Tracking system R&D for the DarkSHINE experiment

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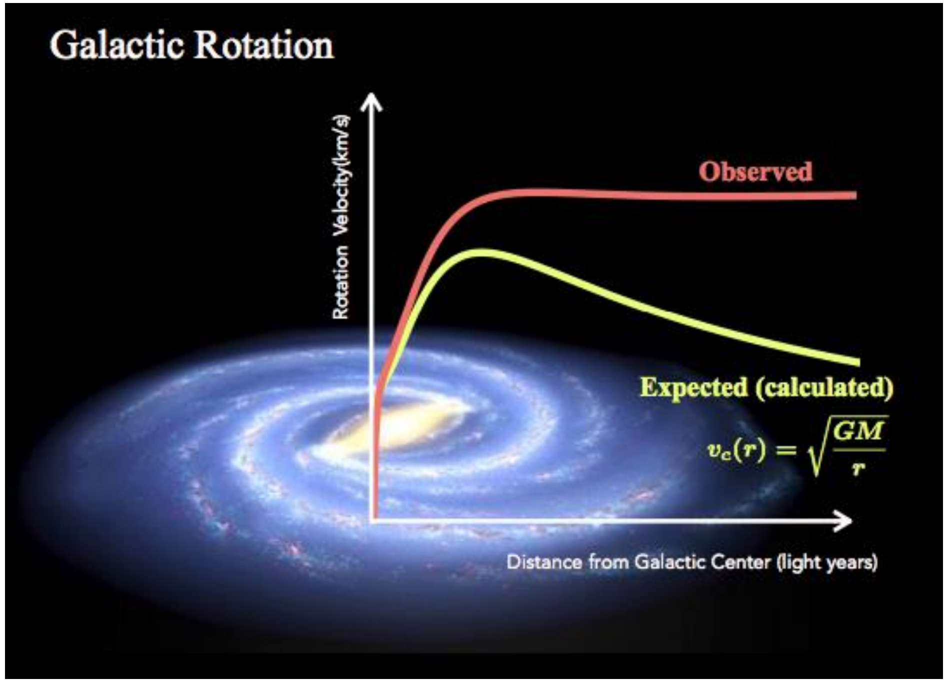
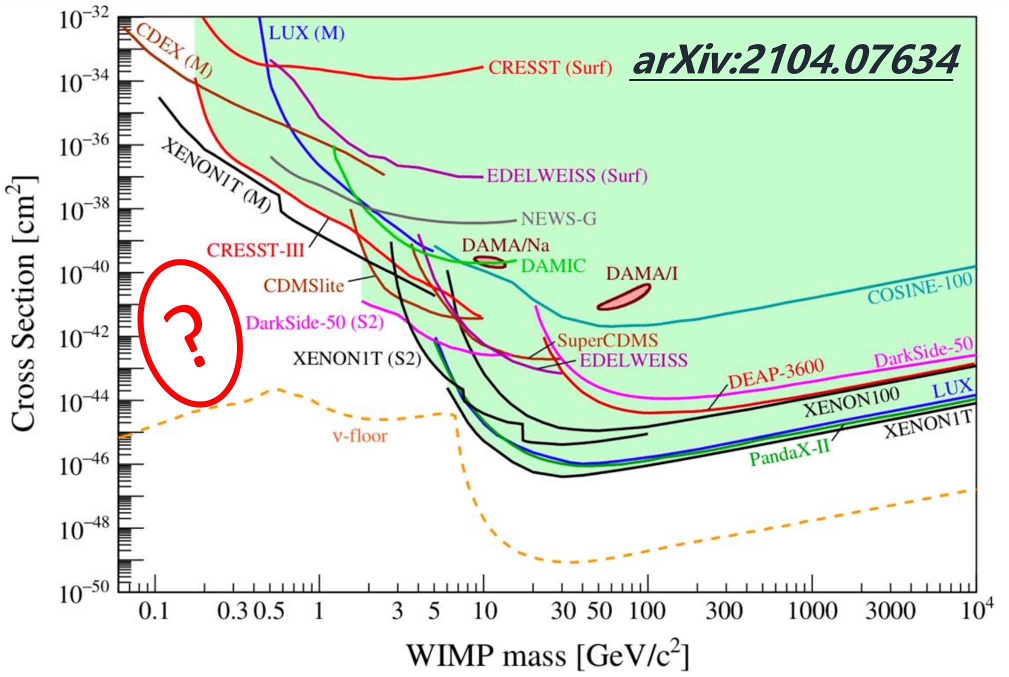
Tsung-Dao Lee Institute

Shaan Xi, April17-20 2025

Physics motivation

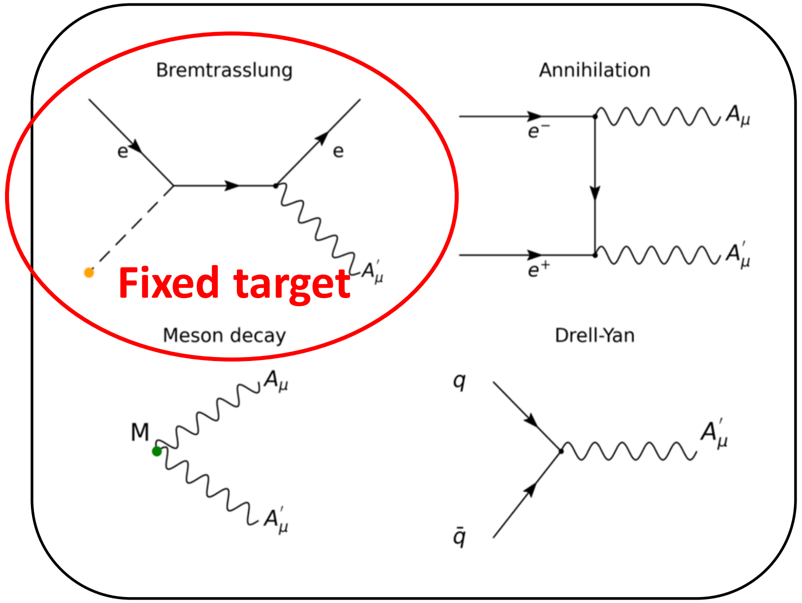




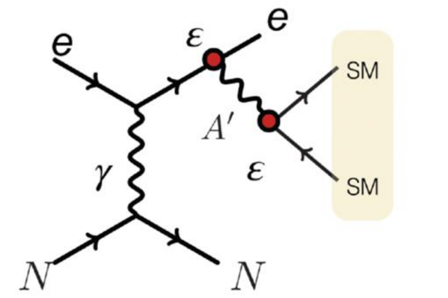
- Cosmological observation has proved the existence of dark matter
- No evidence that dark matter as WIMP exists yet, a large parameter space ruled out in GeV~TeV mass range
- In the sub-GeV range, dark photon hypothesis is brought out as the force carrier and portal between ordinary matter and dark sector

Physics process and anticipated signatures

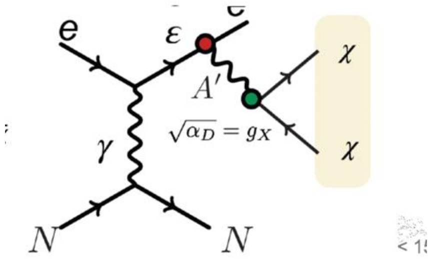
Dark photon production modes



VISIBLE DECAY MODE $m'_A < 2m_X$



INVISIBLE DECAY MODE $m'_A > 2m_X$



Having two interaction vertices → production rate highly supressed

$$N \propto \epsilon^4 \ll N \propto \epsilon^2(1-\epsilon^2) \approx \epsilon^2$$

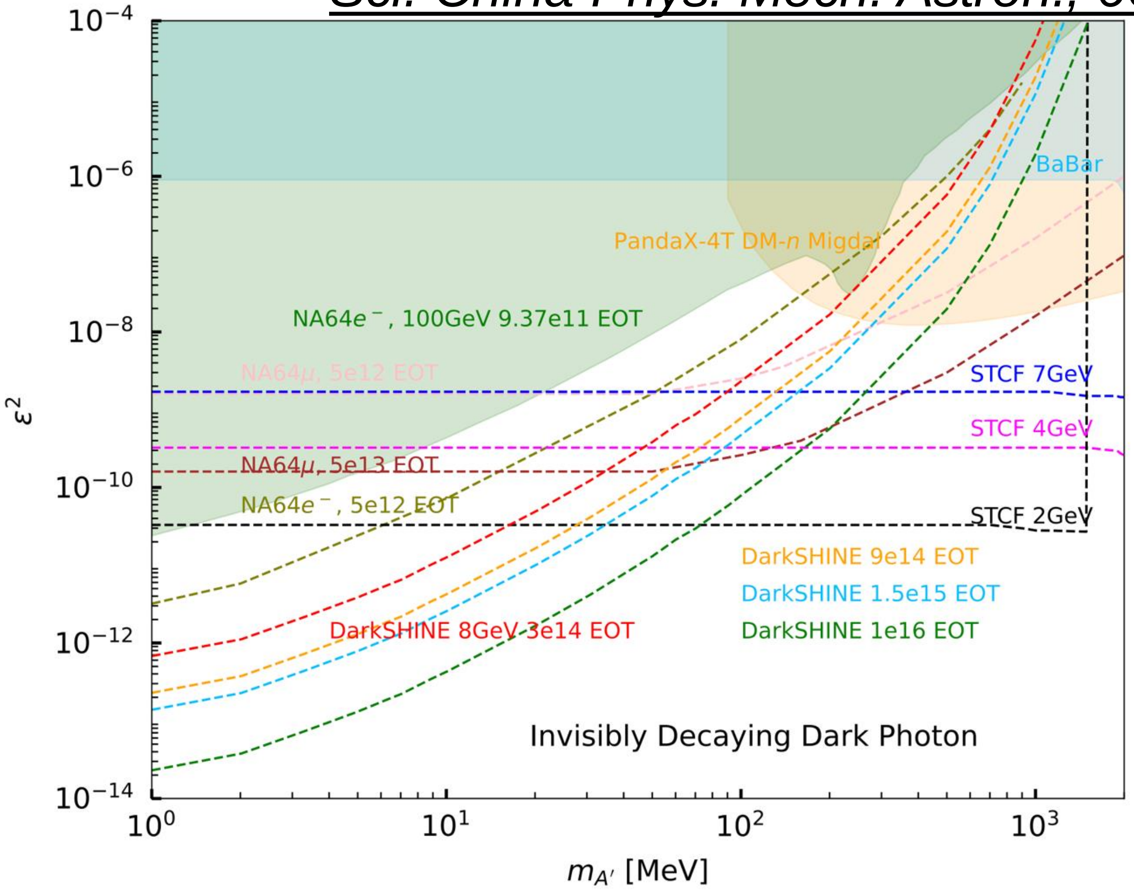
Focusing on invisible decays of dark photon into light dark matter

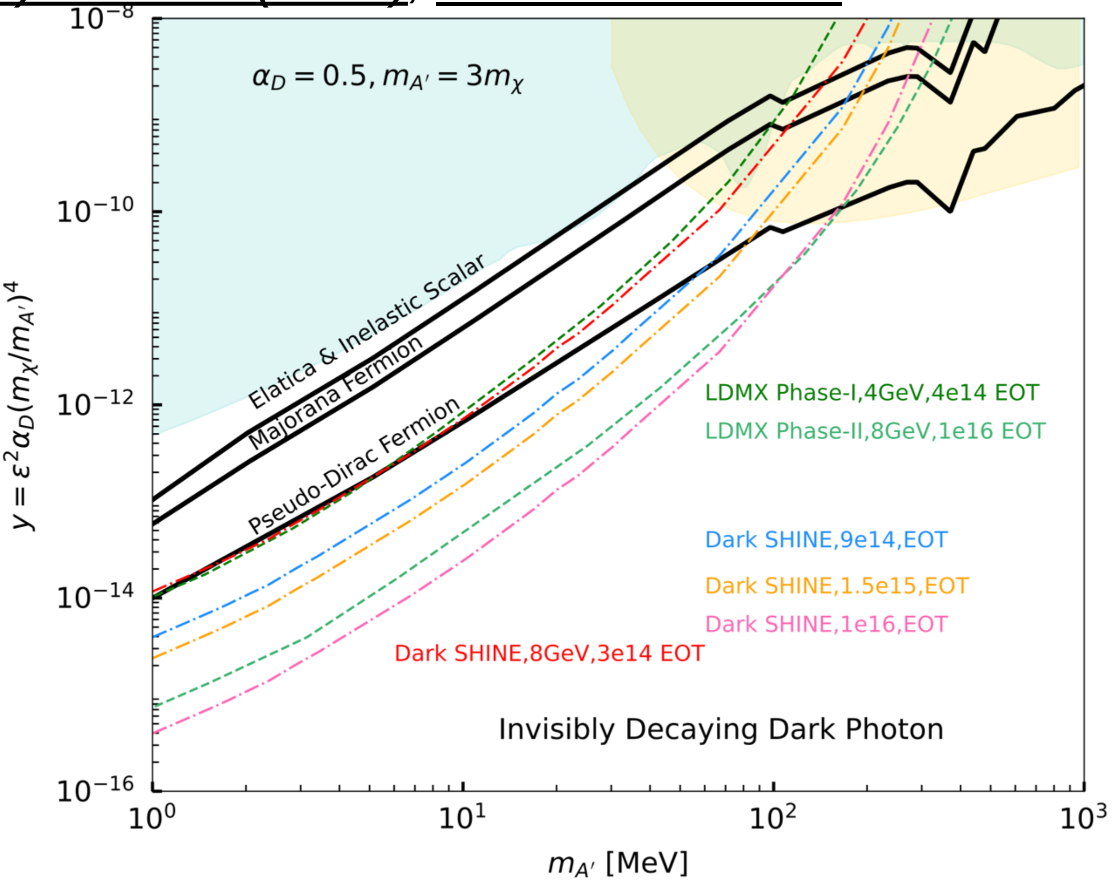
- **Experimental signatures:** missing energy, missing momentum.
- **DarkSHINE:** single electron on target experiment, searching for dark photon.

Prospective studies (a year = 3e14EOT)

- **The DarkSHINE experiment can provide competitive results on hunting for dark photon (left), also very sensitive to some popular dark matter models (right).**

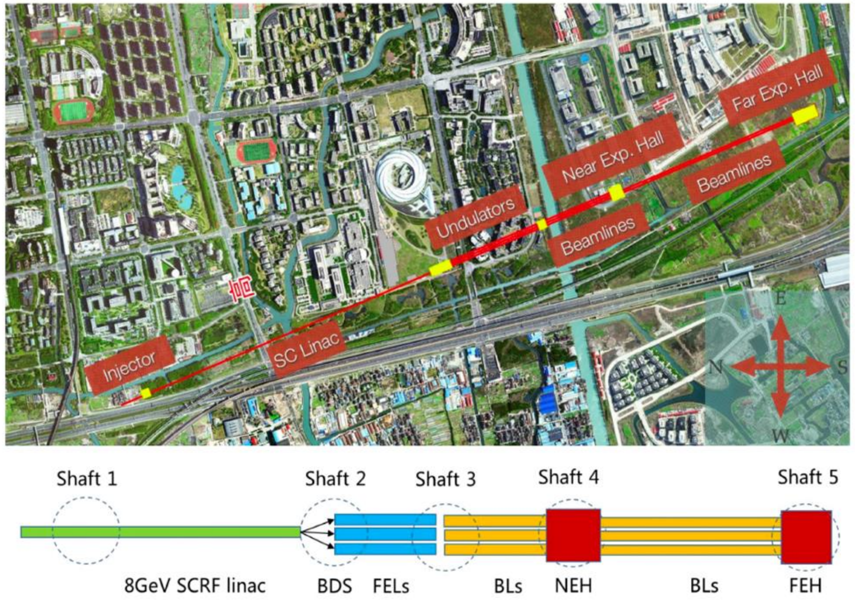
Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023); arxiv:2411.09345

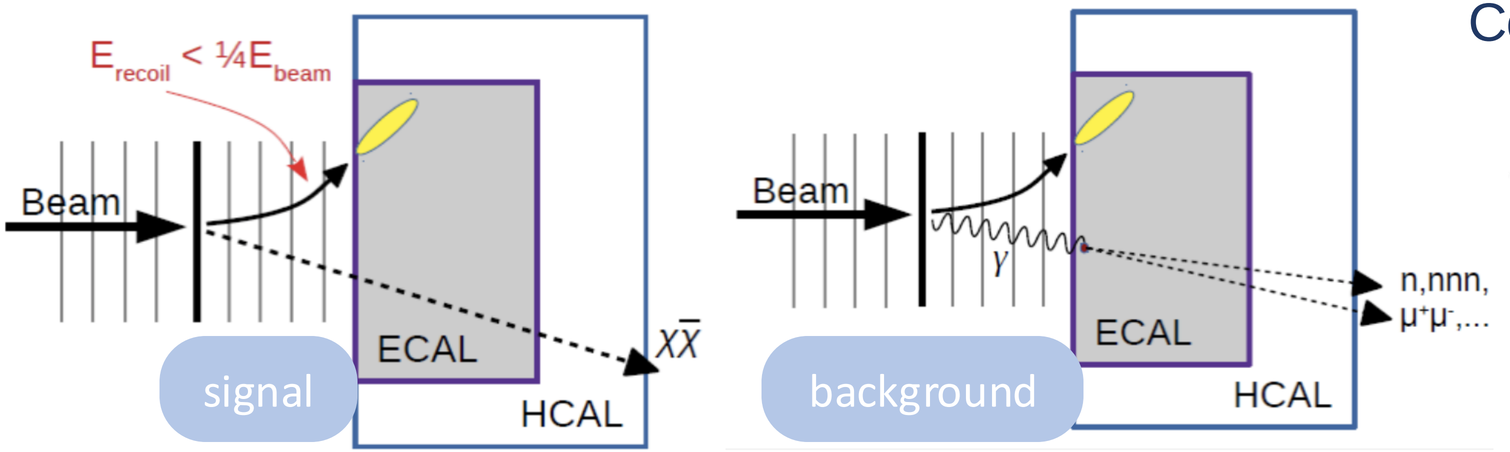




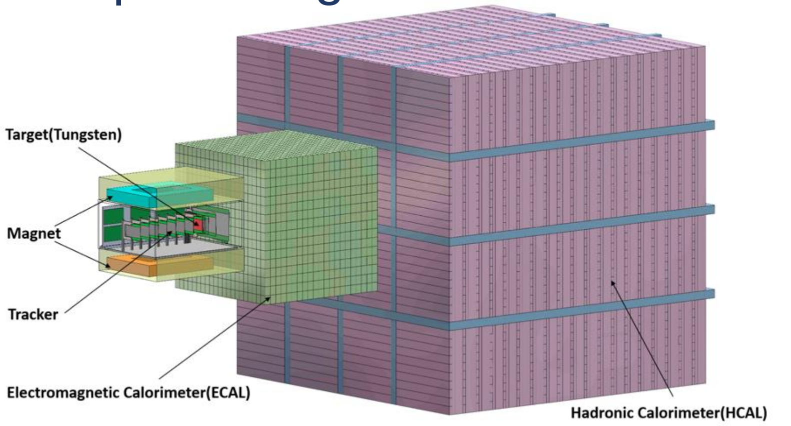
DarkSHINE experimental approaches

- **High repetition rate single electron beam**
  - The beam can be provided by SHINE based on SXFEL
  - Properties : 8GeV, 10MHz, single electron on target
- **Energy + Momentum loss detection**
  - Tracking system, ECAL, HCAL

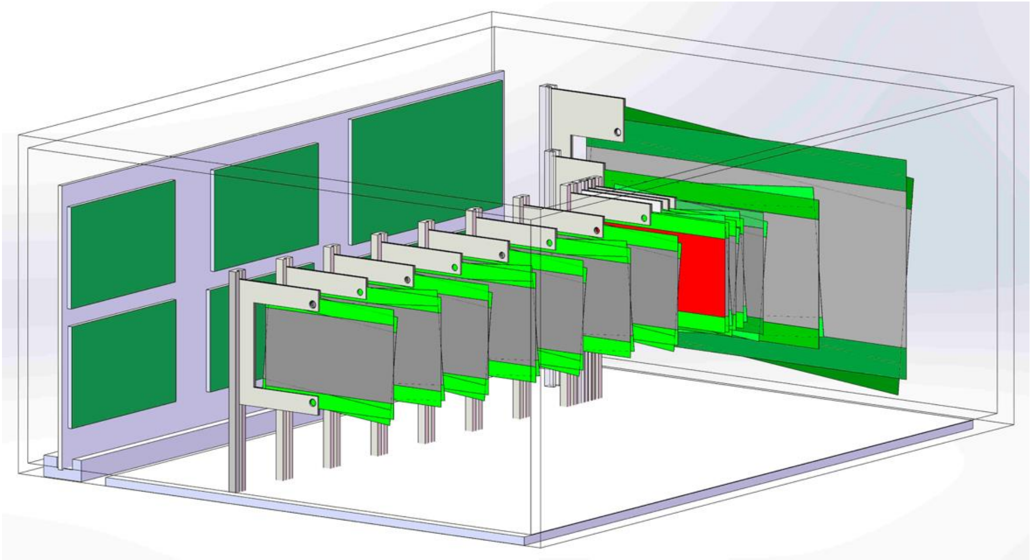




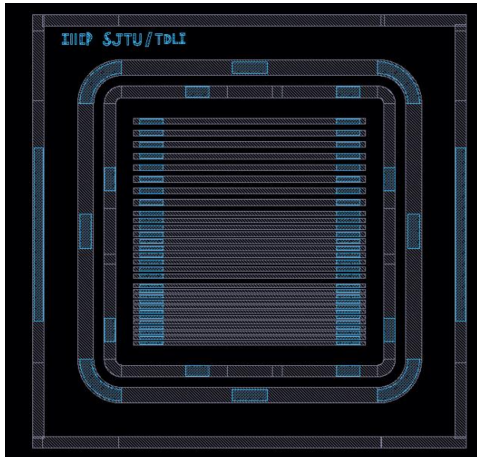
Conceptual diagram of the detector



Tracking system design



arXiv:2310.13926
Nucl Sci Tech 35, 201 (2024)



Pitch (μm)	Strip (μm)
100	50
60	40
45	30

- Silicon strips detector under 1.5T magnetic field , ~10 μm position resolution.
- 7 layers of tagging + 6 layers of recoil tracker, two silicon strips sensors each layer to enable resolution in y axis.

- AC-LGAD silicon strip sensor 3638x3638 μm^2 for performance study.
- In collaboration with IHEP-CAS HGTD team

Performance

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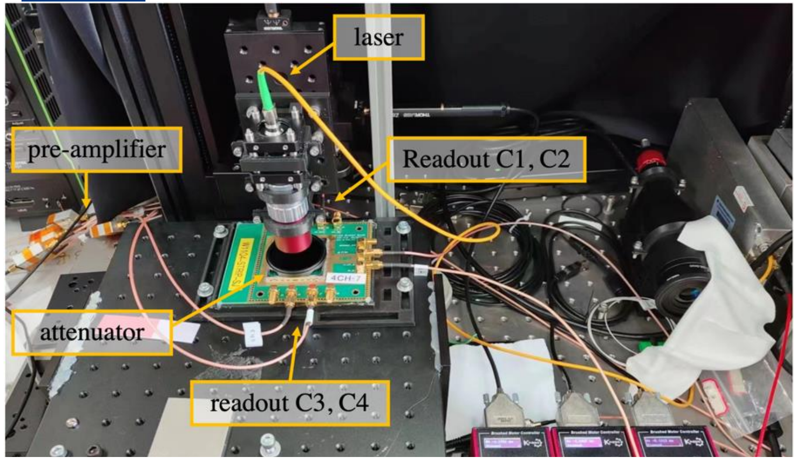

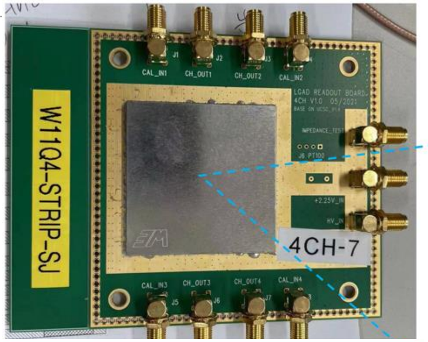

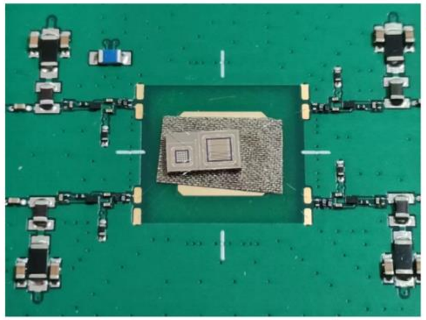

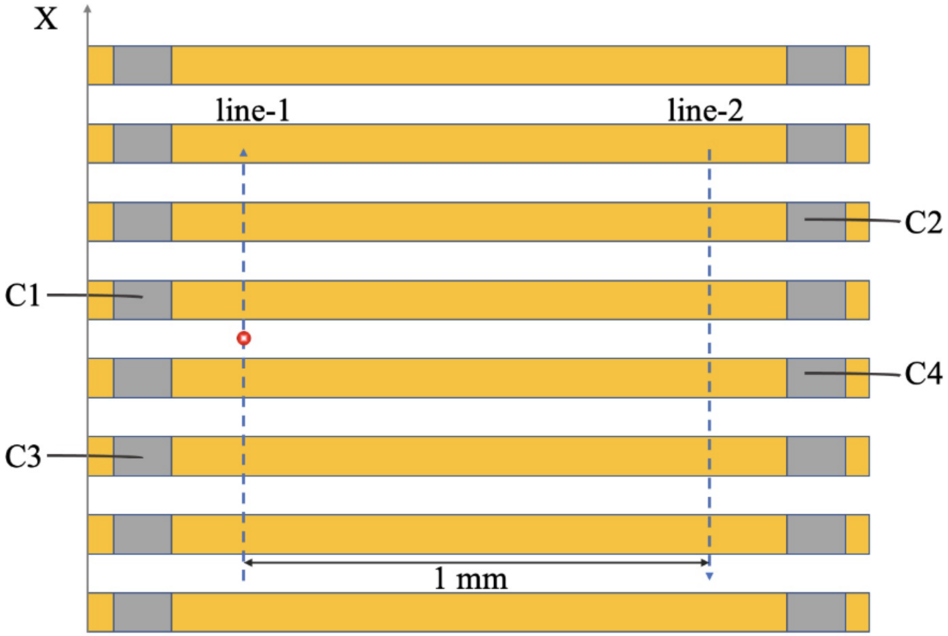

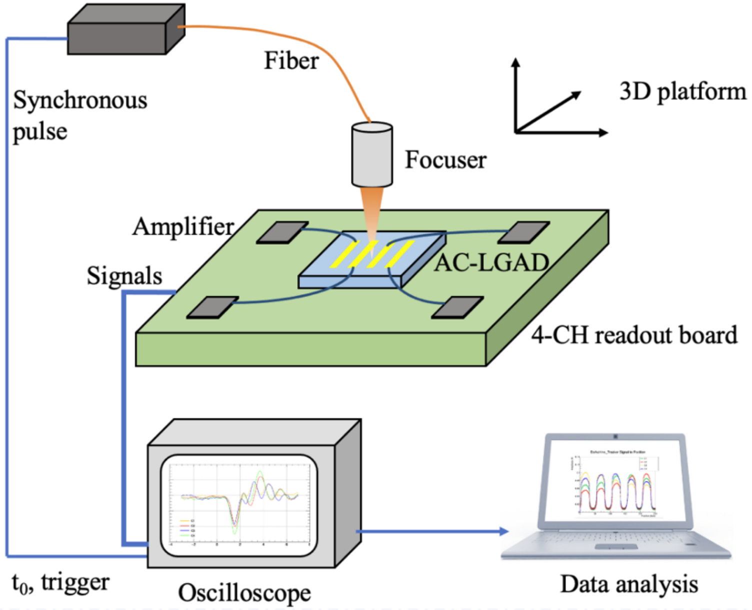

- **Performance testing: laser beam as signal source**
  spot diameter 6 ~ 10 μm
- **Spatial resolution: step 2 μm, 1000+ scans per point**
- **Time resolution: 1000+ scans at x=0**

Performance

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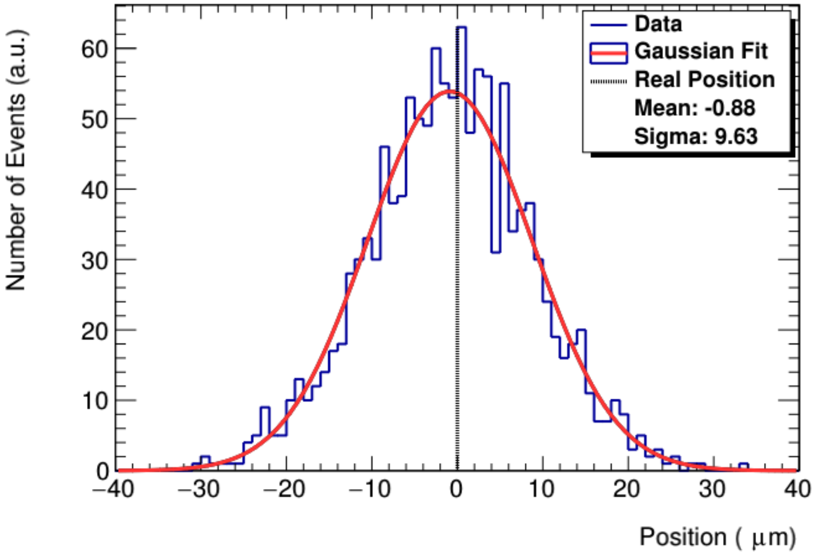
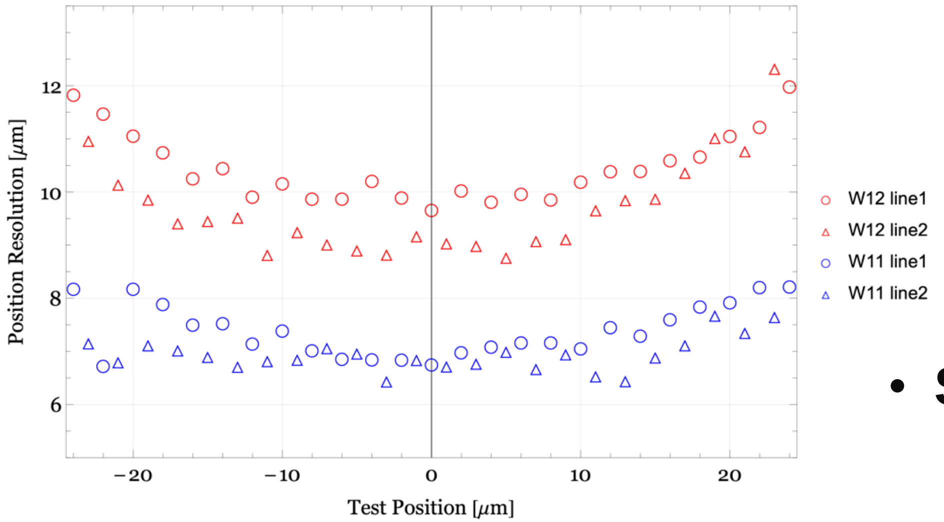
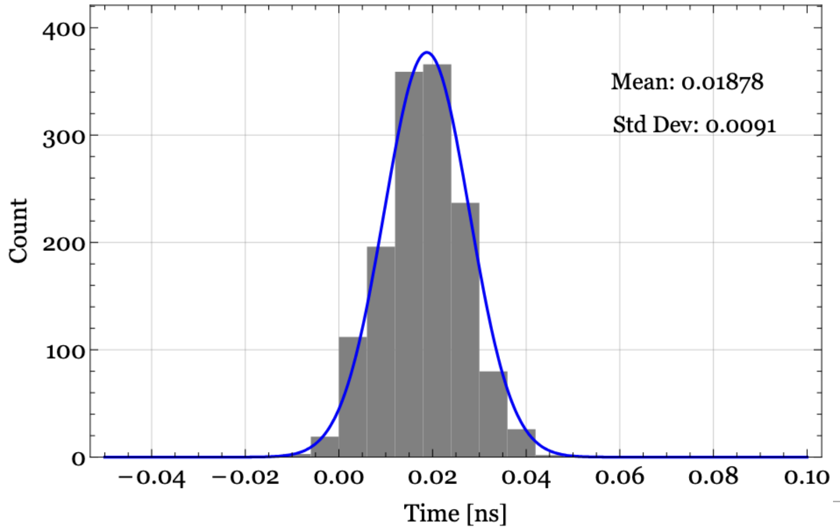
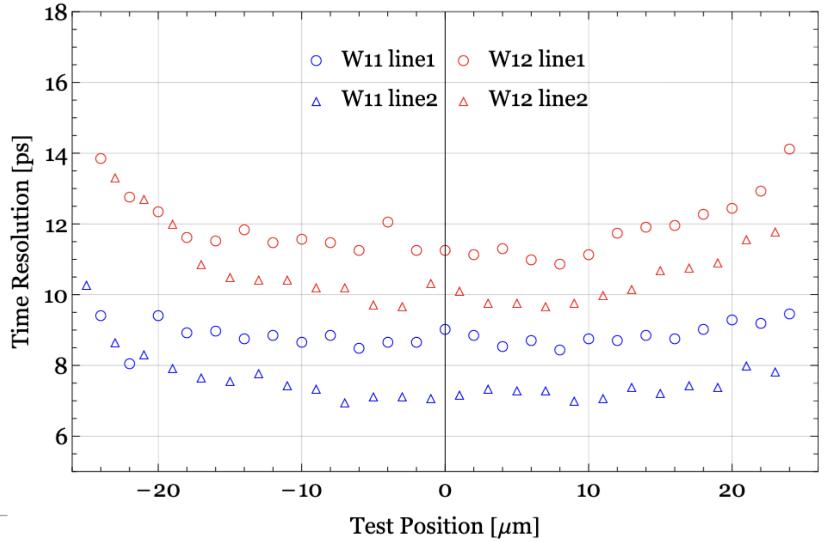




- **Spatial resolution**

  7 ~ 12 μm

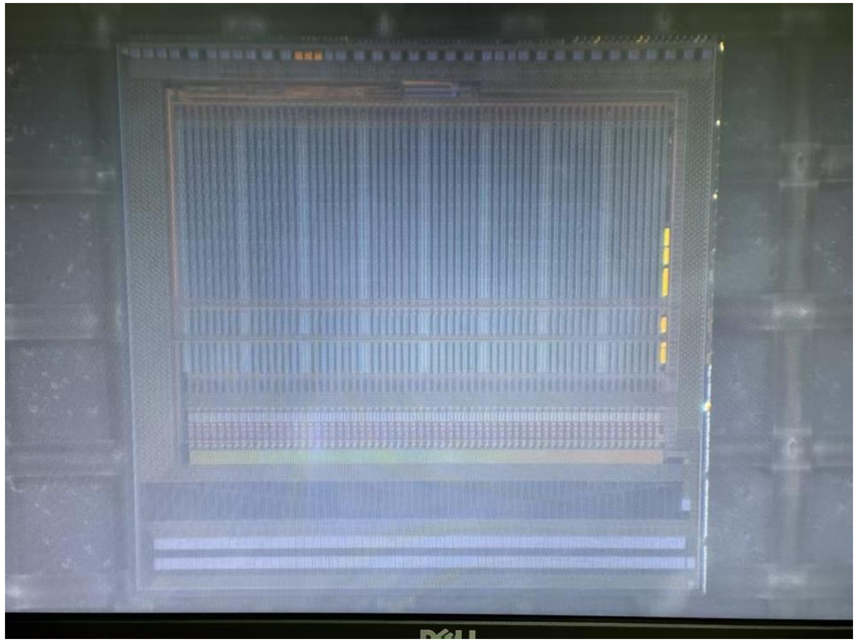


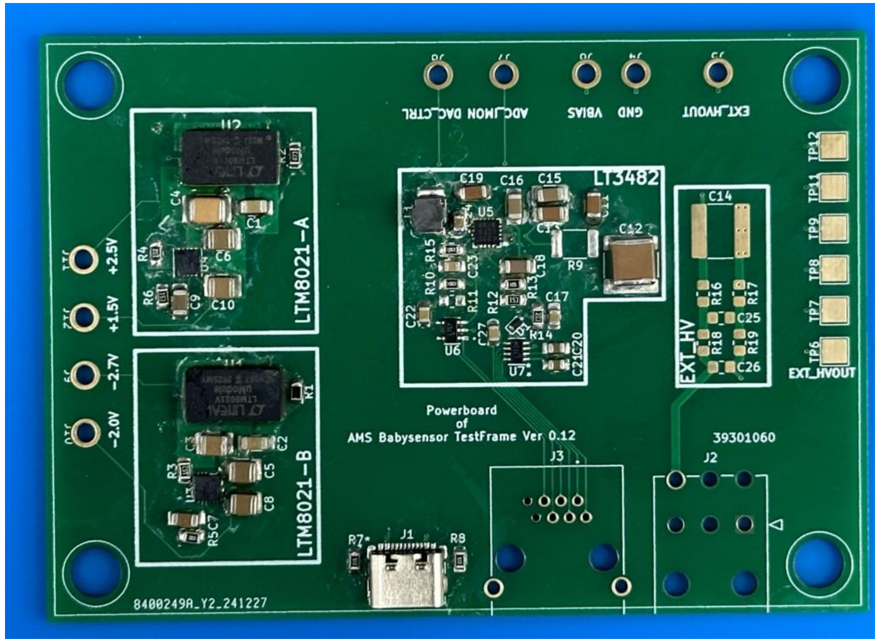


- **Time performance**

  6 ~ 14ps

Electronics (under development)





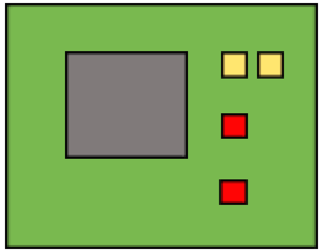
- **IDE1140 is chosen as the preamplifier-shaper asic.**
- **Power board for asics and sensor powering is developed. We are still working on sensor board, amplifier and ADC.**
- **The design is referred to AMS experiment, thanks Prof Zijun Xu and Mengke Cai from IHEP**

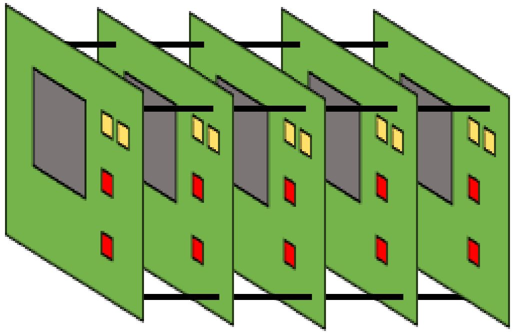
Future plans

Sensor board

Amplifier

ADC





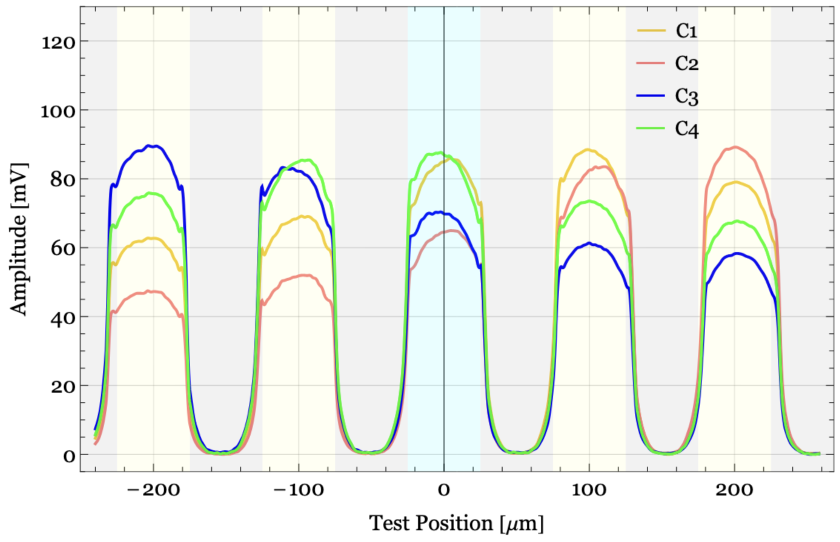
- **Design the full electronics**
- **Manufacture the prototype**
- **Beamtest, etc.**

- **Welcome your collaboration!**

Summary

- **DarkSHINE: a fixed-target experiment searching for dark photon invisible decay.**
- **Competitive sensitivity has been studied for dark photon and light dark matter**
  - *Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023).*
- **Detector key technology R&D updates have been presented**
  - AC-LGAD silicon strips: *Nucl.Sci.Tech. 35 (2024) 11, 201*.
  - LYSO+SiPM ECAL: *Nucl.Sci.Tech. 36(2025) 3, 41*.
  - Scintillator + Iron absorber HCAL: *Nucl.Sci.Tech. 35 (2024) 9, 148*.
- **Aiming for detector prototype manufacture and CDR.**

Backup



$$x = (f_i - \alpha_i)/\beta_i, i = 1, 2, 3, 4$$

where x is the impact position, f_i is the signal fraction of each channel, α_i is the signal fraction of each channel at $x = 0$, and β_i is the change rate of the signal fraction of each channel with the impact position. We set $x = 0$ at centre of

$$f_i = \frac{A^i_{\max}}{A^1_{\max} + A^2_{\max} + A^3_{\max} + A^4_{\max}}, i = 1, 2, 3, 4$$

$$\sigma_{\text{time}} = \sigma_{(t_1+t_2-t_3-t_4)/4}$$

Introduce extra $U(1)_X$ symmetry → New Gauge Field X → Dark Photon Mediator A′
$U(1)_{em}$ → $U(1)_{em} \times U(1)_X$

5th fundamental interaction in our universe

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + A_\mu j^\mu_{em} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} + X_\mu j^\mu_X$$

SM Photon γ **Dark Photon A′**

$\varepsilon X_{\mu\nu}F^{\mu\nu}$

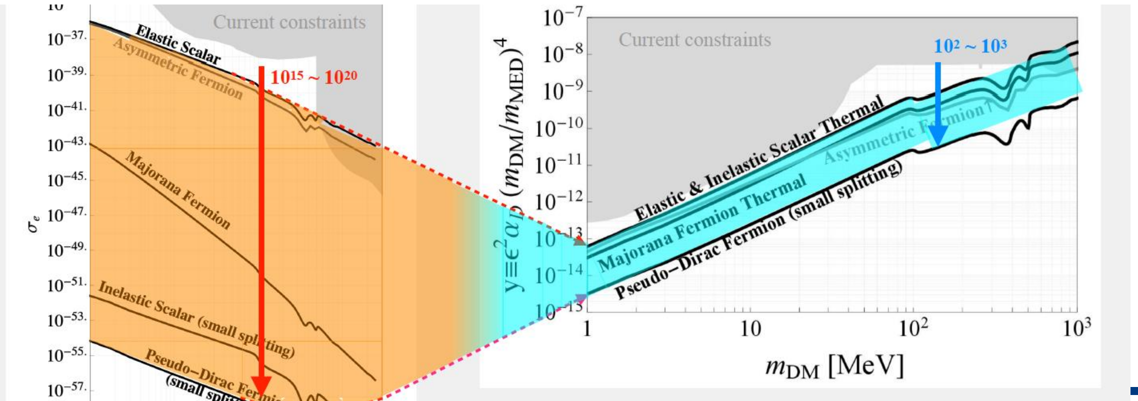
- A′ & γ kin. mixing
- Renormalizable and Gauge Invariant
- Straightforward for experimental search
  - Free param, kin. mixing (ε)、mass ($m_{A'}$)

4 Renormalizable "Portals"

Axion	$\frac{1}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu} a$	Axion/ALP	Higgs	$\lambda H^2 S^2 + \mu H^2 S$	Exotic Higgs decay?
Vector	$\epsilon F^{Y,\mu\nu} F'_{\mu\nu}$	Dark photon	Neutrino	$\kappa (HL)N$	Sterile neutrino?

Direct Detection

Accelerator based experiments



- In accelerator-based experiments, this difference can be reduced to $10^2 \sim 10^3$ orders of magnitudes, due to the fact of insensitive to DM's mass and spin in its production.