The FASER experiment and detector performance from the first data

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on behalf of FASER collaborations
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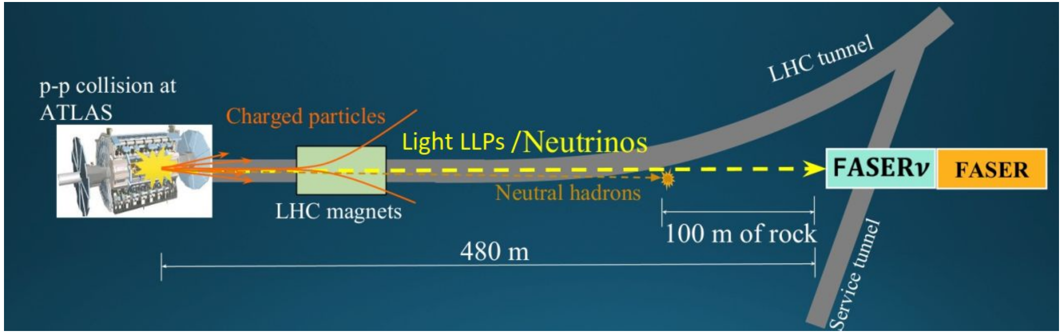
FASER is supported by:
Heising-Simons foundation and Simons Foundation.

ForwArd Search ExpeRiment

- **Faser is designed to search for long lived particles (LLP) and neutrinos produced in pp collision in ATLAS IP:**
  - The LLP is produced in the decay of SM meson which are predominantly produced very collimated with the beam direction
  - Even small detectors on (or close to) the LOS can have good sensitivity in these scenarios
    - e.g. 1% of pions with E > 10 GeV are produced in the forward 0.000001% of the solid angle (η > 9.2)
  - 480m from ATLAS IP in the forward regions
  - 100m rock to shield most of the background



arXiv:2207.11427

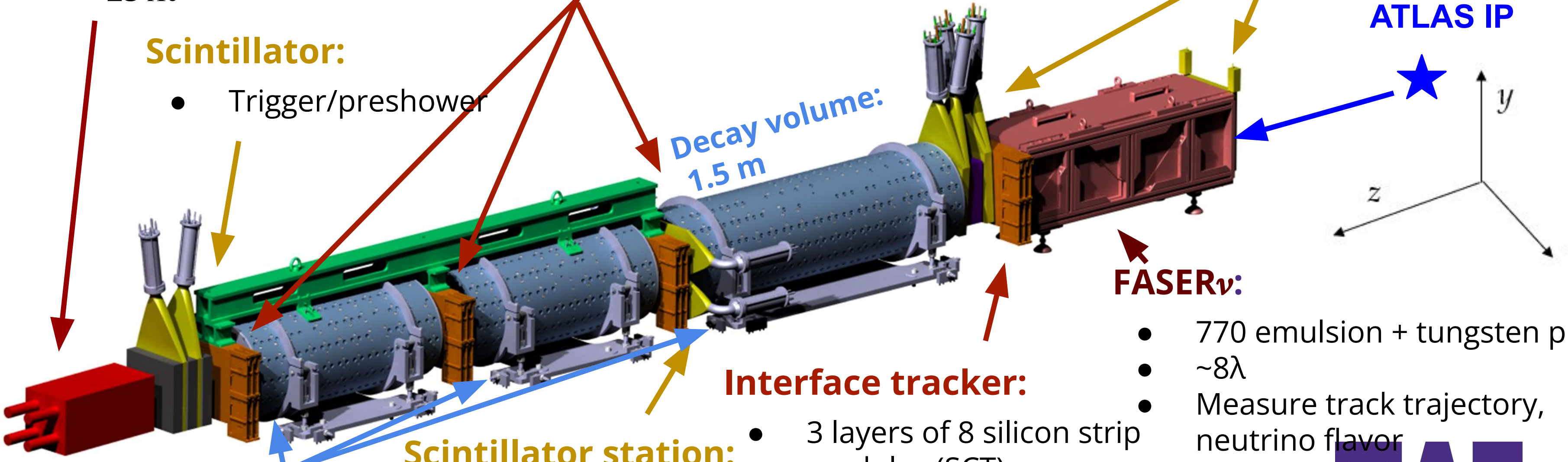
FASER detector

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

Scintillator:
- Trigger/preshower



FASERν:
- 770 emulsion + tungsten plate
- ~8λ
- Measure track trajectory, neutrino flavor

Interface tracker:
- 3 layers of 8 silicon strip modules (SCT)

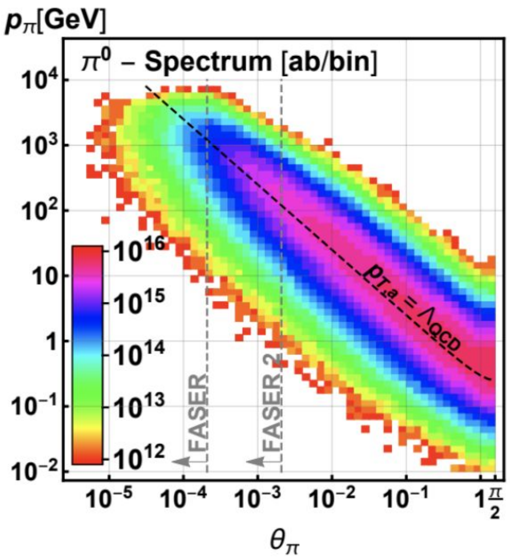
Scintillator station:
- Trigger/timing
- More details in INST16,P12028 (2021)

Magnets:
0.55 T

Long-lived particles

- > Searches for new weakly interacting light particles, coupling to SM in forward region $pp \to \mathrm{LLP} + X, \quad \mathrm{LLP\ travels} \sim 480\ \mathrm{m}, \quad \mathrm{LLP} \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \gamma\gamma, \ldots,$
  - Produced in decays of light mesons (e.g. π^0, K)
  - Light SM particles abundantly present in pp collisions, primarily in large pseudorapidity
  - Dark photon, axion-like particle (ALP) ...

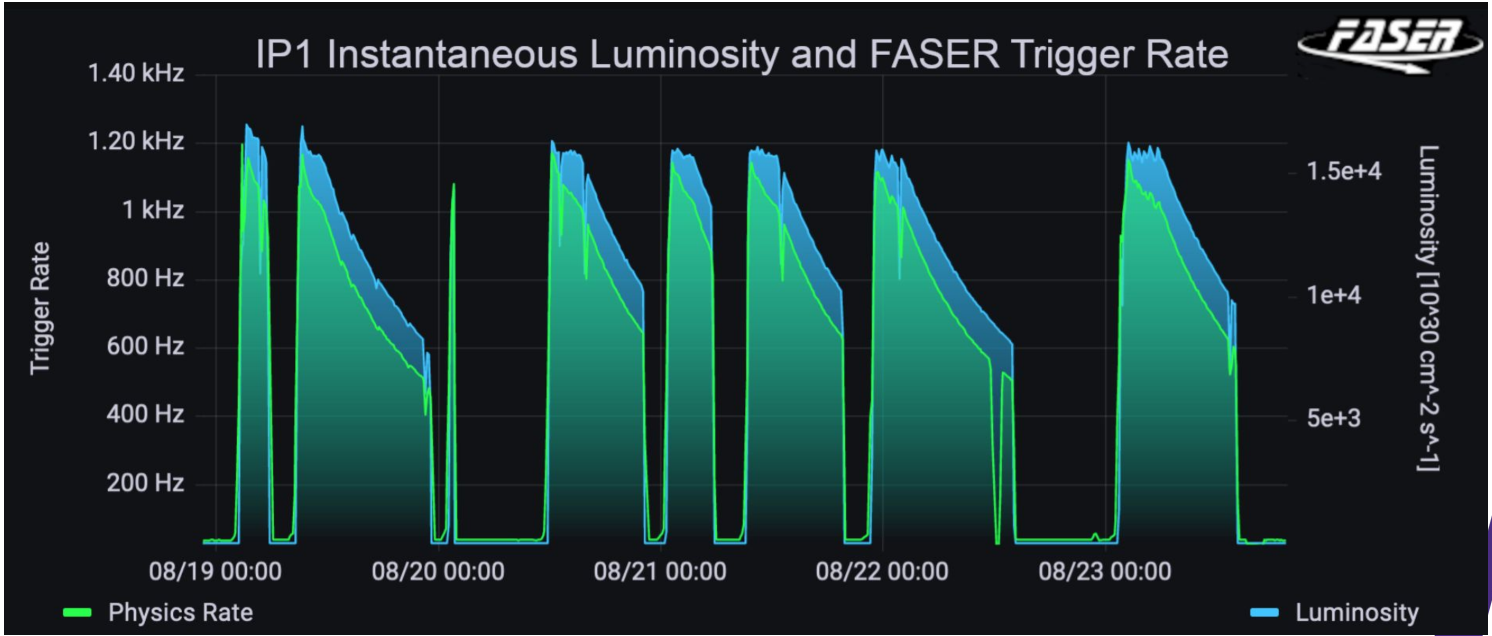
- By being on the LOS maximises the acceptance for potential signals
- In Run-3 of the LHC we expect O(10^{14}) π^0 to be produced in the FASER acceptance.



More details in PRD.99.095011 (2019)

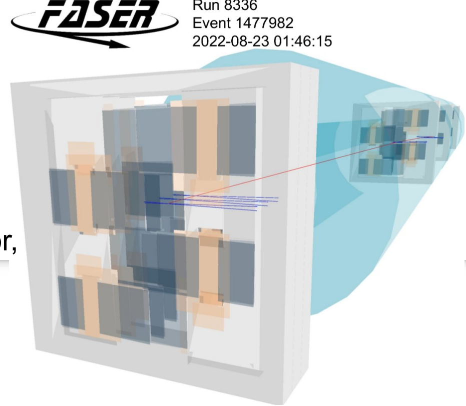
FASER operations

- FASER successfully collected ~40/fb of 13.6 TeV collision data in 2022 running (July -Dec)
- Average trigger rate: ~700Hz
- Detector operations went very smoothly

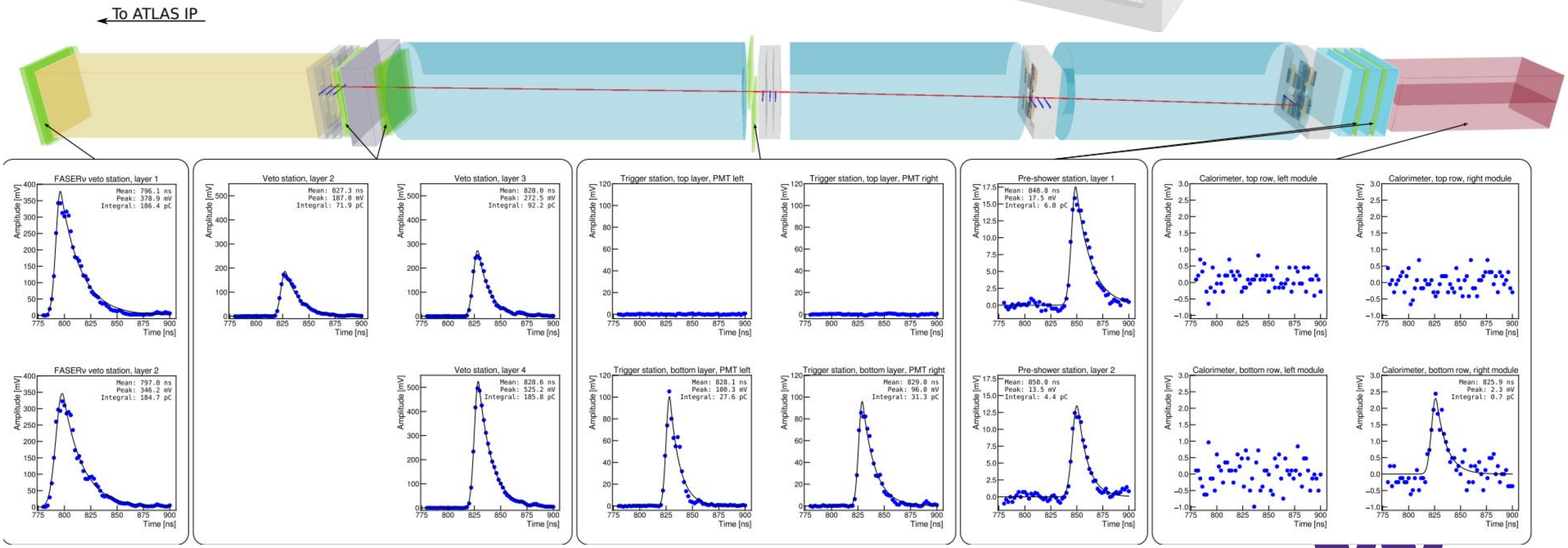


First collision data

Event display of a muon traversing the full detector, all parts of the detector performing as expected.

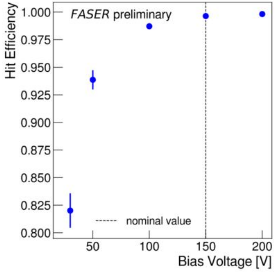


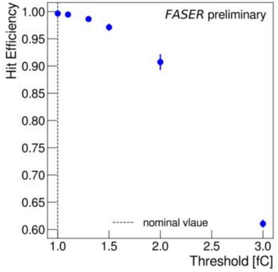
Run 8336
Event 1477982
2022-08-23 01:46:15

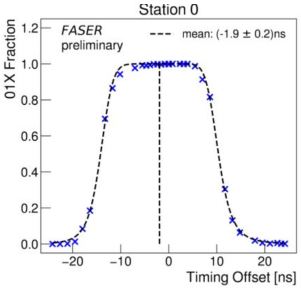


Detector performance - tracker

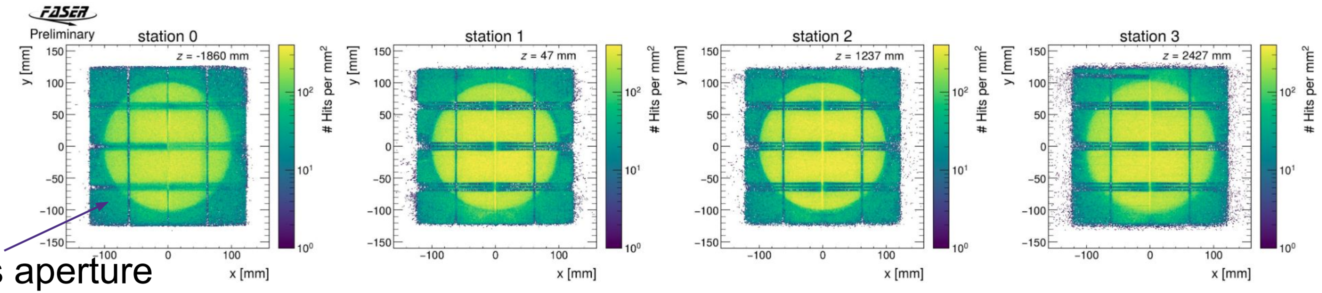
- Build of same silicon strip module (SCT) as ATLAS, module fine time tuned with 390 ps precision
- Hit efficiency of 99.64±0.10% at threshold of 1.0 fC and sensor bias 150V







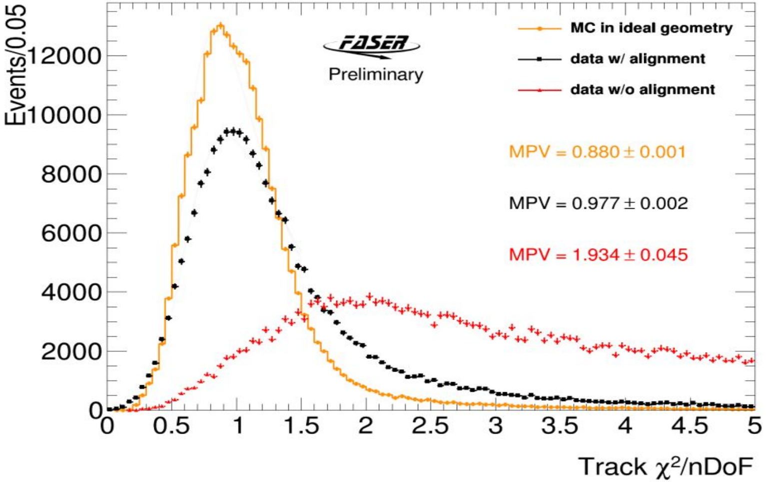
- Total number of dead/noisy strips < 0.5%
- Inefficiency from module edges are expected

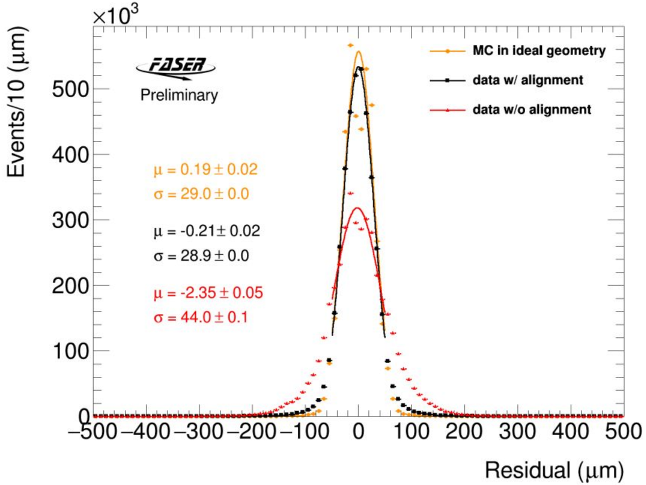


Magnets aperture

Detector performance - alignment

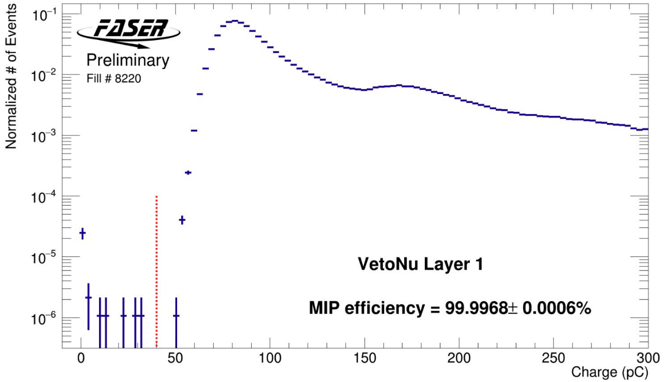
- Iterative local chi2 alignment
- Validated with MC simulation
- Only consider 2 of 6 degree of freedoms, Y translation and Z rotation
  - Silicon strip detector, precision on Y is much better than X
  - Track parameters and residuals are improved significantly
  - Remaining discrepancy will be taken as systematic uncertainty

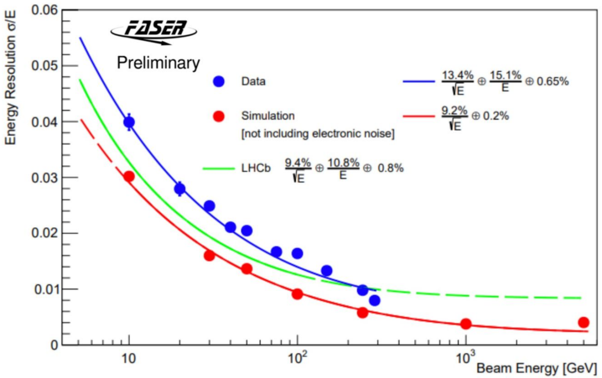


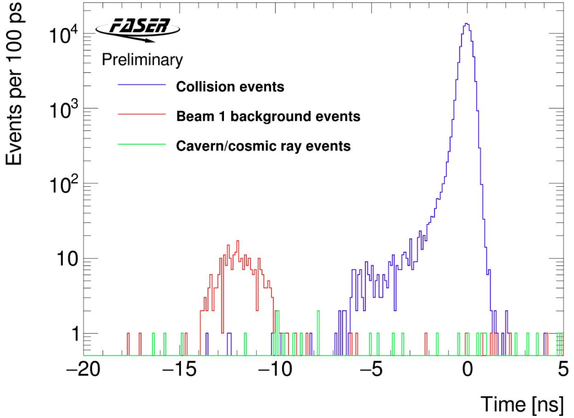


Detector performance - scintillator/calorimeter

- Veto scintillator efficiency from data:
  - >99.99% for each veto scintillator
  - Veto O(10^{10}) muons by combining 5 scintillators
- Calorimeter energy resolution measured with electrons in test beam
  - Resolution at O(1%) at high energy as expected
- Timing resolution ~250ps
  - Reject the beam-1 background efficiently

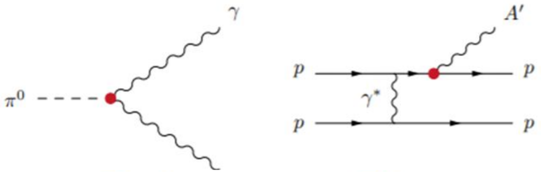


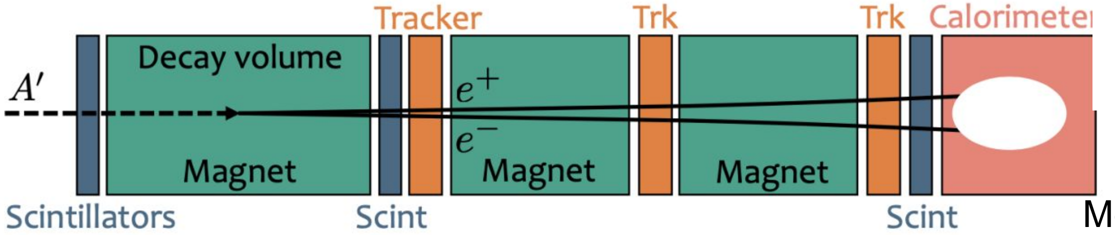




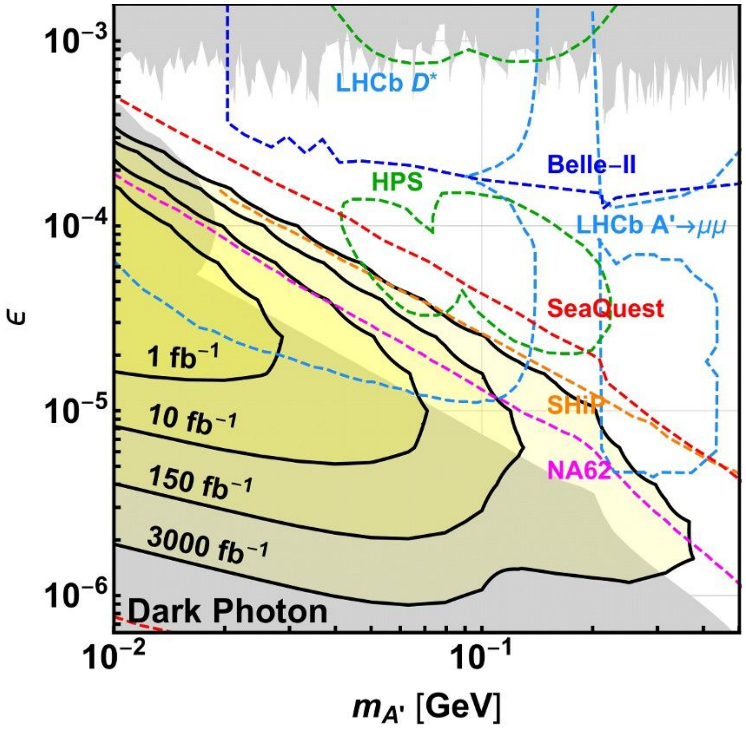
Dark photon

- > Even with 1/fb of data FASER will have sensitivity to unconstrained parameter space
- > Production:
  - – mainly from decays of light mesons, π, η and dark bremsstrahlung.
- > Decays:two charged particles
  - – e^+e^-, $\mu^+ \mu^-$, $\pi^+ \pi^-$





Expected sensitivity assuming no background



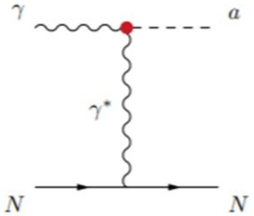
More details in PRD.99.095011 (2019)

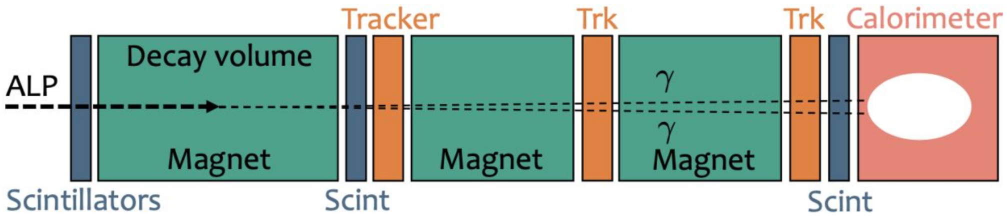
Axion-like particles (ALPs)

In the case of ALPs only couple to photons

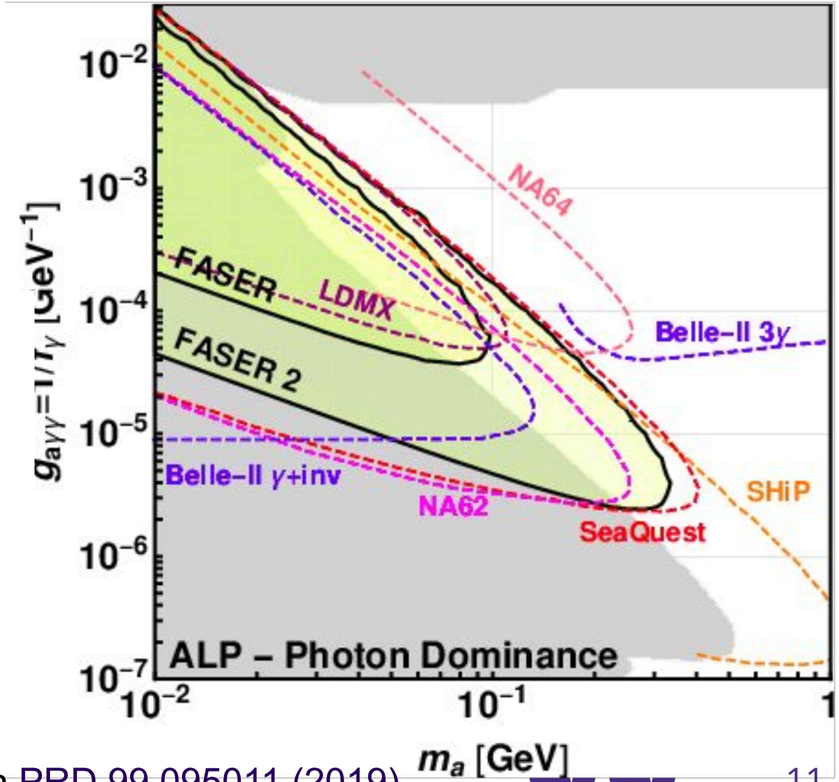
$$\mathcal{L} \supset -\frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{a\gamma\gamma}\, a F^{\mu\nu} \widetilde{F}_{\mu\nu} \ ,$$

- Mainly produced via Primakoff process ($\gamma N \to aN$) In forward region of pp collision
- $a \to \gamma\gamma$ or γe^+e^-





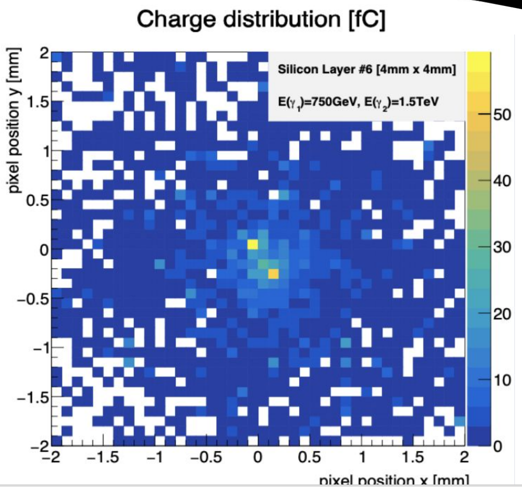
Expected sensitivity assuming no background

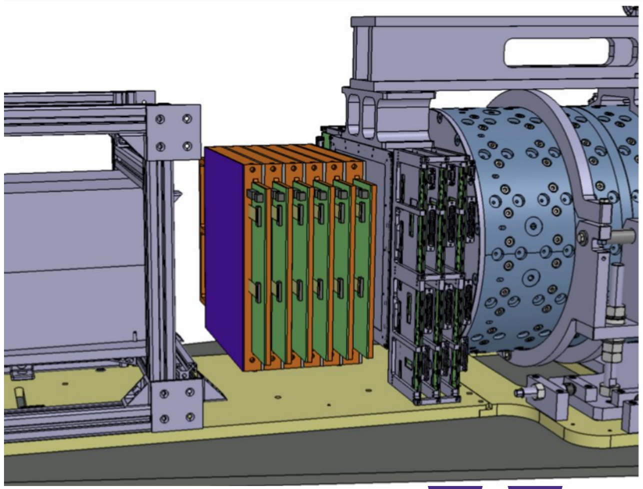


More details in PRD.99.095011 (2019)

Pre-shower upgrade

- Current pre-shower unable to separate closely spaced high energy photons(e.g. from ALP decay)
- Upgrade to enable detecting ALPs$\rightarrow \gamma\gamma$ searches
  - Able to reconstruct 2 high energy photons separately by ~200μm
- New pre-shower: high-resolution silicon pre-shower detector using monolithic pixel ASICs
  - hexagonal pixels of 65μm side
  - Planned to be ready for 2024 data taking

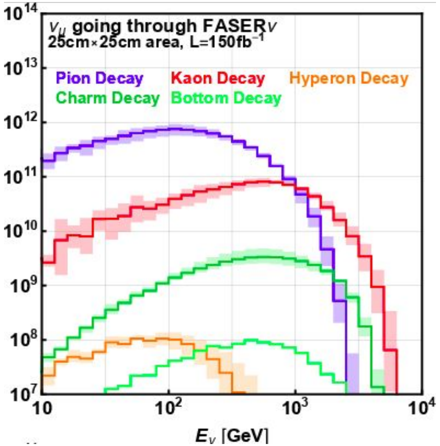




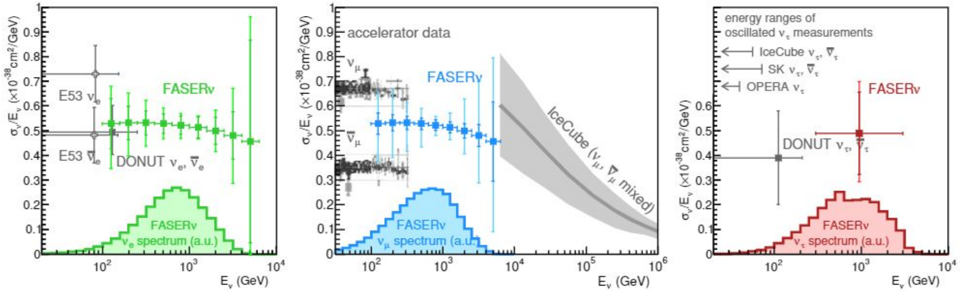
More details in CERN-LHCC-2022-006

Neutrinos from LHC

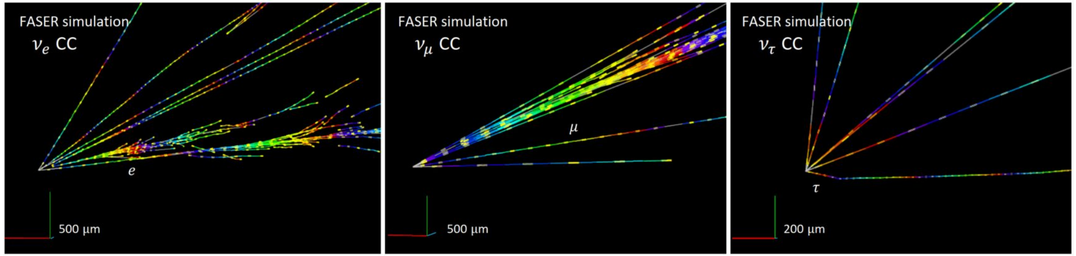
- A huge number of neutrinos produced in the LHC collisions traverse the FASER location covering an unexplored neutrino energy regime
  - Originate from hadron decays, mainly pion, kaon and charm mesons
- FASERν is an emulsion/tungsten detector placed in front of the main FASER detector to detect all flavor of neutrino interactions

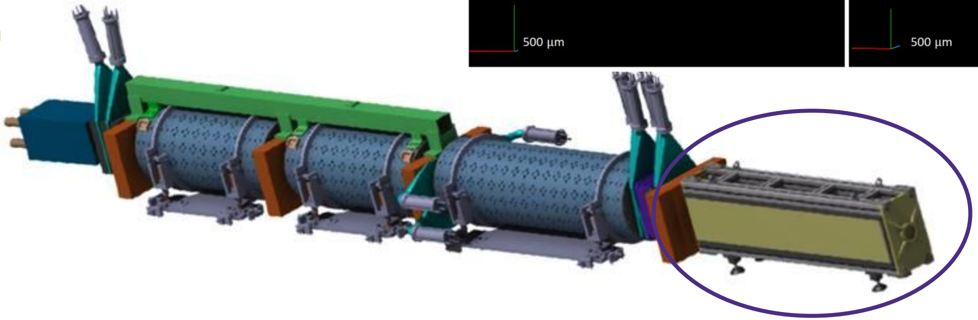


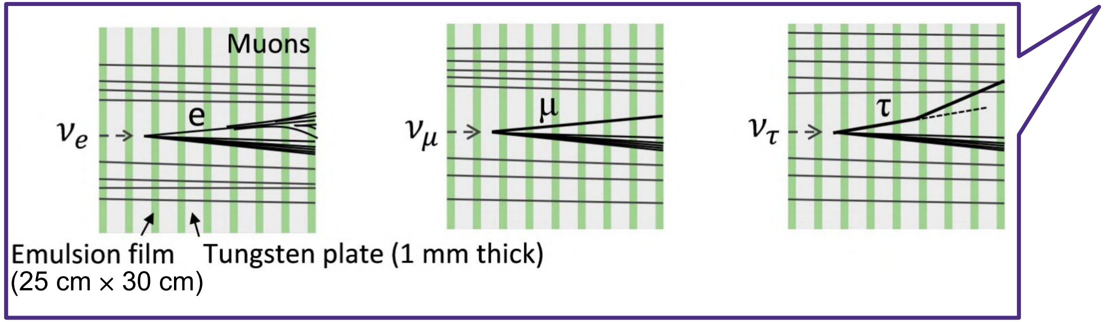
Generators		FASERν		
light hadrons	heavy hadrons	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$
SIBYLL	SIBYLL	901	4783	14.7
DPMJET	DPMJET	3457	7088	97
EPOSLHC	Pythia8 (Hard)	1513	5905	34.2
QGSJET	Pythia8 (Soft)	970	5351	16.1
Combination (all)		1710^{+1746}_{-809}	5782^{+1306}_{-998}	$40.5^{+56.6}_{-25.8}$
Combination (w/o DPMJET)		1128^{+385}_{-227}	5346^{+558}_{-563}	$21.6^{+12.5}_{-6.9}$



FASERν detector







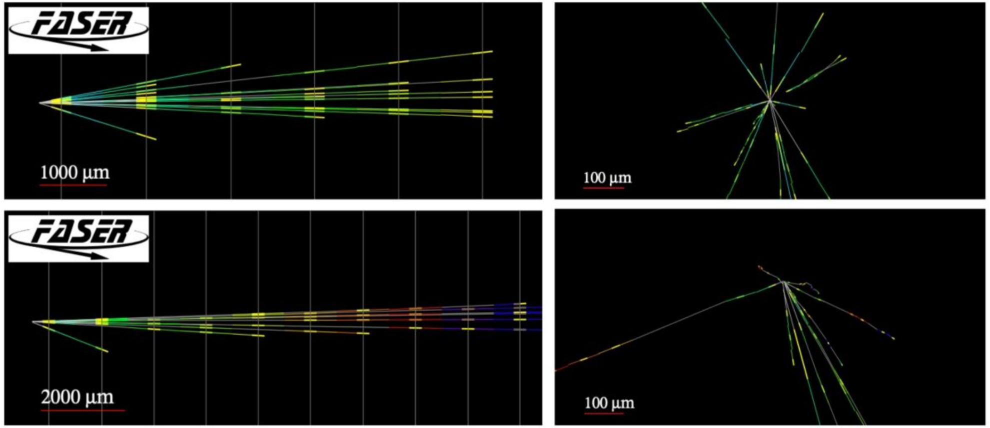
- 730 × 1.1mm thick tungsten plates, interleaved with emulsion films
- 1m long, 1.1 ton detector
- Capable to distinguish all flavours of neutrino
- Emulsion films has excellent position/angular resolution but no time information
- Need to be replaced every ~3 months

Neutrino reconstruction efficiency: >80% with a energy resolution ~30%

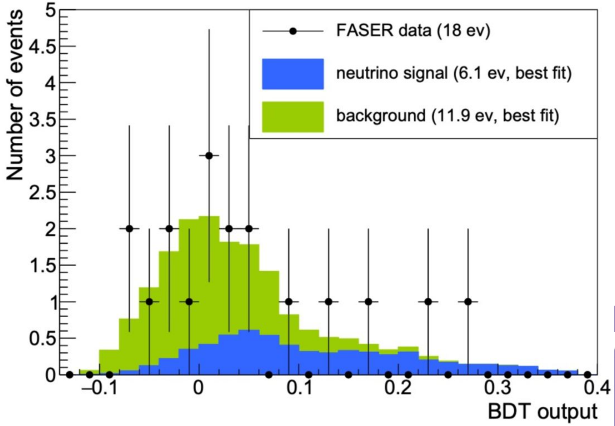
[PRD.104.L091101](PRD.104.L091101)

FASERν pilot run

- A small emulsion detector (10kg target mass) to validate simulation of background particle flux
- 12.2/fb data collected in ~1 month
- 18 neutral vertices detected
- Main background from muon induced neutral hadron
- Best fit on BDT score shows 6.1 neutrino candidates (3.3 expected) with a significance of 2.7σ



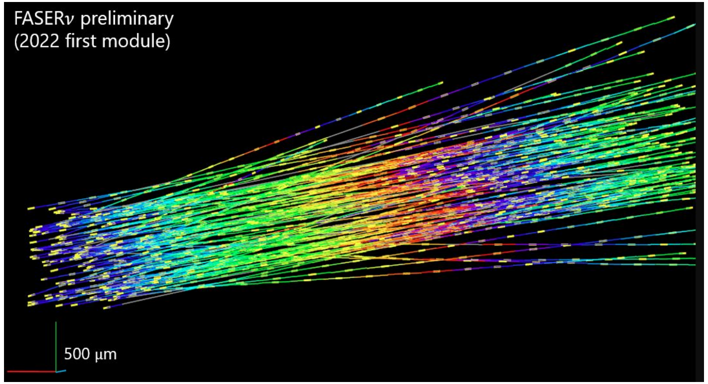
First candidate collider neutrino !

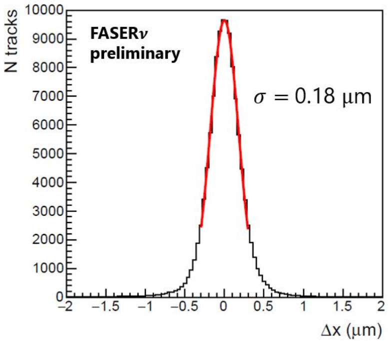


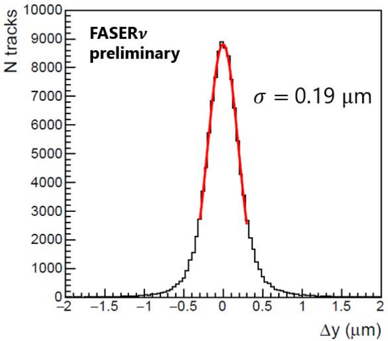
Detector performance - FASERν

- 3 emulsion detectors installed in 2022 running
  - First emulsion detector collected 0.5/fb collision data and used for commissioning and validation of data acquisition and processing
- Measured track multiplicity 2.3×10^4 cm^2/fb^{-1} consist with FLUKA simulation and in-situ measurement in 2018
- Very good spatial resolution (0.2um)
- Across all modules collected 40/fb data

		Integrated luminosity (/fb)	# neutrino interaction expected
2022 1st module	Mar 15 - Jul 26	0.5	~7
2022 2nd module	Jul 26 - Sep 13	10.6	~530
2022 3rd module	Sep 13 - Nov 29	~30	~1000

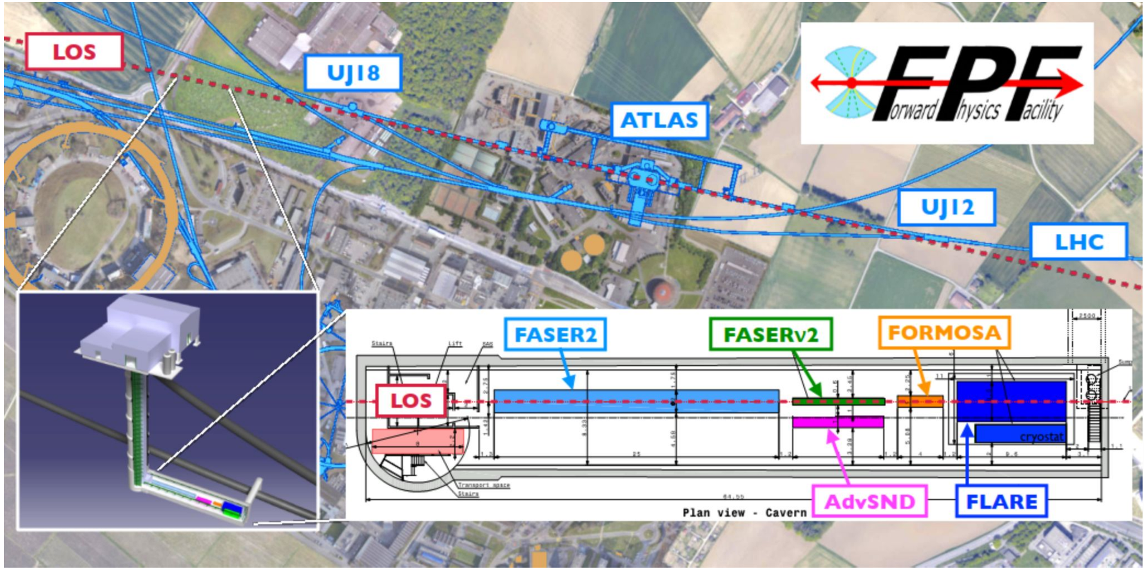




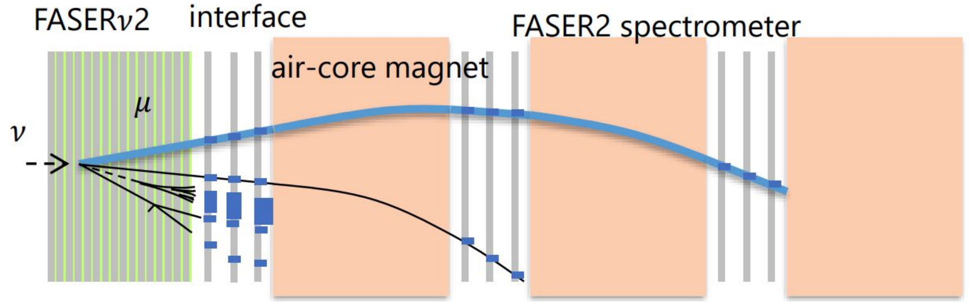


FPF and FASER2

- FASER2 for HL-LHC
  - Radius increased to 1m (FASER is 10cm)
  - Acceptance (π^0) increased to 10% (FASER is 0.6%)
- The FPF is proposal to create a new facility to house a suite of experiments on LOS
  - FASER2
  - FASERnu2
  - AdvSND
  - FLArE
  - FORMOSA



J. Phys. G: Nucl. Part. Phys. 50 030501



40cm×40cm×8m, 20 tons

O(10^5)ν_e ,O(10^6)ν_μ ,O(10^3)ν_τ expected in O(10tons) detector)

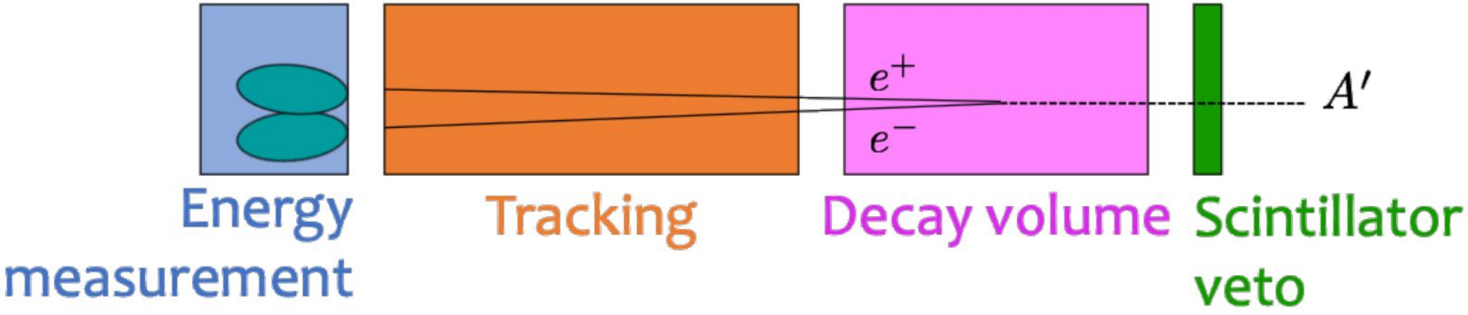
Summary and outlook

- FASER is well constructed and started to collect collision data at July 2022
  - Detector operated well in 2022 running, and collected >40/fb data
  - Will increase the sensitivity for light weakly interacting new particles at the LHC, complementing the other LHC experiments
  - Will make first collider neutrino measurements
- **Aiming to have first results in few weeks**
- Strong physics case emerging for large upgraded FASER2 detectors beyond Run 3, to be housed in the proposed Forward Physics Facility (FPF)

back-up

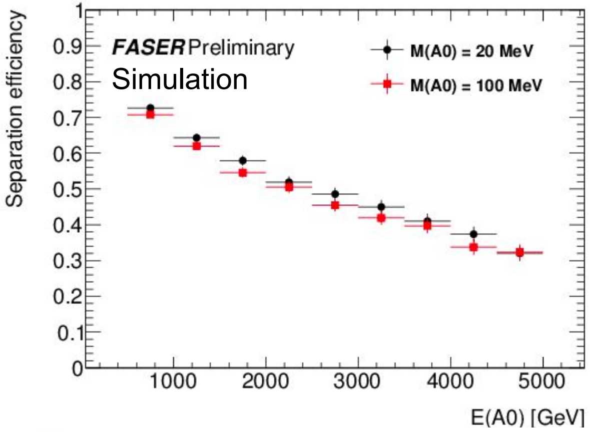
FASER detector

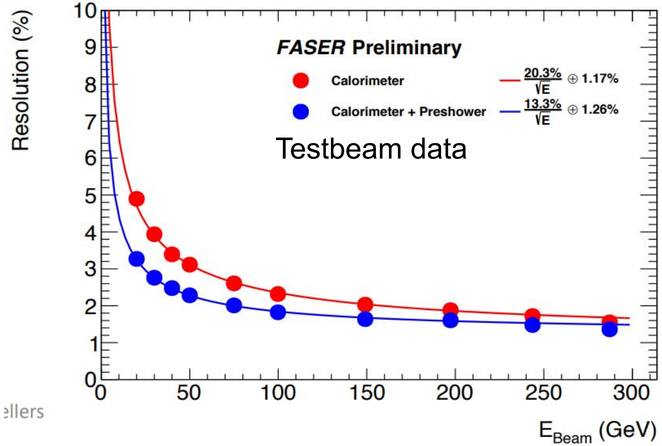
- A veto scintillator to veto charged particles
- A 1.5-meter magnetized decay volume
- A 2-meter magnetic spectrometer with three tracking stations
- An electromagnetic calorimeter
- Three scintillator stations for triggering, veto and precise timing



Key features for BSM search

> Trigger rate O(700 Hz) - dominated by muons
> Muon flux is 1 Hz/cm^2 for $L=2\times10^{34}$ $cm^{-2}s^{-1}$
  – Confirmed by in situ measurements in 2018.
> Tracking detector strip pitch 80 μm with 40 mrad stereo angle
  – ~ 20 μm resolution in precision coordinate
  – ~ 550 μm in the other coordinate
> Good separation for two collimated tracks
> EM shower energy resolution: ~1% for TeV deposits





Detector performance - alignment

> Mean and std of the residuals for each module