

# Dark Photon search with an electron beam dump near large liquid scintillator detector at underground

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# Model for Dark Photon and Dark Matter

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- A simple model to include the dark matter by introducing an extra U(1)'
  - Contains Dark photon (A') and Dark matter

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}^2 A'^2 - \sum_f q_f e (A_\mu + \varepsilon A'_\mu) \bar{f} \gamma^\mu f + \mathcal{L}_{DM},$$

- Dark Photon and EM charged matter coupling:  $\varepsilon e$

**Dark matter sector:** 
$$\mathcal{L}_{DM} = \begin{cases} \bar{\chi}(i\not{D} - m_\chi)\chi, & \text{fermionic DM } (\chi), \\ |D_\mu\varphi|^2 - m_\varphi^2\varphi^*\varphi, & \text{bosonic DM } (\varphi). \end{cases}$$

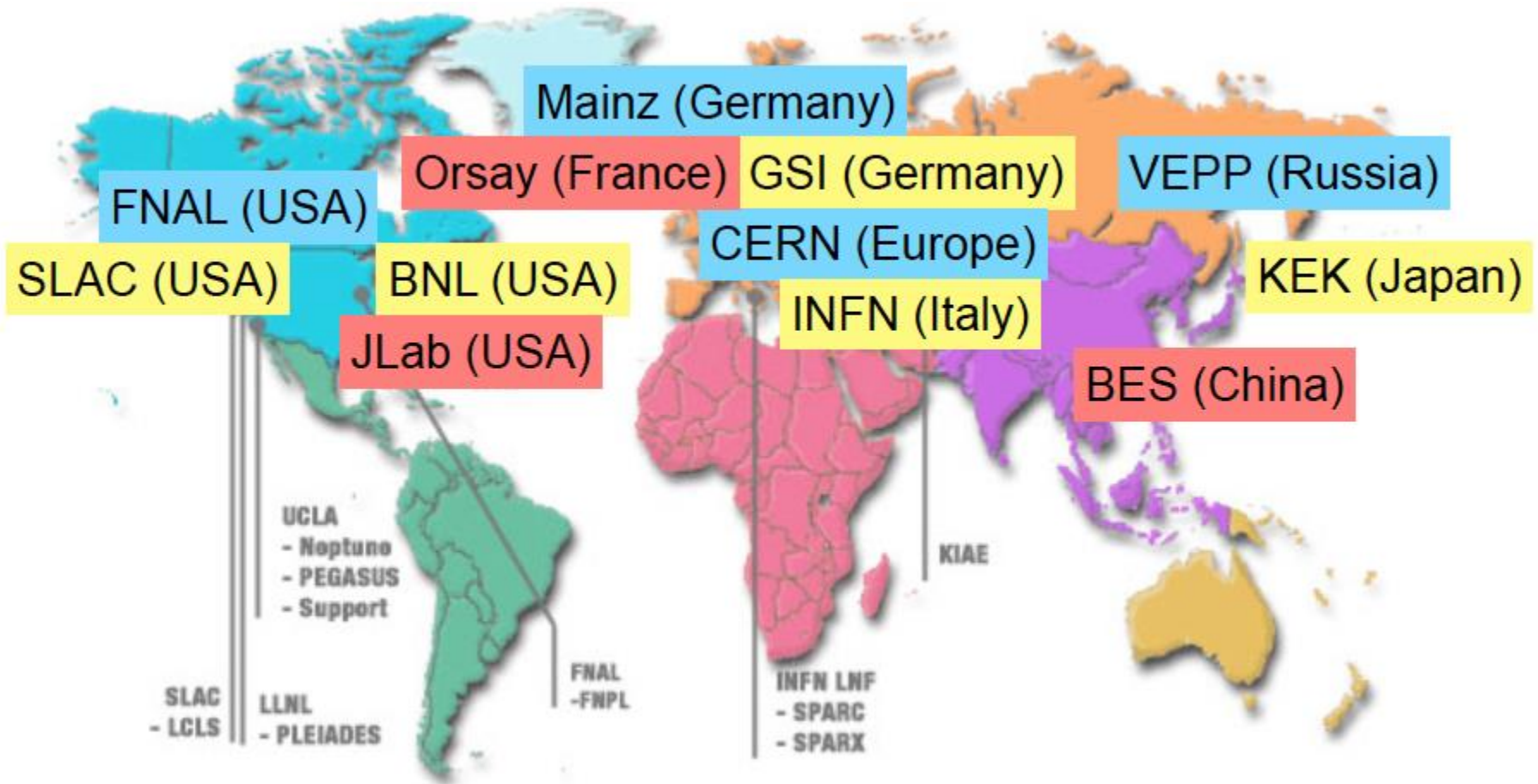
$$D_\mu = \partial_\mu + ig' A'_\mu$$

- Dark Photon and DM coupling:  $g'$  (U(1)' charge)

# Worldwide map for Dark photon search

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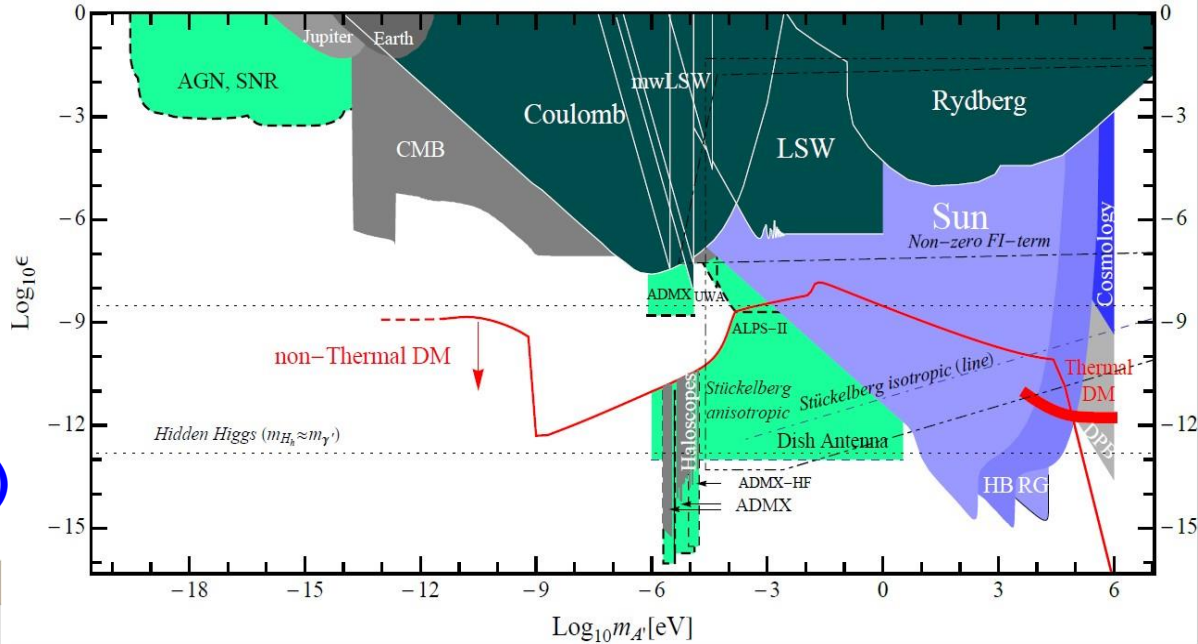
## Ongoing and proposed experiments



# Constraints for A'

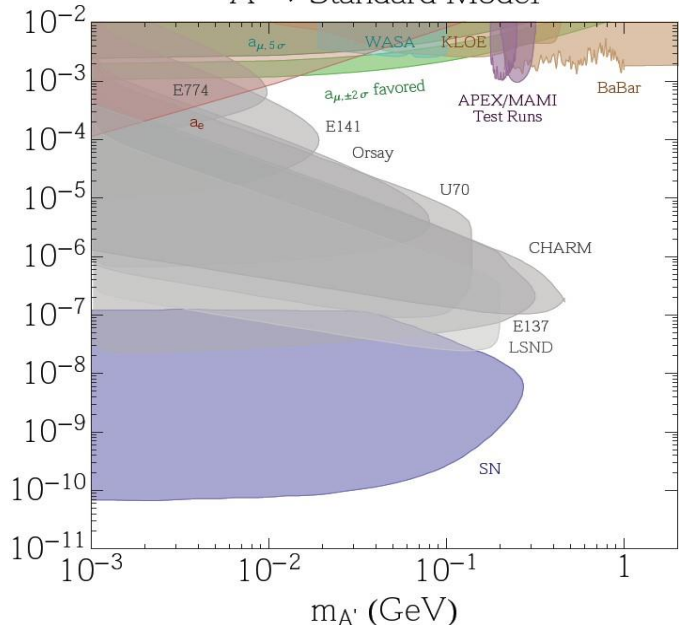
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## Astrophysics and other non-accelerator exps. ( $m_{A'} < 1 \text{ MeV}$ )



## Accelerator exps ( $m_{A'} > 1 \text{ MeV}$ )

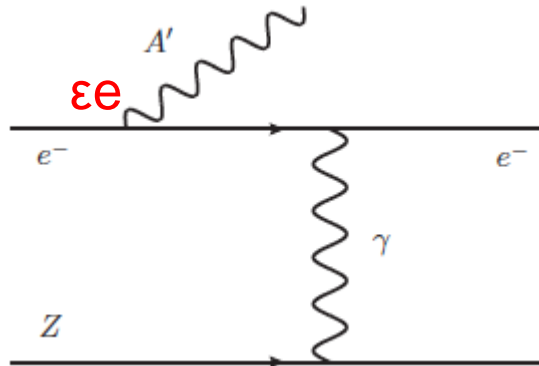
A' → Standard Model



Usually look for A' decays:  
Ex)  $A' \rightarrow e^+ e^-$

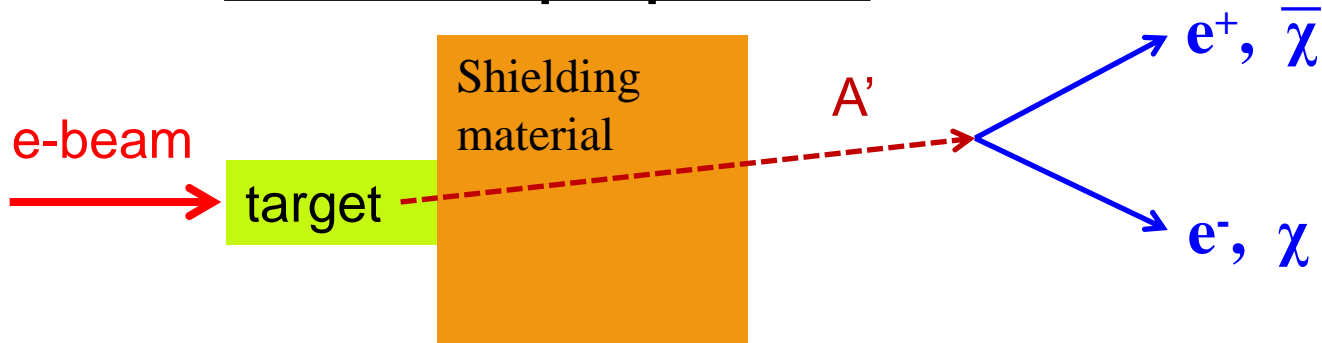
# A' production with electron accelerator (I)

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Production rate:  $\sim \epsilon^2 \sigma_{\text{brem}}$

## e-beam dump experiment



- $m_{A'} > 2 m_e$  :  $A' \rightarrow e^+ e^-$
  - $m_{A'} < 2 m_e$  :  $A' \rightarrow 3 \gamma$  (Highly suppressed)
- $\sim 10 \text{ keV} < m_{A'} < 1 \text{ MeV} \rightarrow$  Dark-Photon Dark Matter

# A' production with electron accelerator (II)

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- A' production rate in a thick target approximation:

$$N_{A'} \sim 10 \times N_e \epsilon^2 \frac{m_e^2}{m_{A'}^2}$$

$N_e$ : No. of incident electrons on target

- Decay length of A' for  $m_{A'} > 2 m_e$

$$L_{dec} \sim 10^{-3} \text{ m} (\gamma/10) (10^{-4}/\epsilon)^2 (100 \text{ MeV}/m_{A'})$$

For  $m_{A'}=1 \text{ MeV}$  and  $\epsilon=10^{-7}$ ,  $L_{dec} > 10 \text{ km}$

# Electron beam dump experiments (I)

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## Old e-beam dump experiments

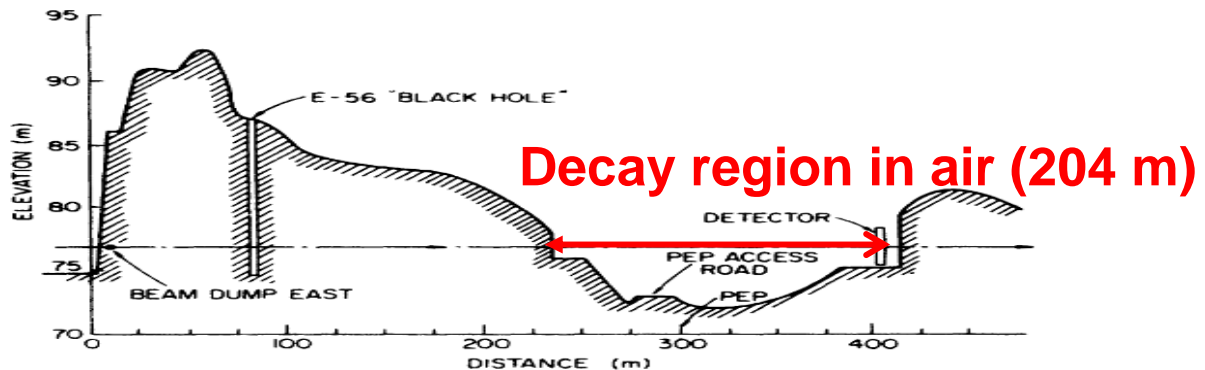
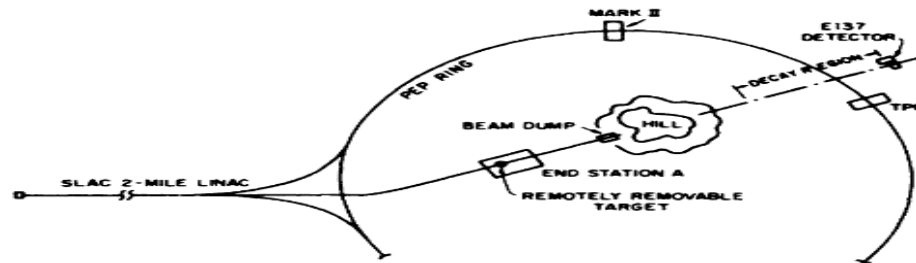
| Experiment                 | target | $E_0$<br>[GeV] | $N_{el}$              |         | $L_{sh}$<br>[m] | $L_{dec}$<br>[m] | $N_{obs}$              | $N_{95\%up}$ |
|----------------------------|--------|----------------|-----------------------|---------|-----------------|------------------|------------------------|--------------|
|                            |        |                | electrons             | Coulomb |                 |                  |                        |              |
| E141 <a href="#">[47]</a>  | W      | 9              | $2 \times 10^{15}$    | 0.32 mC | 0.12            | 35               | $1126_{-1126}^{+1312}$ | 3419         |
| E137 <a href="#">[48]</a>  | Al     | 20             | $1.87 \times 10^{20}$ | 30 C    | 179             | 204              | 0                      | 3            |
| E774 <a href="#">[49]</a>  | W      | 275            | $5.2 \times 10^9$     | 0.83 nC | 0.3             | 2                | $0_{-0}^{+9}$          | 18           |
| KEK <a href="#">[39]</a>   | W      | 2.5            | $1.69 \times 10^{17}$ | 27 mC   | 2.4             | 2.2              | 0                      | 3            |
| Orsay <a href="#">[40]</a> | W      | 1.6            | $2 \times 10^{16}$    | 3.2 mC  | 1               | 2                | 0                      | 3            |

# Electron beam dump experiments (II)

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## E137@SLAC (1988)

- 20 GeV
- Target: Aluminum plates
  - Al target was cooled with cooling water
- 179 m for shielding
- 204 m for decay region



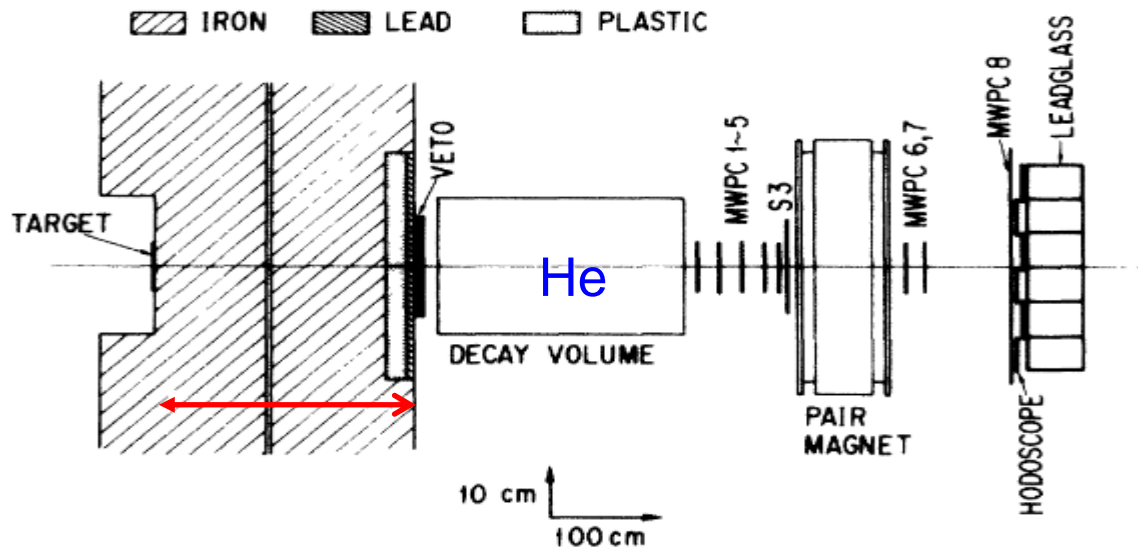


# Electron beam dump experiments (III)

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## KEK (1986)

- 2.5 GeV
- 3.5-cm-thick tungsten
- 2.4 m for shielding
- 2.2 m for decay region



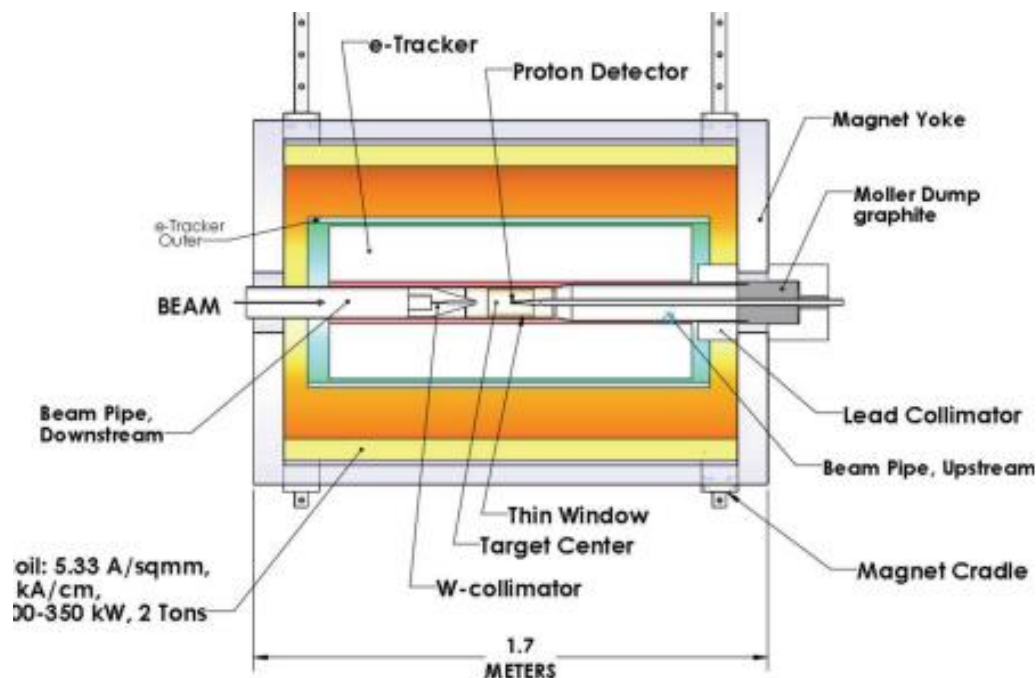
# Electron beam dump experiments (IV)

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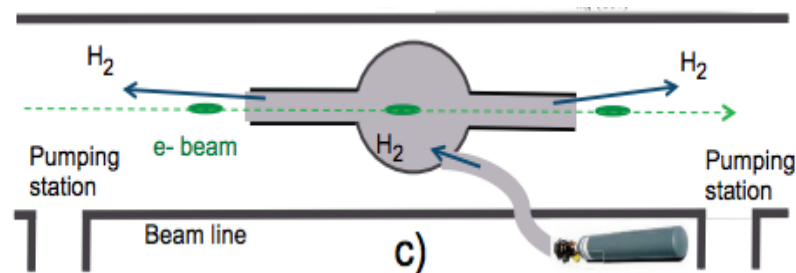
## DarkLight Experiment @ Jlab FEL

- Use the Energy Recovering Linac (ERL)
- Gaseous hydrogen target inside beam pipe.
- 100 MeV, 10 mA  $\rightarrow$  1 MW of power

## Target design



DarkLight Layout for 0.5 Tesla

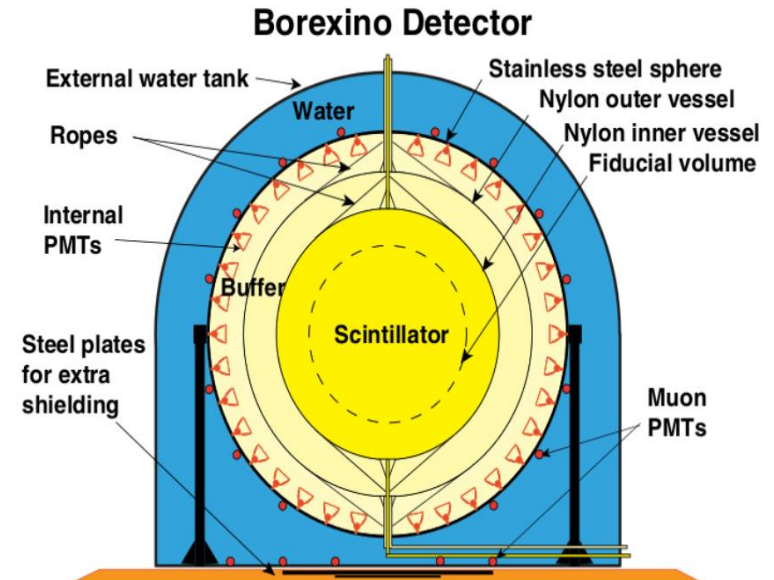
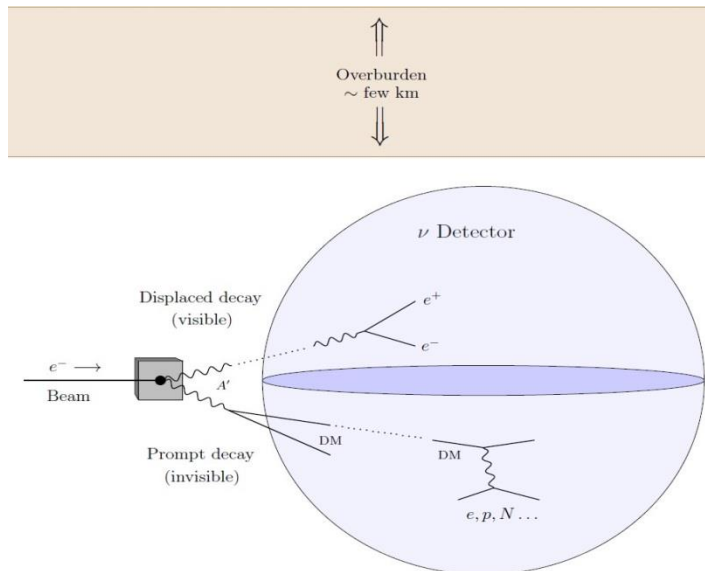


# A' and Dark matter searches @ underground

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We are considering the following features for the proposal,

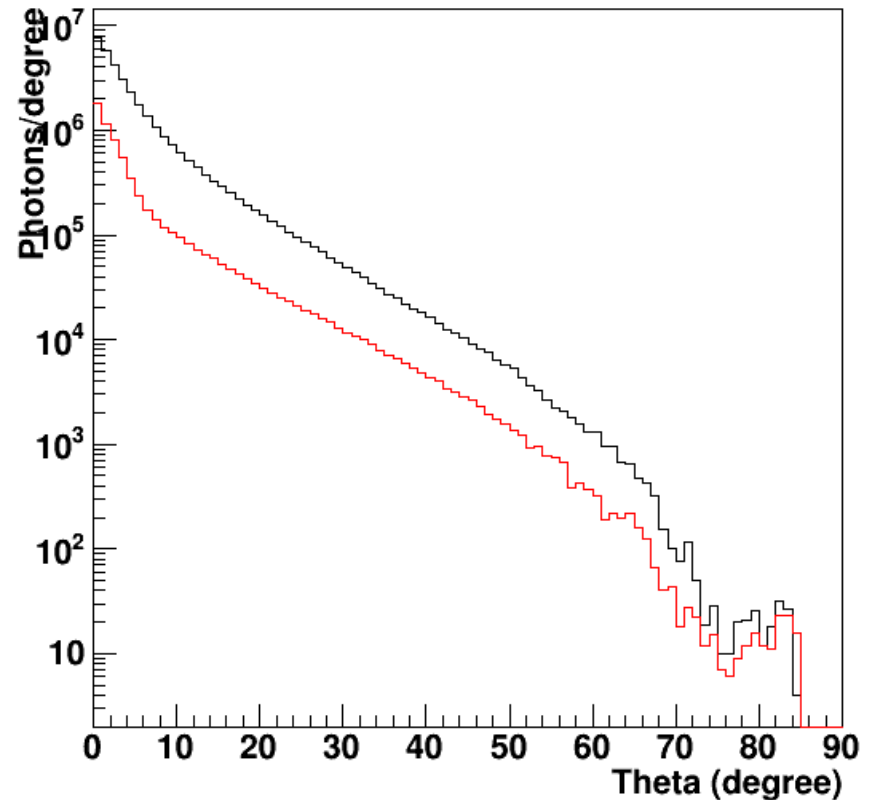
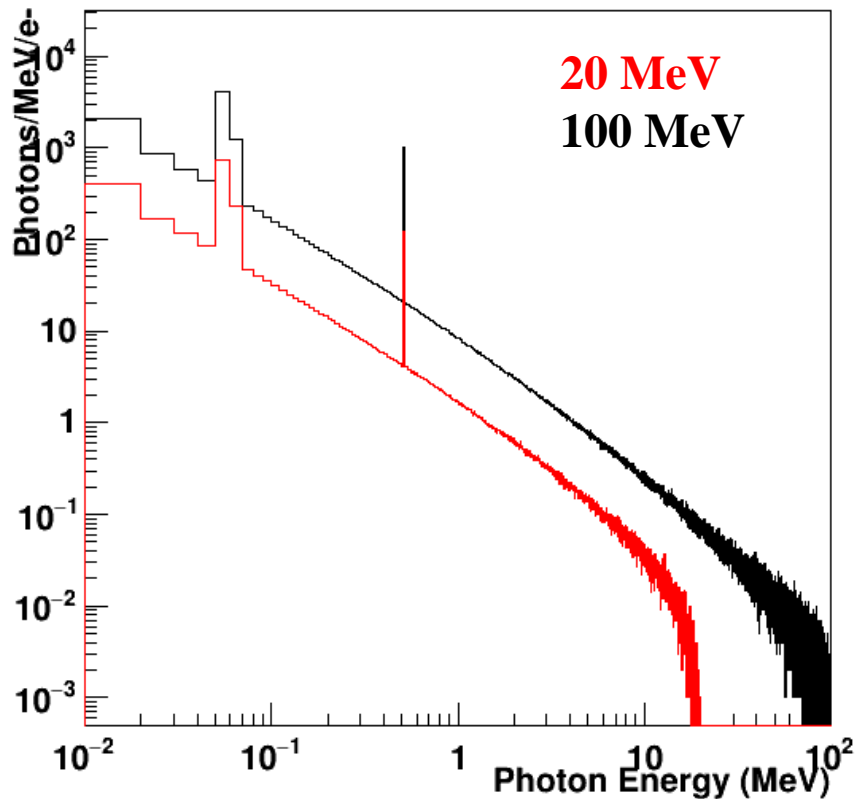
- A large scale detector is located at a deep underground lab.
  - 1 kton of LS with  $\sim 200$  keV threshold
  - Good detection efficiencies for e and  $\gamma$  events
- Electron accelerator near by the detector
  - 1 MW power with continuous beam
  - e-beam energy: 20 MeV  $\rightarrow$  100 MeV upgrdable.



# Energy and angular distribution

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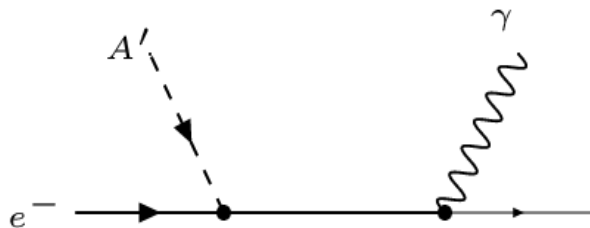
- GEANT 4 simulation:  $e^- + \text{tungsten} \rightarrow \text{gamma} + X$
- $\sim 10$  photons/ $1 e^-$  for  $E_\gamma > 1 \text{ MeV}$



# A' and Dark matter detection

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- We are searching for  $m_{A'} < 1 \text{ MeV}$ 
  - A' detection with Compton-like process

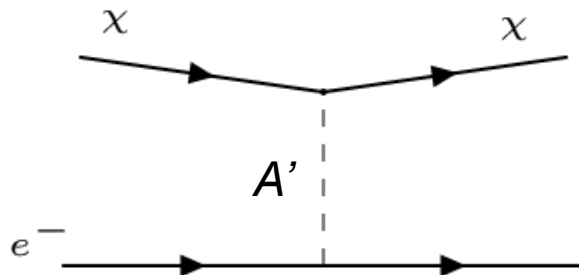


$$- \sigma \sim \alpha^2 \epsilon^2$$

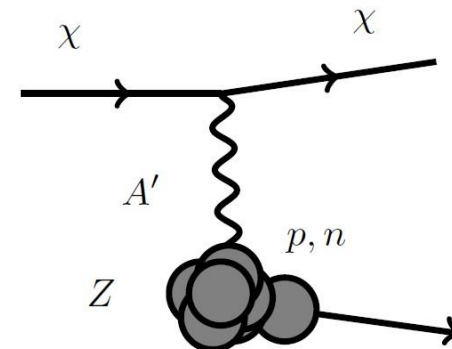
- X-section is dominant in  $\sim 1 \text{ MeV}$

- Dark matter detection

electron recoil



nuclear recoil



# Back-of-envelope estimation for A' search

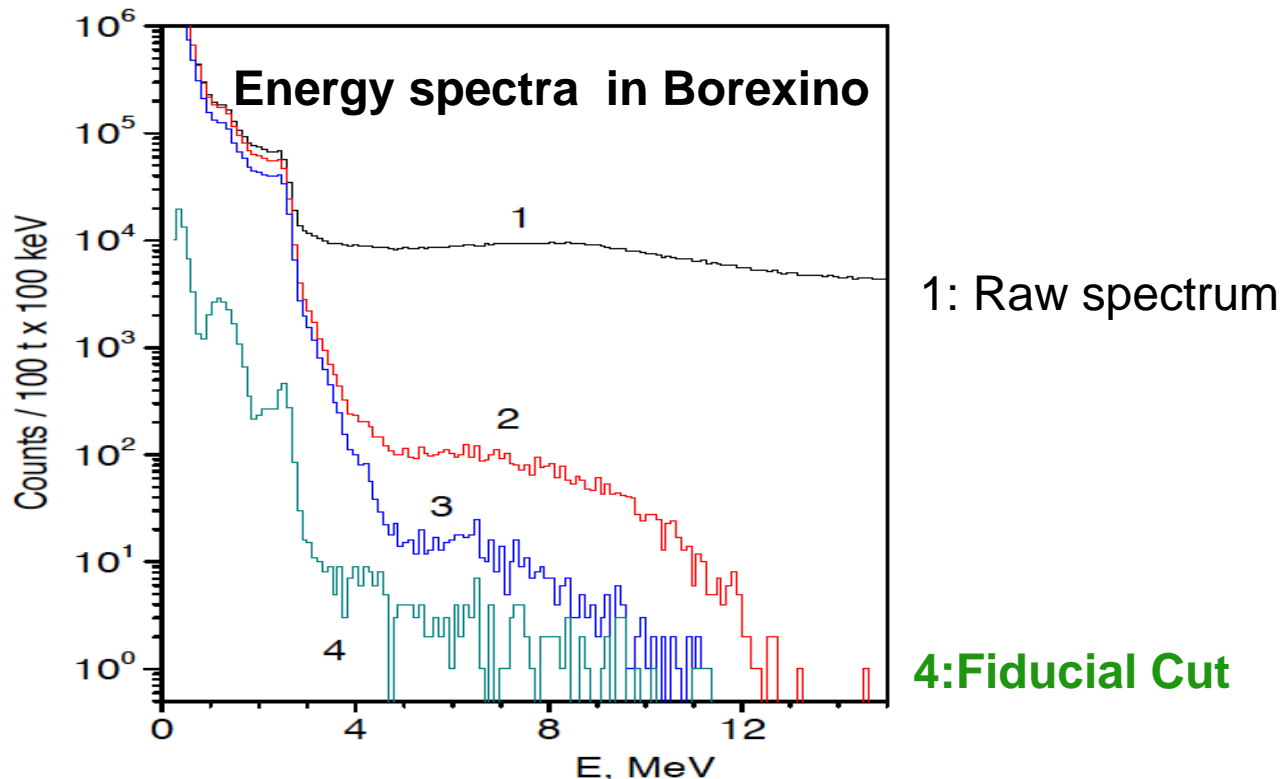
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## 1 MeV-mass A' with 1 MW and 20 MeV e-beam

- Sensitivity for 1 year running:

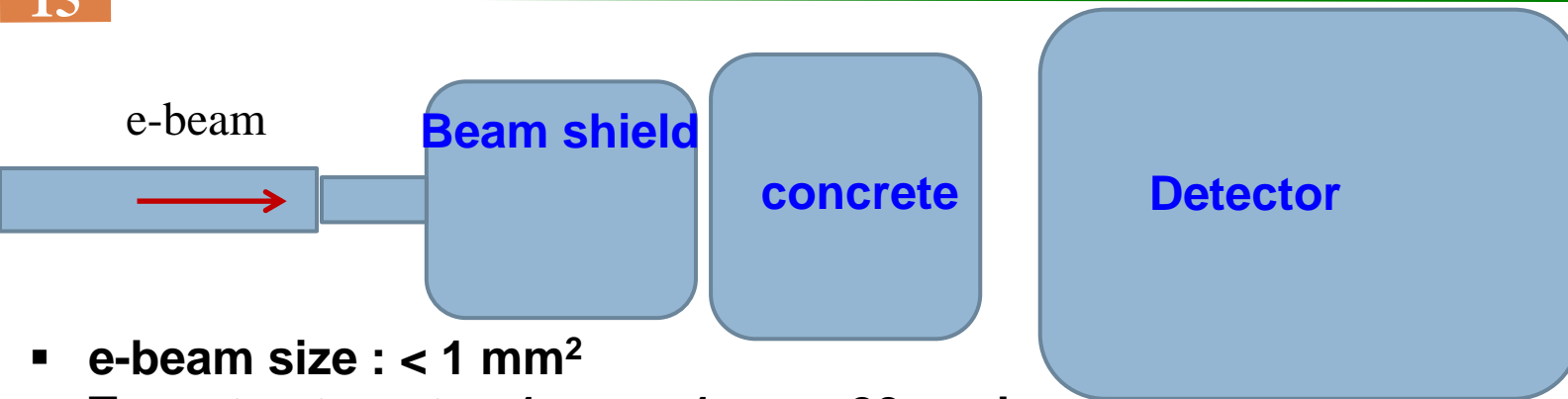
$$N_{A'} \times \sigma_{\text{comp}} \times N_e \sim \epsilon^4 \rightarrow \epsilon < 1.8 \times 10^{-8} \text{ @ 90\% C.L.}$$

$N_e$ : number of electron in fiducial mass (100 ton) of LS.

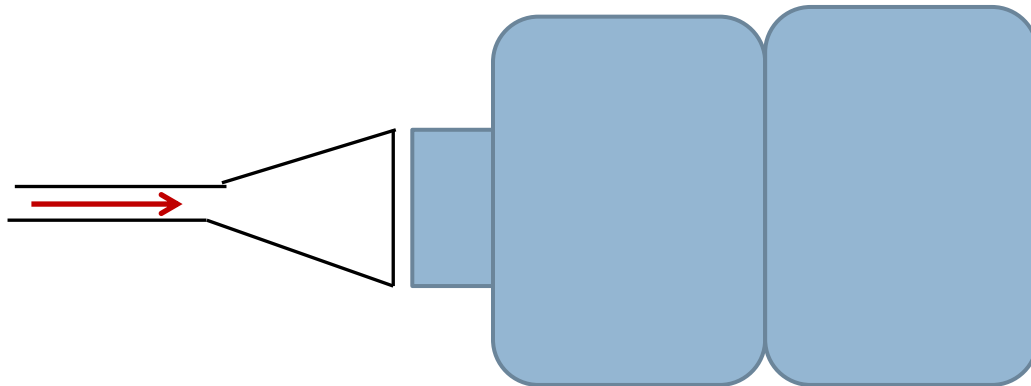


# Beam line consideration

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- e-beam size :  $< 1 \text{ mm}^2$
- Tungsten target:  $\sim 1 \text{ cm} \times 1 \text{ cm} \times 20 \text{ cm}$  long
- Beam shield with iron:  $1 \text{ m} \times 1 \text{ m} \times \sim 2 \text{ m}$
- Concrete:  $\sim 1 \text{ m}$  thick
- Beam window and target can be melted with 1 MW beam power:  
 $1 \text{ MW}/1 \text{ mm}^2$



- Defocusing e-beam on beam window and target:  $> 10 \text{ cm}^2$
- Target with cooling:  $10 \text{ cm} \times 10 \text{ cm} \times 20 \text{ cm}$   
-  $1 \text{ MW}/\text{mm}^2 \rightarrow 100 \text{ W}/\text{mm}^2$

# Summary

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- **High power electron accelerator near by large detector would provide an unique program for CUP in future.**
  - **Dark photon mass below 1 MeV is difficult region in over ground experiment.**
  - **Low mass dark matter search**
- **Before starting this experiment at underground, we need to check whole system at over ground**
  - **accelerator**
  - **target system**
  - **beam dump, background and radiation safety**