Recent Progress of DarkSHINE R&D

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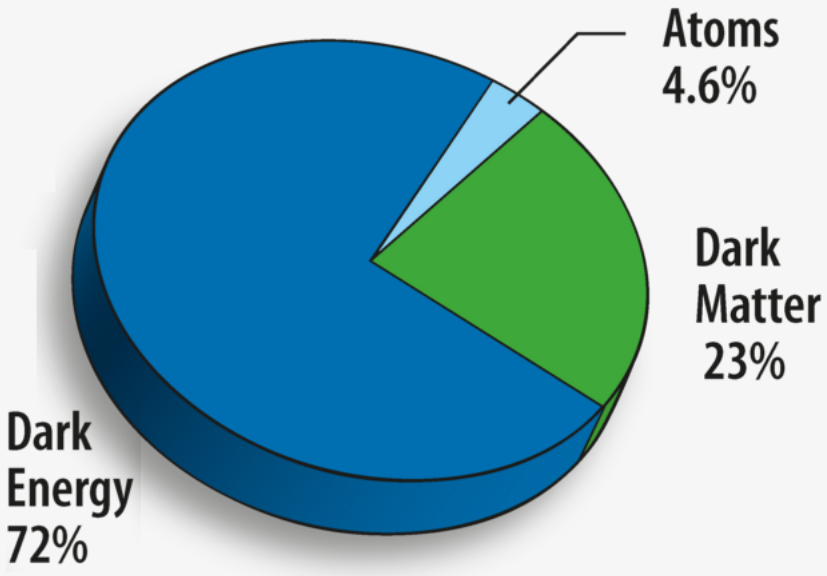
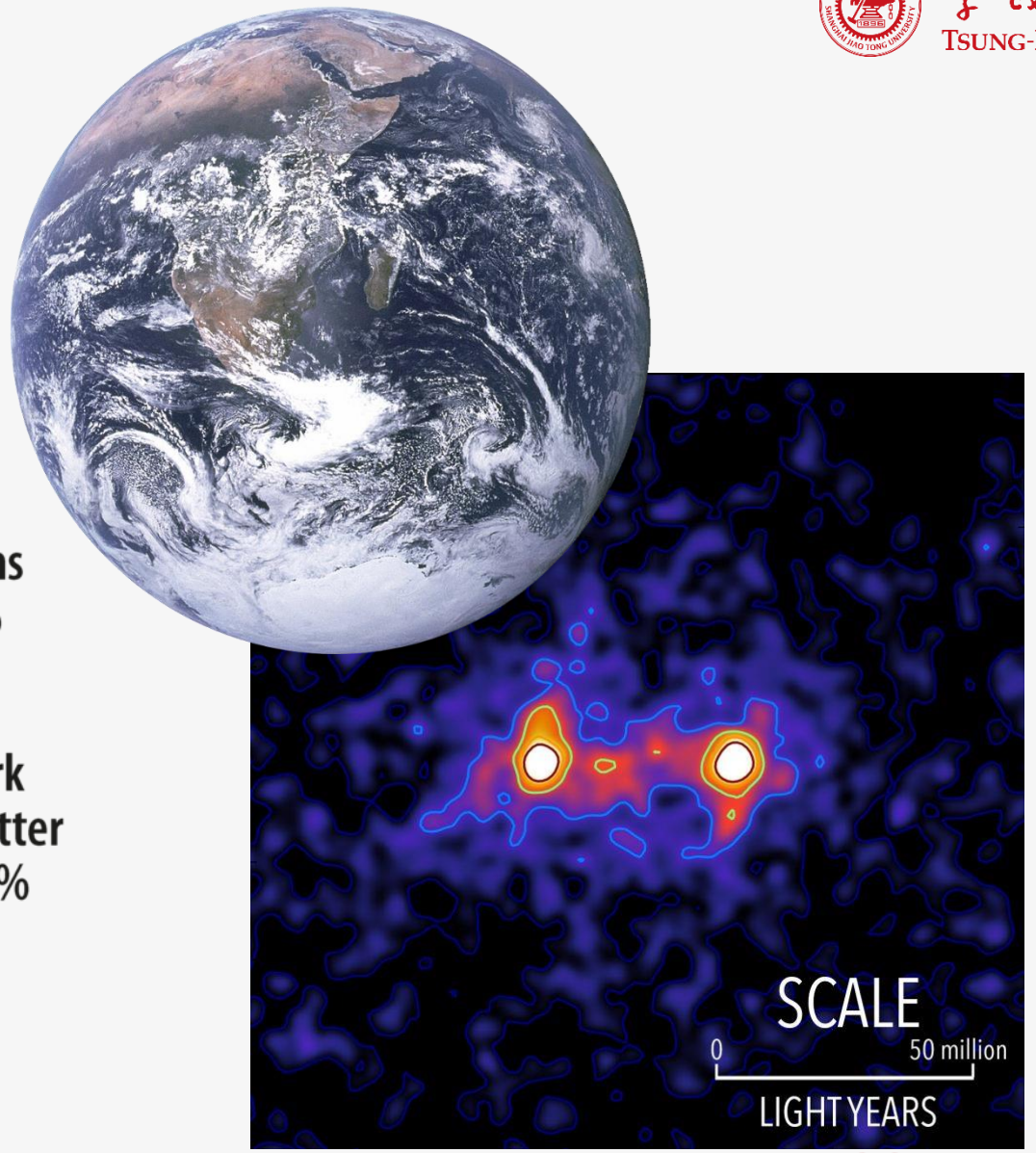
What Beyond Our Knowledge

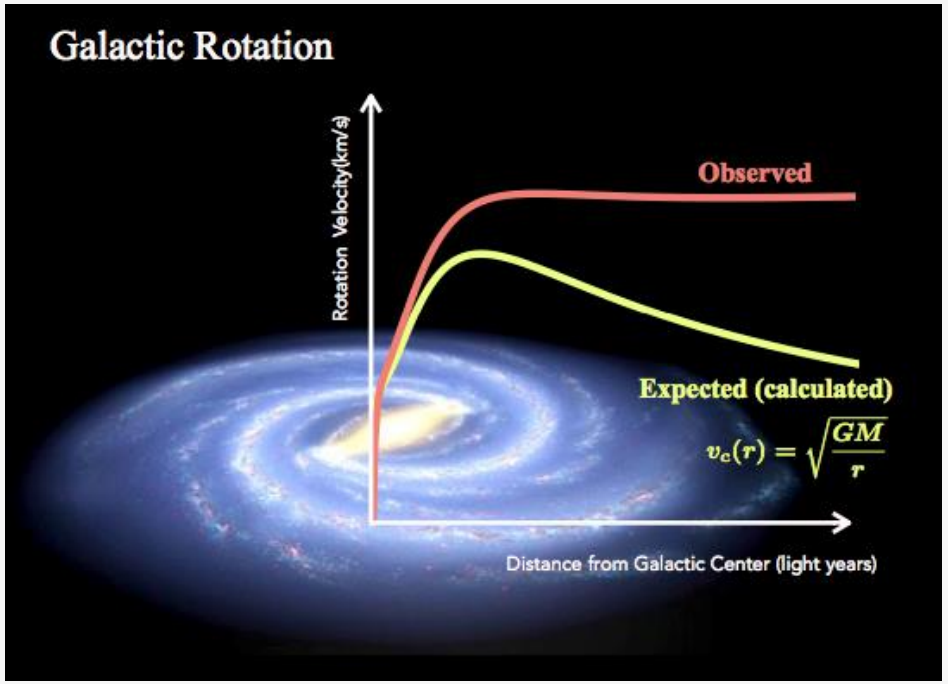
- The observed universe: 5% of mass-energy of the universe
- What we don't know: **dark matter**, dark energy

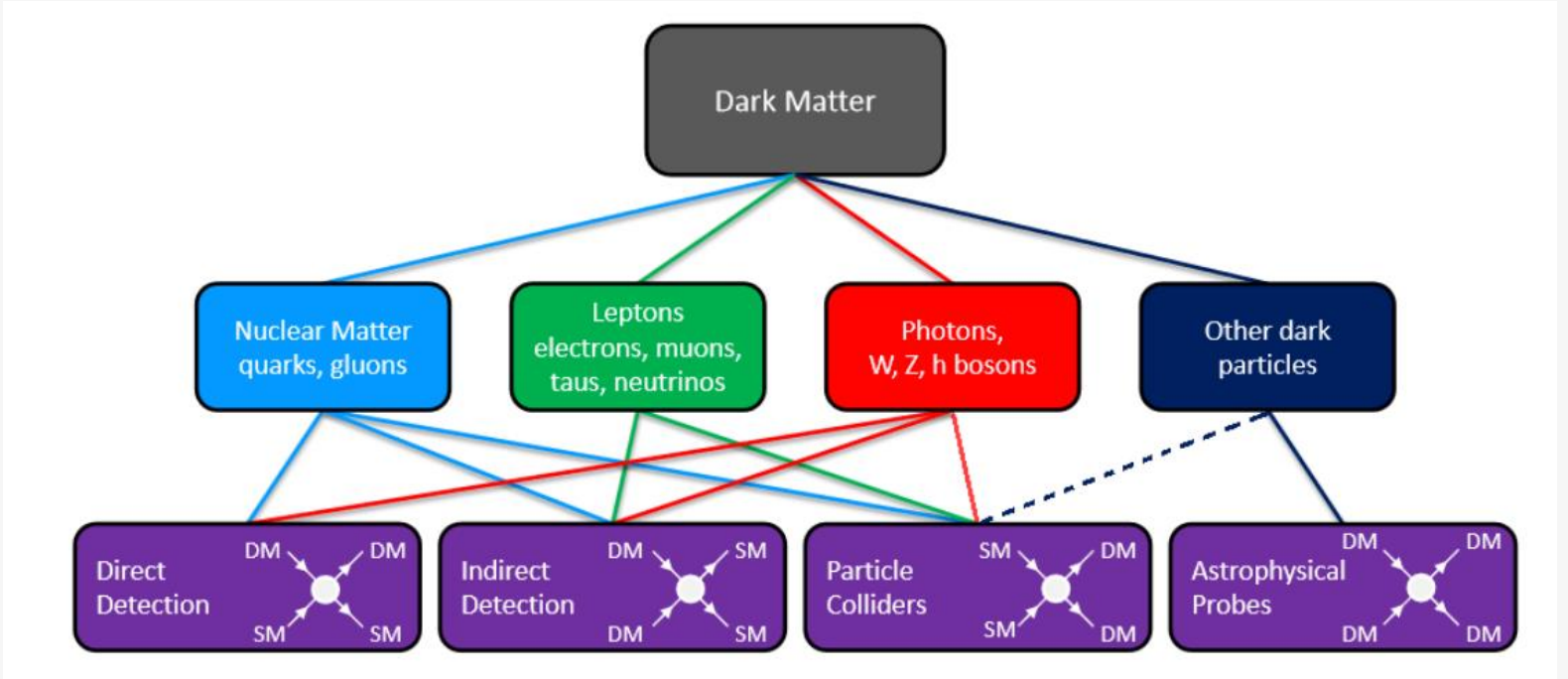




Dark Matter Evidence

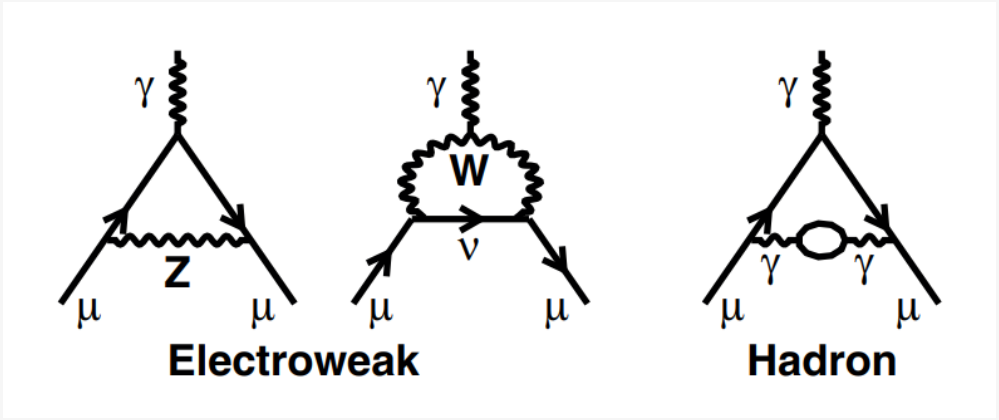
- DM evidence from astronomical observations and gravitational effects:
  - Galactic rotation curves, gravitational lensing, cosmic microwave background anisotropies, …
- Characteristics: non-baryonic, electrically neutral, gravitational -> WIMP, …

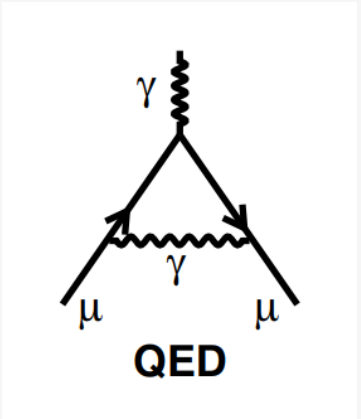


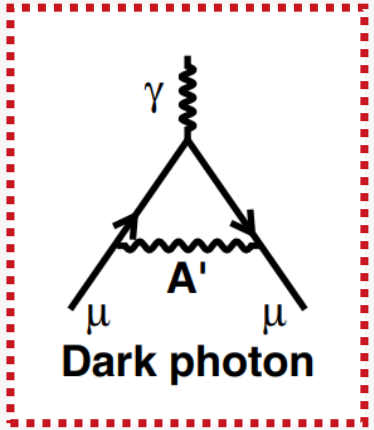


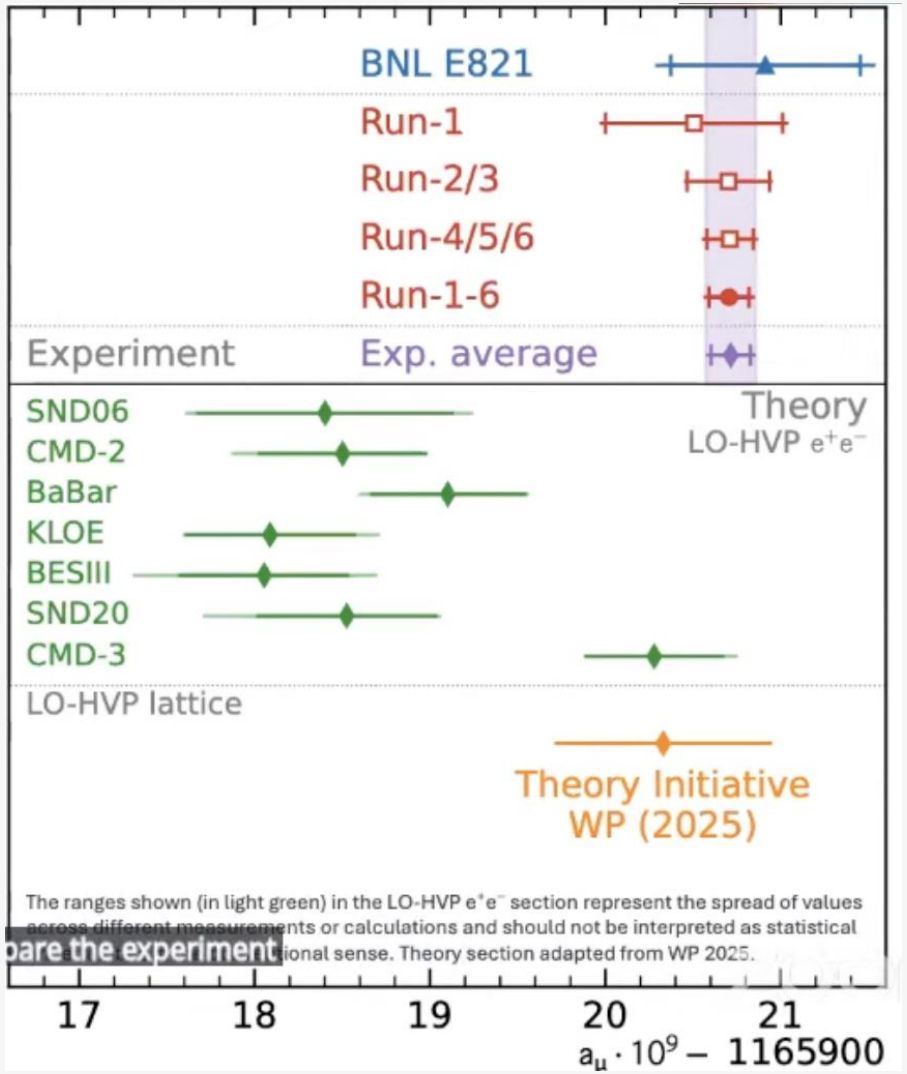
Evidence from g-2?

- Dark photon may contribute to electron/muon anomalous magnetic moment





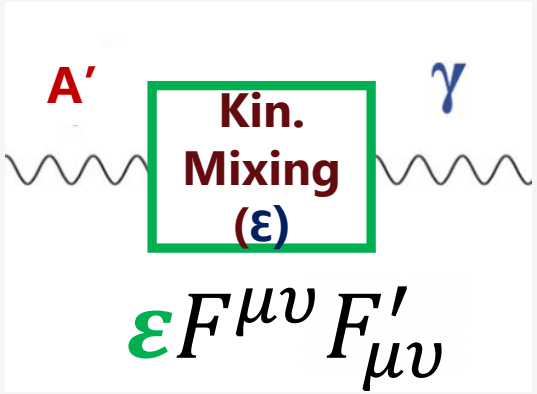




Dark Photon Theory in a Nutshell

- Dark photon is an important portal between SM particles and dark matter

$$L = L_{SM} + \varepsilon F^{\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}$$



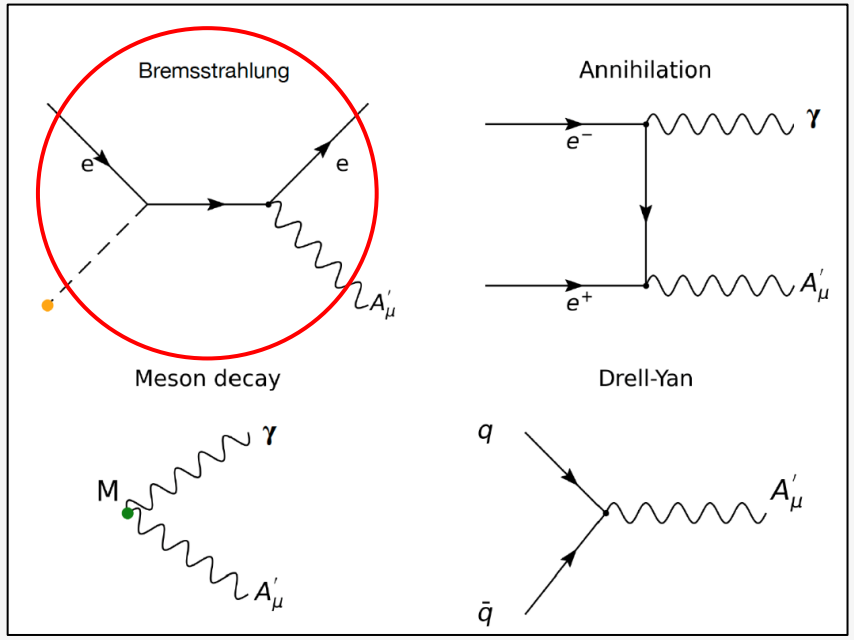
Dark Photon A′

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

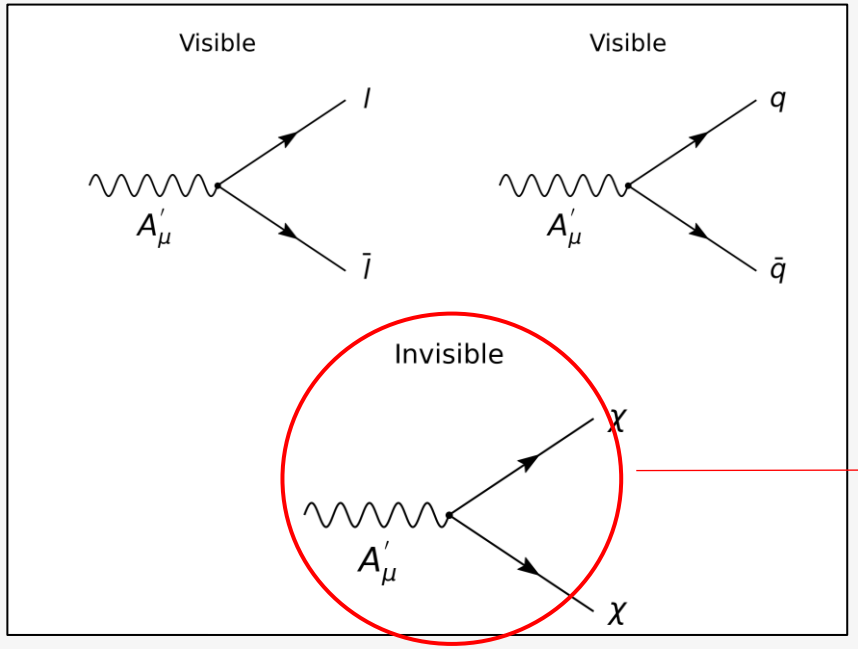
B. Holdom, Phys. Lett. B 166, 196 (1986)
R. Foot & X.-G. He, Phys. Lett. B 267, 509 (1991)

Physics Process and Anticipated Signatures

- Processes to search for dark photon: **bremsstrahlung**, annihilation, meson decay and Drell-Yan process



Dark photon production

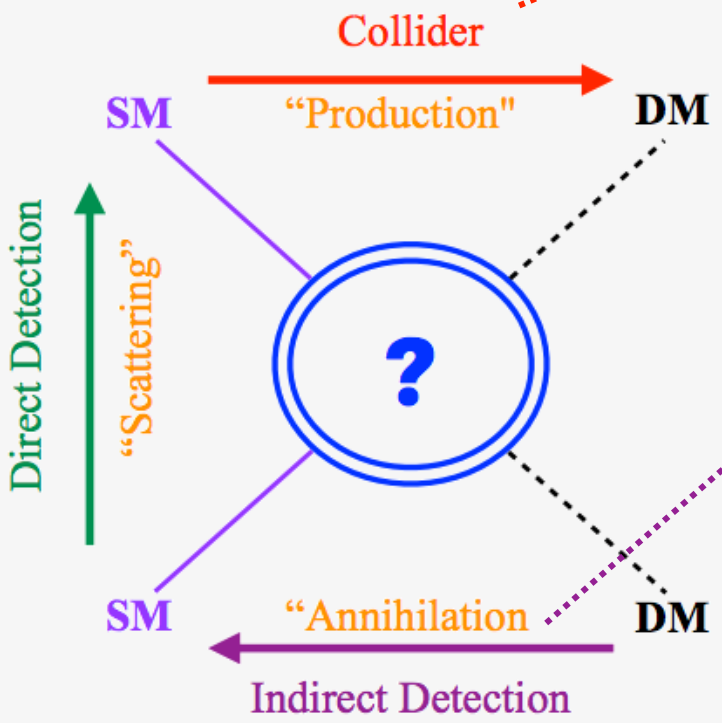


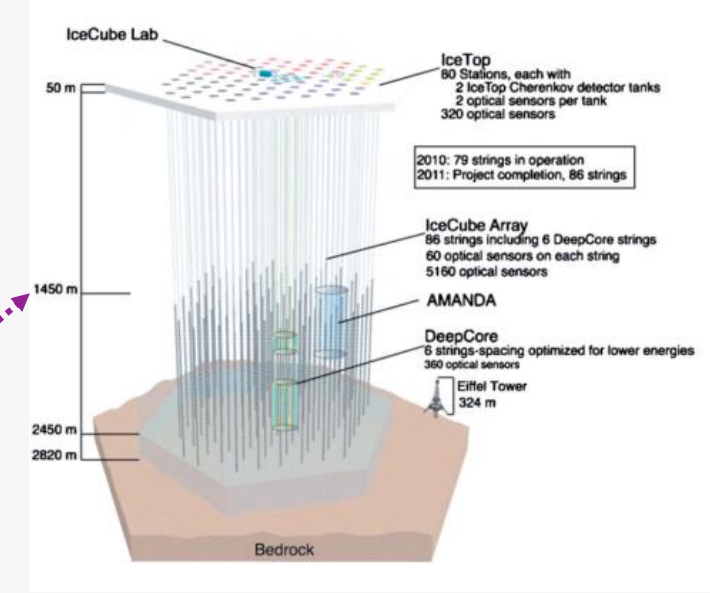
Dark photon decay

- **Goal:** constraints on the kinetic mixing parameter ε
- **Challenge:** small production rate → suppress SM bkg
- **Experimental signatures:** missing energy, missing momentum.

Dark Matter Detection

- **Collider**: LHC, …
- **Direct**: PandaX, XENONnT, …
- **Indirect**: IceCube, …
- More statistics?



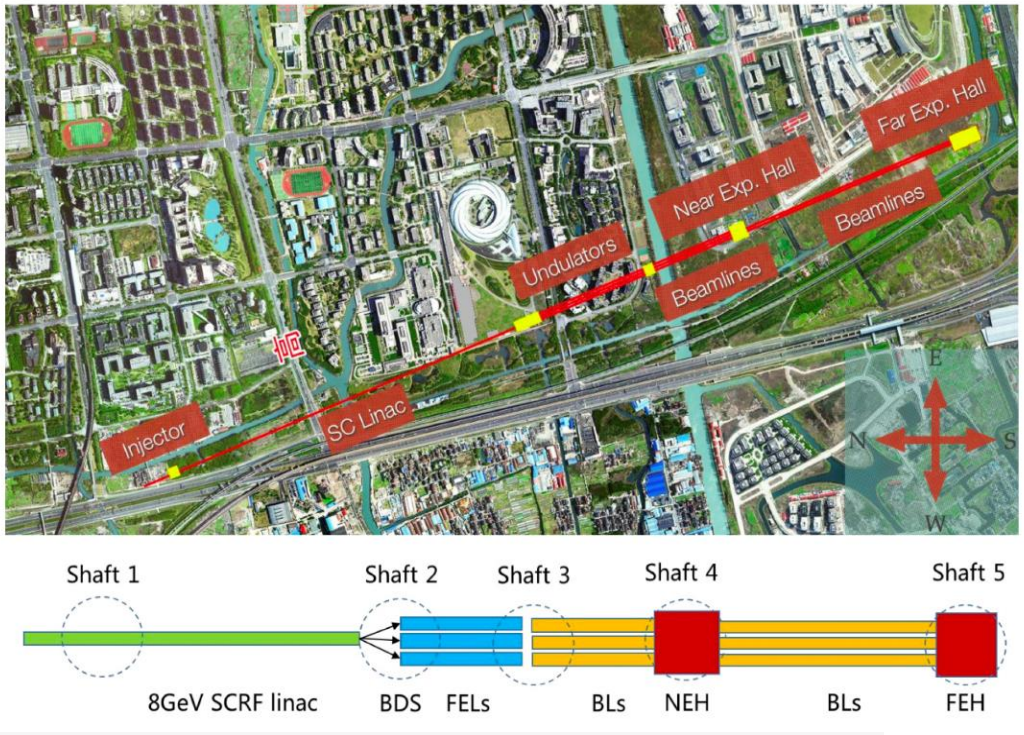


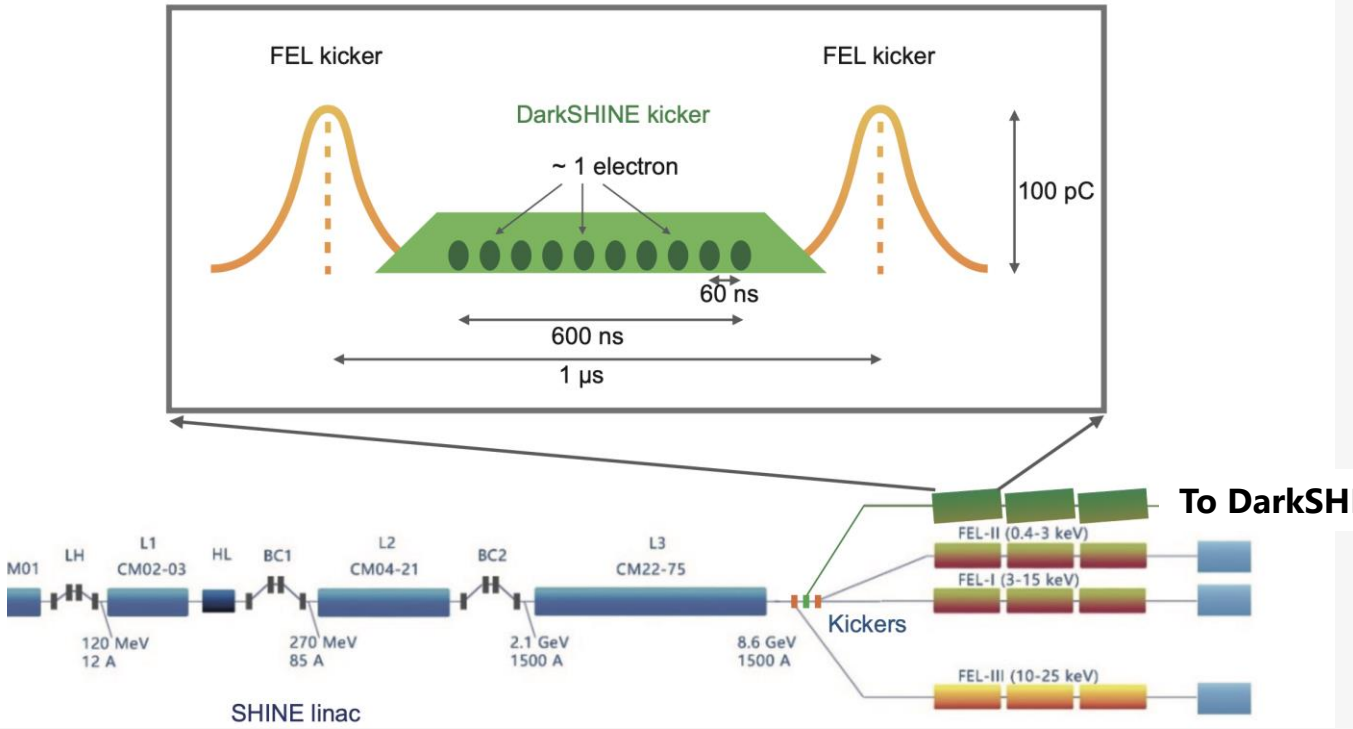
The SHINE Facility

- Shanghai High Repetition-Rate XFEL and Extreme Light Facility (SHINE) can provide high repetition rate single electron beams

Beam energy	Rate	e⁻ on target
8 GeV	1 MHz	~3x10^{14}/yr

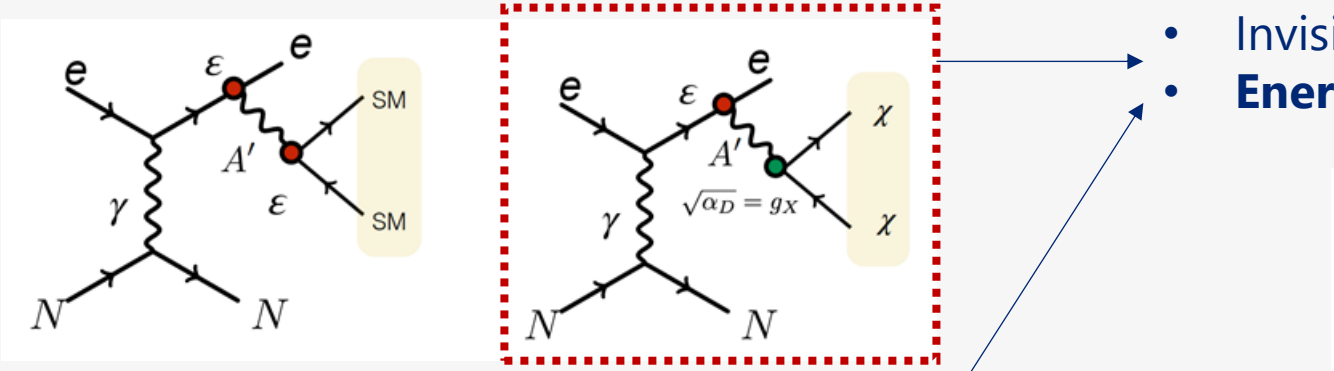
- **Under construction in ZhangJiang area (2018-2026)**
- **Beamline R&D: ShanghaiTech. / SARI,CAS**



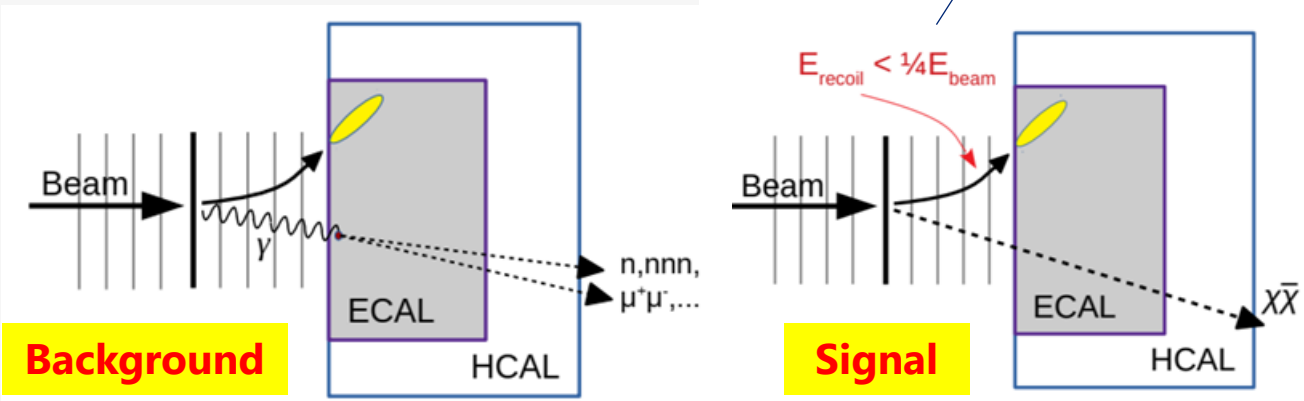


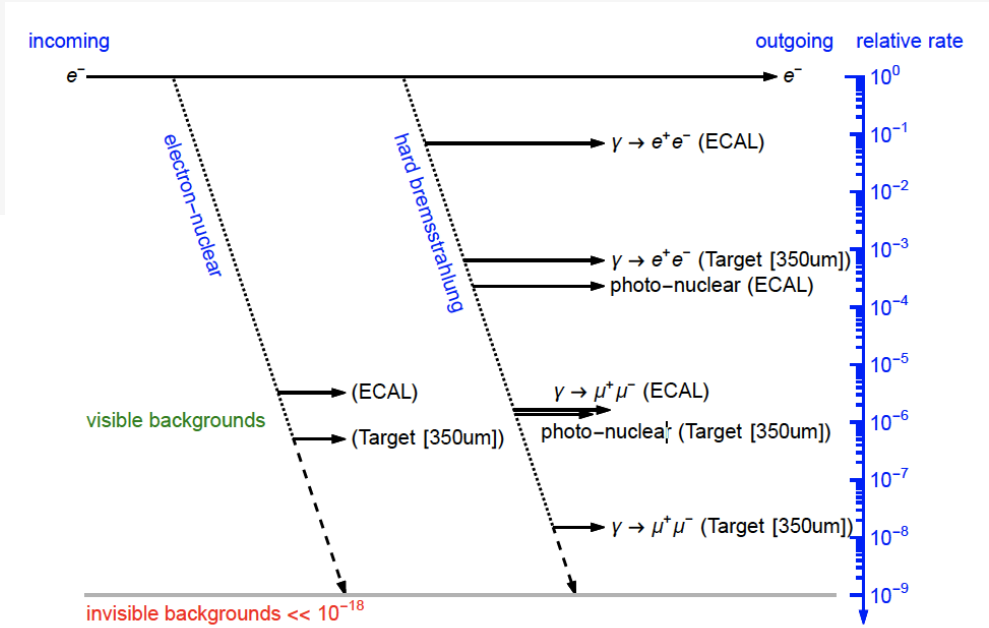
DarkSHINE Experiment

- **High repetition rate single electron beam** from SHINE allows more striking record of single electron-on-target dark photon events
- **DarkSHINE** Experiment: high statistics, precise measurement & fast detector response



- Invisible decay, 1 SM-BSM vertex
- **Energy + Momentum loss** detection

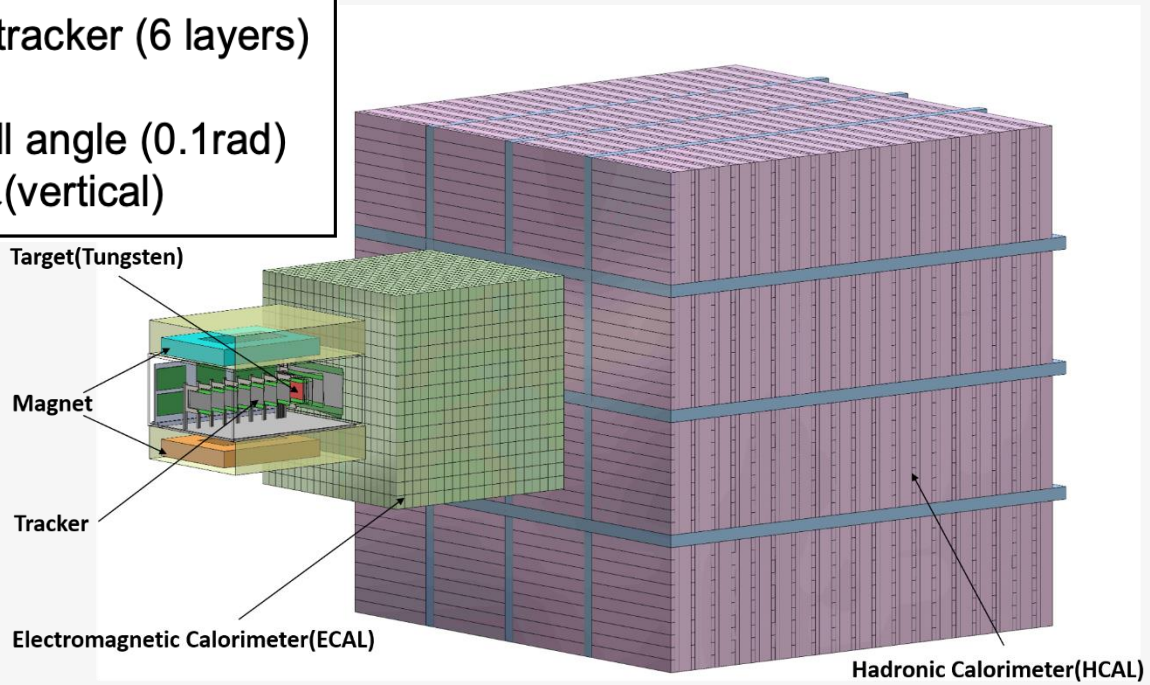




DarkSHINE Detector Configuration

- The DarkSHINE detector hardware technical R&D is carried out in parallel to the full detector system simulation and prospective study/optimization

- **Tracker:**
  - Tagging tracker (7 layers) + recoil tracker (6 layers)
  - Incident and recoil electron tracks
  - Two silicon strip sensors w/ a small angle (0.1rad)
  - Resolution: $6\mu m$(horizontal), $60\mu m$(vertical)



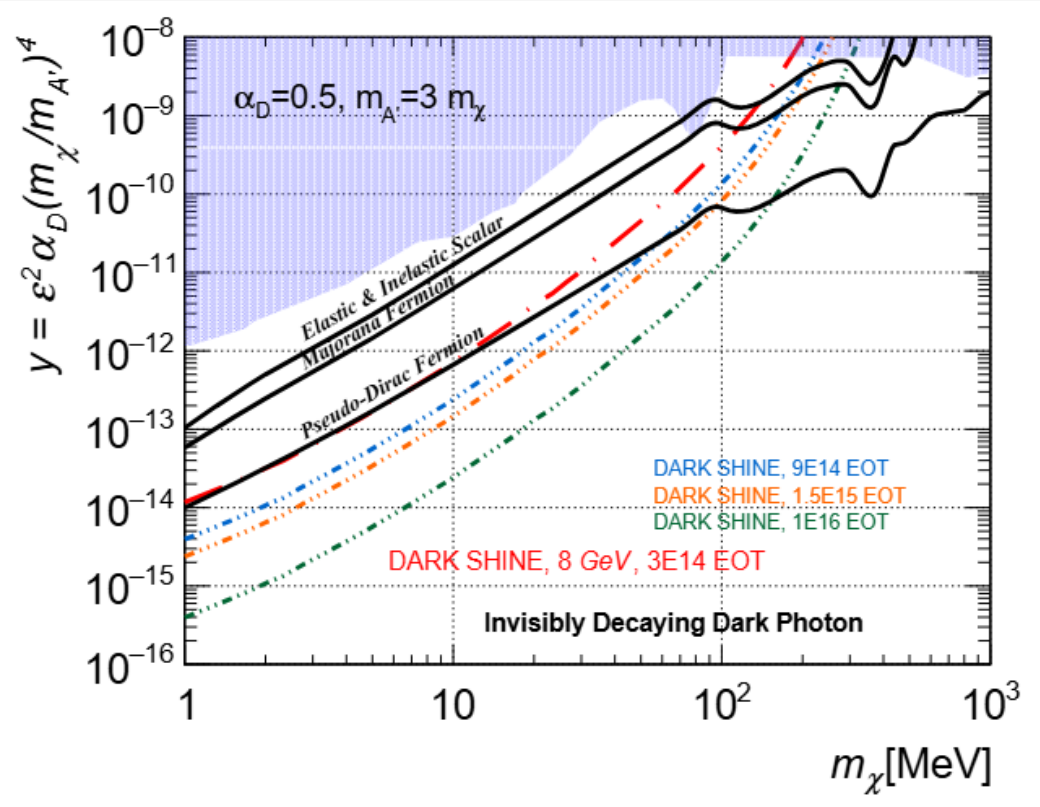
- **ECAL:**
  - Electron & photon
  - Scintillator: LYSO(Ce)
    high light yield (30000 p.e/MeV), fast decay time (40 ns), low electronic noise
  - 20×20×11 crystals
    $2.5\times2.5\times4cm^3$
  - Energy resolution of LYSO: 10%

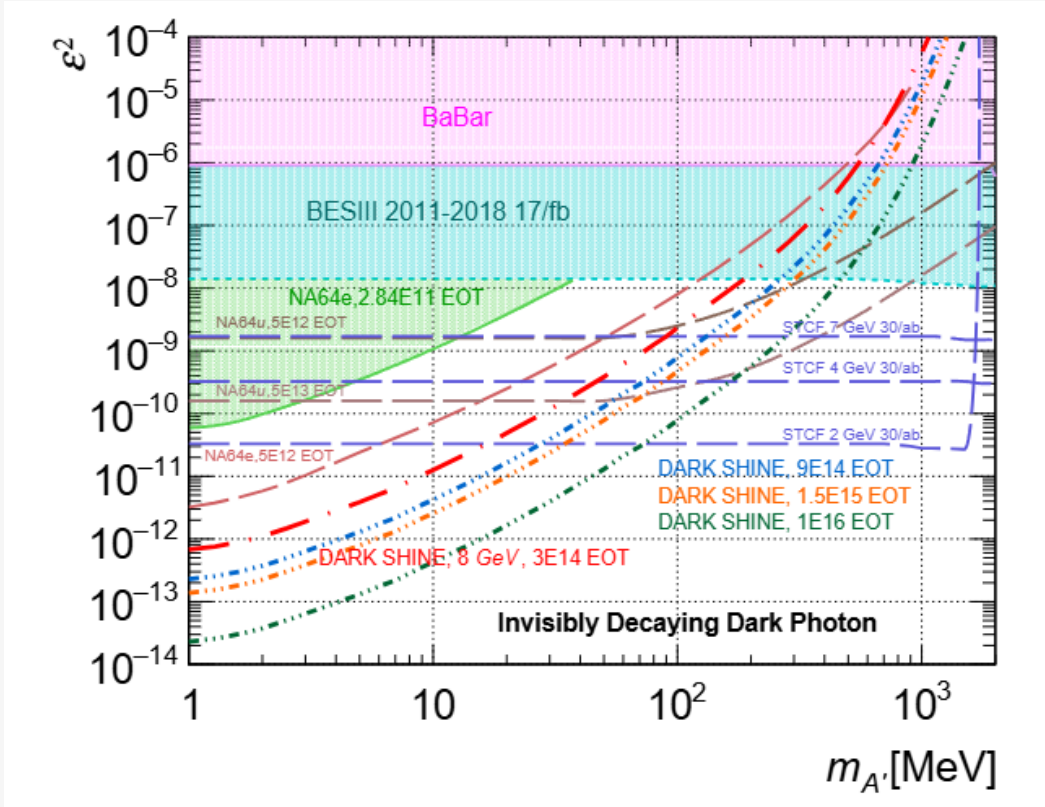
- **HCAL:**
  - Veto hadronic background
  - Scintillator w/ steel absorber
  - 4×4×1 modules

- **Additional system:**
  - Magnet:1.5T magnetic field
  - Readout electronics

First Results

- 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



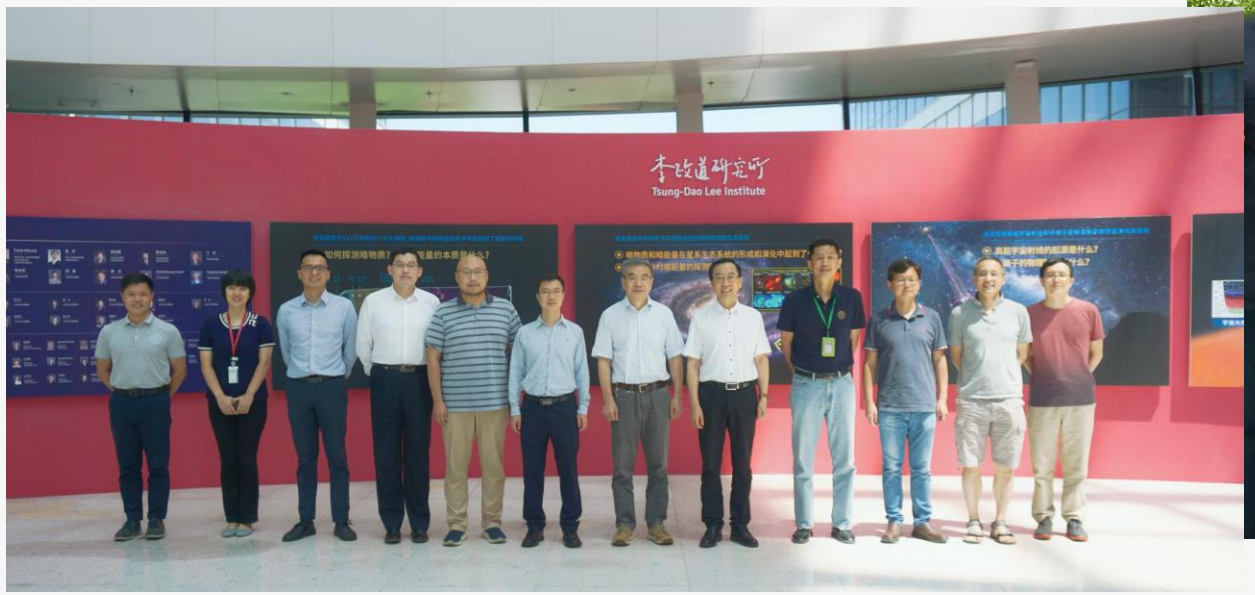


Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023)

Recent Progress of DarkSHINE R&D

- Recent progress after the first publication
- DarkSHINE CDR: arXiv:2411.09345

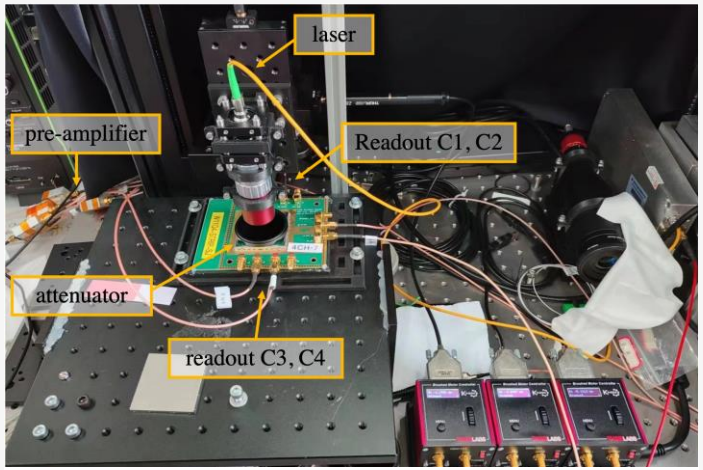
- Upgrade of the detector configuration
- Prototype design and test
- New opportunities from the electron beam
- …

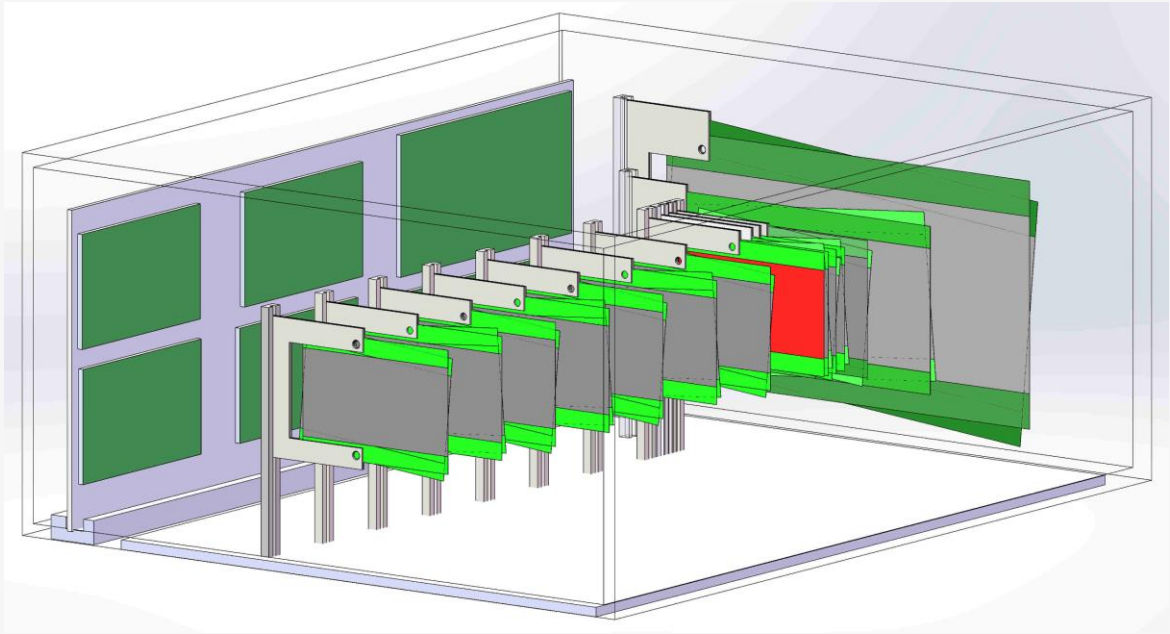


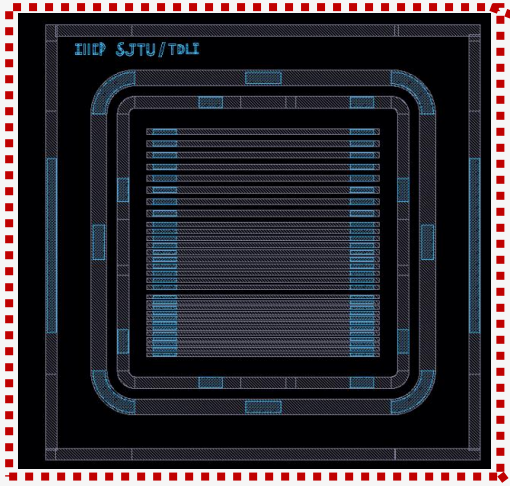
New Development of Tracking System

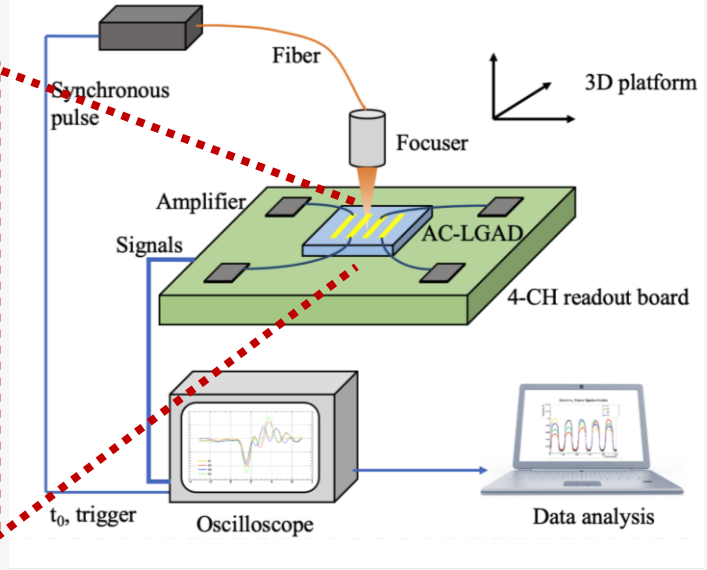
- Configuration: 7-+6-layer silicon strip detector, 1.5T magnetic
- Expected resolution: ~10 μm

- Performance testing in collaboration with IHEP-CAS
  - **Spatial** resolution test: step 2 μm, >1000 scans per point
  - **Time** resolution test: >1000 scans at x=0

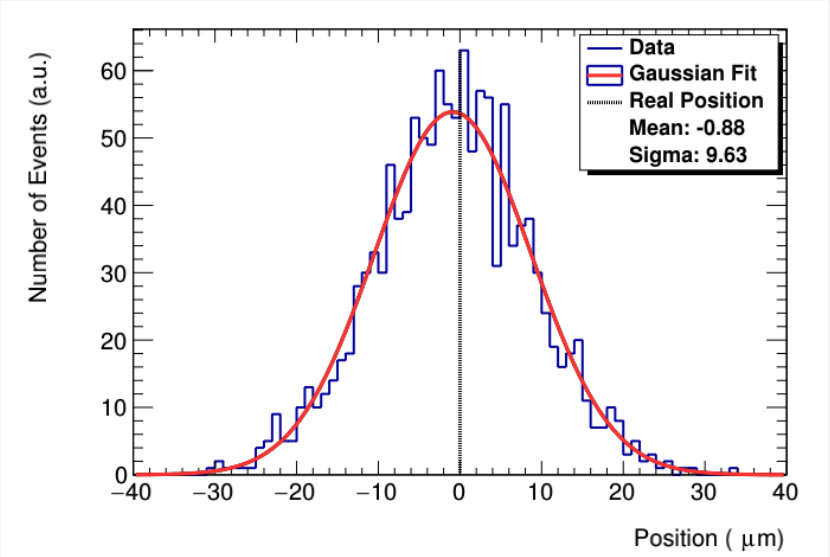


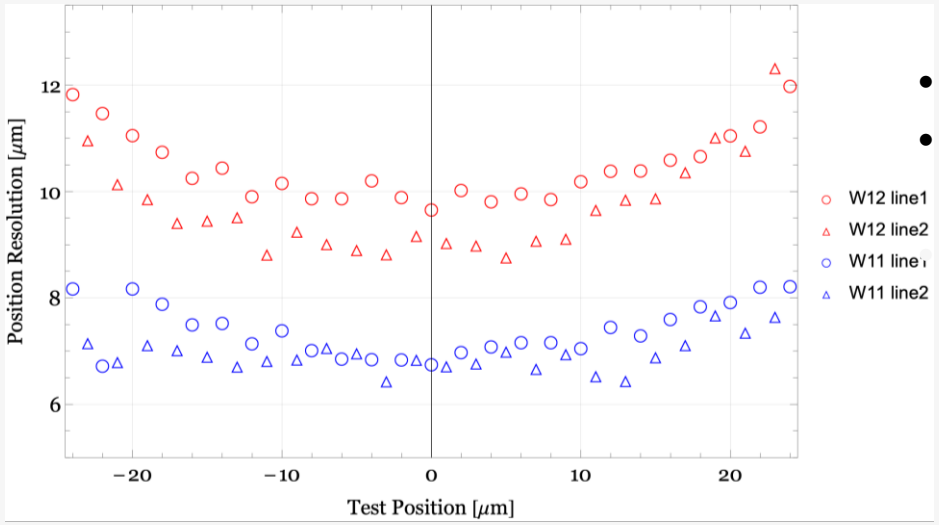




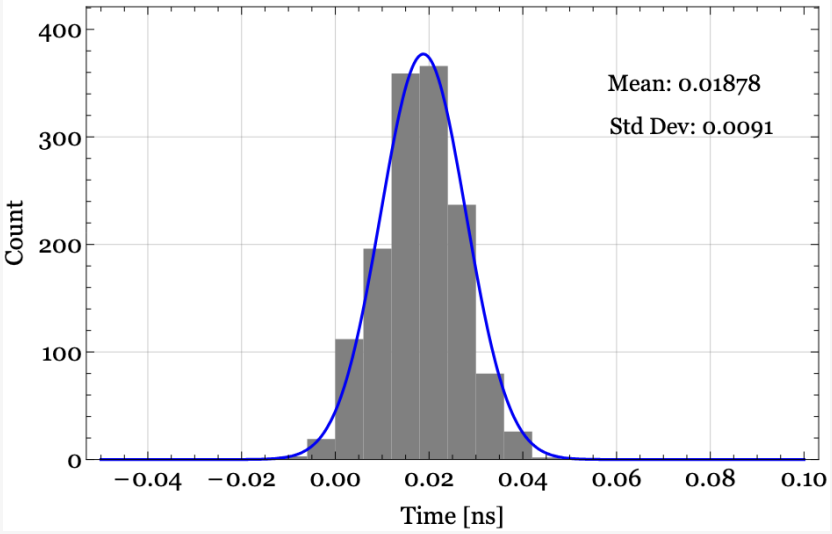


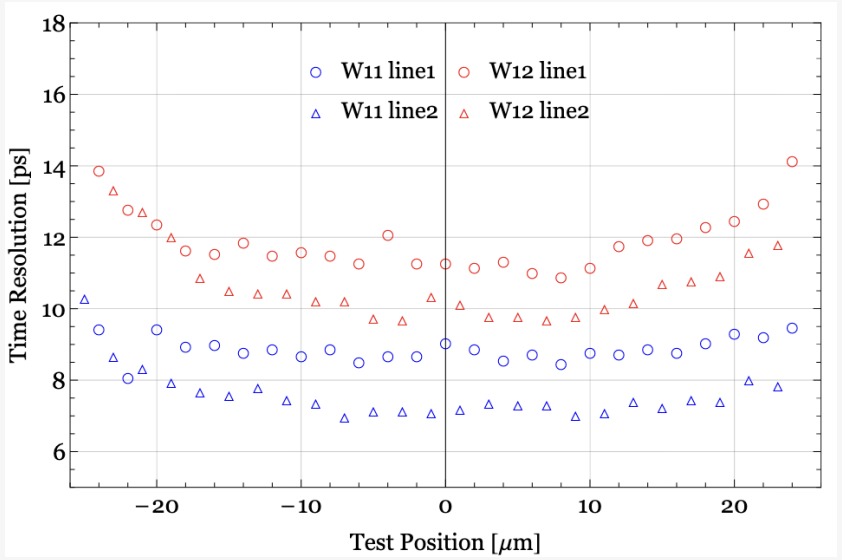
Performance Test for Silicon Strips





- **Spatial** resolution: 7~12 μm
- -> <3% p resolution for tagging tracker
  ~6% for recoil tracker



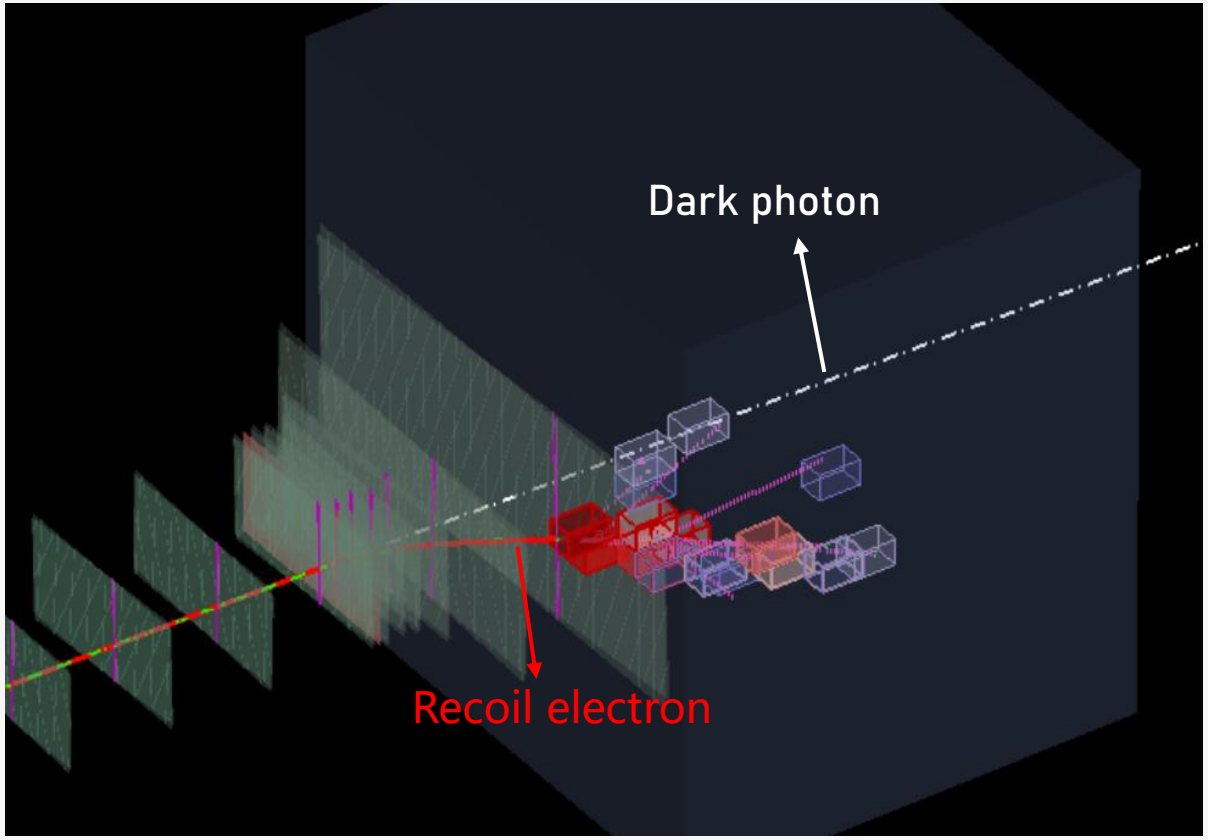


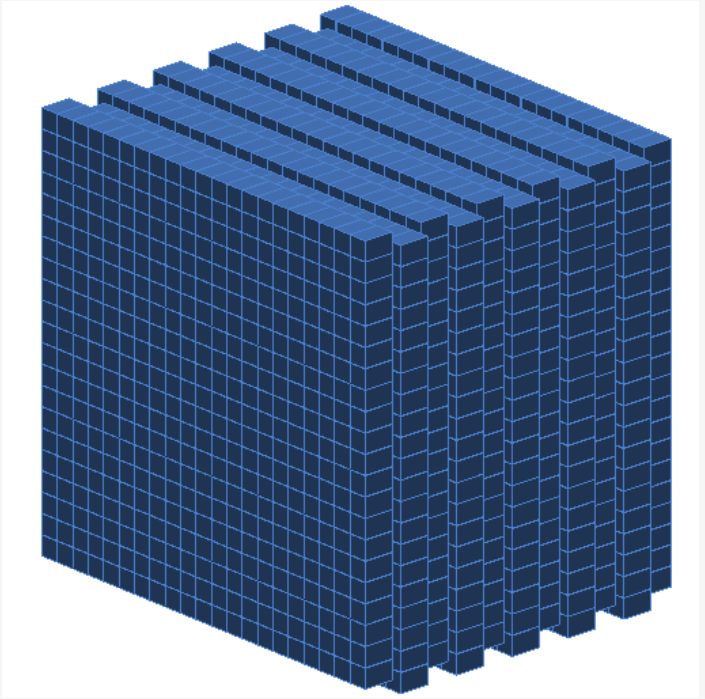
- **Time** resolution: 6~14 ps

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

New Development of ECal

- An **LYSO** calorimeter, 2.5×2.5×4 cm^3 cells, 20×20×11 channels
  - To precisely measure the energy of **recoiled electrons** and **bremsstrahlung photons**
  - Requirements: **fast response**, **radiation-hardness**, large volume

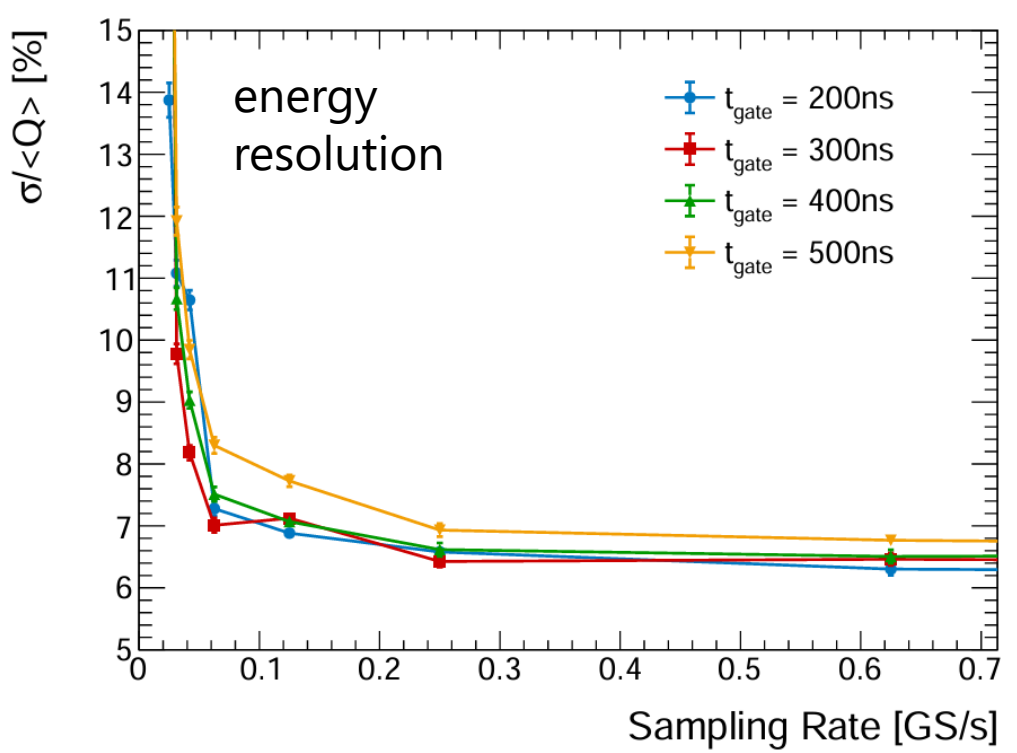


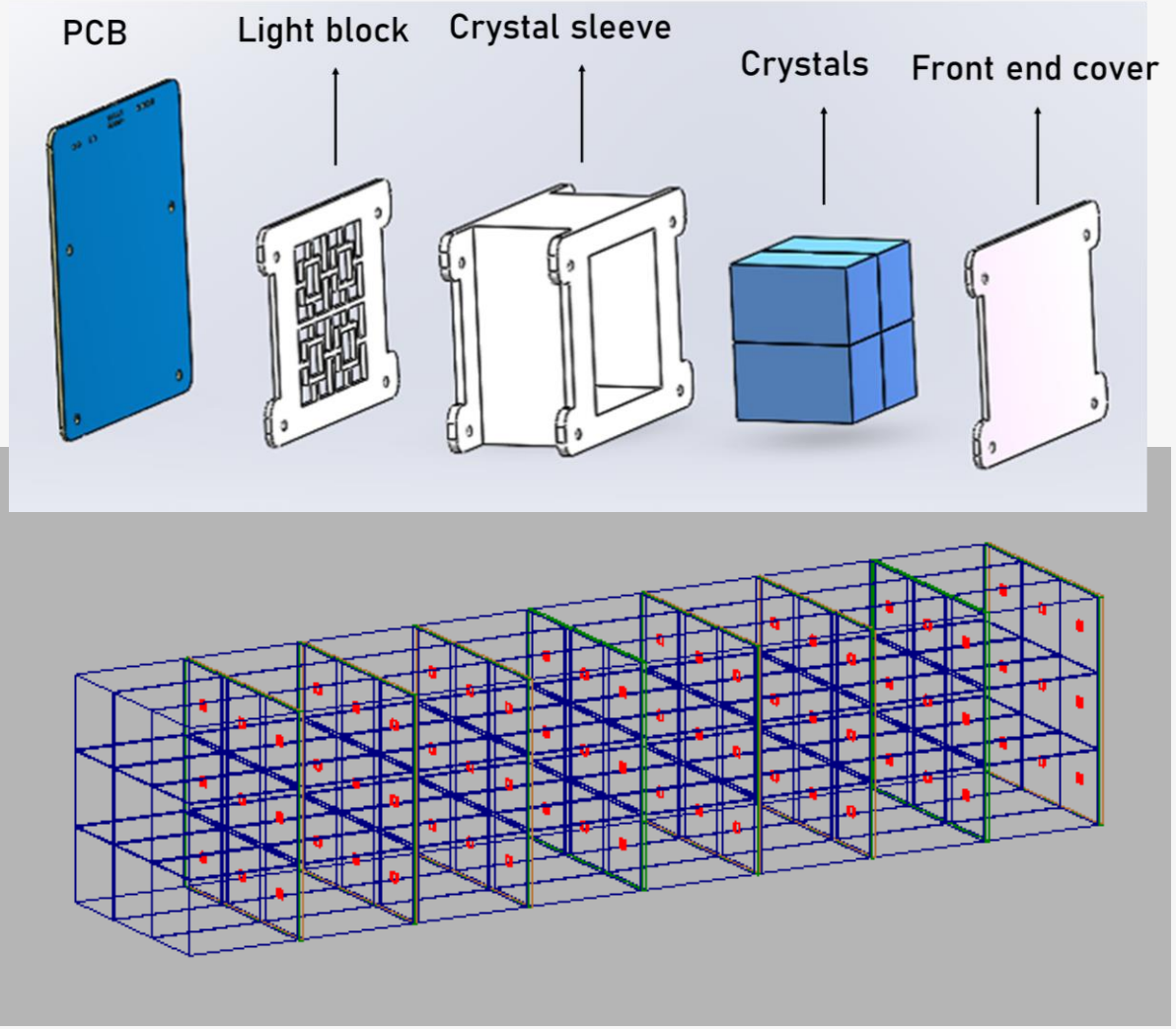


staggered arrangement

Prototype Design and Test

- Prototype for technology exploration and validation
- Beam test @ CERN targeting end of this month





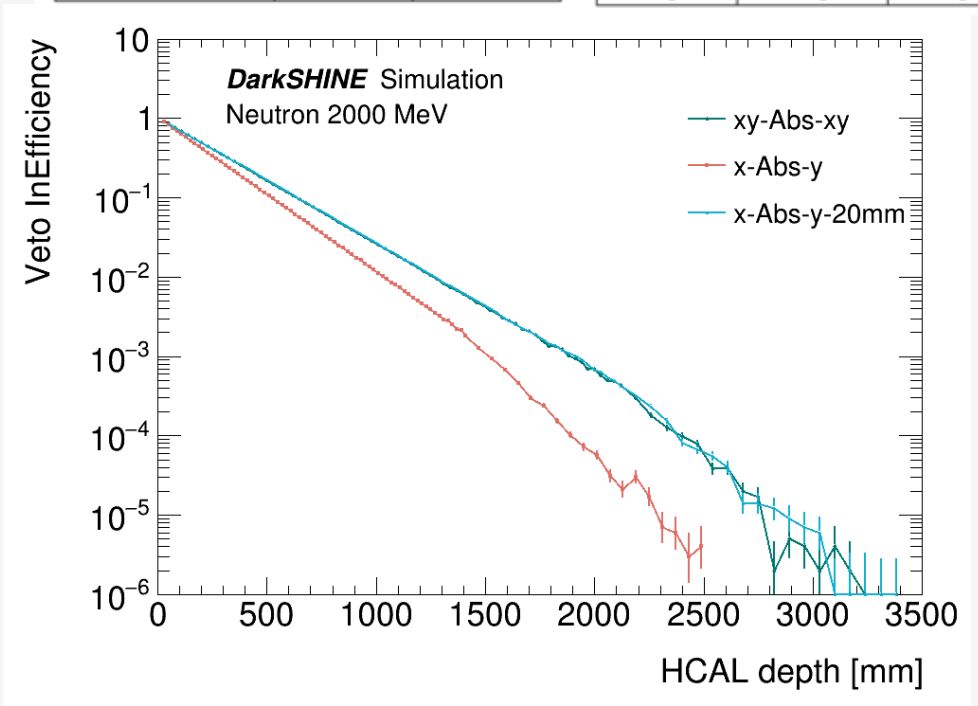
ECal, arXiv (submitted to JINST)

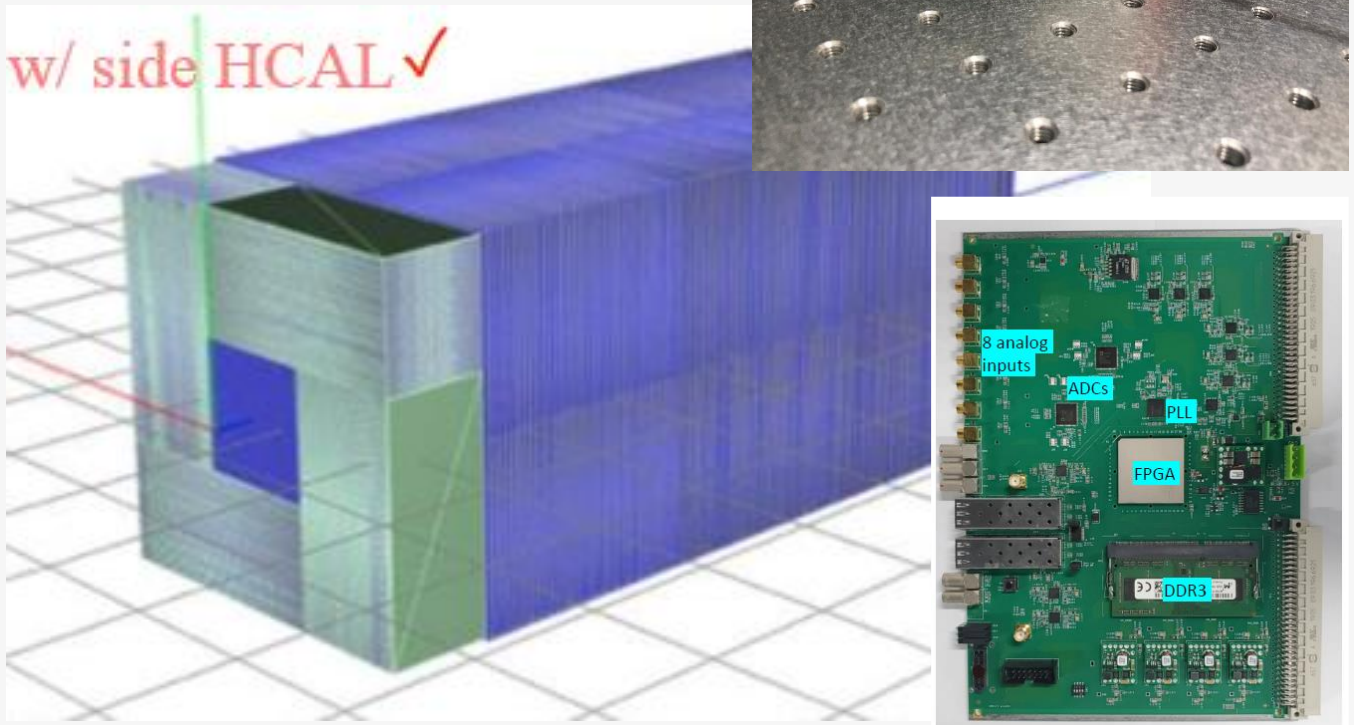
New Development of HCal

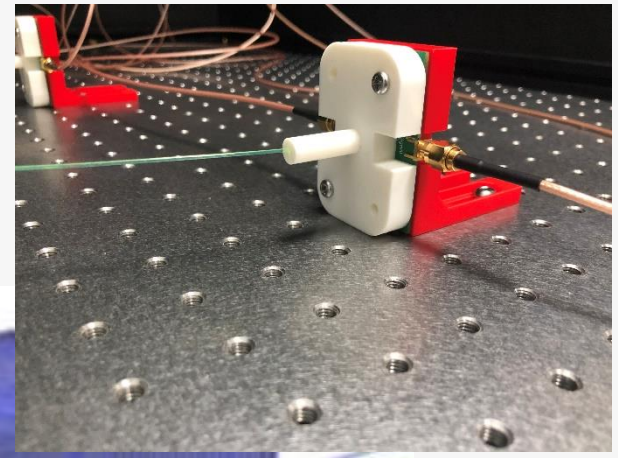
- Veto backgrounds escaping ECal (neutron, muon, …)
- First results from the test platform published

Veto InEff ×E-06	n	k^0
100[MeV]	$1170^{+10.9}_{-10.8}$	$31600^{+55.5}_{-55.4}$
500[MeV]	$18.4^{+1.46}_{-1.36}$	$5.40^{+0.839}_{-0.733}$
1000[MeV]	$3.70^{+0.714}_{-0.606}$	$3.70^{+0.714}_{-0.606}$
2000[MeV]	$2.70^{+0.626}_{-0.516}$	$11.5^{+1.19}_{-1.08}$

π^0	p	μ
$7.30^{+0.958}_{-0.852}$	$30700^{+61.5}_{-61.3}$	$409^{+6.49}_{-6.39}$
$0.1^{+0.184}_{-0}$	$8.04^{+1.34}_{-1.16}$	$15.0^{+1.33}_{-1.22}$
$0.1^{+0.184}_{-0}$	$0.1^{+0.958}_{-0}$	$2.00^{+0.555}_{-0.443}$
$0.1^{+0.188}_{-0}$	$0.1^{+2.78}_{-0}$	$0.1^{+0.184}_{-0}$

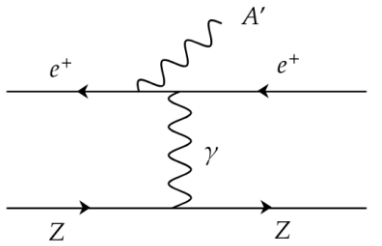






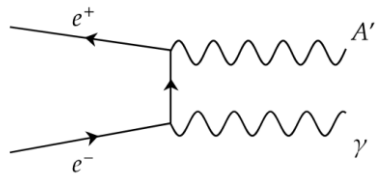
New Development of Physics: Positron on Target

- **Positron** on target introduces **new diagrams** and **increases differential cross section** in certain kinematic regions
- -> may help improve the sensitivity



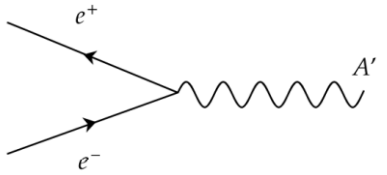
Bremsstrahlung

$$\frac{d\sigma_{brem}}{x} = 4\pi\varepsilon^2\alpha_{EM}^3\xi\sqrt{1-\frac{m_{A'}^2}{E_{e^+}}}\frac{1-x+\frac{x^2}{3}}{m_{A'}^2\frac{1-x}{x}+m_e^2x}$$



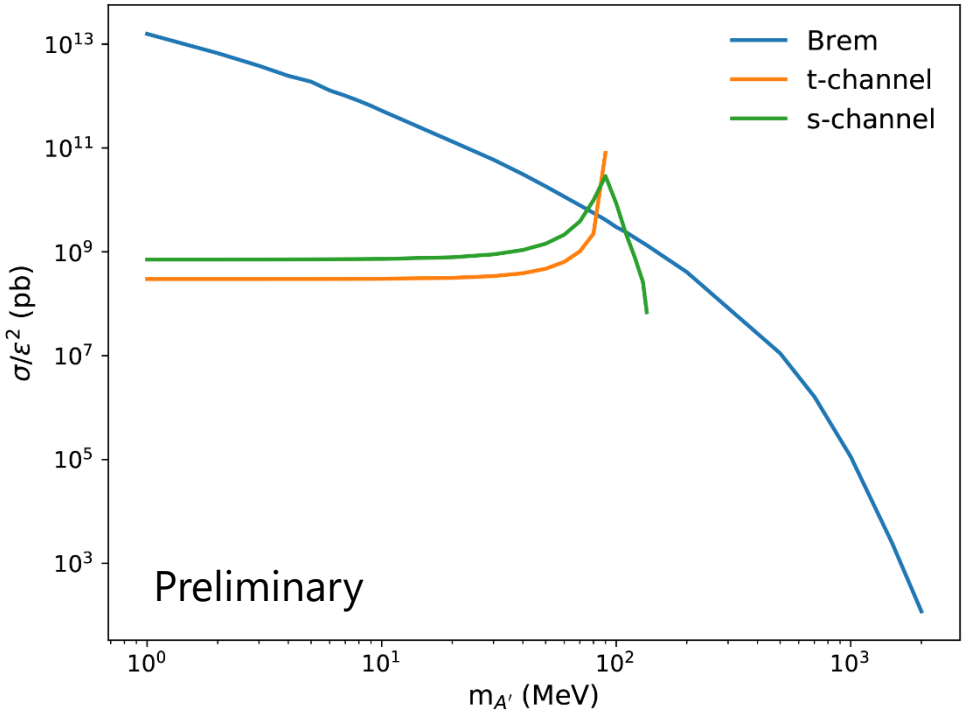
t-channel

$$\sigma_{\text{t-channel}} = \frac{8\alpha_{EM}^3\epsilon^2}{s^2}\left[\left(\frac{s-m_{A'}^2}{2s}+\frac{m_{A'}^2}{s-m_{A'}^2}\right)log\frac{s}{m_e^2}-\frac{s-n}{2s}\right.$$

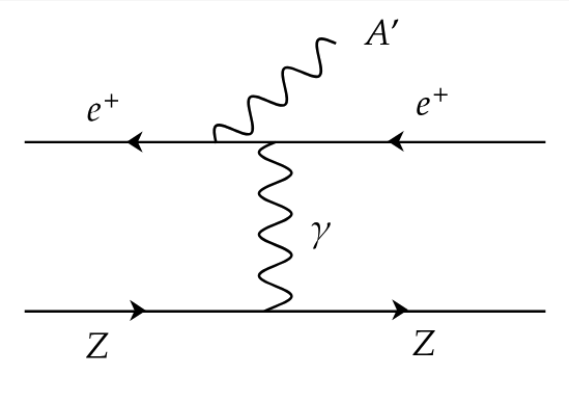


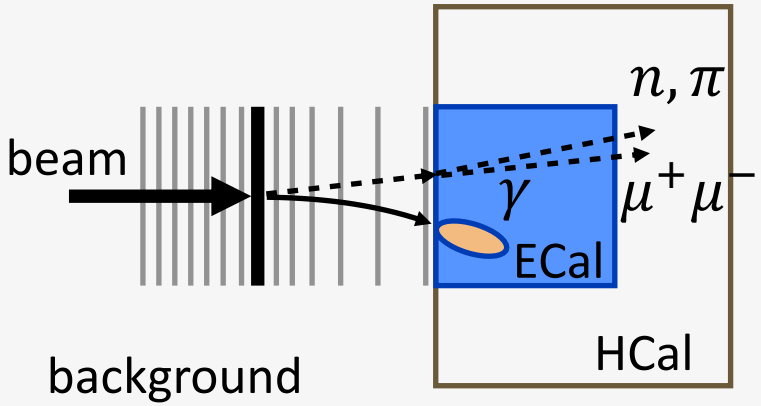
s-channel

$$\sigma_{\text{s-channel}} = \frac{4\pi\alpha_{EM}\alpha_D\epsilon^2}{\sqrt{s}}\frac{q\kappa}{(s-m_{A'}^2)^2+m_{A'}^2\Gamma_{A'}r}$$

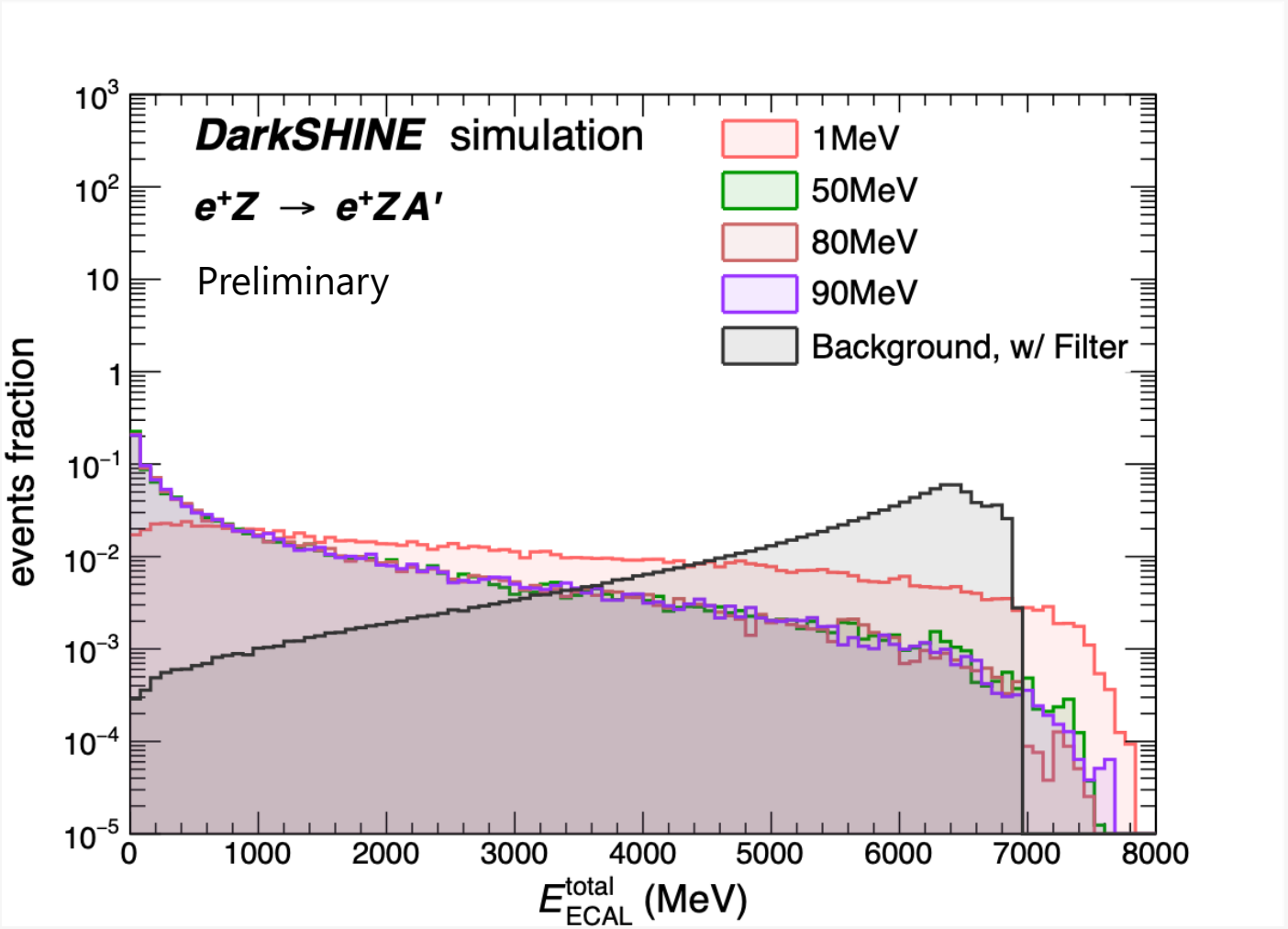


Signal: Positron Bremsstrahlung

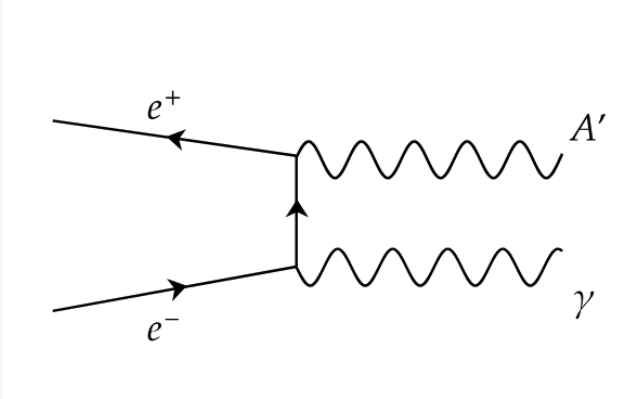


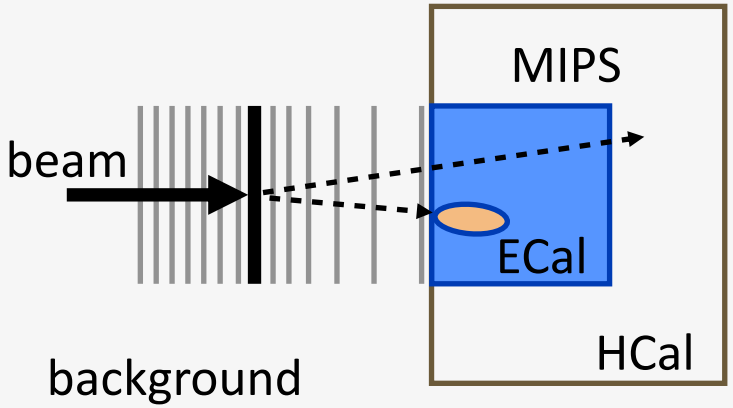


- Soft recoil electron
- Large missing momentum

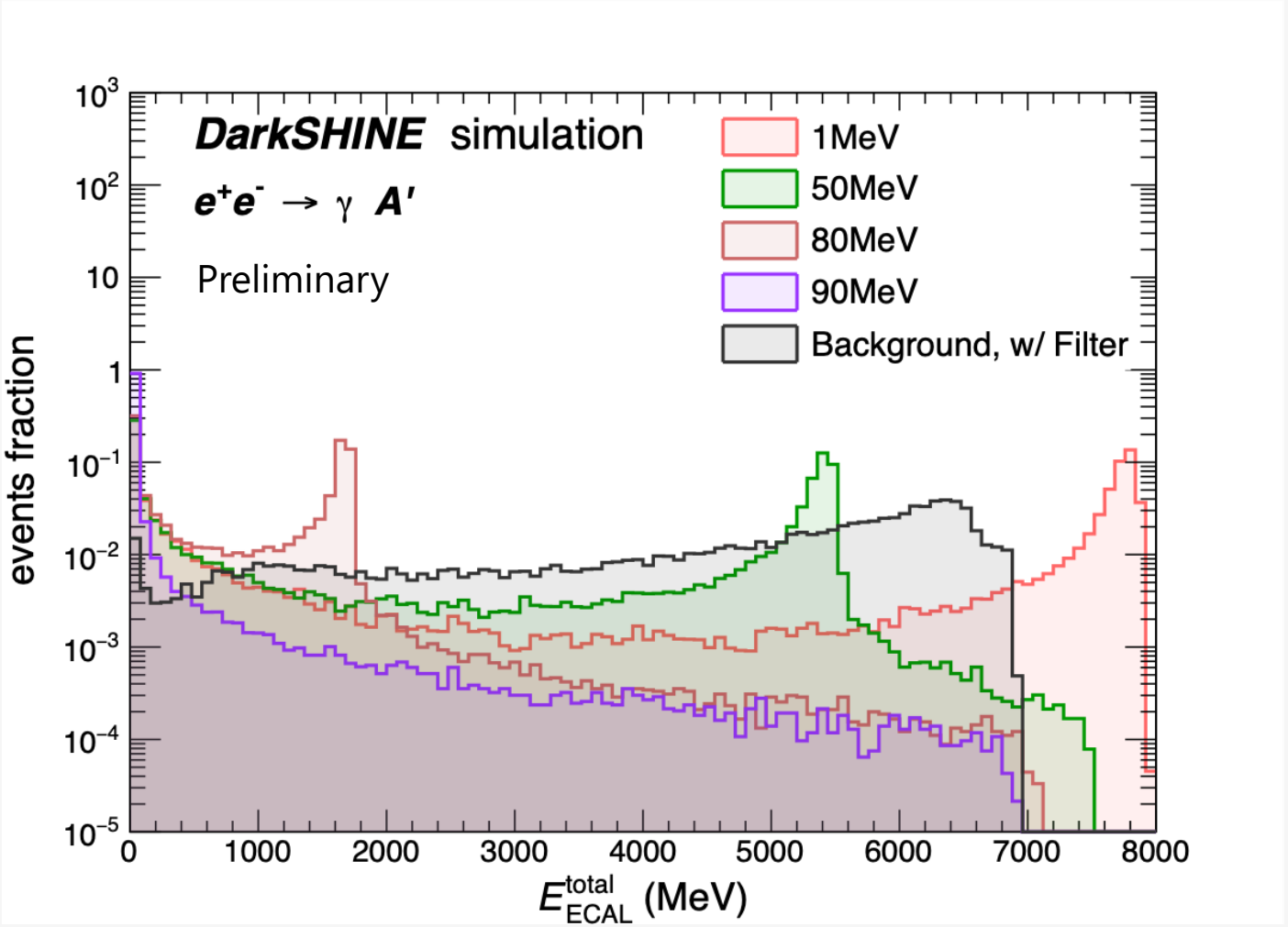


Signal: T-Channel

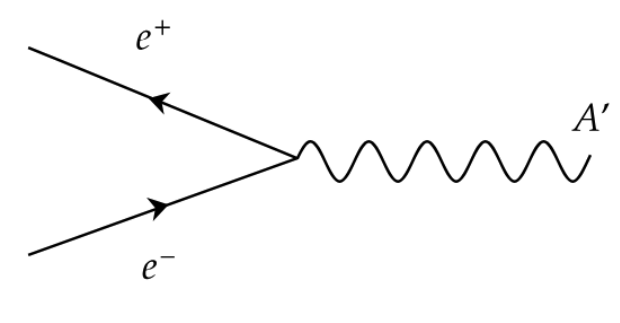


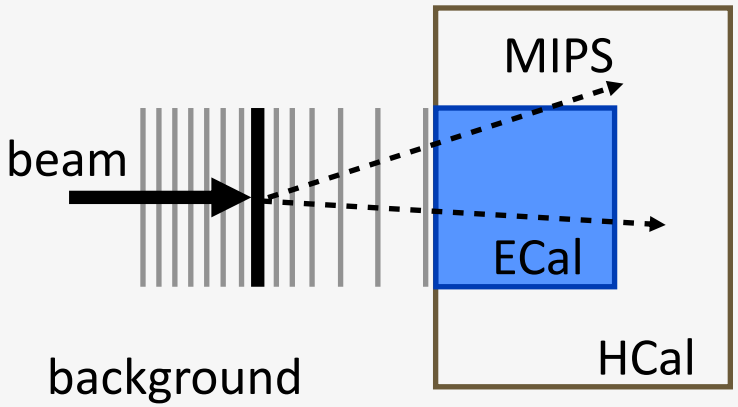


- One recoil electron

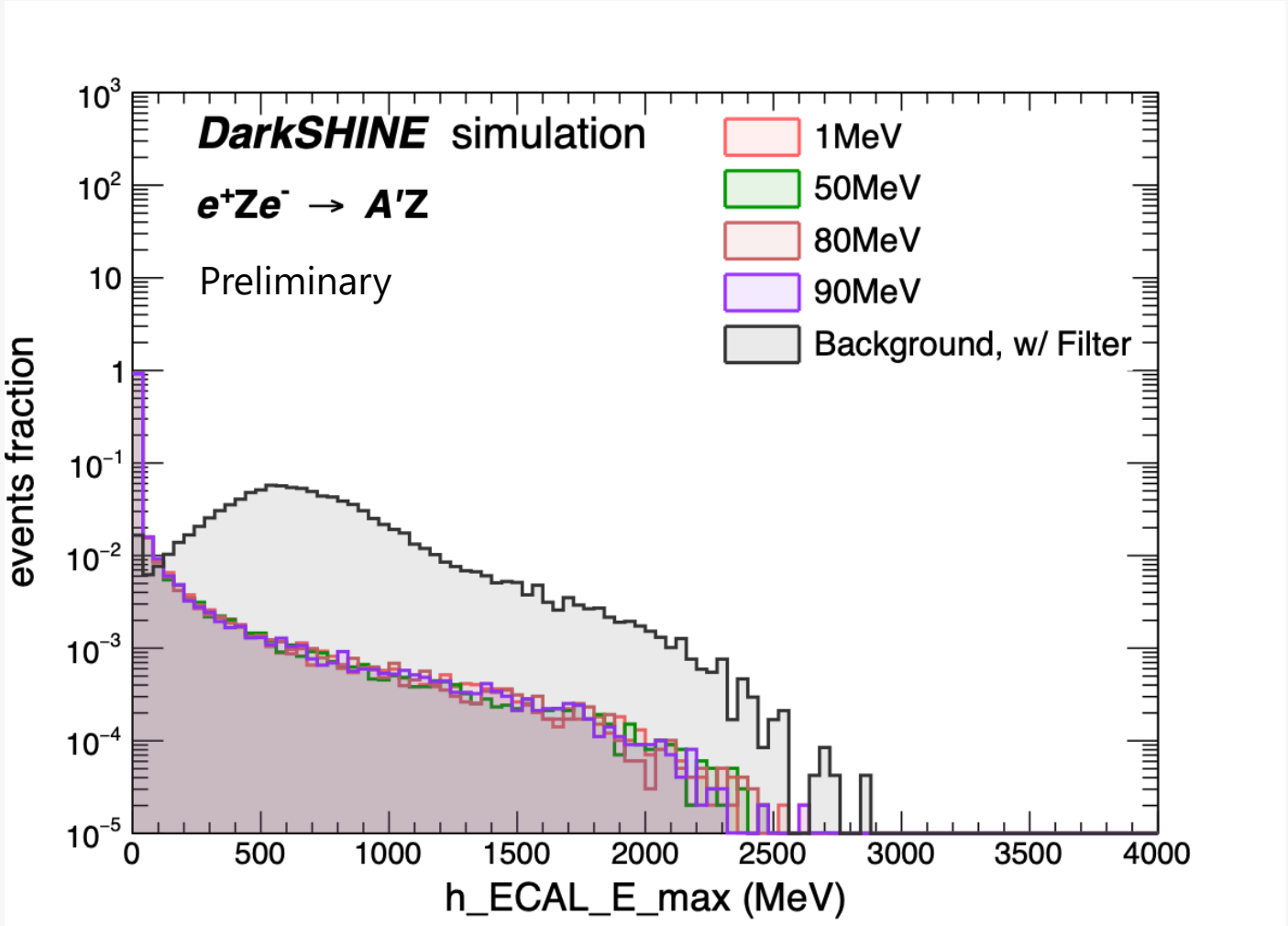


Signal: S-Channel





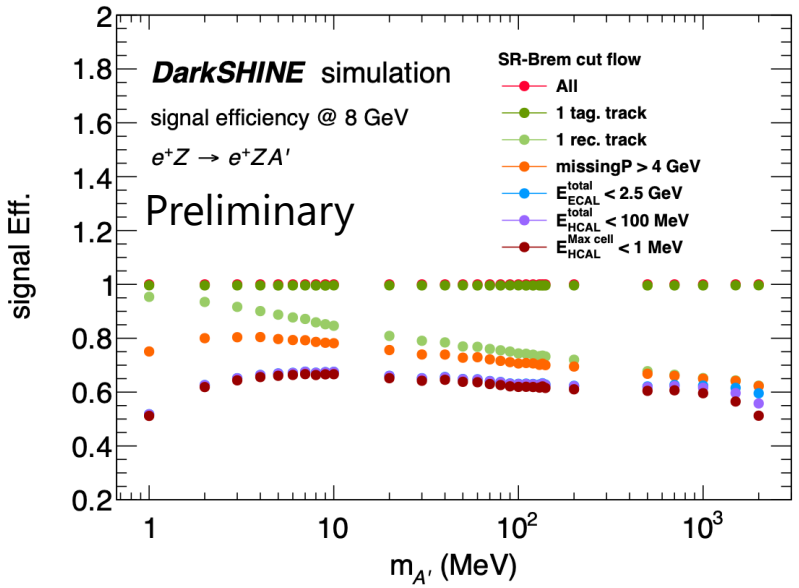
- No signatures in detectors



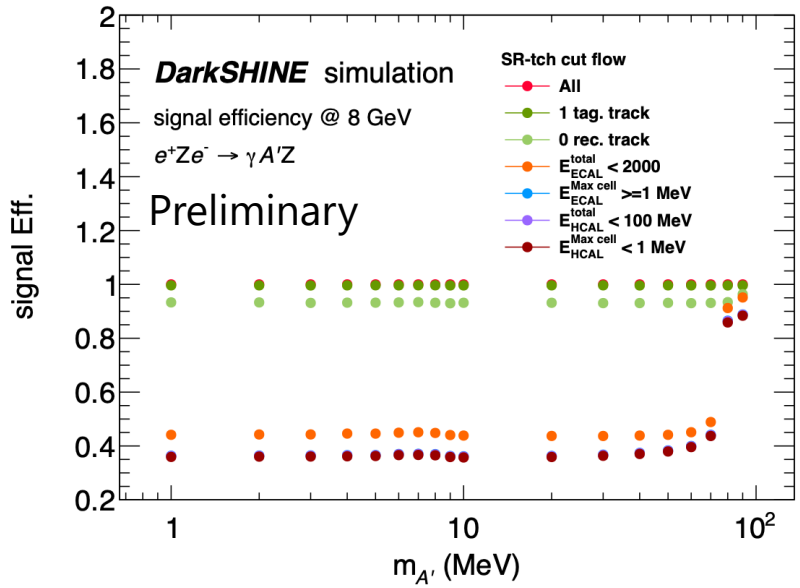
Signal Efficiency

- Signal efficiency based on current detector configuration and software
- **40%~50%** for **bremsstrahlung and t-channel**, **80%** for **s-channel**

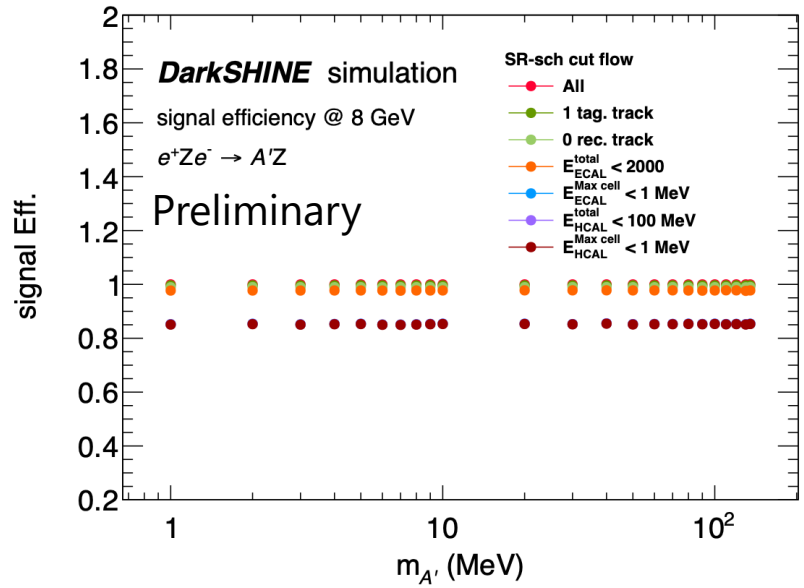
- Background counts: 10^{-4}~ 10^{-2} @ 10^{14} POT



bremsstrahlung



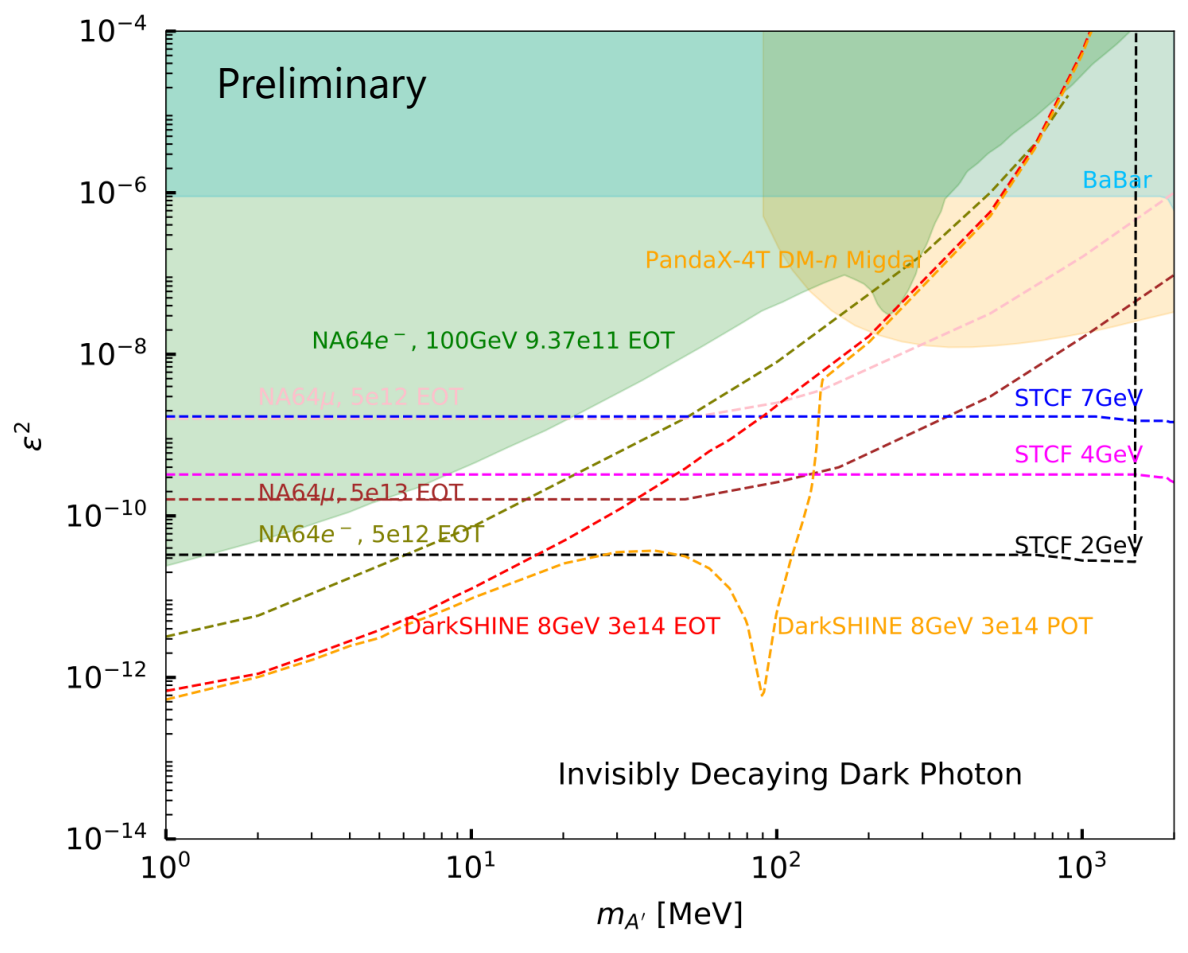
t-channel

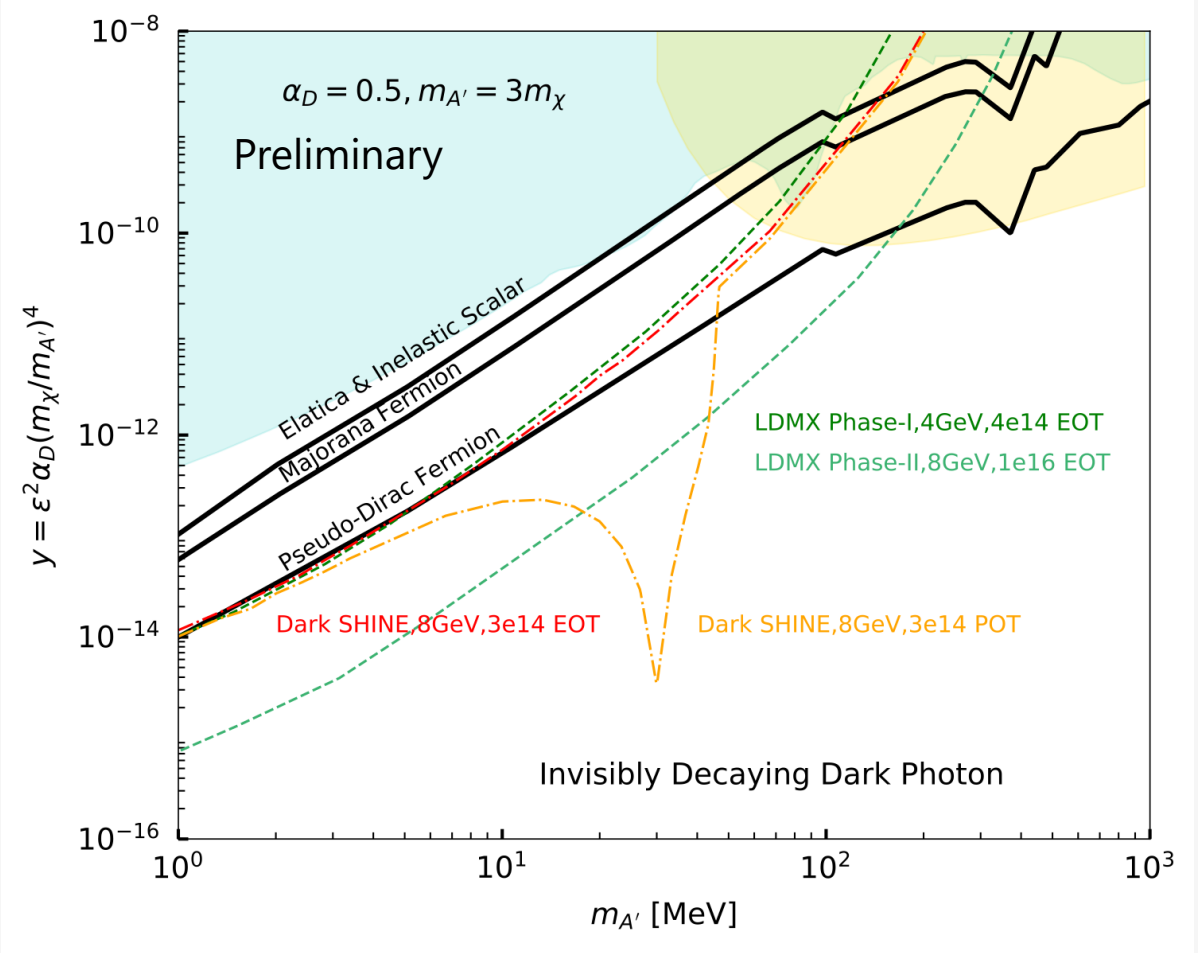


s-channel

Limit from Positron on Target

- Extra sensitivity from POT for light dark matter





Conclusions

- The DarkSHINE experiment is a fixed target experiment, using an electron beam to search for light dark matter

- First round of prospective analysis sensitivity of DarkSHINE has been studied
- Competitive sensitivity: **Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023)**

- **Conceptual design report** released on arXiv
- Detector key technology R&D progress presented
  - NST papers: tracker, ECal & HCal
- Preliminary results on positron beam shown with extra sensitivity

- **We welcome more theory motivations and thoughtful ideas to promote the DarkSHINE coming true!**

上海交通大學

SHANGHAI JIAO TONG UNIVERSITY

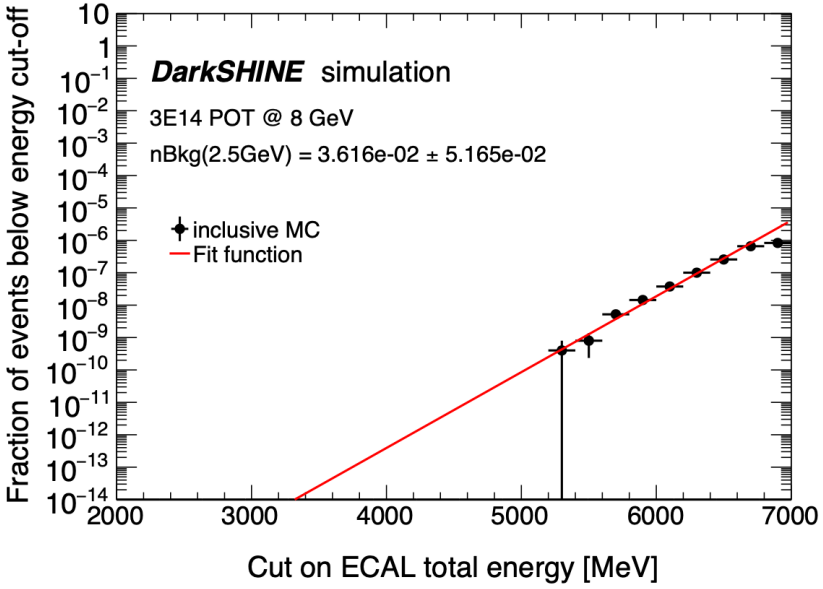
Thank You!

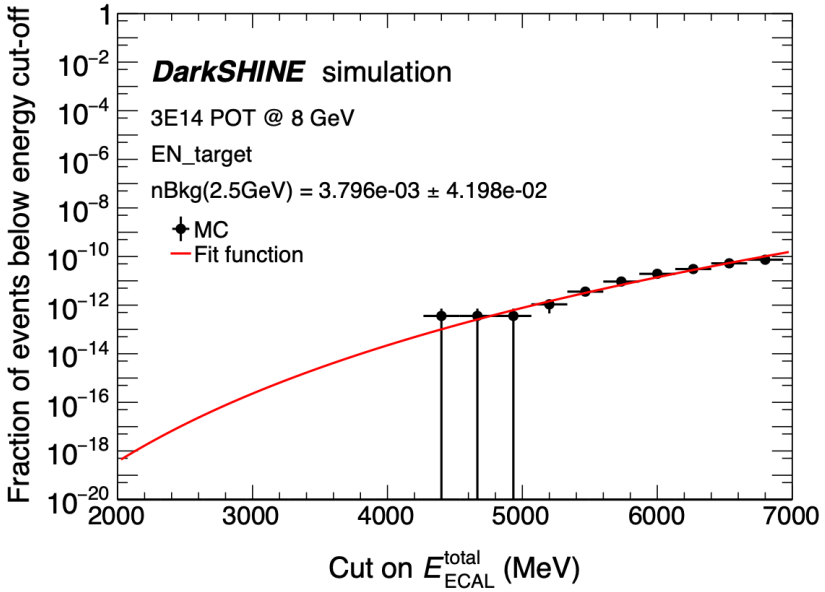
饮 水 思 源　爱 国 荣 校

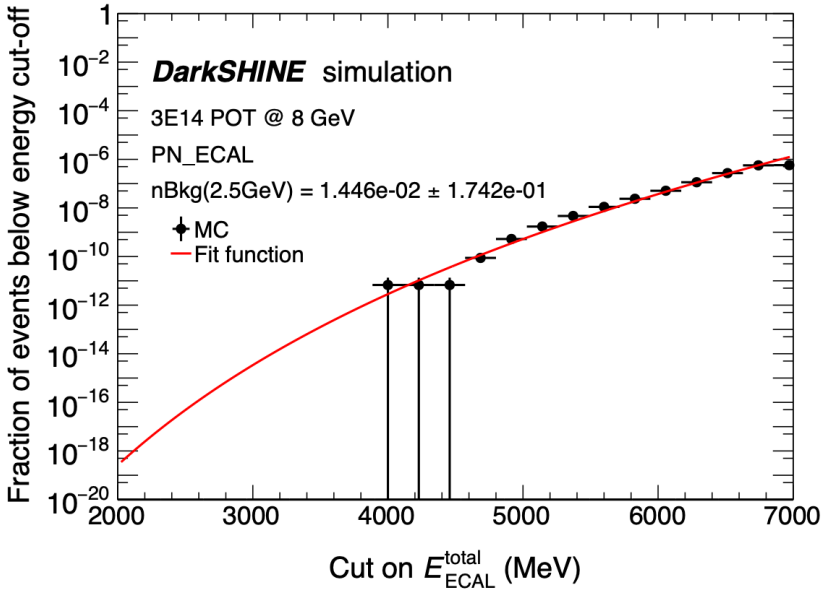
Background Estimation from Extrapolation

- **Brem** signal region
- Leading background: EN/PN ECal

Process	EN ECal	EN target	PN ECal	PN target	Total
Yield	1.3×10^{-2}	3.8×10^{-3}	1.4×10^{-2}	4.9×10^{-5}	3.2×10^{-2}



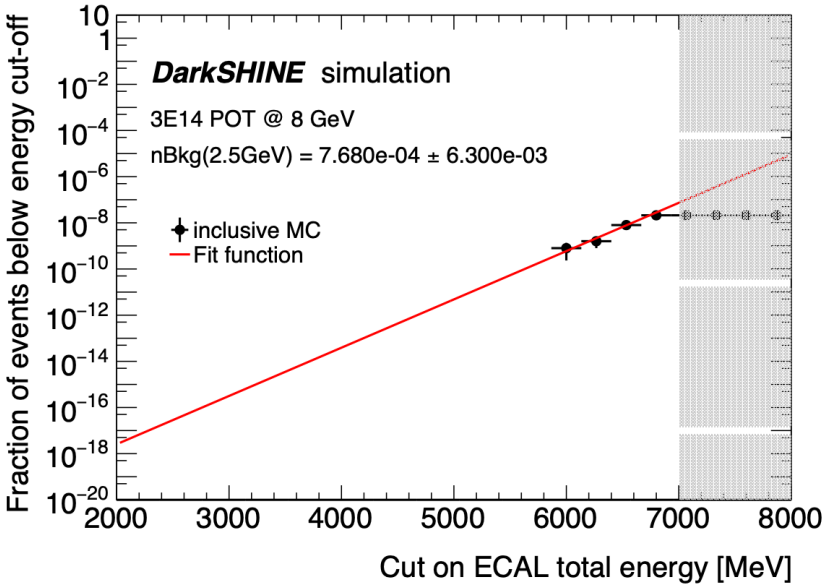


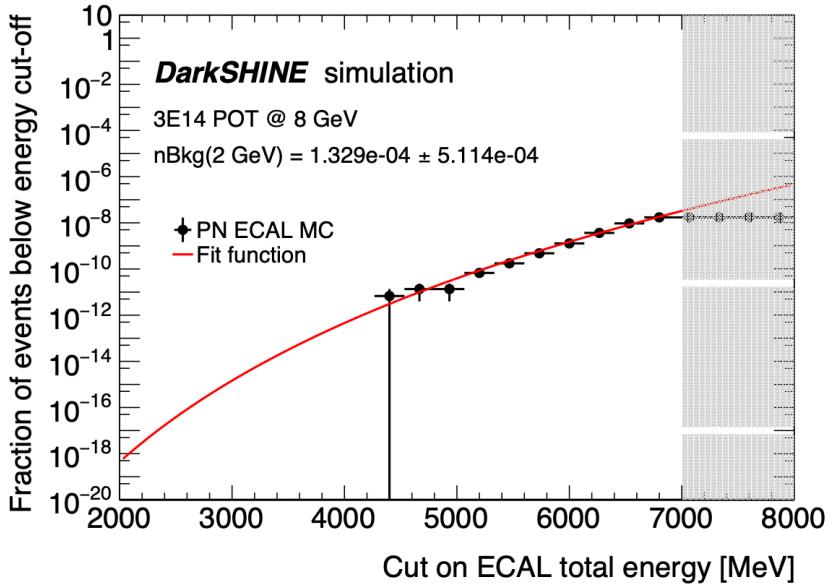


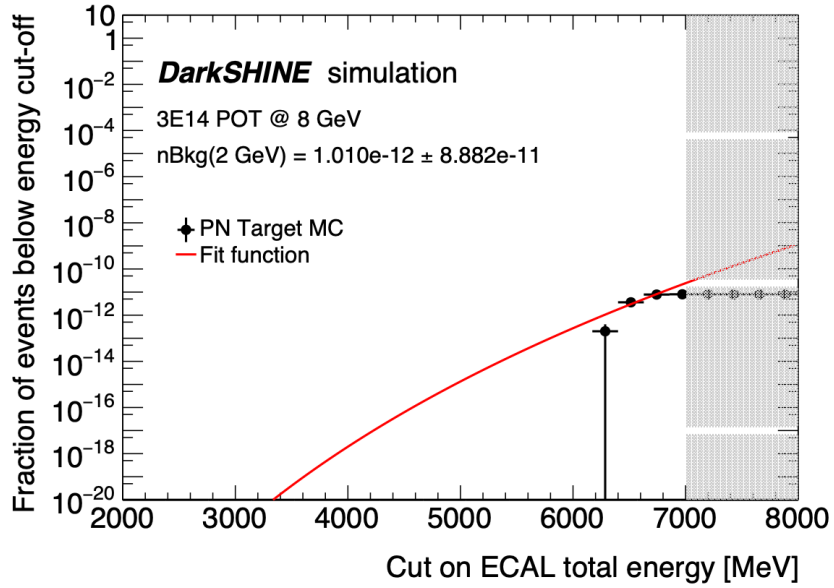
Background Estimation from Extrapolation

- **T-channel** signal region
- Leading background: PN ECal
- EN process rejected by track multiplicity and ECal cell energy

Process	EN ECal	EN target	PN ECal	PN target	Total
Yield	~0	~0	1.3×10^{-4}	1.0×10^{-12}	1.3×10^{-4}







Background Estimation from Extrapolation

- **S-channel** signal region
- Leading background: PN ECal
- EN process rejected by track multiplicity and ECal cell energy

Process	EN ECal	EN target	PN ECal	PN target	Total
Yield	~0	~0	1.6×10^{-4}	4.6×10^{-8}	1.6×10^{-4}