The Recent Progress from FASER, Focusing on the Axion-Like Particle Search and Dark Photon Search

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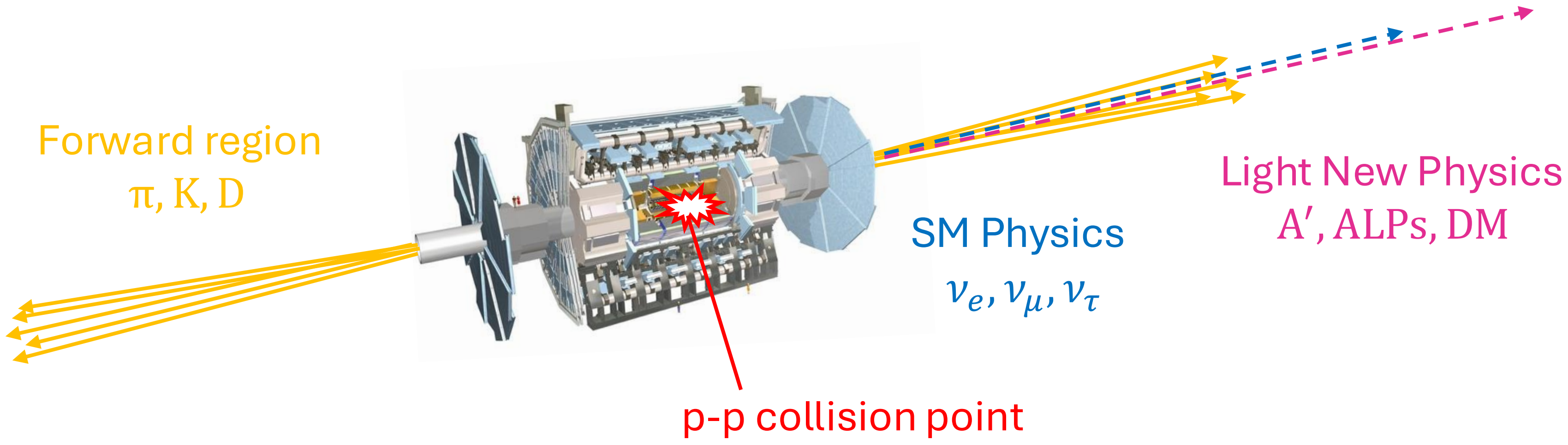
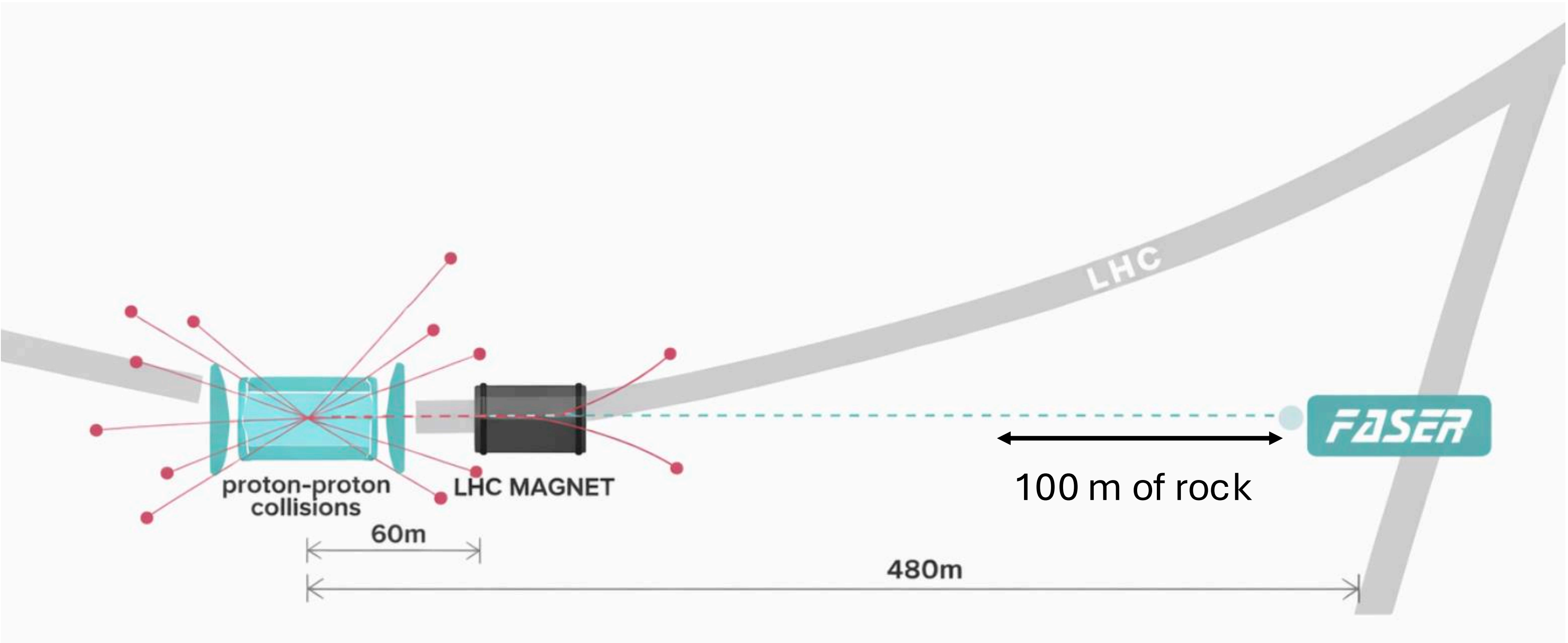
Introduction

- In recent years, light and weakly coupled particles have attracted increasing attention.
  - Naturally explain the correct dark matter relic density.
  - Offer possible explanations for discrepancies between low-energy experiments and theoretical predictions.
- Weakly coupled particles are typically long-lived and travel macroscopic distances before decaying into Standard Model (SM) particles.
- At the LHC, these particles are highly boosted and emitted in a strongly collimated forward direction.



ForwArd Search ExpeRiment (FASER)

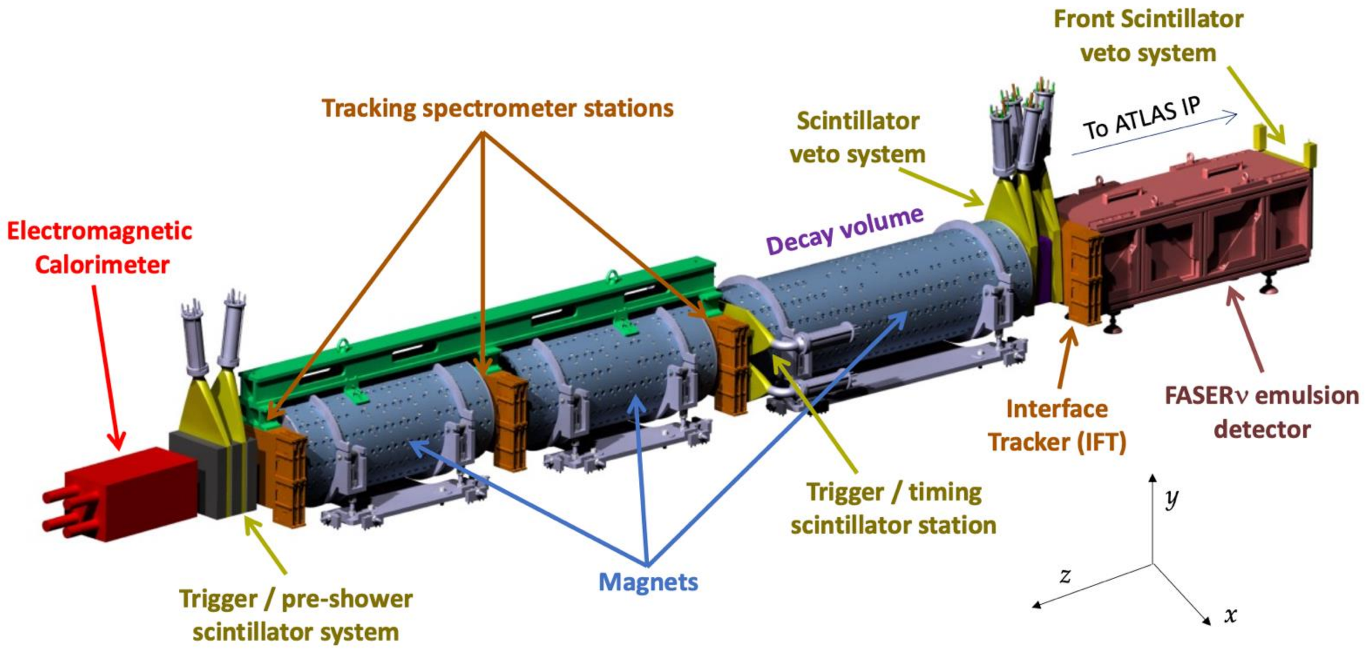
- Designed to **search for Long-Lived Particles (LLPs)** and **study TeV neutrinos** produced in p-p collision at the ATLAS Interaction Point.
- A detector is installed 480 m downstream in the forward direction from the ATLAS proton-proton interaction point.
- A low-background environment is achieved by the LHC magnets and 100 m of rock shielding.

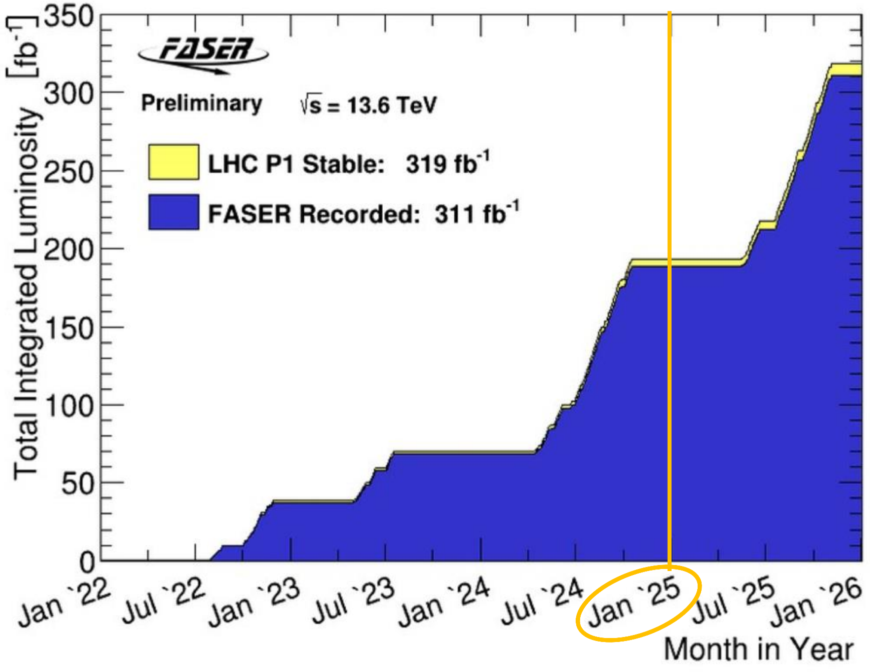


FASER detector

- Small inexpensive detector →
  - 20 cm aperture
  - ~7 m length

- Data taking started in July 2022 and is scheduled to continue until July 2026.
- The new preshower detector was installed in February 2025.





- By January 2026, an integrated luminosity of 311 fb^{-1} has been recorded.
- Current FASER analyses use data up to January 2025.

Today's topic

This talk introduces the current dark photon search and ALP search at FASER.

- Dark photon search
  - Update of the results presented in 2023
  - Improved statistics and analysis methodology
  - Preparation is on going for the Moriond in March
- ALP search
  - Update of the results presented in 2025
  - Improved statistics and analysis methodology
  - Preparation is on going for the Moriond in March
- Future prospect
  - New preshower detector
  - Prototype detectors for Run4

[Dark photon status]

	Previous analysis	Current analysis
Integrated luminosity	$27.0\ \mathrm{fb}^{-1}$	$177.4\ \mathrm{fb}^{-1}$
Excluded limits	$\varepsilon \sim 4 \times 10^{-6} - 2 \times 10^{-4}$ $m_{A'} \sim 10\ \mathrm{MeV} - 80\ \mathrm{MeV}$	Awaiting result

[ALPs status]

	Previous analysis	Current analysis
Integrated luminosity	$57.7\ \mathrm{fb}^{-1}$	$176.5\ \mathrm{fb}^{-1}$
Excluded limits	$g_{aWW} \sim 10^{-4}$ GeV $m_a < 300\ \mathrm{MeV}$	Awaiting result

Dark photon search

Dark photon

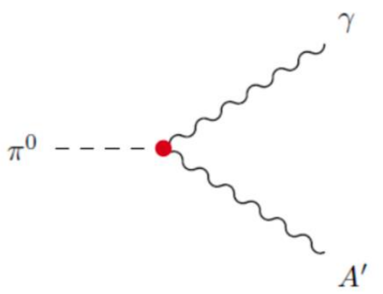
- Dark photon(A')
  - Predicted as a portal particle connecting the Standard Model and the dark sector
  - Provides a natural explanation for thermal relic dark matter

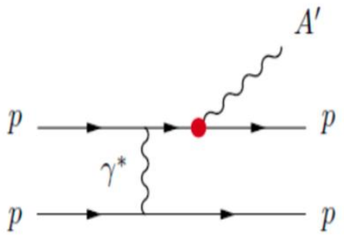
$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon e \sum_f q_f \, A'^\mu \bar{f} \gamma_\mu f$$

Dark photon with mass $m_{A'}$ couples to the SM via kinematic mixing parameter ϵ

Production

- Main Sources
  - Light meson decay (π^0, η)
  - Dark Bremsstrahlung





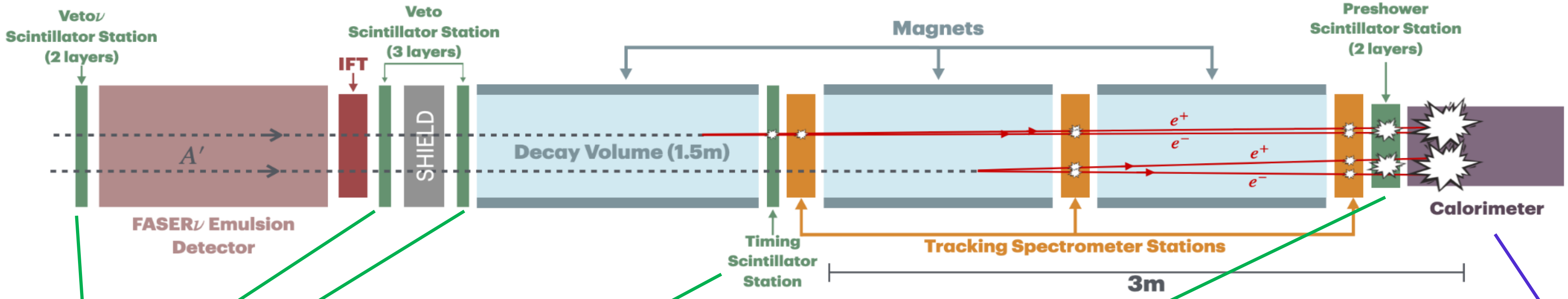
Decay

- Dominant decay mode
  - $A' \rightarrow e^+e^-$
- FASER sensitive:
  $\epsilon \sim 10^{-5}, m_{A'} \sim 10 - 100$ MeV
- For $2m_e < m_{A'} < 2m_\mu \sim 211$ MeV,
  $\mathrm{Br}(A' \rightarrow e^+e^-) \approx 100\%$

Dark photon analysis

- Data set : 2022, 2023, 2024 physics run data(total luminosity is 177.4 fb^{-1})
- Target signal : $A' \rightarrow e^{+}e^{-}$
- Event selection :

1) One plus track signal region : Decay inside the decay volume with at least one track
2) Segment signal region : Decay downstream of the decay volume with at least two segmentations
3) Two track signal region : Decay inside the decay volume with two tracks



Veto Scintillator cut
1) One plus track SR: no signal
2) Segment SR : no signal
3) Two track SR : no signal

Timing Scintillator cut
1) One plus track SR: signal
2) Segment SR : no signal
3) Two track SR : signal

Preshower cut
1) One plus track SR: signal
2) Segment SR : PS ratio > 4
3) Two track SR : signal

Calorimeter energy cut
1) One plus track SR: ≥ 500 GeV
2) Segment SR : ≥ 500 GeV
3) Two track SR : ≤ 500 GeV

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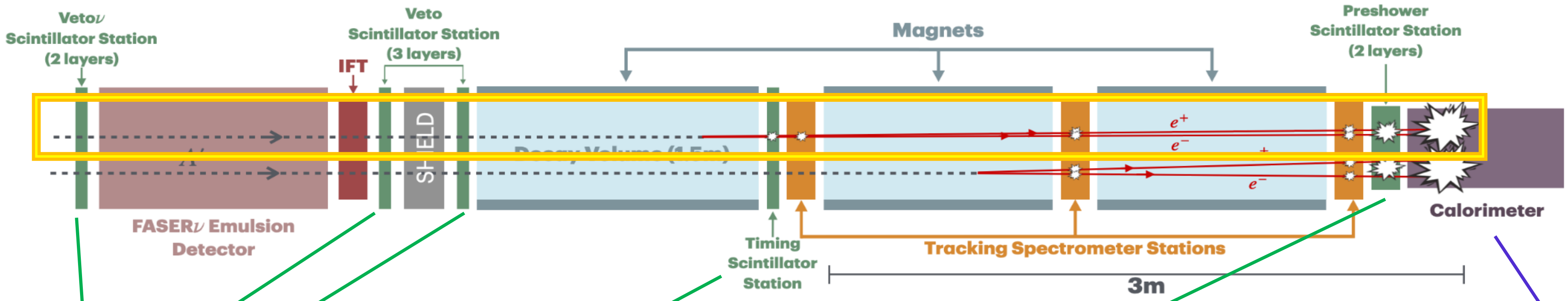

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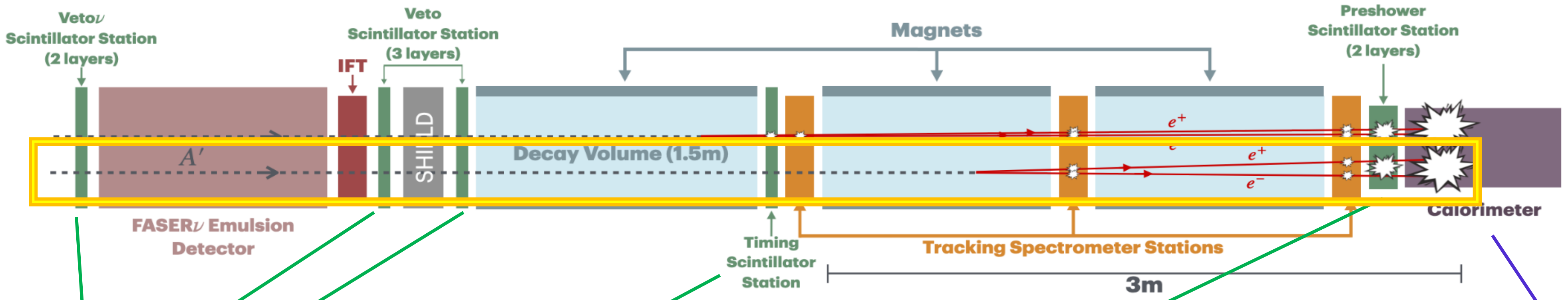

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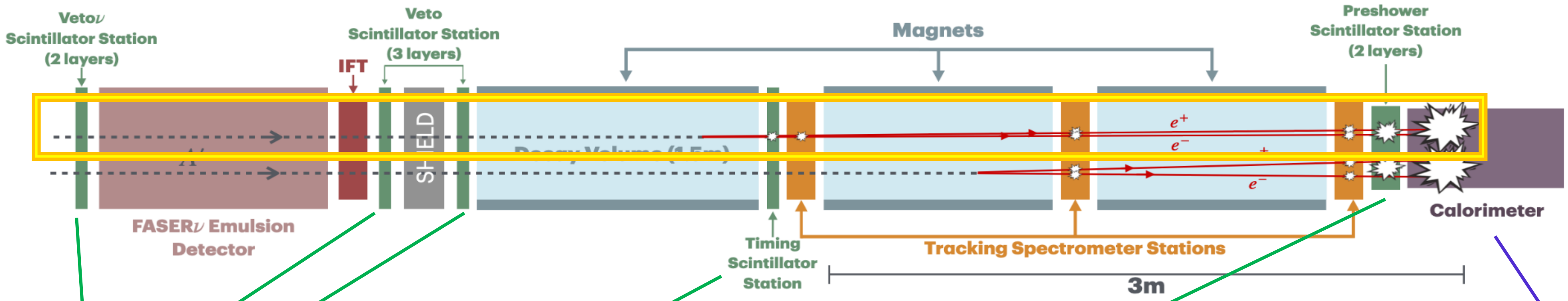

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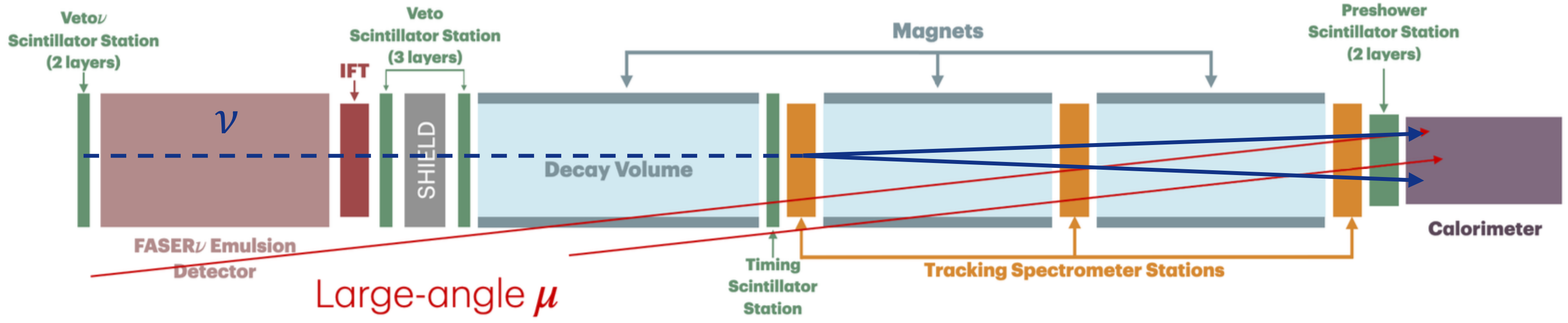
3) **Two track SR : $\leq$ 500 GeV**

Dark photon Backgrounds

The LHC magnets and about 100 m of rock allow FASER to operate in a very low-background environment.

- Background components

1) Neutrino background
2) Geometric Muon background
3) Neutral Hadron background
4) Cosmic background
5) Beam background
6) Veto inefficiency



- Neutrino-induced background events are the dominant contribution. ⟶ still negligible in rate
- Geometric muon background contributes only to the segment signal region.
- All other background contributions are estimated to be zero in all signal regions.

Backgrounds are suppressed to negligible levels.

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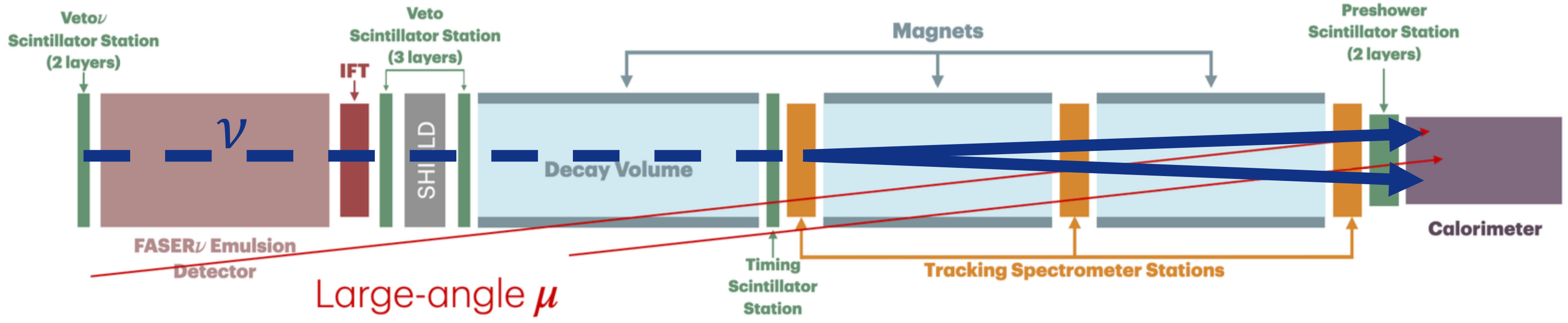

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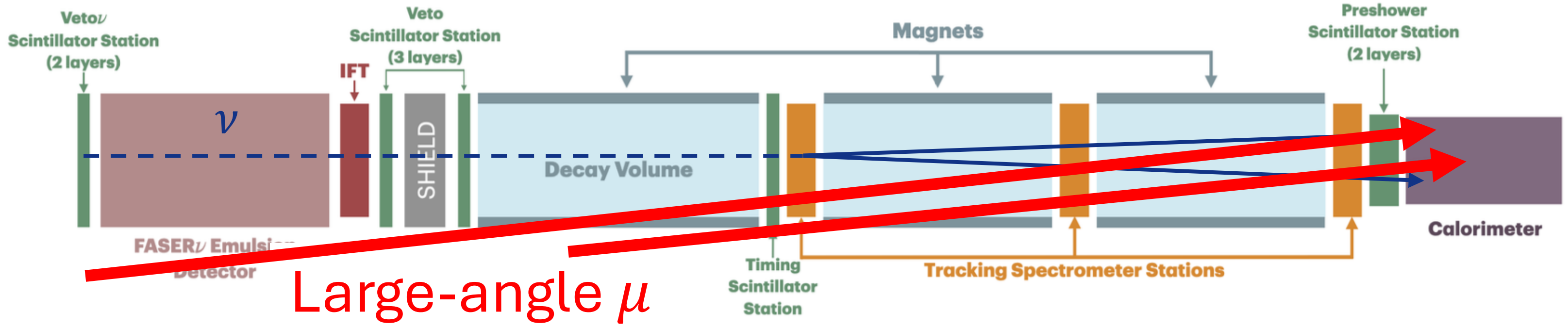

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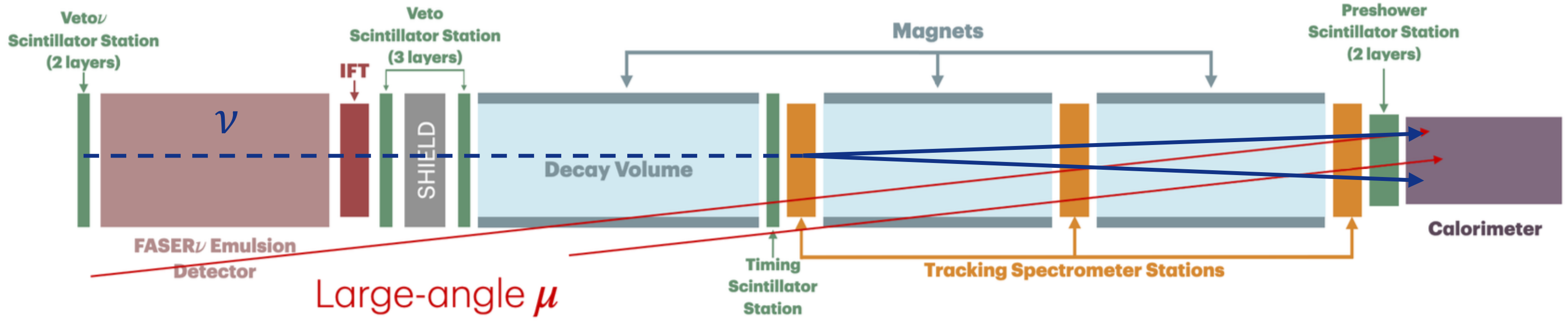

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Dark photon Systematics

- Systematics components

1) Signal Systematics
   - MC statical uncertainty
   - Luminosity uncertainty
   - Modeling of the dark photon flux

2) Detector Systematics
   - Preshower systematics
   - Calorimeter systematics
   - Veto Scintillator systematics
   - Timing Scintillator systematics

Source	Value	Effect on Signal Yield
Theory, Statistics and Luminosity		
Dark Photon Generation (from mesons)	15%	15% ± 13% (44%)
Dark Photon Generation (from dark Bremsstrahlung)	22%	22% ± 30% (132%)
Luminosity	1.9%	1.9%
MC Statistics	$\sqrt{\sum W^2}$	1-3%
Tracking: One Track		
Momentum Scale	5%	<0.5%
Momentum Resolution	5%	<0.5%
Single Track Efficiency	1.22%	1.22%
Tracking: Two Track		
Two Track Efficiency	~ 1% (3.5%)	~ 1% (3.5%)
Tracking: Segment		
Segment Efficiency	2.8-6.07%	2.8-6.07%
Preshower		
Preshower Ratio	3.6%	3% ± 3% (10%)
Calorimeter		
Calo E Scale	5.46%	3% ± 3% (11%)

Systematic studies are ongoing and the values may be updated.

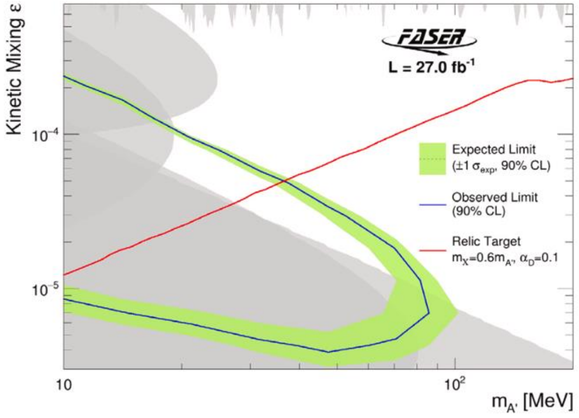
Summary of systematic uncertainties for three signal regions

Expected sensitivity

- Provides a direct test of the thermal dark photon target at the LHC.
- Improvement beyond the 2023 result is expected.
- The data remain blinded.
- Final results are planned to be presented at Moriond.

Previous results

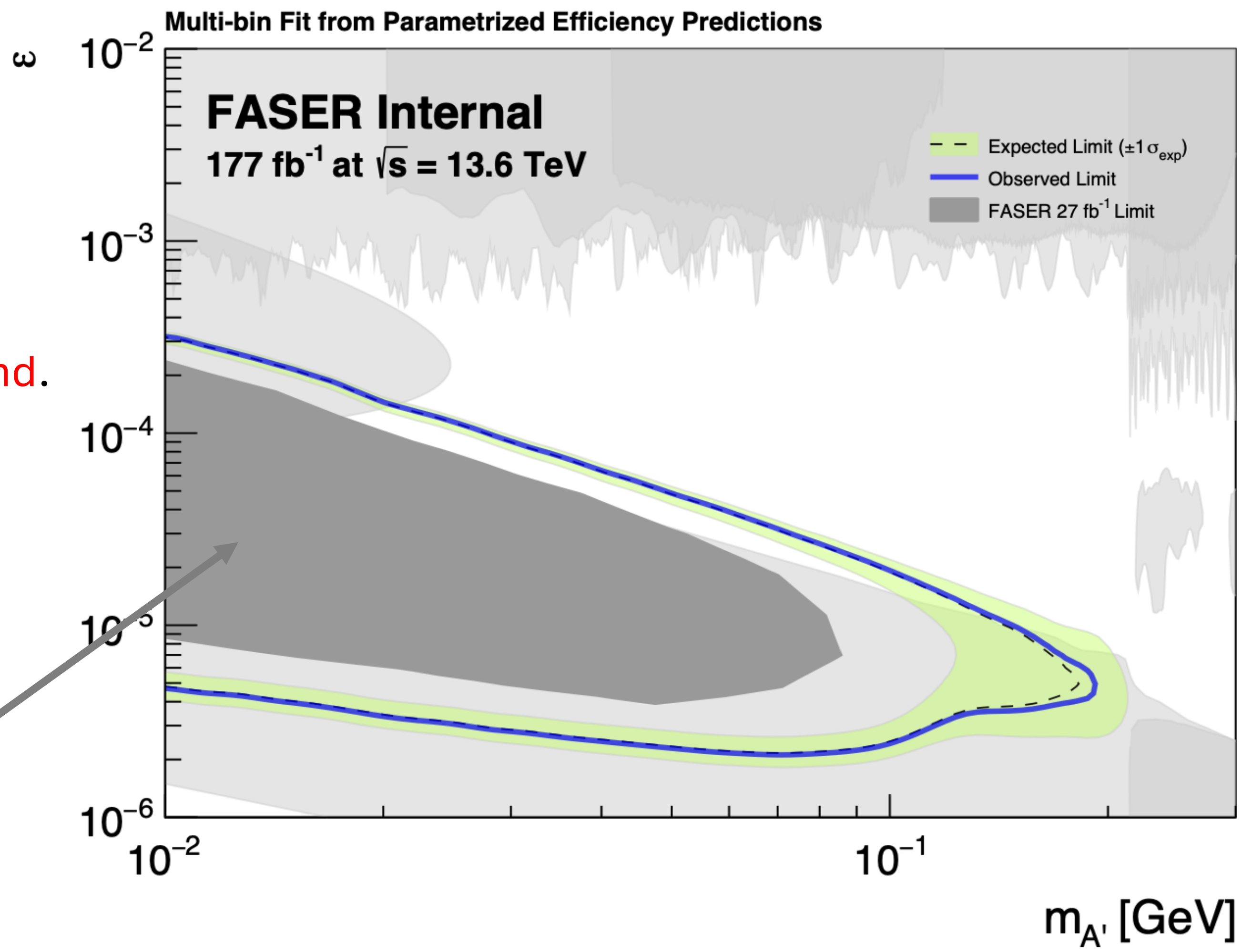
- Published in 2023 (FASER Coll., PLB 846 (2023) 138378)
- Only use 2022 data (27.0 fb^{-1})
- No events seen in the SR.



[Excluded region]

$\varepsilon \sim 4 \times 10^{-6} - 2 \times 10^{-4}$

$m_{A'} \sim 10\ \text{MeV} - 80\ \text{MeV}$



- The observed limit assumes **0 Dark photon events**.

ALPs search

ALPs

- ALPs(a) :

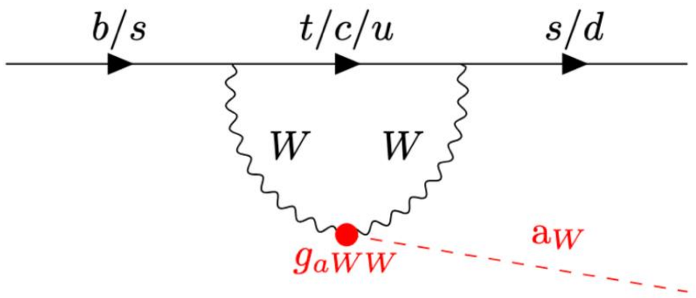
Models in which ALPs couple to $\mathrm{SU}(2)_{\mathrm{L}}$ gauge bosons before electroweak symmetry breaking (EWSB) exhibit particularly favorable phenomenology for FASER.

$$\mathcal{L} \supset -\frac{1}{2} m_a^2 a_W^2 - \frac{1}{4} g_{aWW} a_W W^{a,\mu\nu} \widetilde{W}^a_{\mu\nu}$$

ALPs with mass m_a couples to the SM via parameter g_{aWW}

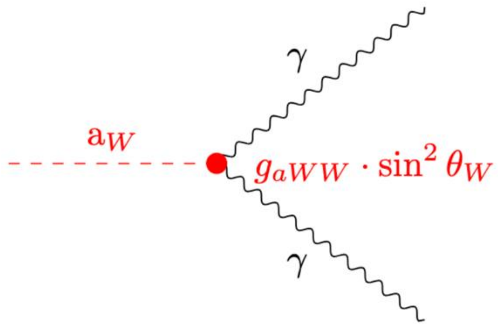
Production

- Main Sources
  - FCNC decay ($B^0, B^{\pm}$ decay)



Decay

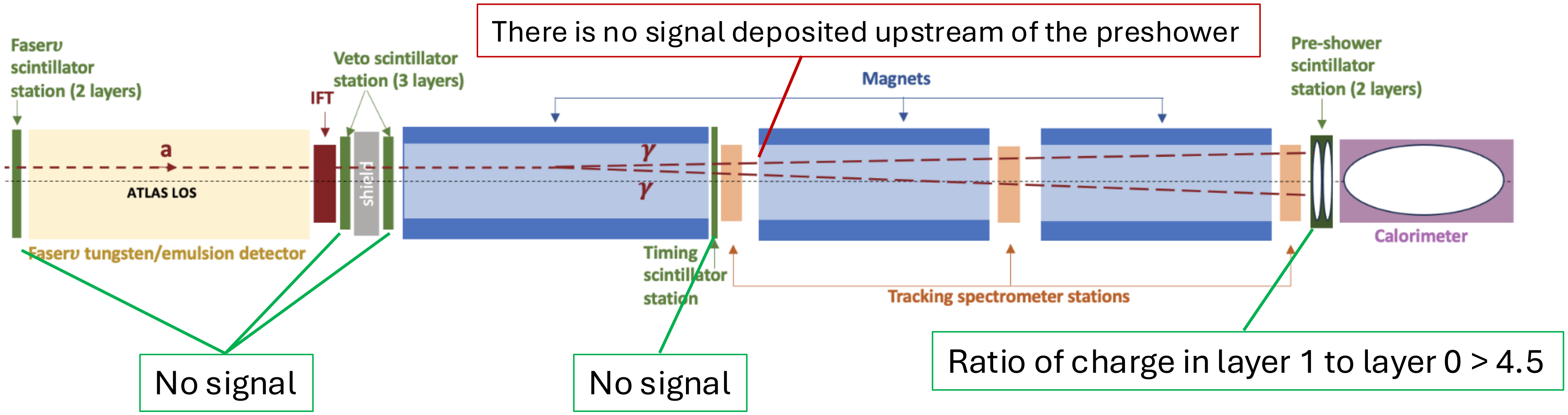
- ALP-W dominantly decays into two photons
  - $a \to \gamma\gamma$ (dominant at low mass: ~100%)



ALPs analysis

- Data set : 2022, 2023, 2024 physics run data(total luminosity is 176.5 fb^{-1})
- Target signal : $a \rightarrow \gamma\gamma$
- Event selection:

1) Single bin signal region : Requirement of 1.5(1.0) TeV in the calorimeter
2) Multi bin signal region : Divide the data into bins based on the calorimeter energy (250-300 GeV, 300-600 GeV, 600- 1000 GeV, +1000 GeV)



ALPs Backgrounds

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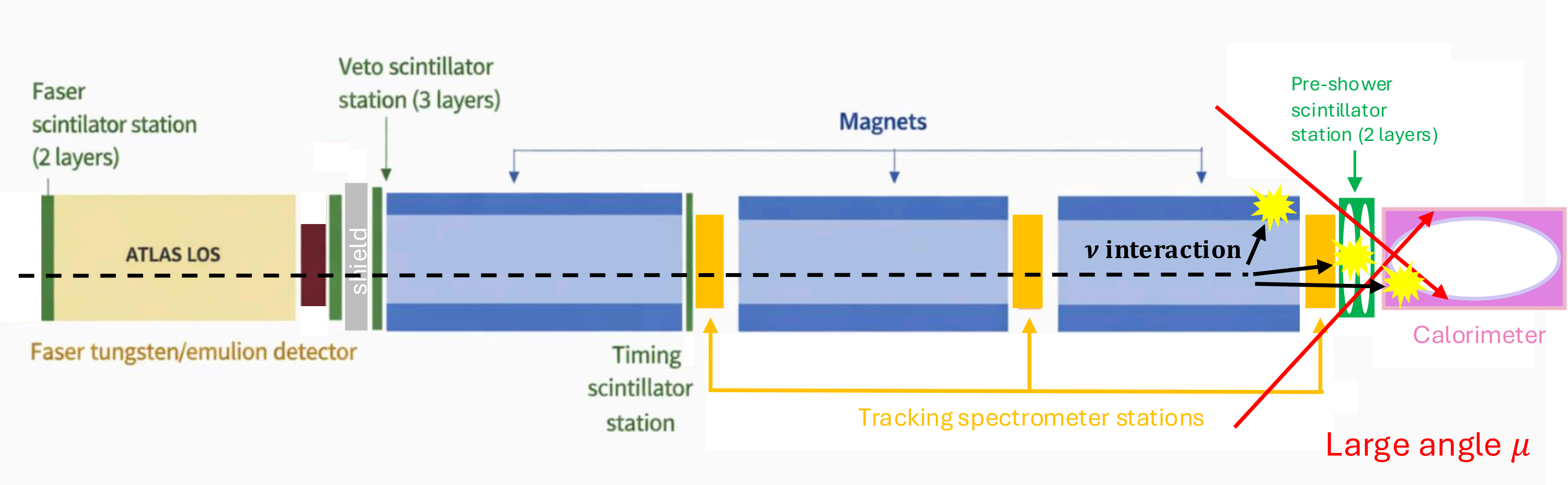

- Neutrino-induced background events are the dominant contribution.
  - Electron neutrino events provide the dominant contribution.
- Geometric muon background is sufficiently small compared to the neutrino-induced background.
- All other background contributions are estimated to be zero in all signal regions

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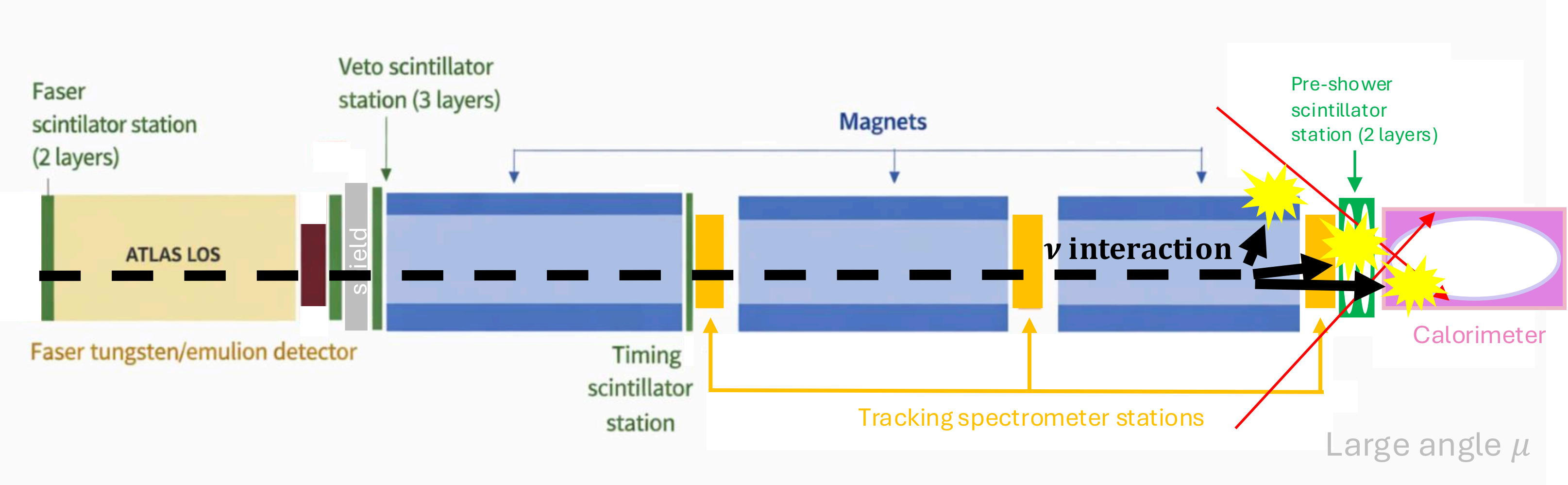

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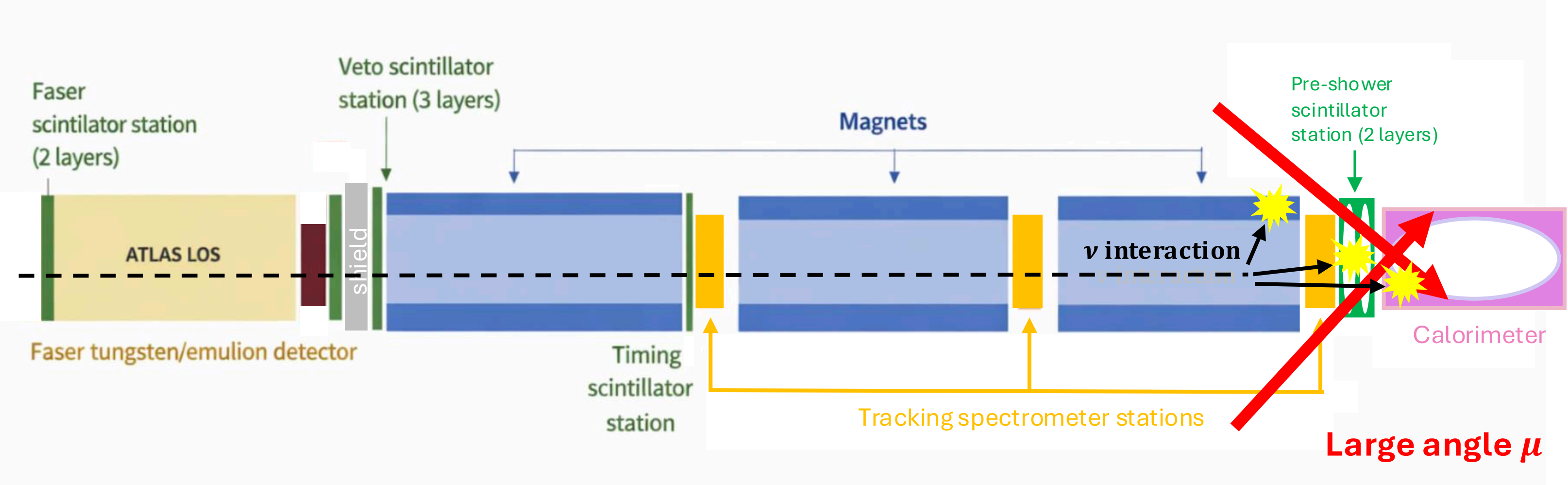

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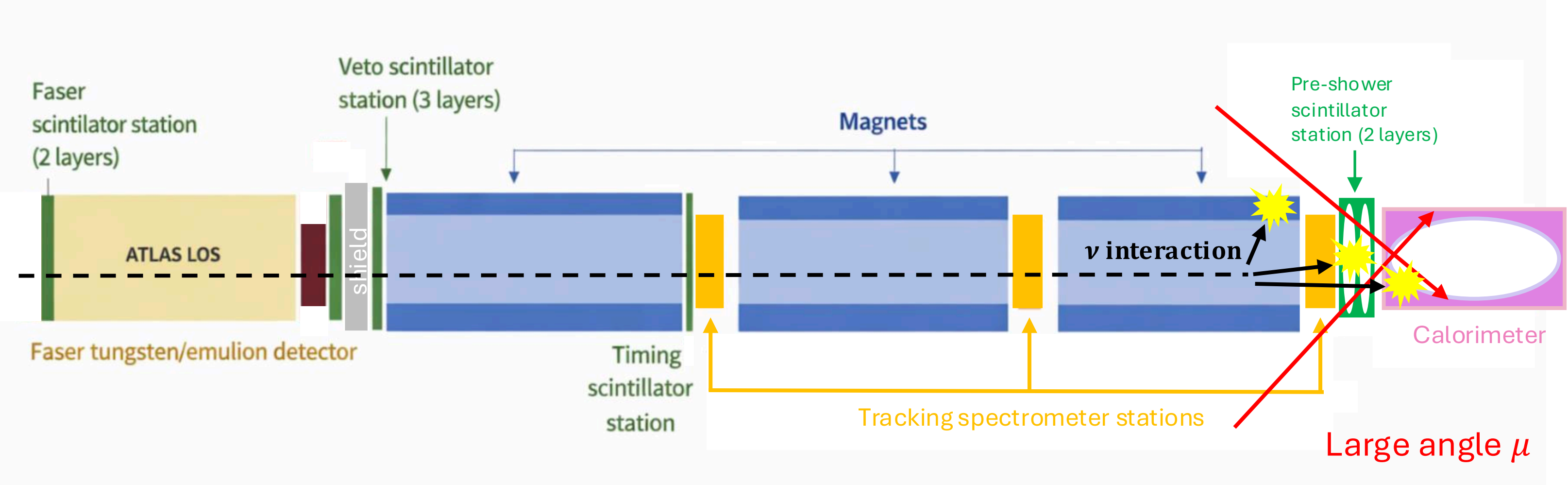

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ALPs Systematics

- Systematics components

1) Signal Systematics
   - MC statical uncertainty
   - Luminosity uncertainty
   - Modeling of the ALPs flux

2) Detector Systematics
   - Preshower systematics
   - Calorimeter systematics
   - Veto Scintillator systematics
   - Timing Scintillator systematics

Systematic studies are ongoing and the values may be updated.

Source	Value	Effect on signal yield
ALP Signal Generator	30-70%	30-70% (30-60%)
Luminosity	2.2%	2.2%
MC Statistics	$\sqrt{\sum W^2}$	1-7% (1-2%)
Preshower Ratio	3.2%	1-4% (1-4%)
Preshower Layer 1	3.4%	0-0.2% (0-0.2%)
Calo E scale	5.46%	0-25% (0-20%)

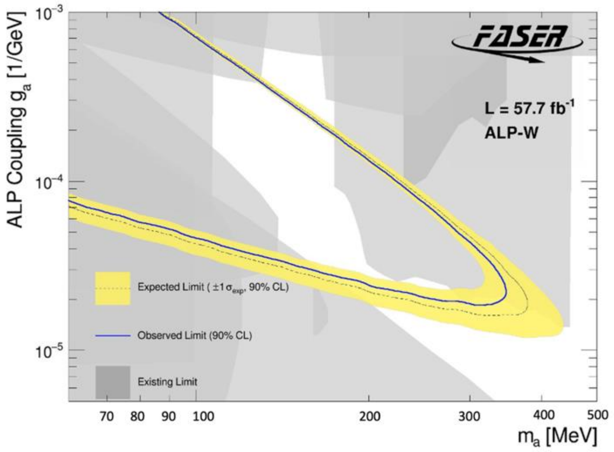
- The systematic uncertainty is dominated by the uncertainty on the signal generators.

Expected sensitivity

- This analysis has the potential to improve upon the current world-leading sensitivity.
- The data remain blinded.
- Final results are planned to be presented at Moriond.

Previous Result

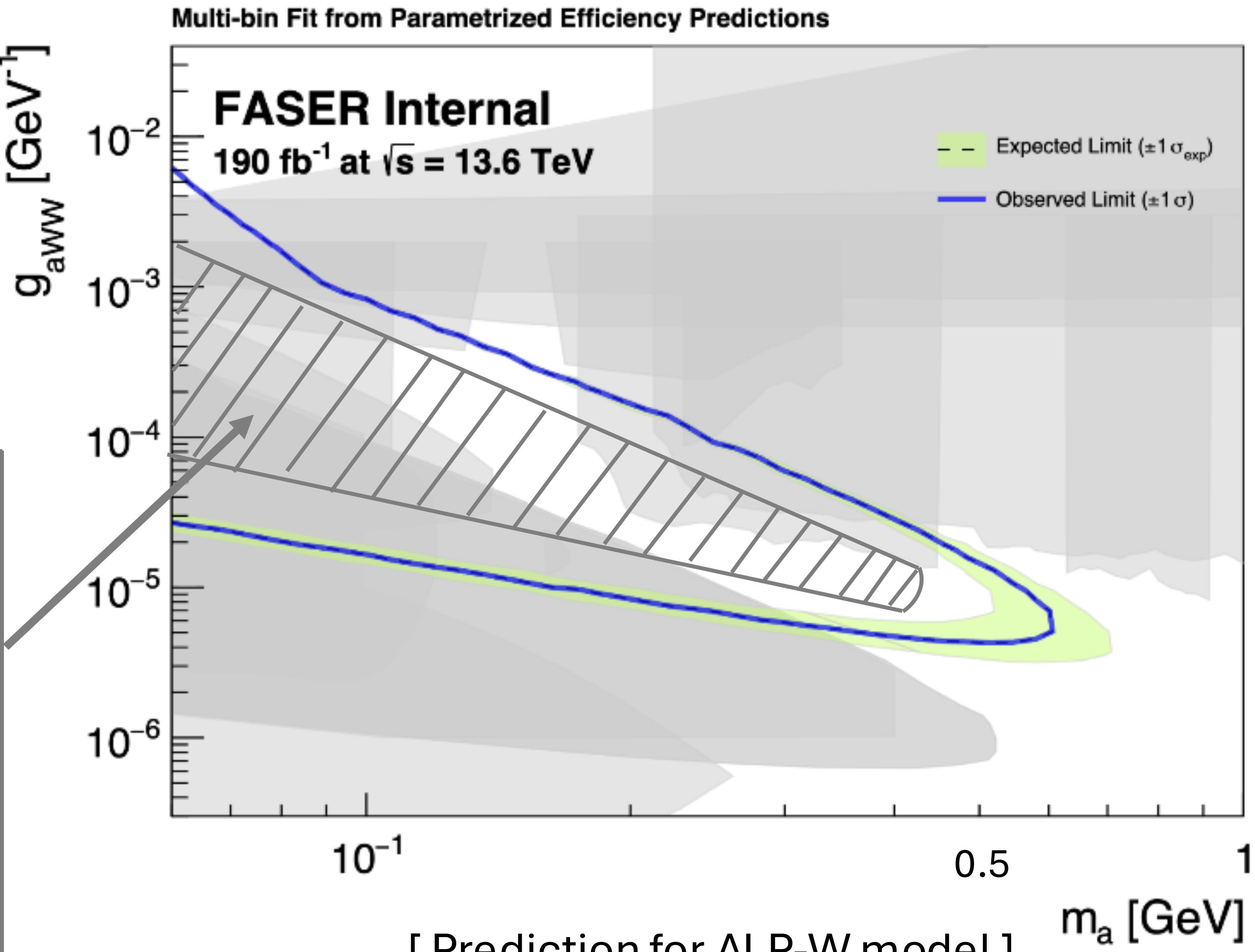
- Published in 2025 (FASER Coll., JHEP 01 (2025) 199)
- Use 2022 and 2023 data (57.7 fb^{-1})
- 1 events seen in the SR



[Excluded region]

$g_{aWW} \sim 10^{-4}$ GeV

$m_a < 300\ \mathrm{MeV}$



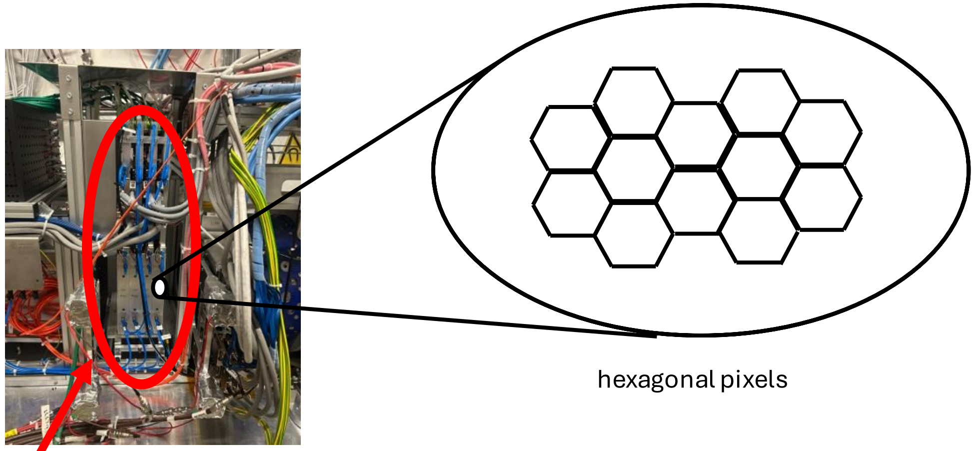
[Prediction for ALP-W model]

- Set placeholder background(0.01)
- Not considering systematic uncertainties

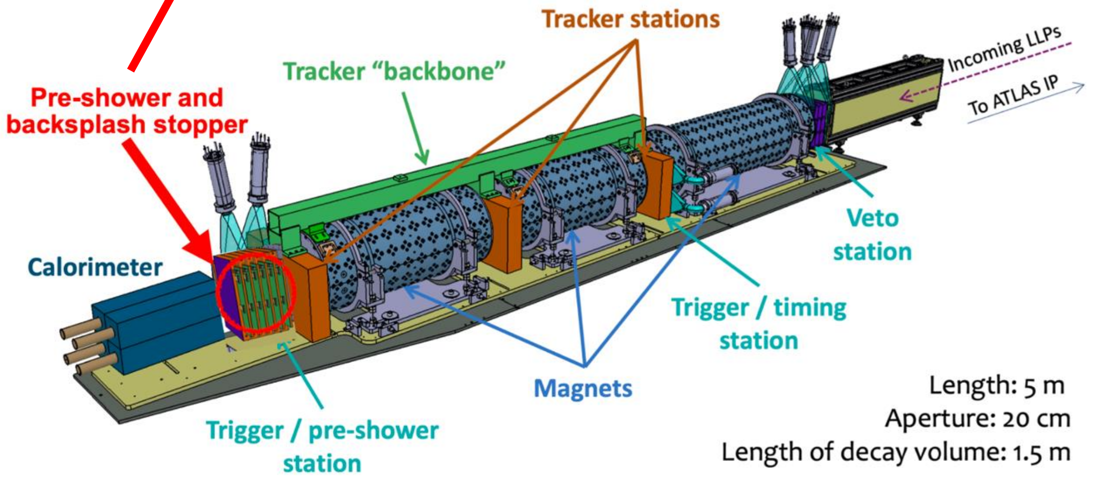
Future prospect

New Preshower Detector

- A new preshower detector using a monolithic silicon pixel sensor was installed in February 2025.



hexagonal pixels



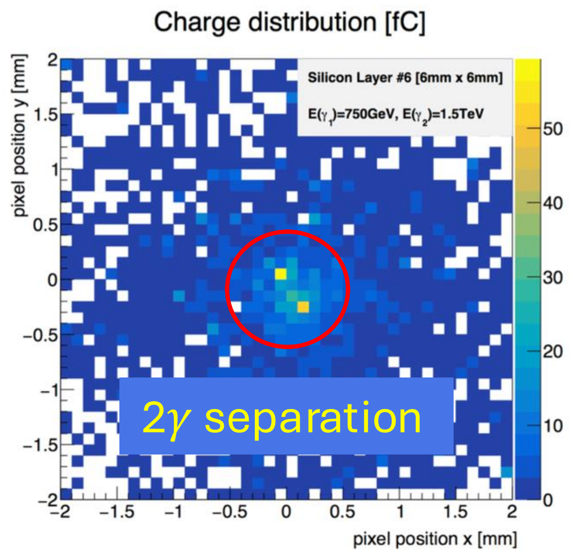
- Four alternating layers of tungsten absorbers and silicon pixel detectors

- Sensor area composed of hexagonal pixels
  - Side of length : ~ 65 μm
  - Vertical pixel pitch : ~ 112 μm
  - Horizontal pixel pitch : ~ 98 μm

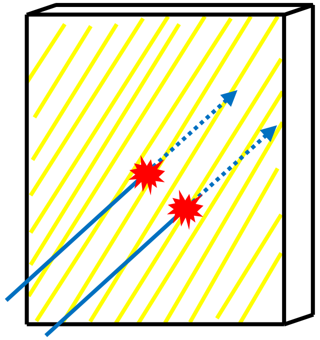
- Structure of a Single Layer
  - 12 modules
  - 6 ASICs per module
  - 26624 pixels per ASCI

→ Total : ~11.5 M pixels per layer

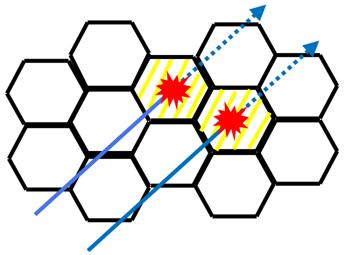
New Preshower Detector



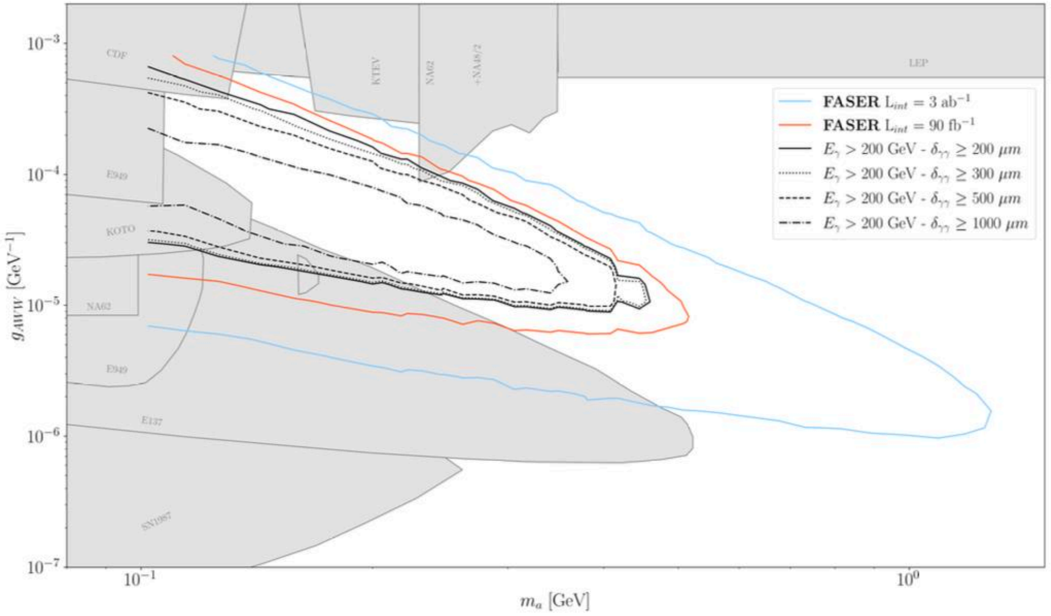
- The main purpose is to separate two photons and increase the ALP sensitivity.
- Current analysis uses a scintillator-based preshower.
  - The two photons cannot be spatially resolved.
  - Event selection relies solely on the deposited charge.
- The new silicon pixel preshower detector can resolve the two photons.
  - Background events can be suppressed even at high statistics such as Run4.
  - Improvement in the ALP search sensitivity is expected.



scintillator-based preshower



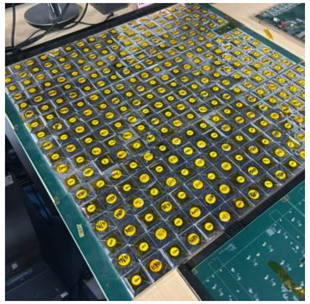
silicon pixel preshower



Prototype Detectors for Run4

AHCAL and FASERCal were installed as a prototype for Run 4.

- AHCAL
  - Active Layer × 40 + Absorber × 39 + Veto × 2
  - SiPM × 18 × 18 (324 channels per layer)
  - Installed in this January



- FASERCal
  - 20 layers of scintillating cubes
  - 48x48 cubes per layer
  - Installed in this January

These detectors are placed off-axis(away from the beam collision axis)

⟶ Expected to improve sensitivity to new particles

Summary

- The FASER provides an opportunity to search for long-lived particles produced at the LHC interaction point and emitted in the forward direction.

- Searches for dark photons and ALPs are ongoing.

  → **Final results are expected to be presented at Moriond.**

- A new preshower detector was installed in February 2025, and data taking is ongoing.

  → Expected to improve ALPs sensitivity

- Prototype detectors(AHCAL and FASERCal) for Run4 were installed this January.

  → Data taking will start in March.