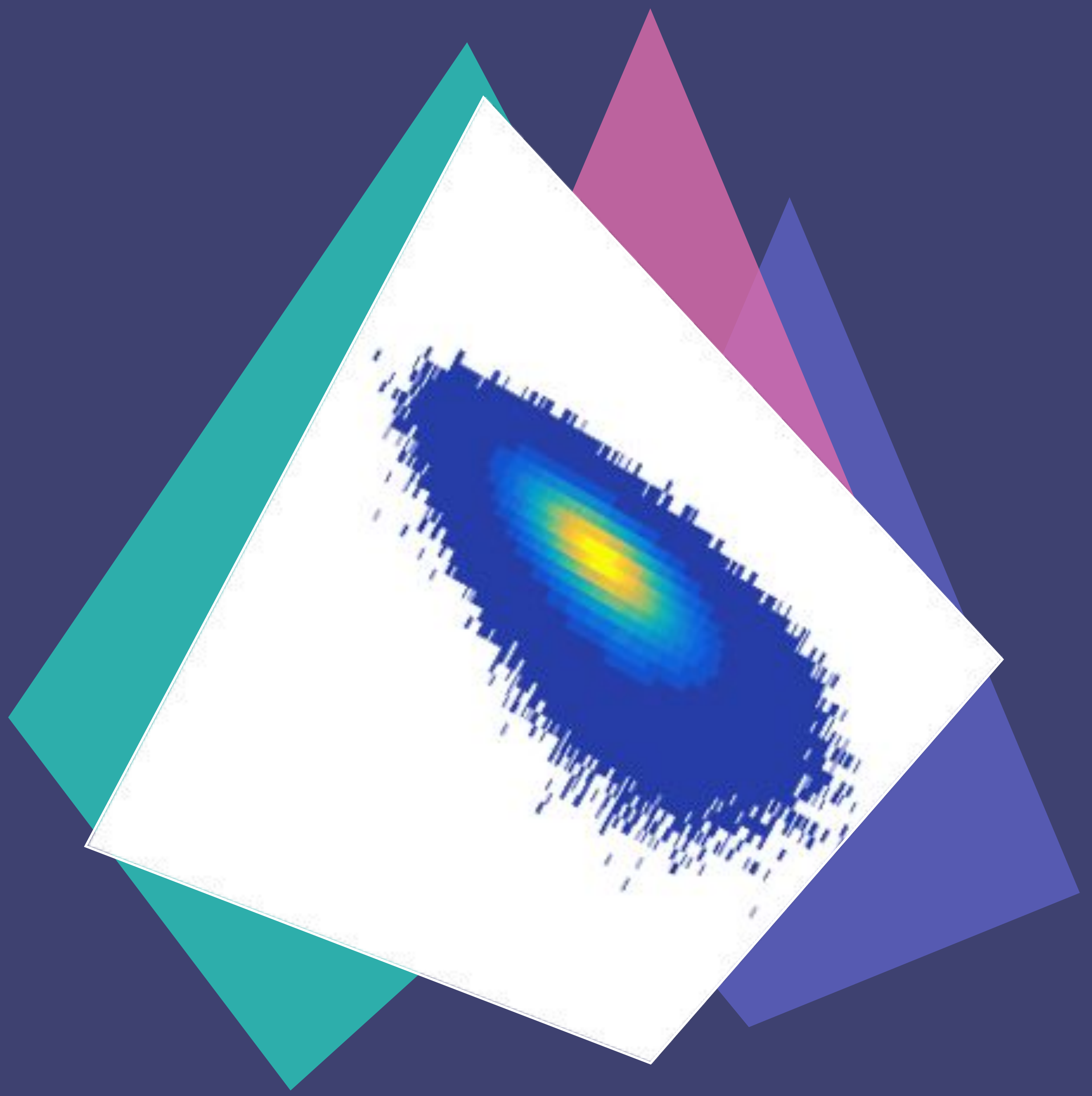

Hunt for Hidden Photons in the LZ Experiment

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Outline

01 LUX-Zeplin Experiment
- LZ Collaboration
- Detector Working Principle
- Projected Sensitivity for WIMP-Nucleon Scattering

02 Hidden Photons
- Hidden Photon Lagrangian and Kinetic Mixing
- Direct Detection: Hidden Photoelectric Effect
- Connection to ALP Searches

03 HP search in LZ
- Background Considerations
- Signal Models and Analyses
- Sensitivity Projection: Hidden Photons

04 Discussions

LZ Collaboration

38 institutions

250 scientists, engineers, and technicians

Collaboration Meeting @ SLAC, March 2017

LUX-ZEPLIN

- Dark Matter Direct Detection Experiment
- Detector Located at Sanford Underground Research Facility(SURF), South Dakota, USA

LZ Detector

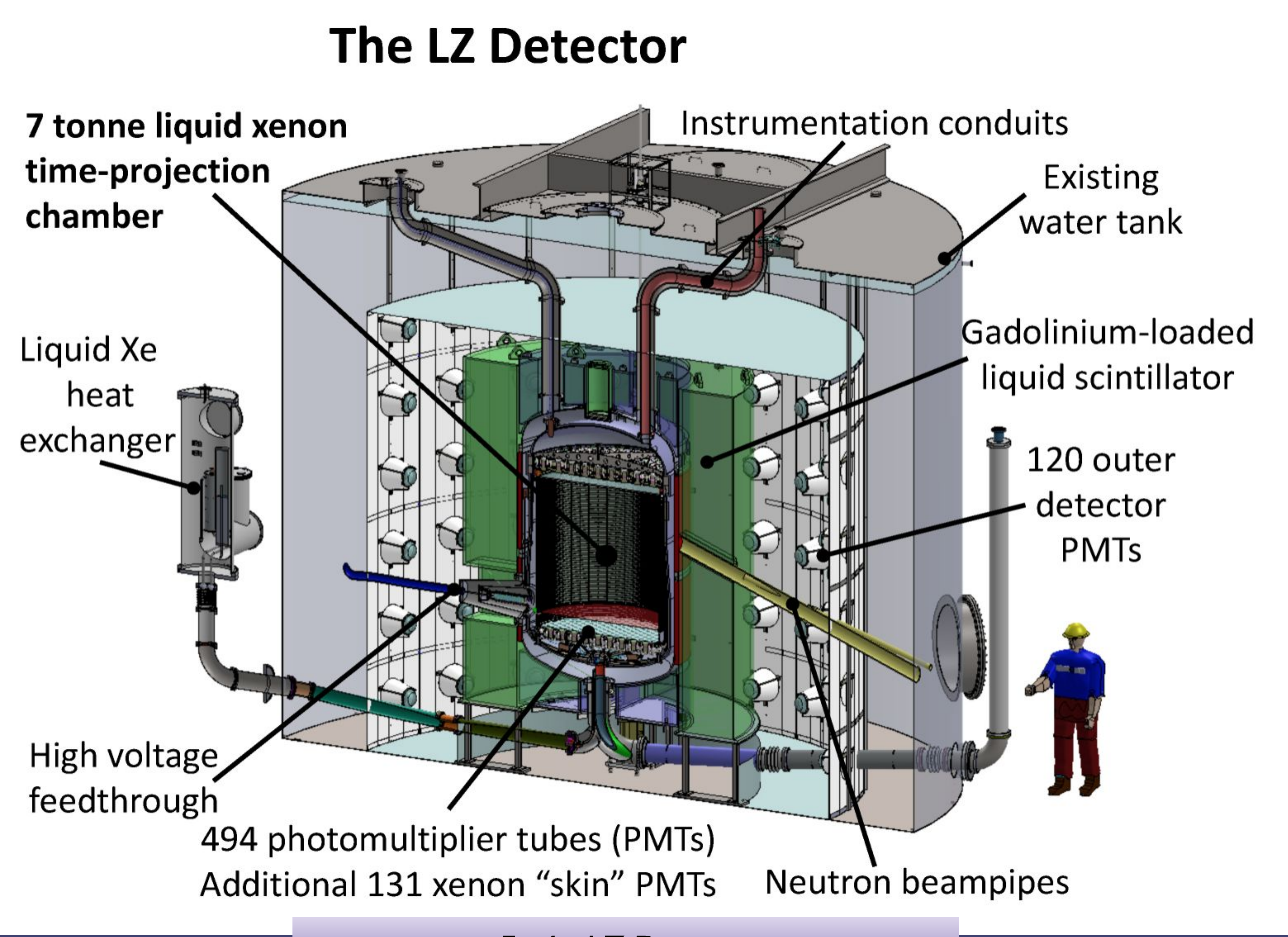

Fig.1 . LZ Detector

- liquid xenon Time Projection Chamber (LXe-TPC)
- 7 tonnes of LXe
- ~50x larger fiducial mass
- 494 PMTs
- (Additional veto) 131 xenon "skin" PMTs
- science run to start in 2020
- 1000 live days * 5.6 tonnes planned exposure

How the detector works

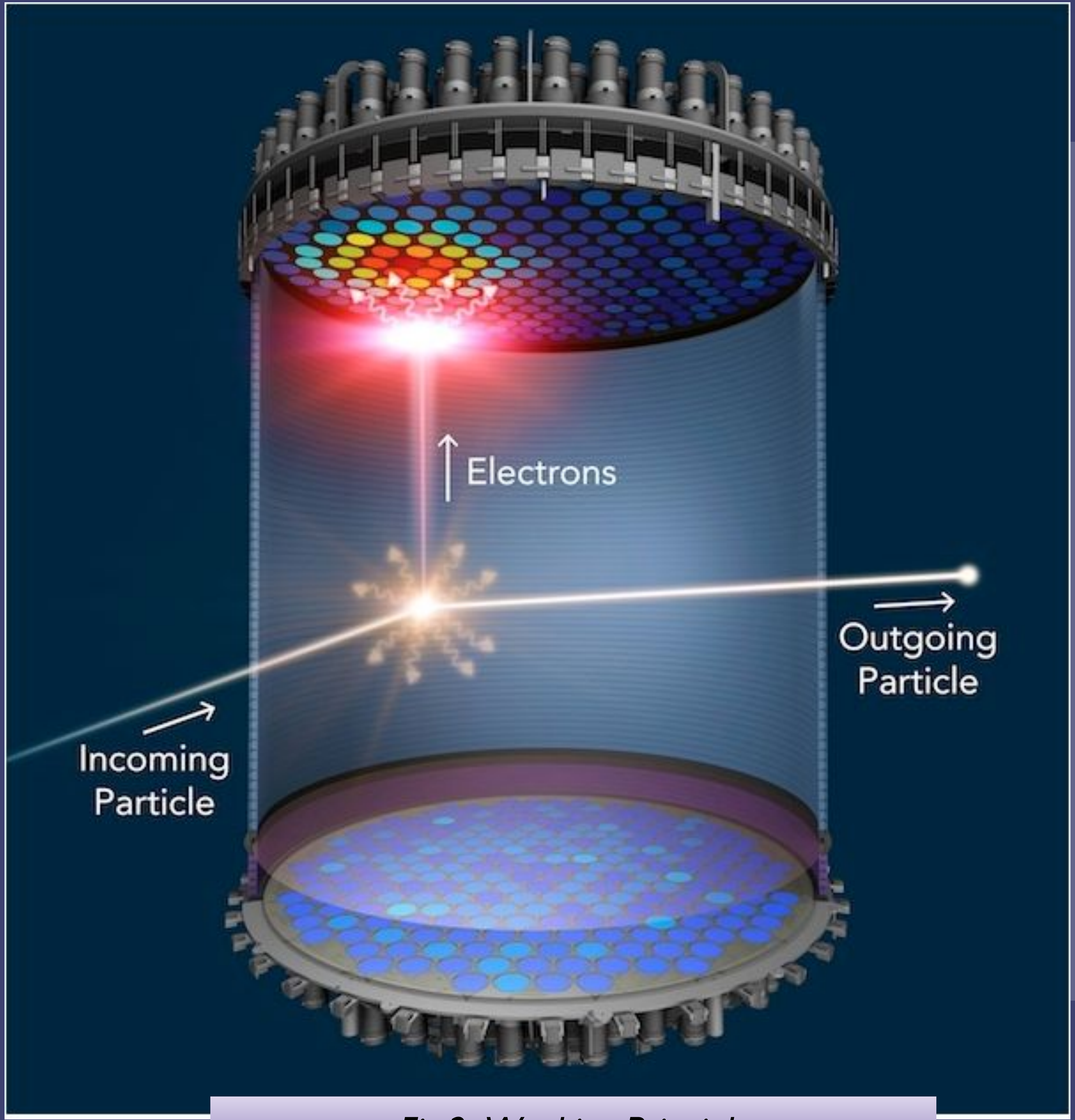

Fig.2 .Working Principle

- Signals due to particle interactions:
  - S1 : Primary Scintillation Signal (prompt photons, directly measured by PMTs)
  - S2: Secondary Ionisation Signal (from electroluminescence of electrons extracted in gaseous phase)
- Energy and Position Reconstruction by S1-S2 Signals

Projected Sensitivity: SI WIMP-nucleon elastic scattering

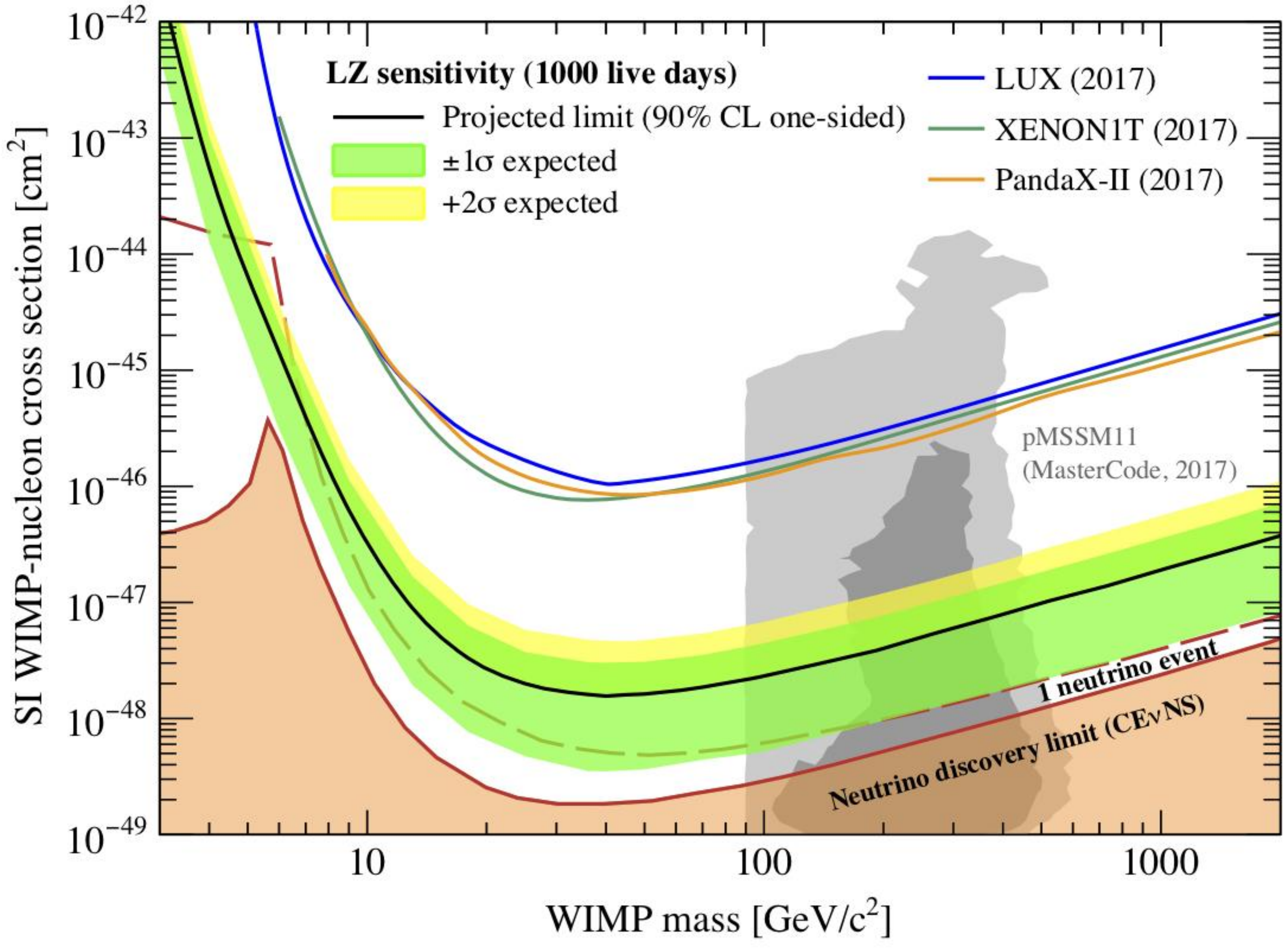

Fig.3 . LZ projected sensitivity to SI WIMP-nucleon elastic scattering for 1000~live days and a 5.6~tonne fiducial mass [9]

- Weakly Interacting Massive Particles (WIMPs): An well-motivated Dark Matter candidate
- What LZ mainly Looks For: WIMP- Nuclear Recoils
- for 1000~live days and a 5.6~tonne fiducial mass.
- The best sensitivity of 1.6 x 10^{-48} cm^2 is achieved at a WIMP mass of 40 GeV/c^2.
- The -2σ expected region is omitted based on the expectation that the limit will be power constrained [8]

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But….What if Dark Matter is not a WIMP?

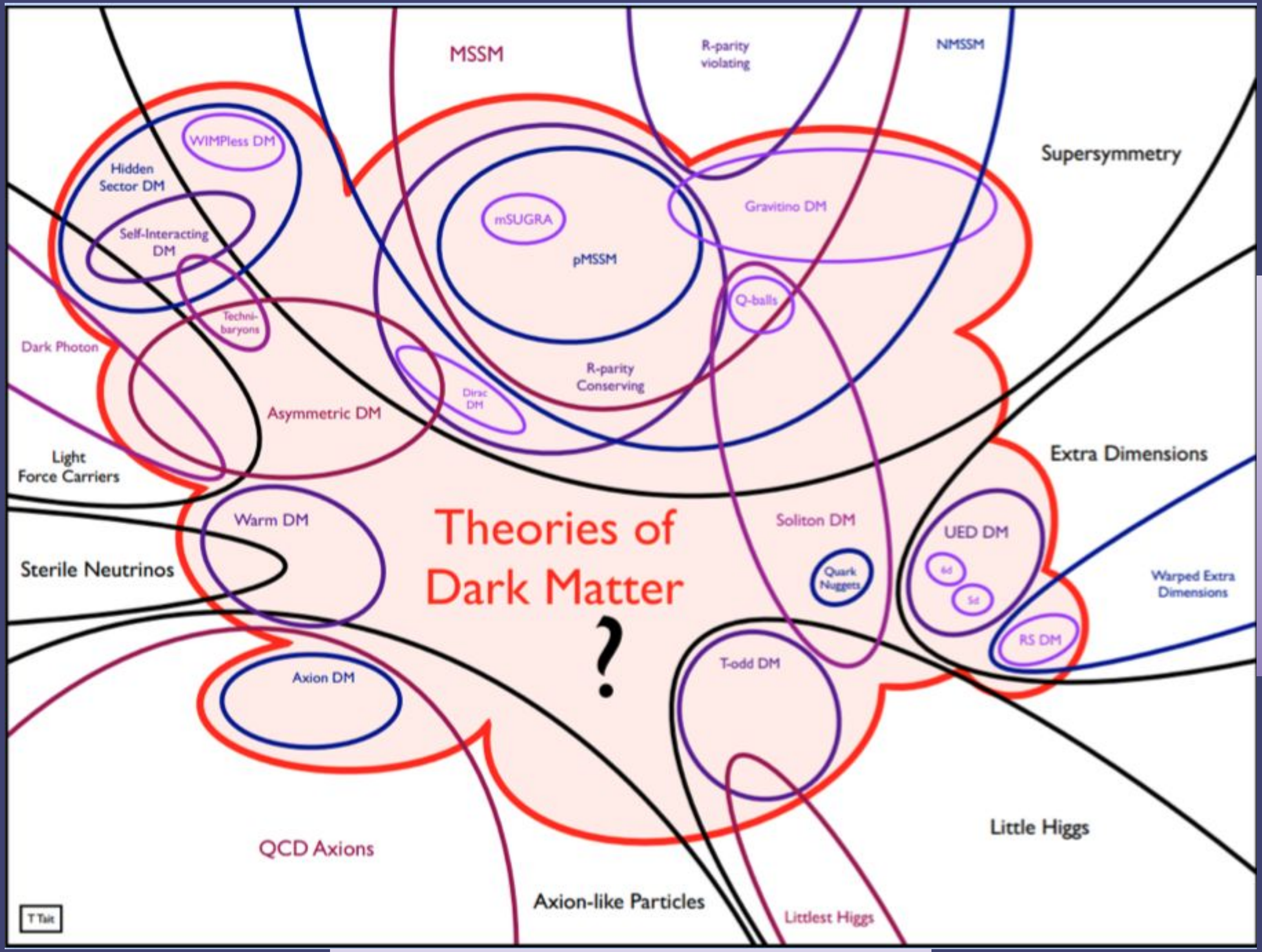

Fig.4. A Vast Possible Theories

- A vast possible scenario…..
- Hence a vast possible searches….

Standard Model

U(1) × **SU(2)** × **SU(3)**

Gauge group of EM interaction:
- *1 charge (e.g. electron)**
- *1 gauge boson (photon)*

Gauge group of Weak interaction:
- *2 charge types (2 weak isospin charges)*
- *3 Gauge bosons (W^+,W^-,Z)*

Gauge group of Strong interaction:
- *3 charge types (colour charges)*
- *8 gauge bosons (gluons)*

Is this structure that Obvious?
No!

Then….Can there be any additional gauge forces?

** positrons treated as electrons going back in time*

Hidden Photon Extension Motivated from Dark Matter

U(1) × ***SU(2)*** × ***SU(3)*** × ***U'(1)***

Simplest Case:
Only One Extra U(1) gauge group

Lagrangian

$$L = L_{SM} + L_{D} + L_{mediator}$$

- L_{SM}: SM Lagrangian
- L_{D}: Dynamics in the Hidden Sector
- $L_{mediator}$: Interaction between SM and hidden sector

- Dark Matter (DM) is secluded from SM
- extra ***U'(1)*** gauge boson as a mediator of SM-DM interactions: Hidden Photons
- Coupling through the mechanism of kinetic mixing
- Correct DM relic abundance can be obtained automatically (M. Pospelov et al. [6])
- Several Other models incorporating U(1) extensions do exist

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Kinetic Mixing and Structure Constants

- Tree level SM photon γ- hidden photon γ′ interaction is forbidden
- Simplest Case : by a loop of non-SM charged heavy particles, ψ′
- γ and γ′ couple to them with strengths e and g_D
- Properties of ψ′ particles :
  - they are charged; hence sensitive to EM interaction
  - have not been detected yet in experiments like LHC: mass scale should be above the weak scale
  - this mass scale constrains the coupling strength of γ′ to γ
  - At Lower Energies < Weak Scale: ψ′ can be integrated out.

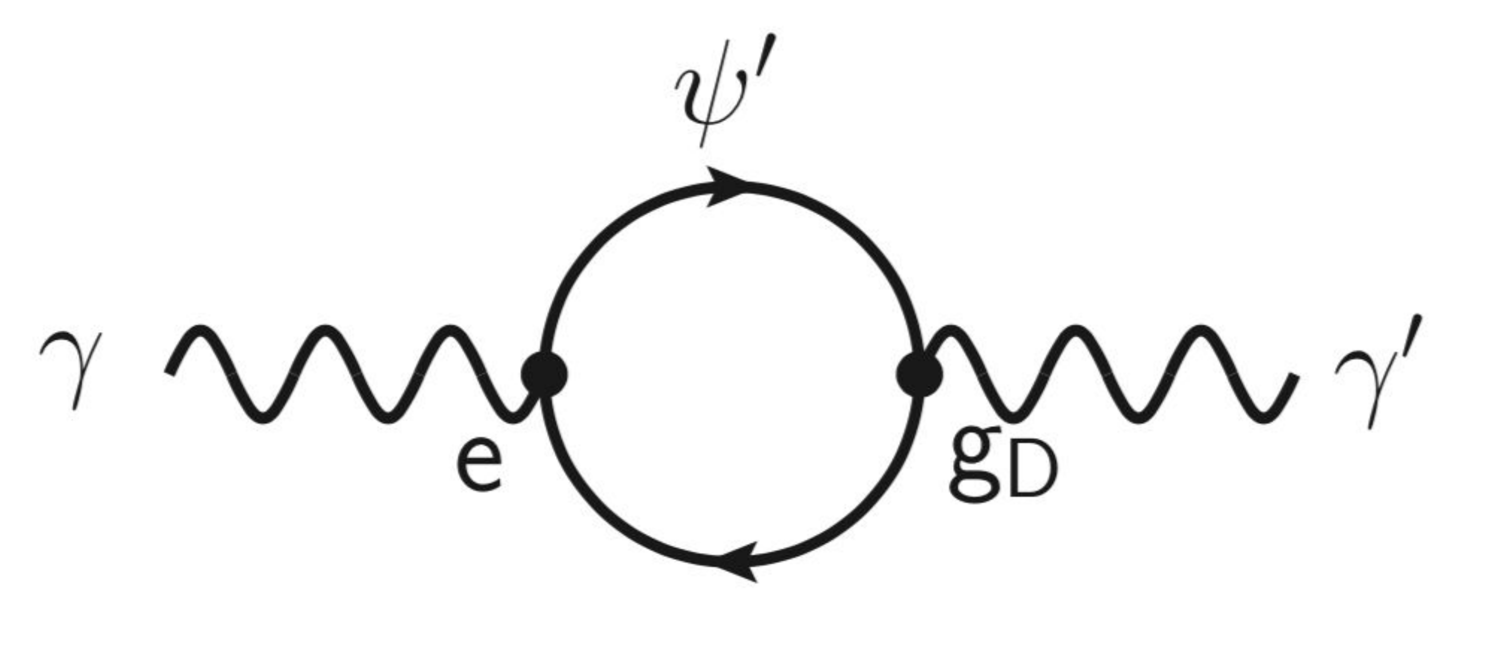

Fig.5. Feynman diagram of kinetic mixing

Below Electroweak Scale

$$L_{mediator} = \varepsilon e\, j_A^{\mu} A'_{\mu}$$

kinetic mixing factor

EM Current

hidden photon field

Electromagnetic Fine Structure Constant $\alpha = \frac{e^2}{4\pi}$

Hidden Fine Structure Constant $\alpha' = \frac{g_D^2}{4\pi}$

kinetic mixing factor

$\varepsilon = (\alpha'/\alpha)^{1/2} = g_D/e$

Hidden Photon Lagrangian: Minimal Model

- single new broken U(1) gauge symmetry and
- kinetic mixing between the corresponding dark photon field A'

$$\mathcal{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m^2_{A'}A'^{\mu}A'_{\mu} + \epsilon e A'^{\mu}J^{EM}_{\mu}$$

$F'_{\mu\nu}$ dark photon field

$m_{A'}$ dark photon mass, generated by the Higgs or Stueckelberg mechanism

J^{EM}_{μ} EM current with coupling e

ϵ Kinetic Mixing Factor

- models with unbroken U(1) gauge symmetry result in a massless dark photon carrying a long-range interaction.
- A massless dark photon, however, will experimentally be hard to distinguish from the Standard Model photon.

Direct Detection: Hidden Photoelectric Effect

- Analogous to the photoelectric effect in SM
- Line Spectra

$$\frac{\sigma_{abs} v}{\sigma_{pe}(\omega = m_{HP})c} = \frac{\alpha'}{\alpha}$$

 v is the velocity of the HP

σ_{abs} = cross-section of the absorption for HP

σ_{pe}= cross- section of the photoelectric effect

Event Rate:(in LXe)

$$R_{HP}[1/\text{kg}/\text{day}] = \frac{4 \times 10^{23}}{A} \frac{\alpha'}{\alpha} \frac{\sigma_{pe}[\text{barn}]}{m_{HP}[\text{keV}]}$$

A = 131.3 is an atomic mass of xenon of natural composition

(Assuming a dark matter density of 0.3 GeV/cm^{3})

Connection to Axion Like Particle (ALP) Searches

Hidden Photoelectric Effect for HPs

$$R_{HP}[1/\text{kg/day}] = \frac{4 \times 10^{23}}{A} \frac{\alpha'}{\alpha} \frac{\sigma_{pe}[\text{barn}]}{m_{HP}[\text{keV}]}$$

Axio-electric effect for ALPs

$$R_{ALP}[1/\text{kg/day}] = \frac{1.2 \times 10^{19}}{A} g_{Ae}^2 \sigma_{pe}[\text{barn}] \cdot m_{ALP}[\text{keV}]$$

$$R_{HP}/R_{ALP} = 3.3 \times 10^4 \times (\alpha'/\alpha) \times (g_{Ae})^{-2} \times (1/m_{HP}\, m_{ALP})$$

Once we have a constraint on (α′/ α) for HP

we can convert that to a constraint on g_{Ae} for ALPs

Background Model

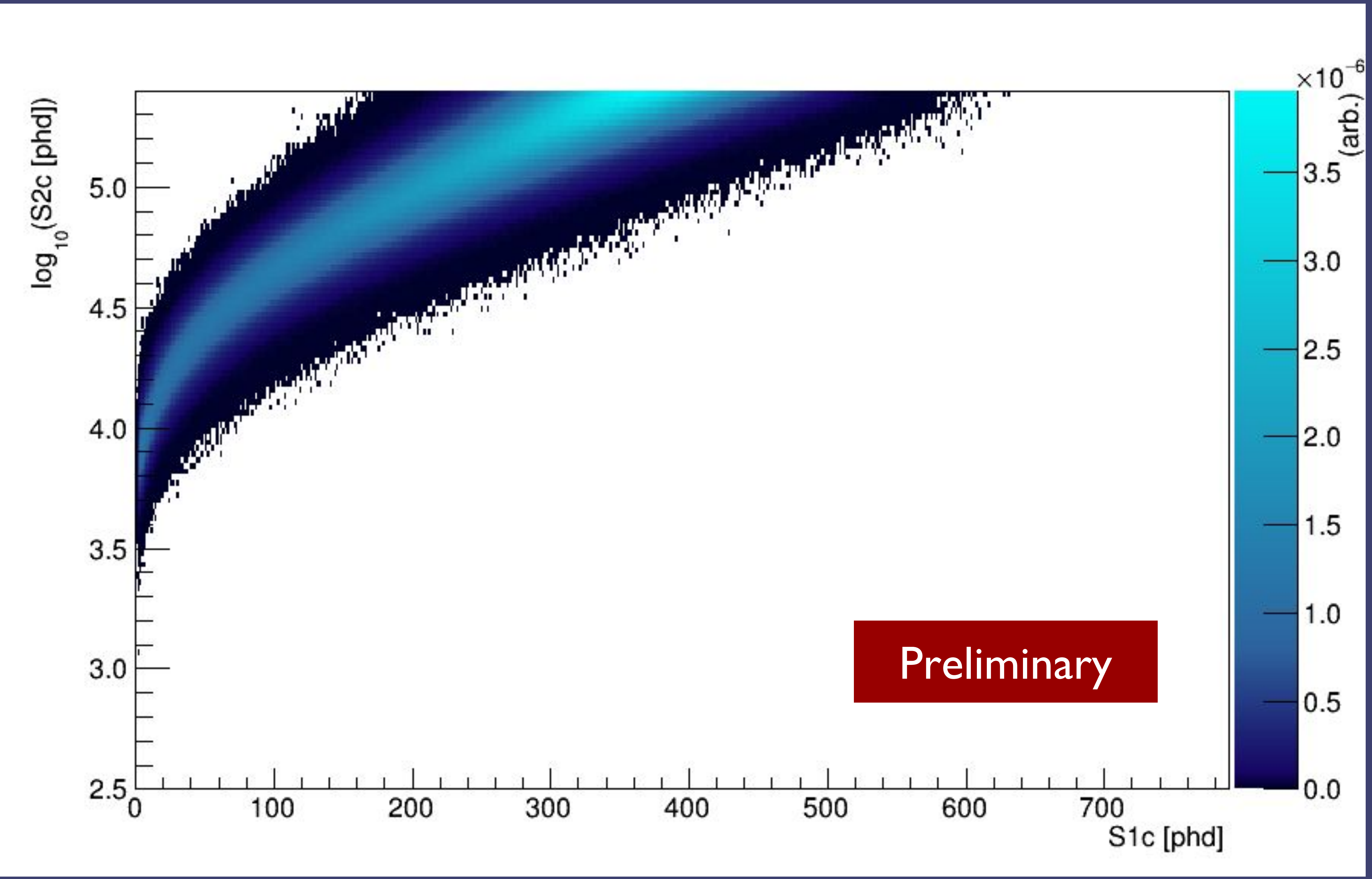

Fig.6. ER Background Model

- Vast Majority of of Backgrounds in ER band
- This Analysis: Used the same Background Models as in WIMP search
- ER Background Model upto 100 keV

Table 1. ER Background Components

Background	Components
ER	Solar pp+Be7 Neutrinos
	Xe136 2vBB Decay
	Kr85
	Rn-222
	Rn-220
	Detector ERs

Signal Model

- Investigated Hidden Photon Masses from 2 keV to 85 keV
- Theoretical event rates calculated according to Slide 13
- Signal Models generated using NEST (Nobel Element Simulation Technique)

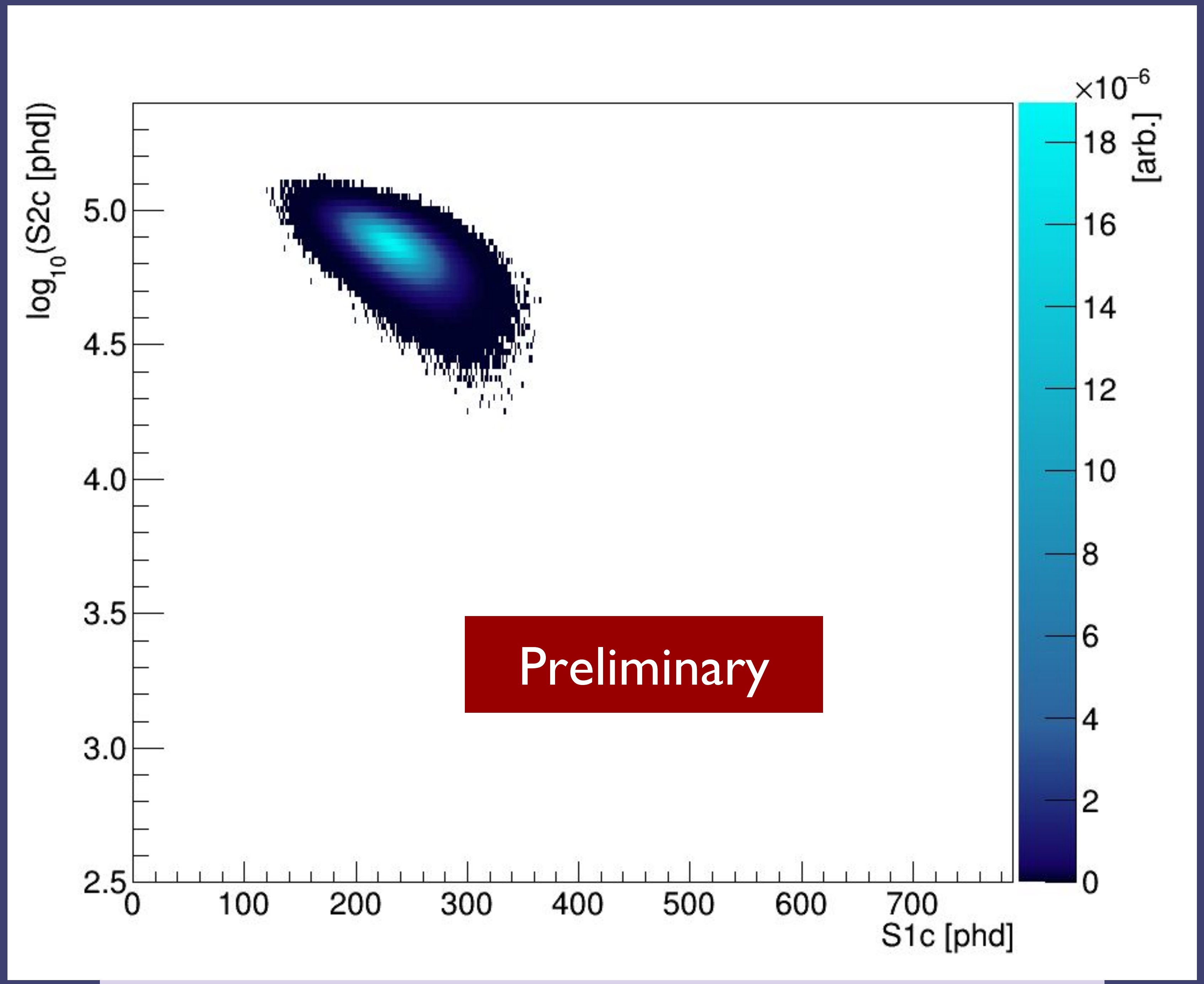

Fig.7. Hidden Photon Signal Model (40 keV)

Energy Reconstruction

$$E_R = W \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right)$$

For Projected Detector:

***g_1=0.118735** phd/photon,*

***g_2=79.2291** phd/electron*

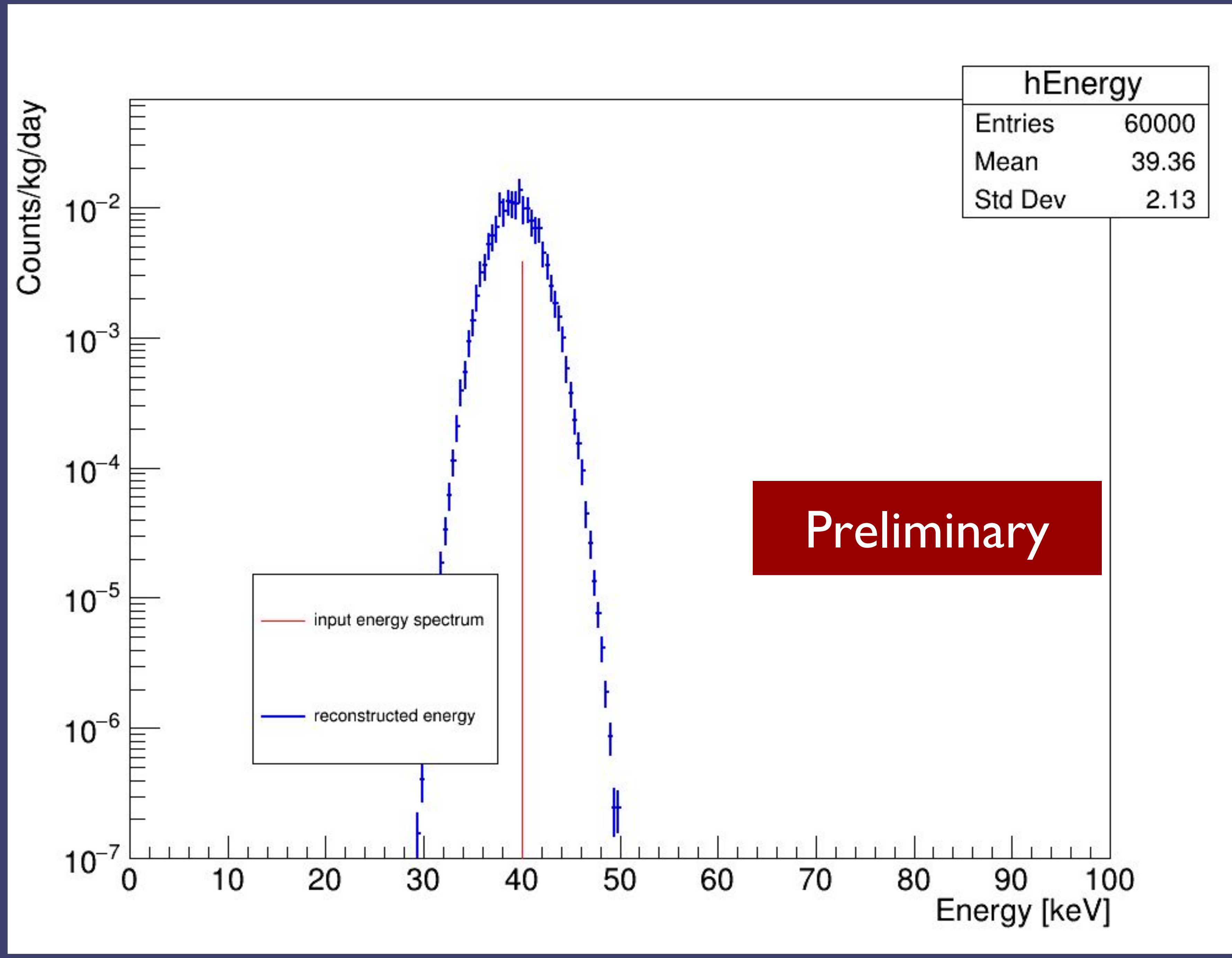

Fig.8. Reconstructed Energy

LZ Projected Sensitivity for Hidden Photo-electric Effect

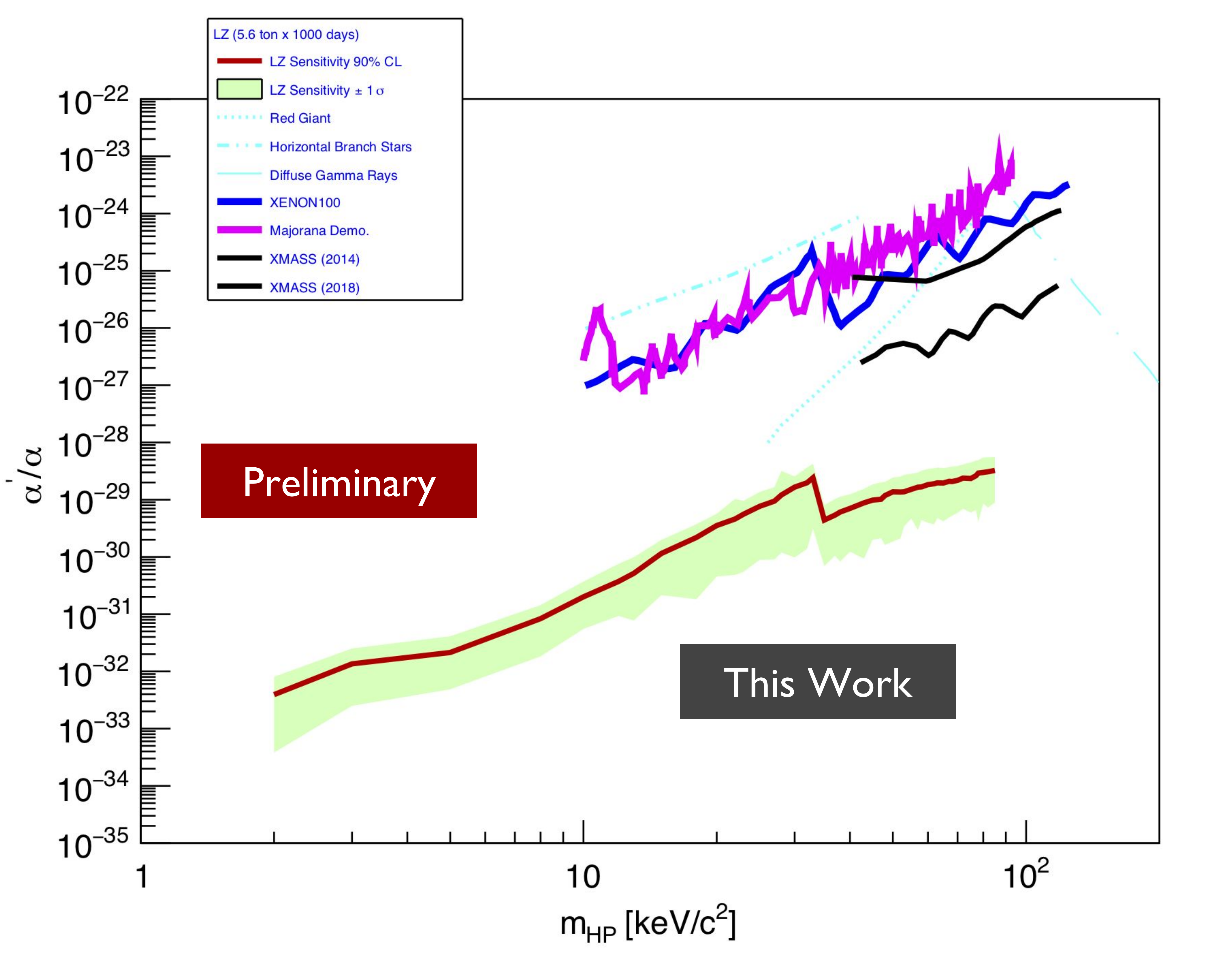

Fig.9. Sensitivity Projection

Sensitivity Estimation: Hidden Photons

- Statistical Analysis: Profile Likelihood Ratio (PLR) Method
- Hidden Photon Mass (This Work) 2-85 keV
- Experimental limits taken from XMASS 2018 paper [3]

Discussions

- Hidden Photon Sensitivity: we expect more than ~2 order of magnitude improved sensitivity for (α'/α)
- Scaling to ALP sensitivity: Work in progress

Questions?

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Backup Slides

Searches For Hidden Photons in LZ

- ***Background Models:***
  - Used Same Background Models as in WIMP search (ER Background Upto 100 keV)
- ***Signal Models:***
  - Investigated Hidden Photon Masses from 2 keV to 85 keV
  - Theoretical event rates calculated according to *Slide 13*
  - Signal Models generated using NEST (Nobel Element Simulation Technique)
- ***Sensitivity Estimation: Hidden Photons***
  - Profile Likelihood Ratio (PLR) Method