons, axion like particles, neutrinos......

tend to fly to the forward region: escaped

Physics potential in forward region





Forward region ocupied by beam pipe

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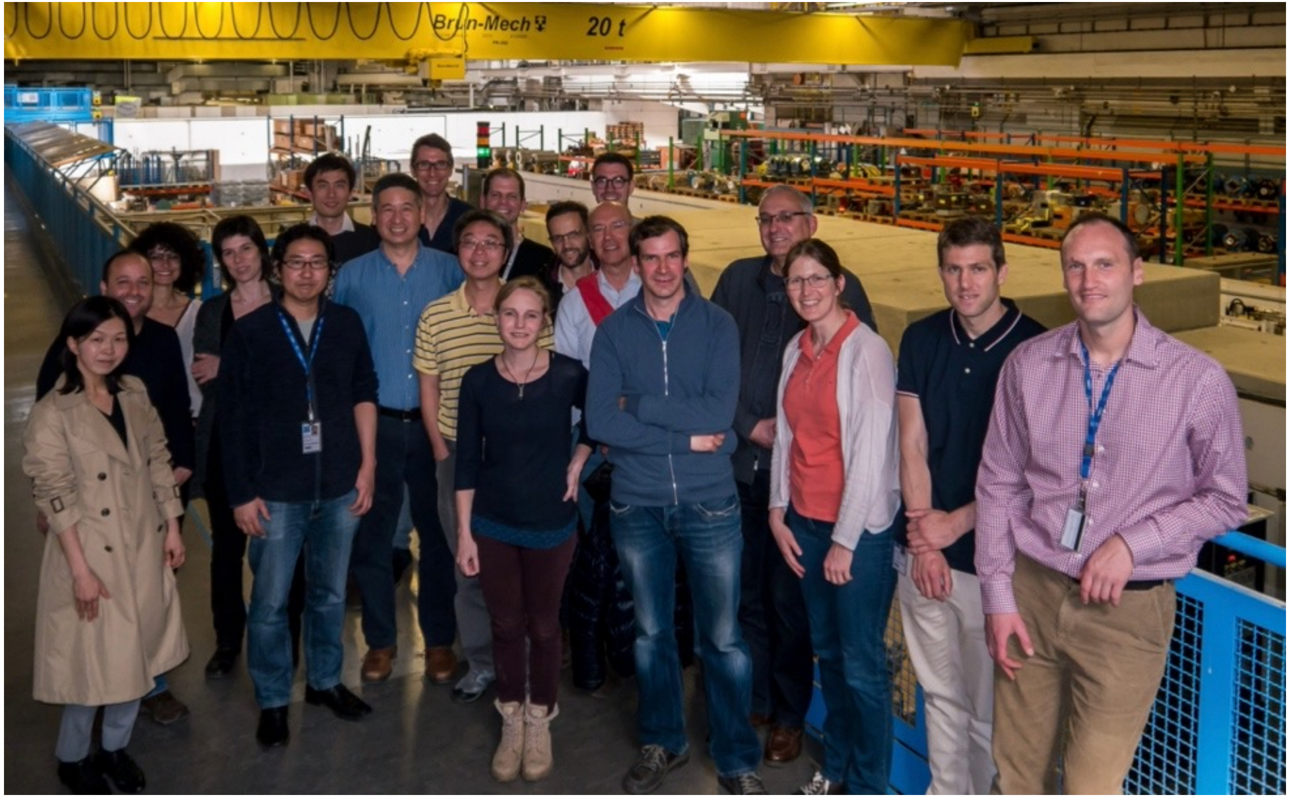
FASER Collaboration

- Founded at CERN in 2019 with 16 institutions



FASER Collaboration

123 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

UNIVERSITY OF LIVERPOOL
UNIVERSITÄT BONN
CHIBA UNIVERSITY
UNIVERSITY OF OREGON

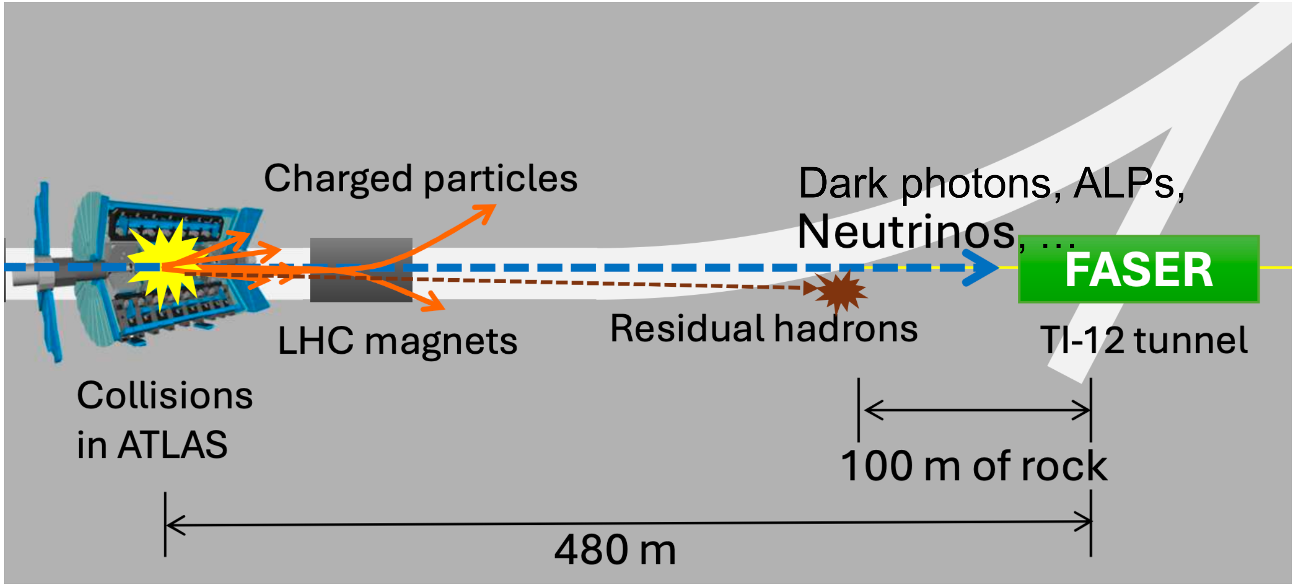
INFN
International laboratory covered by a cooperation agreement with CERN
清華大學 Tsinghua University
ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
UNIVERSITY OF SUSSEX

ETH zürich
Nikhef
Fermilab
UKRI Science and Technology Facilities Council Rutherford Appleton Laboratory
MANCHESTER 1824 The University of Manchester

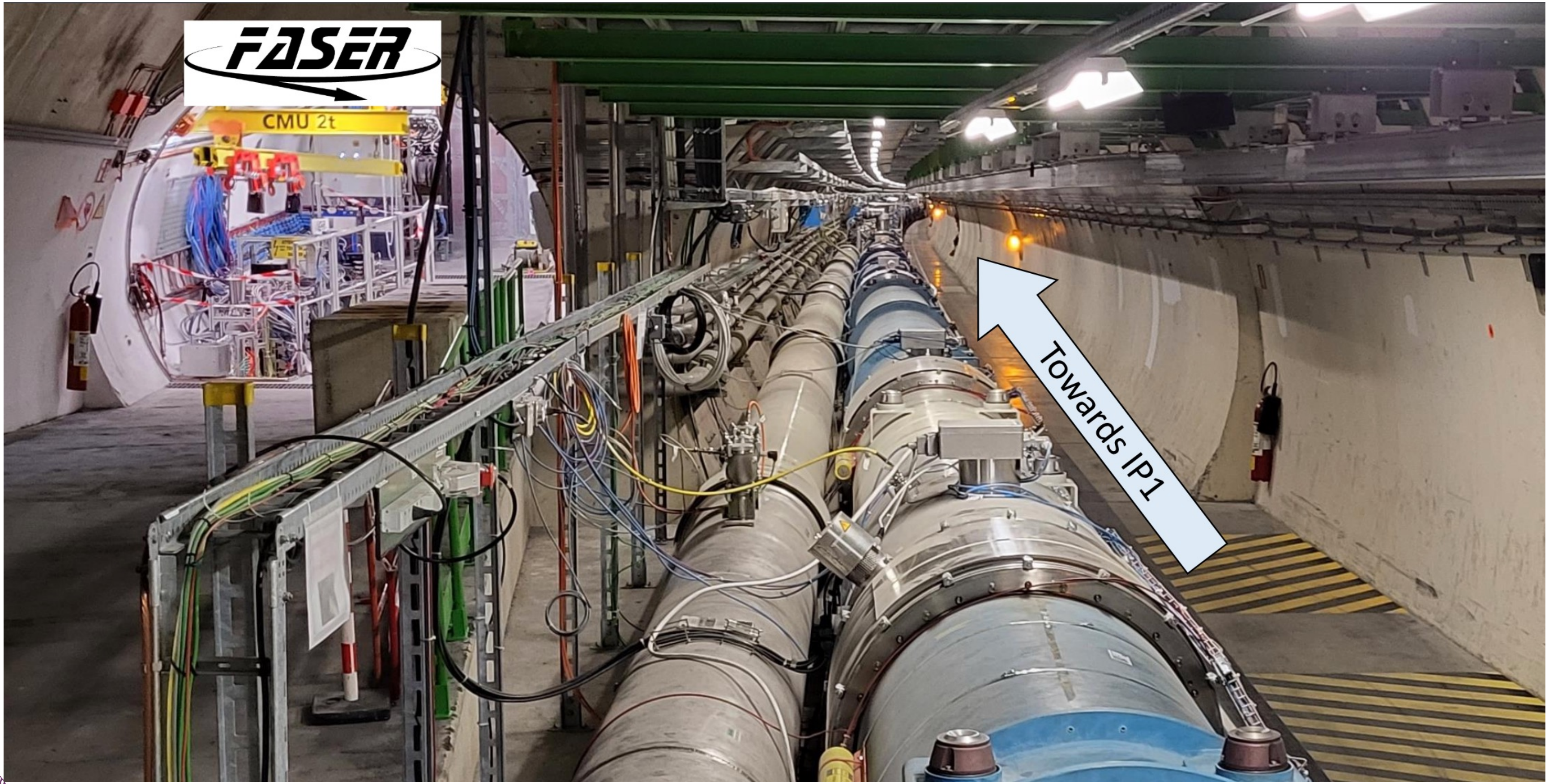
ForwArd Search ExpeRiment (FASER)

Search for **weakly interacting long-lived particles** (BSM) and study **high energy (~TeV) neutrinos** produced in *pp* collisions at ATLAS Interaction Point (IP), starting in 2022 together with LHC Run-3



On the beam axis: covered pseudorapidity of $\eta \gtrsim 8.5$

ForwArd Search ExpeRiment (FASER)

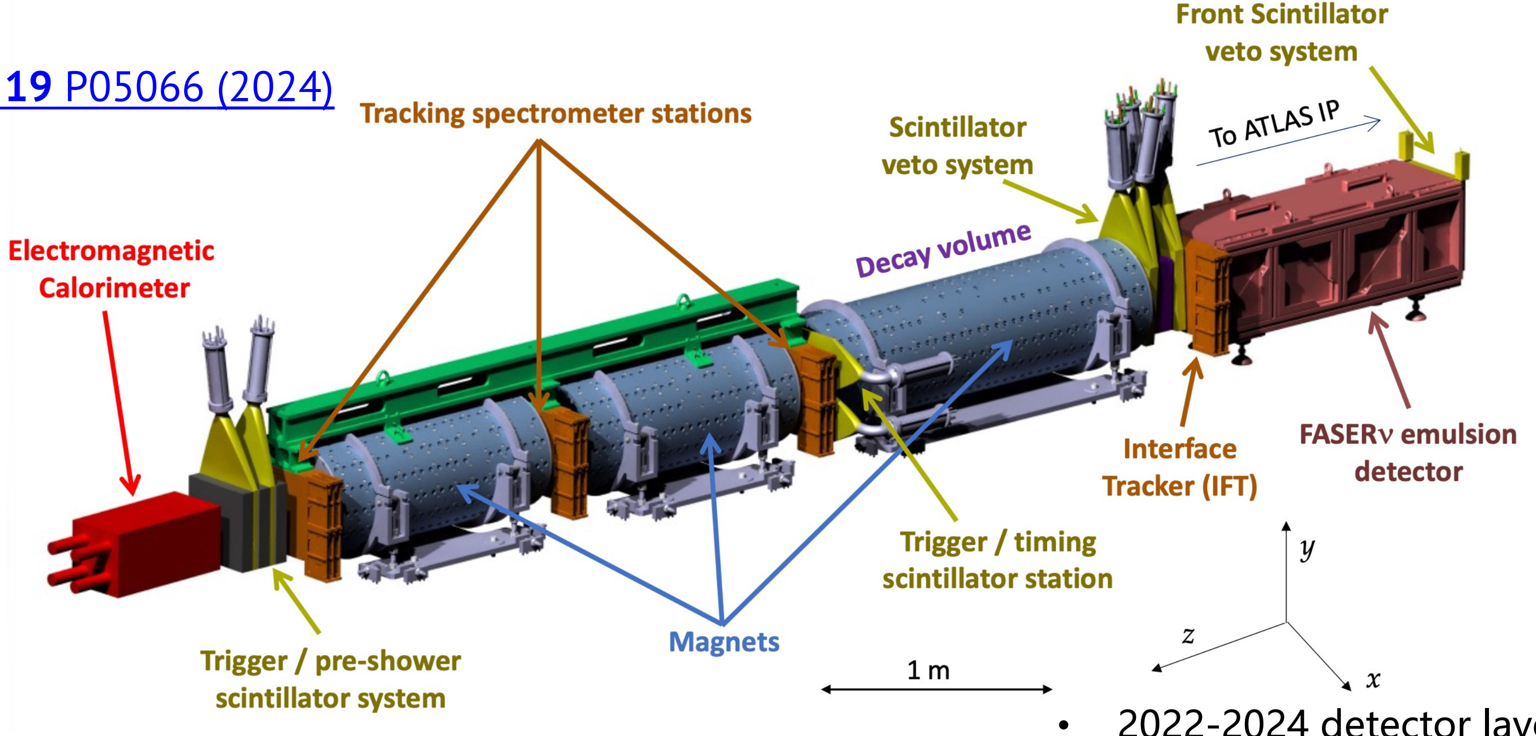


ForwArd Search ExpeRiment (FASER)

The FASER detector

FASER detector composed of a dedicated neutrino sub-detector based on emulsion technology (FASERν) + several electronic sub-detectors

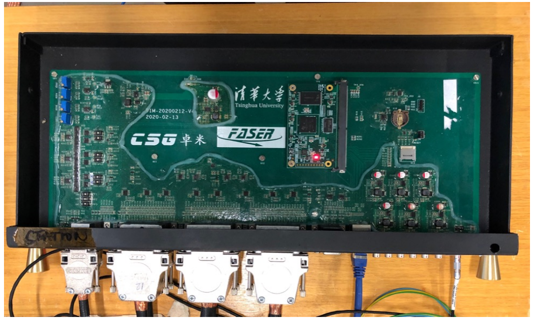
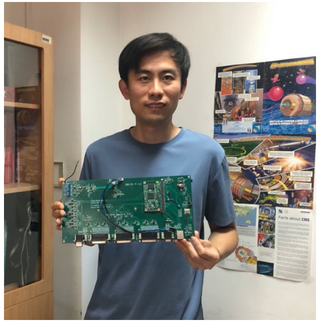
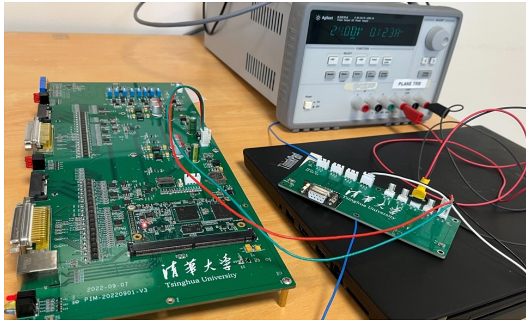
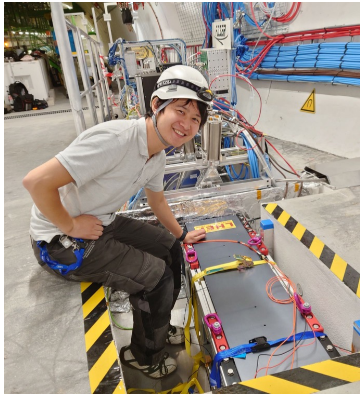
[*JINST* **19** P05066 (2024)](#)

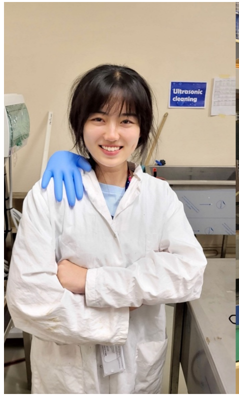
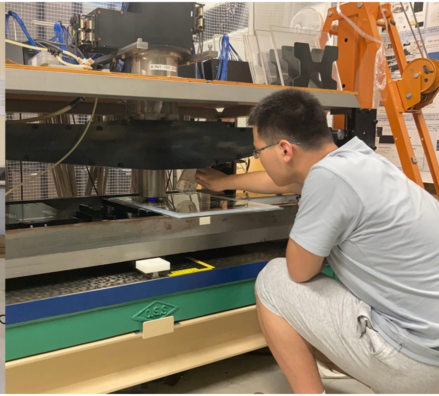


- 2022-2024 detector layout
- Pixel-based pre-shower detector installed in 2025

ForwArd Search ExpeRiment (FASER)

Over the past 7 years, Chinese teams made important contributions in the detector design, construction, operation, software development, data acquisition, and physics analysis…

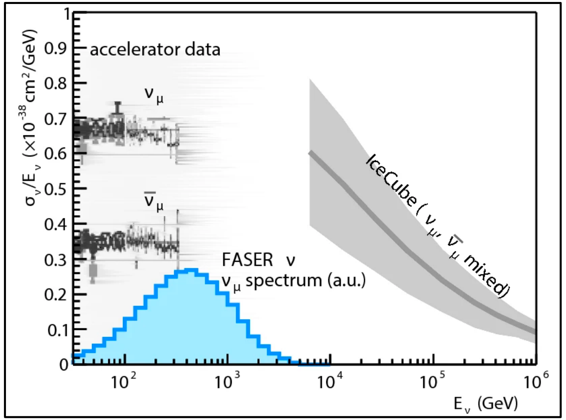
Why study collider neutrinos?

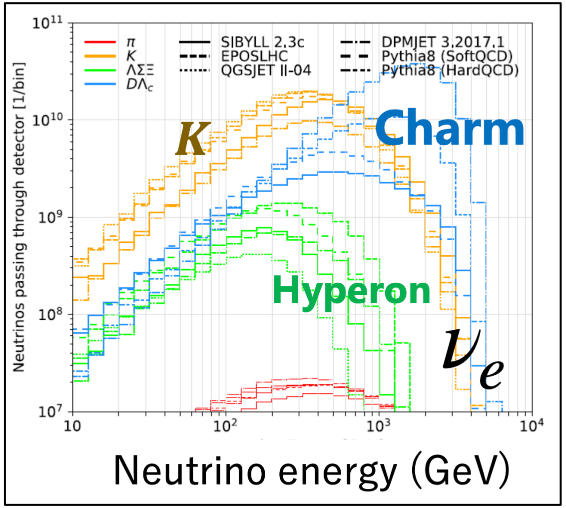
1. Neutrino interactions (all flavors) at **unexplored TeV energies**

2. Probe of **forward hadron production**, novel inputs for:
   - QCD (gluon PDFs at low-x, intrinsic charm)
   - Astroparticle physics (collider counterpart of high-energy cosmic rays interactions: cosmic ray muon puzzle)

3. Probe of **hadron structure** (proton/nuclear PDFs)

4. Background to **BSM searches**

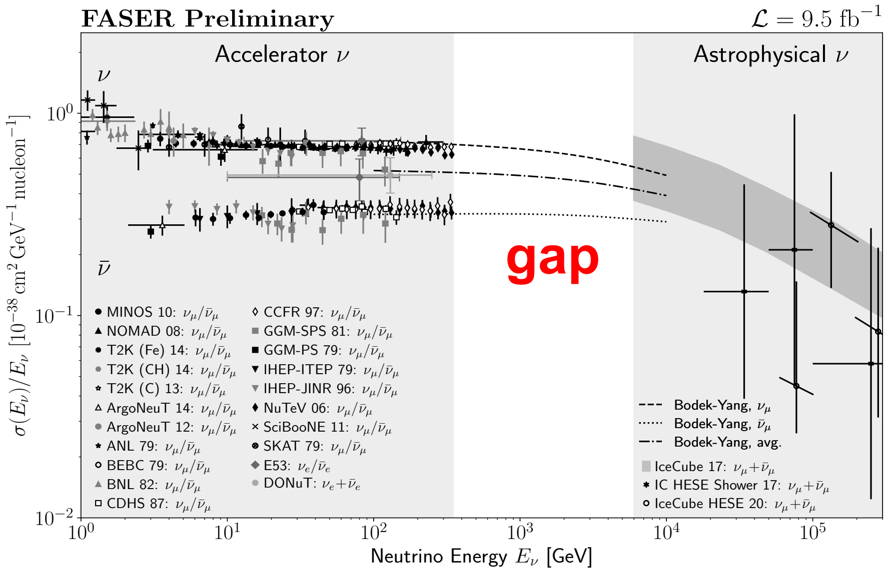


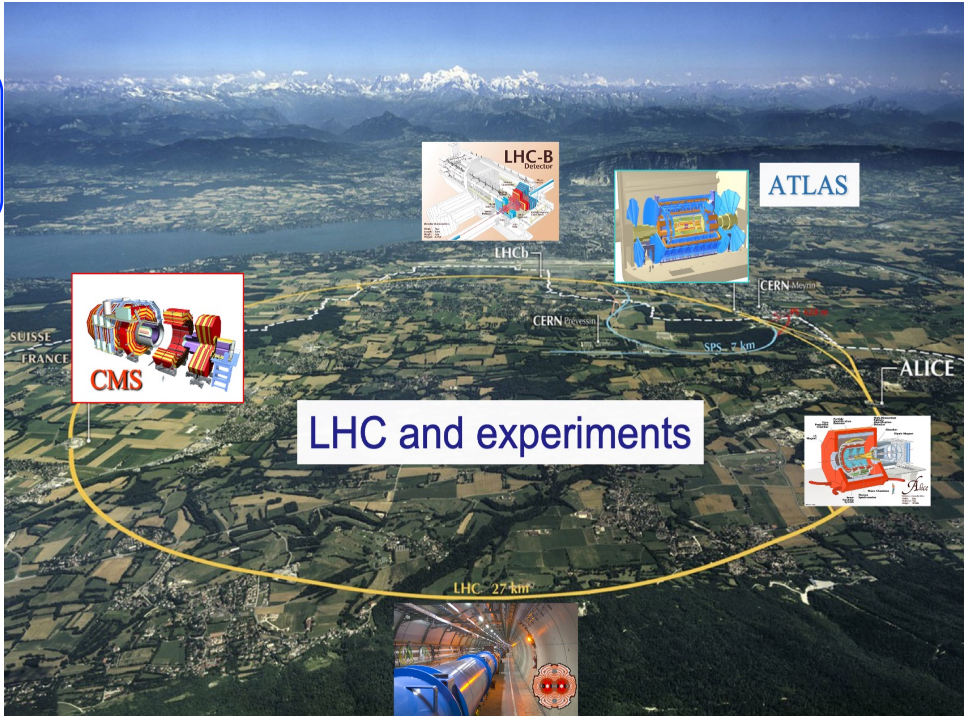


Why study collider neutrinos?

Reactor, fixed-target…
lower energy

Cosmic-ray
uncontrollable

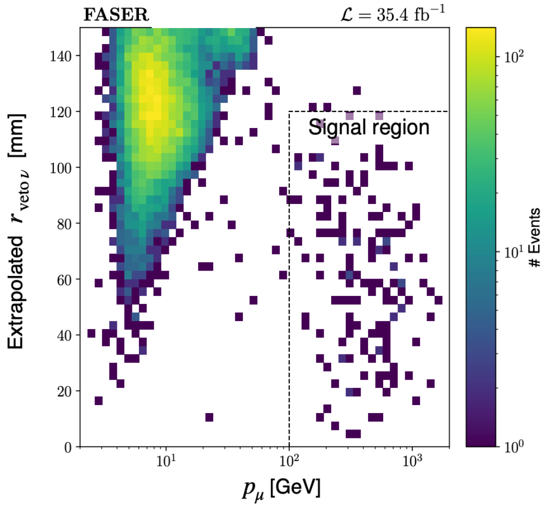




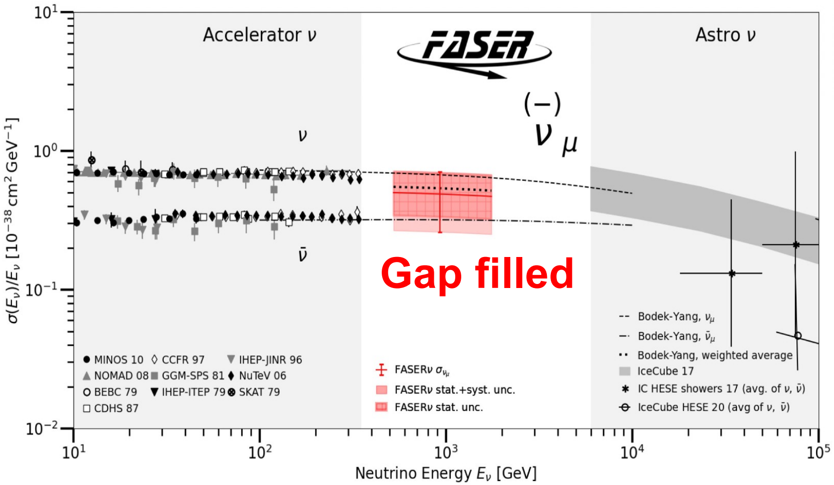
4 big detectors at LHC:
can not detect neutrinos directly

Neutrinos at FASER

- FASER has released several neutrinos measurements in past years
  - 2023: **First direct observation** of neutrinos produced in collider events, >16 σ
  - 2024: **Highest** energy neutrinos from artificial sources, 1.5 TeV
  - 2024: Started to **fill the gap** between fixed-target and astroparticle measurements



[Phys. Rev. Lett. **131**, 031801 (2023)]



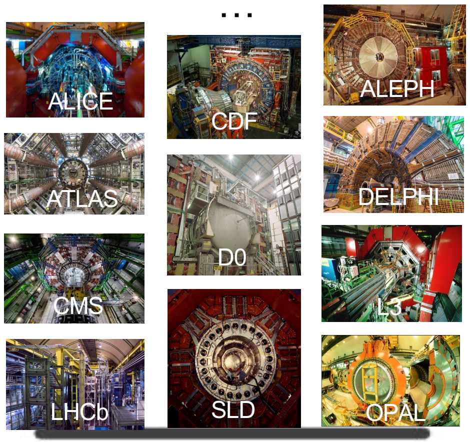
[Phys. Rev. Lett. **133**, 021802 (2024)]

Neutrinos at FASER

FASER

“Tabletop,” 18 months,
~$1M

153 neutrinos



All previous
collider detectors

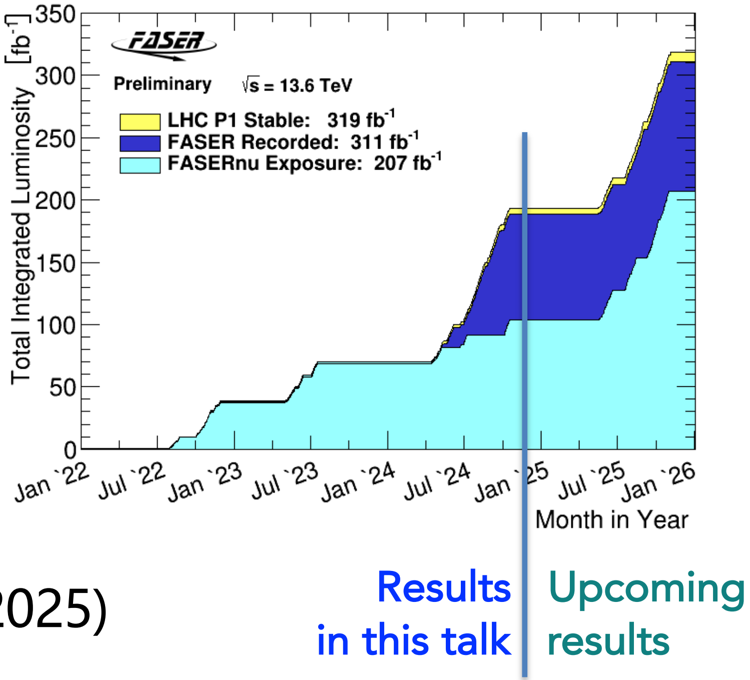
Building-size, decades,
~$1B

0 neutrinos

16σ discovery, opening a new window
at the high energy frontier

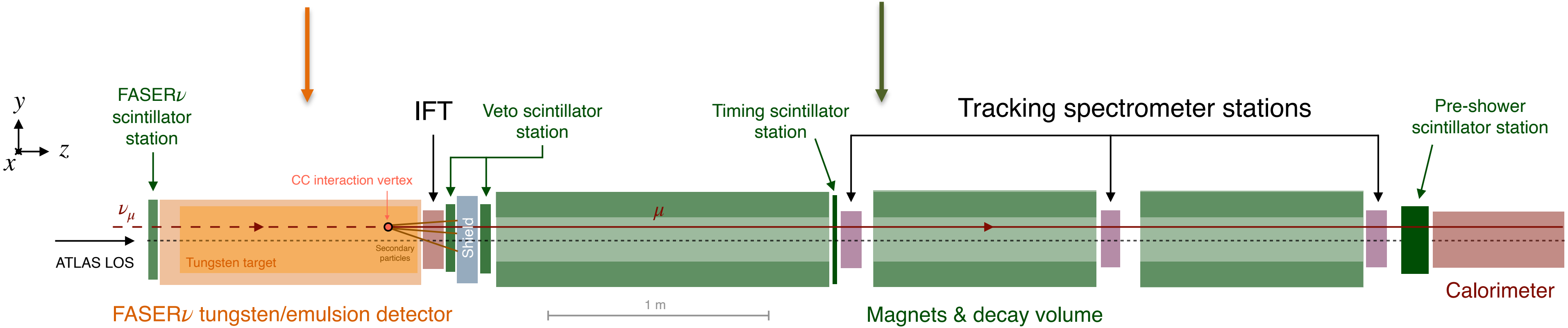
New results this year

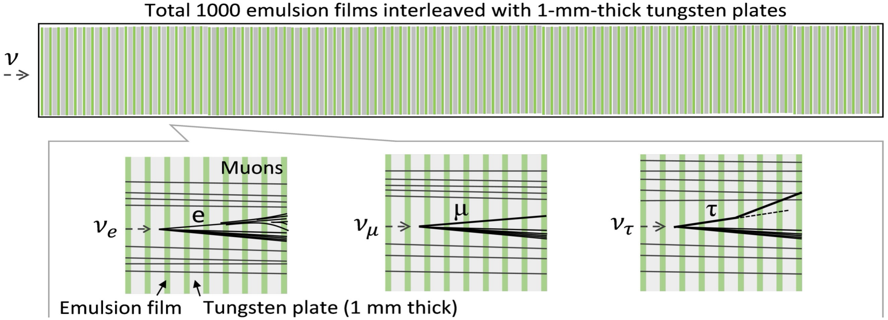
- Successfully recorded >97% of data since 2022
  - Luminosity provided by ATLAS
- **New results in this talk use**
  - **190 fb^{-1} of 2022-2024 electronic data**
  - **9.5 fb^{-1} of 2022 emulsion data**



- Till today: 311 fb^{-1} data recorded (2022-2025)
  - 207 fb^{-1} with emulsion detector

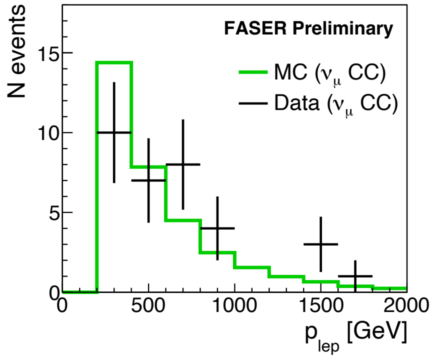
Neutrino measurements in FASER are performed both with **passive detector** (emulsion) and **electronic detectors**

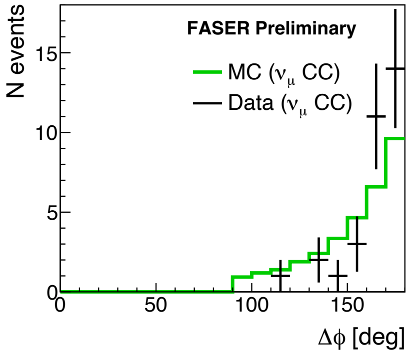


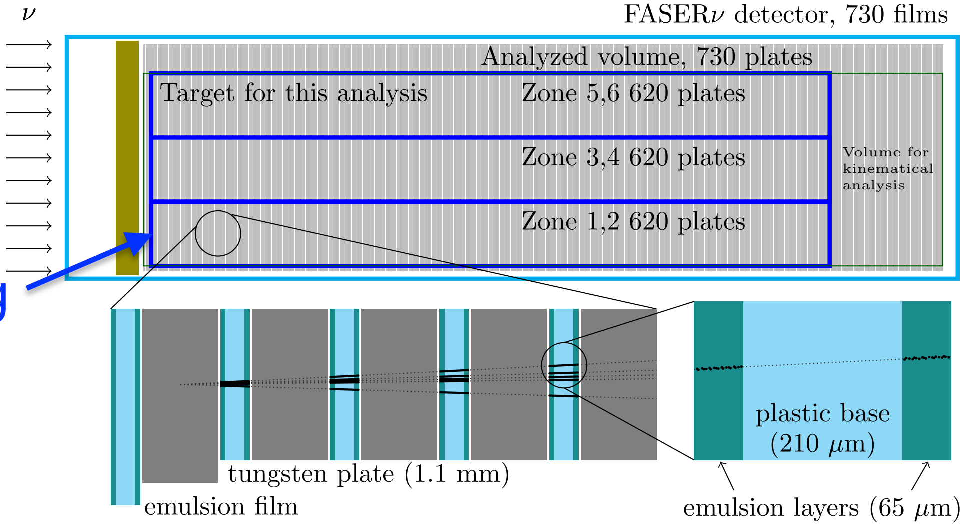


FASERν

- 730 alternating layers of tungsten sheets and emulsion films
  - High position resolution (< 0.3 μm)
  - Separate identification of ν_e CC and ν_μCC candidates
  - Small background from neutral hadrons rejected using kinematic criteria
- New results use 9.5 fb^{-1} and 681 kg target mass (blue boxes)
  - ~2x increase wrt moriond2025





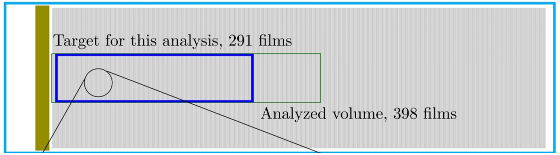


CERN-FASER-CONF-2026-002

FASERν differential cross sections

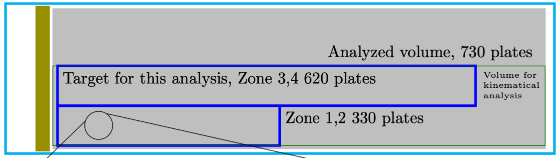
2024	2025	2026
128.8 kg	314.7 kg	**681 kg**

2024



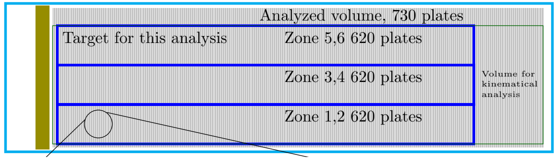
	ν_e CC	ν_μ CC
Expected signal	$1.1-3.3$	$6.5-12.4$
Expected background	$0.025^{+0.015}_{-0.010}$	$0.02^{+0.09}_{-0.07}$
Observed events	4	8

2025

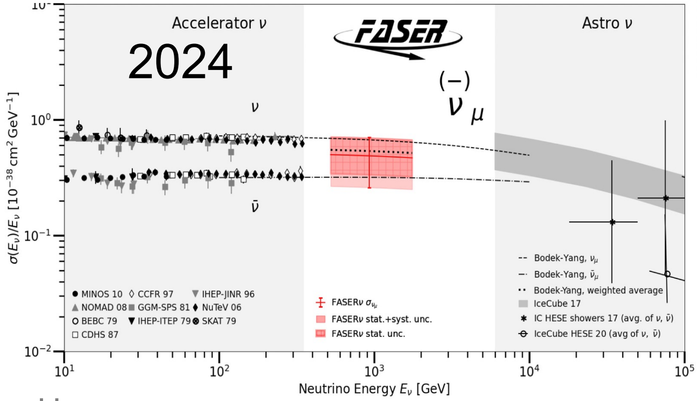


	ν_e CC	ν_μ CC
Expected signal	2.8–7.2	16.2–28.7
Expected background	$0.06^{+0.04}_{-0.02}$	$0.54^{+0.22}_{-0.17}$
Observed events	5	20

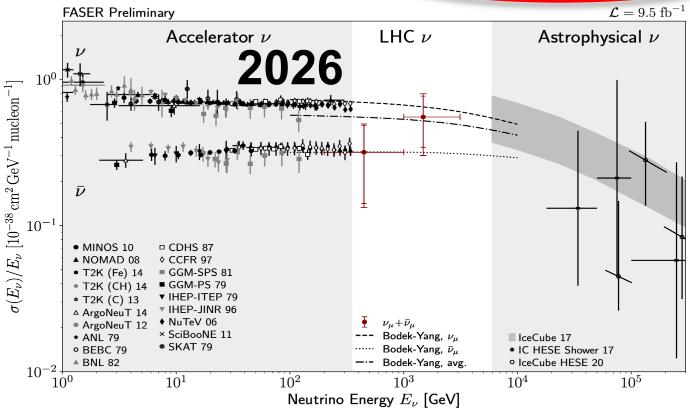
2026



	ν_e CC	ν_μ CC
Expected signal	$7.7^{+6.3}_{-2.5}$	$40.0^{+14.5}_{-9.7}$
Expected background	$0.13^{+0.08}_{-0.05}$	$1.17^{+0.62}_{-0.40}$
Observed events	7	33



ν_μ CC

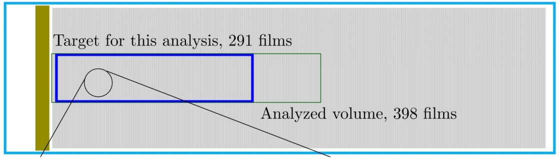


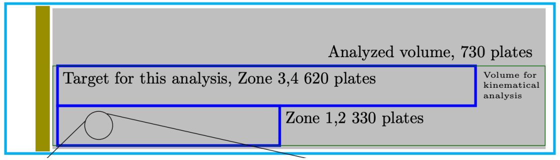
Phys. Rev. Lett. **133**, 021802 (2024)

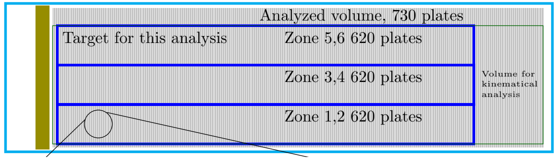
CERN-FASER-CONF-2026-002

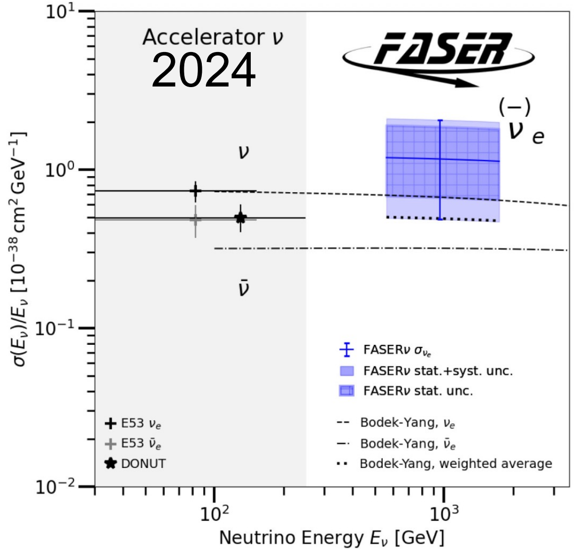
FASERν differential cross sections

2024	2025	**2026**
128.8 kg	314.7 kg	**681 kg**

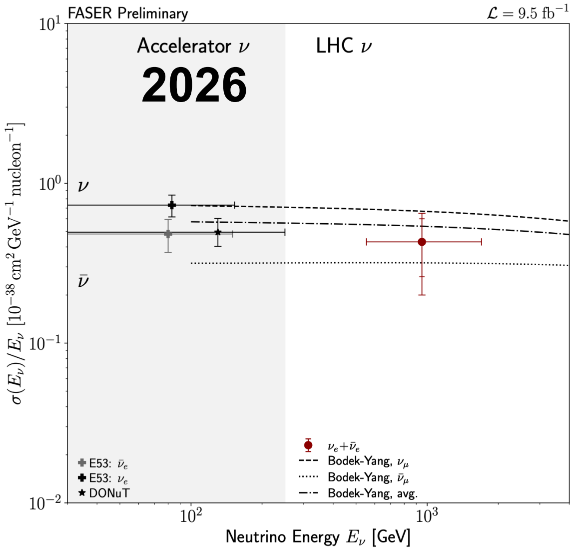








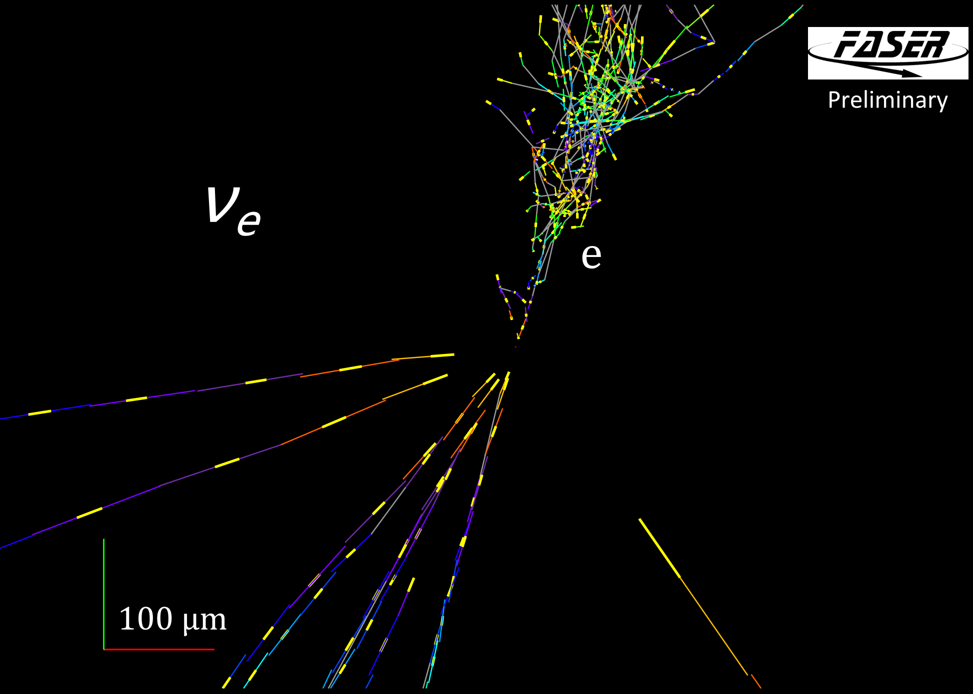
ν_e CC



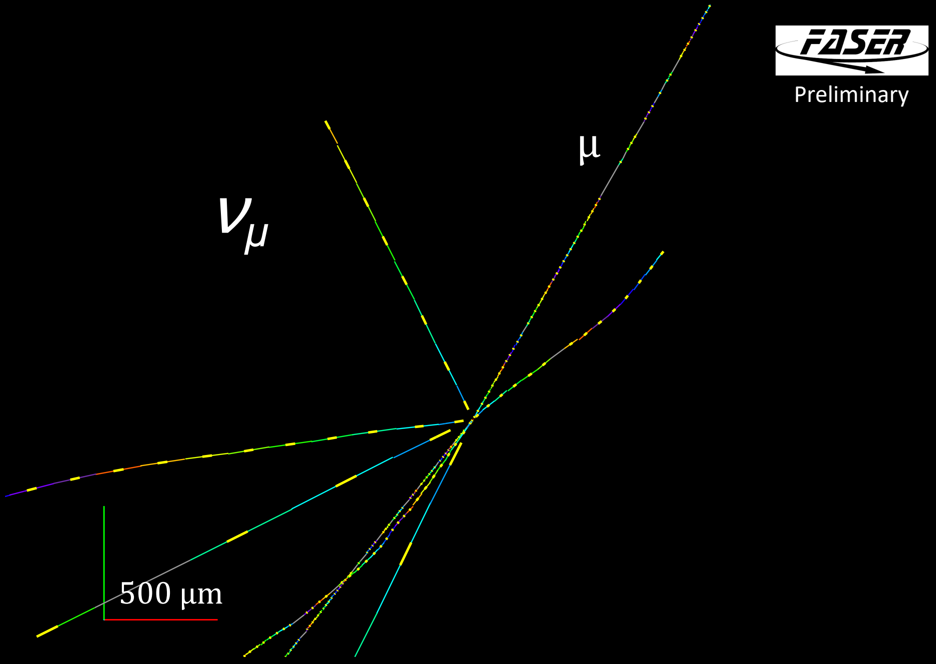
FASER ν analysis

Beam view

Electron energy 470 ± 190 GeV



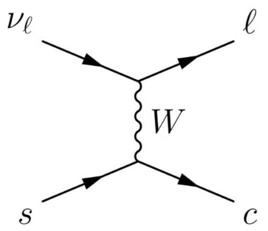
Muon energy 540 ± 160 GeV

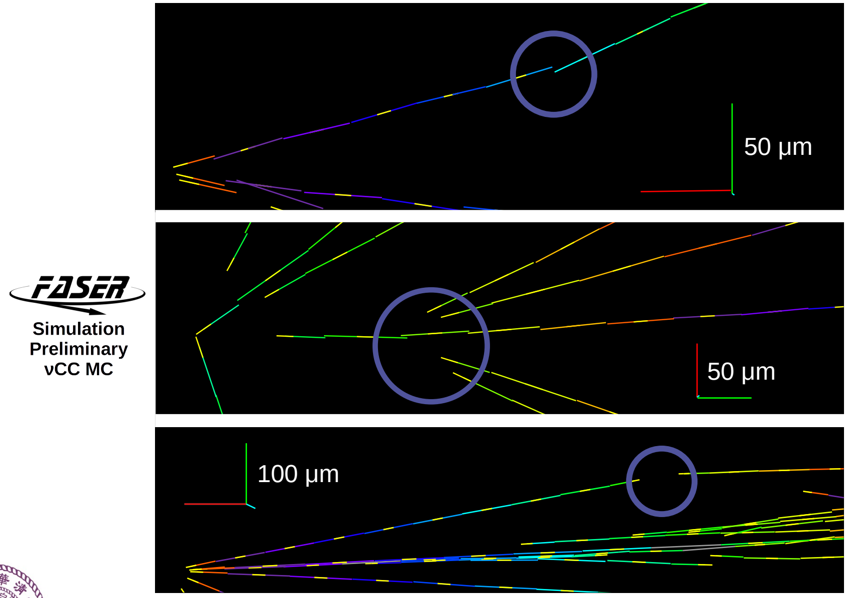


CERN-FASER-CONF-2026-002

Search for associated charm production

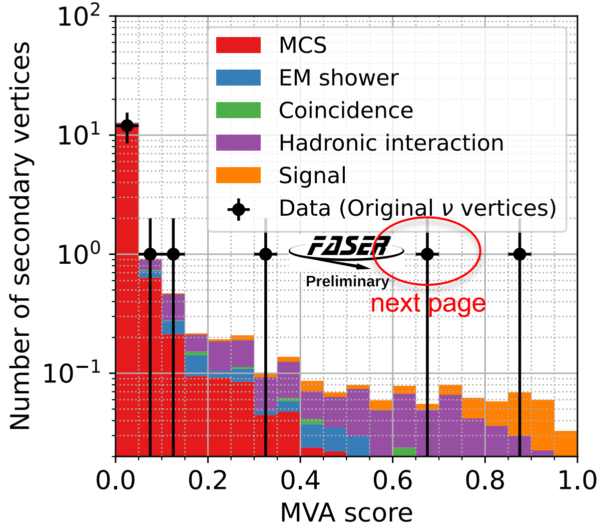
- Based on the 7 ν_e and 33 ν_μ interaction candidates in 9.5 fb^{-1} of data (681 kg)
  - **First search** for charm hadrons produced in association with ν_e or ν_μ interactions at TeV energy
  - Improve our understanding of both the nucleon structure and the weak force
- Displaced vertex reconstruction: an important step towards ν_τ search





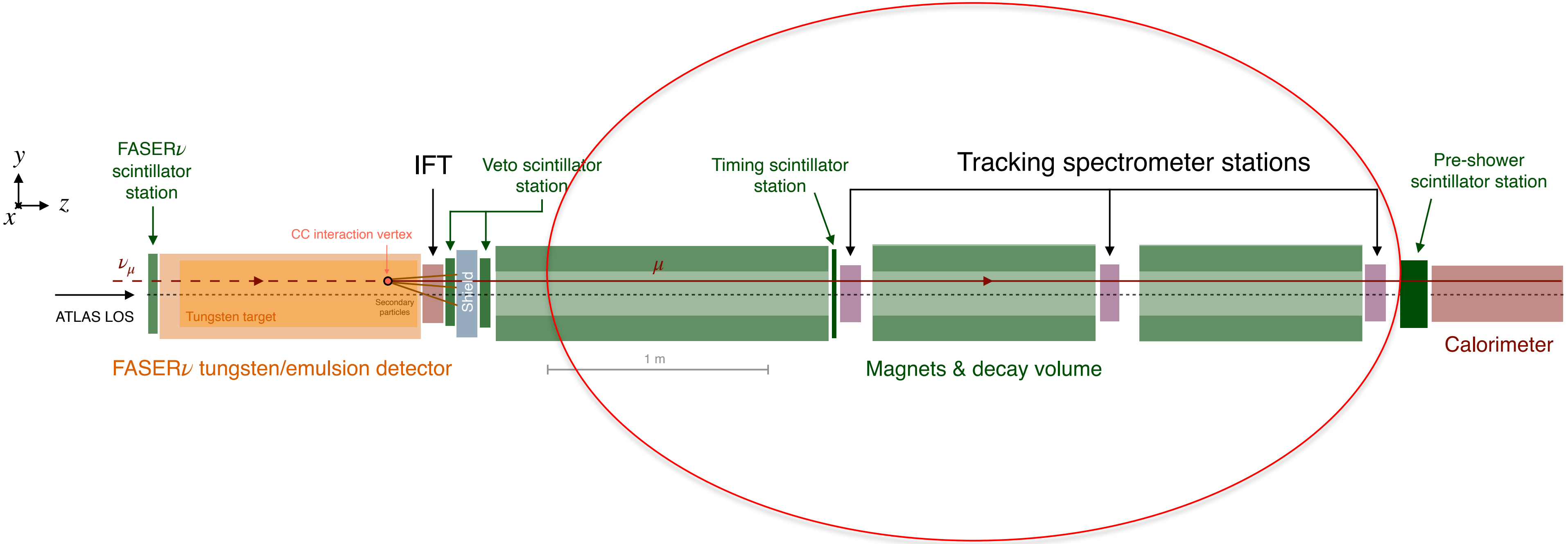
- MVA analysis based on kinematic variables

partially (12 events) unblinded:

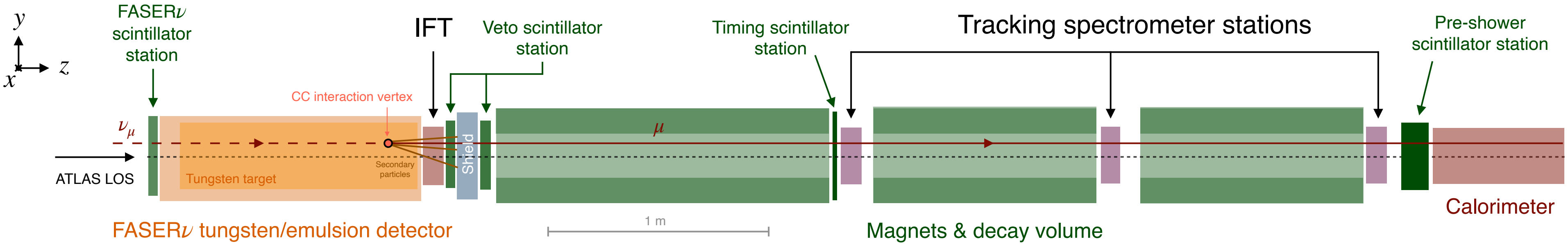


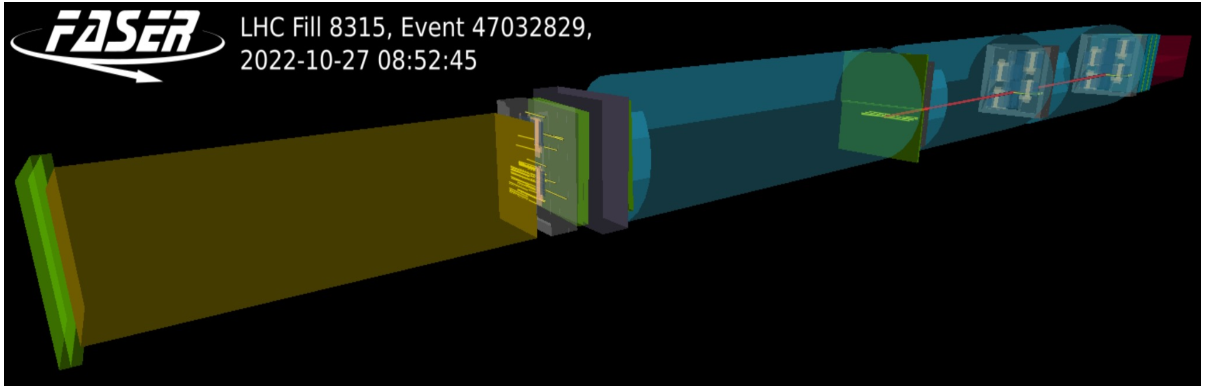
CERN-FASER-CONF-2026-003

Electronic spectrometer



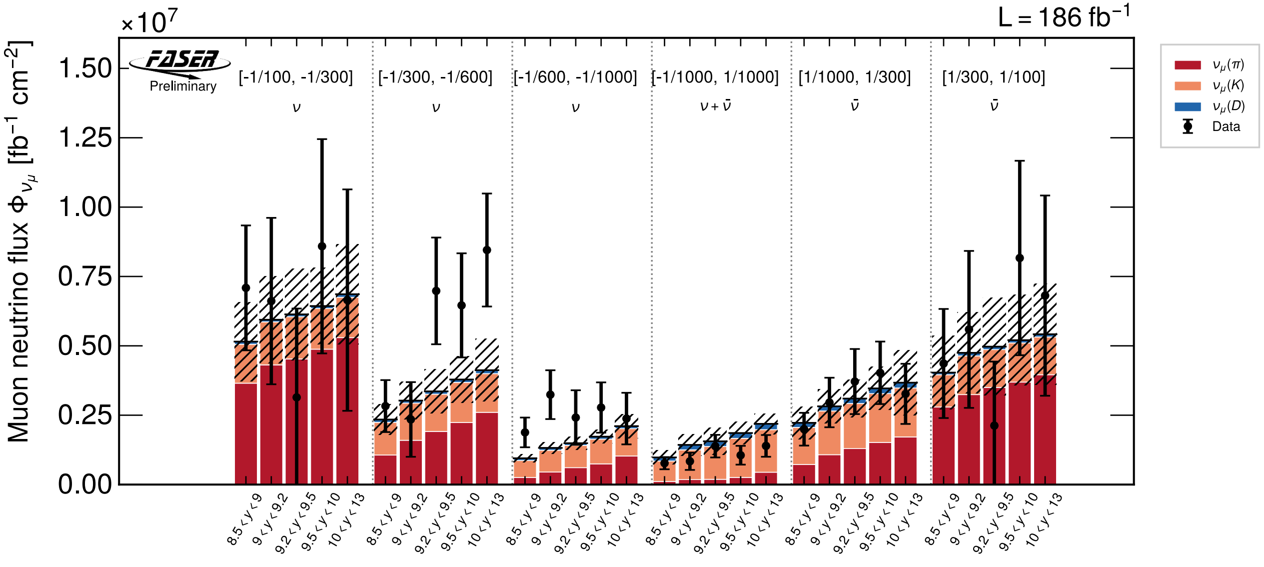
- ν_μ CC: muon appearance signature in electronic spectrometer using FASERν as tungsten target
  - No signal in FASERν scintillators
  - Exactly one good quality spectrometer track

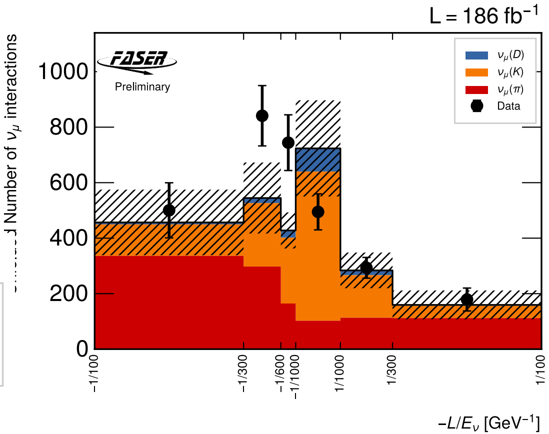


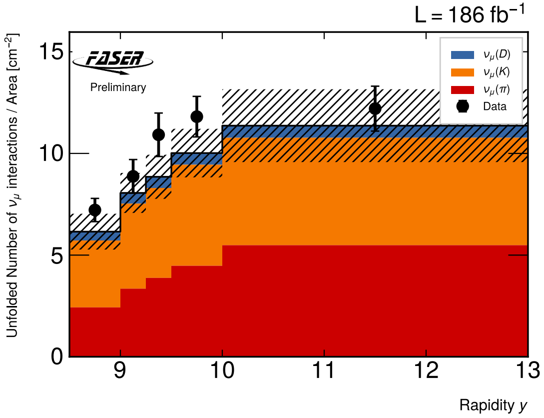


ν_μ CC double-differential measurement

- Updated with 2022-2024 data: 186 ± 4.1 fb^{-1} (2.8x)
- $766.8 \pm 28.7\,(\text{stat.}) \pm 7.3\,(\text{syst.})$ signals are observed
  - Small background: muons that miss the veto scintillators

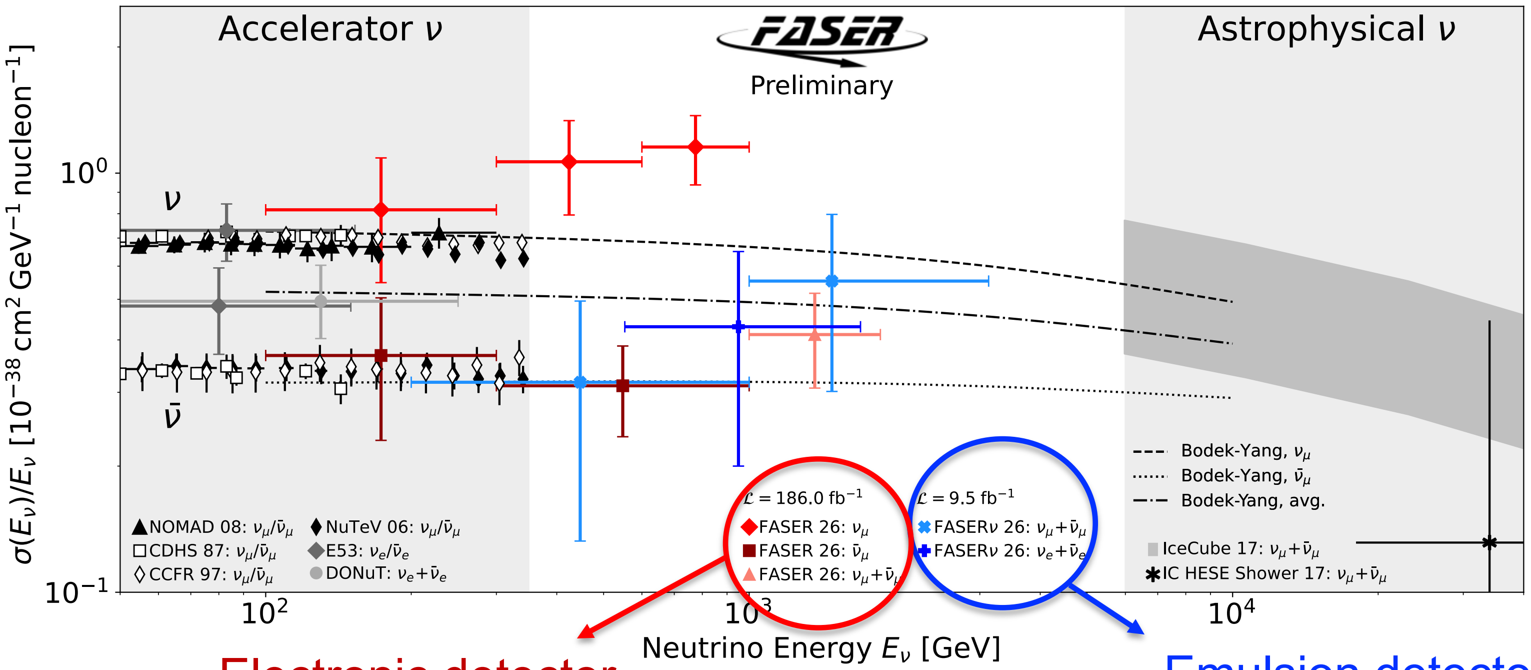






Differential cross-section

2026 New!



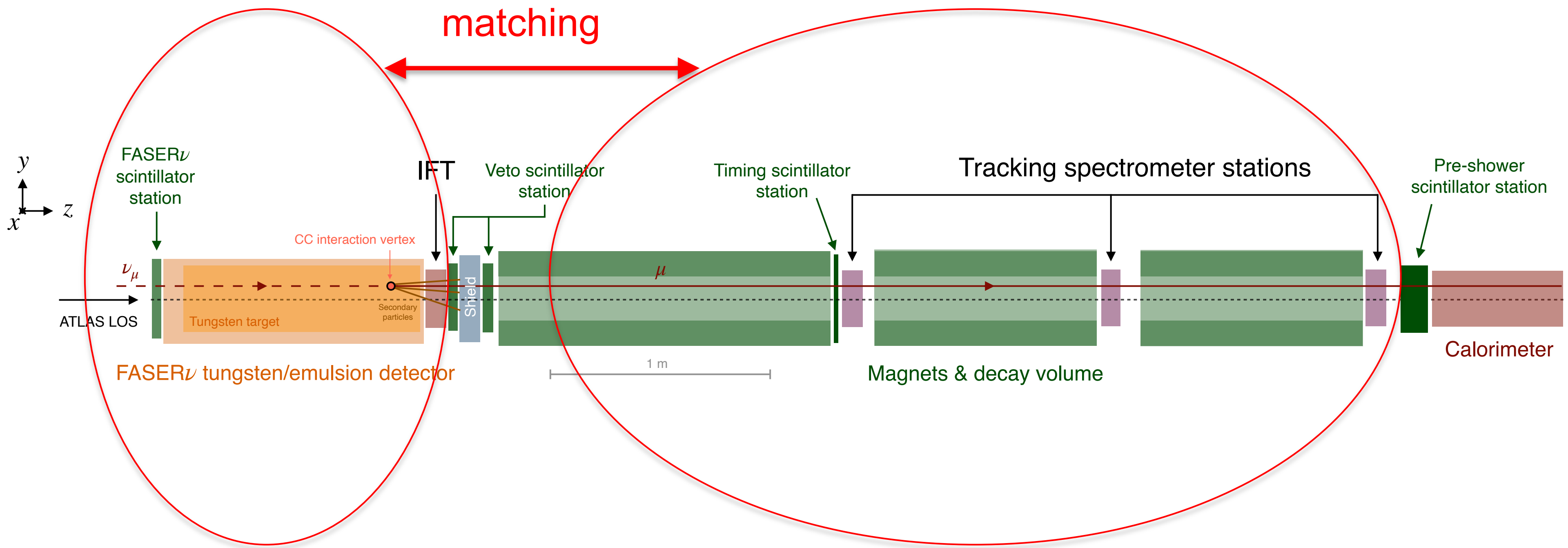
Electronic detector

Emulsion detector

CERN-FASER-CONF-2026-005

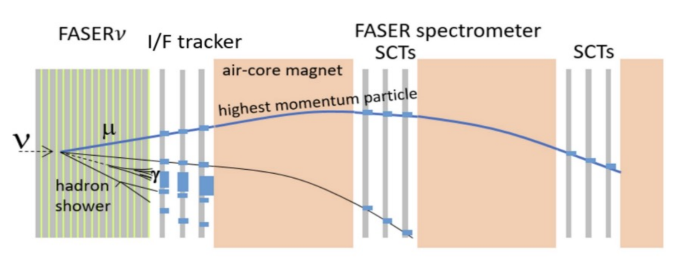
CERN-FASER-CONF-2026-002

Emulsion-spectrometer matching

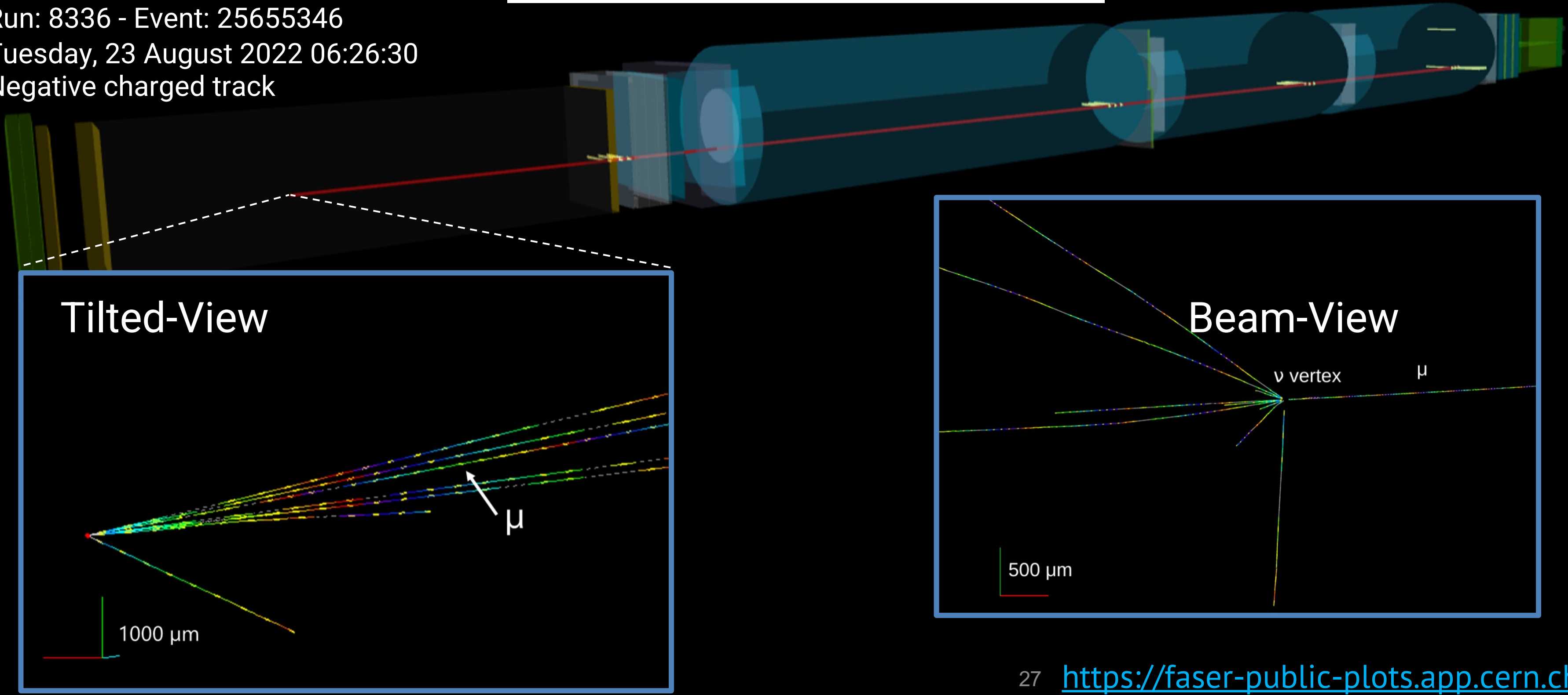


FASER

Preliminary

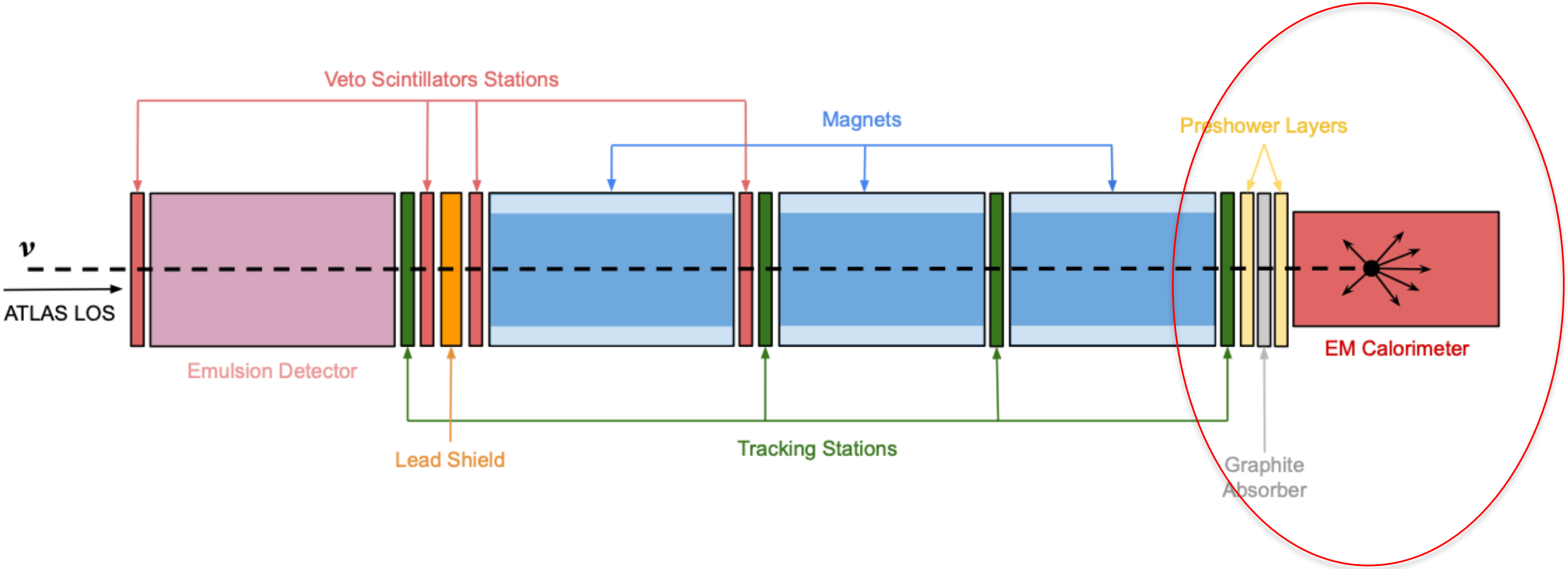


Run: 8336 - Event: 25655346
Tuesday, 23 August 2022 06:26:30
Negative charged track



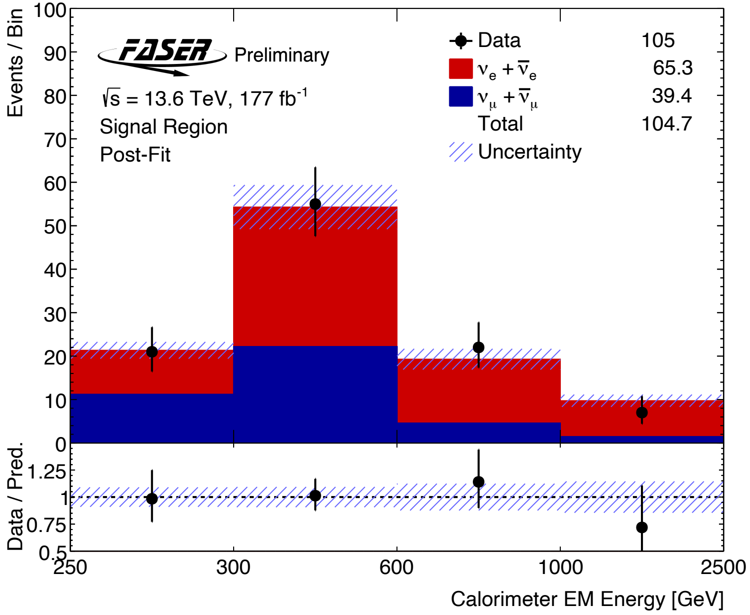
 https://faser-public-plots.app.cern.ch/

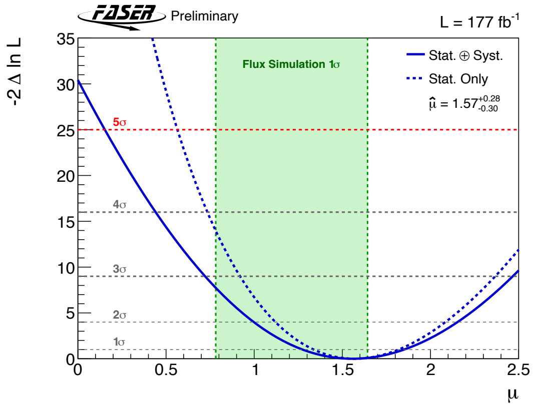
Calorimeter electron neutrinos



Calorimeter electron neutrinos

- Measurement of electron neutrinos interacting in EM calorimeter
- Main background: muon neutrinos
  - Extrapolate from ν_μ differential measurement to constrain uncertainty





Observation (5.5σ)

65.3 ν_e (CC + NC) in the EM calorimeter

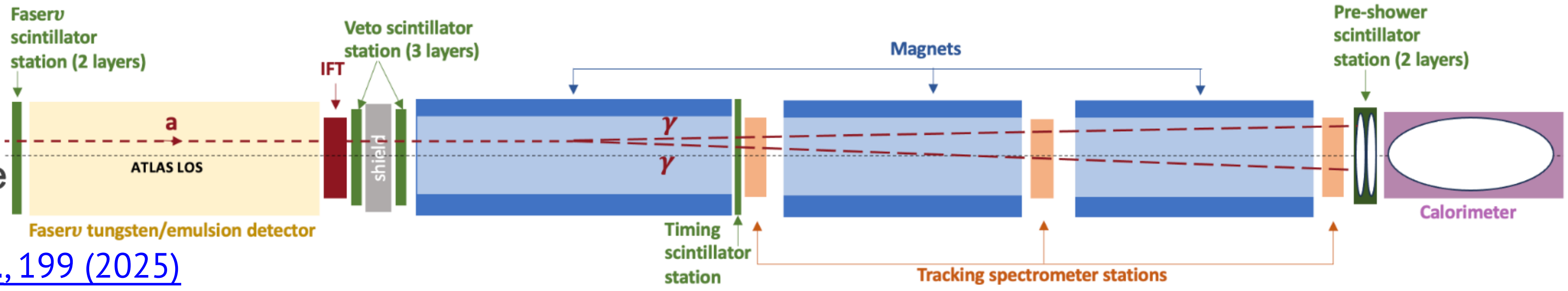
Highest energy event E= 2.1 TeV

Key milestone towards energy-dependent differential cross-section measurements for ν_e and important background to BSM searches

CERN-FASER-CONF-2026-004

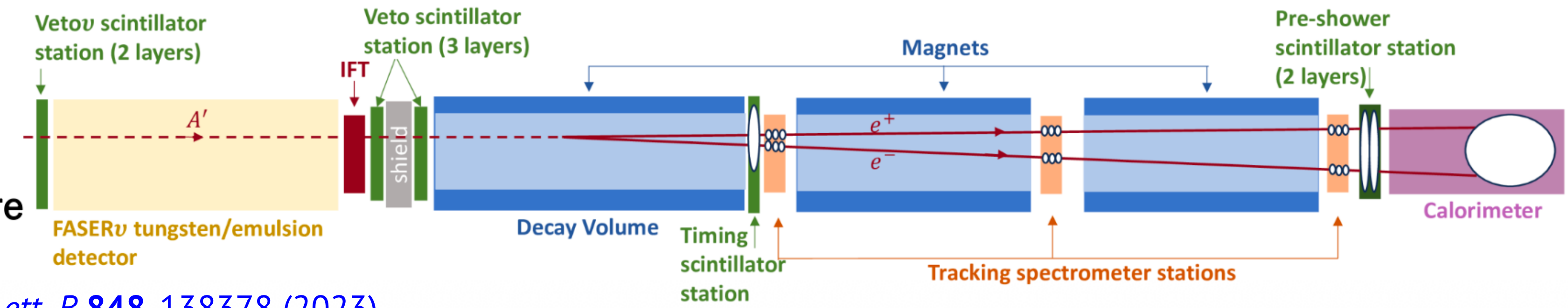
BSM searches

ALP-like signature



[JHEP **01**, 199 (2025)]

Dark photon signature

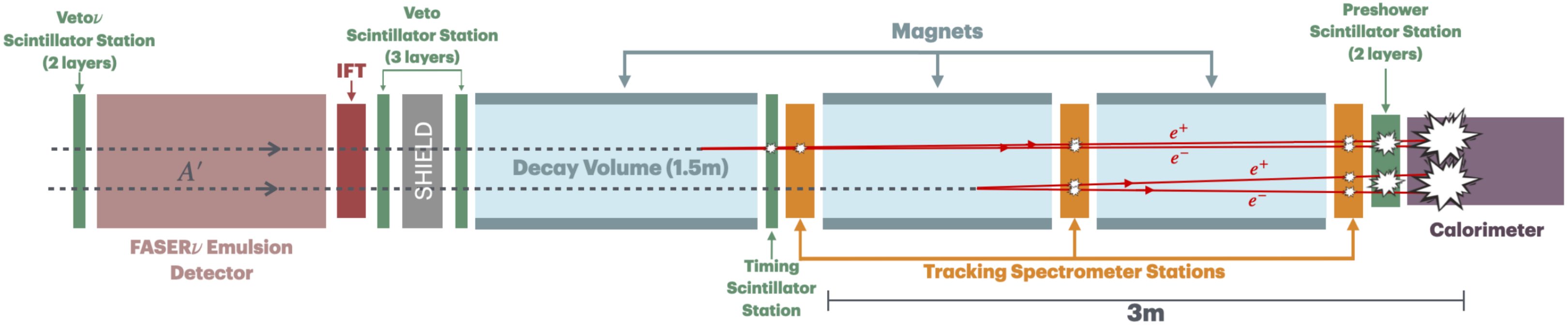


[Phys. Lett. B **848**, 138378 (2023)]

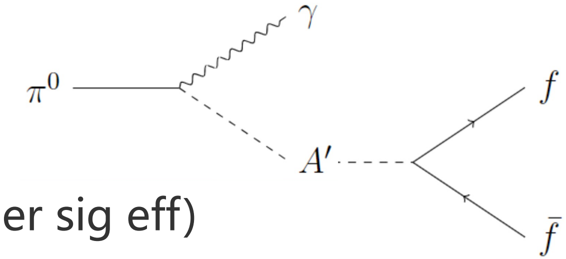
*Detector shown in 2022-24 configuration. In 2025 we added a new pixel based preshower to help separate closely spaced photons.

Newly updated results in next page

New results from dark photons searches



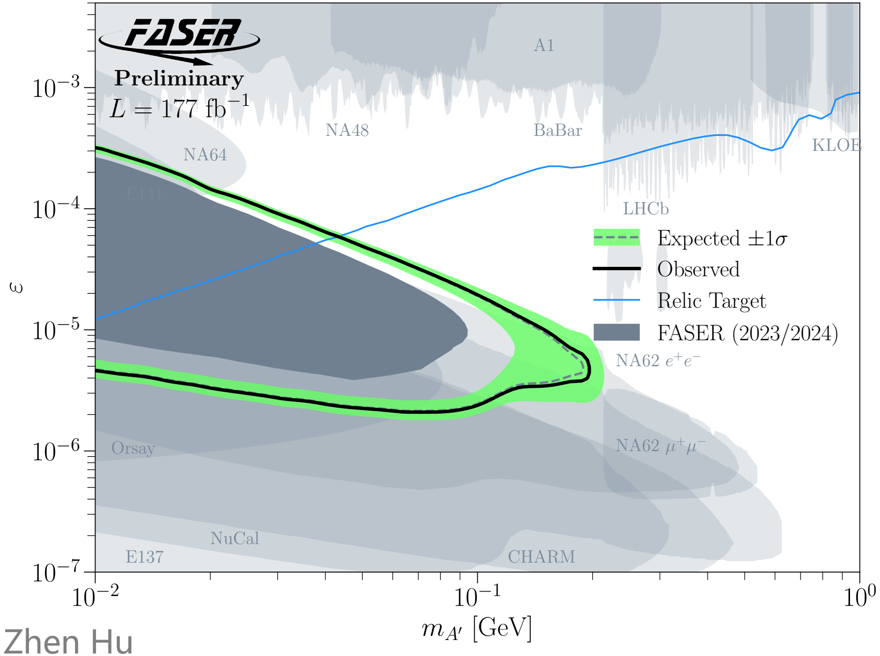
- New analysis with 2022-2024 data (6.5x more data)
  - Long-lived A’ produced in light meson decays at the IP

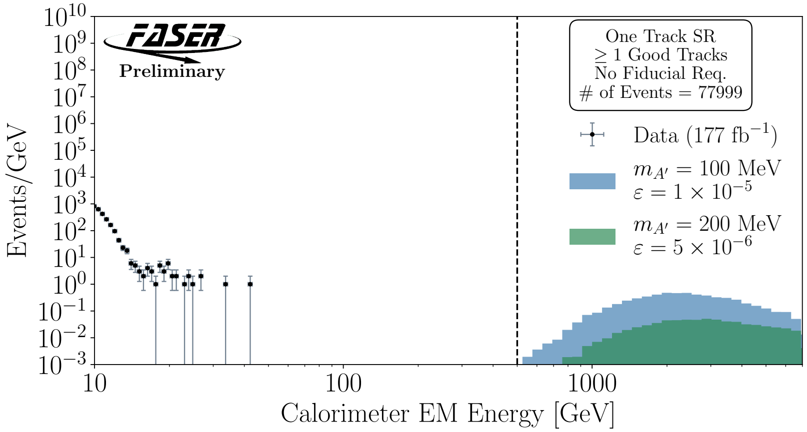


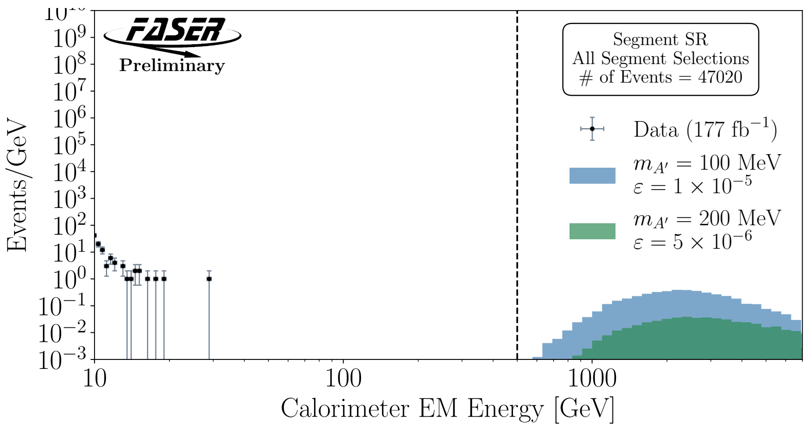
- New signal regions:
  - **≥1 track,** or **≥2 track segments** in station 2(3) (2.5x higher sig eff)
- Small background from neutrinos:
  - **≥1 track**: $0.050^{+0.024}_{-0.039}$ bkg events in SR
  - **≥2 track segments**: 0.025 ± 0.014 bkg events in SR
  - Other backgrounds negligible: muons missing the vetos, neutral hadrons, veto inefficiencies, non-collision backgrounds, beam backgrounds ……

New results from dark photons searches

- First update to dark photon search since **2023**
  - **0 events** observed in all SRs
  - New world-leading constraints on dark photons with mass ~10 MeV-150 MeV and $\varepsilon \sim 10^{-5}$-10^{-4}







CERN-FASER-CONF-2026-001

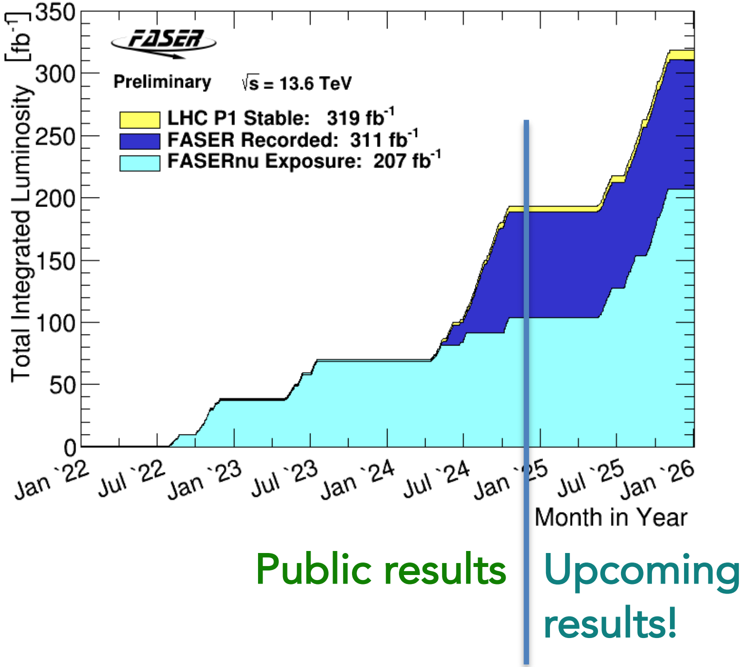
Outlook

- Fruitful new results covering FASER neutrino and BSM studies
  - 5 new conf notes for Moriond 2026 (4 on neutrino and 1 on dark photon)

  https://faser.web.cern.ch/briefings

- New signatures and analysis techniques
- Today: 311 fb^{-1} data recorded (2022-2025)
  - 207 fb^{-1} with emulsion detector

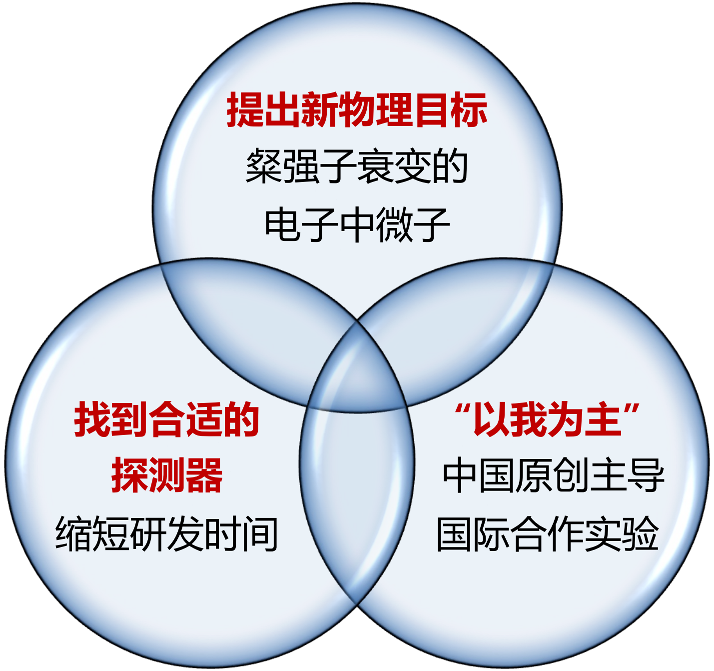
  (95% of emulsion data to be analyzed)
  - Upgraded preshower from 2025 onwards



FASER升级新项目

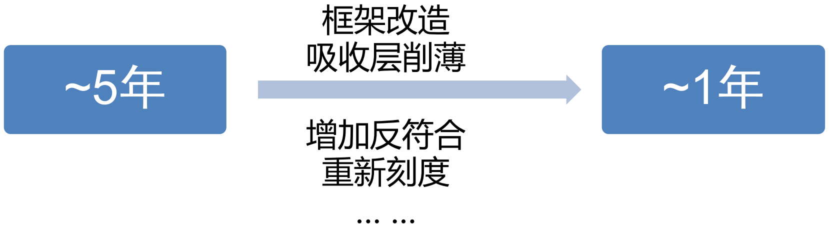
- FASER已经成功运行5年
  - 困境：核乳胶探测器（离线）不适应高亮度
- **新技术升级**迫在眉睫
  - 美国：SOLE
  - 英国：FASERνSi
  - 德国：GridPix
- 新升级方案

“离轴探测器AHCAL”



离轴探测器AHCAL

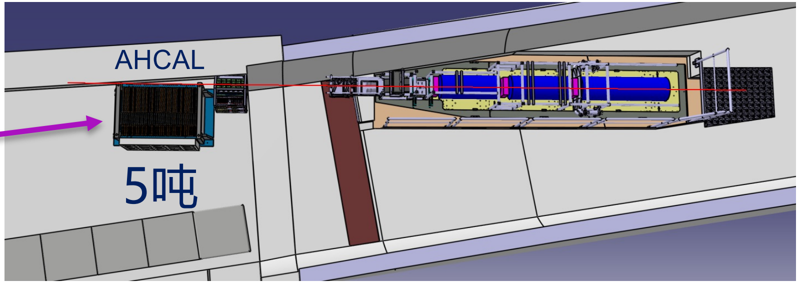
- 2026年是LHC三期取数最后一年
  - **只剩一年的时间窗口**
  - 其他方案都来不及
- AHCAL：高粒度铁-闪烁体成像型强子量能器
  - **中国（中科大、上交大、高能所等）自研的原理样机**
  - **大幅缩短**探测器研发周期，但仍面临许多挑战

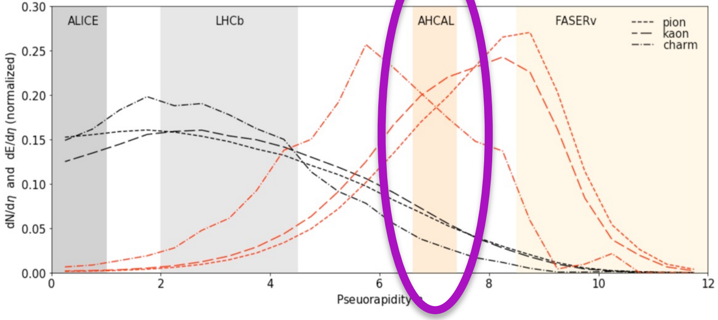


  - 2026年取数，预计2027年取得物理成果！

离轴探测器AHCAL

- 有望首次探测粲强子衰变的ν_e
  - 摆放在**离轴**位置，η~7处**恰好有空间**
  - 首次测量粲衰变ν_e通量





地利

- **从储藏室走向世界前沿**
  - 为CEPC研发，新物理目标赋予其新生
  - 得到各方（探测器研发团队、FASER合作组）大力支持！
  - **预期之外的惊喜，是双赢的结果**

人和

物理目标

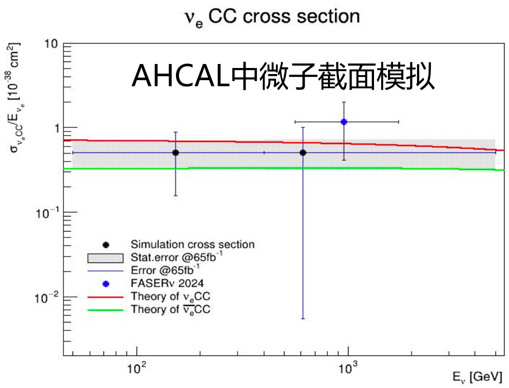
1. 有望**首次**在LHC上观测到粲衰变产生的电子中微子
   - **首次测量粲衰变 ν_e** 通量，验证标准模型

65 fb^{-1}	ν_e CC		ν_μ CC	ν_τ CC	NC
Off-axis	From light hadron	From charm hadron			
AHCAL	33.0 ± 0.46	84.3 ± 0.74	496.2 ± 1.8	7.56 ± 0.22	199.9 ± 1.1

仅用2026年数据有望探测到几十个事例

2. **提升**TeV能区**中微子截面**的精度和能量范围
   - 将截面不确定性**降低到70%以下**

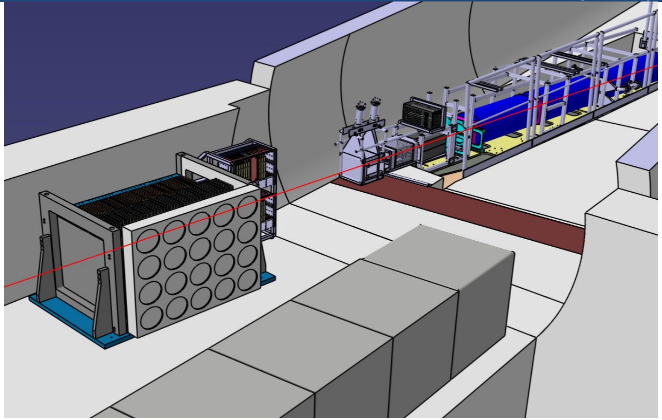
3. 将胶子PDF的约束范围**扩展至10^{-6}**
   - **完善**QCD，限制天体物理中微子通量
   - 对未来环形对撞机（SppC，FCC）的截面计算**至关重要**

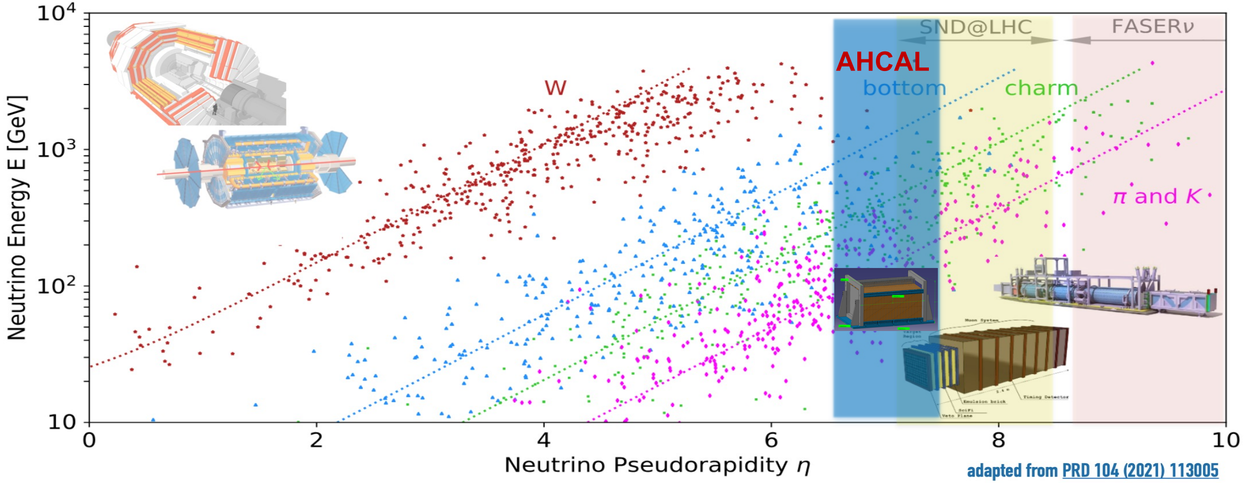


New detectors for 2026 and HL-LHC

- FASER has been **approved for Run 4 at the HL-LHC**
  - ✓ Several detector proposals under consideration, both on-axis and off-axis (arXiv:2503.19775)

- **2 prototypes (off-axis) for Run 4** are already installed and are **taking data now**!
  - ✓ **AHCAL** (prototype CEPC hadronic calorimeter)
  - ✓ **FASERCal** (based on T2K SuperFGD scintillating cubes)

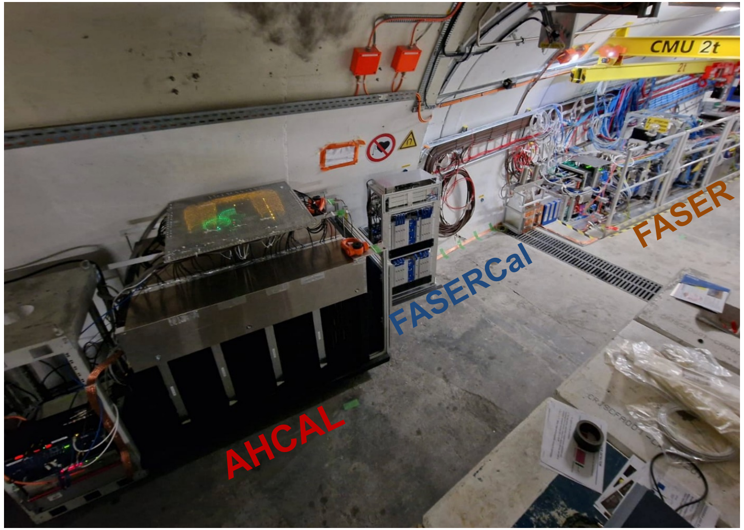




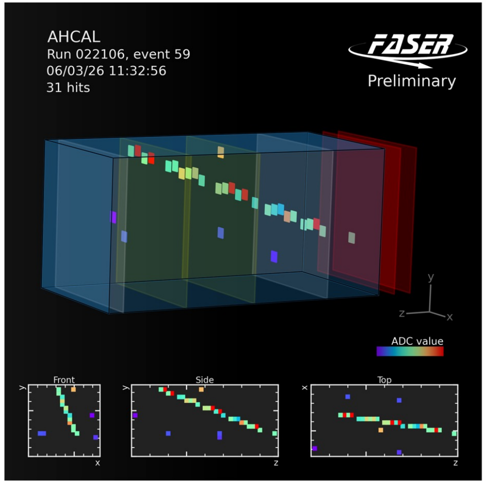
adapted from PRD 104 (2021) 113005

Looking forward ...

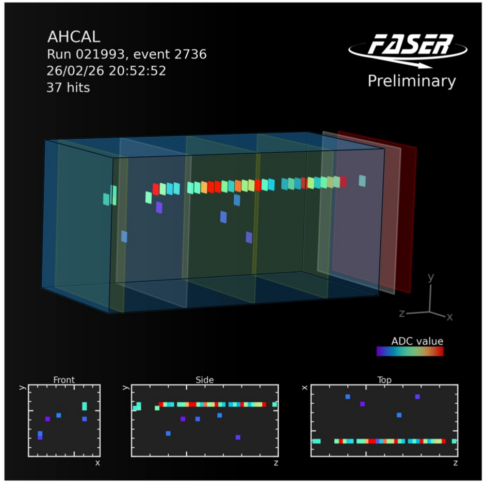
Successfully installed: 01/2026



a cosmic muon



first LHC muon



https://faser-public-plots.app.cern.ch/

- Many new results on the way with more Run 3 data!
- FASER upgrade will extend the neutrino & BSM programs to Run 4
  - Total Run 3 + Run 4 luminosity expected to exceed 1 ab^{-1}

STAY TUNED

Thank you!

FASER COLLABORATION

123 collaborators, 27 institutions, 11 countries

FASER is supported by:

We also thank:

- LHC for the excellent performance
- ATLAS Collaboration for providing luminosity information
- ATLAS SCT Collaboration for spare tracker modules
- ATLAS for the use of their ATHENA software framework
- LHCb Collaboration for spare ECAL modules
- CERN FLUKA team for the background simulation
- CERN PBC and technical infrastructure groups for the excellent support

BACKUP

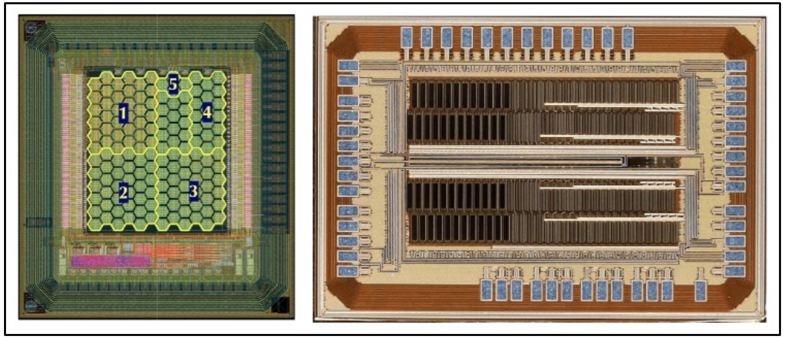
https://faser.web.cern.ch/briefings

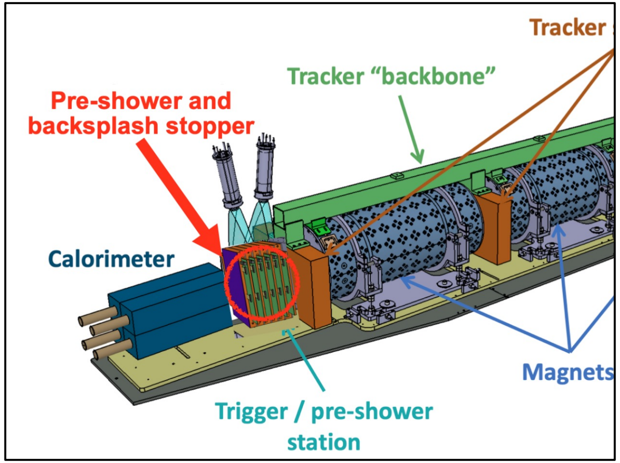
arxiv:2602.17575	ν_μ energy reconstruction
CERN-FASER-CONF-2026-001	Search for dark photons
CERN-FASER-CONF-2026-002	Neutrino cross section with emulsion data
CERN-FASER-CONF-2026-003	Search for neutrino-induced charm hadrons
CERN-FASER-CONF-2026-004	ν_e in calorimeter
CERN-FASER-CONF-2026-005	ν_μ in spectrometer
https://faser-public-plots.app.cern.ch/	AHCAL; Emulsion-spectrometer matching

Preshower upgrade

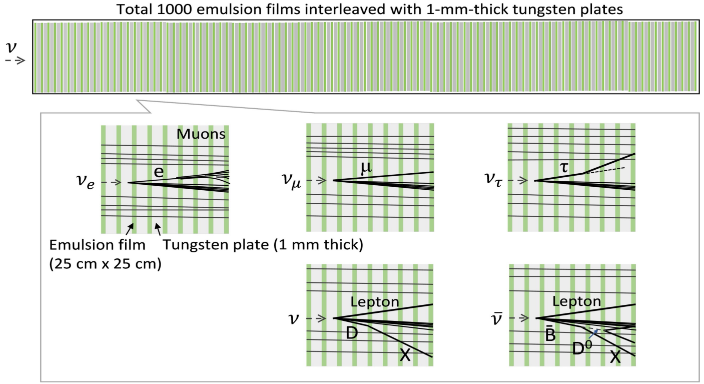
CERN-LHCC-2022-006

- ALPs decays to 2 photons generally separated by < 1 mm
  → cannot be resolved in current detector.
- **Preshower upgrade:**
  - Layers of monolithic silicon pixel detectors (high-granularity hexagonal pixels) with tungsten absorber
  - Identify photons separated by ~200 μm
  - Installed in February 2025

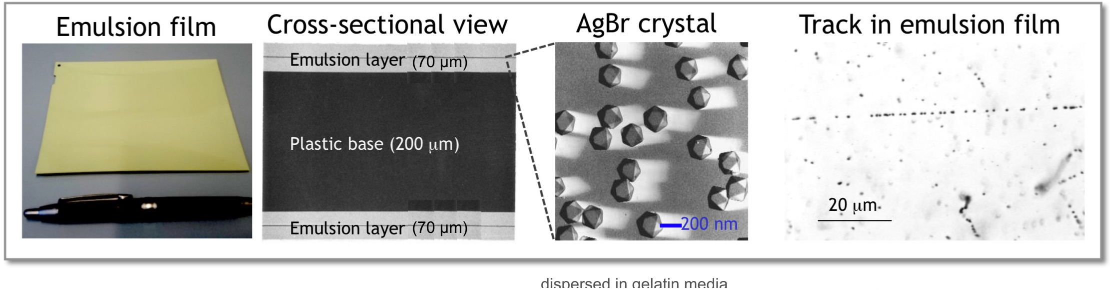


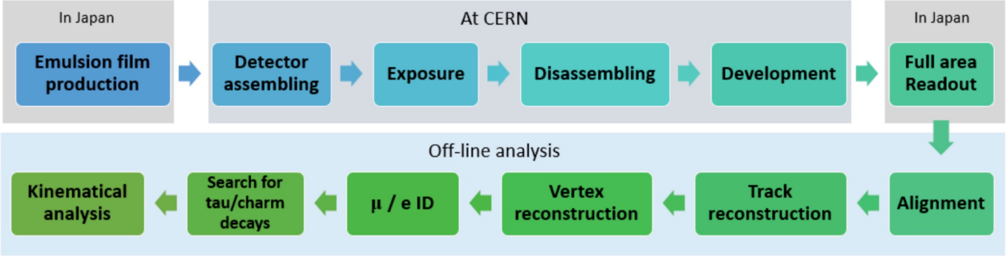


FASERν detector



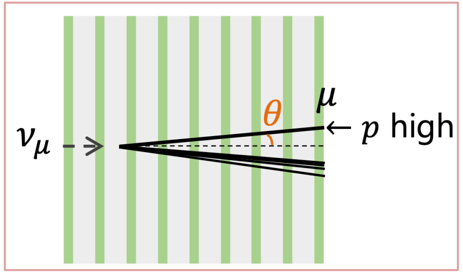
- FASERν: tungsten emulsion detector
  - 3D tracking detector, 50 nm precision, no timing
    – Total mass 1.2 tons, 285 X_0, 10.1 λ_{int}
- Needs to be exchanged every ~3 months (during technical stops) to control track density $\lesssim 1\times10^6$ tracks/cm^3
  – 10 emulsion detectors in total needed for 2021-2024 data

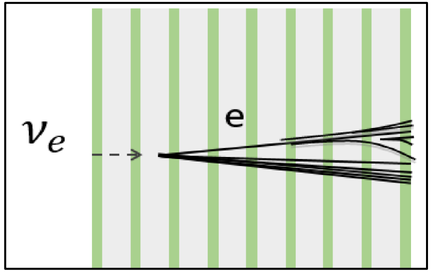


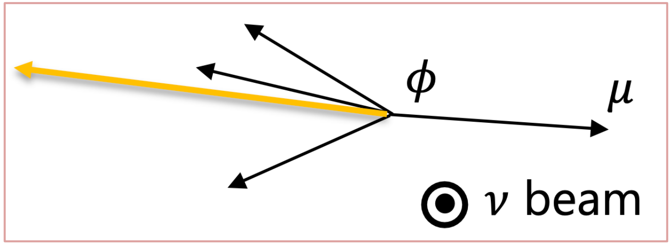


FASERν analysis

- CC neutrino candidates selected from vertices with at least 5 tracks:
  - **Electrons:** short track, EM shower
  - **Muons**: long track (>100 layers), no secondary particles
- Large angular separation between lepton and CC remnants.





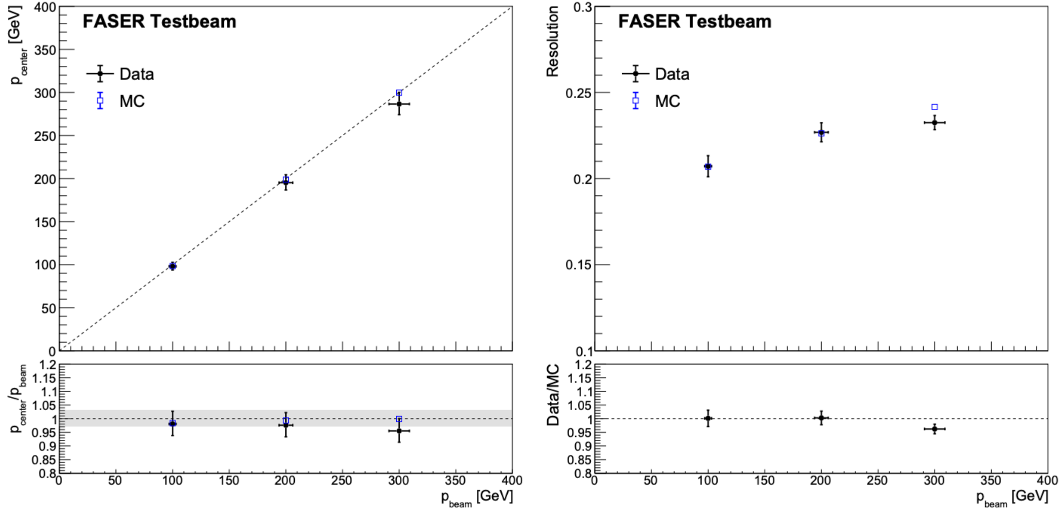


High purity selection
Vertex reconstruction ($N_{track} \geq 5$, $N_{track}(\tan\theta \leq 0.1) \geq 4$)
E_e or p_μ >200 GeV
$\tan\theta_e$ or $\tan\theta_\mu$ >0.005
ϕ>90°

CERN-FASER-CONF-2026-002

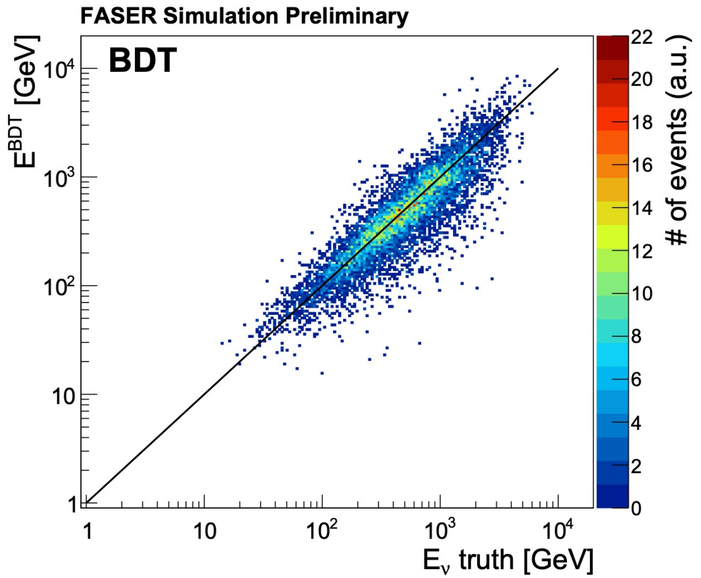
Neutrino energy reconstruction

- Muon momentum measurement
  - Using multiple coulomb scattering (MCS)
  - Validated in testbeam：



20-23% resolution for 100~300 GeV

- New neutrino energy reconstruction in ν_μ events
  - Using a regression BDT

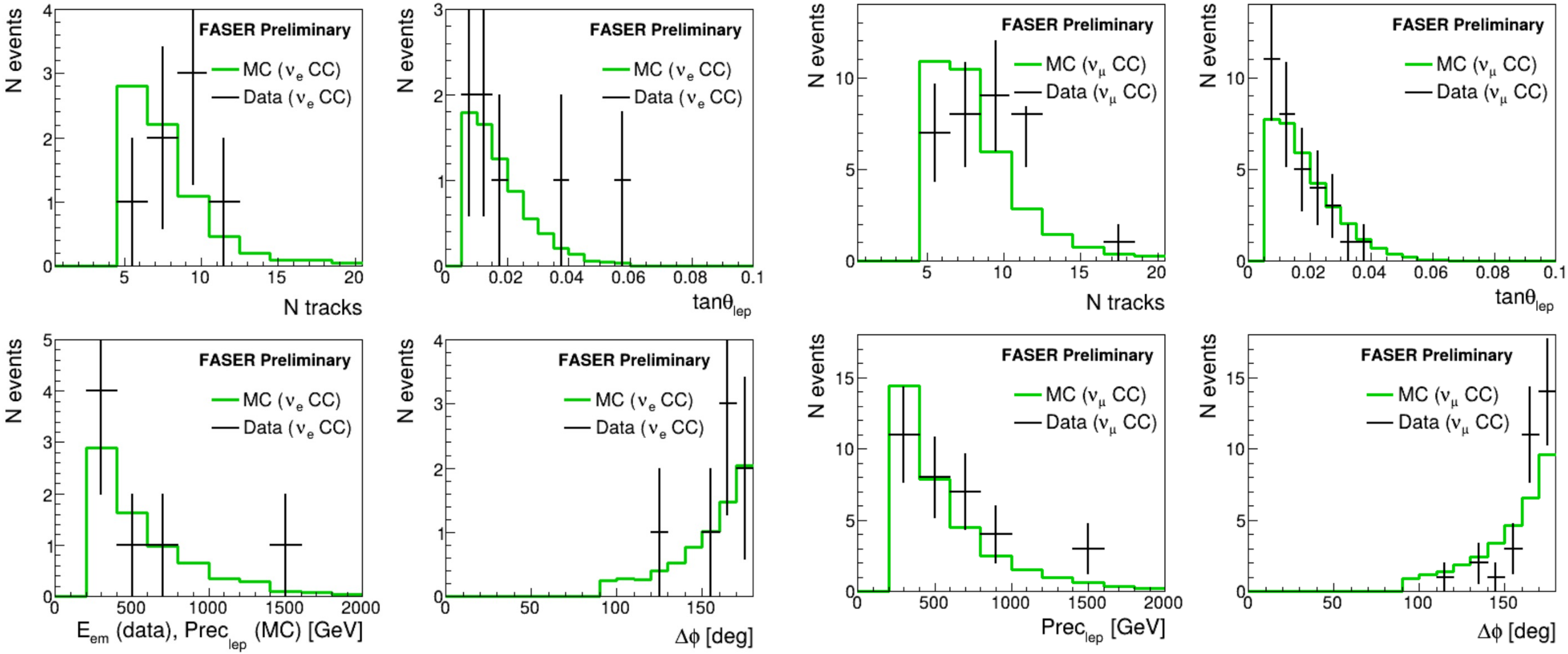


20 - 30% below 1 TeV
30 - 40% above 1 TeV

arxiv:2602.17575

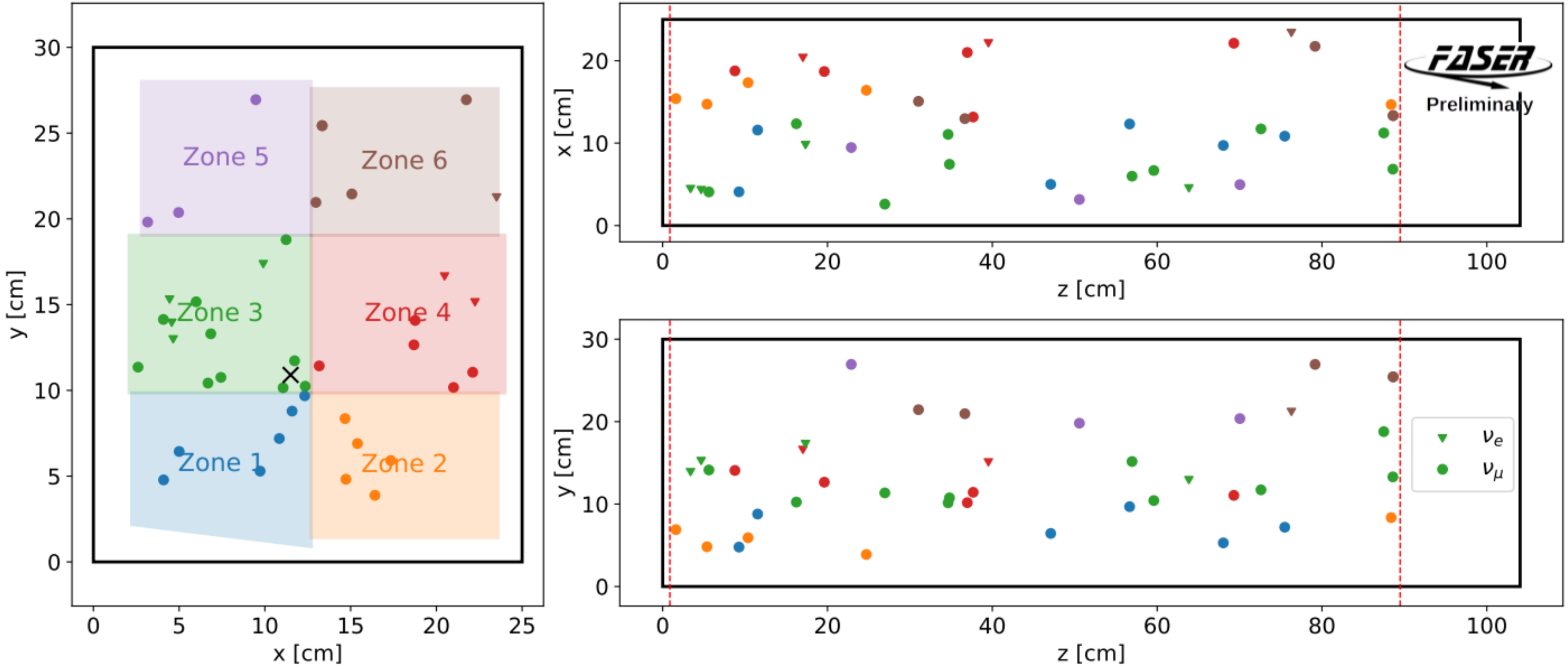
Zhen Hu

FASERν analysis



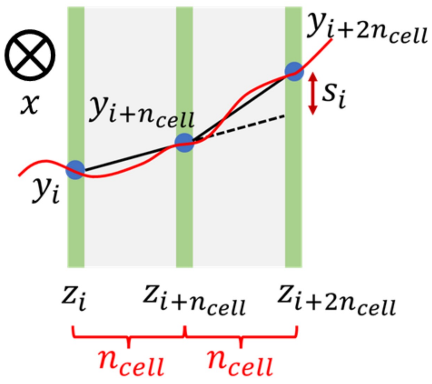
CERN-FASER-CONF-2026-002

FASERν analysis

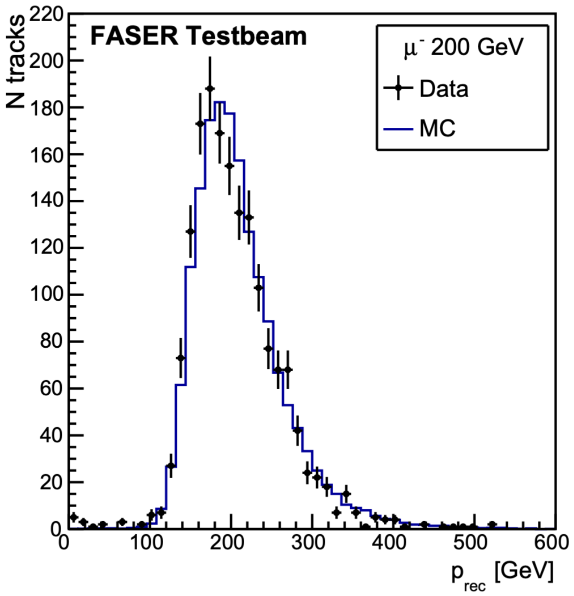


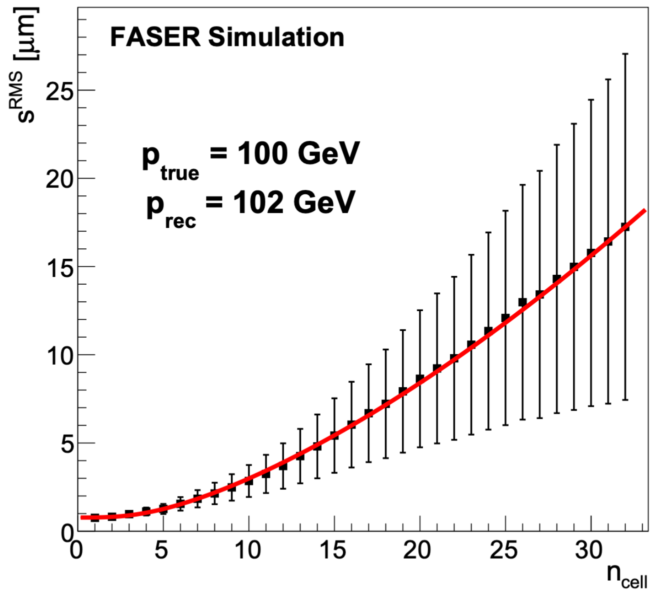
CERN-FASER-CONF-2026-002

FASERν muon momentum reconstruction



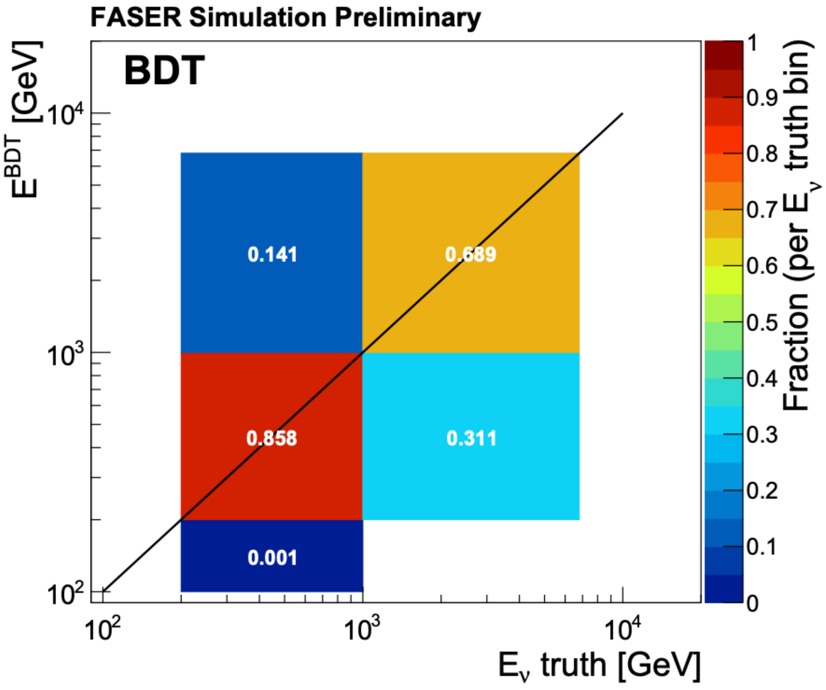
$$\theta_{\text{plane}}^{\text{RMS}} = \frac{0.0136\ \text{GeV}}{\beta p c}\sqrt{\frac{z}{X_0}}\left\{1 + 0.038\ln\left(\frac{z}{X_0\beta^2}\right)\right\}$$

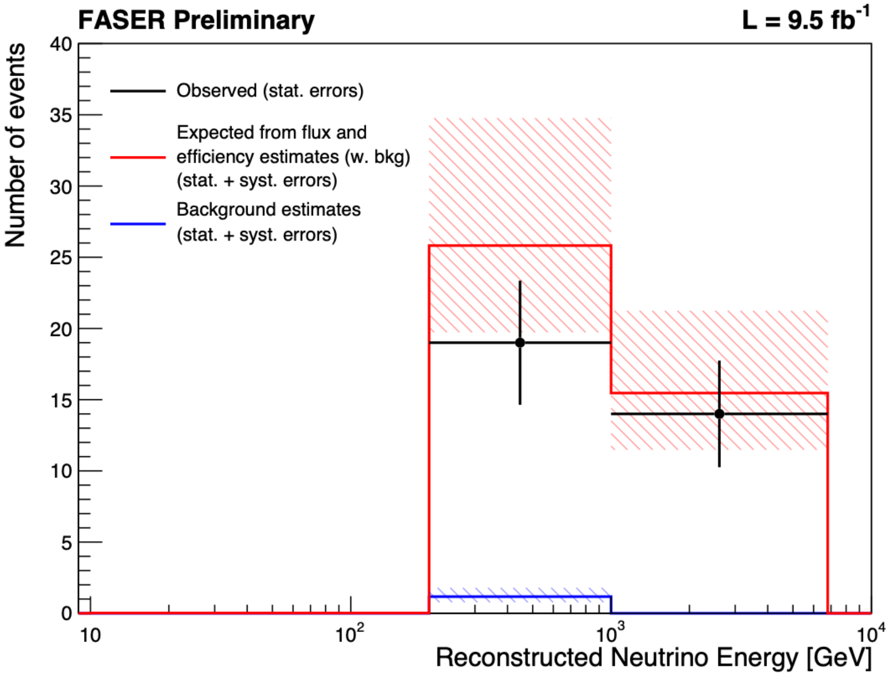




arxiv:2602.17575

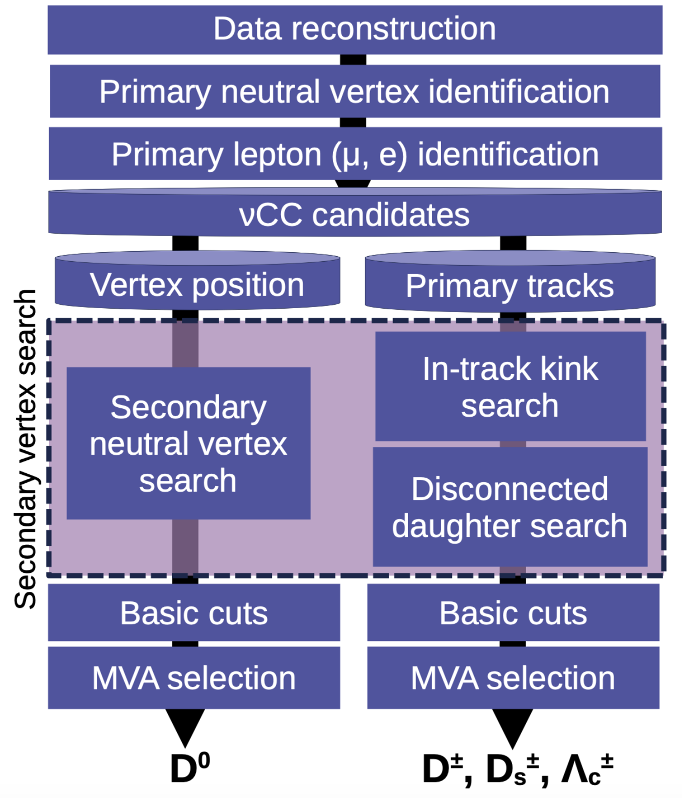
FASERν differential cross section

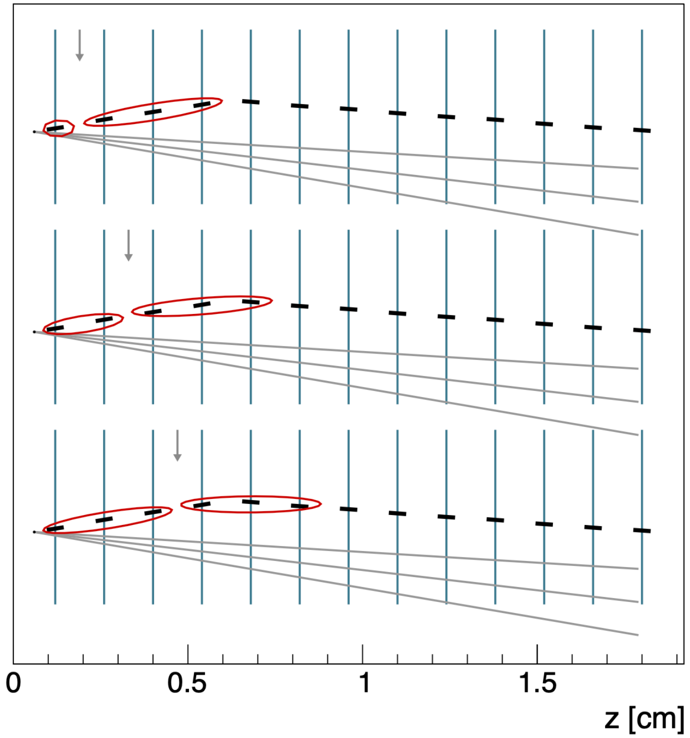




CERN-FASER-CONF-2026-002

Search for associated charm production





CERN-FASER-CONF-2026-003

Search for associated charm production

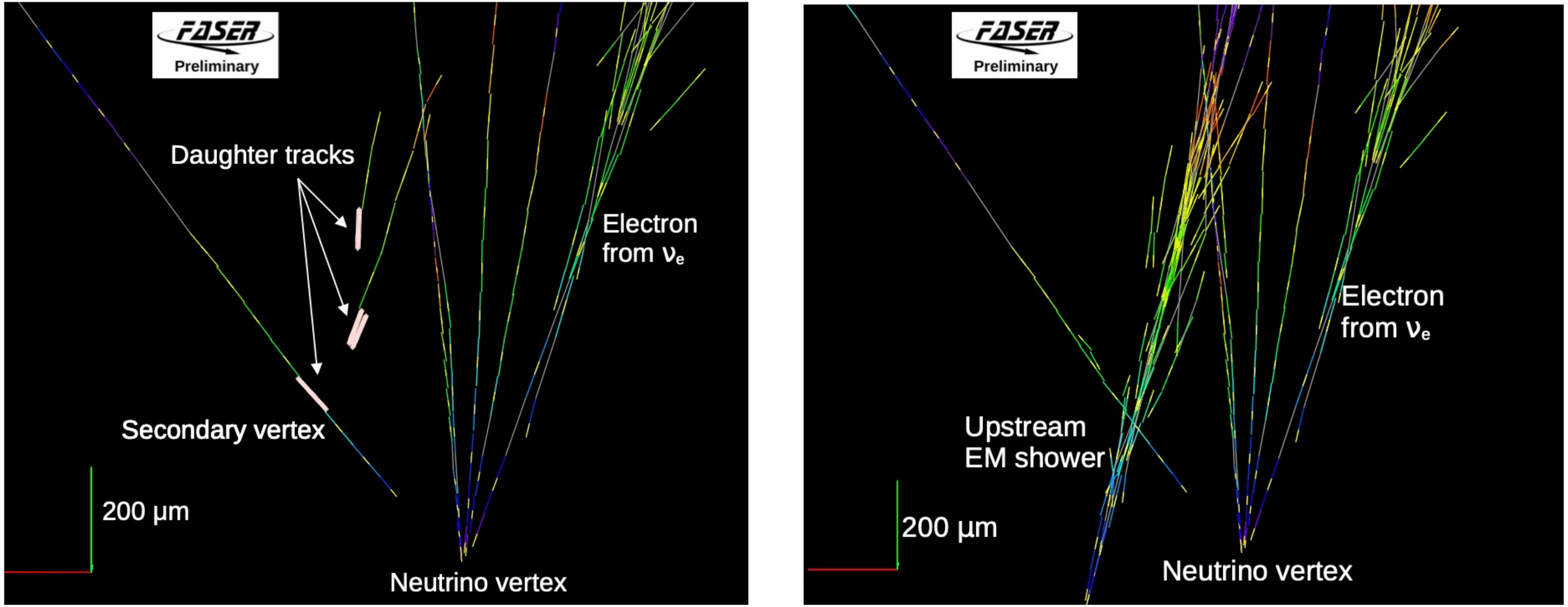


FIG. 15. Event display with a tilted view of the candidate with the highest MVA score (0.87) among the secondary vertices from the neutrino candidates in Ref. [29]. Left: the primary neutrino vertex and its primaries, and the secondary vertex and the daughter tracks found by the secondary vertex search, where the first segment of each daughter track is highlighted. Right: the same event display with the upstream EM shower of which the disconnected daughters are a part of.

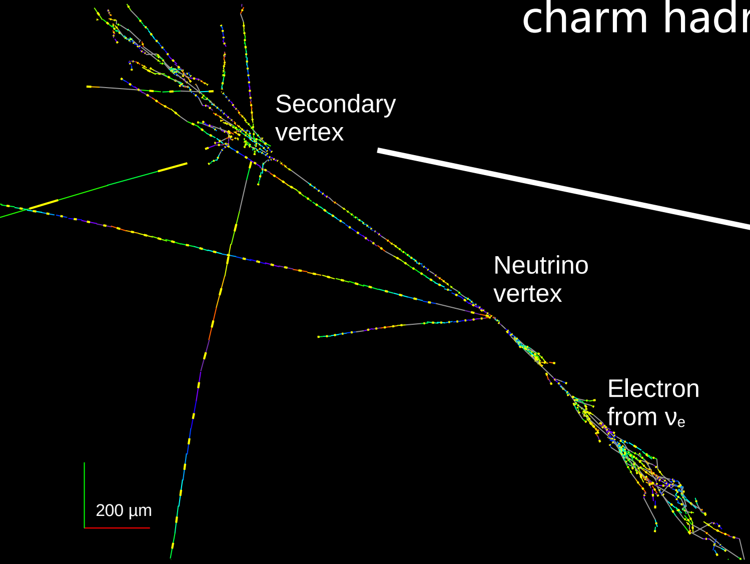
CERN-FASER-CONF-2026-003

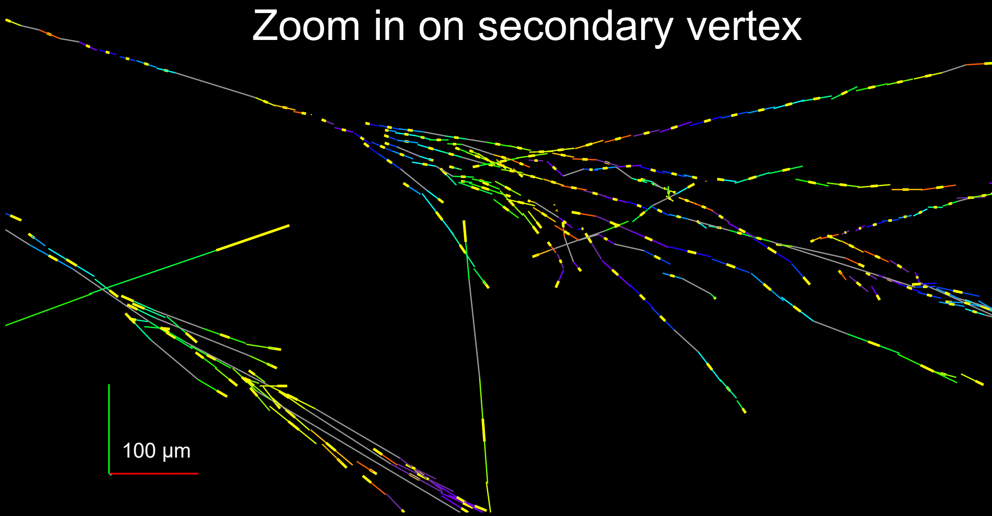
Search for associated charm production

FASER Preliminary

The candidate with the 2nd highest MVA score (0.67):

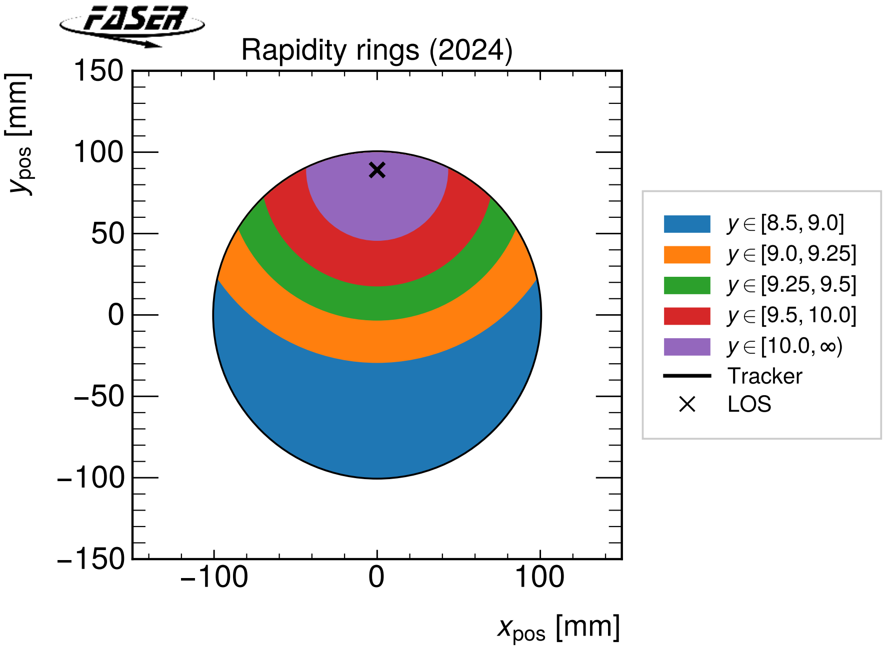
charm hadron decay or hadronic interaction

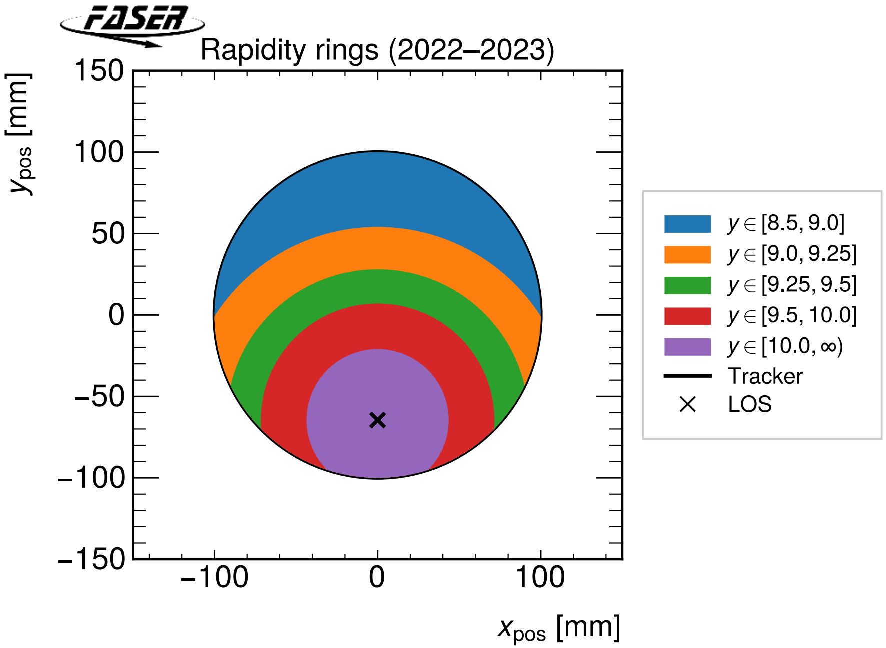




CERN-FASER-CONF-2026-003

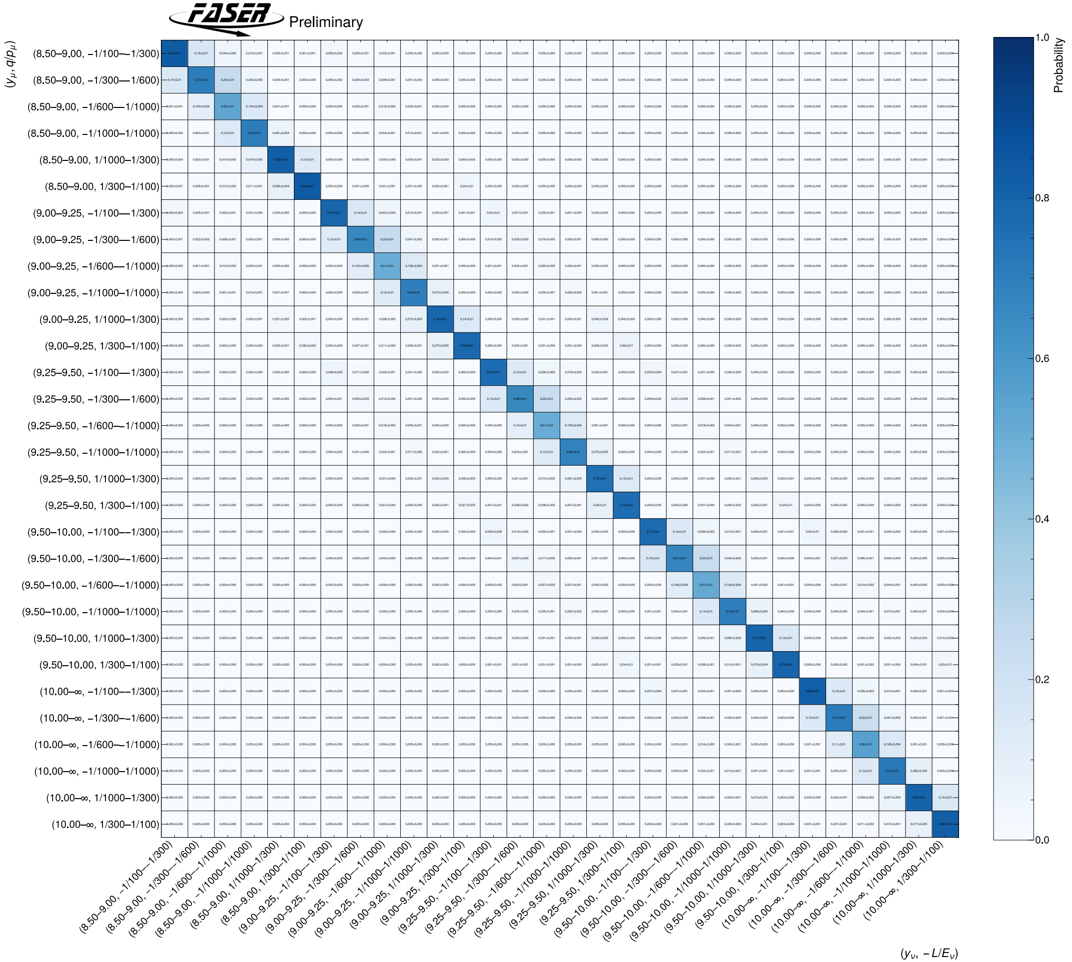
ν_μ differential measurement

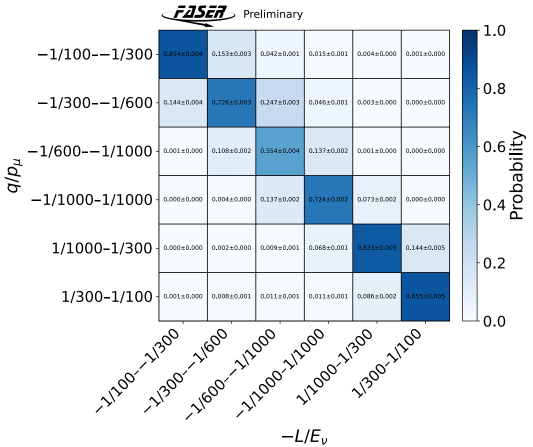


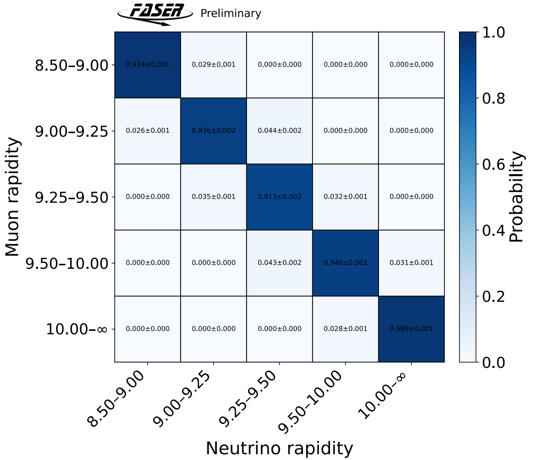


CERN-FASER-CONF-2026-005

ν_μ differential measurement



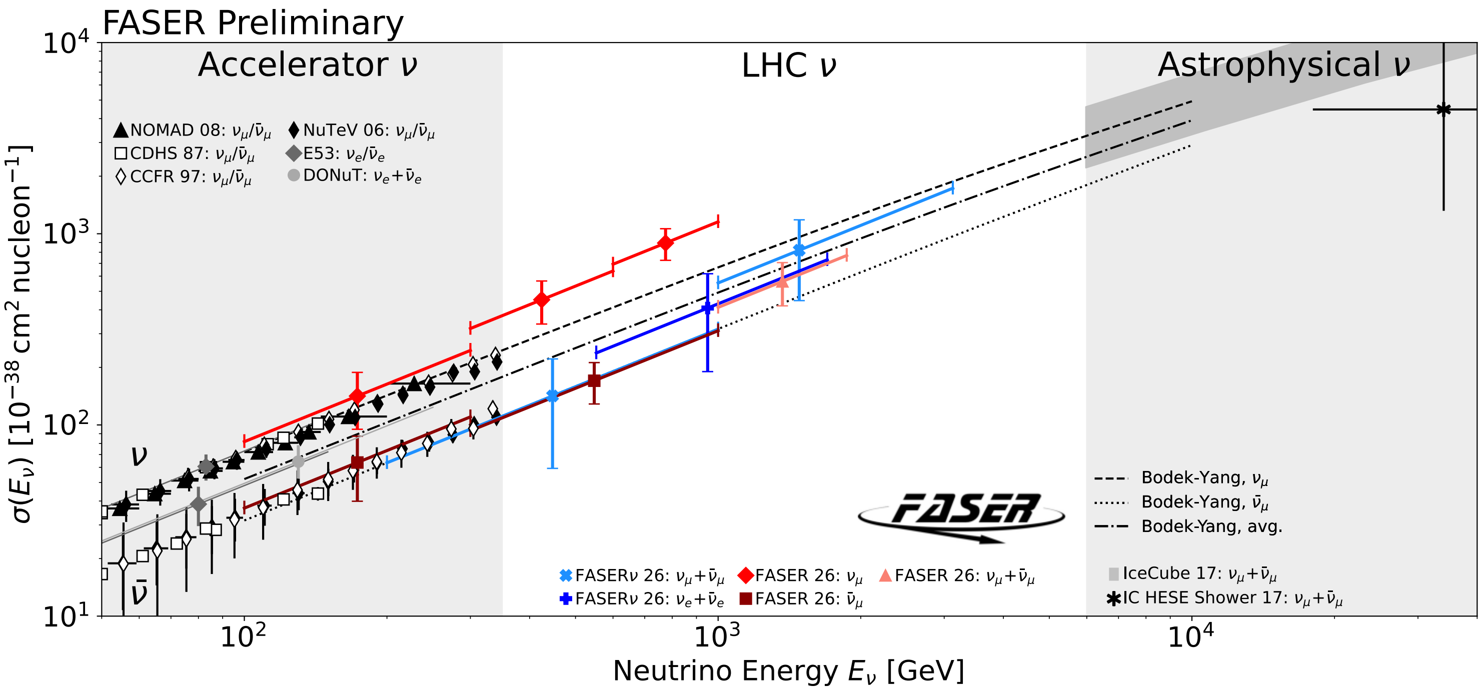




CERN-FASER-CONF-2026-005

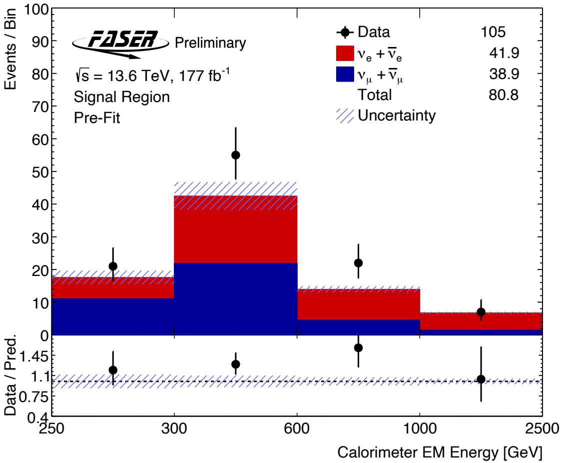
Differential cross-section

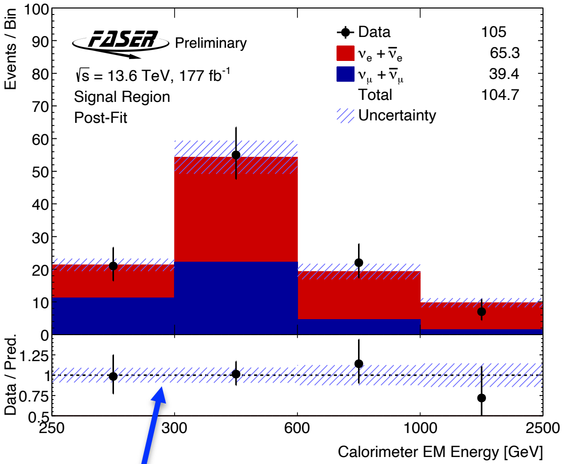
$$\Phi_l = \frac{n_{\nu,l}}{\sigma_{\text{eff},l} \cdot A_{\text{eff},l} \cdot n_t \cdot \int \mathcal{L}, dt} \qquad \sigma_l = \frac{n_{\nu,l}}{\Phi_{\text{sim},l} \cdot A_{\text{eff},l} \cdot n_t \cdot \int \mathcal{L}\, dt}$$

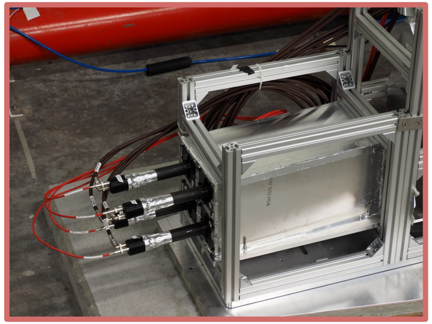


CERN-FASER-CONF-2026-005 CERN-FASER-CONF-2026-002

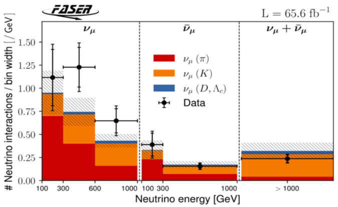
Calorimeter electron neutrinos





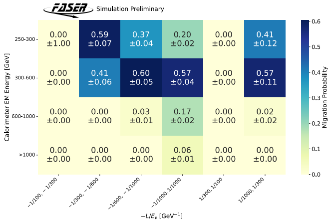


E_{Calo} [GeV]	[250-300]	[300-600]	[600-1000]	[+1000]	Total
$\nu_e + \bar{\nu}_e$	6.52 ± 3.32	20.62 ± 12.59	9.44 ± 7.01	5.32 ± 4.40	41.90 ± 27.32
$(\nu_\mu + \bar{\nu}_\mu)$ FV	9.85 ± 2.76	19.52 ± 4.97	3.94 ± 1.02	1.26 ± 0.32	34.57 ± 9.07
$(\nu_\mu + \bar{\nu}_\mu)$ Out-FV	1.11 ± 0.30	2.12 ± 0.54	0.52 ± 0.12	0.14 ± 0.03	3.89 ± 0.99
$\nu_\tau + \bar{\nu}_\tau$	0.10 ± 0.18	0.22 ± 0.37	0.04 ± 0.09	0.03 ± 0.04	0.40 ± 0.67
Signal $(\nu_e + \bar{\nu}_e)$	6.52 ± 3.32	20.62 ± 12.59	9.44 ± 7.01	5.32 ± 4.40	41.90 ± 27.32
Background	11.06 ± 2.78	21.87 ± 5.01	4.50 ± 1.03	1.43 ± 0.32	38.86 ± 9.15
Expected	17.58 ± 4.33	42.49 ± 13.55	13.94 ± 7.09	6.75 ± 4.41	80.76 ± 29.38
Observed	**21**	**55**	**22**	**7**	**105**



ν_μ CC interactions in bins of neutrino energy

×



Migration matrix: neutrino energy to calorimeter energy

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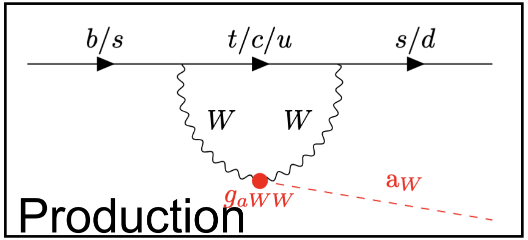
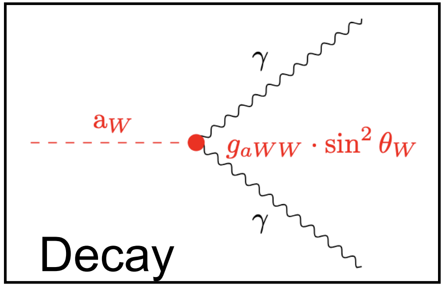
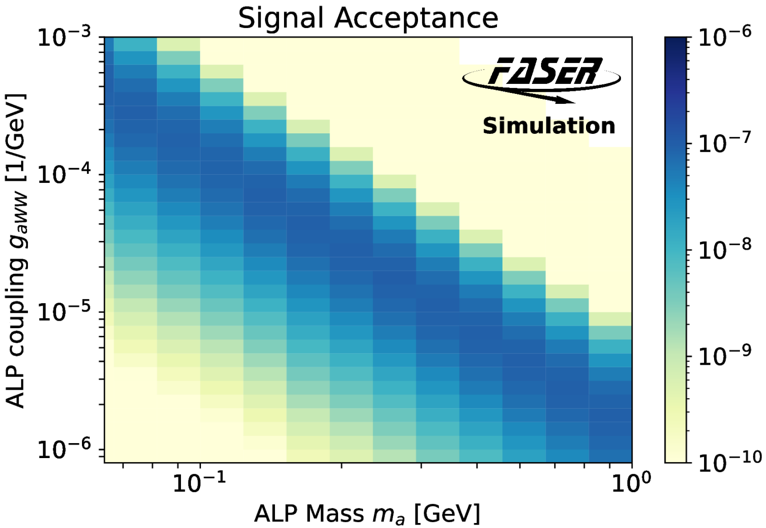
Axion Like Particles (ALPs)

- Search for a light pseudoscalar particle decaying to a pair of photons.
- ALPs reaching FASER have momentum up to TeVs.
- Using 58 fb^{-1} of 2022 + 2023 data.







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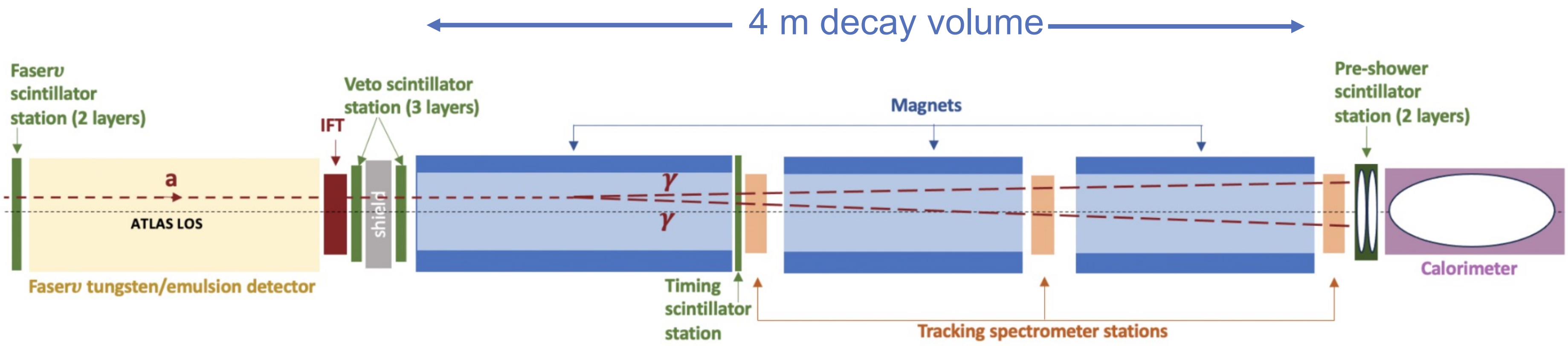
Axion Like Particles (ALPs)



No charge deposited in scintillators

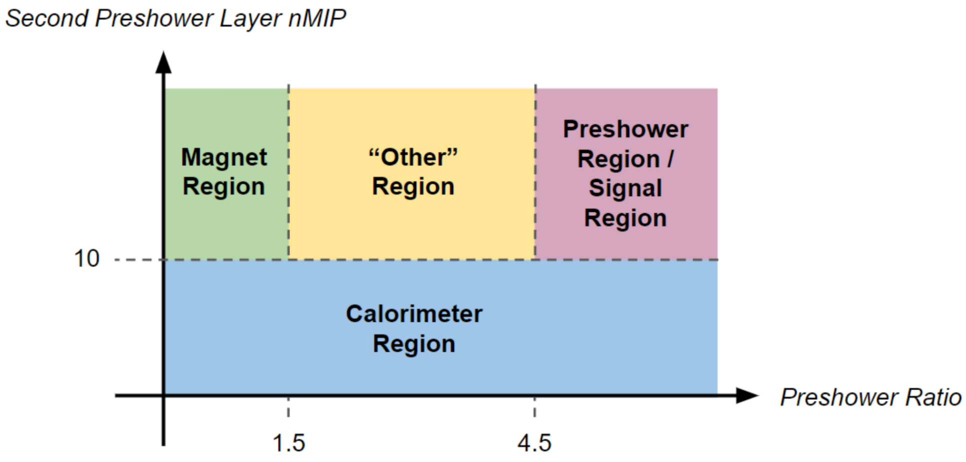
Decays to pair of photons

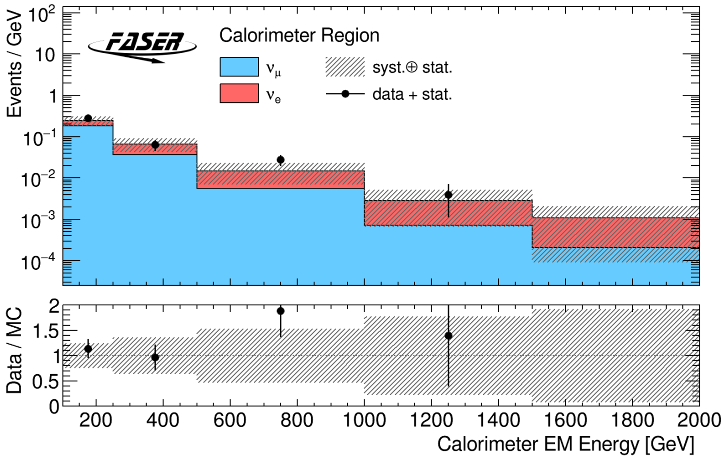
Preshower charge > 10 MIPs, ratio > 4.5

Calorimeter energy > 1.5 TeV

Axion Like Particles (ALPs)

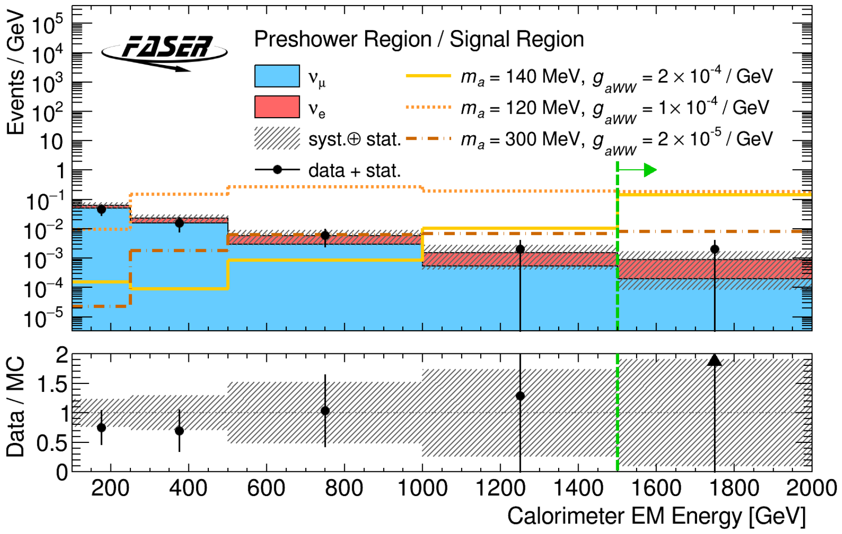
- Dominant background: neutrino interactions → 0.4 ± 0.4 events
- Negligible backgrounds from other sources:
  neutral hadrons, large-angle muons, non-collision/cosmic
- Backgrounds validated in control regions

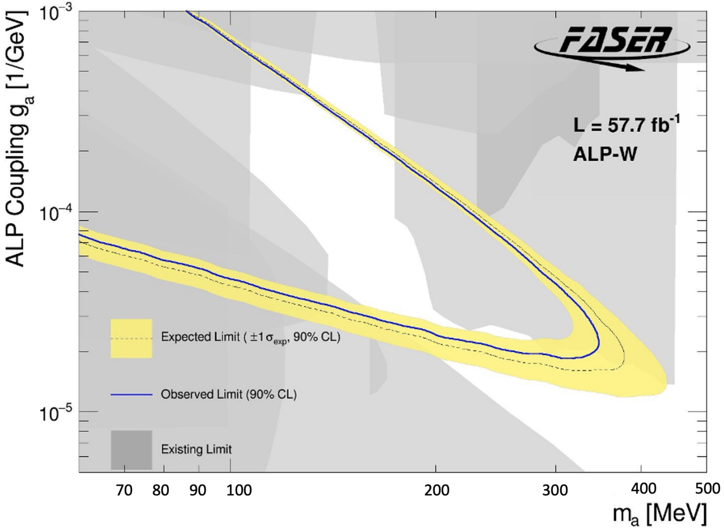




Axion Like Particles (ALPs)

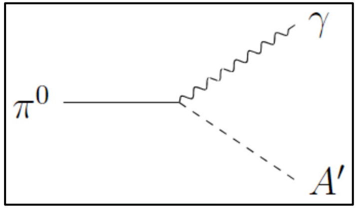
- Expect 0.4 ± 0.4 from ν interactions
- 1 observed event
- Exclude uncovered parameter space significantly



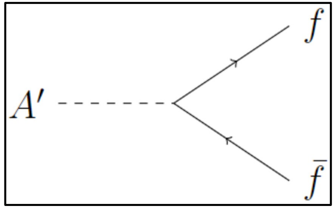


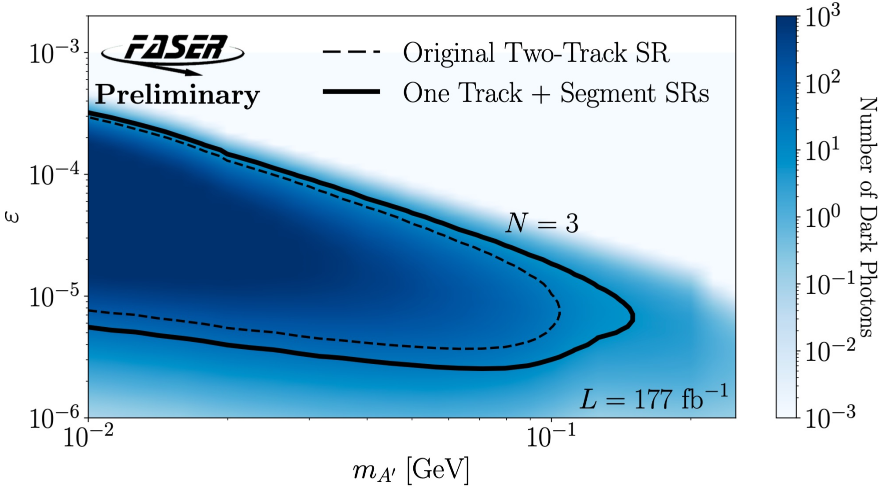
Dark Photons

Production



Decay





Source	Value	Effect on Signal Yield
Theory, Statistics and Luminosity		
Dark Photon Generation (from mesons)	15%	15% ± 13% (8%)
Dark Photon Generation (from dark Bremsstrahlung)	22%	22% ± 30% (40%)
Luminosity	1.9%	1.9%
Tracking: One Track		
Momentum Scale	5%	<0.5%
Momentum Resolution	5%	<0.5%
Single Track Efficiency	1.22%	1.22%
Tracking: Segment		
Segment Efficiency	6.07%	6.07%
Preshower		
Preshower Ratio	3.6%	3% ± 3% (10%)
Calorimeter		
Calo E Scale	5.46%	3% ± 3% (11%)

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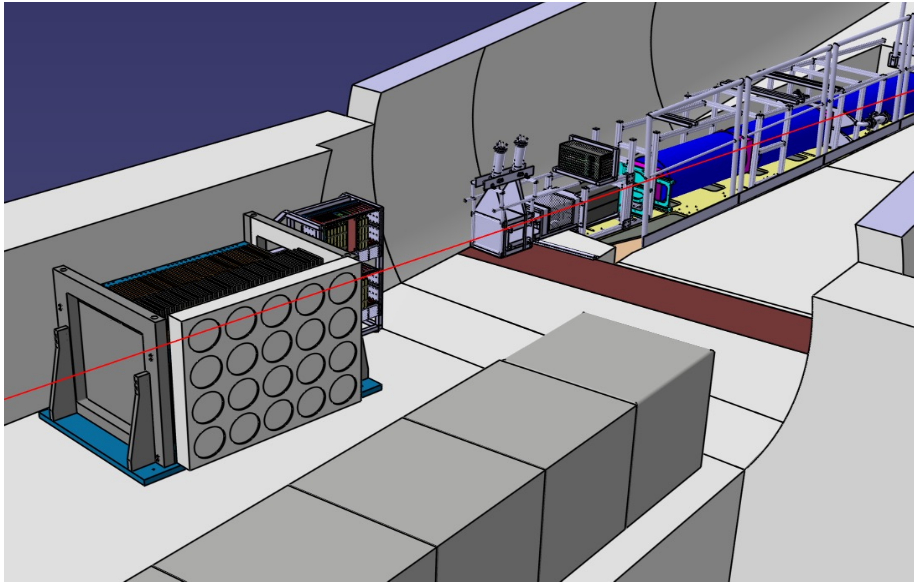
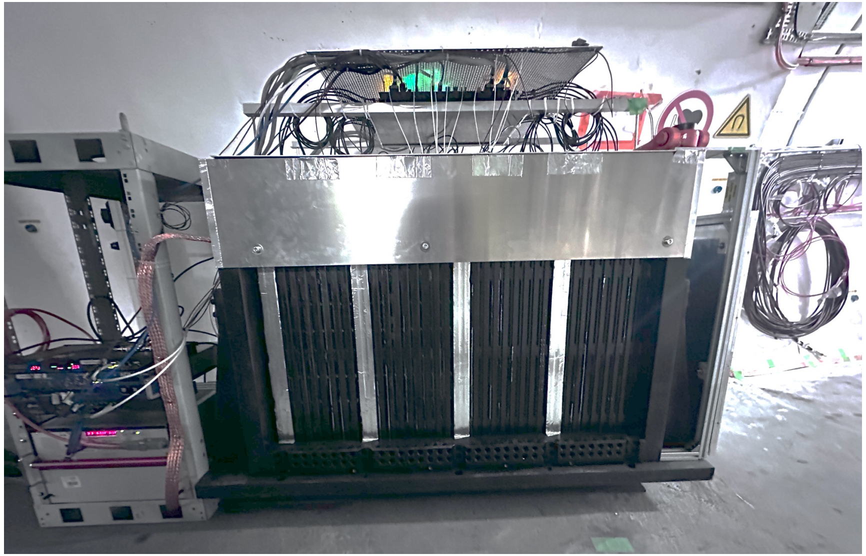
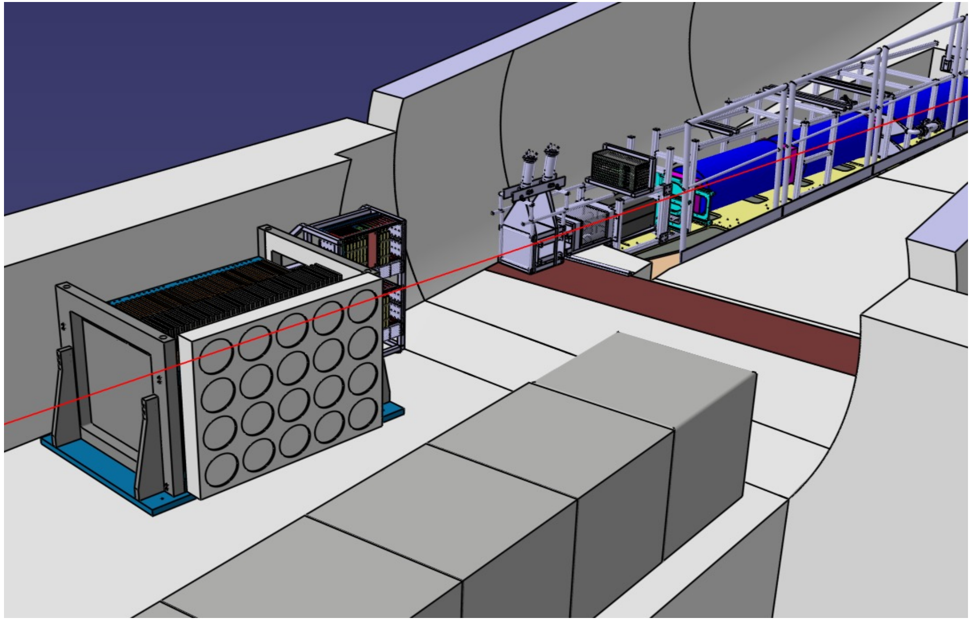
AHCAL

- Emulsion detector: needs to be exchanged every ~3 months (during technical stops) to control track density $\lesssim 1\times10^6$ tracks/cm^3
  - 10 emulsion detectors in total for 2021-2024 data
  - Not suitable for HL-LHC
- Solution: CEPC prototype, upgraded for FASER
  - Project proposed and led by Tsinghua and USTC groups

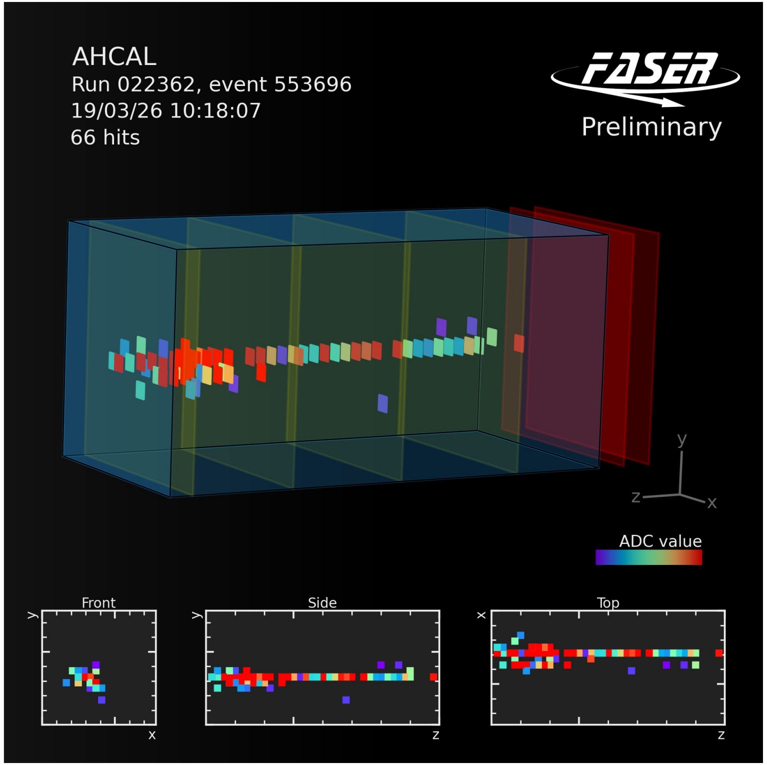


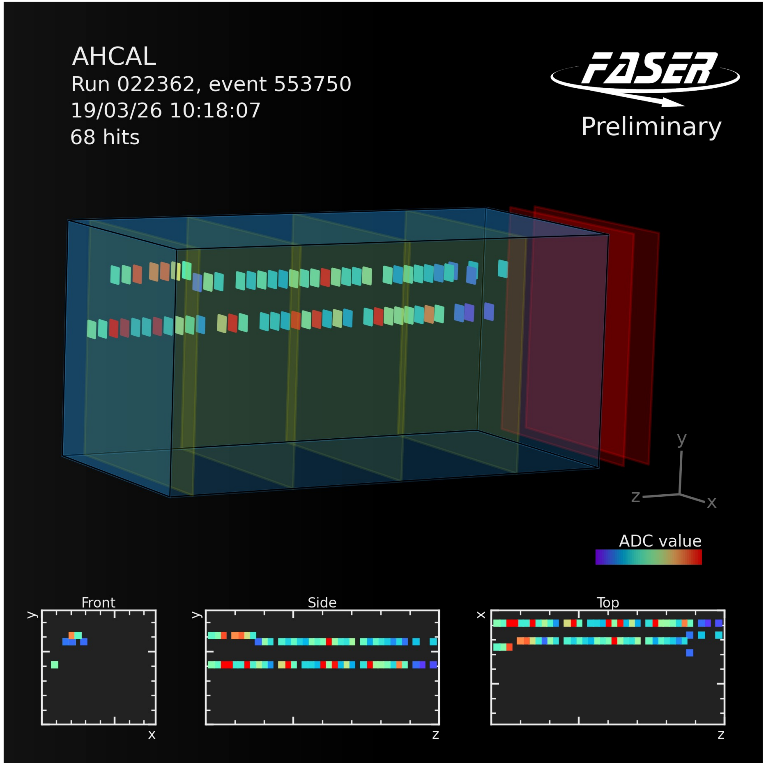
AHCAL





AHCAL





https://faser-public-plots.app.cern.ch/