Recent Results from

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

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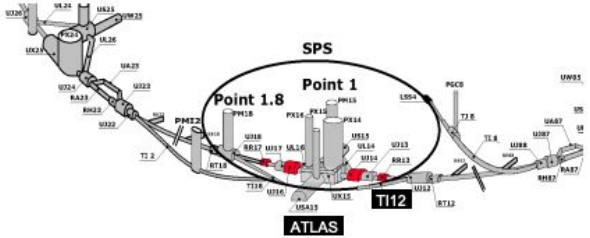
University of Washington
On behalf of the FASER Collaboration

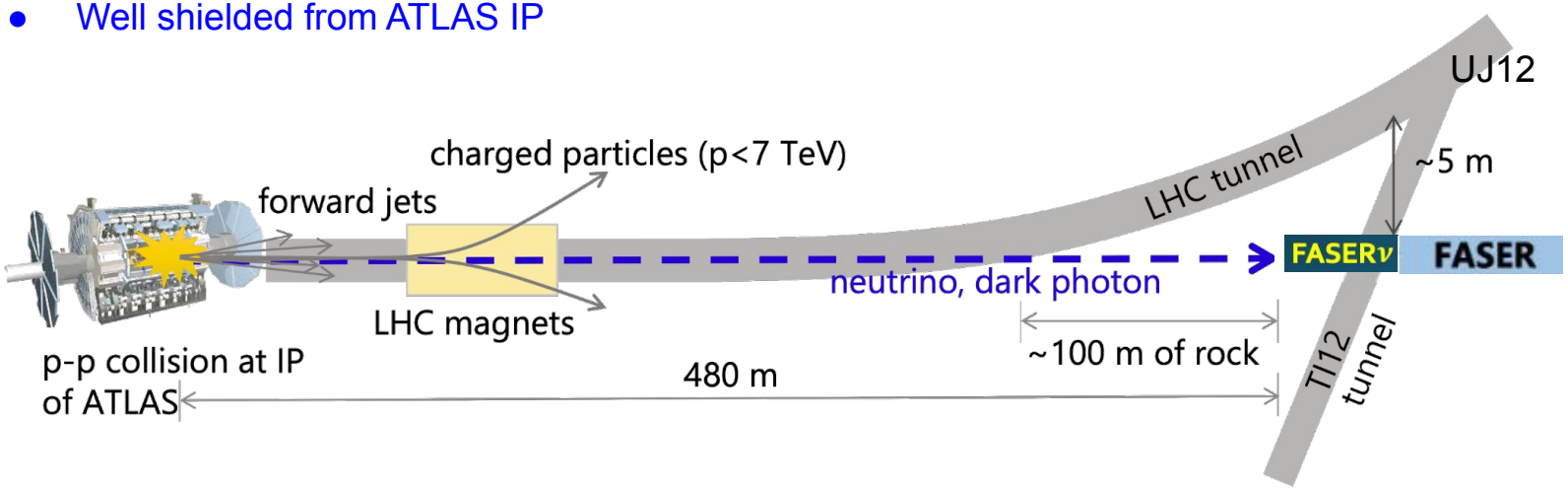
FPCP 2022 May 26 OleMiss

Forward **S**earch **E**xp**ER**iment at the LHC



- Many light particles at LHC produced in π, K, D meson decay
  - N~ 10^{16} pions/10^{12} neutrinos in LHC Run 3 (2022-2025)
  - E~ TeV $\theta_{\text{beam axis}}$ ~ mrad

- 480m downstream from ATLAS, the FASER experiment is placed directly into this beam
  - Proposed to search for long-lived particles and measure high energy neutrino nucleon interaction
  - Well shielded from ATLAS IP

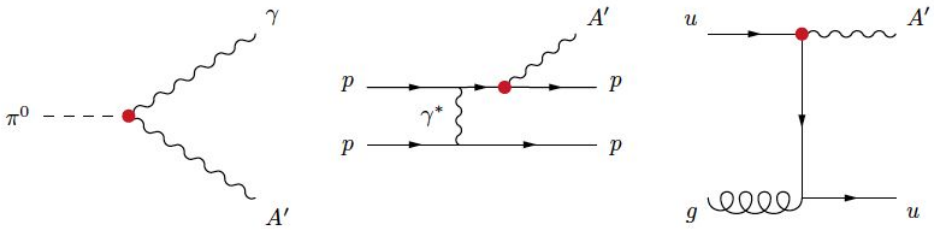


Dark Photon

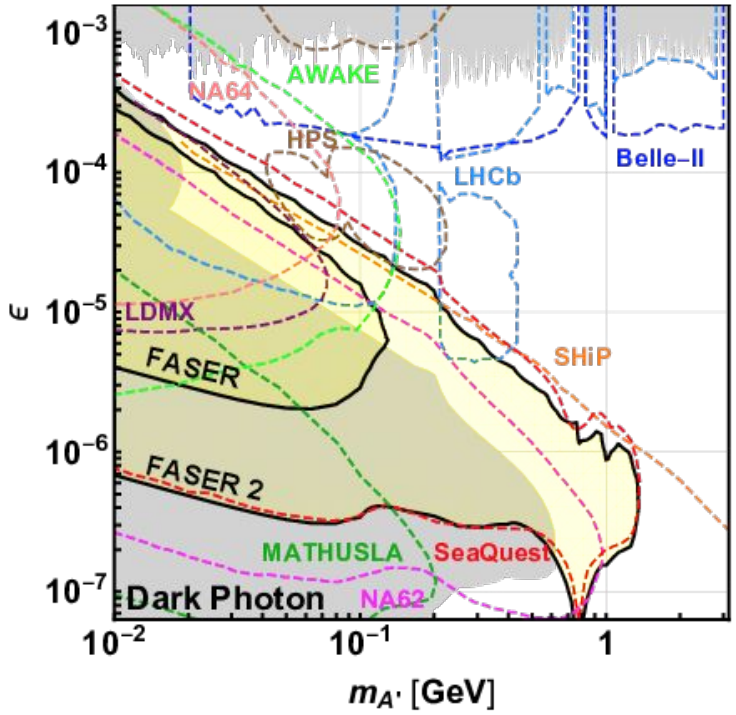
Spin 1, couples weakly to SM fermions

$$\mathcal{L} \supset -\frac{\varepsilon'}{2} F_{\mu\nu} F'^{\mu\nu} + \frac{1}{2} m'^2 X^2$$

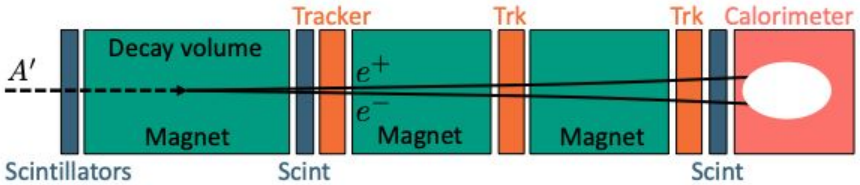
Mainly from decays of light mesons, π, η, dark bremsstrahlung and hard scattering



480m



A' → e+e-, μ+ μ-,π+ π-

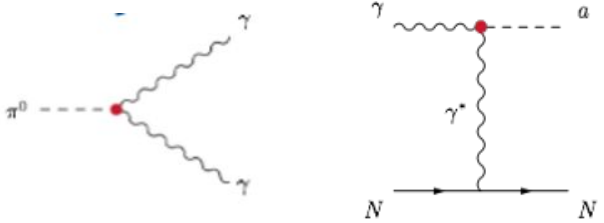


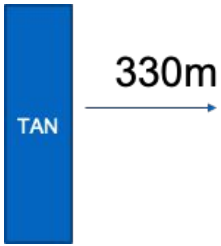
Axion-like Particles

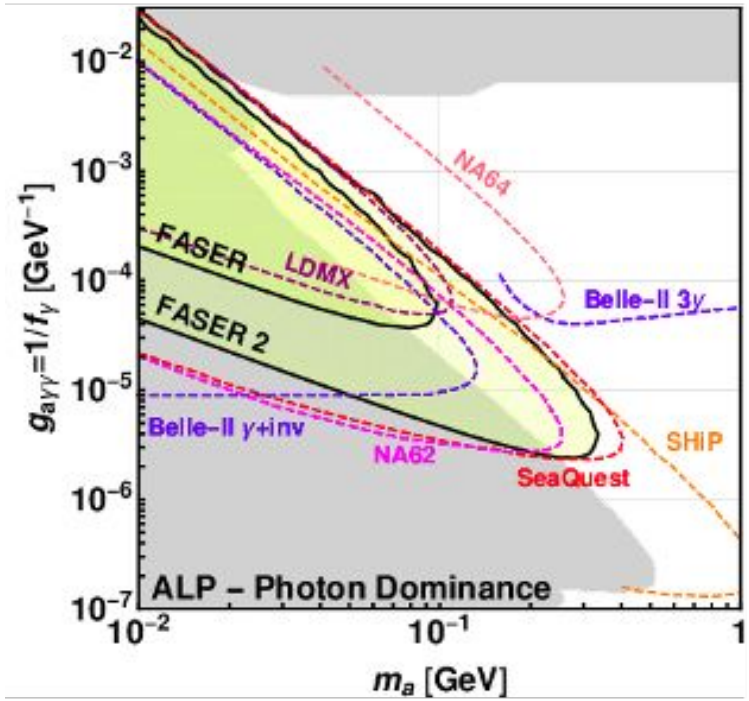
ALPs only couple to photons

$$\mathcal{L} \supset -\frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{a\gamma\gamma}\, a F^{\mu\nu} \widetilde{F}_{\mu\nu} \ ,$$

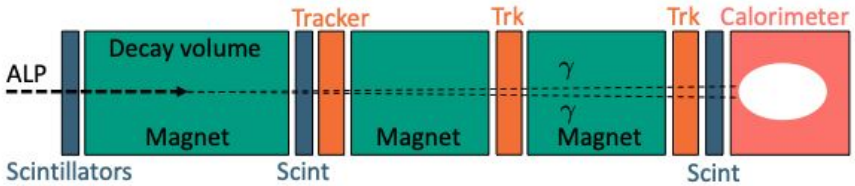
Mainly produced via Primakoff process ($\gamma N \to aN$)





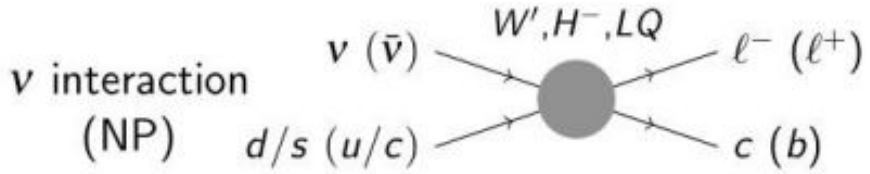


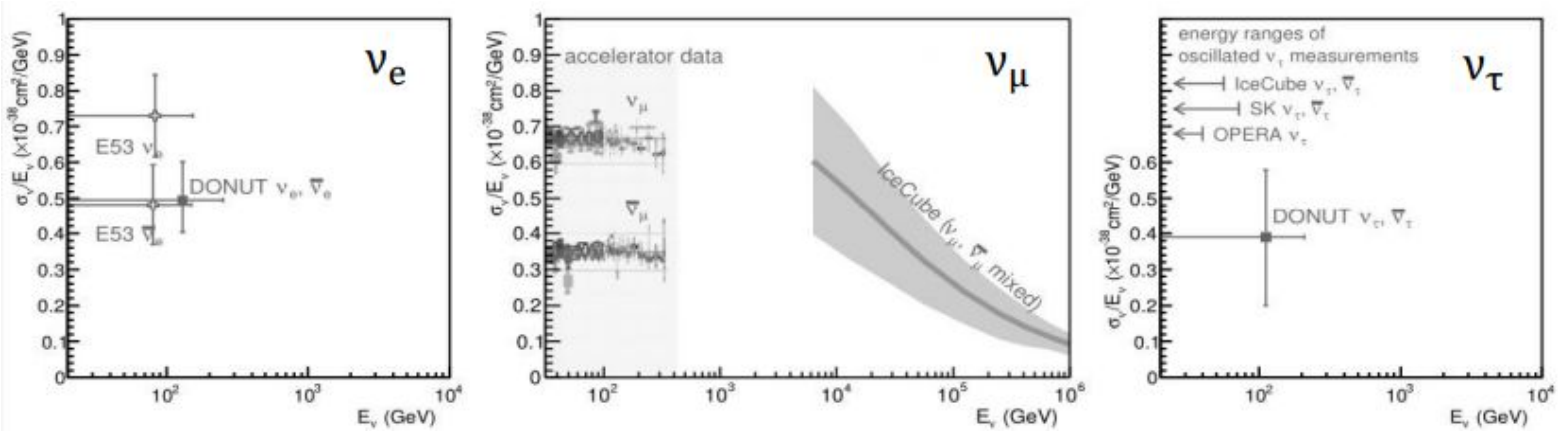
$a \to \gamma\gamma$ or γe^+e^-



Exploring neutrinos at the TeV energy

Sensitive to new physics by measuring scattering cross sections and studying each flavor





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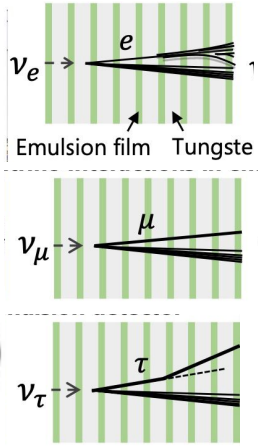

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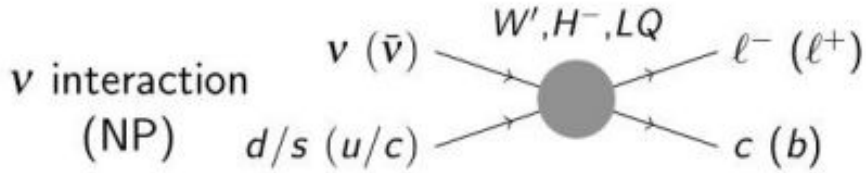
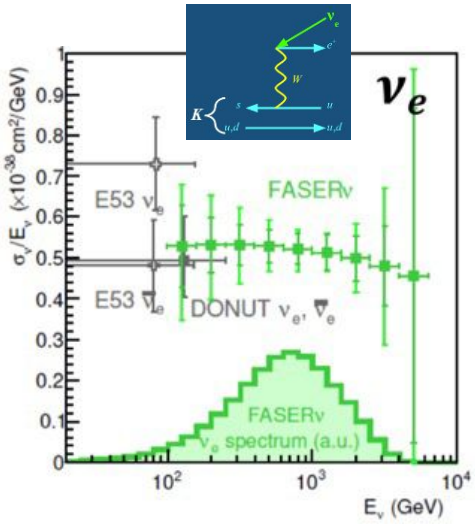
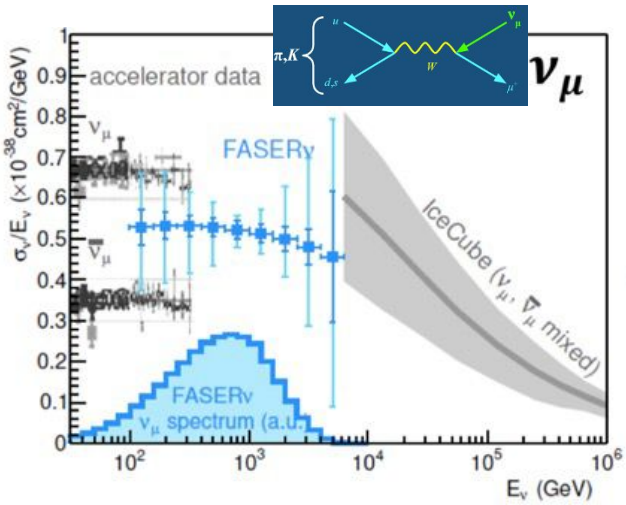
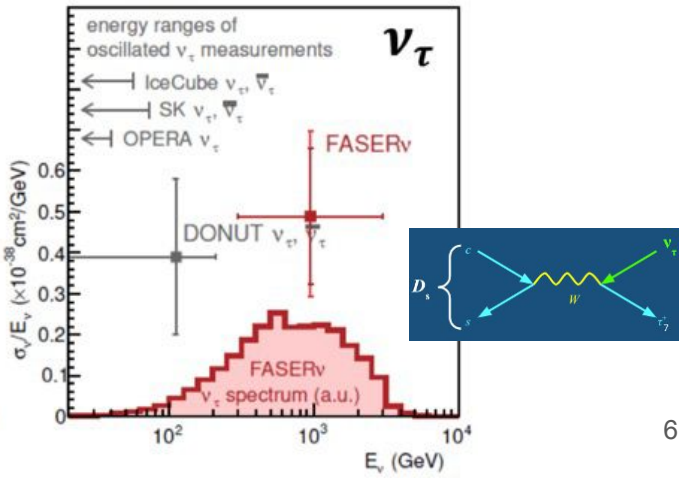
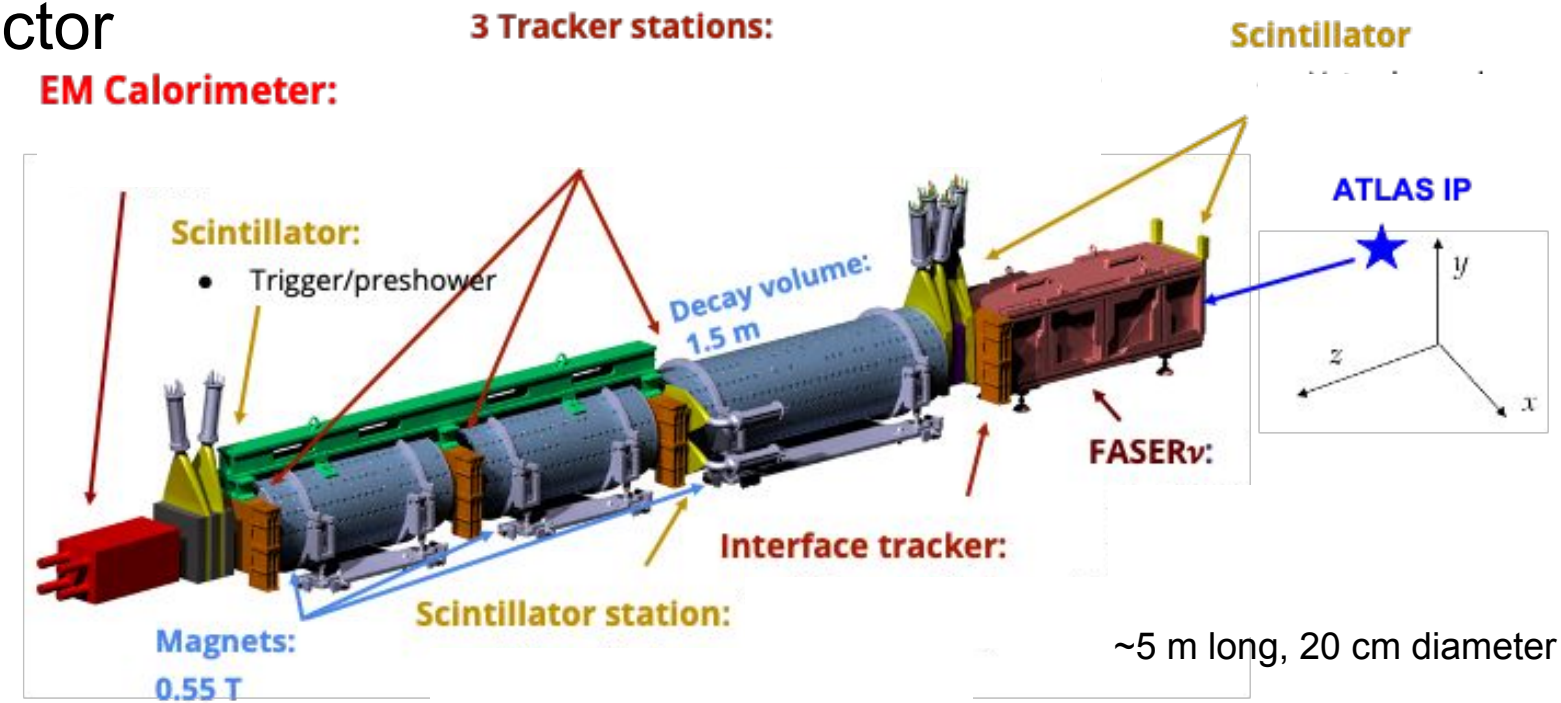




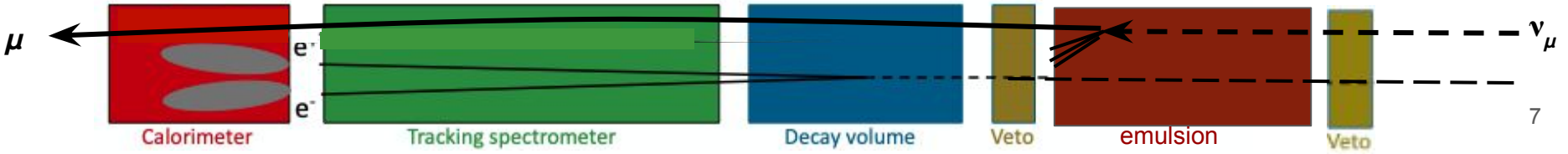




Detector



~5 m long, 20 cm diameter

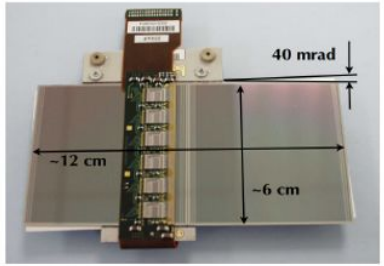


Silicon Tracker

Paper available from [NIMA (2022) 166825]

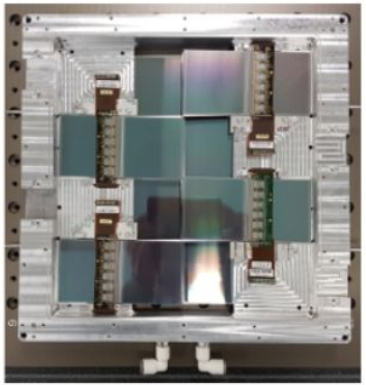
- Based on ATLAS SCT modules:
  8 modules x 3 layers x 4 stations = 96 modules
  - Resolution: 17 um x 580 um
  - Good separation for two collimated tracks

- 4 stations commissioned and installed
  - 99.9% strips are active
  - Expected noise/gain are confirmed
  - Thermal performance looks good
  - Interlock/safety are carefully verified



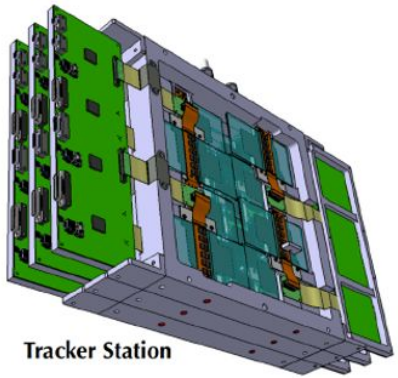
SCT module

80 um pitch, 768 strips/side
40 mrad stereo angle



Tracking layer

24 cm x 24 cm
sensitive area



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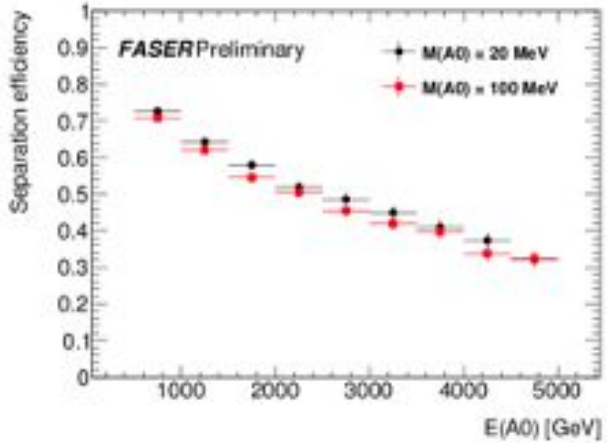


Scintillator and Calorimeter

Four scintillator stations are commissioned and installed

- > 99.9% efficiency, enough to trigger LLP decay inside the FASER detector
- Confirmed by in situ measurements in 2018.

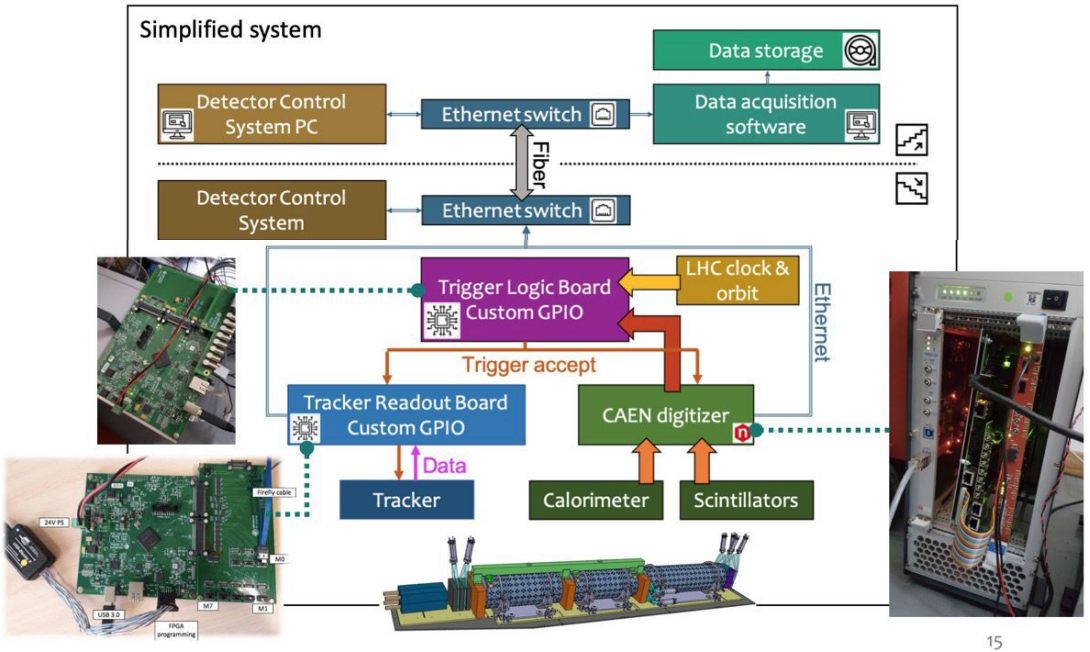
Calorimeter based on LHCb ECAL module is also installed. One module has:

- 12 cm x 12 cm (25 X_0)
- 66 layers of (2mm lead and 4mm scintillator)
- Resolution ~1% for 1 TeV electron energy deposits

Trigger and Data acquisition

Readout electronics in TI12

- Tracker: Custom General purpose I/O (GPIO) board
- Scintillator and Calorimeter: CAEN digitiser
- Trigger: Custom GPIO board
  - 500 Hz expected rate (dominant by muon flux, 1 Hz/cm^2 for L=2×10^{34} cm^{-2}s^{-1})
  - Clock and bunch taken from LHC
- Ethernet switch -> Servers on surface

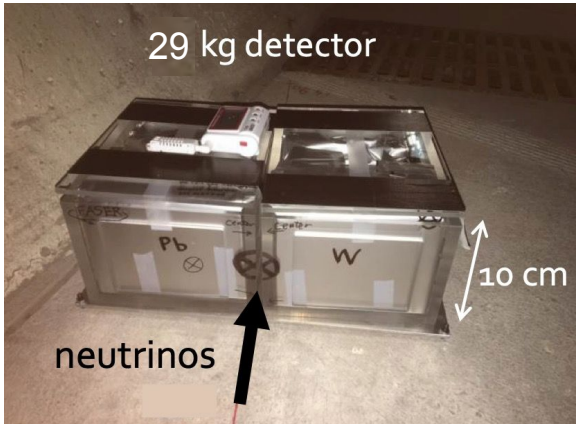


All components are installed and pass 1KHz test
Paper is published: [2021 JINST 16 P12028]

FASERν Emulsion/Tungsten

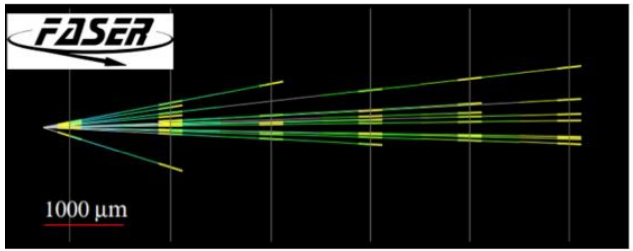
Charged particle ionization recorded and can be amplified and fixed by chemical development of film

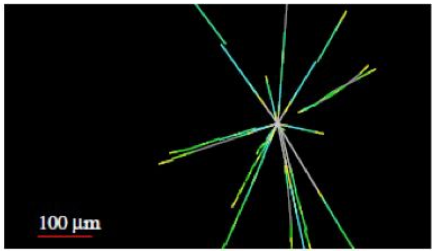
- 770 emulsions interleaved with 1-mm-thick tungsten plates (1.1 tonnes)
- Track position resolution ~50 nm
- Angular resolution ~0.35 mrad
- No Timing information

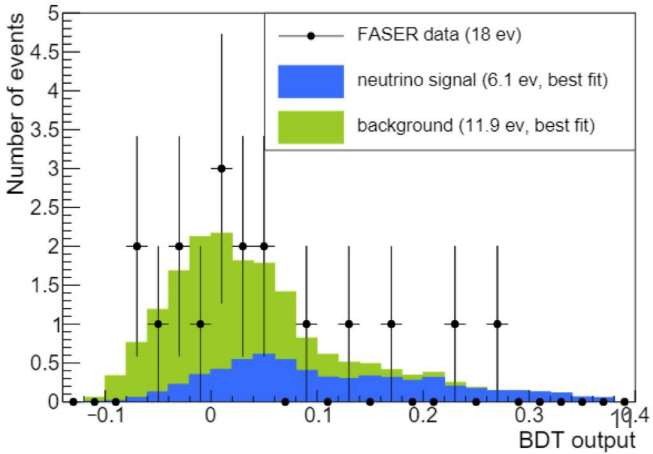


Pilot detector (29 kg) exposed in TI18 for 1 month in 2018

- Observed first c
- ollider ν candidates (2.7σ) with 12.2 fb^{-1} data!
- [Phys. ReV. D 104, L091101]







FASER in TI12

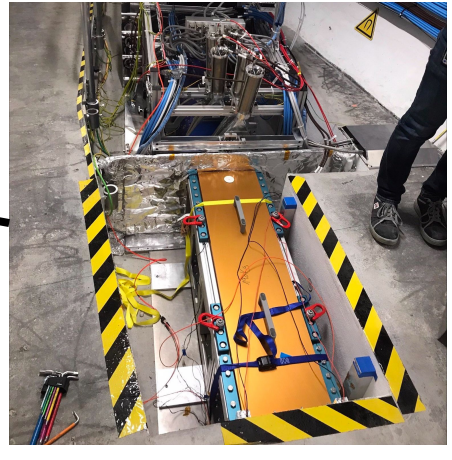
LOI arXiv:1811.10243
TDR arXiv:1812.09139

Successfully Installed in TI12 March 2021

- Detector paper being finalised for publication
- In situ commissioning with cosmic events and beams since

Current partial (30%) FASERv

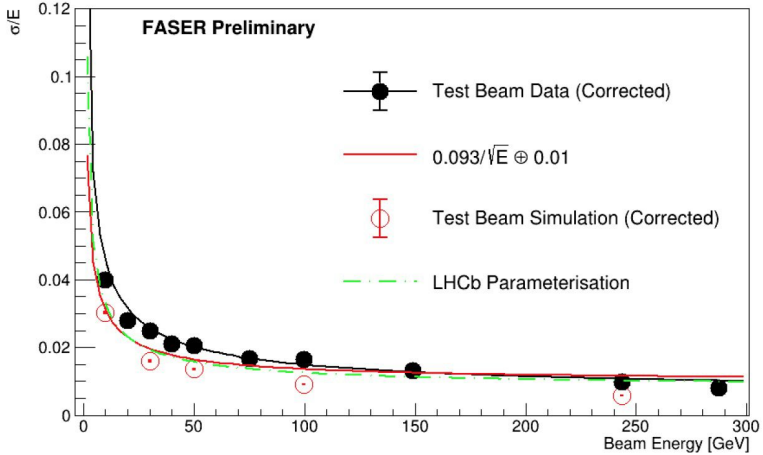
- Frequent exchange in Run 3
- 1st full detector July 26 (TS1)
- 2nd full detector Sep 13 (TS2)

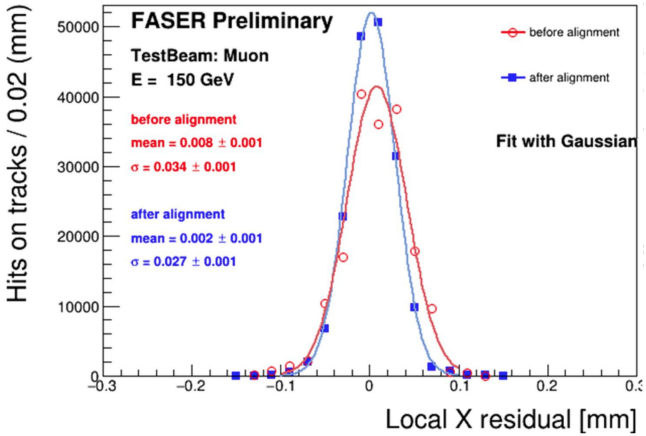


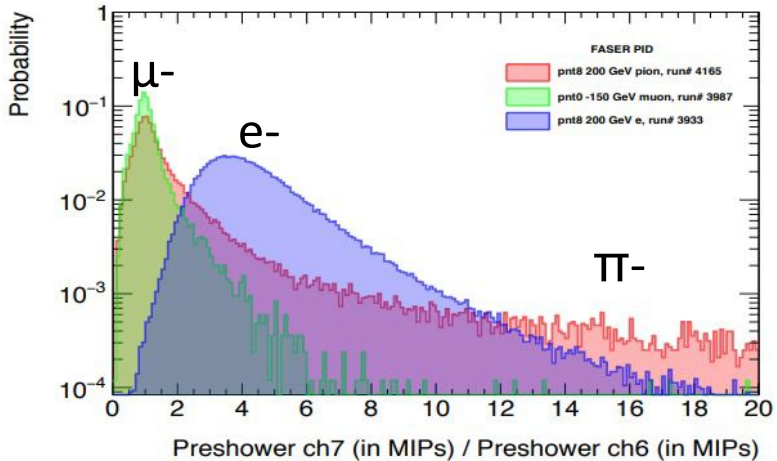
Test Beam Summer 2021

e (5-300 GeV)
μ (150 GeV)
π (200 GeV)

Reasonable energy resolution confirmed

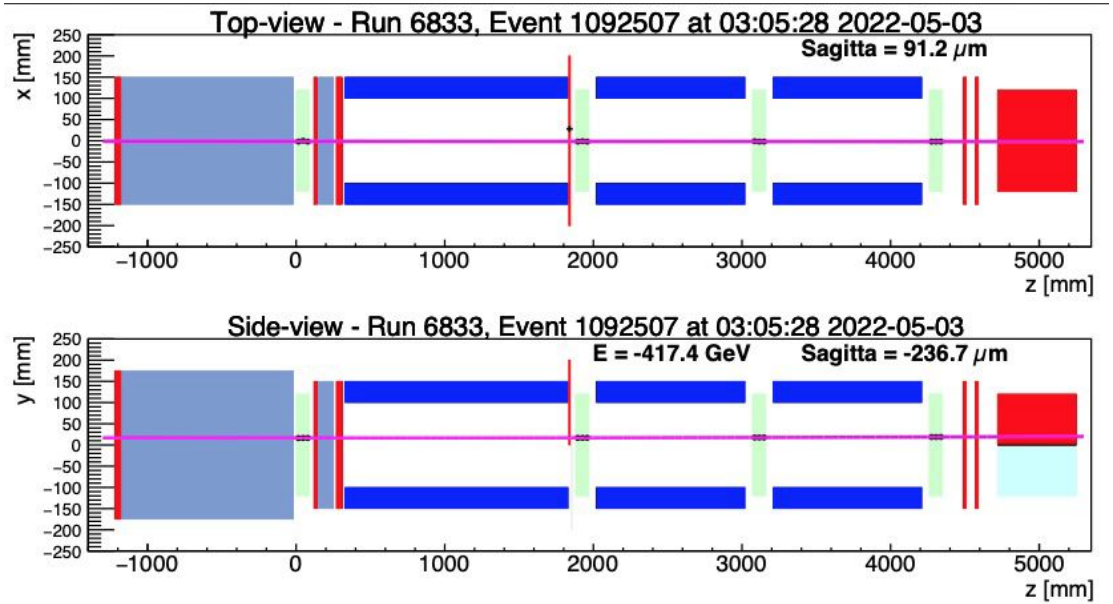






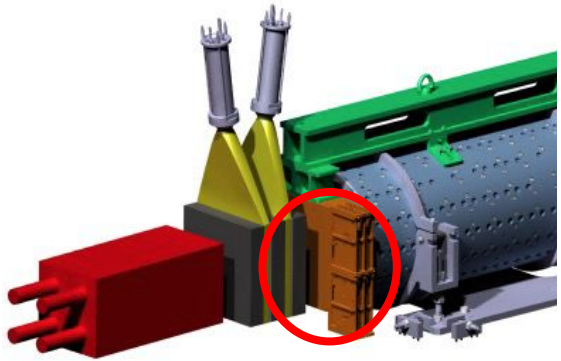
First beam particles in May 2022

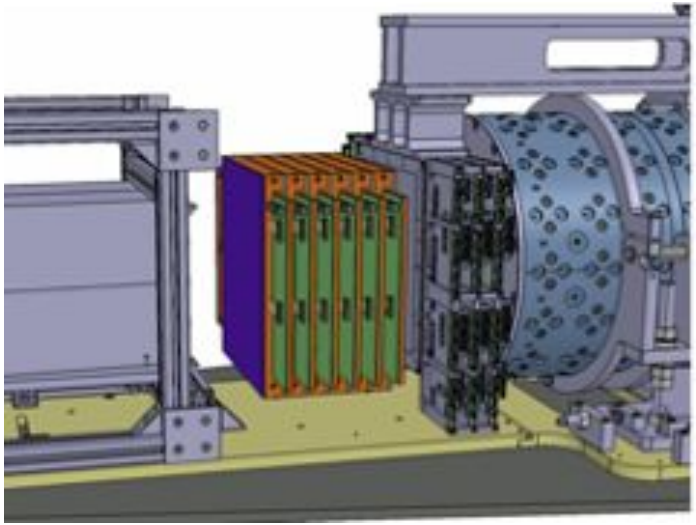
- Saw first beam particles from recent 6.8 TeV beam optics tests!
- First particles traversing full detector, including Fwd Veto and IFT
- Good readiness confirmed toward Run 3



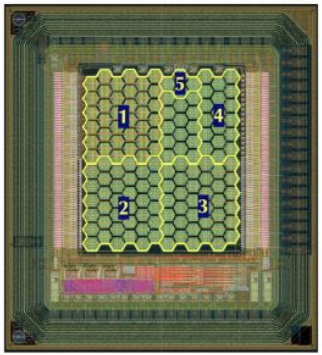
Preshower upgrade for 2023/2024

- Preshower scintillator will be replaced by hybrid pixel detector (100μm pitch, 130nm SiGe BiCMOS)
- Upgrade to enable detecting ALPs→ $\gamma\gamma$ searches (2 photon separation by ~200μm)
- Installation by the end of 2023, and data-taking from 2024
- Approved by CERN. See TDR CERN-LHCC-2022-006

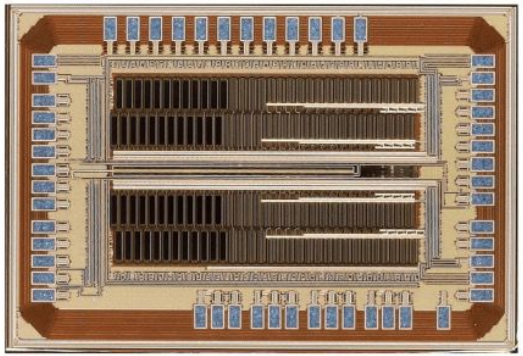




W-Si Detector



hexagonal pixels



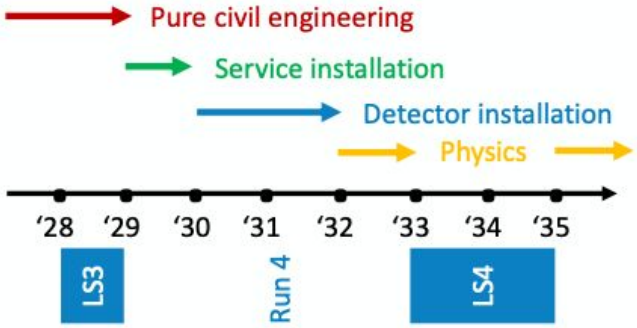
Prototype chip

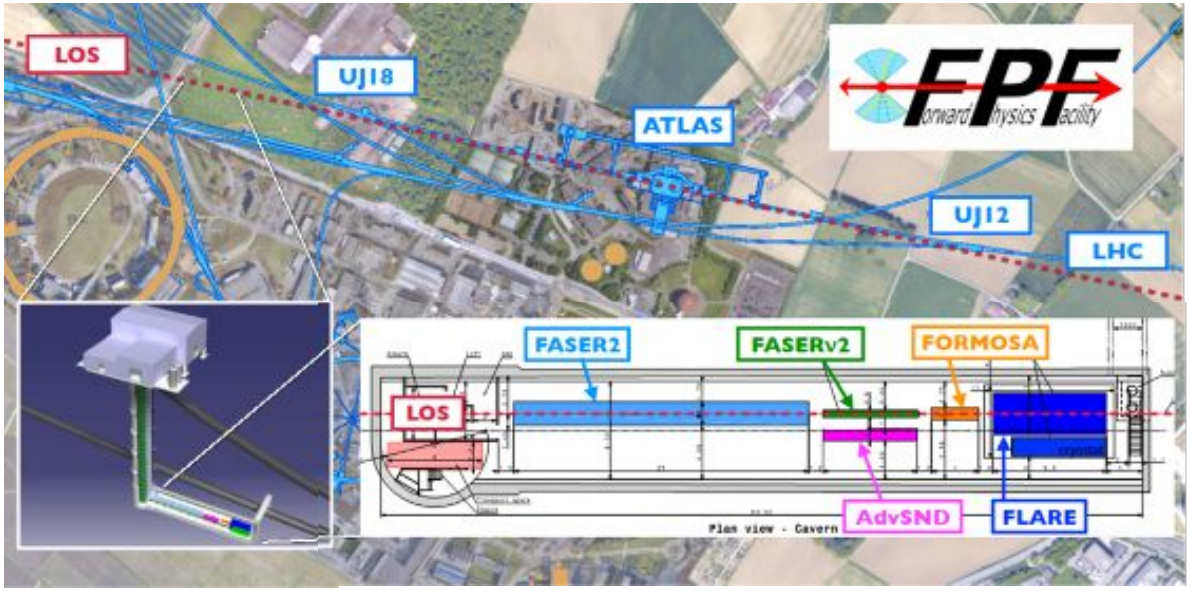
Forward Physics Facility toward HL-LHC

Snowmass White paper
arXiv:2203.05090

A new dedicated facility ~600 m to west of ATLAS (IP1)

Rich and broad physics programs:
- Extending BSM dark sector searches
- Neutrino physics
- New inputs for QCD and astrophysics





- Very preliminary cost: ~40 MCHF (62% civil engineering/38% service)
- Experiments on top

Summary

- FASER - a new forward experiment at the LHC in the unused tunnel, TI12
  - Give access to light weakly-coupled particles in MeV-GeV range
  - Probe TeV-energy neutrino in all flavors - First collider neutrino candidate is published!
- Ready for data taking in LHC Run 3 from 2022:
  - All detectors installed in TI12
  - Great progress of test beam analysis and commissioning to verify expected performance
- Upgrade toward enhancing **forward physics program**
  - Near term preshower upgrade for ALP search
  - Longer term Forward Physics Facility enabling broad physics programs
    - Tight timeline for construction
    - More discussions in Seattle Snowmass Community Summer Study July 17-26 2022

Snowmass 2021

http://seattlesnowmass2021.net/

Backup

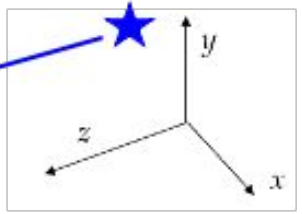
Detector

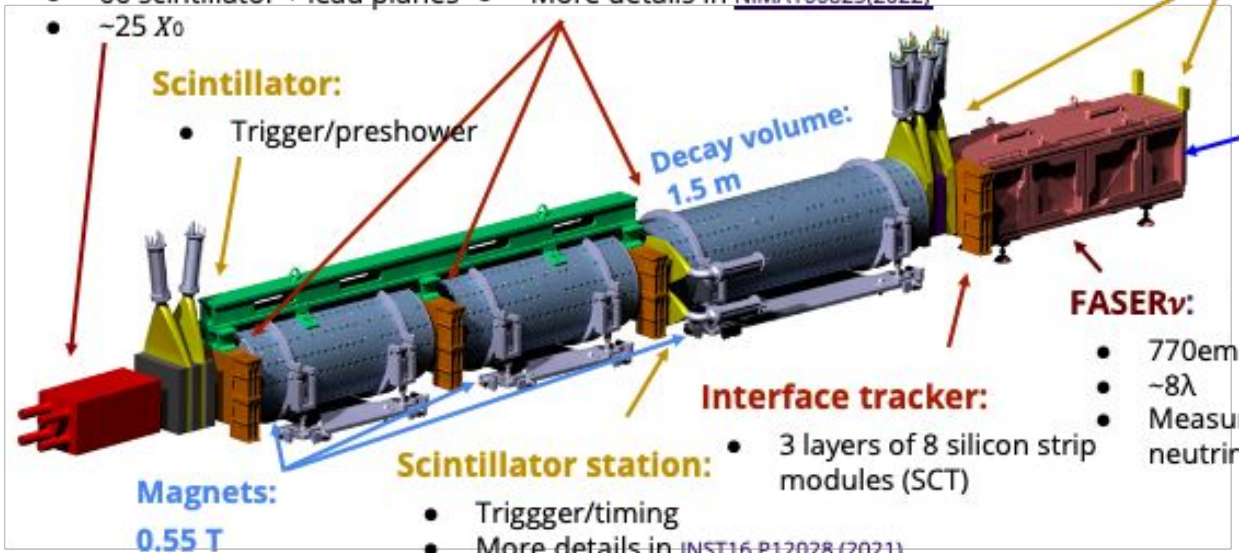
EM Calorimeter:
- 66 scintillator + lead planes
- ~25 X_0

3 Tracker stations:
- Each has 3 layer of 8 silicon strip modules
- Measure track trajectory
- More details in NIMA166825(2022)

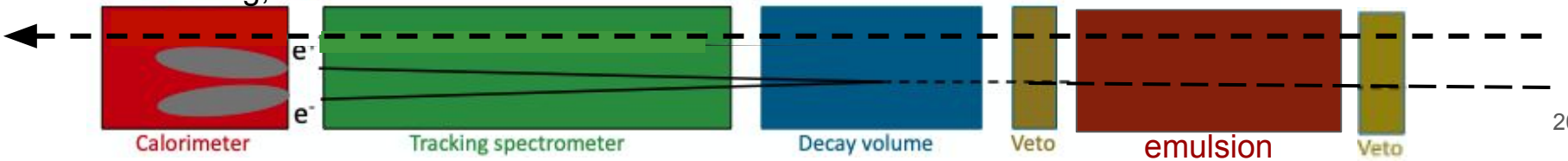
Scintillator
- Veto charged particles

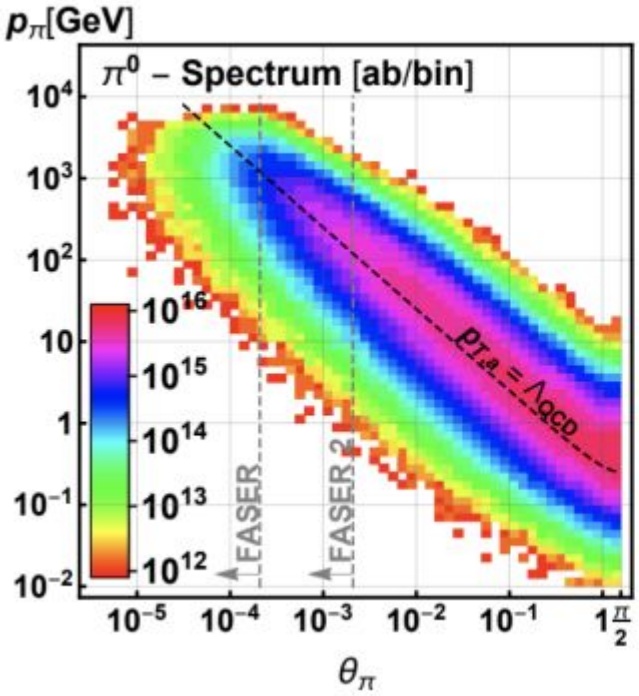
ATLAS IP

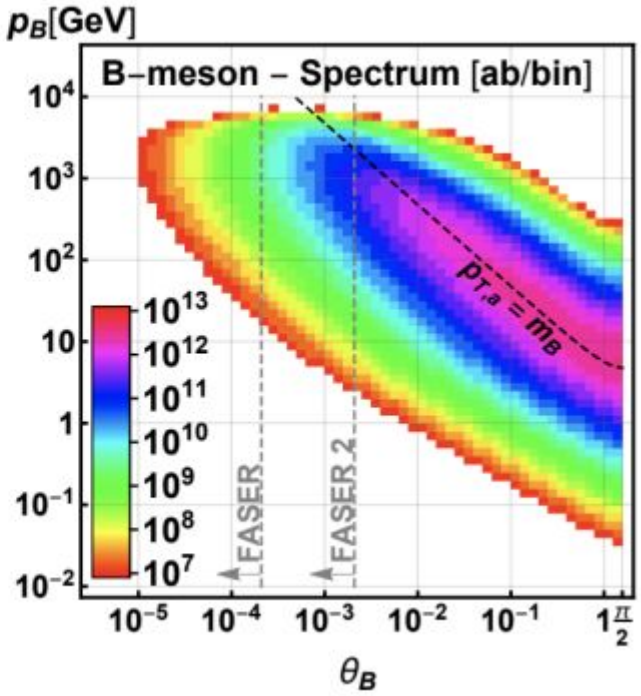




~5 m long, 20 cm diameter

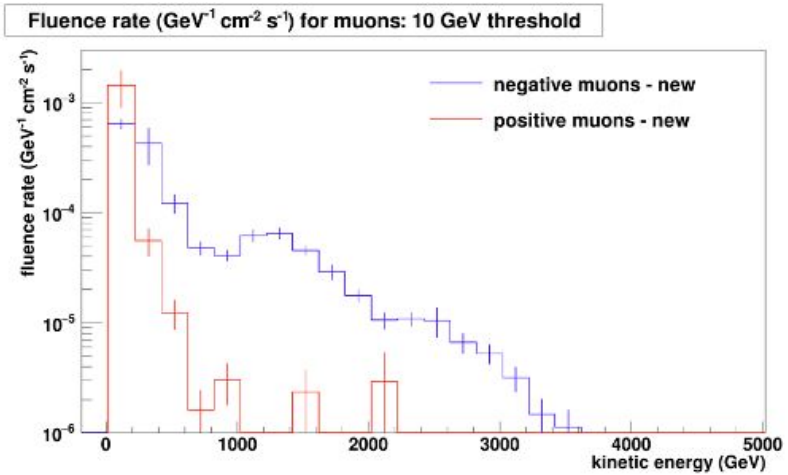


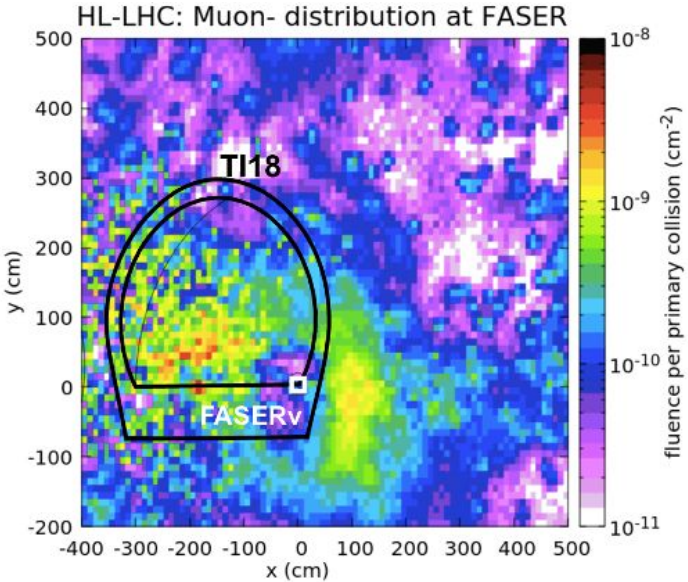

p_π[GeV]
π^0 – Spectrum [ab/bin]
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
$p_{T,a} = \Lambda_{QCD}$
FASER
FASER 2
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$\frac{\pi}{2}$
θ_π


p_B[GeV]
B–meson – Spectrum [ab/bin]
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{13}
10^{12}
10^{11}
10^{10}
10^9
10^8
10^7
$p_{T,a} = m_B$
FASER
FASER 2
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$\frac{\pi}{2}$
θ_B

Beam Backgrounds

- FLUKA simulations and in situ measurements have been used to assess the backgrounds expected in FRASER
- FLUKA simulations studied particles entering FASER from:
  - – IP1 collisions, off-orbit protons hitting beam pipe aperture, beam-gas interactions
- Expect a flux of high energy muons (E>10 GeV) of 0.5 $cm^{-2}s^{-1}$ at FASER for $2x10^{34}cm^{-2}s^{-1}$ luminosity from IP1 collisions





Large muon charge asymmetry at FASER due to LHC bending magnets

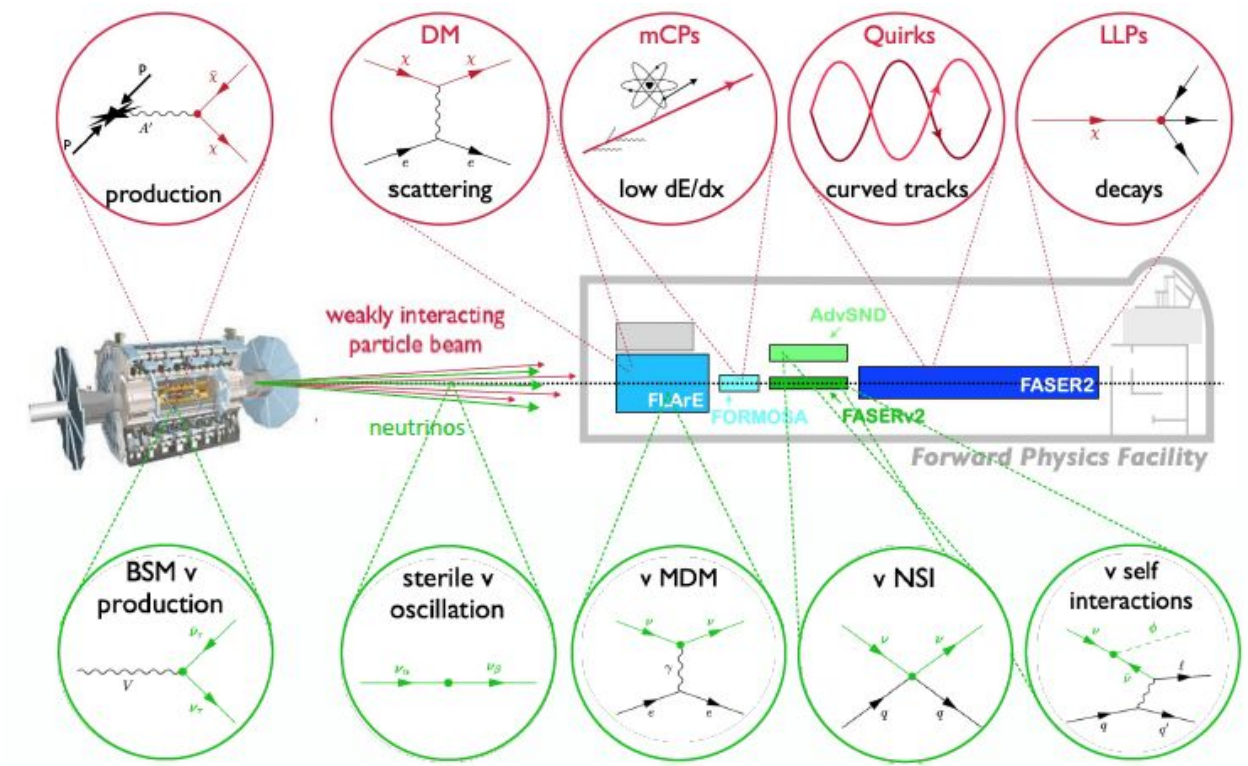
Physics Program of Forward Physics Facility

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

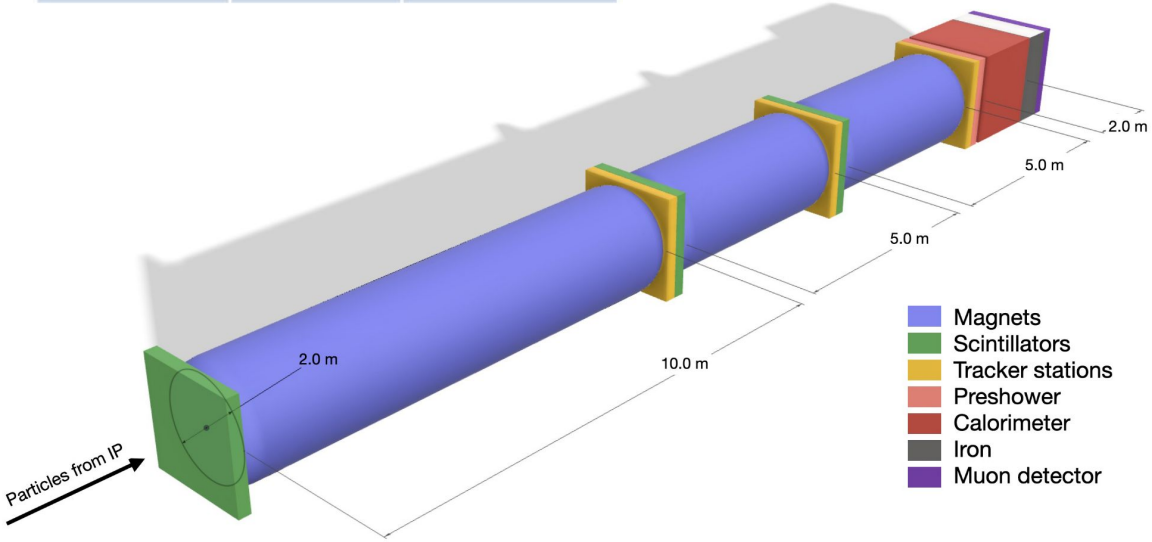


FASER2

scaled up version of FASER2 with ~100 x active area

- Veto: similar scintillator-based
- Magnets: Superconducting w/ B = 1 T
- Tracker: much larger using e.g. SiFI/SiPM
- Calo/Muon: enhanced PID & position resol.

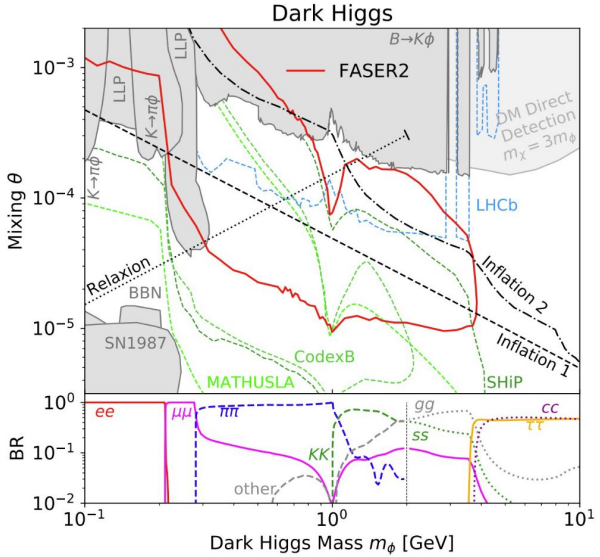
	FASER	FASER2
R [m]	0.1	1
DV [m}	1.5	10
TS [m]	2.6	10

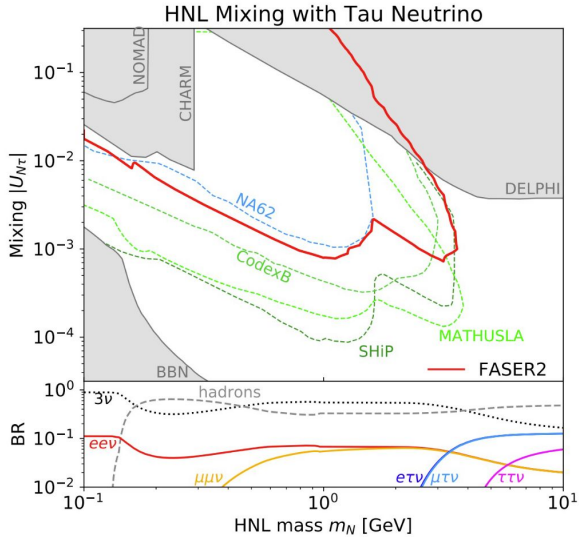


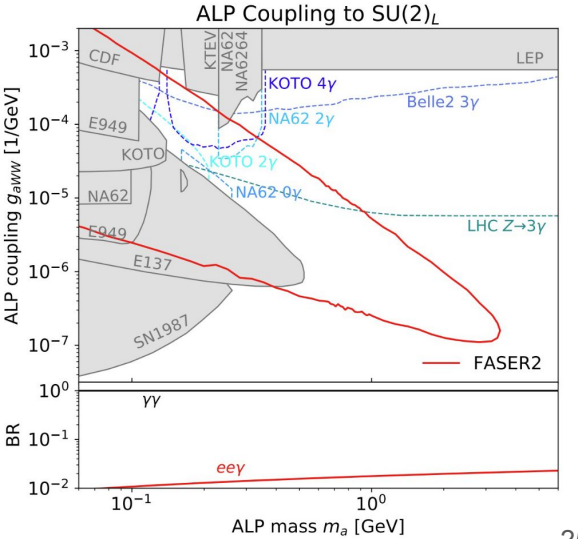
FASER2 Physics

- Wide LLP program probing many models
- Dark vectors, (pseudo) scalars, ALPs, HNLs, …
- Extended sensitivity to higher mass

Benchmark Model	FASER (Run3 (2022-2025))	FASER 2 (HL-LHC (2029-))
Dark Photons	√	√
$B-L$ Gauge Bosons	√	√
$L_i - L_j$ Gauge Bosons	—	—
Dark Higgs Bosons	—	√
Dark Higgs Bosons with hSS	—	√
HNLs with e	—	√
HNLs with μ	—	√
HNLs with τ	√	√
ALPs with Photon	√	√
ALPs with Fermion	—	√
ALPs with Gluon	√	√
Dark Pseudoscalars	—	√

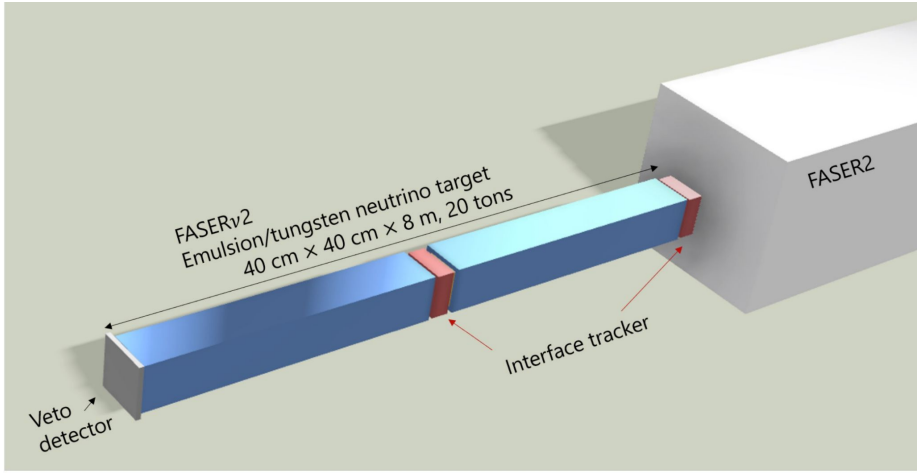


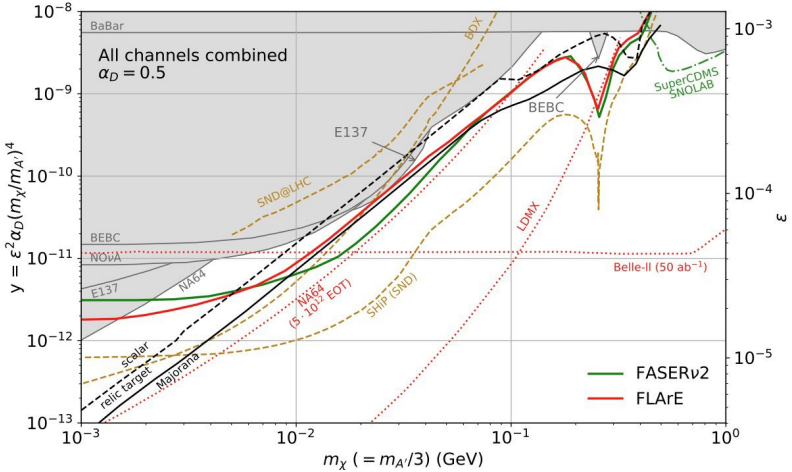




FASERν2

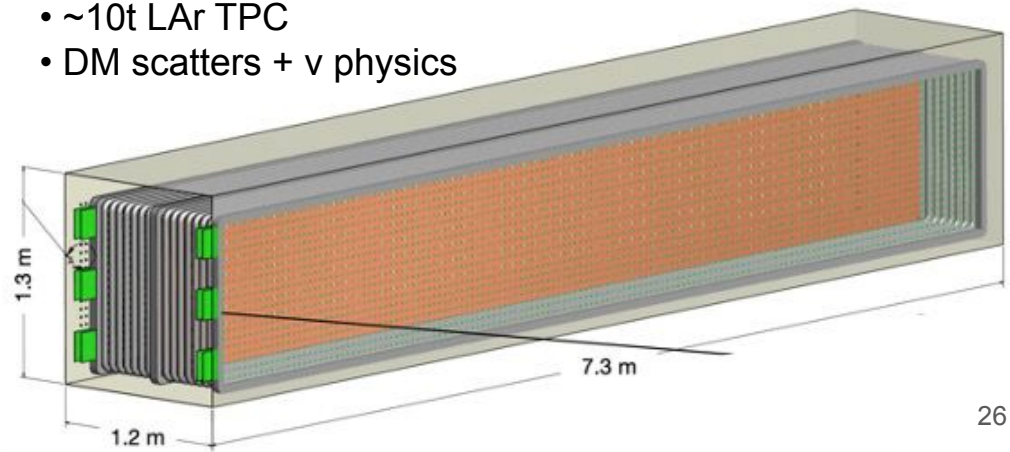
- ~20t emulsion + tungsten detector
- Focus on νT





FLArE: Forward Liquid Argon Experiment

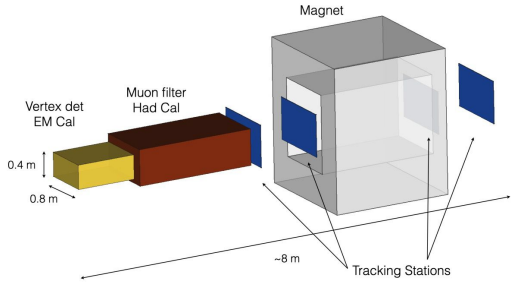
- ~10t LAr TPC
- DM scatters + ν physics



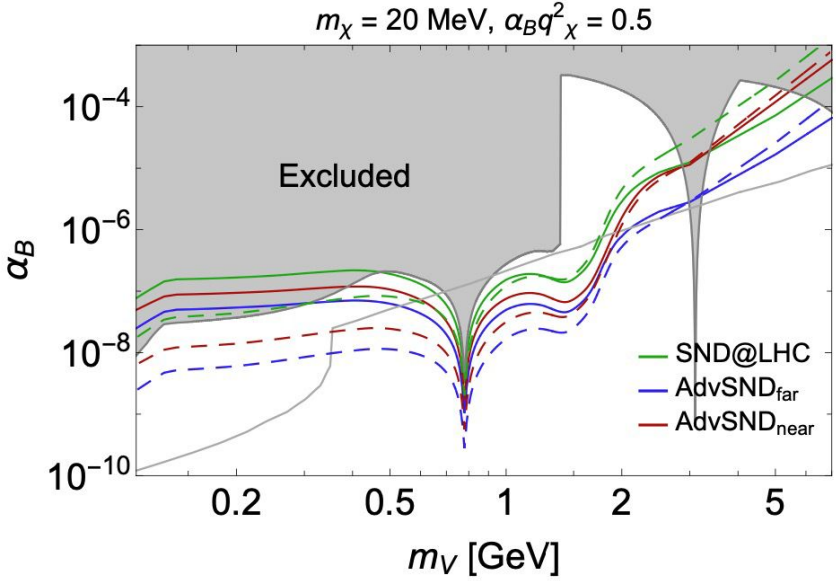
Other experiments

AdvSND

- Off-axis ν detecto



- Forward charm prod. + low-x gluon PDF



FORMOSA: FORward MicrOcharge SeArch
- Scintillator/tungsten detector
- For milli-charged particles