Shu Li (李数)
T.D. Lee Fellow (Tsung-Dao Lee Institute)

上海交通大学 SHANGHAI JIAO TONG UNIVERSITY | 李政道研究所 Tsung-Dao Lee Institute

Career:

- 2008 ~ 2012: PhD, USTC & CPPM-CNRS/IN2P3, France
- 2013 ~ 2017: Postdoc, Duke Univ., based @CERN
- **2017 ~ : T.D. Lee Fellow @ TDLI (National Talent Program)**

Research Interest:

- TeV physics at **LHC** and future colliders
  - Higgs, EWK, DM & BSM phenomena
- Deep Machine Learning
- High performance calorimeter R&D
- Light DM Exp. at SHINE (**Dark SHINE**)

Appointments:

- **Convener** of LHC EWK Multi-Boson Group and Editor of CERN Yellow Report, 2018 ~ Present
- **Member** of ATLAS Higgs Working Group coordination and Monte Carlo Project Manager, 2016 ~ Present
- **Team Leader** of TDLI ATLAS Group and **Deputy Institution Representative** of ATLAS China USTC-SDU-SJTU-ZZU cluster
- **Principal Investigator** of the Dark SHINE R&D project, 2021~Present
- **Outstanding Early Career Award** for CCEPP, Chinese Academy of Sciences, 2020

Cheers w/ Experimentalists

Hobbies

Talk to Theorists

Quest towards the *Futures*

Research Profile: Veture with Fundamental Force Carriers

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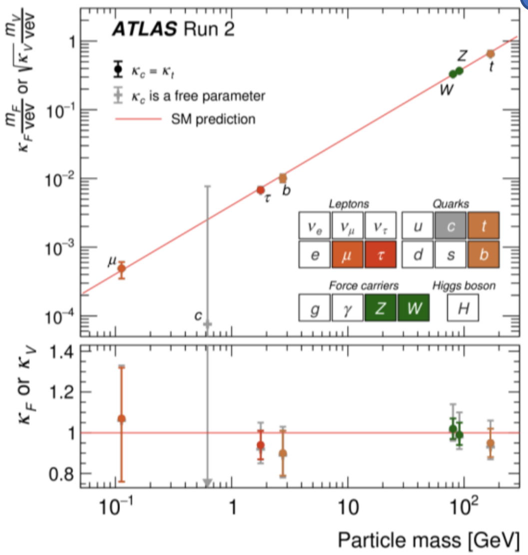
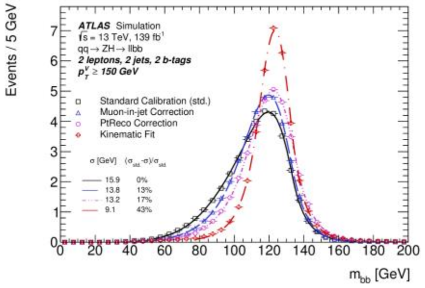
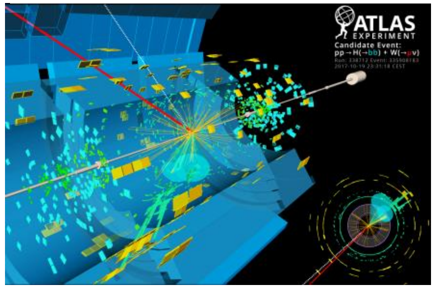
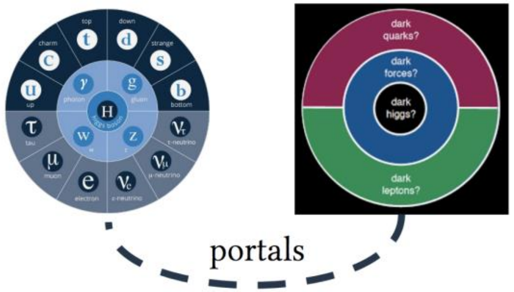
Nature 607 (2022) 52



Work out giant leap of precision

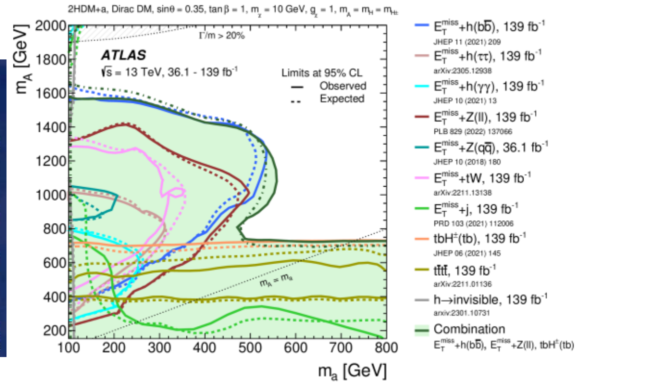




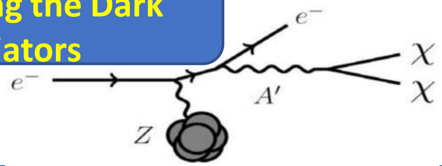


Higgs Portal to BSM
How much DM loves Higgs?

Phys. Rev. Lett. 125 (2020) 251802
& ATLAS 1st Science Bulletin



Dark SHINE R&D
Engineering the Dark Mediators



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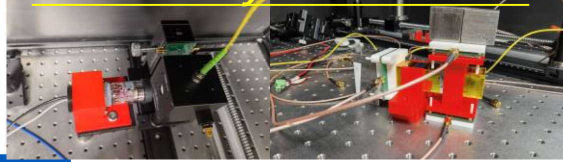
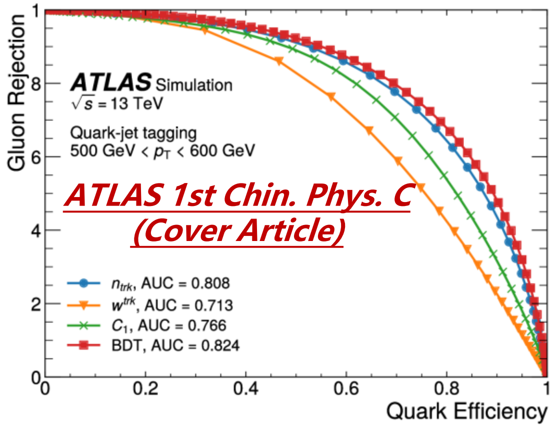
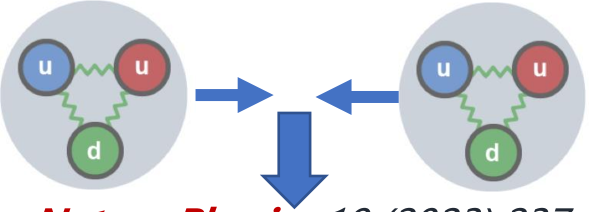


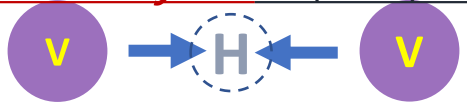
Differentiate quarks/gluons
A Large Boson-Boson Collider

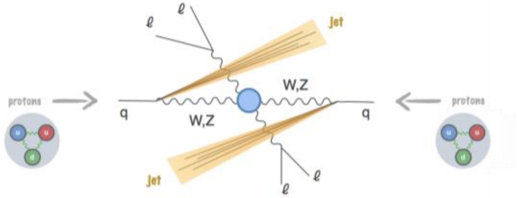


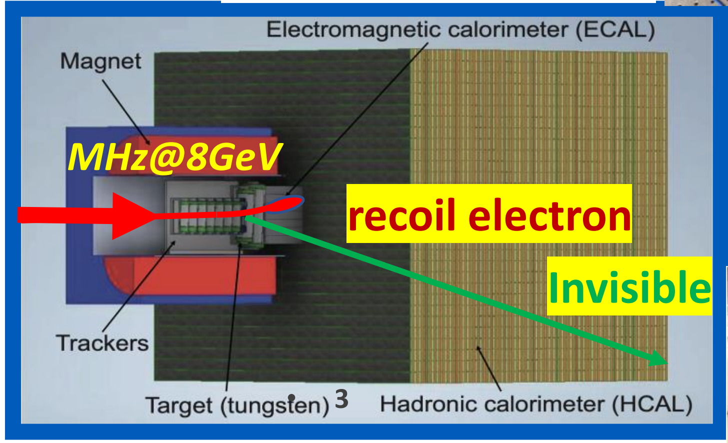
ATLAS 1st Chin. Phys. C (Cover Article)



Nature Physics 19 (2023) 237







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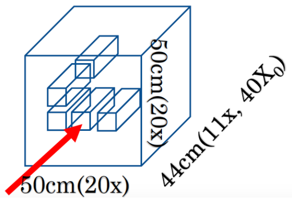
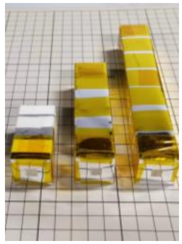
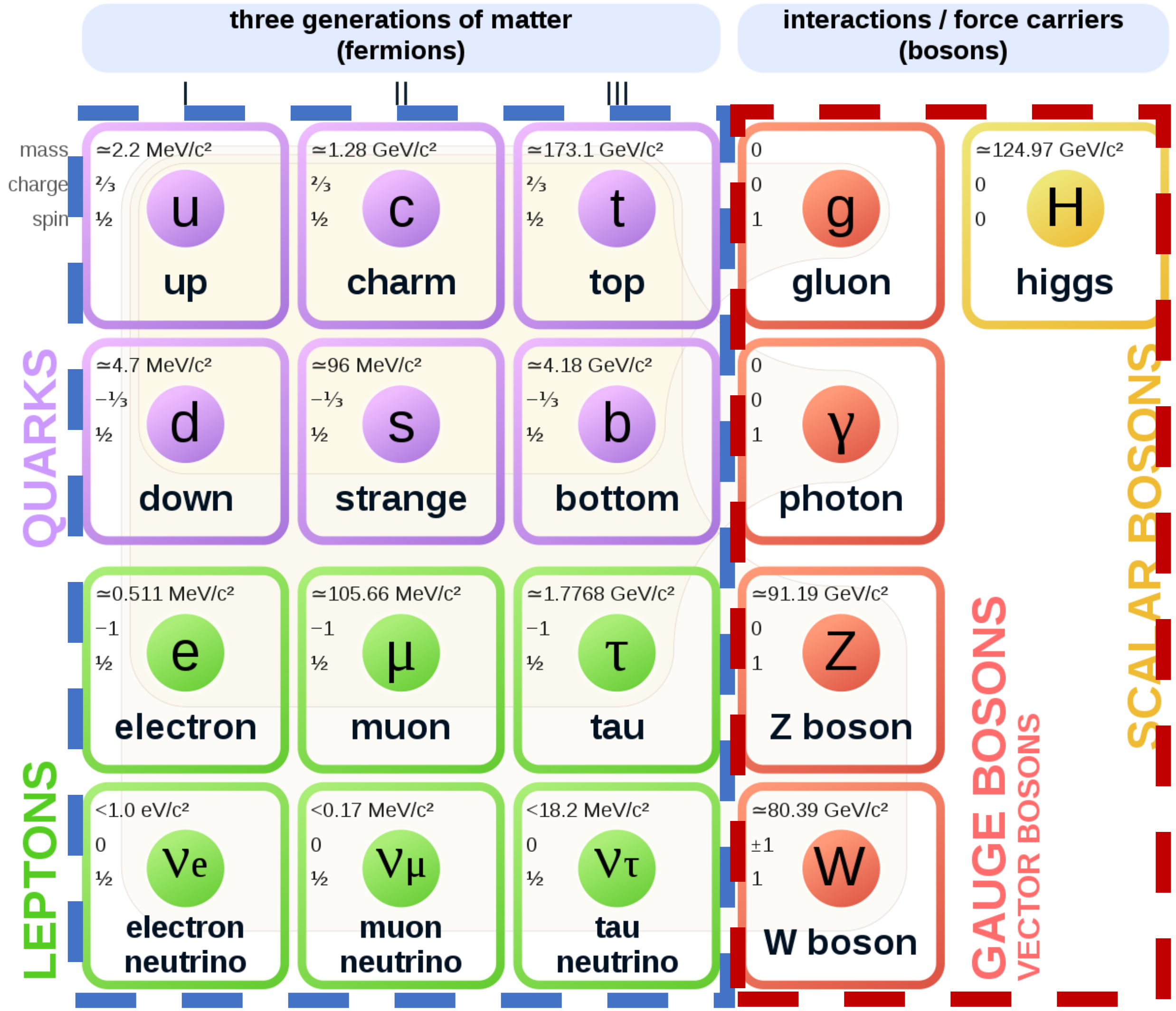




Looking into the SM particle bible

Standard Model of Elementary Particles



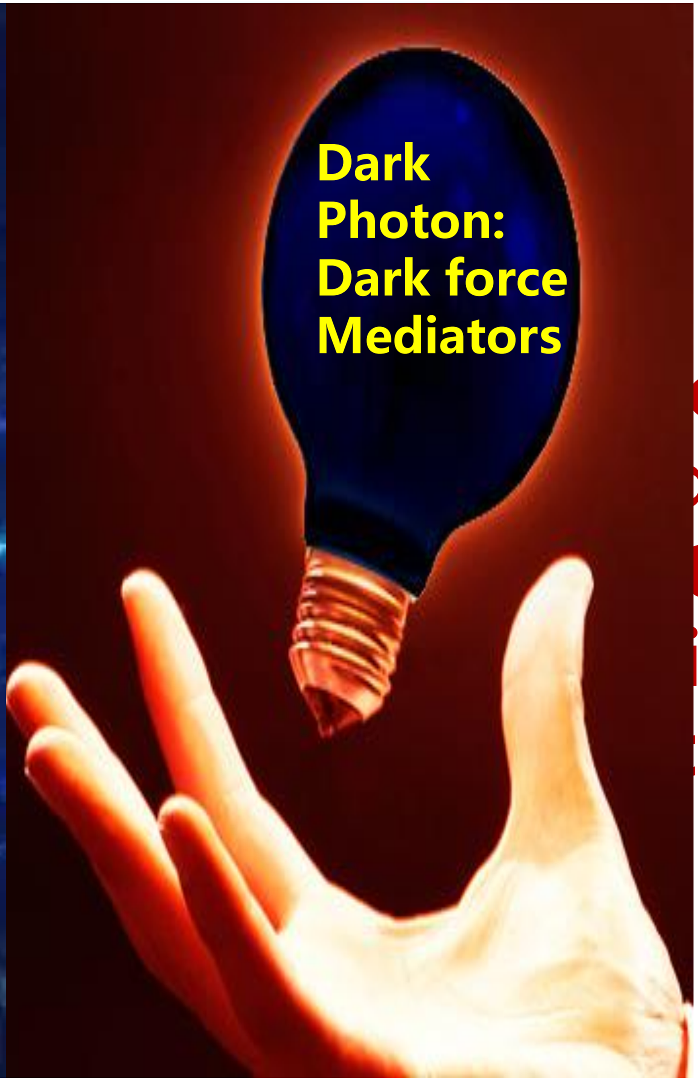
Fermions: making up ordinary matter

Bosons: mediator portal for ordinary matter

Searching for Dark Force Mediators

The world of Dark Matter

Dark Matter candidate particles



Dark Matter Mediators

Dark Photon Theory in a nutshell

Introduce extra $U(1)_X$ symmetry → New Gauge Field X → Dark Photon Mediator A′

$U(1)_{em}$ → $U(1)_{em} \times U(1)_X$

5^{th} 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′**

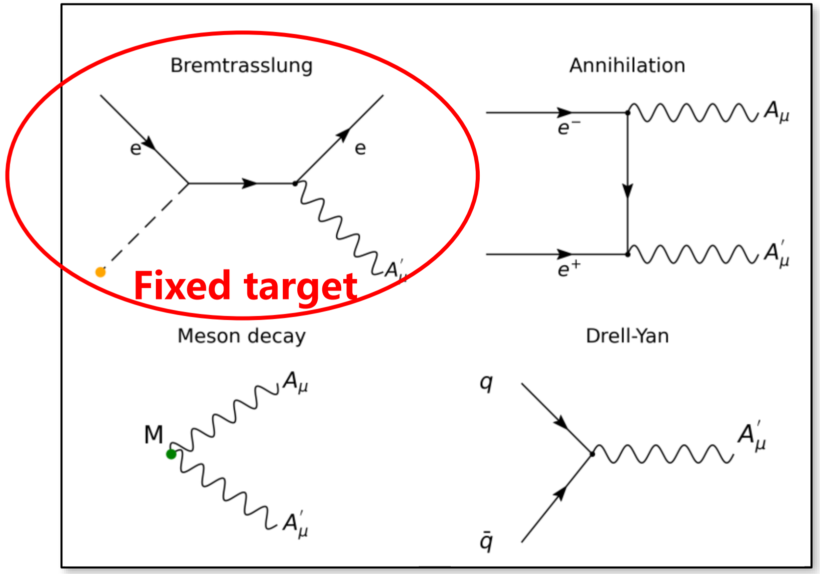
$$\varepsilon X_{\mu\nu}F^{\mu\nu}$$

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

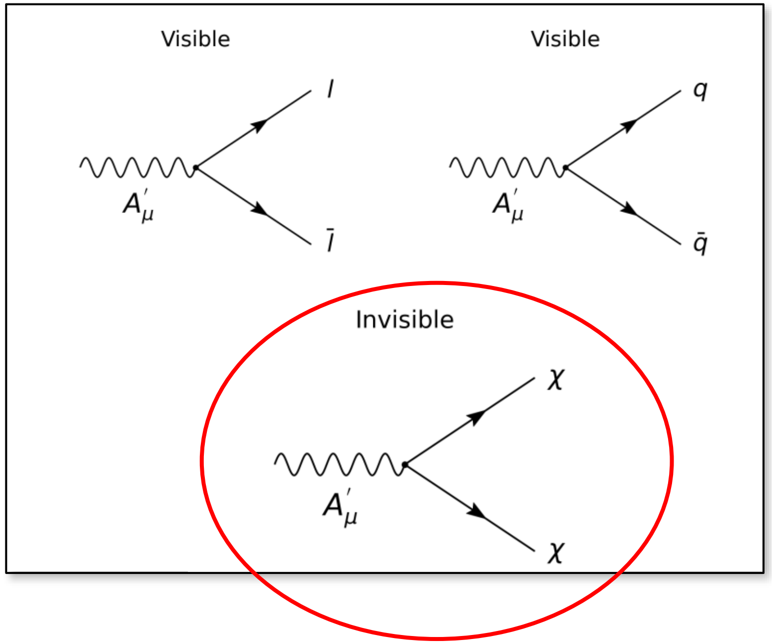
B. Holdom, Phys. Lett. B 166, 196 (1986)
R. Foot & X.-G. He, Phys. Lett. B 267, 509 (1991)

Physics process and anticipated signatures

Processes to search for **dark photon A'** : Bremsstrahlung, Annihilation, Meson decay and Drell-Yan process



(Dark photon production)



(dark photon decay)

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

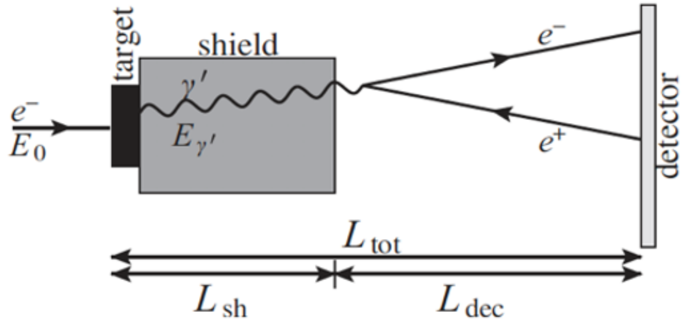
Invisible vs visible searches

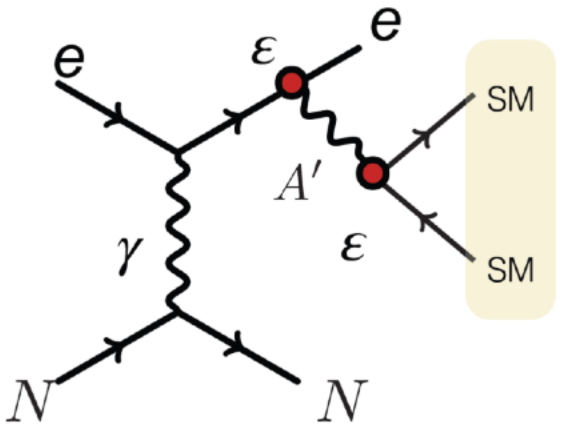
- **Dark photon can be produced in electron-nuclei interaction (electron-on-target).**
- **Two ways of detection, via its**

VISIBLE DECAY MODE $m'_A < 2m_X$

- **Visible decay**

Having two interaction vertices → production rate highly supressed

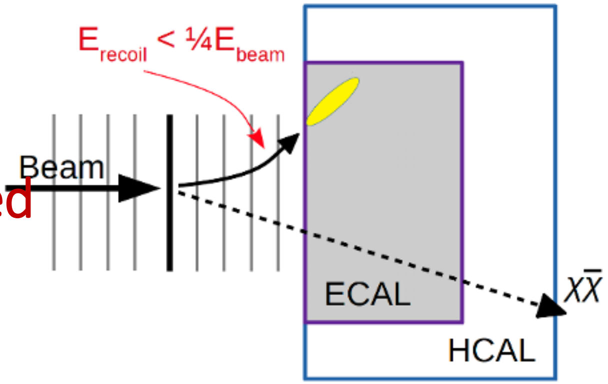


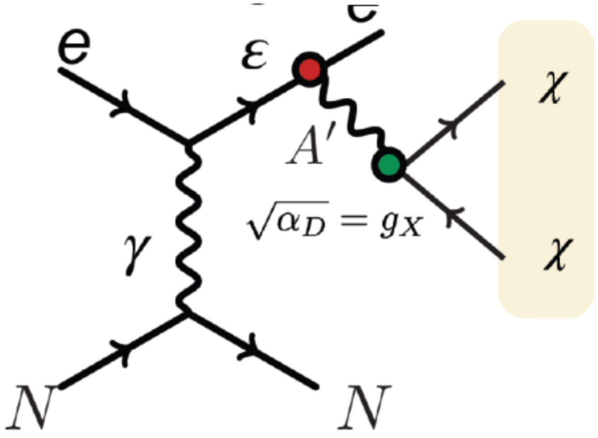


$$N \propto \epsilon^4 \quad \ll \quad N \propto \epsilon^2(1-\epsilon^2) \approx \epsilon^2$$

INVISIBLE DECAY MODE $m'_A > 2m_X$

- **Invisible decay**

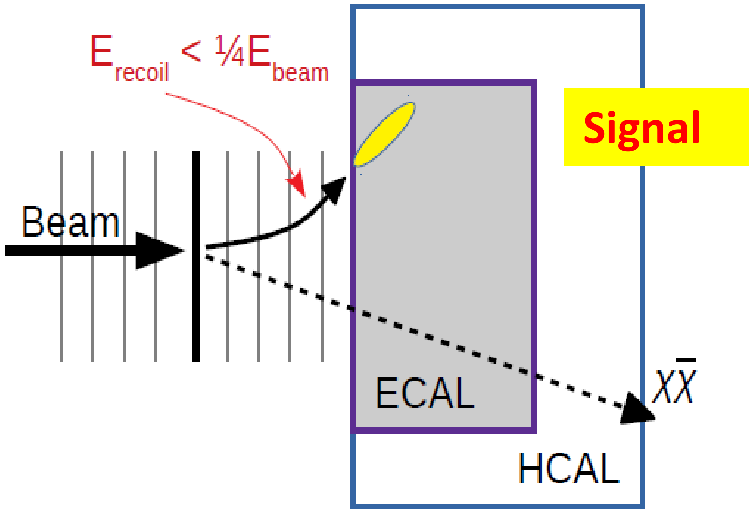


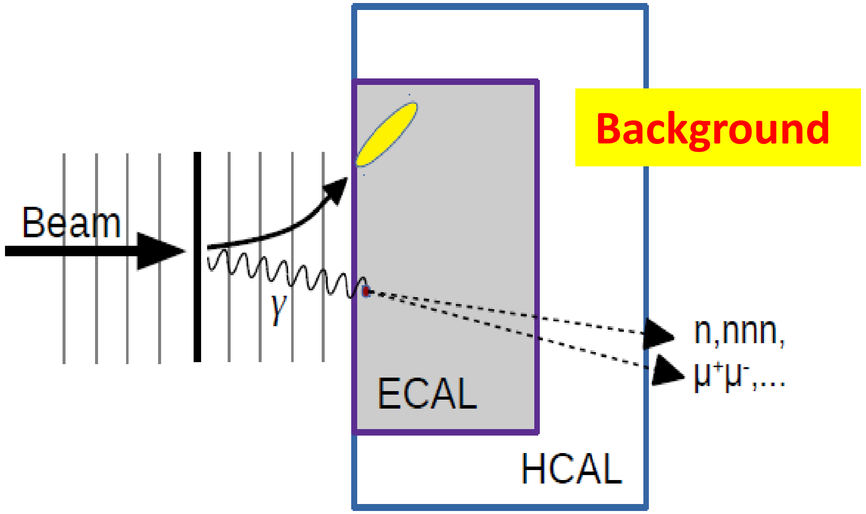


Interaction probability could be enhanced
→ better sensitivity!

Experimental approaches

- **High repetition rate single electron beam**
  - More striking record of single electron-on-target event energy loss after recoiling
  - Require: fast detector responses and readout electronics, radiation hardness to allow high e-on-target statistics.
- **Energy + Momentum loss detection**
  - Synergy of high precision tracking and calorimetry





→ **Layout the new approach**

- Single electron beam on target
- High repetition rate
- "Missing momentum" information

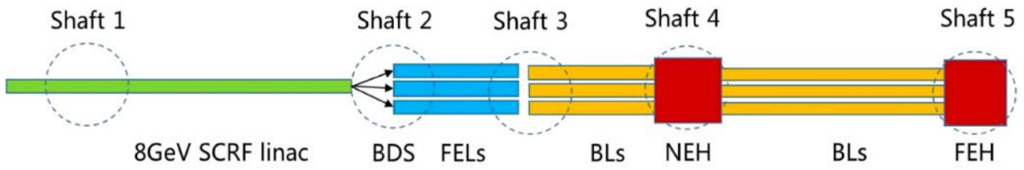
- **Searches at collider and beam-dump experiment:**
  - BESIII, Belle-II, LHC, …
  - NA64, LDMX, DarkLight, DarkMESA…

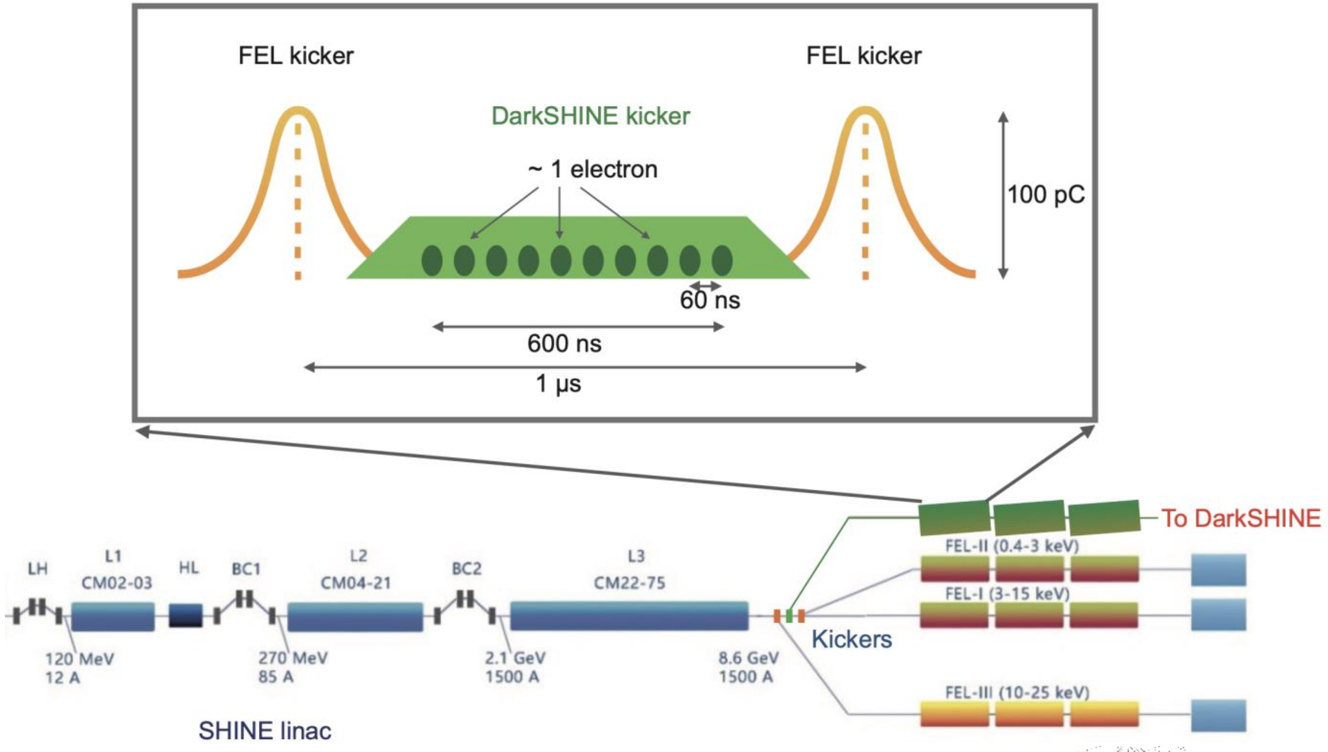
The SHINE Facility

Shanghai High Repetition-Rate XFEL and Extreme Light Facility (SHINE) can provide high repetition rate single electron beams → with dedicated kicker to be designed and deployed

- **Electron energy: 8 GeV, Frequency: 1MHz**
- **Beam intensity: 100pC (6.25E8 electrons/bunch)**
- **~3x10^{14} electrons-on-target (EOT) per year.**

- **Under construction in ZhangJiang area (2018-2026)**
- **Beamline R&D: ShanghaiTech. / SARI,CAS**
- **Detector R&D: SJTU / FDU / USTC / SIC-CAS / IHEP**

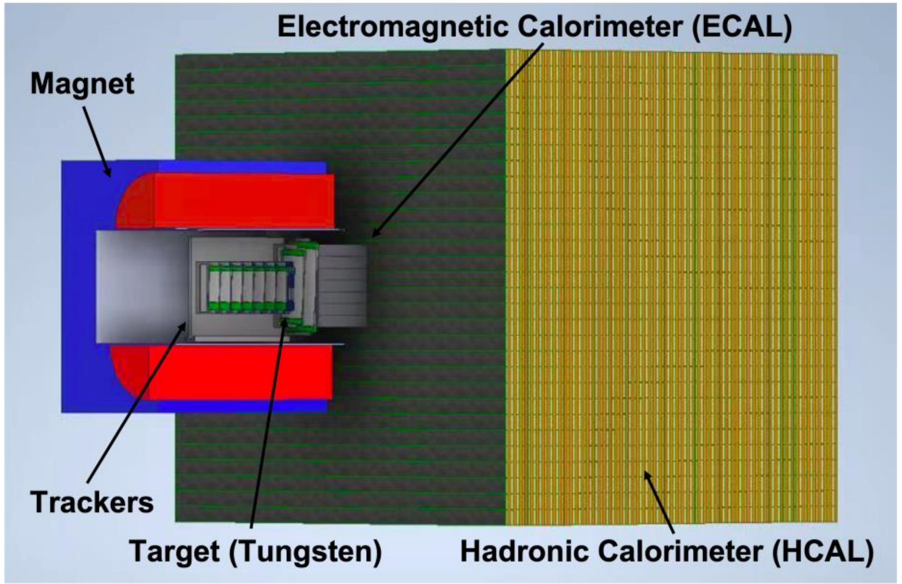




Detector system conceptual design

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

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



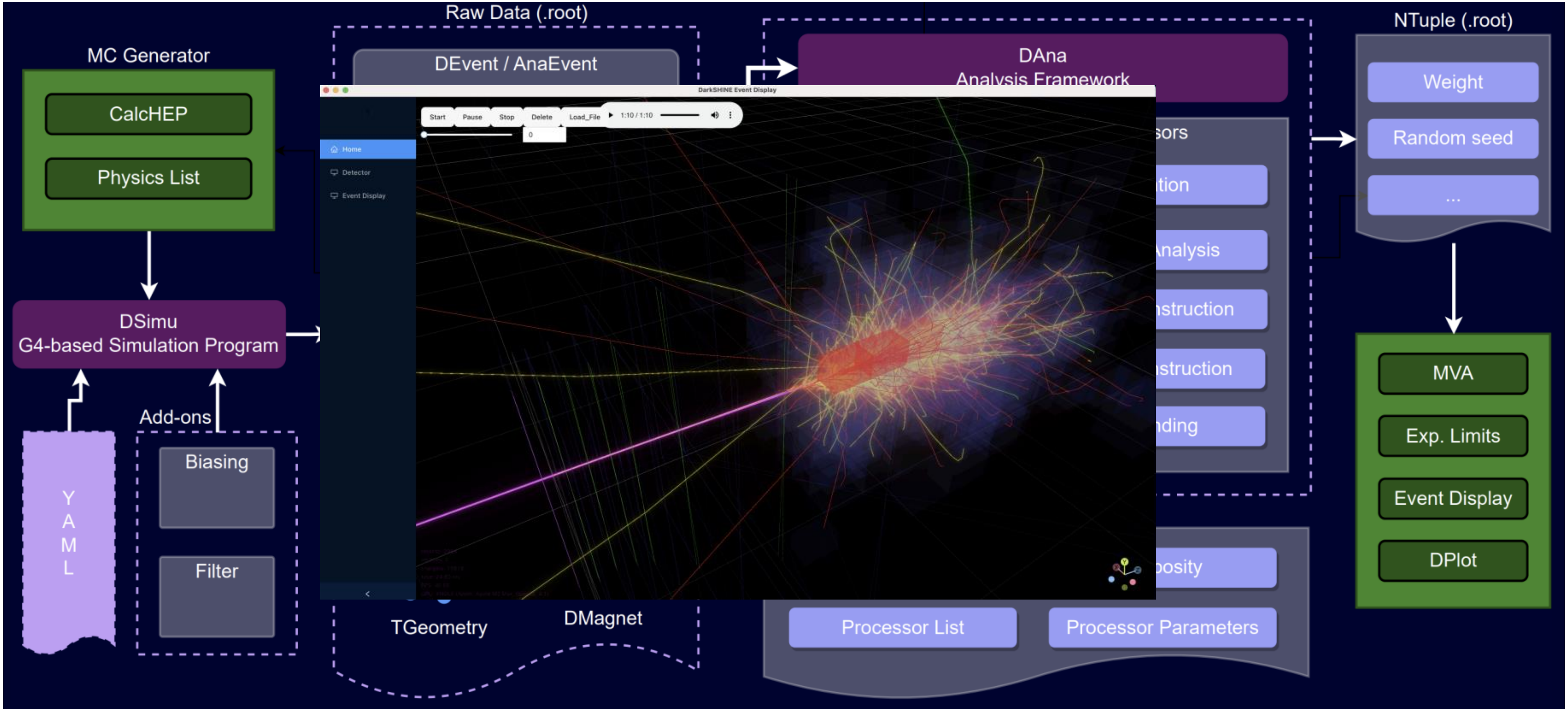
Dark SHINE detector sketch

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.

Software Framework Further Optimization



《Science China》publication with highlights

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

SCIENCE CHINA
Physics, Mechanics & Astronomy

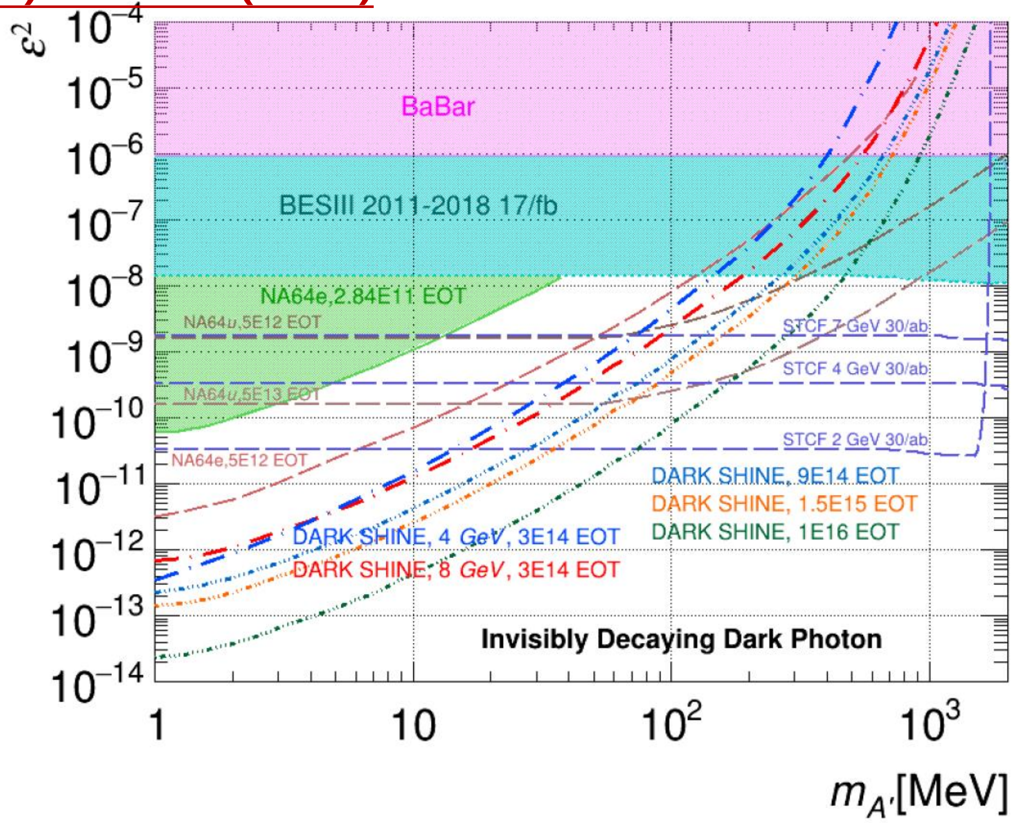
CrossMark

• Article •

June 2022 Vol. 63 No. 1: 000000
https://doi.org/??

Prospective Study of Light Dark Matter Search with a Newly Proposed DarkSHINE Experiment

Jing Chen†[b,c,a], Ji-Yuan Chen[b,c], Jun-Feng Chen[h], Xiang Chen[b,c], Chang-Bo Fu[i,j], Jun Guo[b,c], Le He[f], Zheng-Ting He[a,n], Kim Siang Khaw[a,b,c], Jia-Lin Li[b,c], Liang Li[b,c], Shu Li[a,b,c,d,e]*, Meng Lv[g], Dan-Ning Liu[a,b,c], Han-Qing Liu[b,c], Kun Liu[a,b,c]*, Qi-Bin Liu[a,b,c], Yang Liu[a,b,c], Ze-Jia Lu[b,c], Cen Mo[b,c], Si-Yuan Song[b,c], Xiao-Long Wang[i,j], Yu-Feng Wang†[a,b,c], Zhen Wang[a,b,c], Zi-Rui Wang[m], Wei-Hao Wu[b,c], Dao Xiang[k,a,l], Hai-Jun Yang[b,c,a]*, Jun-Hua Zhang[a,b,c], Yu-Lei Zhang†[b,c], Zhi-Yu Zhao[a,b,c], Xu-Liang Zhu[a,b,c], Chun-Xiang Zhu[b,c], and Yi-Fan Zhu[b,c]



Highlight remarks

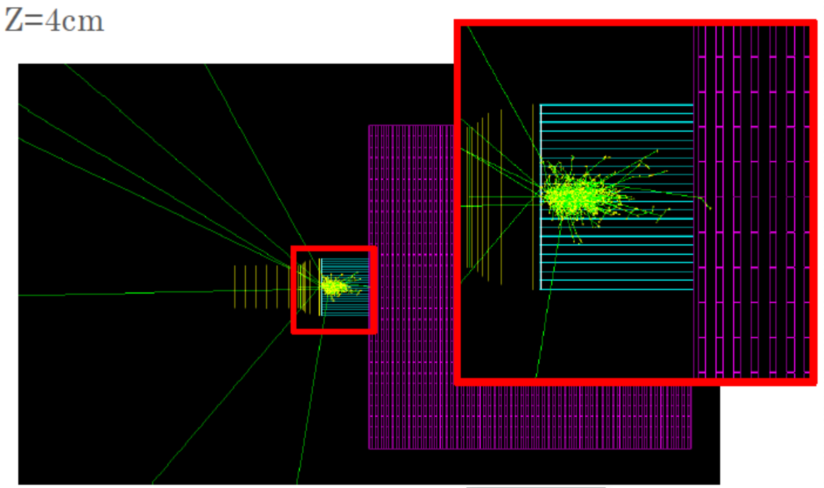
Sci. China-Phys. Mech. Astron. 66(1): 211063 (2023)

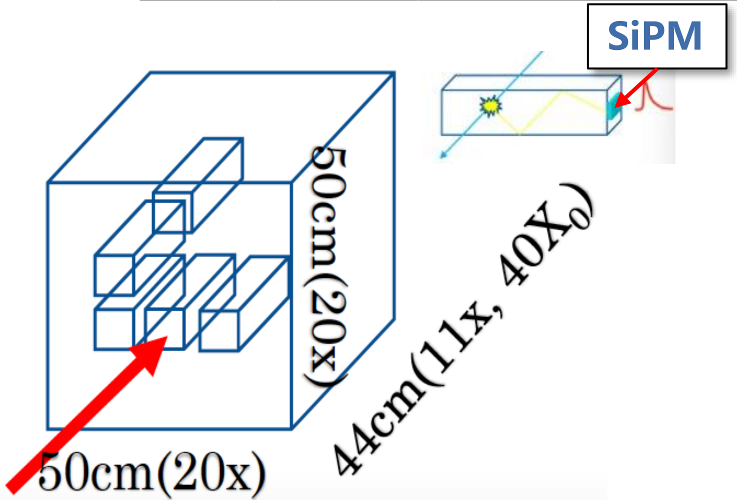
“Editor’s Focus”

Sci. China-Phys. Mech. Astron. 66(1): 211061 (2023)

- Anticipated to have the sensitivity improved by one order of magnitude compared to other experiment (e.g. NA64)
- Aim to deliver 10^{16} EOT stat. and cover most of the sensitivity regions of interests

Crystal ECAL R&D

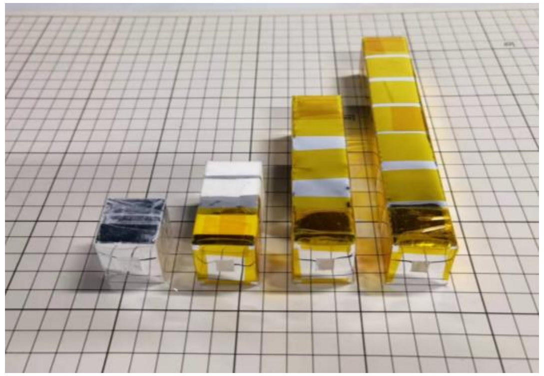


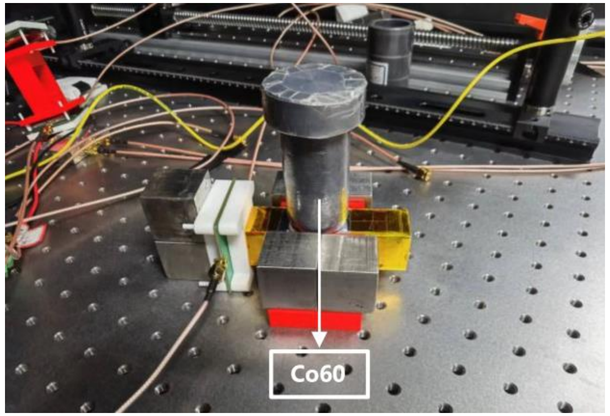


Baseline design of each crystal: X,Y = 2.5 cm, Z = 4 cm (radiation length: 1.14 cm)

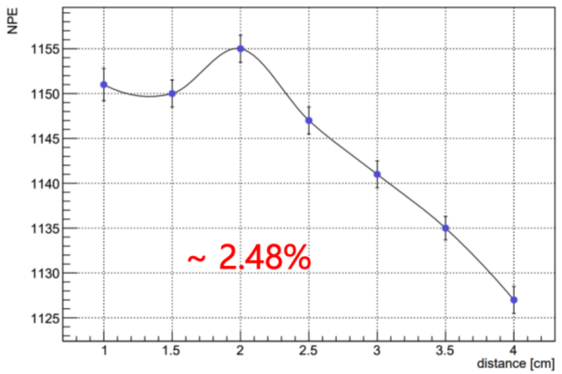
Measure the deposited energy of electron and photon.

- Designed resolution: better energy resolution than 5%.
- LYSO crystal ($Lu_{(1-x-y)}Y_{2y}Ce_{2x}SiO_5$):
  - high light yield (30000 p.e/MeV) with good linearity.
  - short decay time (40 ns).
- **20×20×11 crystals, 2.5cm×2.5cm×4cm**
- Readout with SiPM and waveform sampling.
- More intrinsic radiation and radioactive source tests.



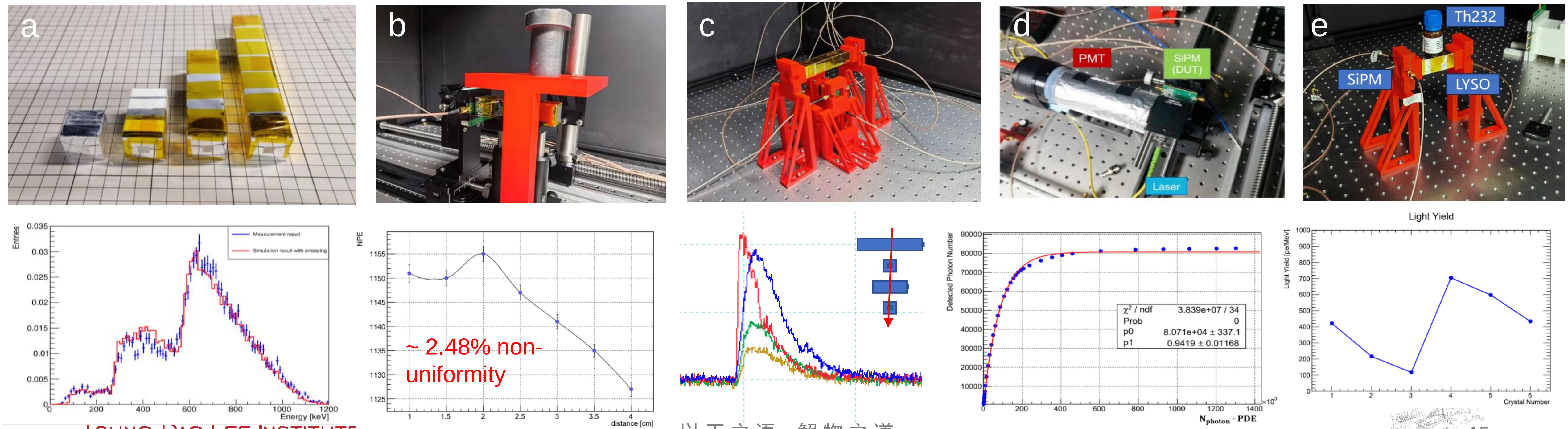


5cm LYSO



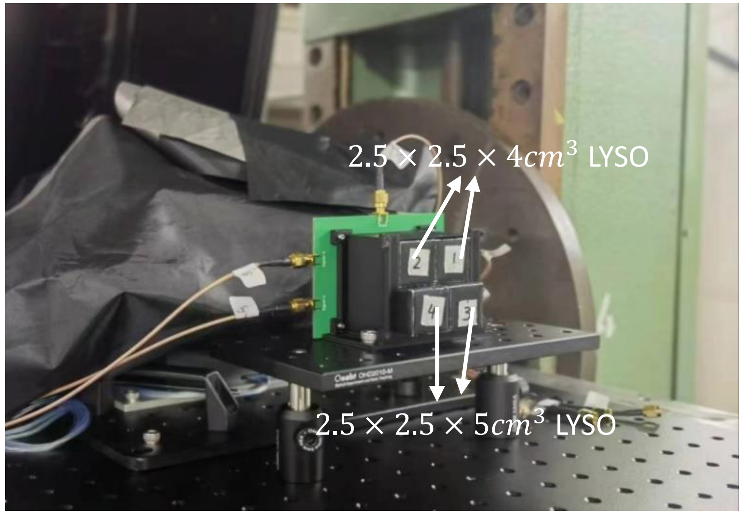
ECAL Unit Test

- Experiments based on LYSO and SiPM to study their properties
  - a. LYSO intrinsic radiation from ${}^{176}_{71}Lu \rightarrow {}^{176}_{72}Hf$
  - b. Uniformity test with ${}^{60}_{27}Co$ source
  - c. Cosmic ray test
  - d. SiPM dynamic range test
  - e. Light yield changed with crystal size

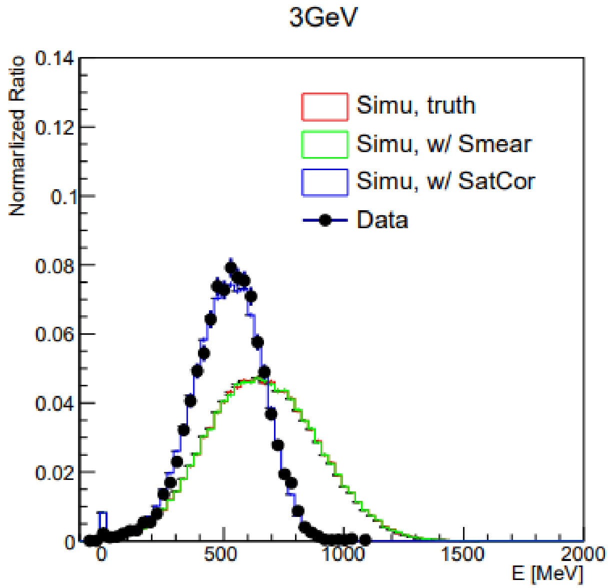


Design and beam test for 1st prototype Module

- Motivation:
  - Performance study under high energy and high repetition beam.
  - Technical validation for the whole detector system
- Prototype conceptual design: hybrid materials with LYSO as core scintillator, and PWO as outer scintillator
- **1st prototype module for beam test (2x2 LYSO) at DESY**
  - 8GeV electron beam, ~2 kHz repetition rate
  - Crystal unit dynamic range test and digitization method validation



Simulation and experiment can be in good agreement



Dark Photon Theory Progresses at TDLI/SJTU

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PHYSICAL REVIEW D **101**, 075016 (2020)

CP-violating dark photon interaction

Kaori Fuyuto,[1,*] Xiao-Gang He,[2,3,4,†] Gang Li,[2,‡] and Michael Ramsey-Musolf[1,5,§]

[1]*Amherst Center for Fundamental Interactions, Department of Physics, University of Massachusetts Amherst, Massachusetts 01003, USA*

[2]*Department of Physics, National Taiwan University, Taipei 106, Taiwan*

[3]*T-D. Lee Institute and School of Physics and Astronomy, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, People's Republic of China*

[4]*National Center for Theoretical Sciences, Hsinchu 300, Taiwan*

[5]*Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125, USA*

JHEP — PUBLISHED FOR SISSA BY SPRINGER

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REVISED: *September 11, 2018*
ACCEPTED: *October 31, 2018*
PUBLISHED: *November 9, 2018*

Constraining photon portal Dark Matter with TEXONO and COHERENT data

Shao-Feng Ge[a,b] and Ian M. Shoemaker[c]

Regular Article -Theoretical Physics

Probing the dark axion portal with muon anomalous magnetic moment

Shao-Feng Ge[1,2,a], Xiao-Dong Ma[1,2,b], Pedro Pasquini[1,2,c]

JHEP — PUBLISHED FOR SISSA BY SPRINGER

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ACCEPTED: *March 19, 2018*
PUBLISHED: *March 23, 2018*

Search for a heavy dark photon at future e^+e^- colliders

Min He,[a] Xiao-Gang He,[a,b,c] Cheng-Kai Huang[b] and Gang Li[b]

JHEP — PUBLISHED FOR SISSA BY SPRINGER

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ACCEPTED: *November 29, 2020*
PUBLISHED: *January 12, 2021*

Dark photon dark matter in the minimal $B-L$ model

Gongjun Choi,[a] Tsutomu T. Yanagida[a,b] and Norimi Yokozaki[c]

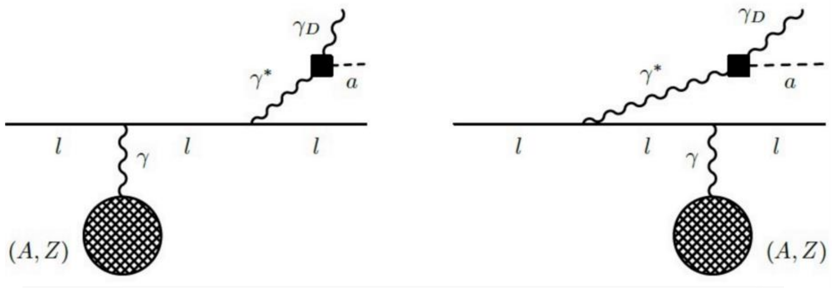
PHYSICAL REVIEW D **102**, 075001 (2020)

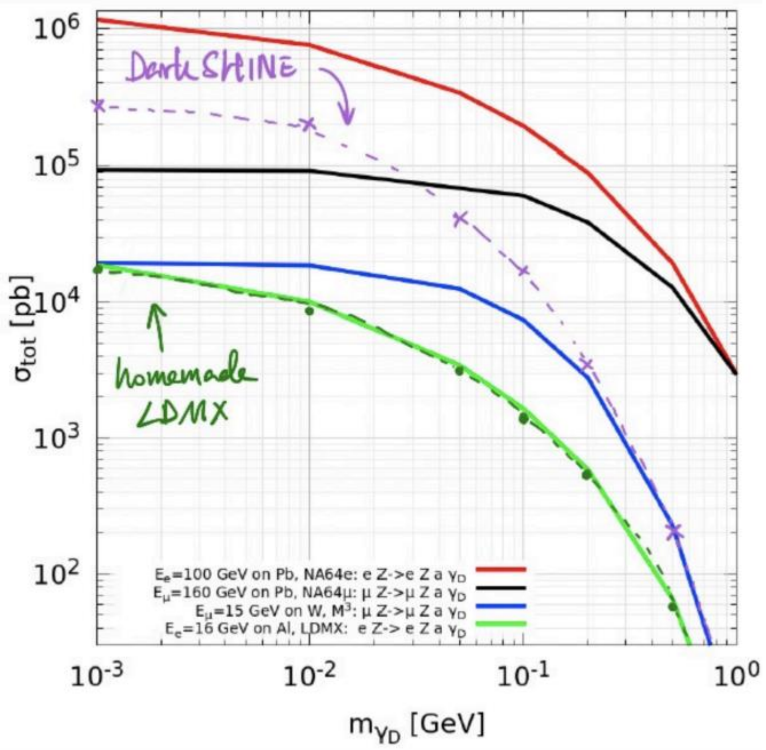
Strongly-interacting massive particle and dark photon in the era of the intensity frontier

Ayuki Kamada,[1] Masaki Yamada,[2,3,4] and Tsutomu T. Yanagida[5,6]

More Physics Opportunities: ALP+DP, positron-on-Target mode

Minimal dark Axion-like particle portal and Axion+DP co-existence





- Dramatically different sensitivity curve of Dark Photon search when changing from **electron beam to positron beam**
- Extra s/t-chan annihilation diagrams come into play for Dark Photon production
- SHINE can also deliver positron beam with low current…

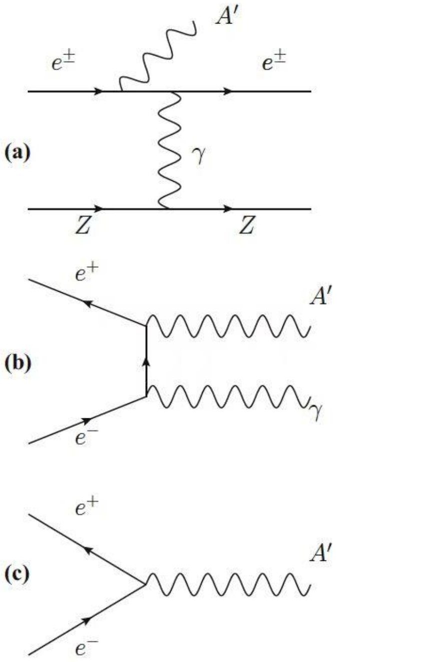
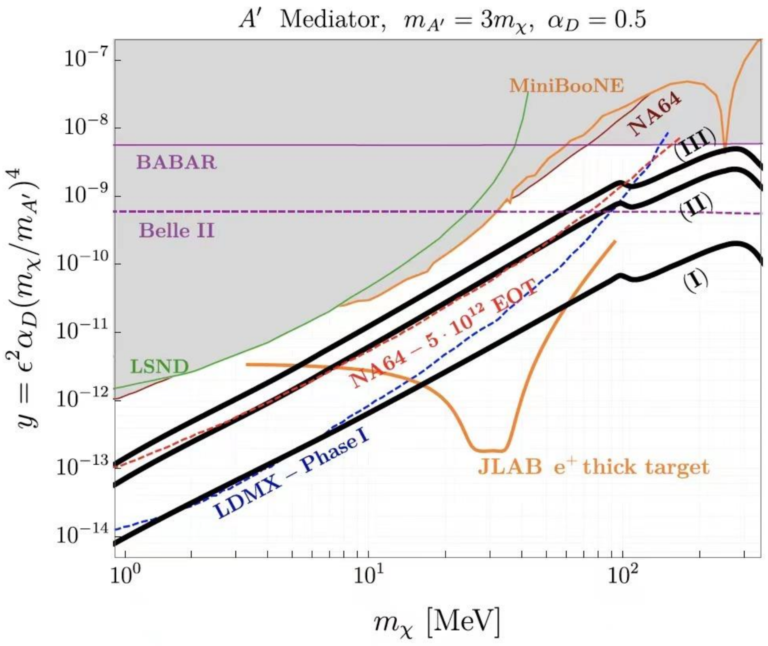


Fig. 1 Three different A' production modes in fixed target lepton beam experiments: *(a)* A'-strahlung in e^-/e^+-nucleon scattering; *(b)* A'-strahlung in e^+e^- annihilation; *(c)* resonant A' production in e^+e^- annihilation



Eur. Phys. J. A (2021) 57:253

More Physics Opportunities: search for muonium

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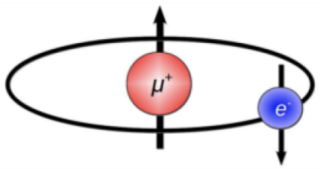
A brief history

- The term Muonium was "stolen" by μ^+e^- when it was discovered in the 1950s

- pure leptonic bound state of **μ^+ and e^-**
- investigate μ-e interactions
- test bound-state QED
- **1S-2S transition frequency** (**4 ppb**)
  ground state HFS (**12 ppb**)
- extract fundamental constants (m_μ/m_e, q_μ/q_e, μ_μ/μ_p)
- probe physics beyond the standard model (LFV, etc ...)

Smallest atom!
Test bound-state QED



"fake" muonium

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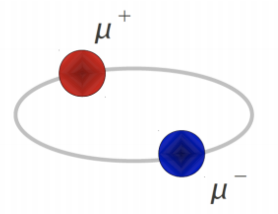
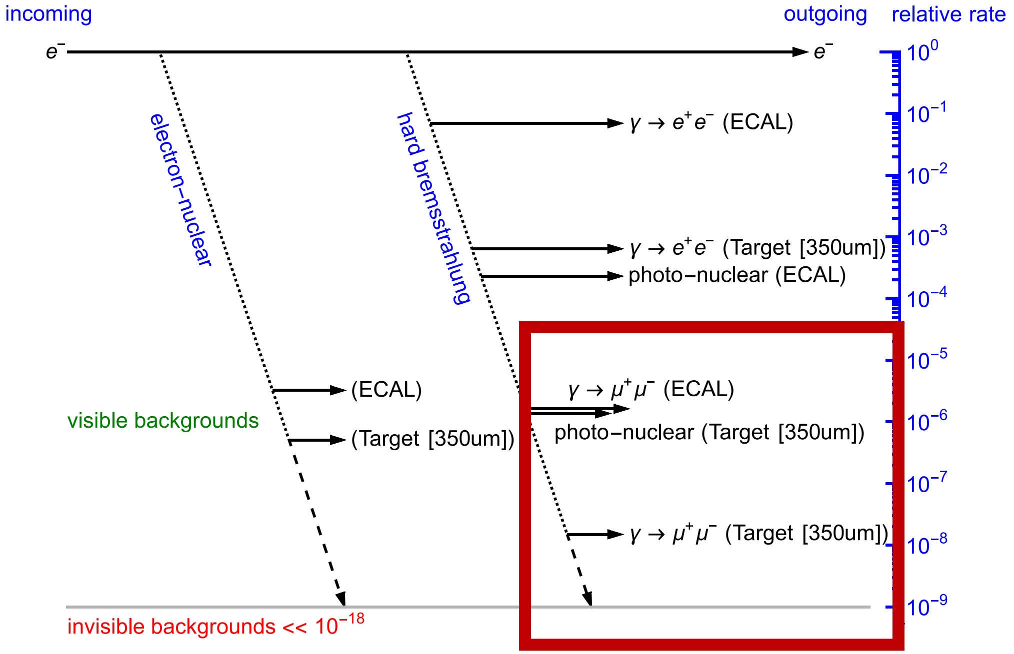


"true" muonium



Inspired by Prof. Kim-Siang Khaw