李政道研究所
TSUNG-DAO LEE INSTITUTE

Recent progress of DarkSHINE experiment

Haijun Yang (for DarkSHINE group)

Shanghai Jiao Tong University

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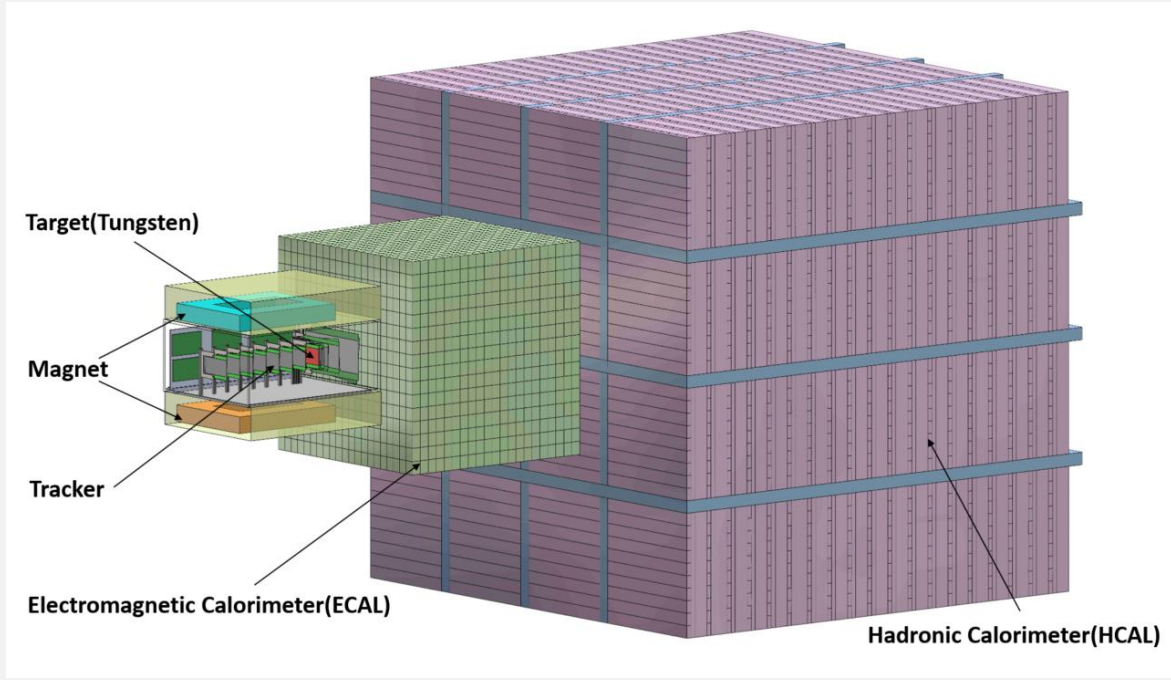
Wisconsin, USA, August 25-29, 2025

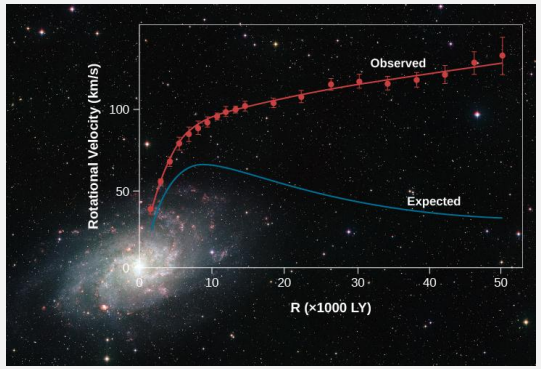
Outline

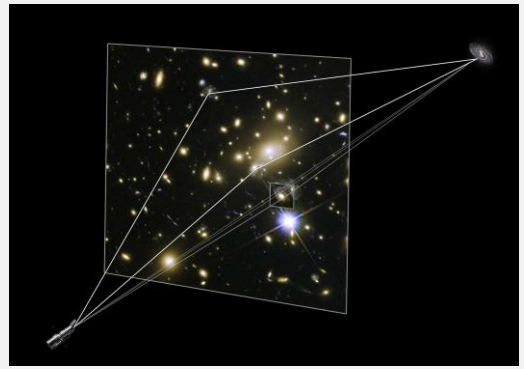
- **Physics motivation of DarkSHINE experiment**
  - Searching for massive dark photon invisible decay (light dark matter)
- **DarkSHINE prospective sensitivity**
- **Detector optimization and performance**
- **Summary**



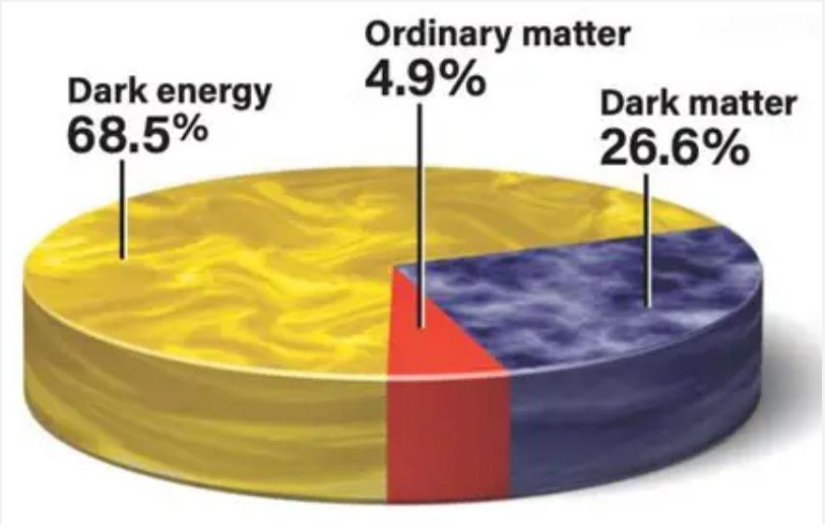
Dark Matter Evidence

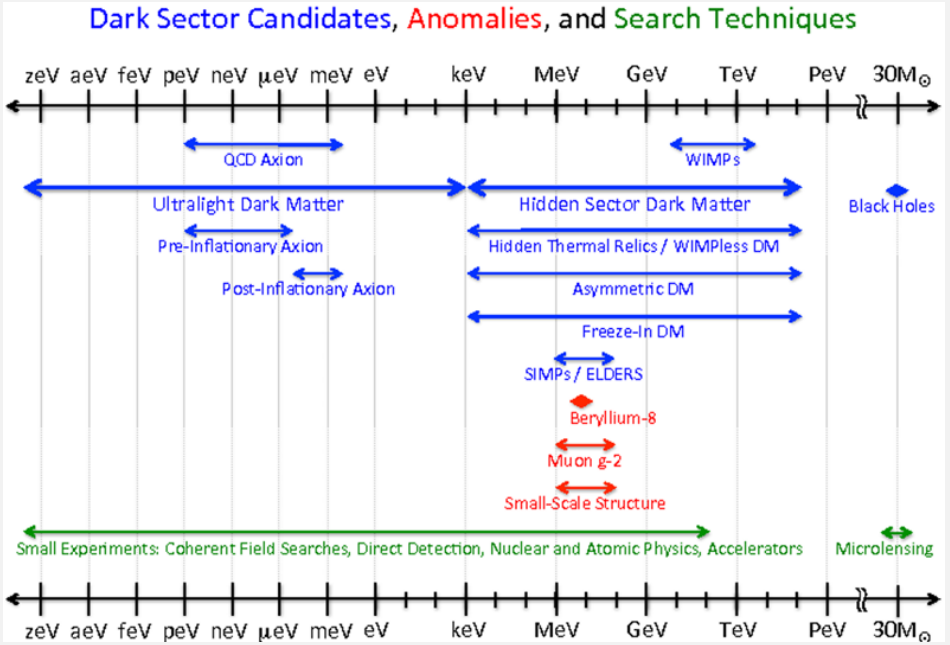
- **Dark matter evidence from astronomical observations and gravitational effects:**
  - Galactic rotation curves
  - Gravitational lensing
  - Dark matter giant cosmic web, …



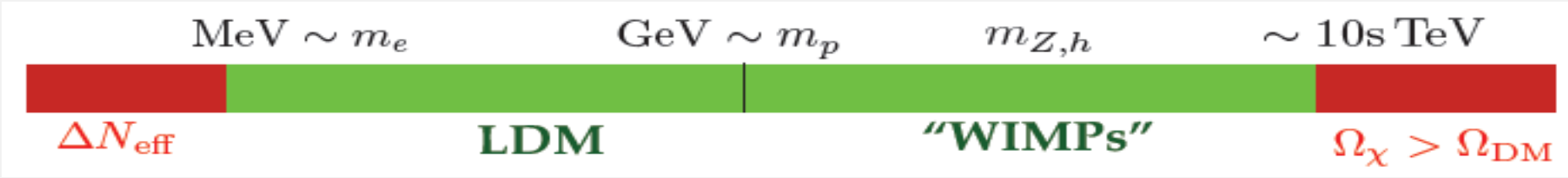


- **Dark matter may exist over a wide mass range, from Ultralight "Fuzzy DM" to Primordial Black Holes.**

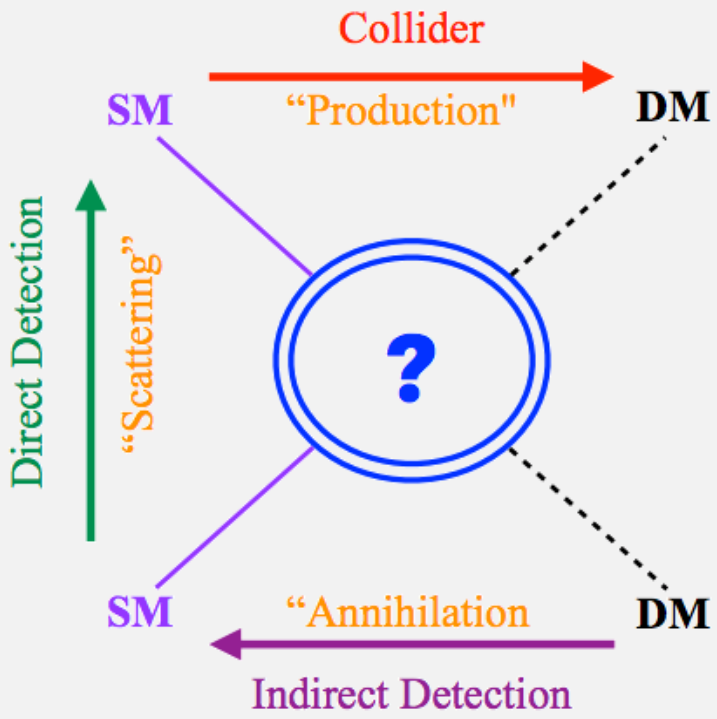


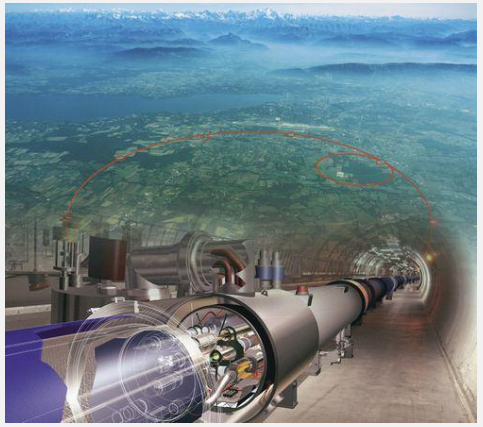


Dark Matter Detection (“WIMP”)



(e.g. PandaX, XENON, LUX, LZ, CDEX, DarkSide)



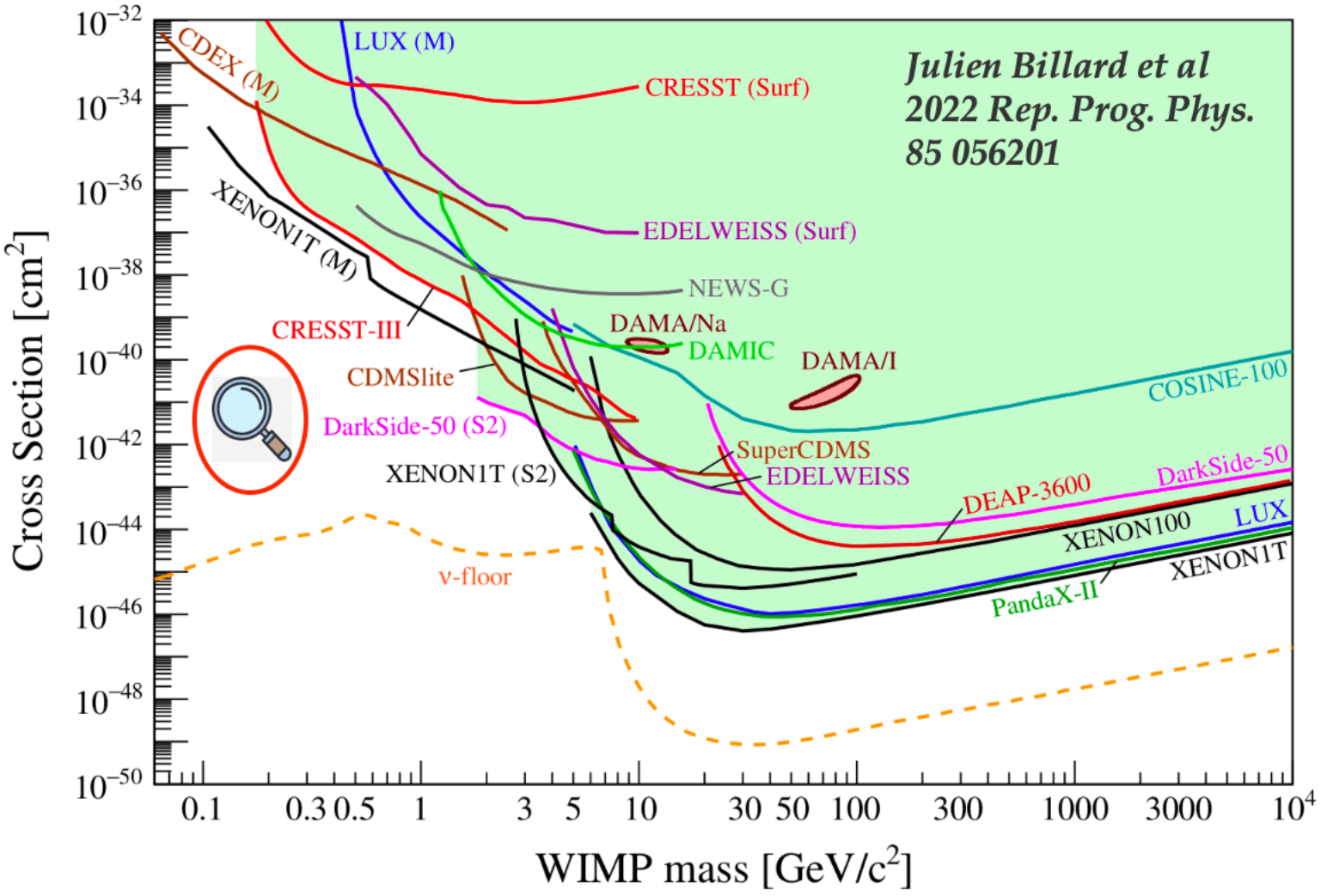


Collider (e.g. ATLAS, CMS, Belle-II, BESIII)

Fixed Target (e.g. NA64，LDMX, DarkSHINE)

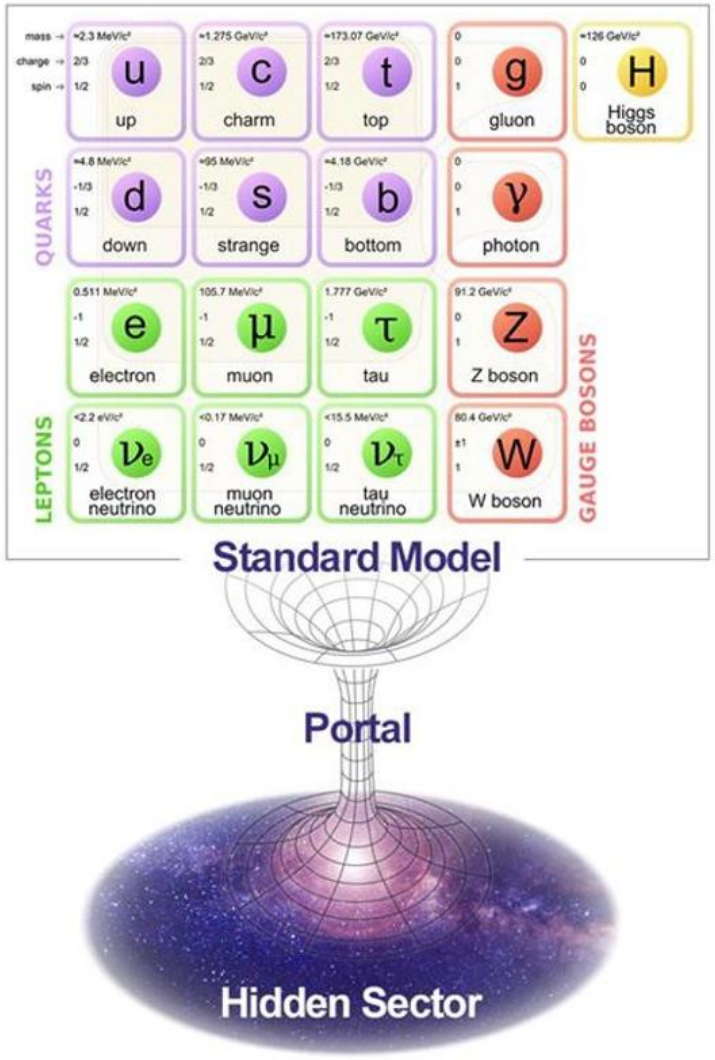
(e.g. AMS, DAMPE, GAPS, IceCube, LHASSO, Trident)

Motivation — search for light dark matter



- Competitive experiments world-wide have been hunting for dark matter candidates from GeV to 10s TeV mass range.
- Sub-GeV regime less explored by direct search experiments.
- Fixed target experiment has great sensitivity at sub-GeV mass range.

Massive dark photon as new force carrier



How Dark Matter may interact with Ordinary Matter?

Dark Matter — Mediator — Standard Model

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?

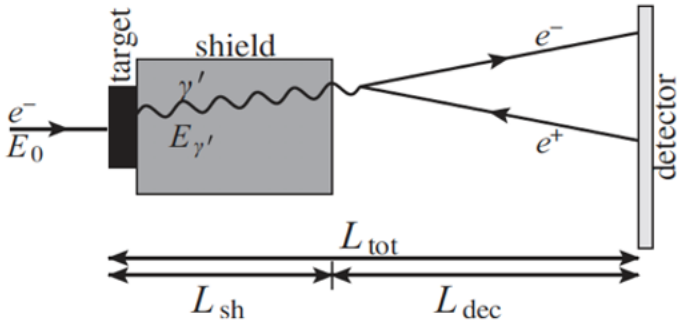
Dark Matter — Dark Photon — ϵ — Kinetic Mixing — Standard Model

New force carried by massive vector boson: dark photon

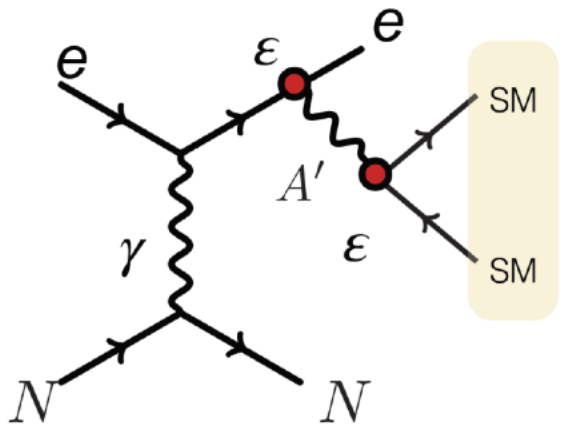
Dark photon detection

- **Dark photon can be produced in electron-nuclei interaction (electron-on-target).**
- **Two ways of detection, via its**
  - **Visible decay**

    Having two interaction vertices → production rate highly supressed

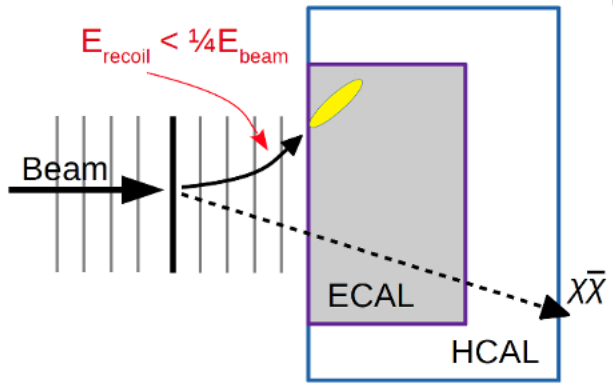


VISIBLE DECAY MODE $m'_A < 2m_X$

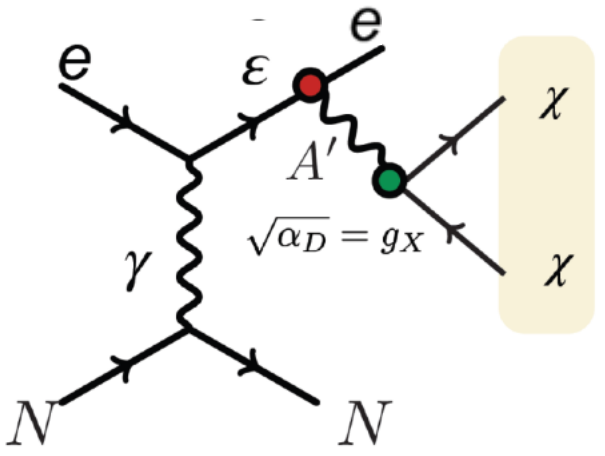


$$N \propto \epsilon^4 \quad \ll \quad N \propto \epsilon^2(1-\epsilon^2) \approx \epsilon^2$$

  - **Invisible decay**



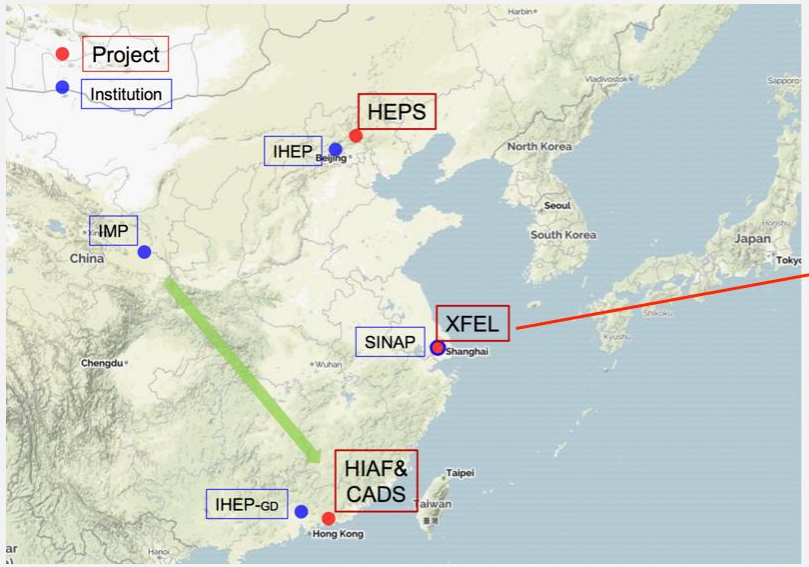
INVISIBLE DECAY MODE $m'_A > 2m_X$

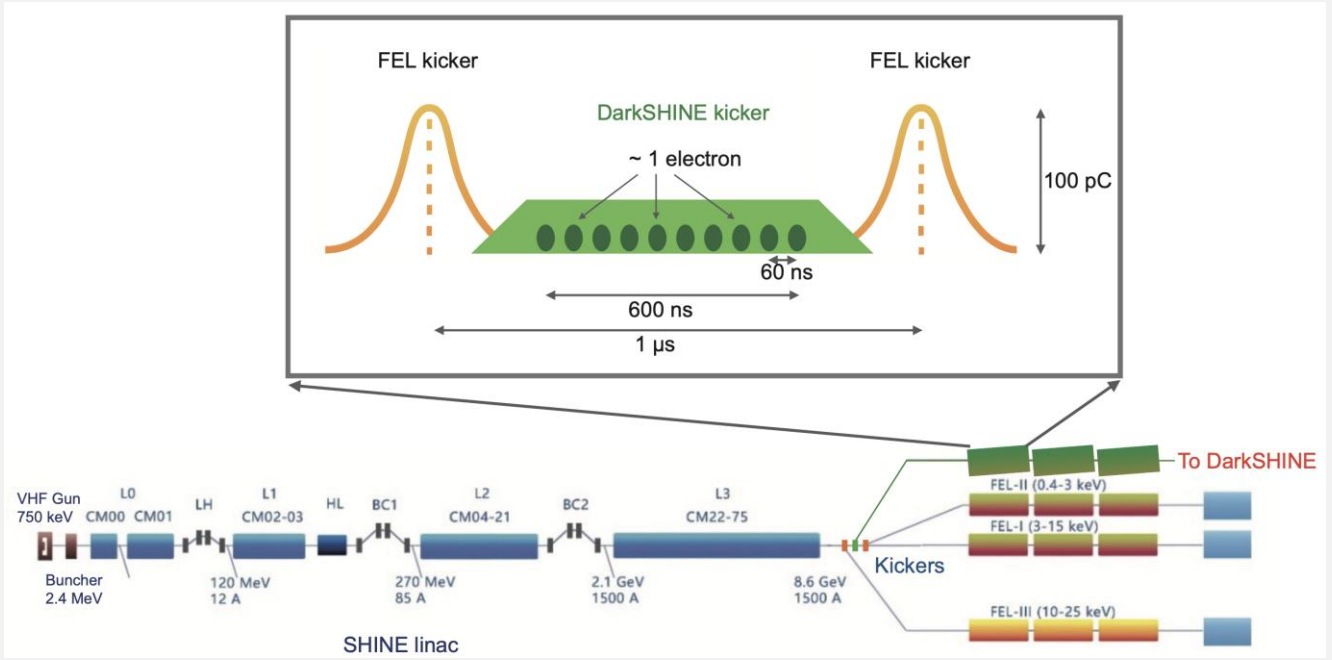


Interaction probability can be enhanced → better sensitivity!

SHINE Facility in Shanghai

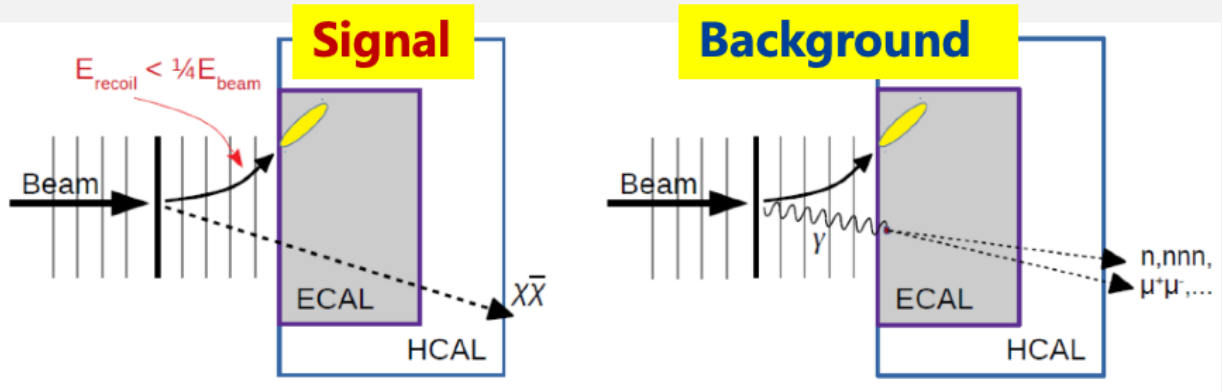
- Shanghai high repetition-rate XFEL facility (SHINE, 3.1km) can provide 8 GeV electron beam.
- SHINE facility is under construction at Zhangjiang area in Shanghai (2018-2026)
- Single electron beam line (1MHz → 10 MHz) can deliver ~3E14 EOT/year.
- Beam line R&D: ShanghaiTech University and Shanghai Advanced Research Institute, CAS
- Detector and physics R&D: SJTU and TDLI

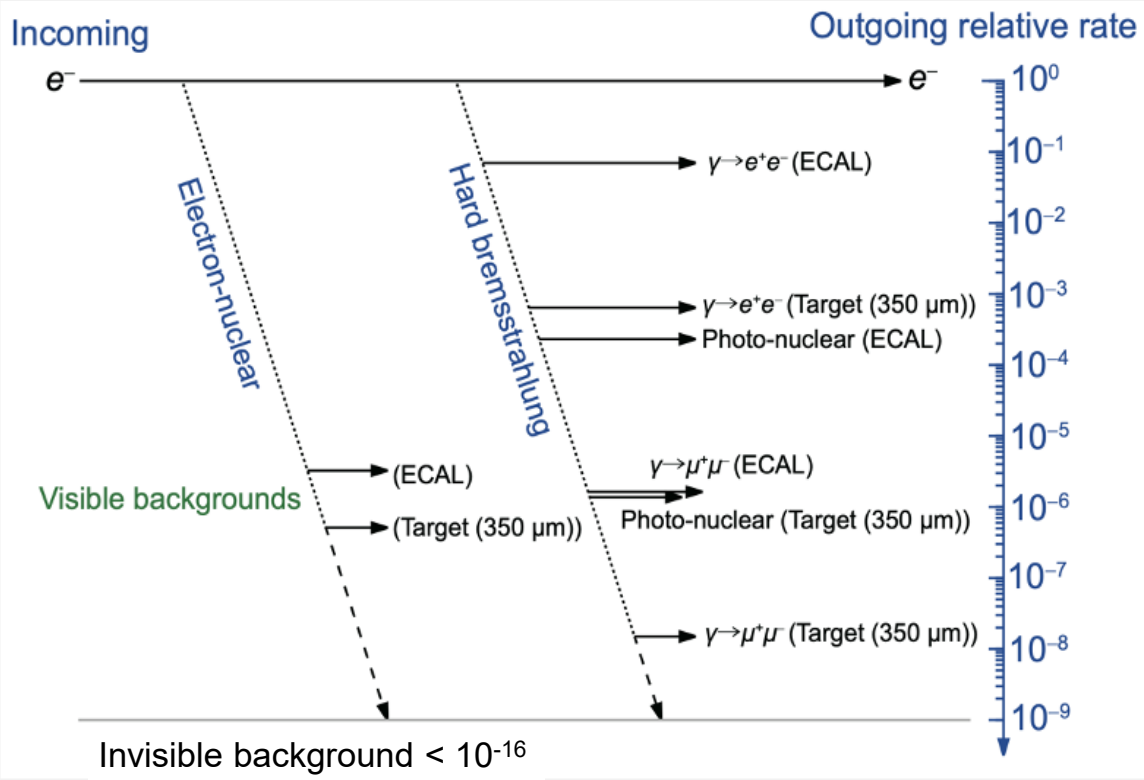


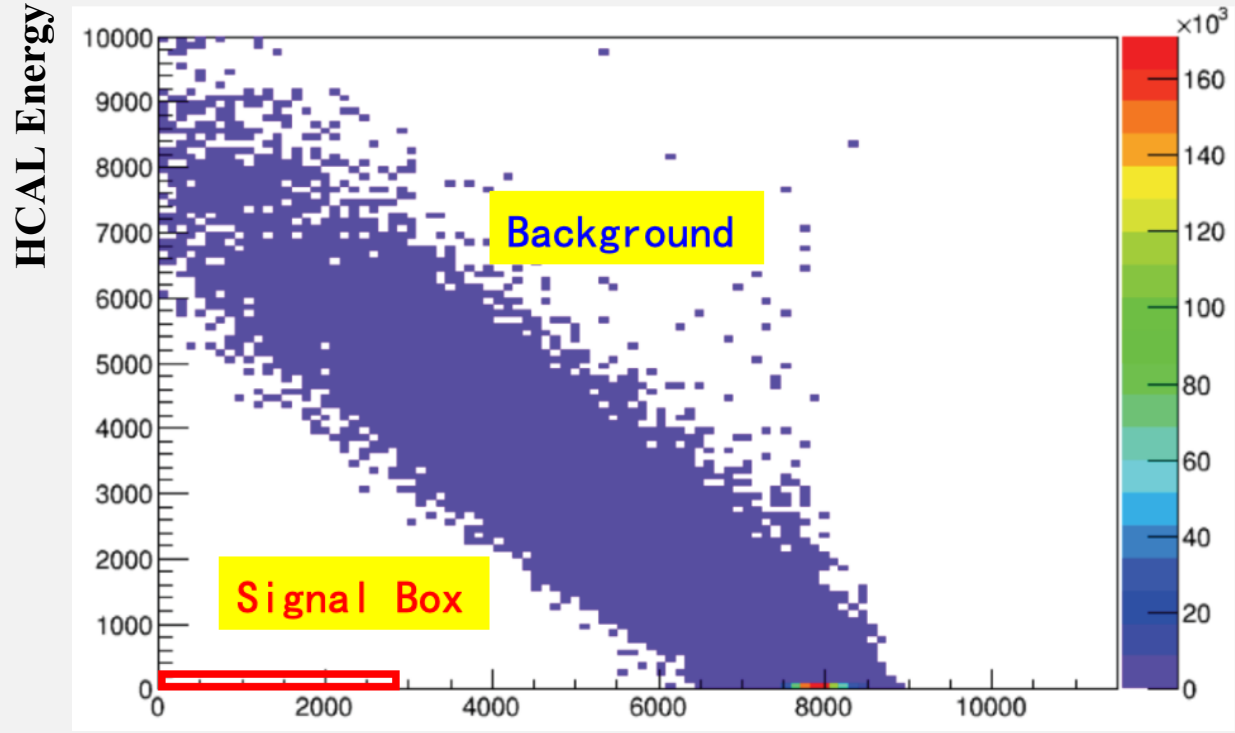


Physics prospective

- High repetition (10 MHz) 8 GeV single electron beam from SHINE.
- Clean dark photon signature
- Ultra low background experiment.

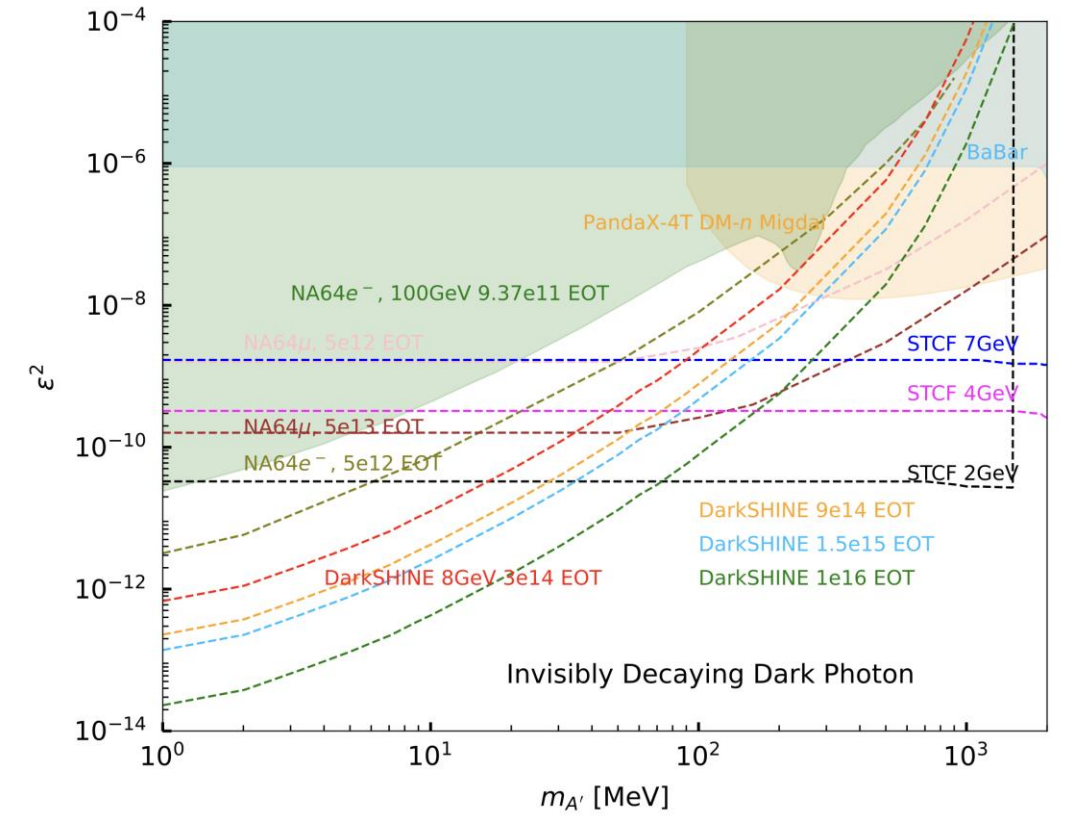


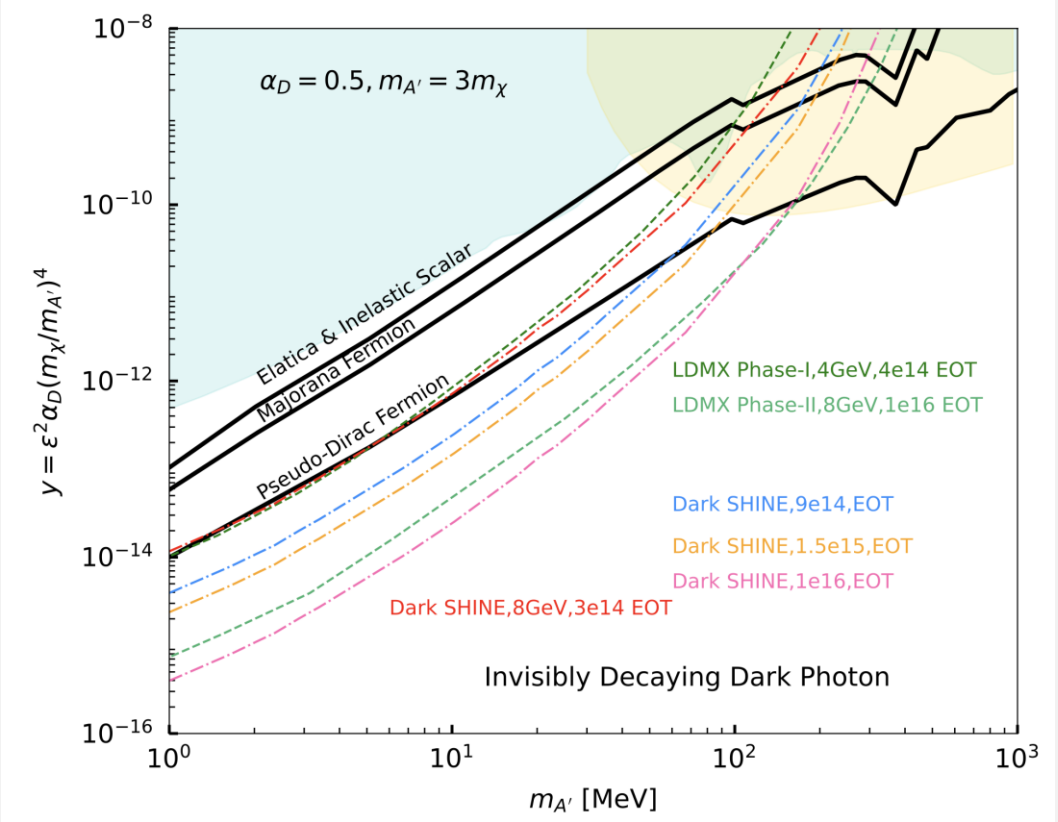




Physics prospective

- **The DarkSHINE can provide competitive results on searching for dark photon, it is very sensitive to various dark matter models based on 2.5E9 MC events.**



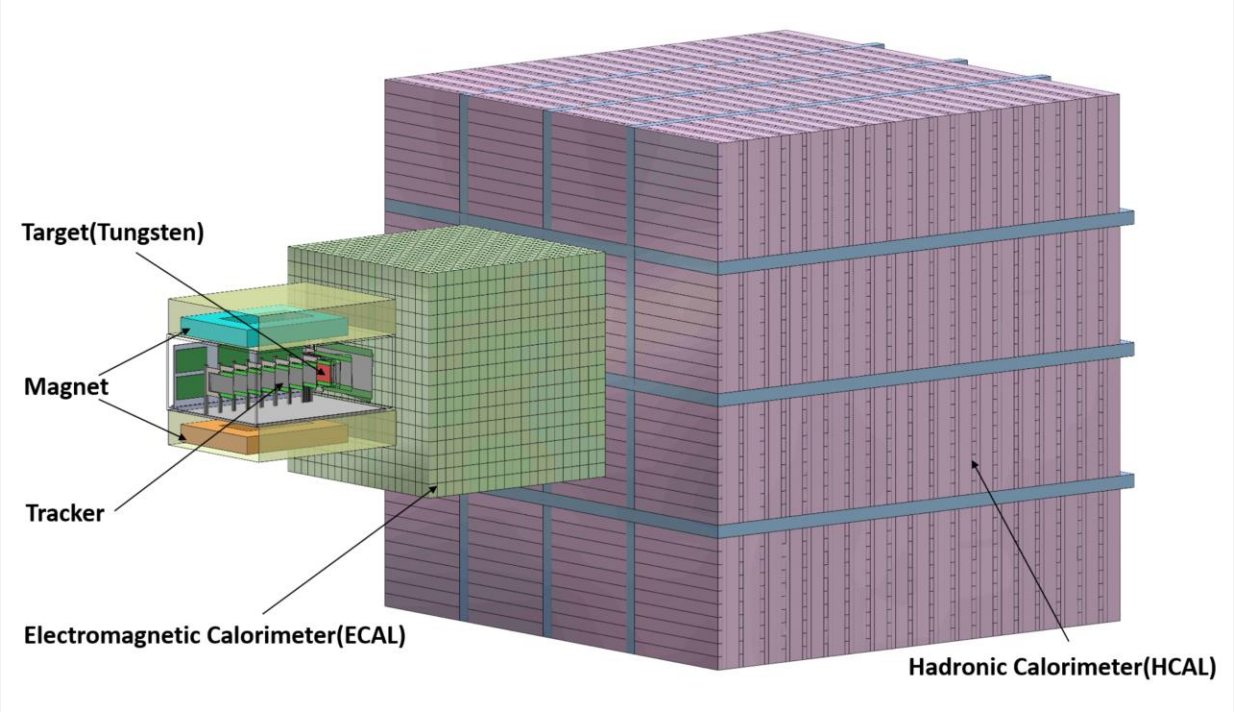


Science China-Phys. Mech. Astron., 66(1): 211062 (2023); arxiv:2411.09345

Optimization of the detector design

DarkSHINE detector sketch *(not to scale of each detector size)*

Tracking system
Measure the track of the incident and recoil electrons.



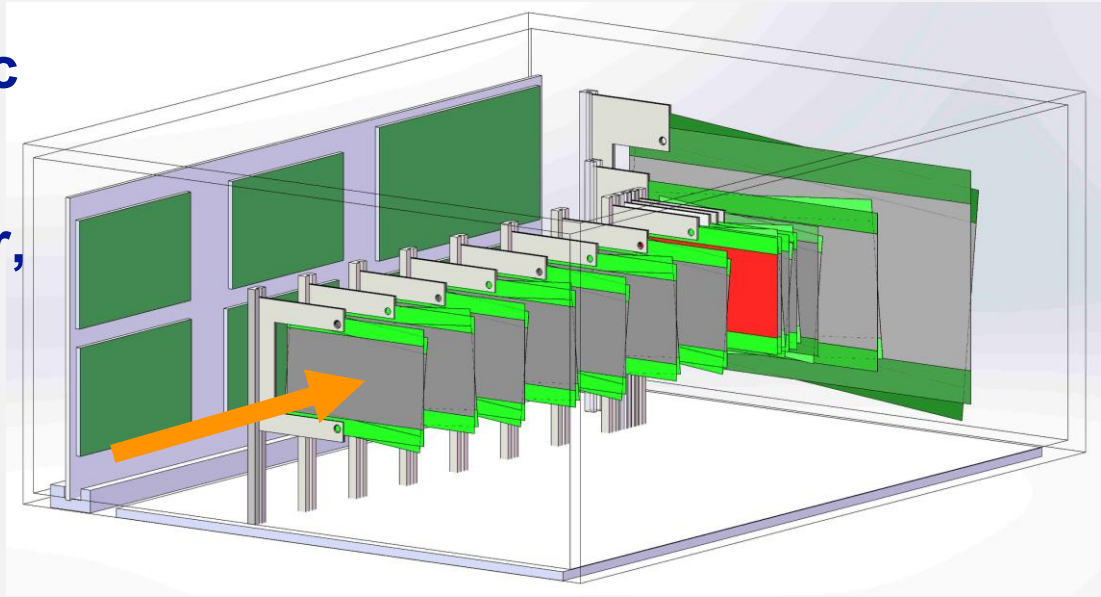
Electromagnetic calorimeter
Measure the deposited energy: electron and photon.

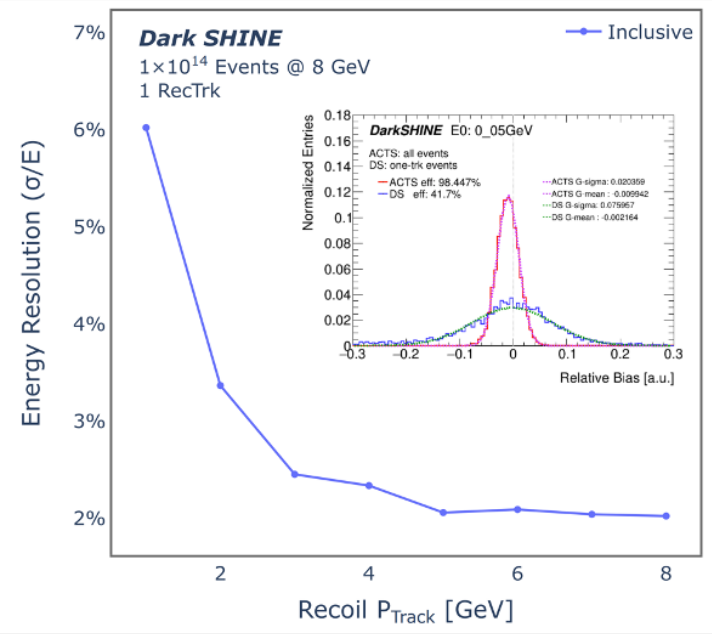
Hadronic calorimeter
Measure the deposited energy: veto muon and hadron backgrounds.

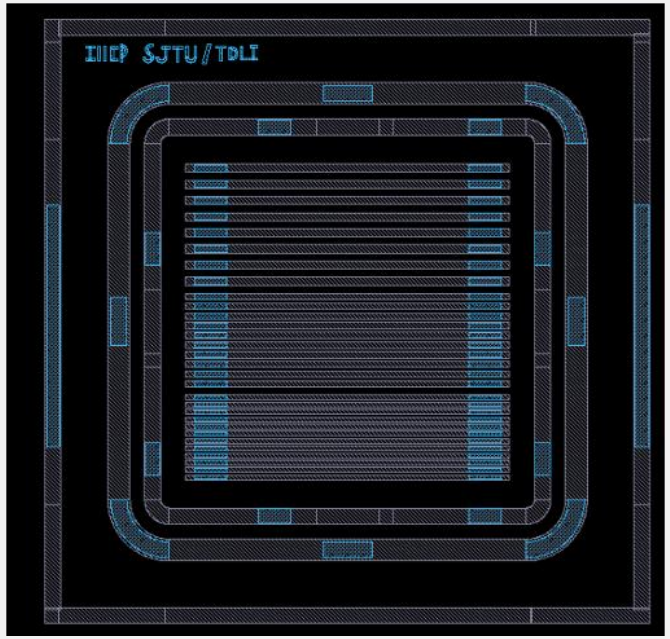
Additional system:
Readout electronics, trigger system, TDAQ, magnetic system (1.5 T), etc.

Tracking system and performance

- Silicon strips detector under strong magnetic field, ~10 μm position resolution.
- 7 layers of tagging + 6 layers of recoil tracker, two silicon strips sensors for each layer.





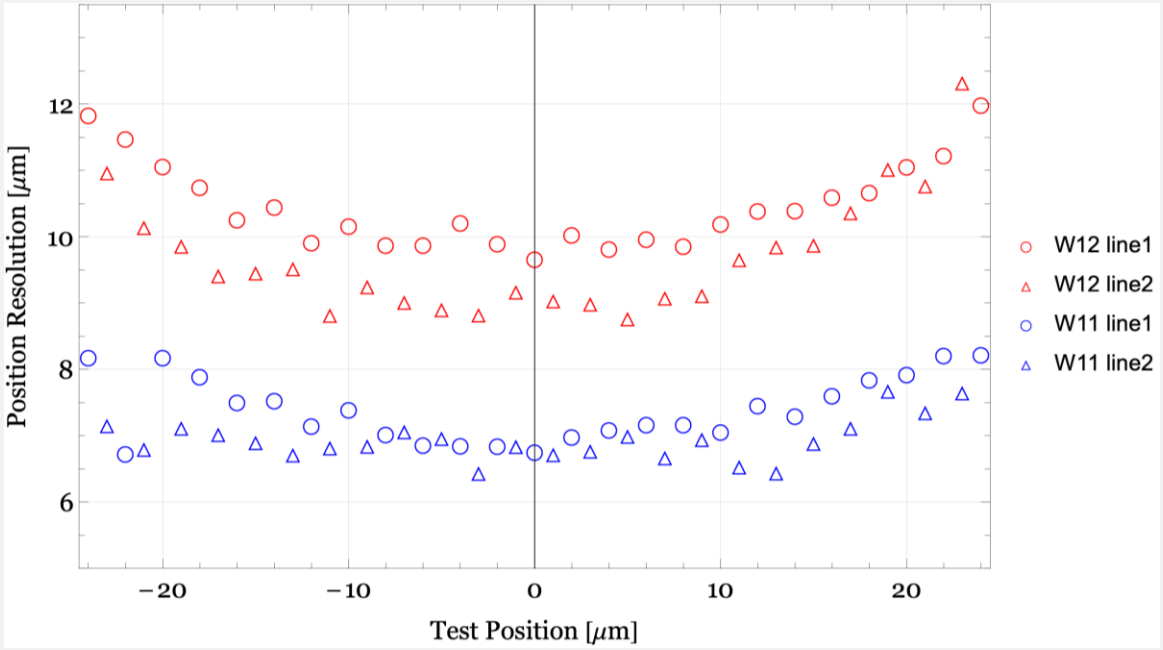


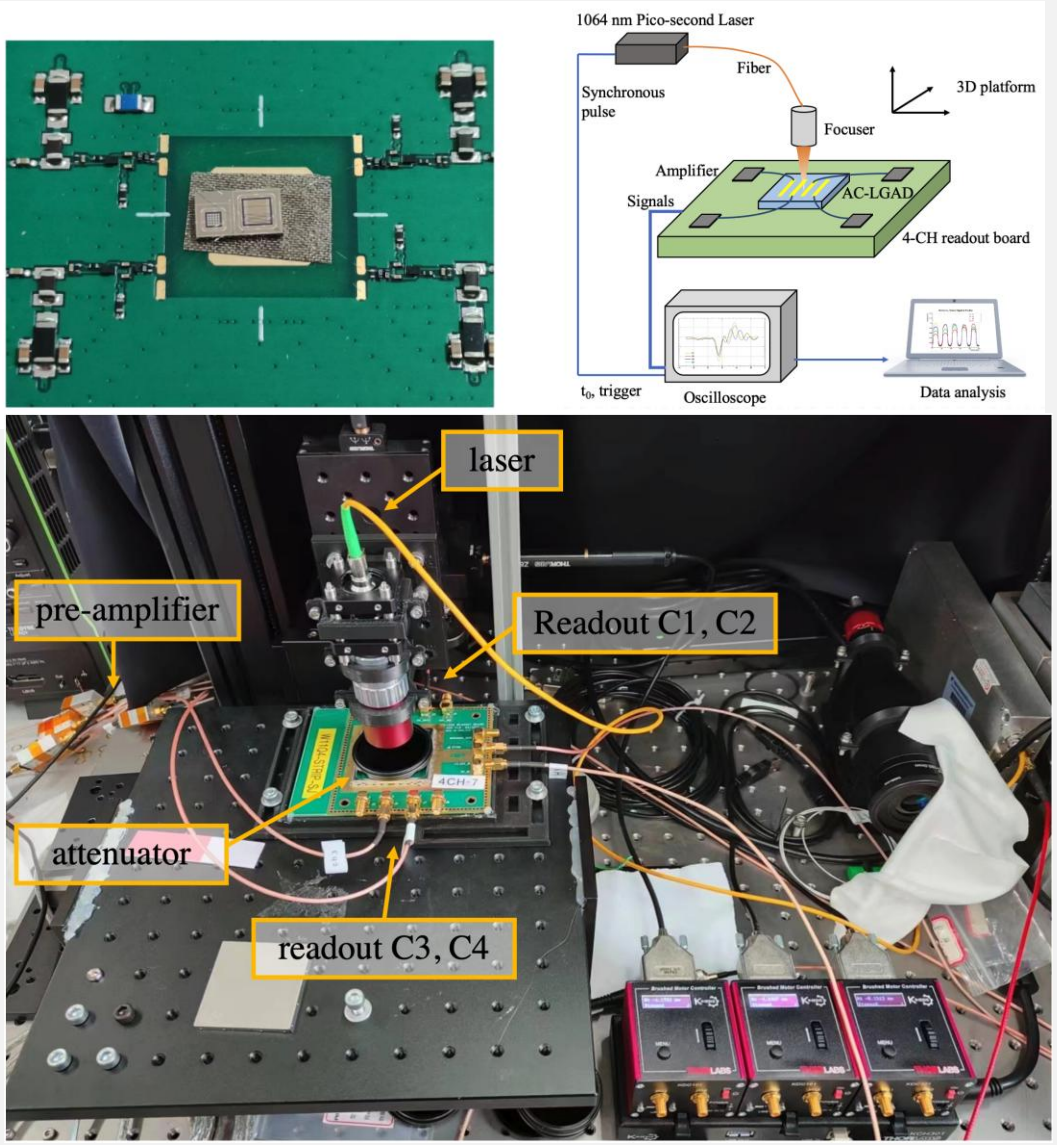
- AC-LGAD silicon strip sensor 1x1 mm^2 with 100 microns pitch size.
- In collaboration with ATLAS HGTD team at IHEP-Beijing.

Tracking system and performance

- **AC-LGAD silicon strip sensor prototype designed and tested.**
- **Achieved spatial resolution 7 ~ 12 μm, with timing resolution ~ 10ps**

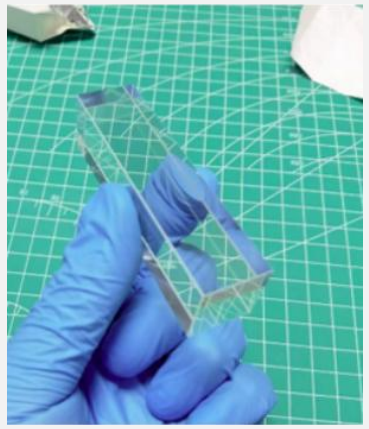
Nuclear Science and Techniques 35 (2024) 201

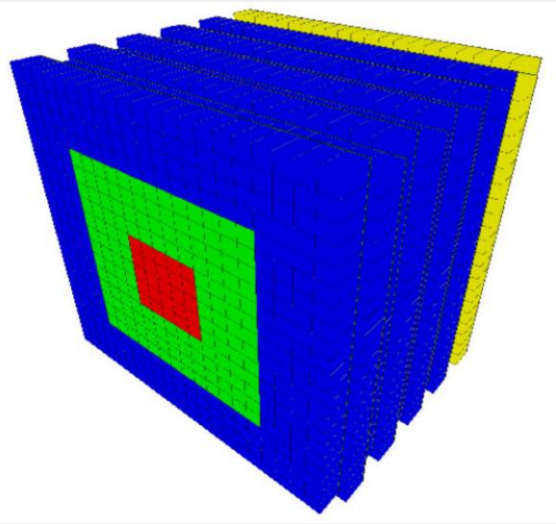




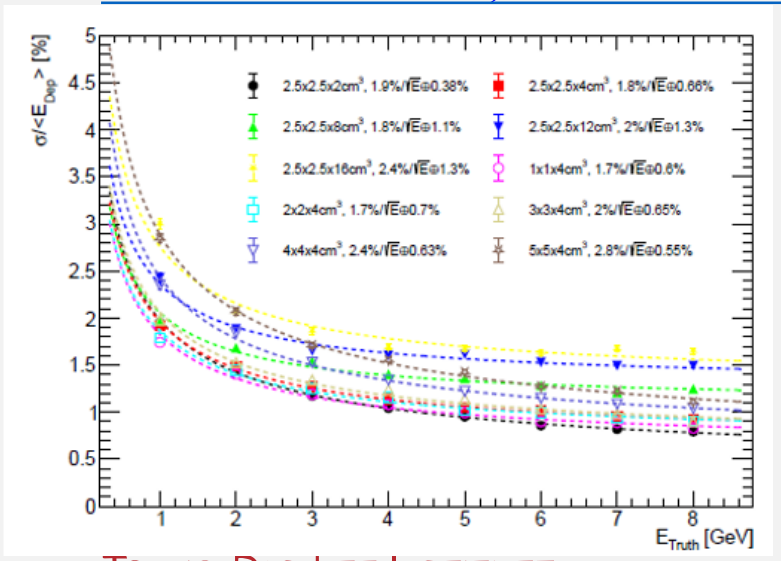
Electromagnetic calorimeter and performance

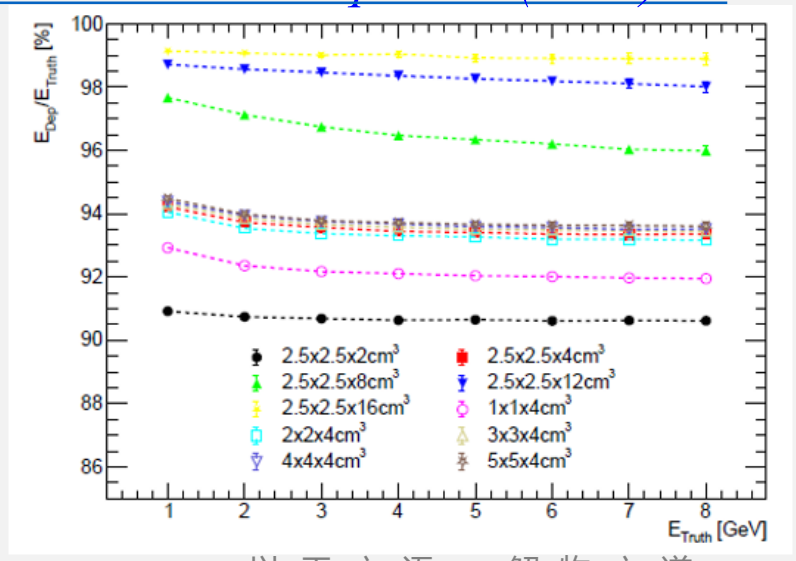
- **Crystal Scintillator + SiPM (S14160-3010PS)**
  - LYSO ($Lu_{(1-x-y)}Y_{2y}Ce_{2x}SiO_5$)
  - 21 x 21 x 11 crystals, each 2.5 x 2.5 x 4 cm^3
  - High light yields, short decay time, hard radiation
- **Energy resolution: 1.8%/√E ⊕ 0.66%.**
- **Ratio of the energy deposited in ECAL: ~94%**

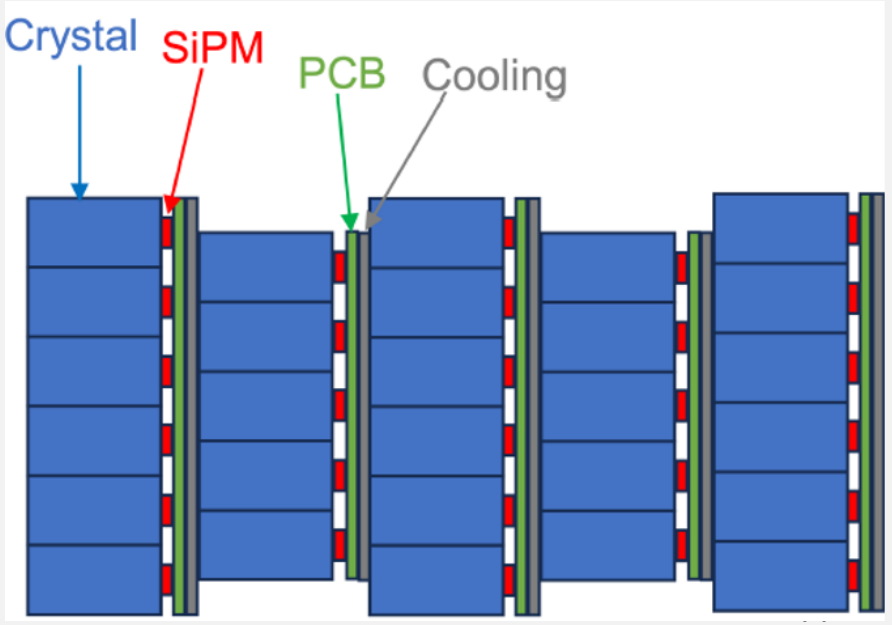




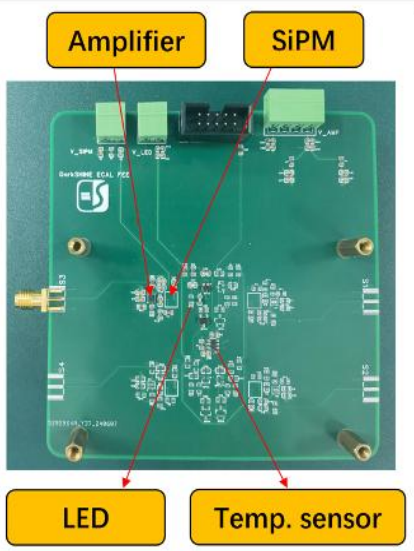
arXiv:2407.17800, Nuclear Science and Techniques 36 (2025) 41

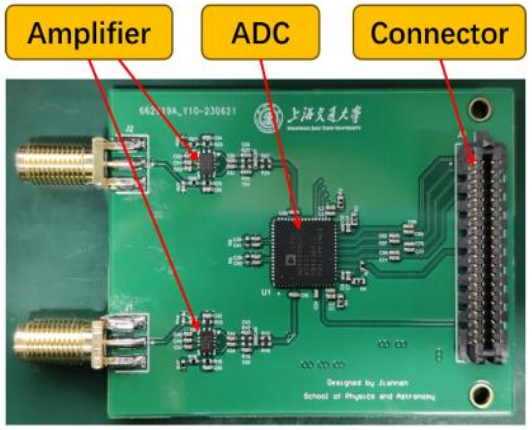


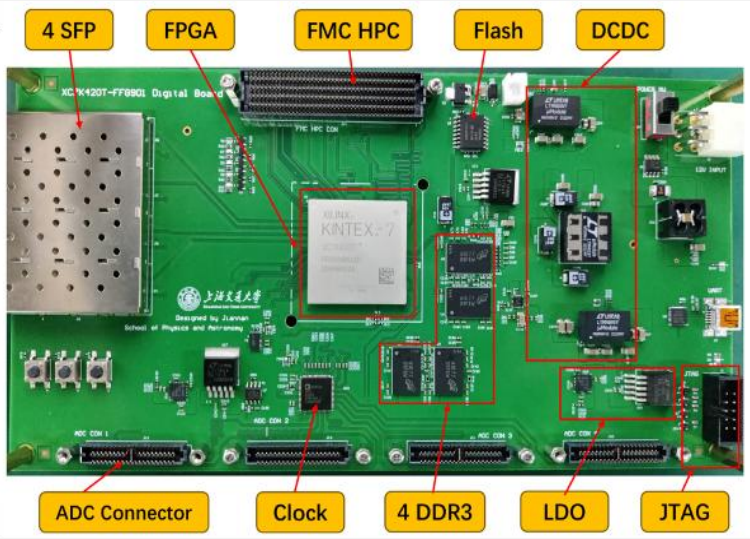


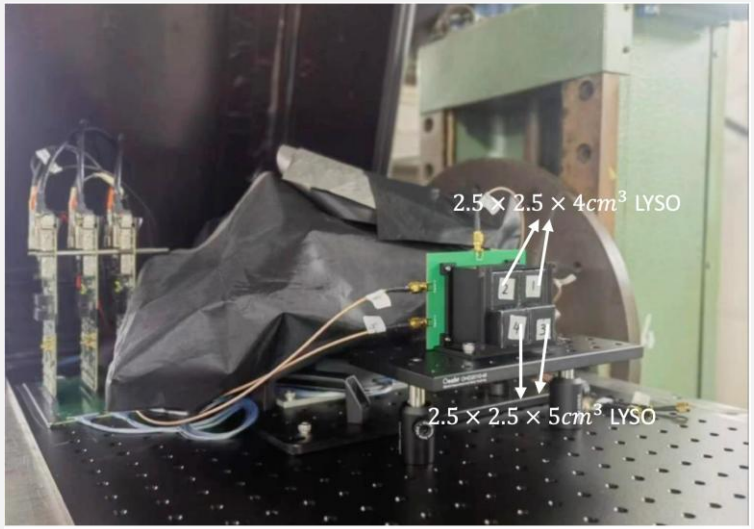


Electromagnetic calorimeter and performance

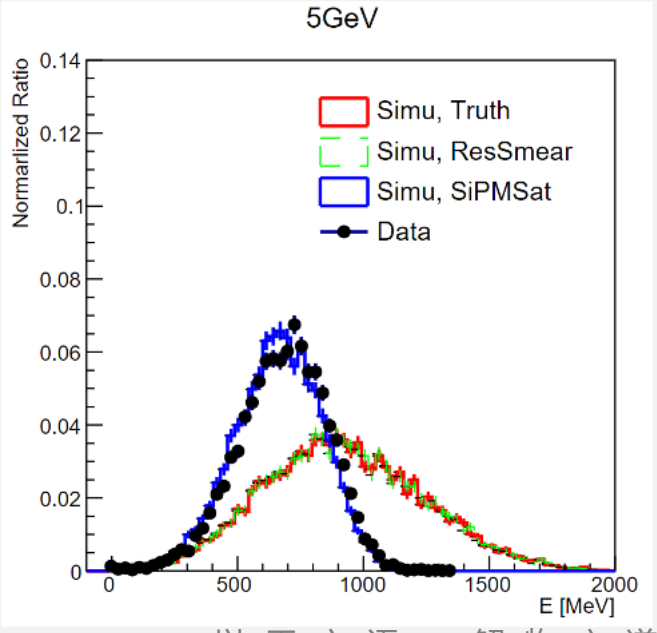








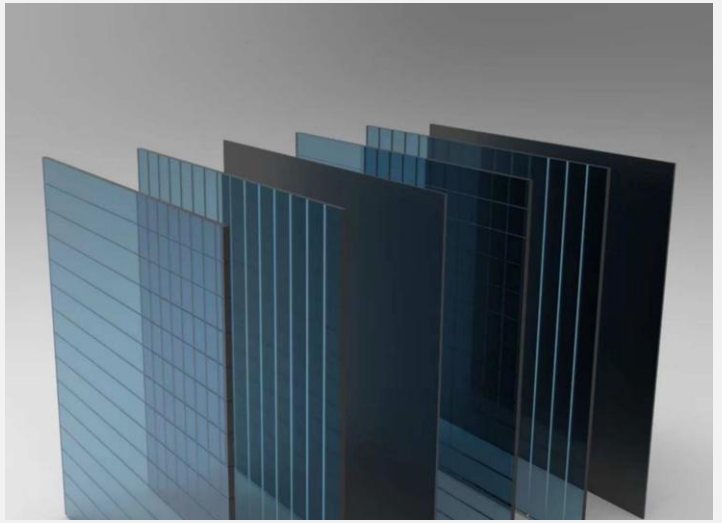
DESY TB22 Oct. 2023

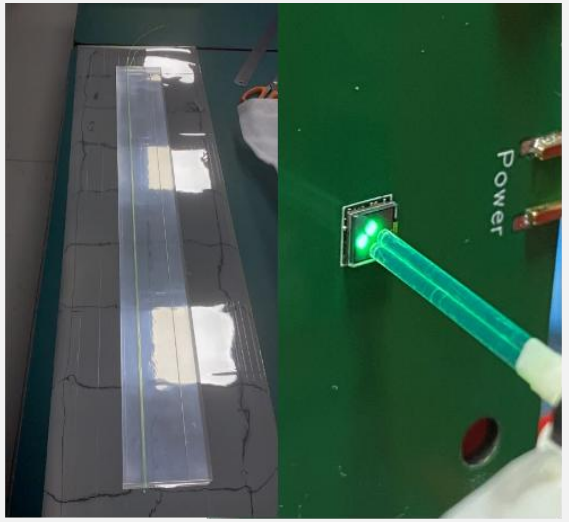


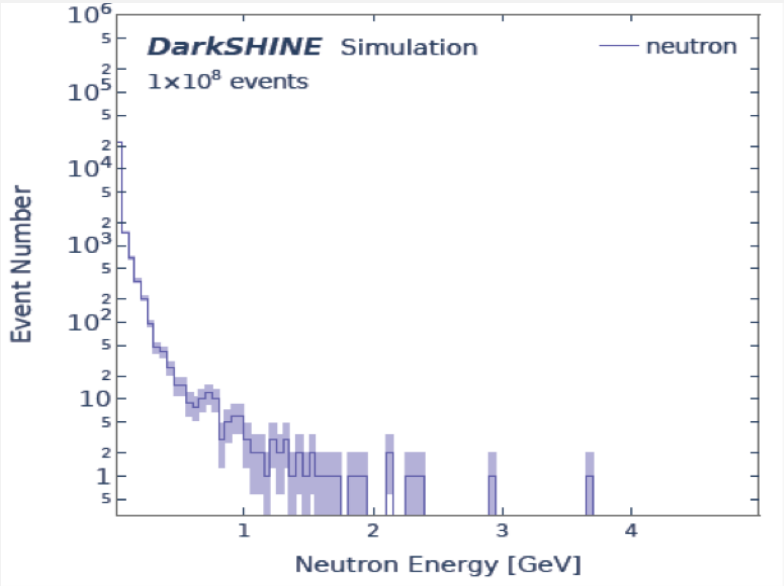
- LYSO unit test has been done.
- 1st mini-prototype module (2x2 LYSO) for beam test at DESY (with CEPC Calorimeter team)
- 1 MHz repetition rate readout board
  - arXiv:2407.20723
  - JINST 20 (2025) P08024

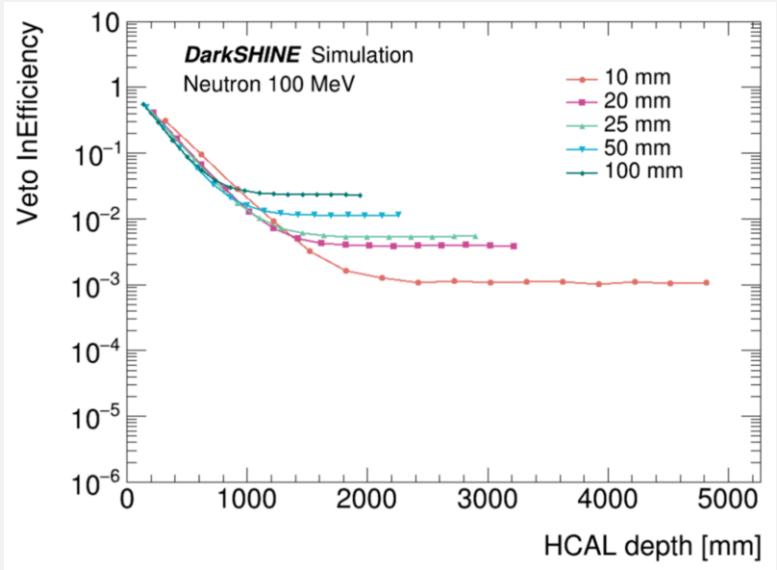
Hadronic calorimeter and performance

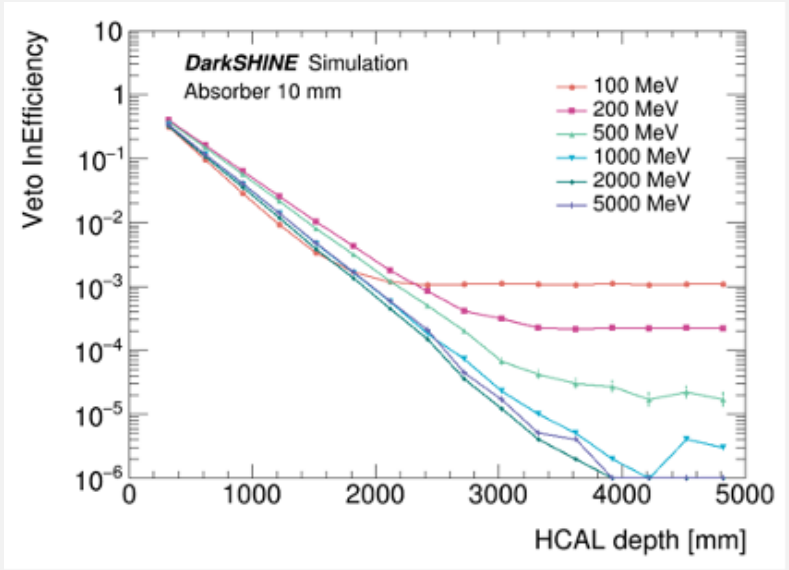
- **Veto hadronic backgrounds ~ 10^{-6}**
- **Plastic scintillator + Iron absorber**
  - **Scintillator**: 75x5 cm^2, 10 mm thick
  - **Absorber:** 75 x 75 cm^2, 10 mm (70 layers) + 50 mm (18 layers) thick
  - **Wavelength shift fiber + SiPM**





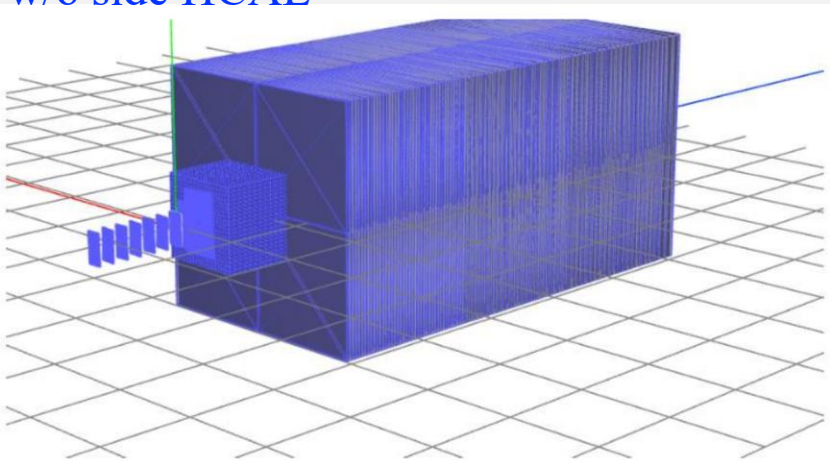




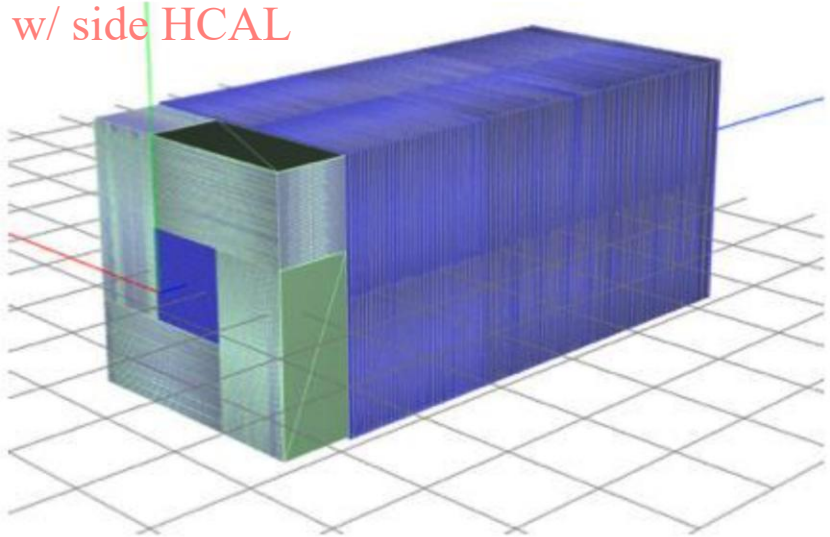


Hadronic calorimeter and performance

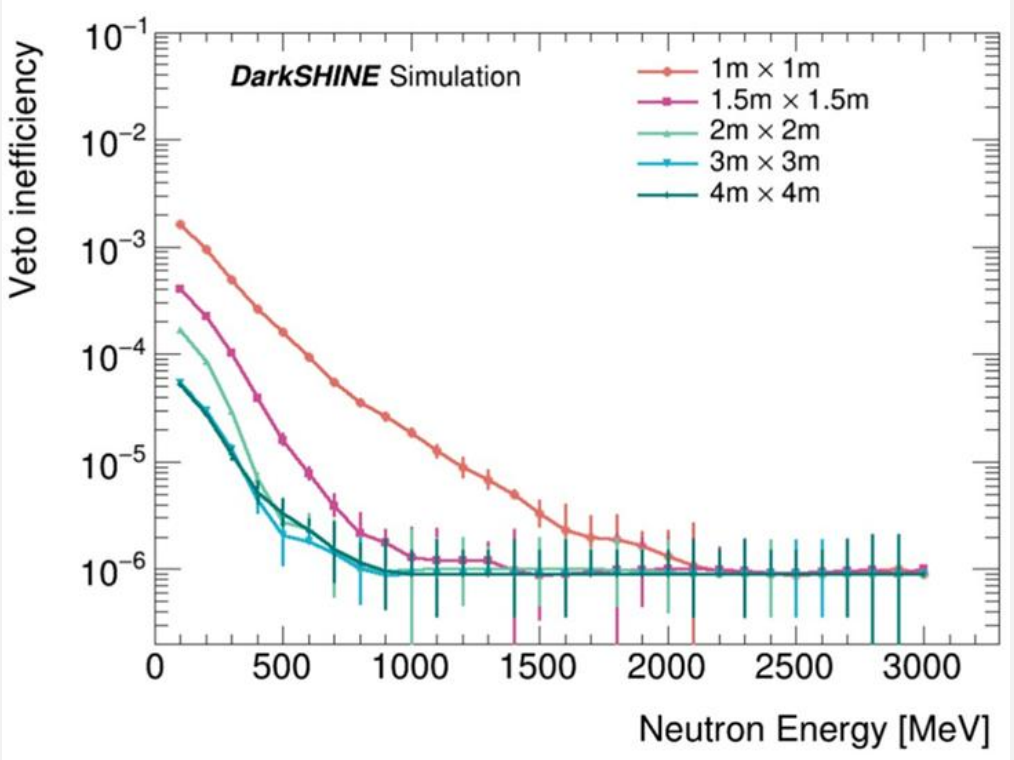
w/o side HCAL



w/ side HCAL



- **Optimization of the HCAL detector**
  - **Maximum total weight of 30 tons**
  - **HCAL size: 1.5 x 1.5 x 2.5 m^3 , >10 λ_I**
  - **with side HCAL can suppress veto ineff by ~3.5**



Summary

- **DarkSHINE: a fixed-target exp. searching for dark photon & light dark matter.**
- **Dark photon detection sensitivity has been studied using MC simulation**
  - *Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023).*
- **Detector key technology R&D have been presented**
  - Tracker (AC-LGAD silicon strips): *Nucl.Sci.Tech. 35 (2024) 201*
  - ECAL (LYSO+SiPM): *Nucl.Sci.Tech. 36 (2025) 41*
  - HCAL (Scintillator + Iron absorber): *Nucl.Sci.Tech. 35 (2024) 148*
  - Readout electronics: *JINST* **20** (2025) P08024
- **Conceptual Design Report is available: *arxiv:2411.09345***

➢ **Aiming for the approval and construction of the DarkSHINE experiment !**

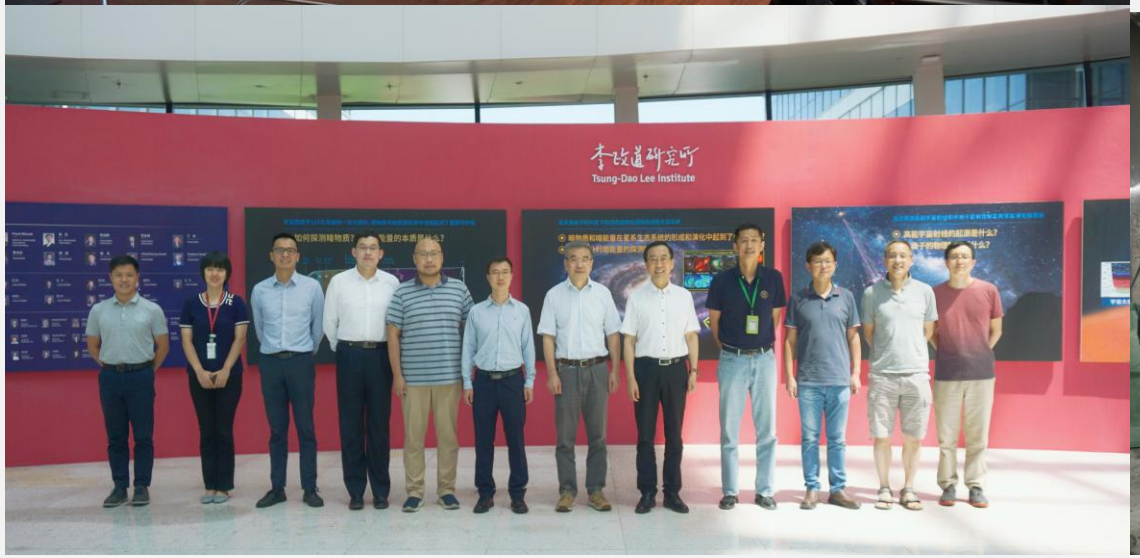
李政道研究所
TSUNG-DAO LEE INSTITUTE

Thanks for your attention !

Summary

欢迎硬X射线自由电子激光团队
访问李所

6th DarkSHINE Seasonal Workshop
Time: 2025.5.22
Venue: TDLI N400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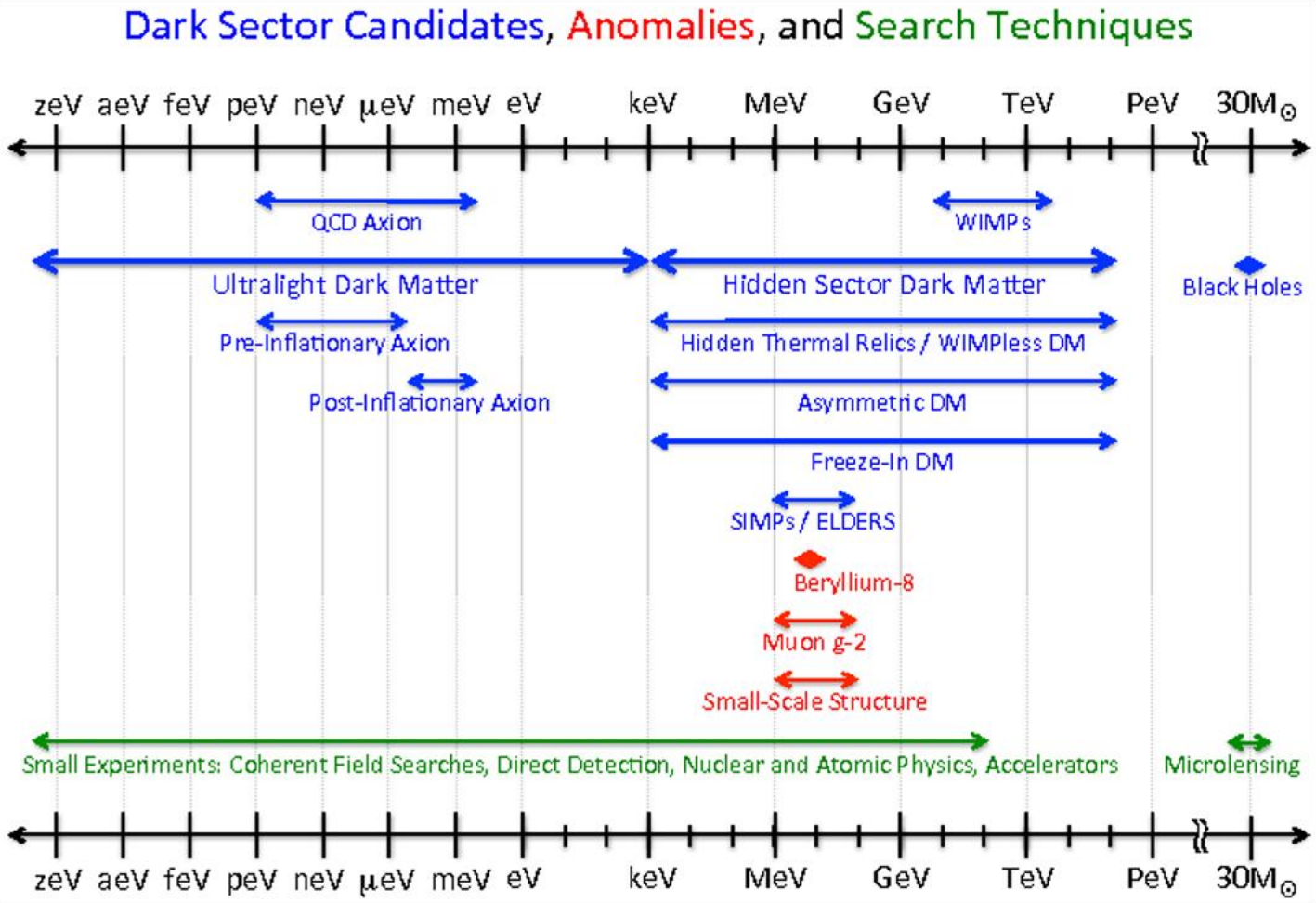
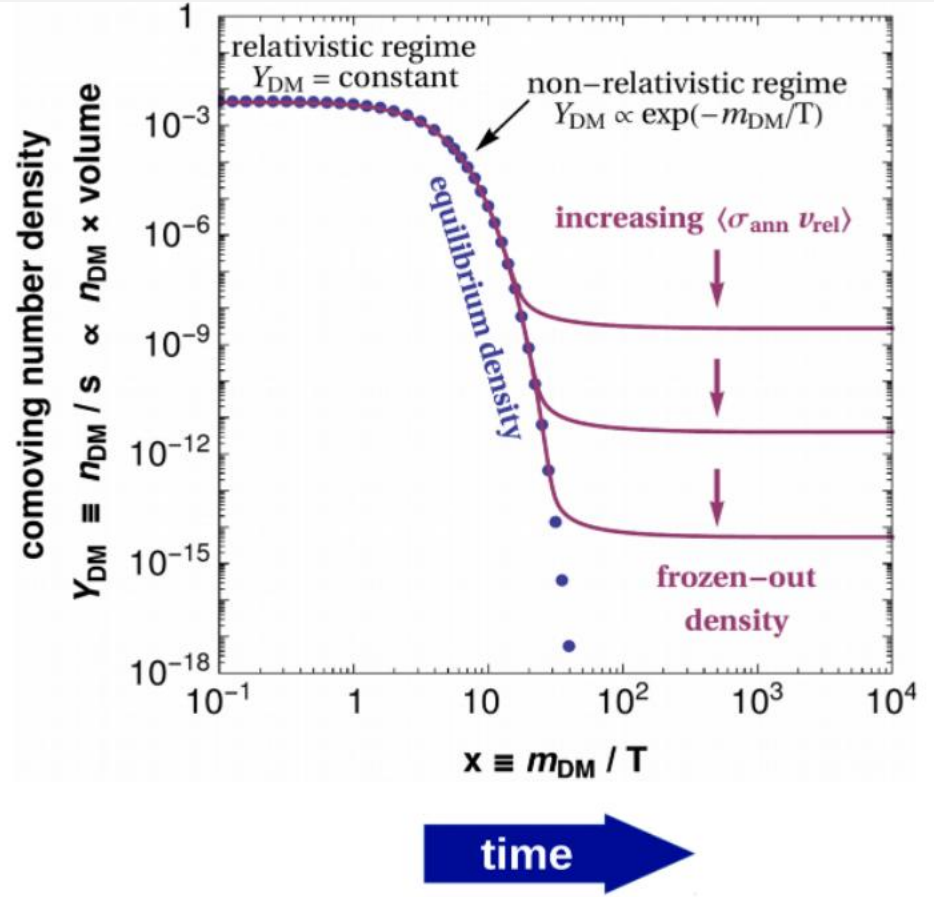
Many dark matter models over a wide mass range

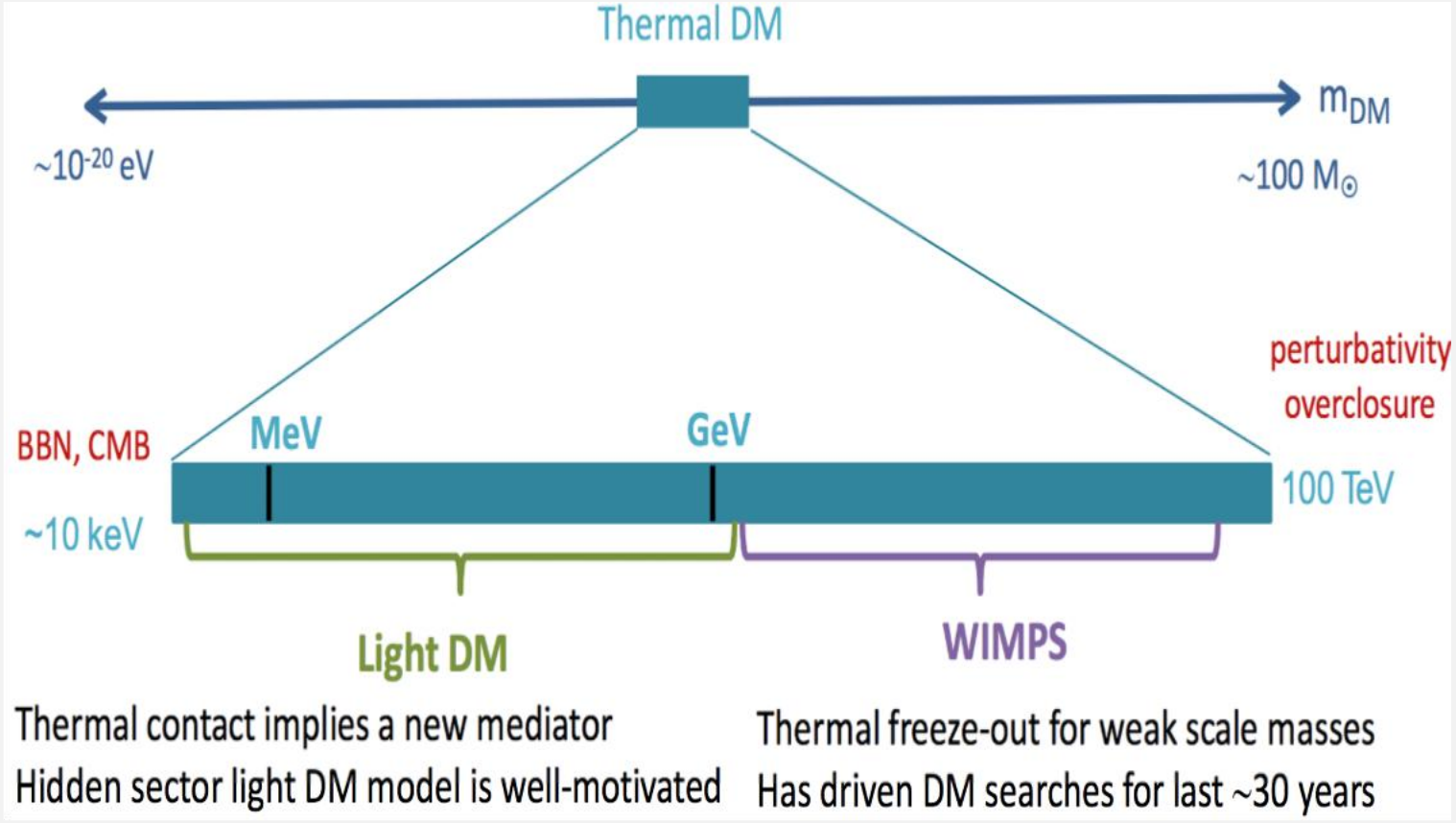


arXiv: 1707.04591; arXiv:1810.01668

Dark matter exists over a wide mass range, from Ultralight "Fuzzy DM" to Primordial Black Holes.

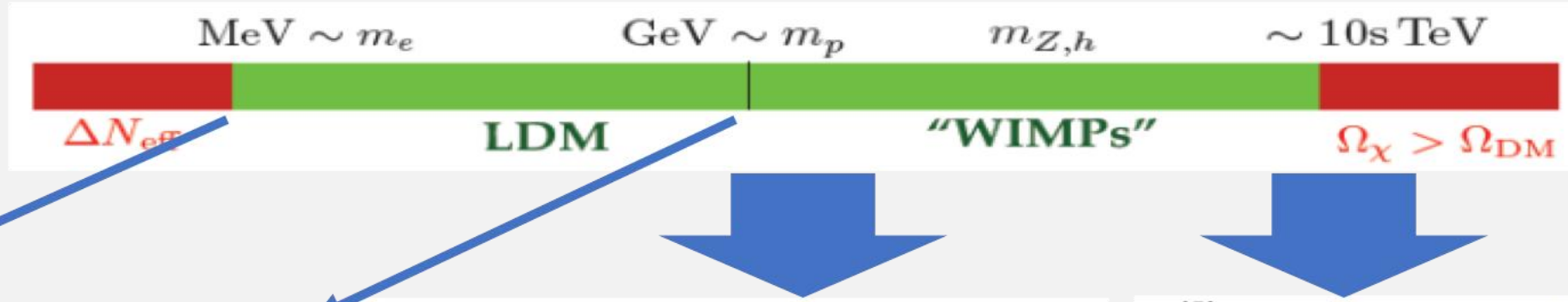
Thermal dark matter is particularly interesting

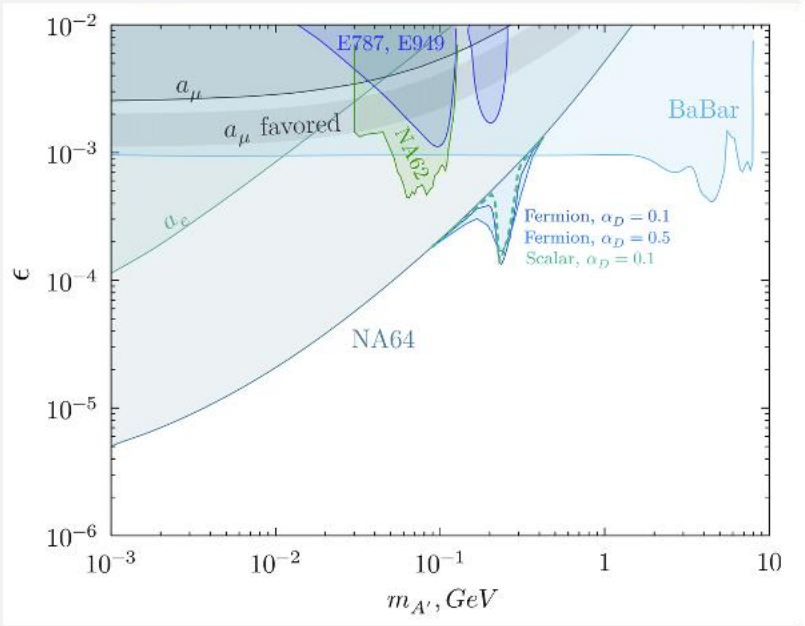


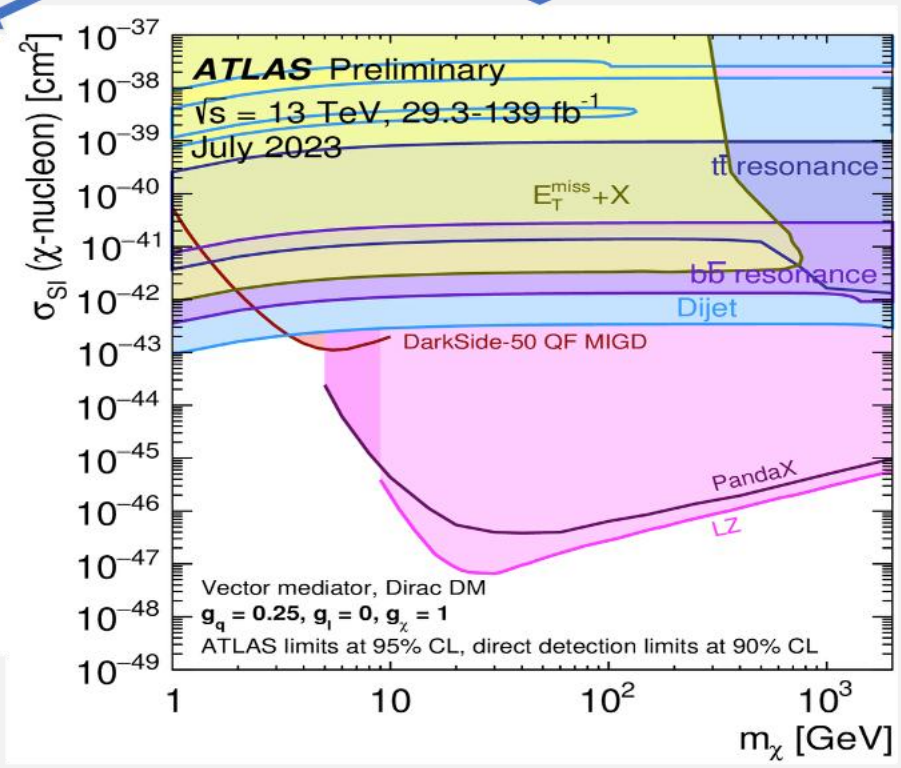


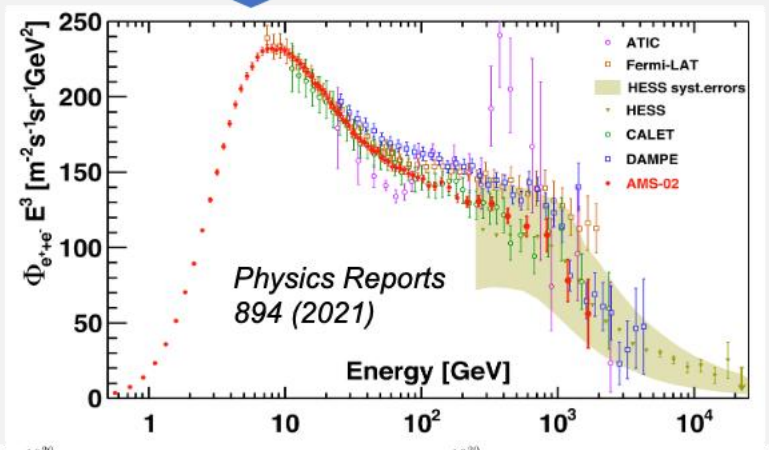
In order to explain the presence of dark matter constituting ~ 27% of the energy content of the universe, the "Freeze-out" mechanism permits a dark matter mass range from MeV to tens of TeV.

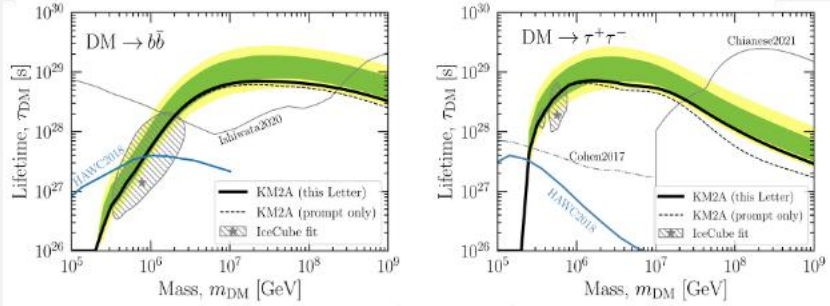
Motivation — search for light dark matter





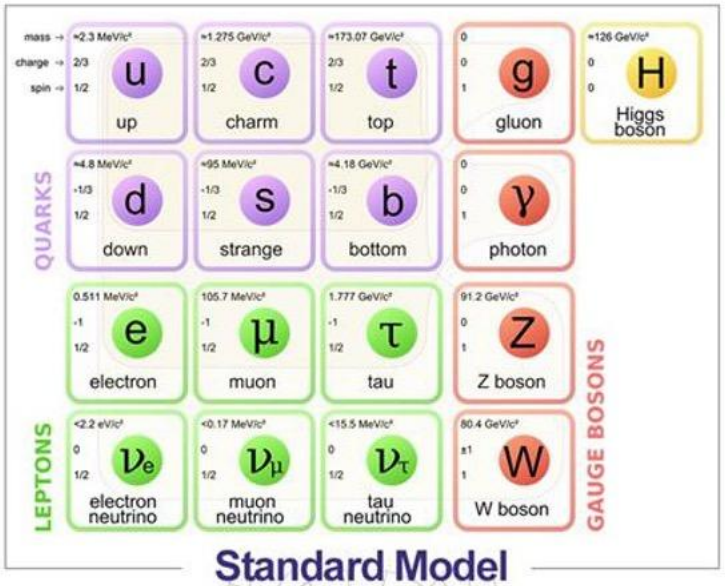




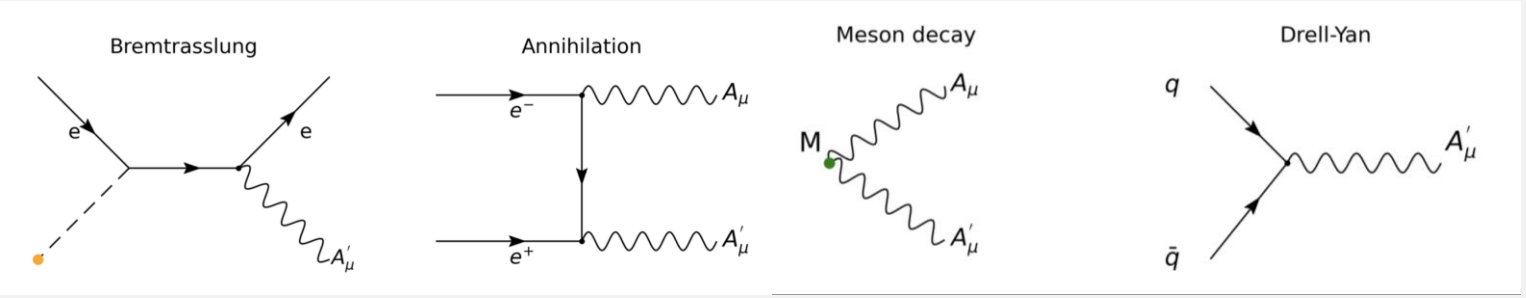


PRL 129, 261103

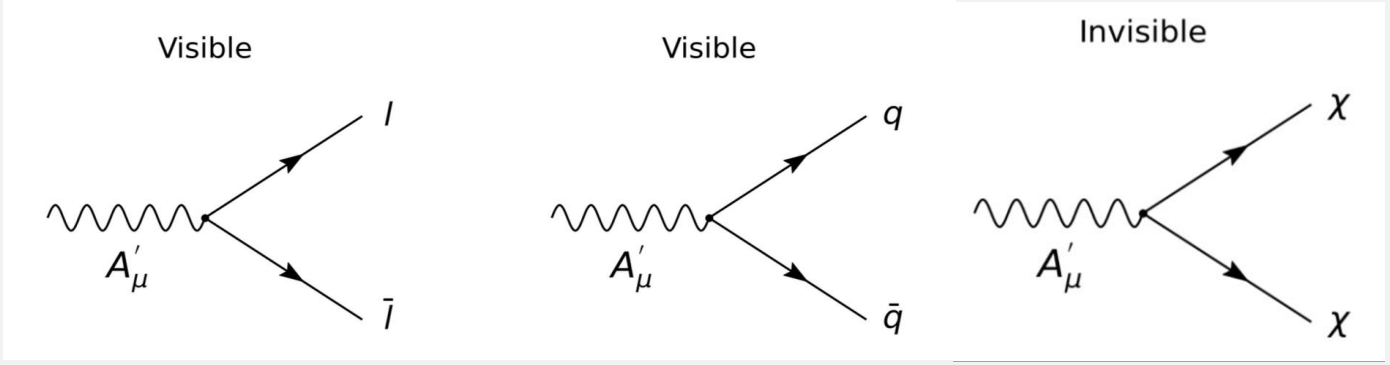
Massive dark photon as new force carrier



Production of dark photons: Bremsstrahlung, Annihilation, Meson decay and Drell-Yan process

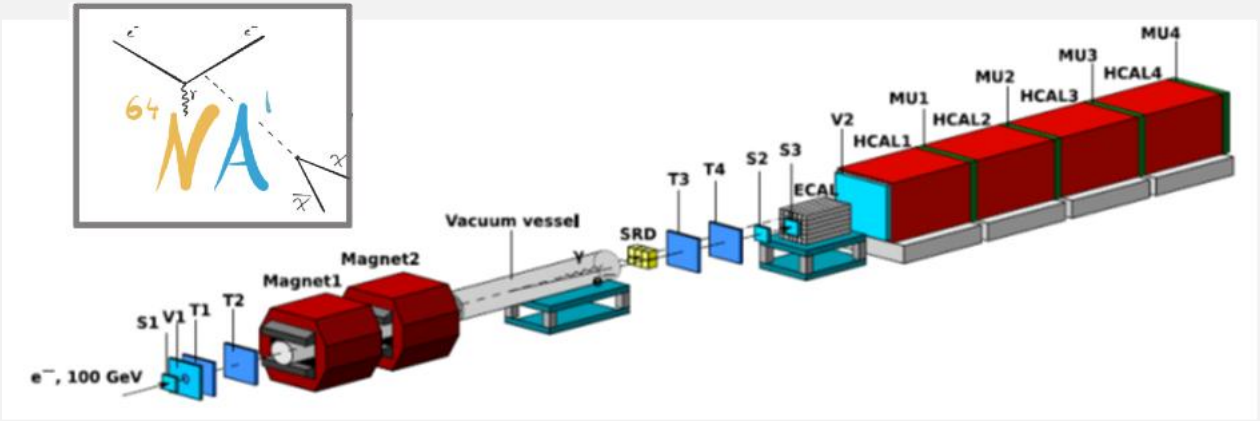


Massive dark photon can decay both visibly and invisibly:

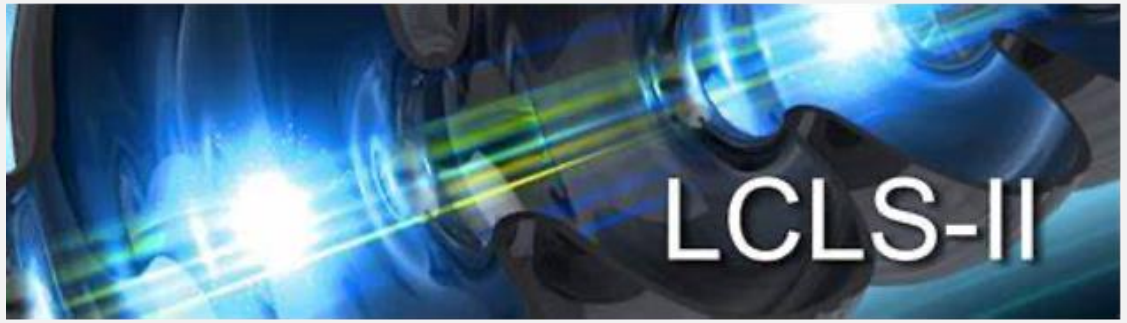


Invisible decays of dark photon

- **Searches at collider and beam-dump experiments:**
  - Missing mass (BESIII, Belle-II etc.)
  - Missing energy (NA64)



- **A new approach based on missing momentum reconstruction**
  - Single electron on target
  - High frequency electron beam
  - “Missing momentum” information



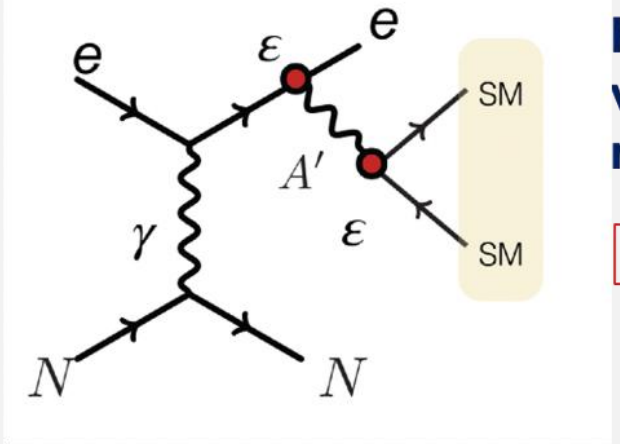
arXiv: 1912.05535

→ Light Dark Matter eXperiment (LDMX) at LCLS-II SLAC (R&D)

→ DarkSHINE experiment at SHINE facility, Shanghai (R&D)

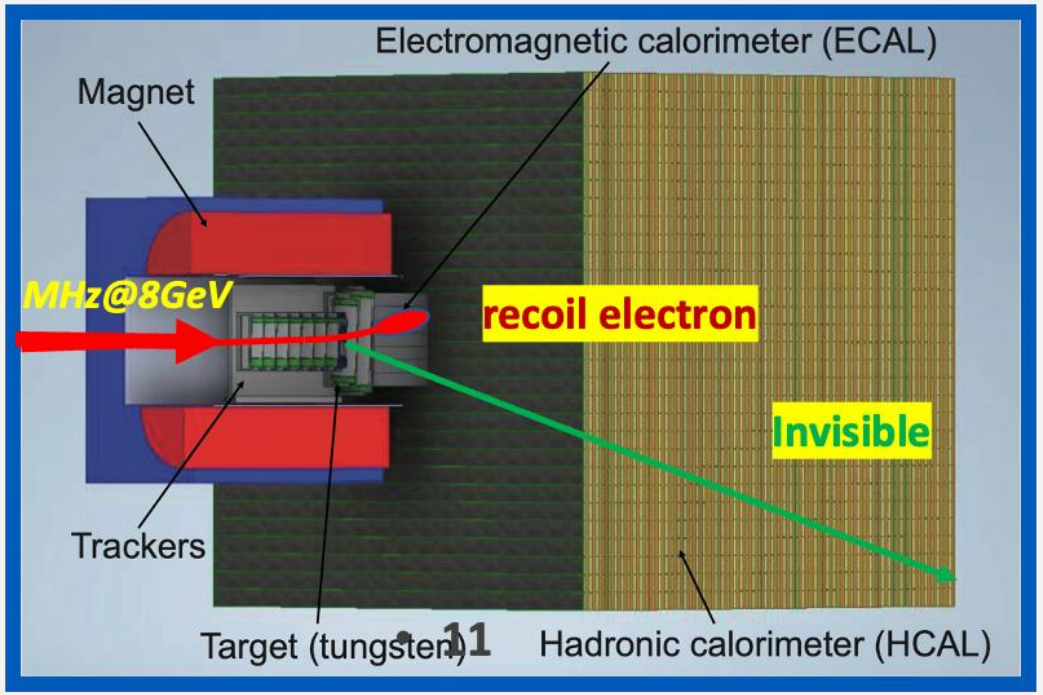
Searching for dark photon invisible decay

VISIBLE DECAY MODE $m'_A < 2m_X$

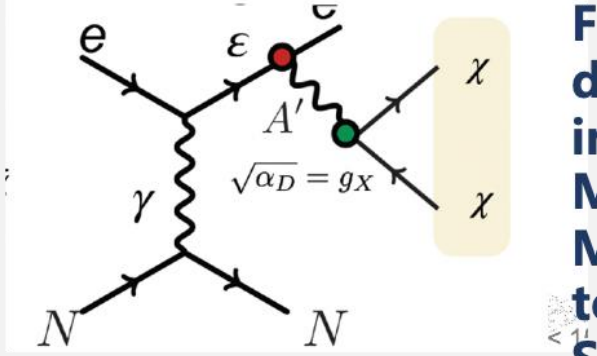


Having two interaction vertices → production rate highly supressed

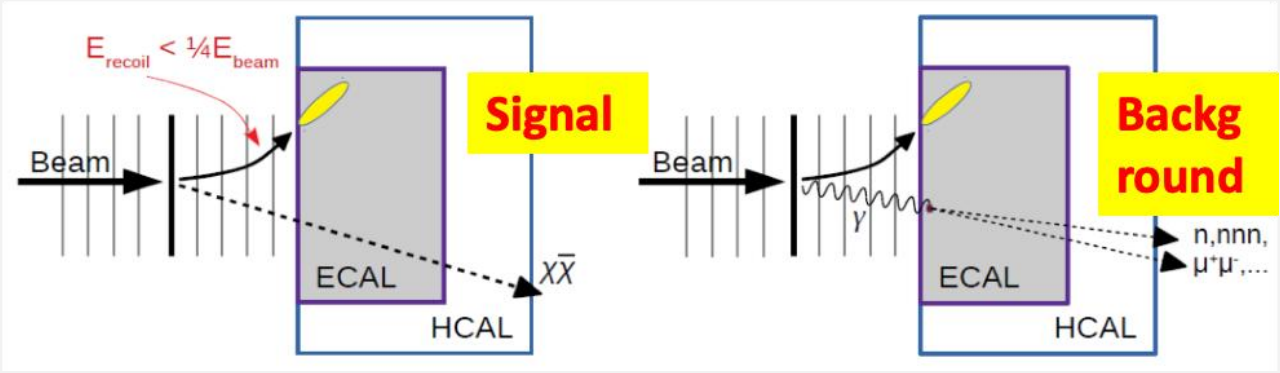
$$N \propto \epsilon^4 \ll N \propto \epsilon^2(1-\epsilon^2) \approx \epsilon^2$$



INVISIBLE DECAY MODE $m'_A > 2m_X$

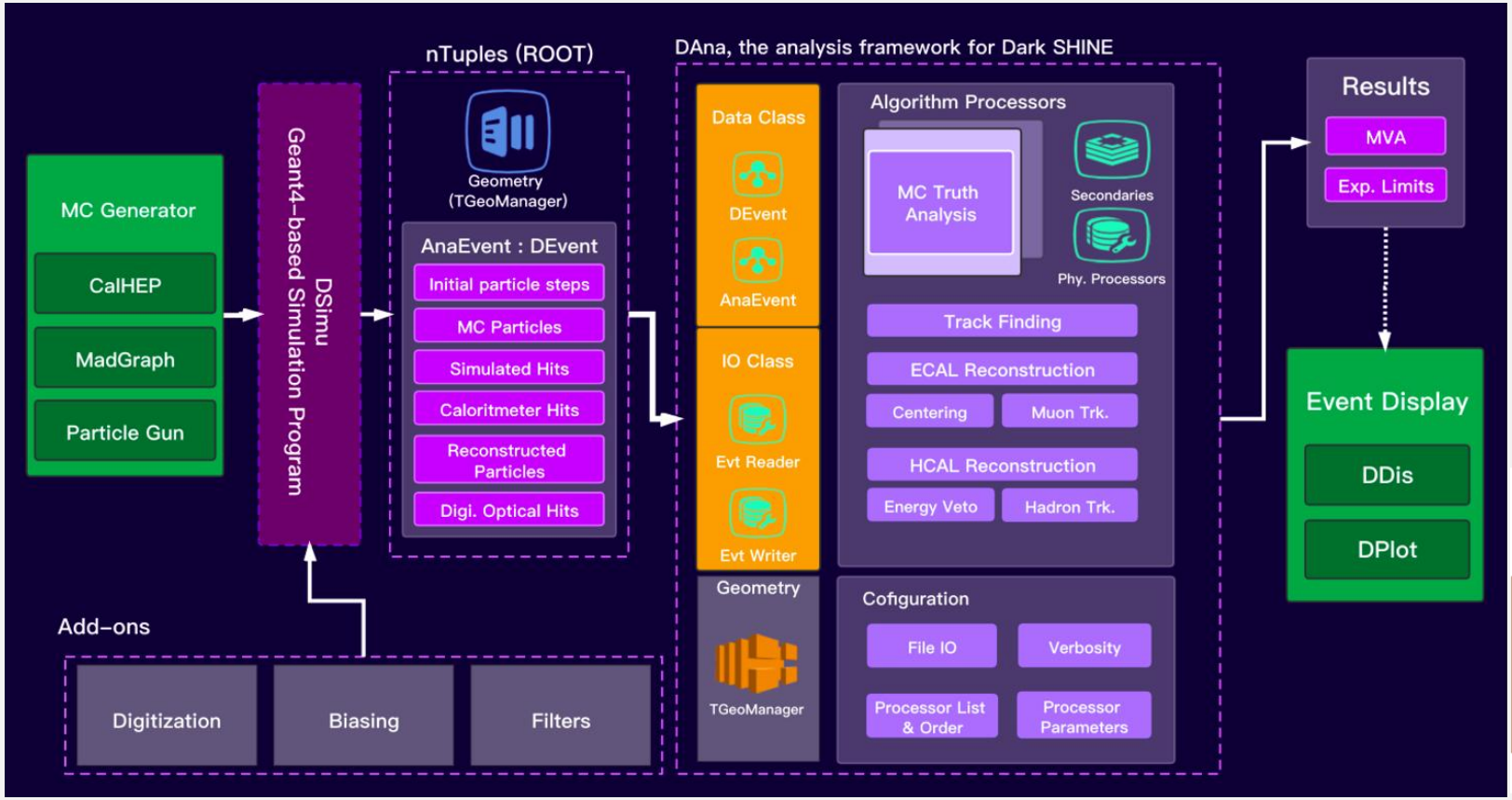


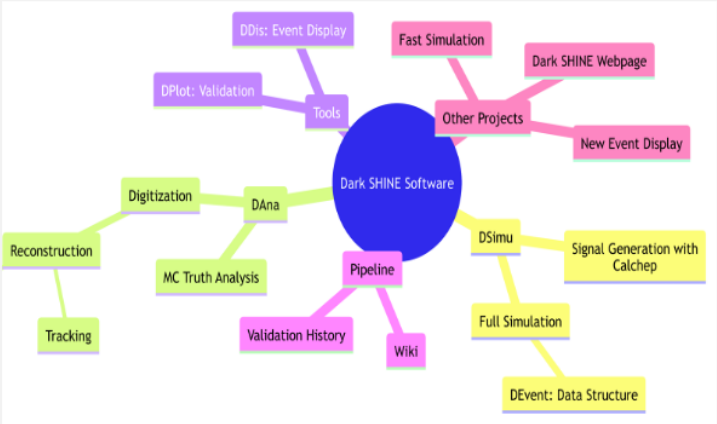
Focusing on invisible decays of dark photon into light dark matter → Missing Energy/Missing Momentum phenomena to hint the Dark Photon Signal

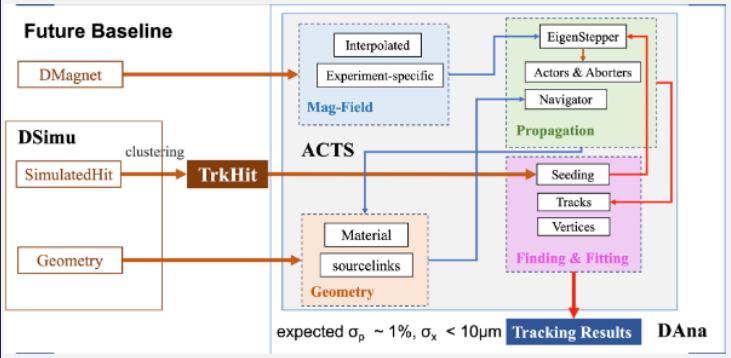


DarkSHINE simulation framework

- **Simulation and analysis framework integrates various functions such as detector simulation, electronic signal digitization, event reconstruction and data analysis, based on *GEANT4* and *ACTs* etc.**

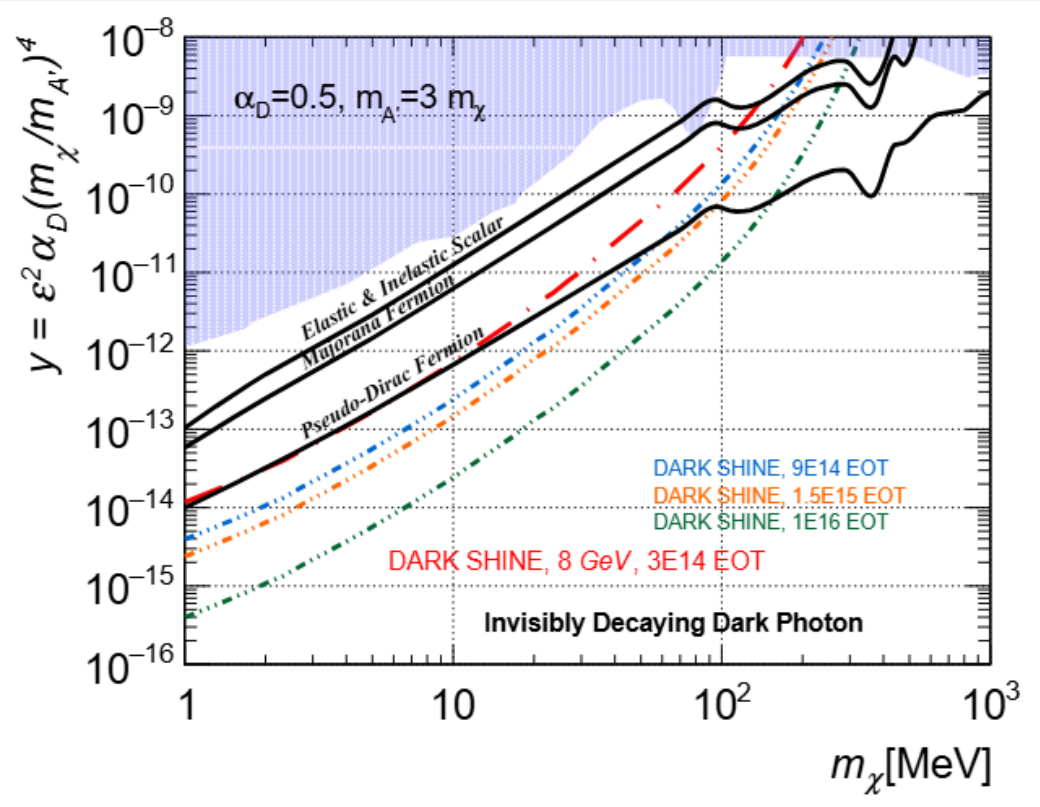


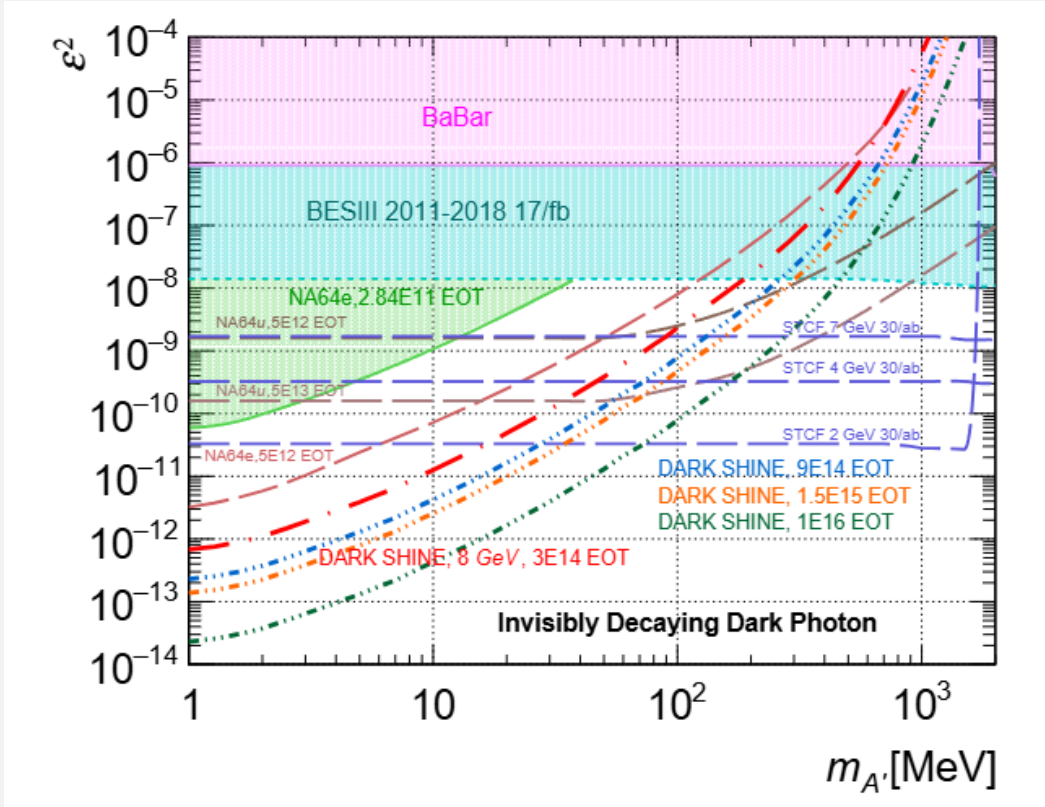




Physics perspective

- Competitive sensitivity from preliminary results
- Expected limit on ε^2 as the function of dark photon mass at 90% C.L. is estimated with predicted luminosity





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