Detecting Dark Matter with DarkSide-50

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quarks leptons

u	c	t
d	s	b

e	μ	τ
ν_e	ν_μ	ν_τ

g	Z	W^+	W^-	γ	H

bosons

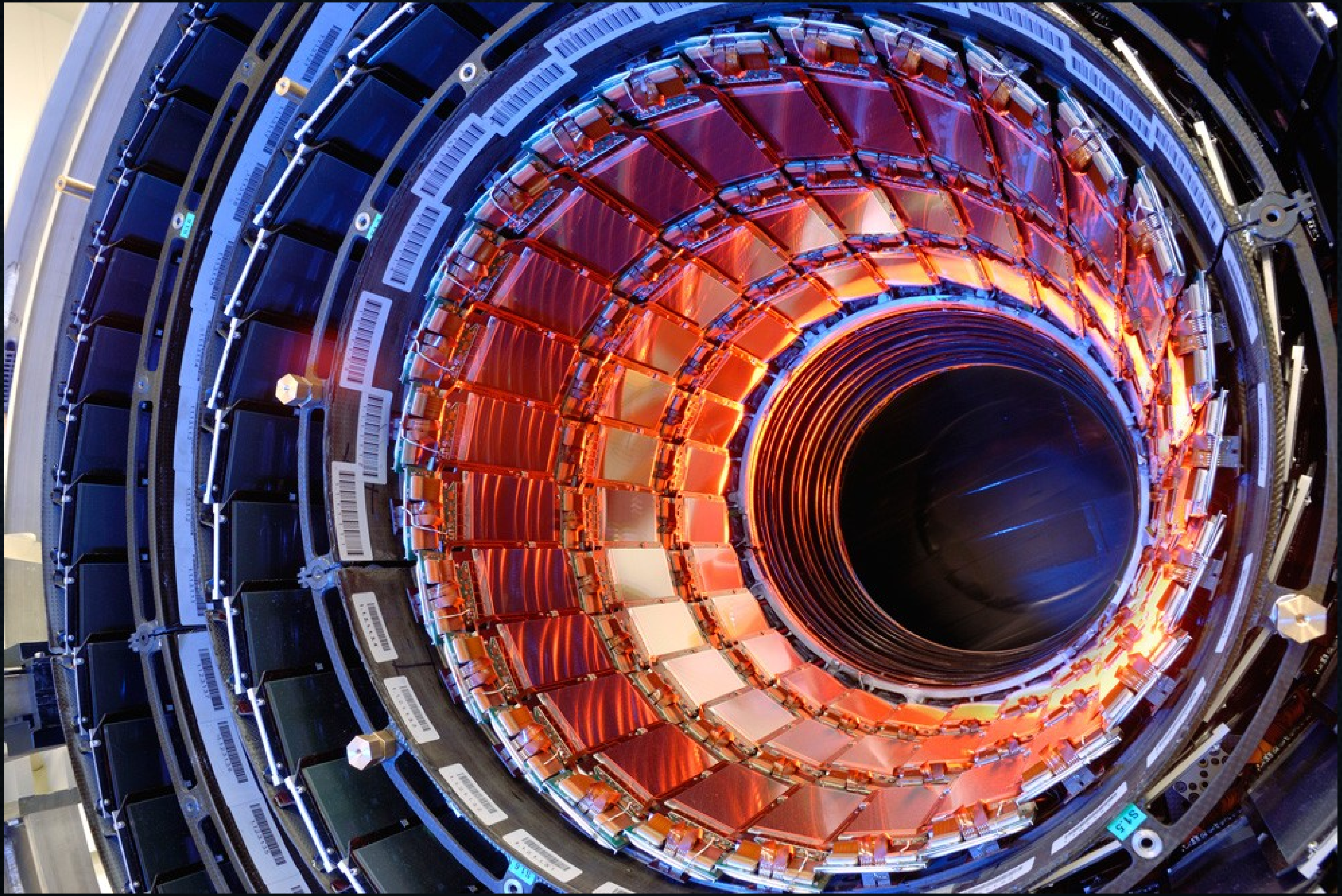
$$
\begin{aligned}
&\mathcal{L}_{SM} = \\
&-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \\
&\frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \\
&\frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + \\
&g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
&M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \\
&\frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \\
&\frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \\
&M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
&\frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h[\frac{2M^2}{g^2} + \frac{2M}{g} H + \\
&\frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - \\
&igc_w[\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - \\
&Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + \\
&Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \\
&igs_w[\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - \\
&A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + \\
&A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \\
&\frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \\
&\frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + \\
&g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + \\
&g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - \\
&A_\mu A_\mu W^+_\nu W^-_\nu) + \\
&g^2 s_w c_w [A_\mu Z^0_\nu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - \\
&2 A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + \\
&2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + \\
&4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- +
\end{aligned}
$$

$$
\begin{aligned}
&2(\phi^0)^2 H^2] - gMW^+_\mu W^-_\mu H - \\
&\frac{1}{2}g\frac{M}{c_w^2} Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0 \partial_\mu \phi^- - \\
&\phi^- \partial_\mu \phi^0) - W^-_\mu(\phi^0 \partial_\mu \phi^+ - \\
&\phi^+ \partial_\mu \phi^0)] + \frac{1}{2}g[W^+_\mu(H \partial_\mu \phi^- - \\
&\phi^- \partial_\mu H) - W^-_\mu(H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)] + \\
&\frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - \\
&ig\frac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) + \\
&igs_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) - \\
&ig\frac{1-2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
&igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \\
&\frac{1}{4}g^2 W^+_\mu W^-_\mu [H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \\
&\frac{1}{4}g^2 \frac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 + 2(2s_w^2 - \\
&1)^2 \phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + \\
&W^-_\mu \phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- - \\
&W^-_\mu \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + \\
&W^-_\mu \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W^+_\mu \phi^- - \\
&W^-_\mu \phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1) Z^0_\mu A_\mu \phi^+ \phi^- - \\
&g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \\
&\bar{\nu}^\lambda \gamma\partial \nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + \\
&m_d^\lambda)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \\
&\frac{2}{3}(\bar{u}^\lambda_j \gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j \gamma^\mu d^\lambda_j)] + \\
&\frac{ig}{4c_w} Z^0_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - \\
&1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \\
&\gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \\
&\frac{ig}{2\sqrt{2}} W^+_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5)e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (1 +
\end{aligned}
$$

$$
\begin{aligned}
&\gamma^5)C_{\lambda\kappa} d^\kappa_j)] + \frac{ig}{2\sqrt{2}} W^-_\mu [(\bar{e}^\lambda \gamma^\mu (1 + \\
&\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa} \gamma^\mu (1+\gamma^5)u^\lambda_j)] + \\
&\frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \\
&\phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + \\
&i\phi^0(\bar{e}^\lambda \gamma^5 e^\lambda)] + \\
&\frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + \\
&m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \\
&\frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - \\
&m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
&\frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j \gamma^5 u^\lambda_j) - \\
&\frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j \gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \\
&\bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \\
&\bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu \bar{X}^0 X^- - \\
&\partial_\mu \bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu \bar{Y} X^- - \\
&\partial_\mu \bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu \bar{X}^- X^0 - \\
&\partial_\mu \bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu \bar{X}^- Y - \\
&\partial_\mu \bar{Y} X^+) + igc_w Z^0_\mu(\partial_\mu \bar{X}^+ X^+ - \\
&\partial_\mu \bar{X}^- X^-) + igs_w A_\mu(\partial_\mu \bar{X}^+ X^+ - \\
&\partial_\mu \bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \\
&\bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] + \\
&\frac{1-2c_w^2}{2c_w} igM[\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \\
&\frac{1}{2c_w} igM[\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
&igMs_w[\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
&\frac{1}{2}igM[\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
\end{aligned}
$$

From http://nuclear.ucdavis.edu/~tgutierr/files/stmL1.html

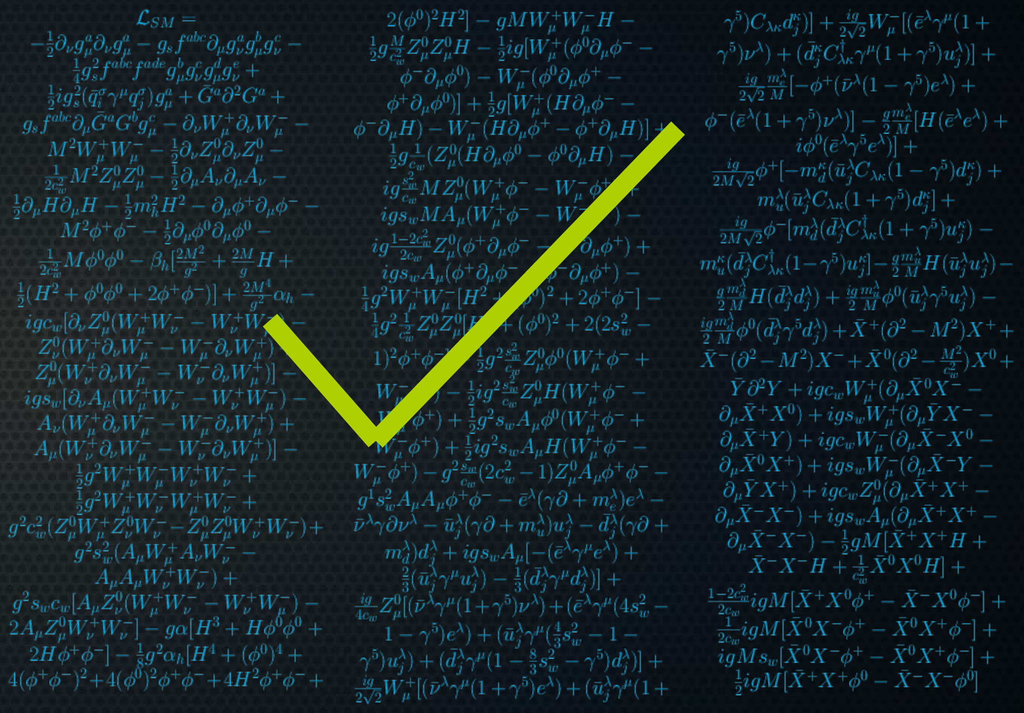
Heavily Tested



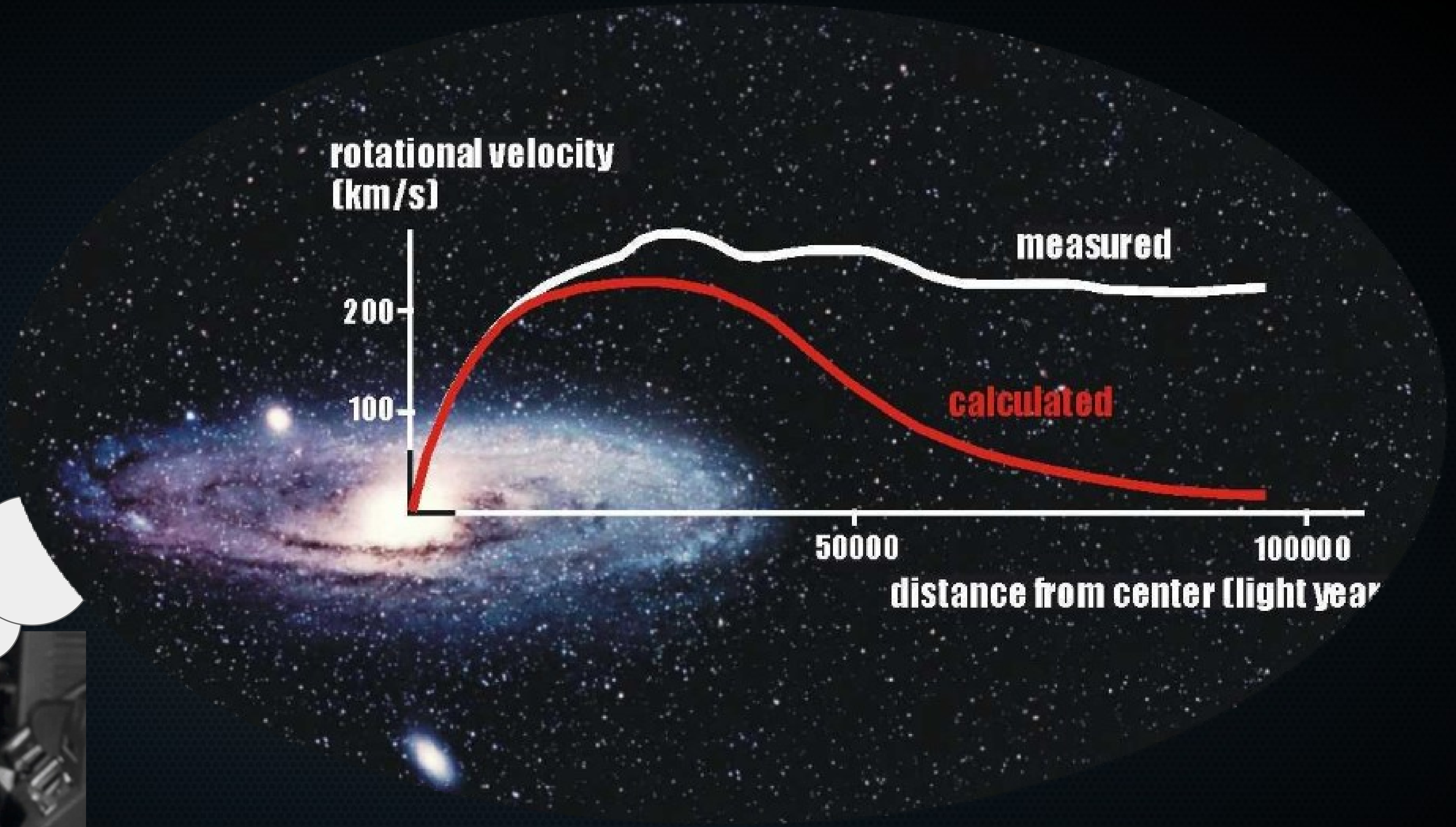
http://inapcache.boston.com/universal/site_graphics/blogs/bigpicture/lhc_11_20/l11_00000001.jpg

And many others...

And it checks out!

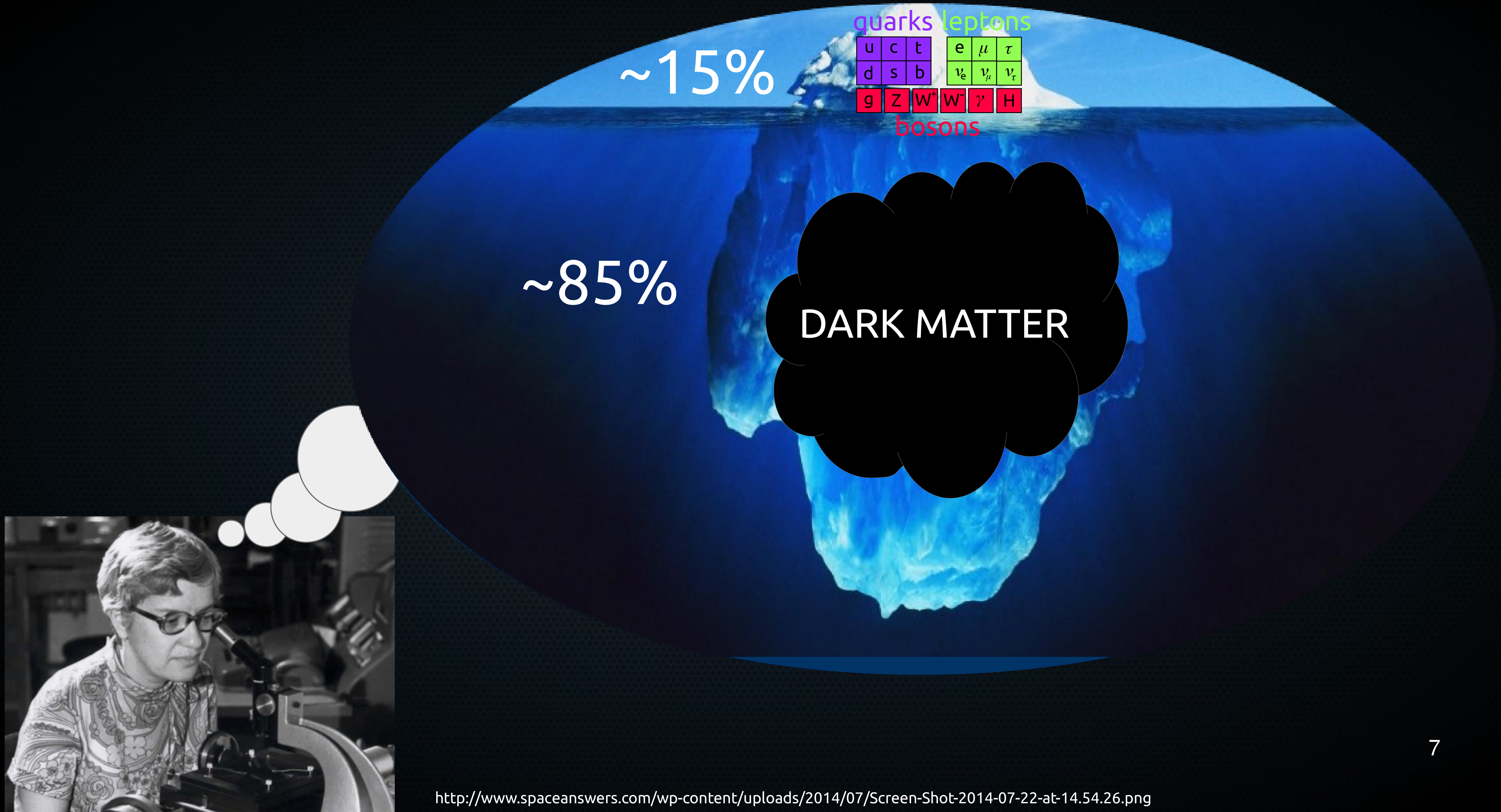


kind of...



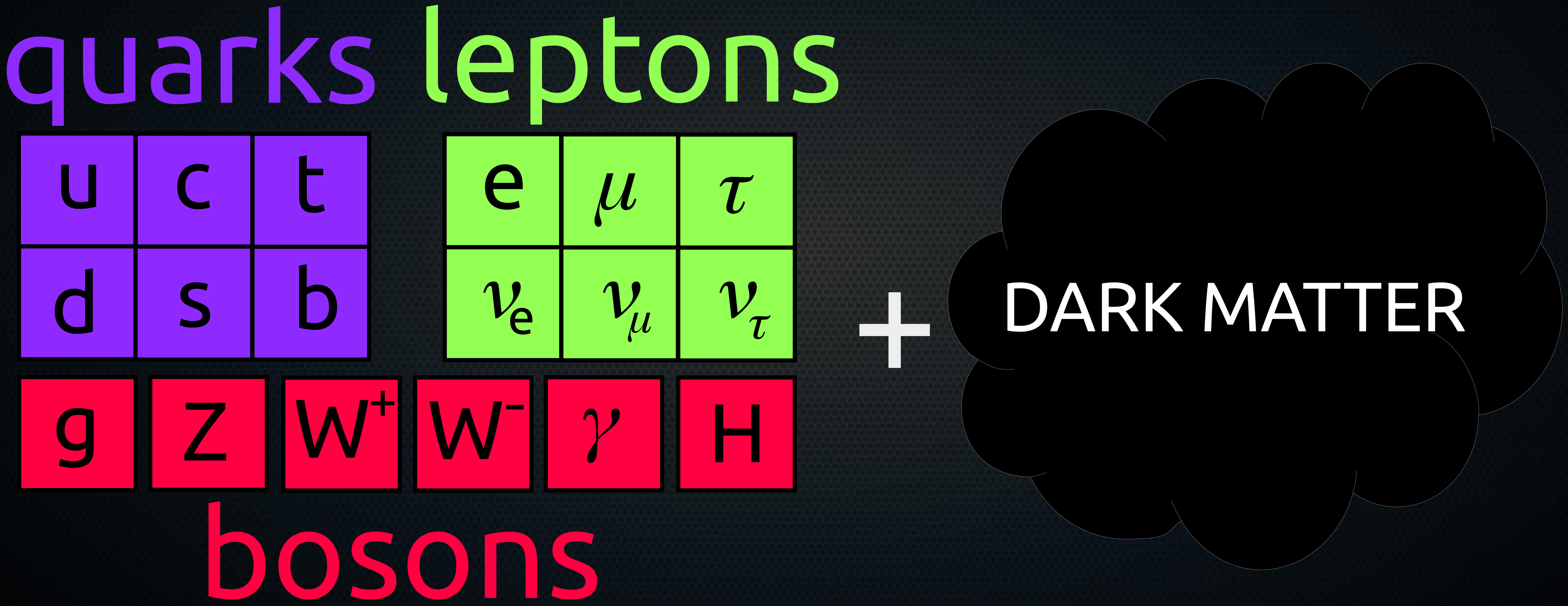
cdms.phy.queensu.ca/Public_Docs/Pictures/Rotationcurve_3.jpg

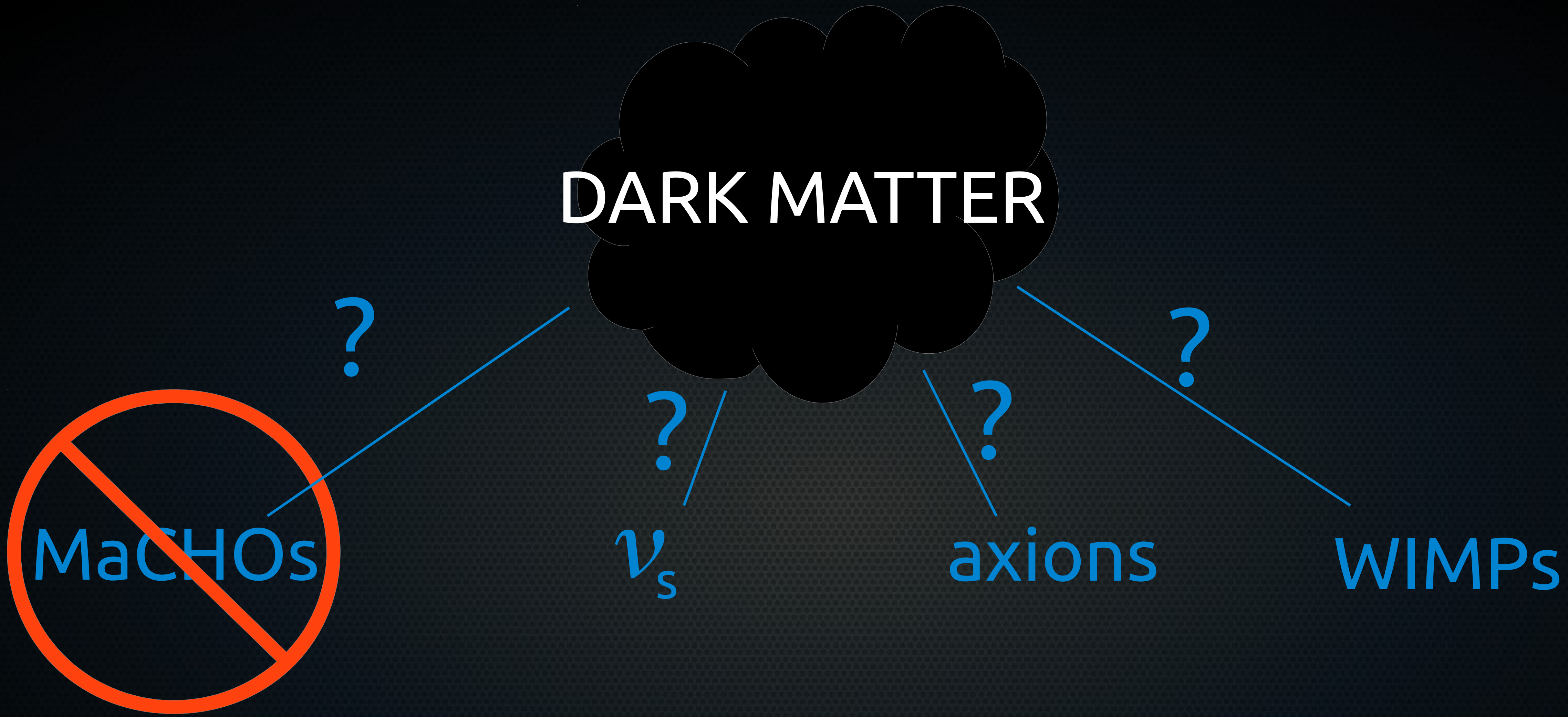
http://www.spaceanswers.com/wp-content/uploads/2014/07/Screen-Shot-2014-07-22-at-14.54.26.png



http://www.spaceanswers.com/wp-content/uploads/2014/07/Screen-Shot-2014-07-22-at-14.54.26.png

...and the evidence piled up...



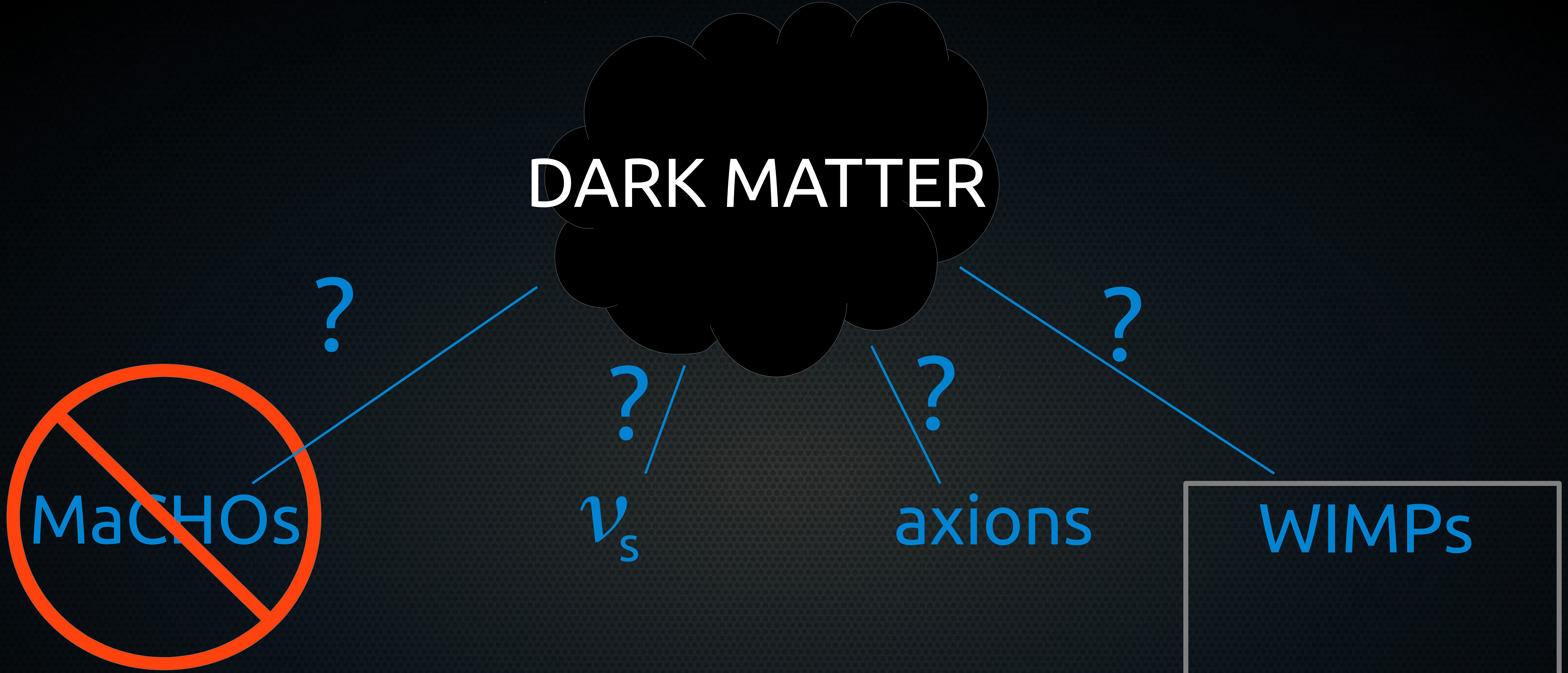


- Massive Compact Halo Objects
- Microlensing measurements
- CMB Measurements

- Cold sterile neutrinos

- Predicted by Peccei-Quinn theory
- May solve the Strong CP problem

- Weakly Interacting Massive Particles
- Predicted by SUSY, Kaluza-Klein, …



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WIMPs: Thermal Relics

Cosmological requirements:

- $\langle \sigma v \rangle \sim 10^{-26}\ cm^3/s$
- Mass ~ 100 GeV/c^2

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} Weak interaction scale

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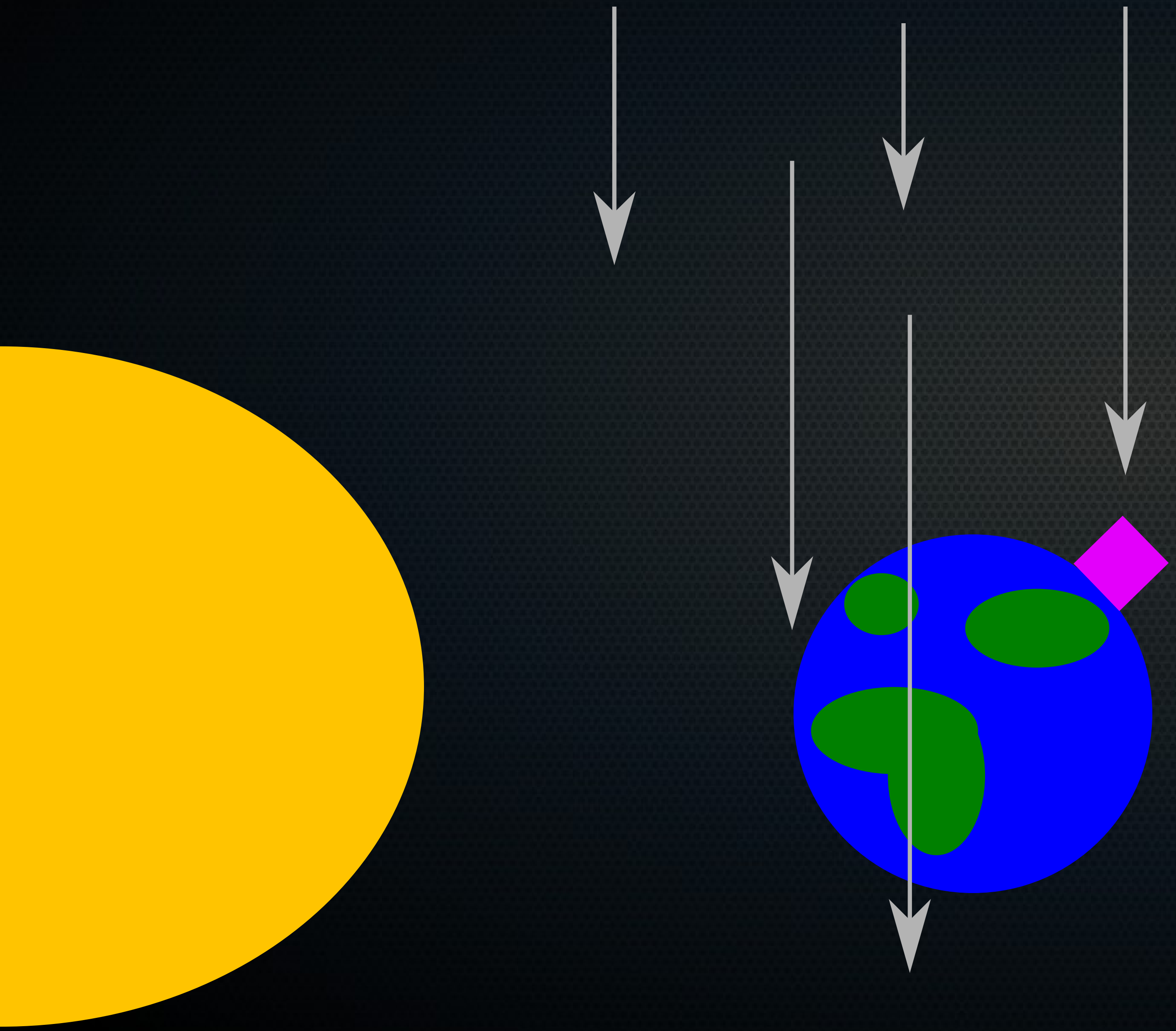
Cosmological requirements:

- $\langle \sigma v \rangle \sim 10^{-26}\ cm^3/s$
- Mass ~ 100 GeV/c^2

Weak interaction scale

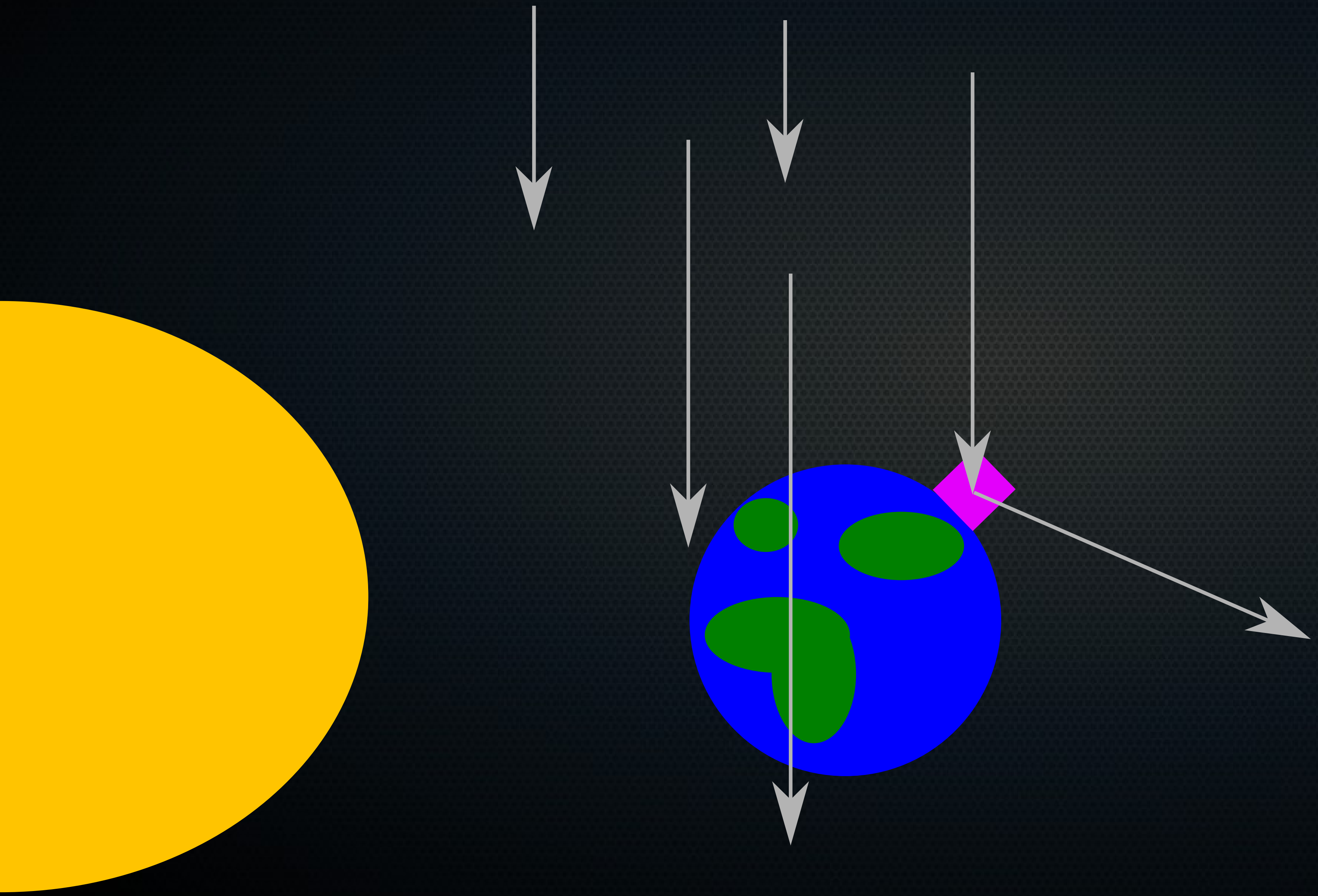
Interactions with non-WIMPs will be very rare

WIMP Detection



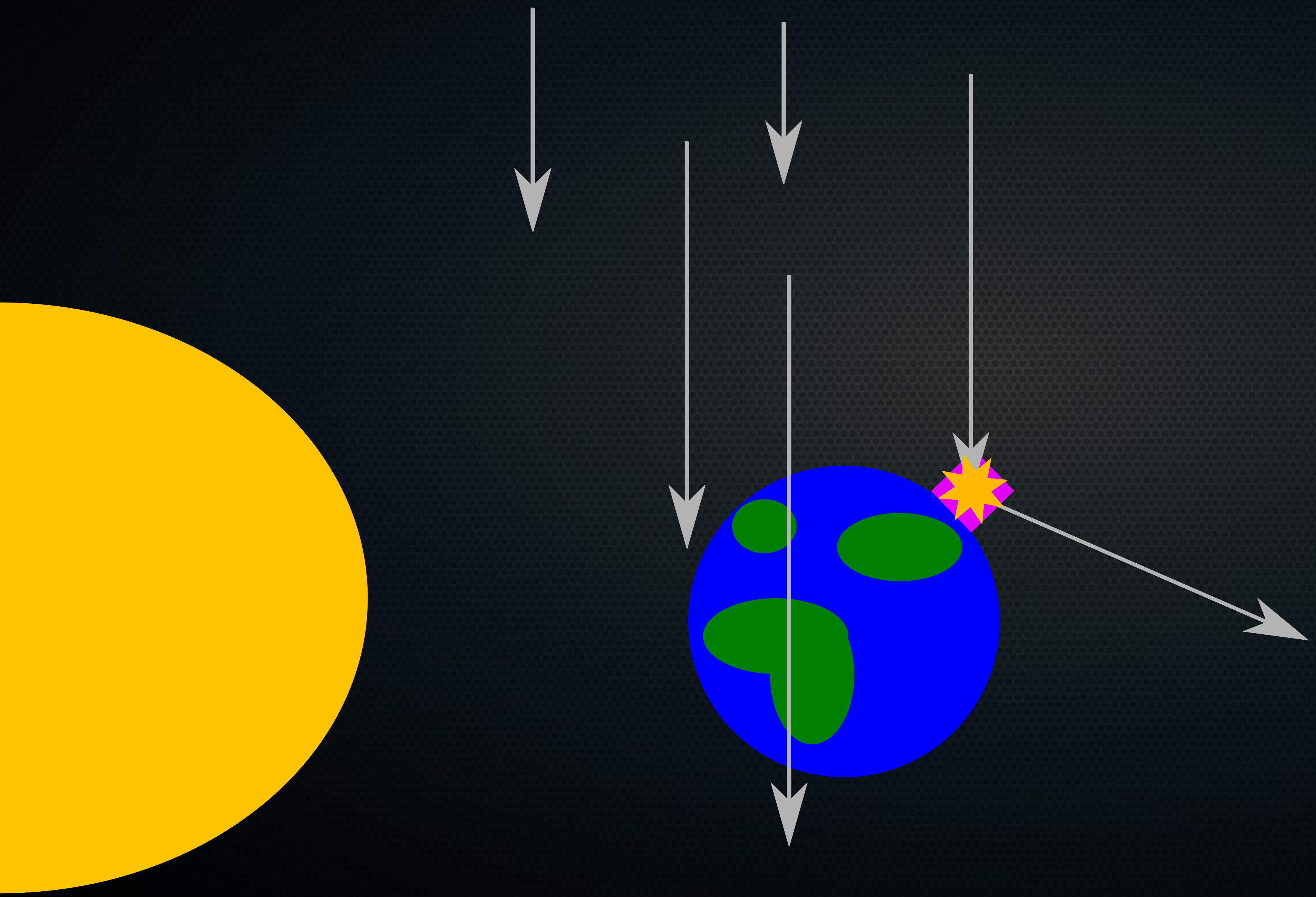
- Earth moves through WIMP wind

WIMP Detection



- Earth moves through WIMP wind
- WIMP scatters in detector

WIMP Detection



- Earth moves through WIMP wind
- WIMP scatters in detector
- Detector produces a signal

The DarkSide-50 Detector

DarkSide-50

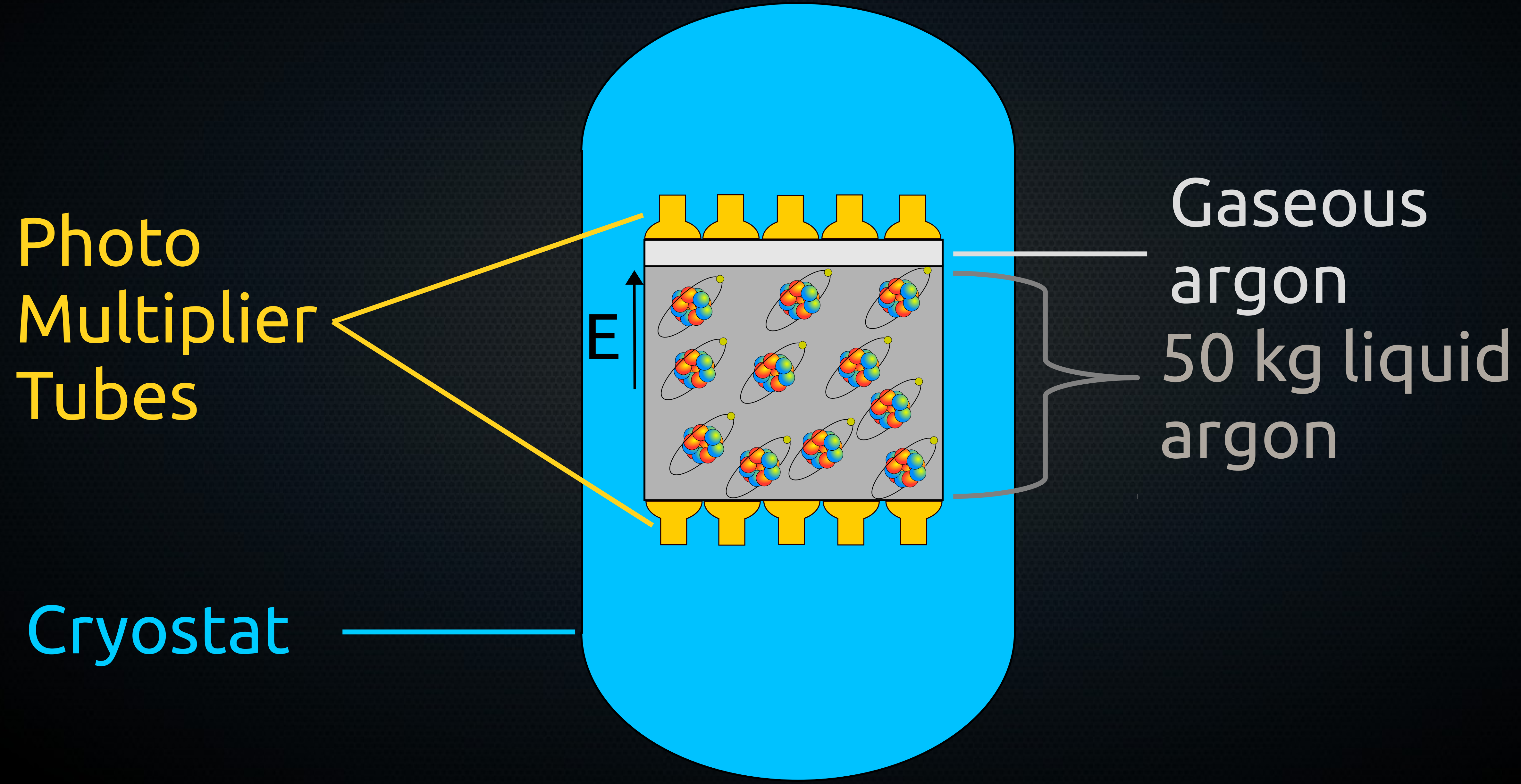
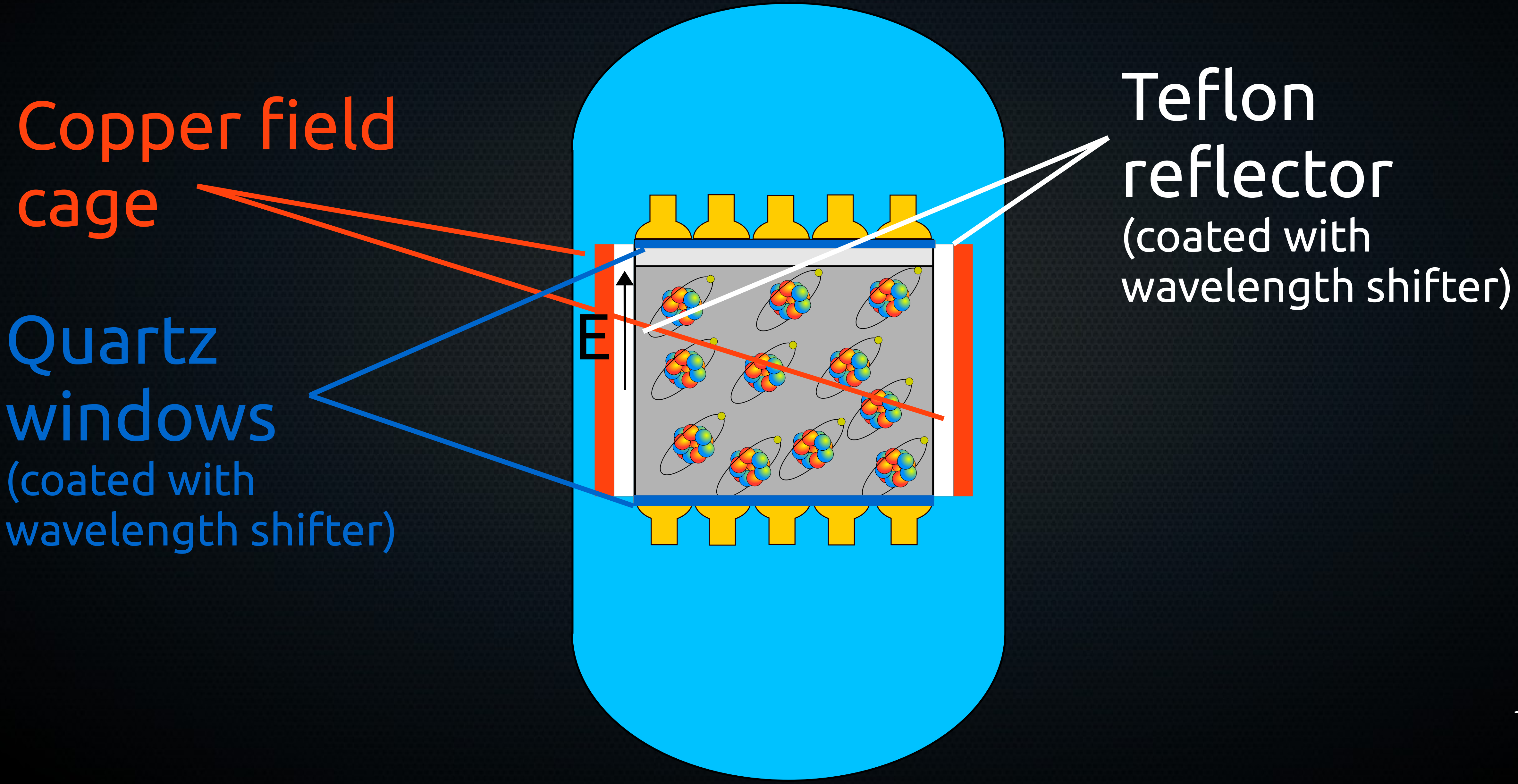


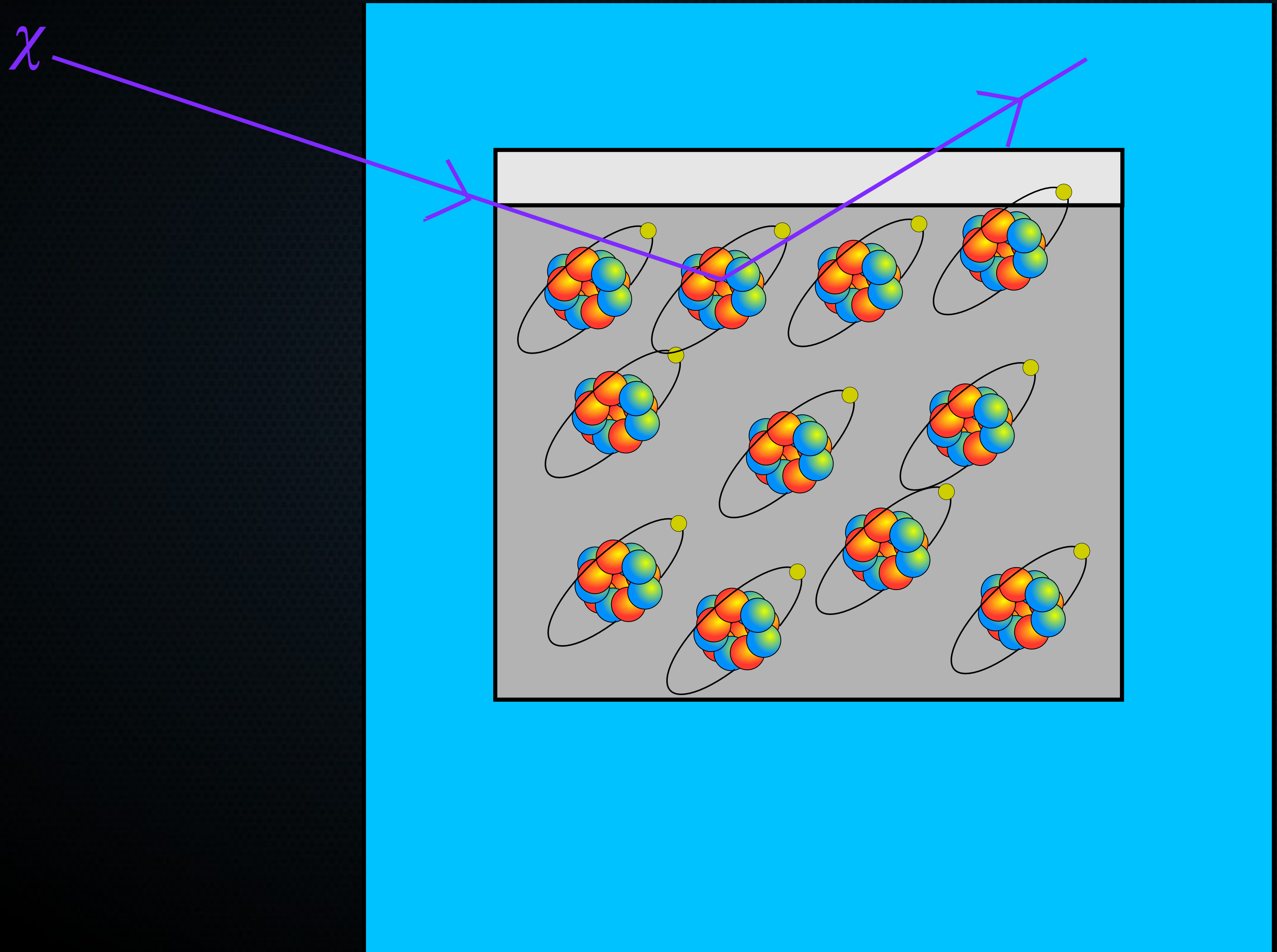
Photo
Multiplier
Tubes
Cryostat
E
Gaseous
argon
50 kg liquid
argon

DarkSide-50



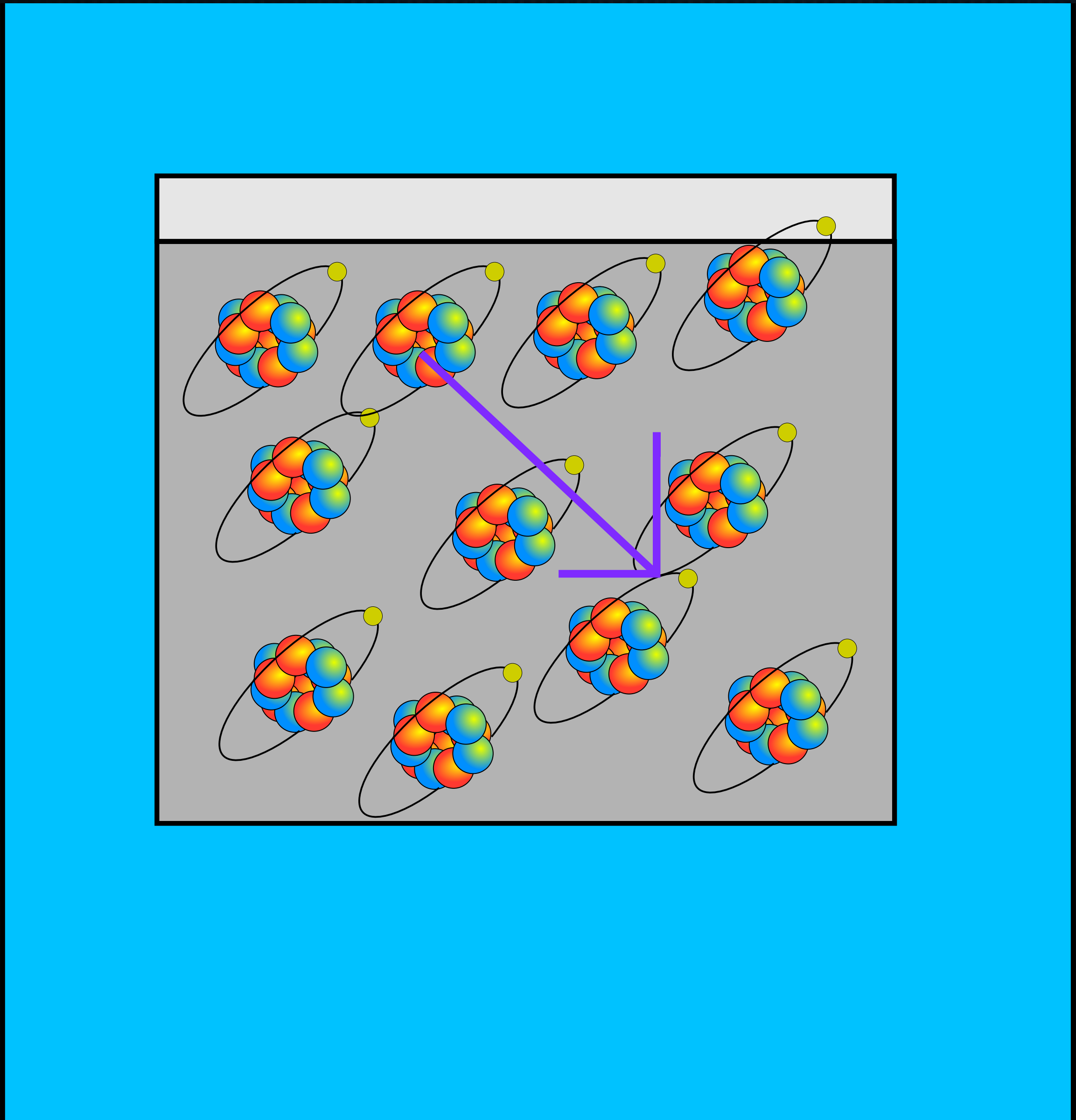
Copper field cage
Quartz windows
(coated with wavelength shifter)
E
Teflon reflector
(coated with wavelength shifter)

Liquid Argon Scintillation



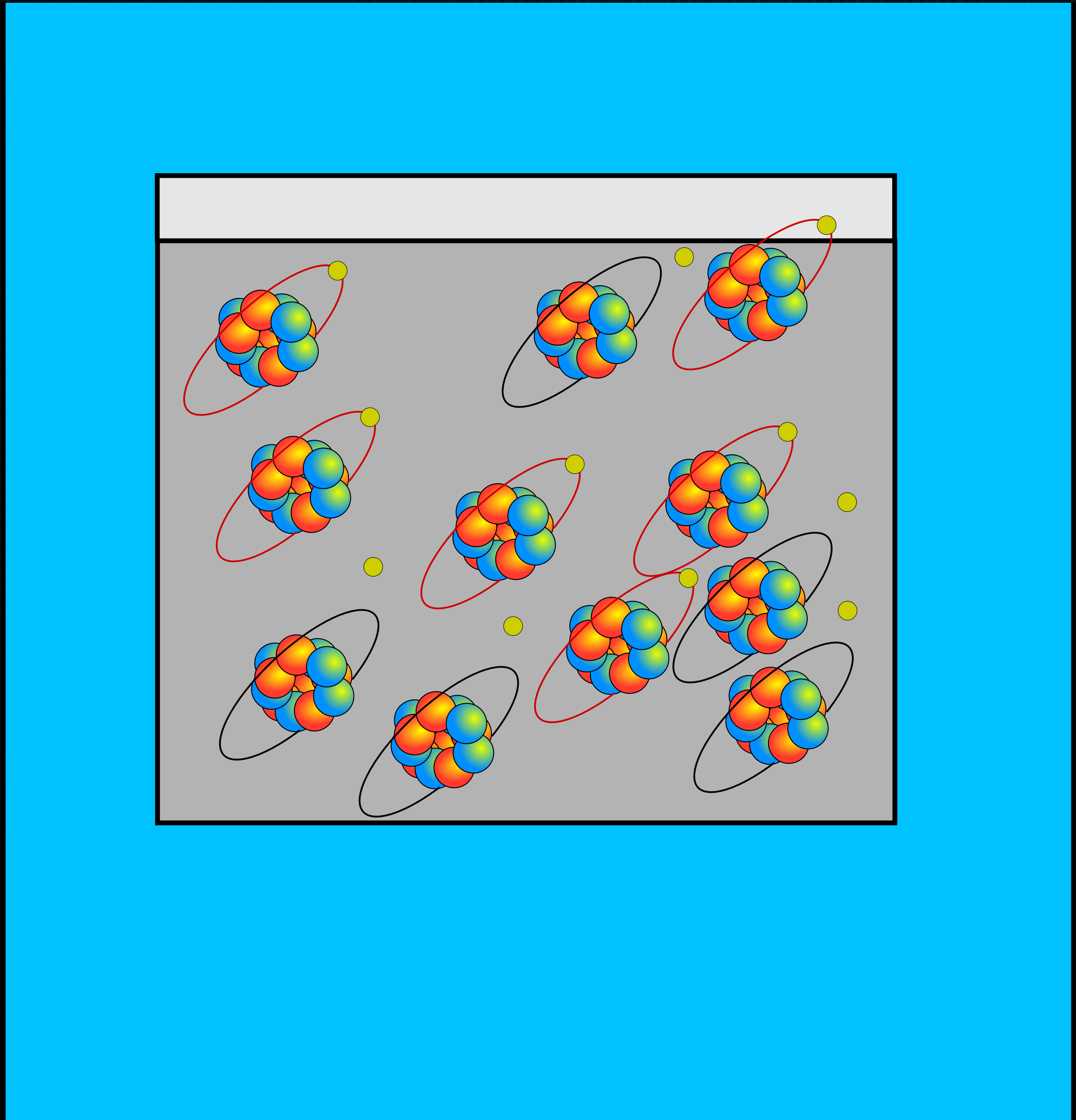
- WIMP scatters of Ar nucleus

Liquid Argon Scintillation



- WIMP scatters of Ar nucleus
- Ar nucleus recoils and scatters off of other Ar nuclei

Liquid Argon Scintillation



- WIMP scatters of Ar nucleus
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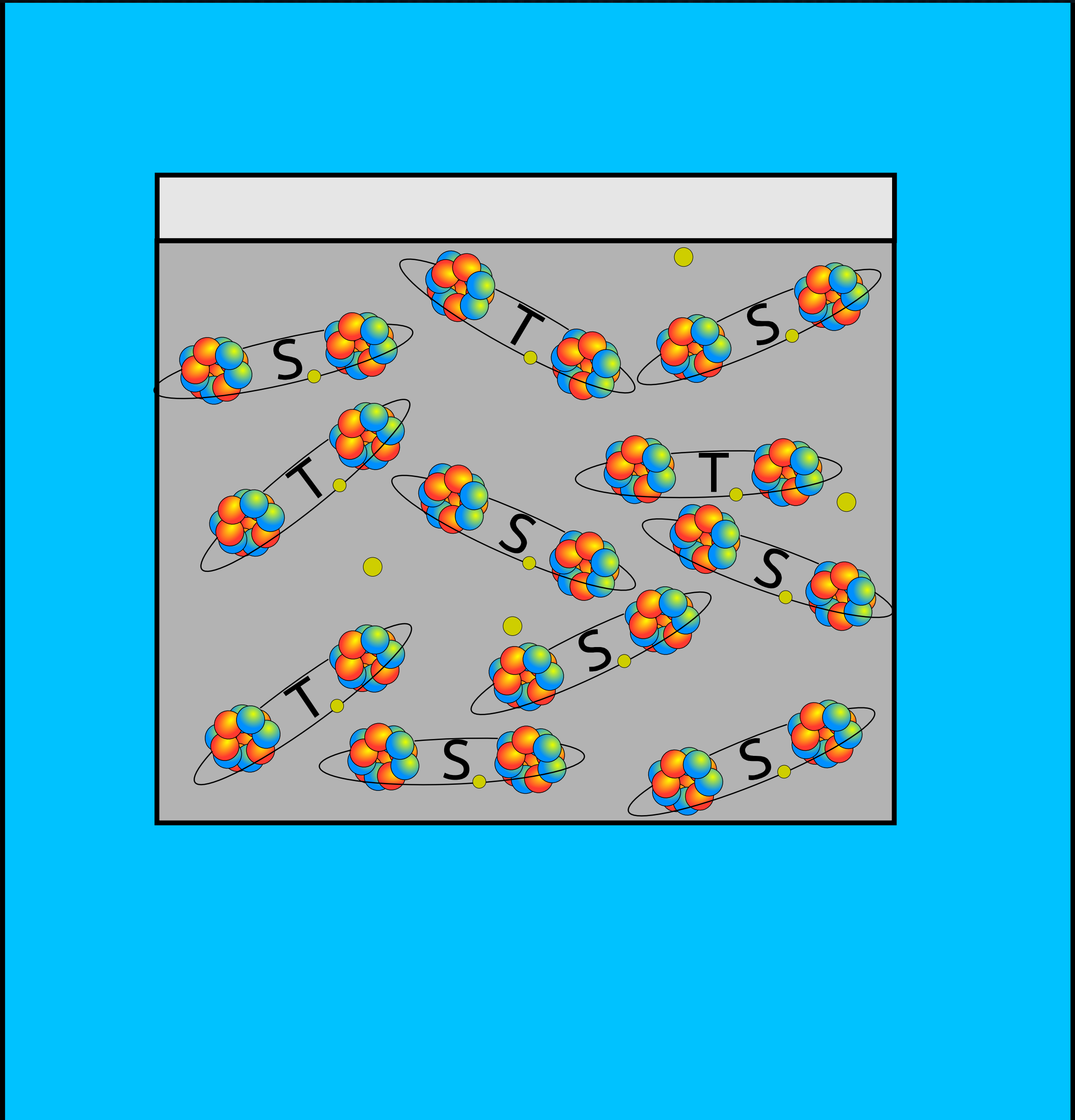
- Ar atoms become excited or ionized

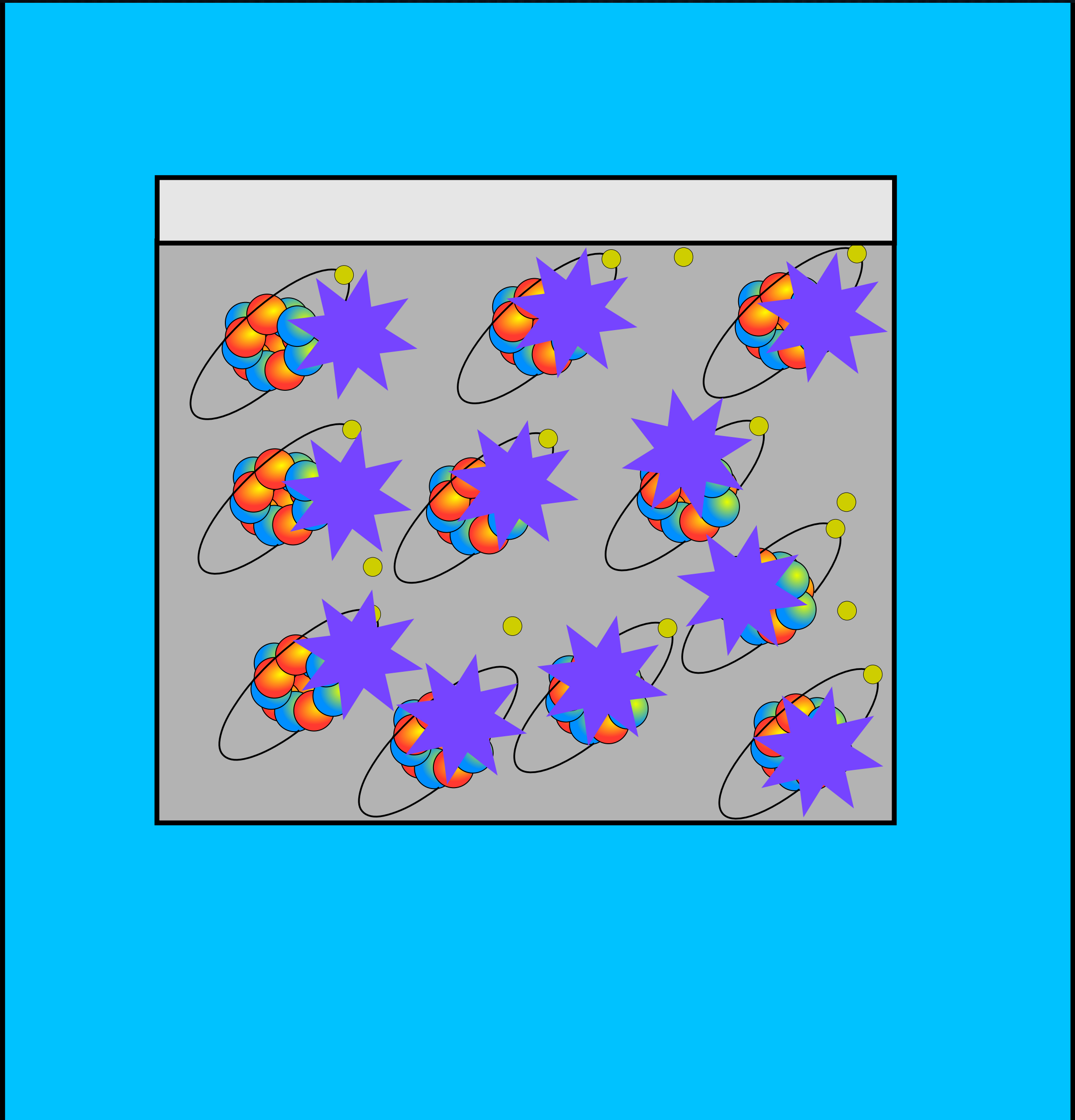
Liquid Argon Scintillation



- WIMP scatters of Ar nucleus
- Ar nucleus recoils and scatters off of other Ar nuclei
- Ar atoms become excited or ionized
- Ionized and excited Ar form dimers with ground state Ar

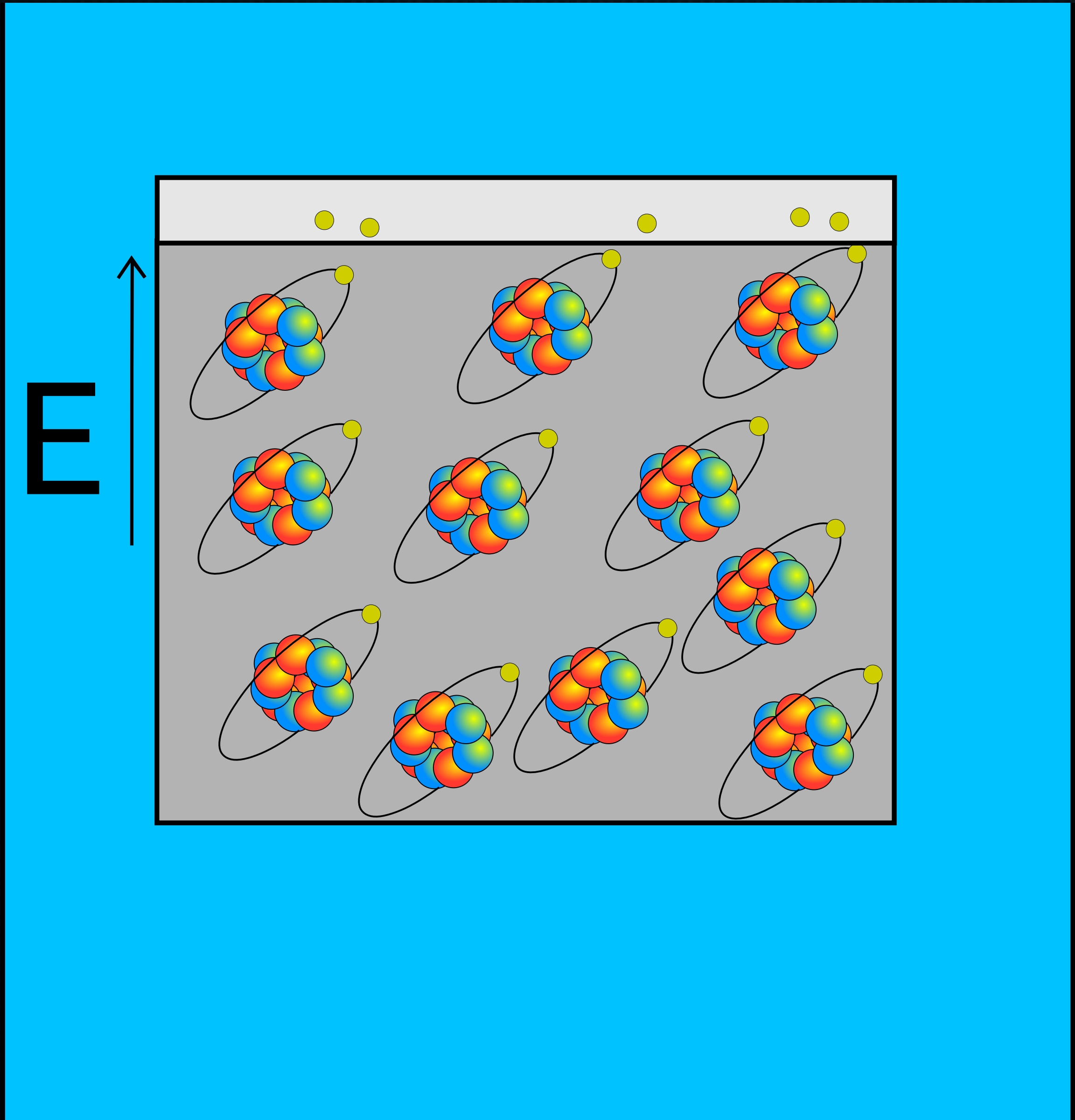
Liquid Argon Scintillation

S1 Signal



- WIMP scatters of Ar nucleus
- Ar nucleus recoils and scatters off of other Ar nuclei
- Ar atoms become excited or ionized
- Ionized and excited Ar form dimers with ground state Ar
- Dimers split apart and release light

Liquid Argon Scintillation



- WIMP scatters of Ar nucleus
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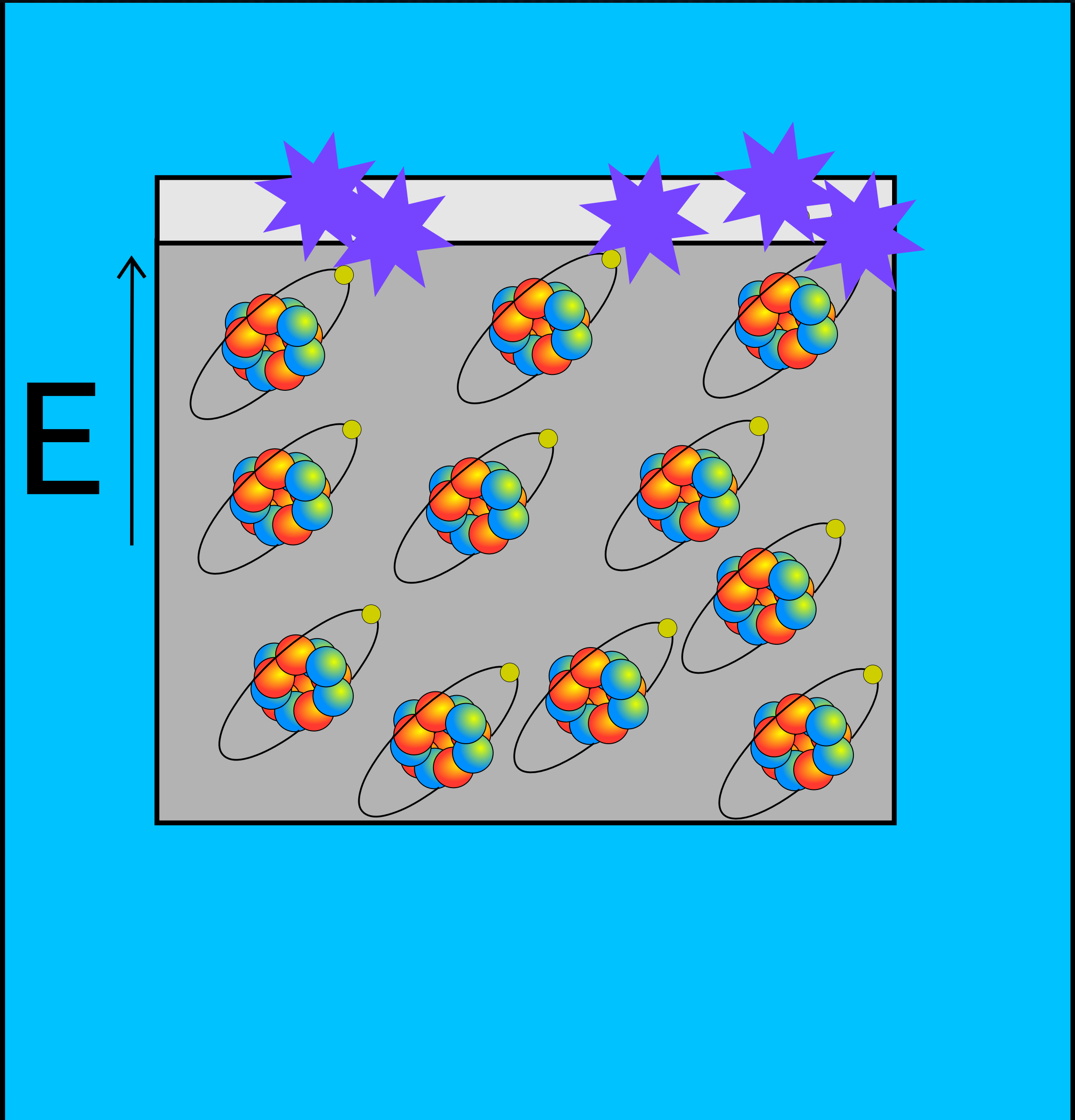
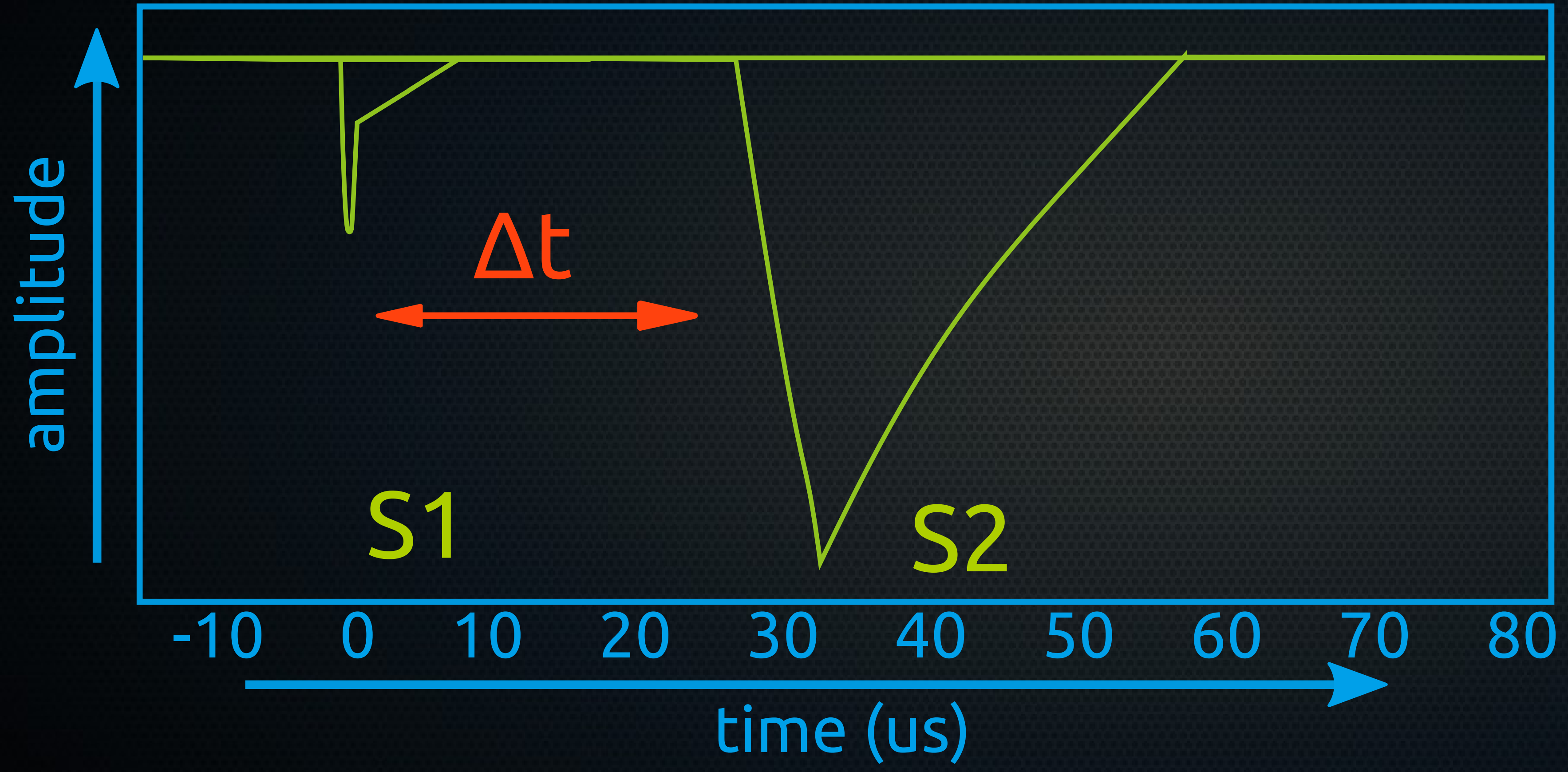
- Dimers split apart and release light
- Ionized e^- drifted to gas layer

Liquid Argon Scintillation

S2 Signal



- WIMP scatters of Ar nucleus
- Ar nucleus recoils and scatters off of other Ar nuclei
- Ar atoms become excited or ionized
- Ionized and excited Ar form dimers with ground state Ar
- Dimers split apart and release light
- Ionized e^- drifted to gas layer
- e^- scintillate in gas layer



What we can learn:

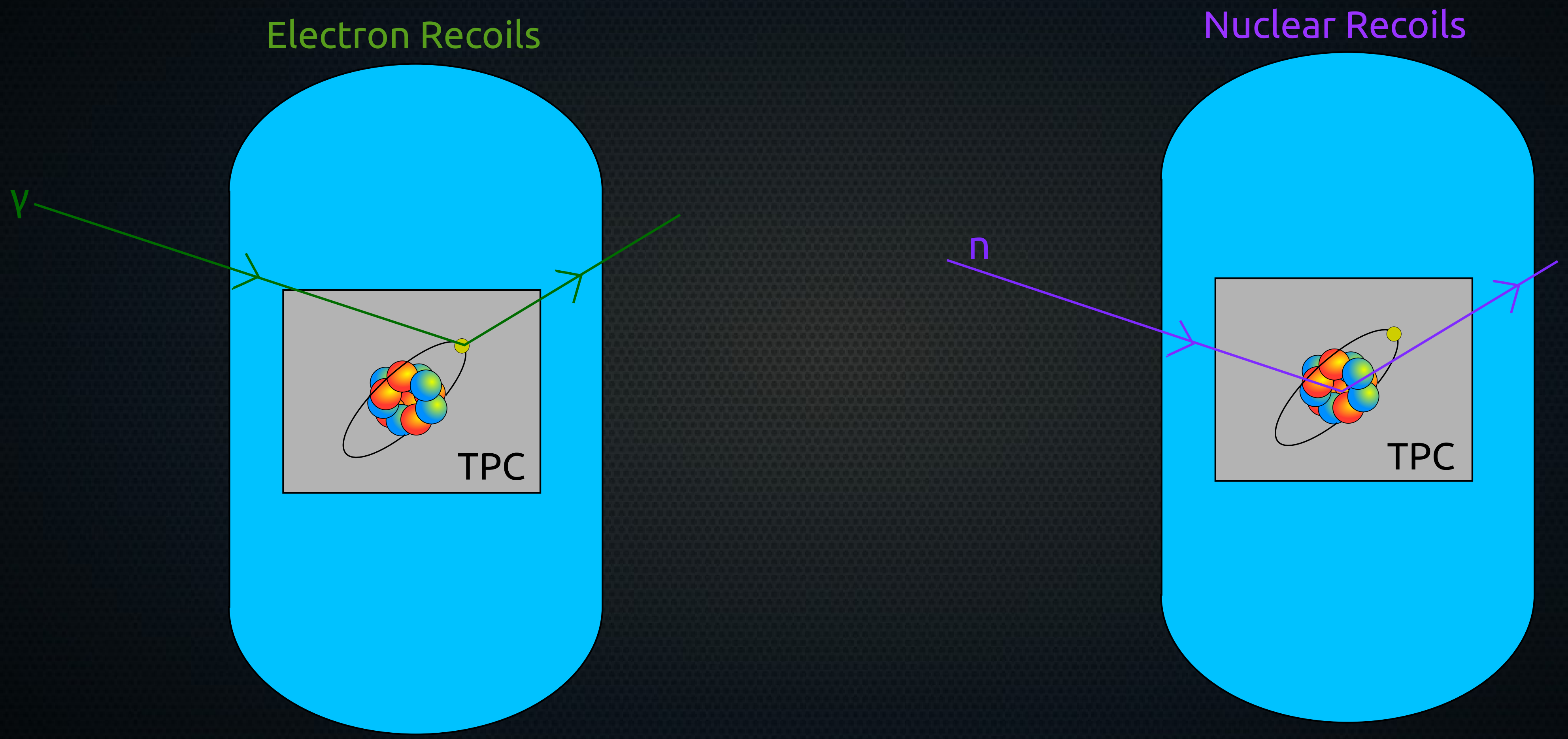
- S1 → Recoil energy
- Δt → z-coordinate
- S2 PMT distribution → x,y-coordinates
- S2/S1 and S1 pulse shape → recoil type

WIMP events are rare

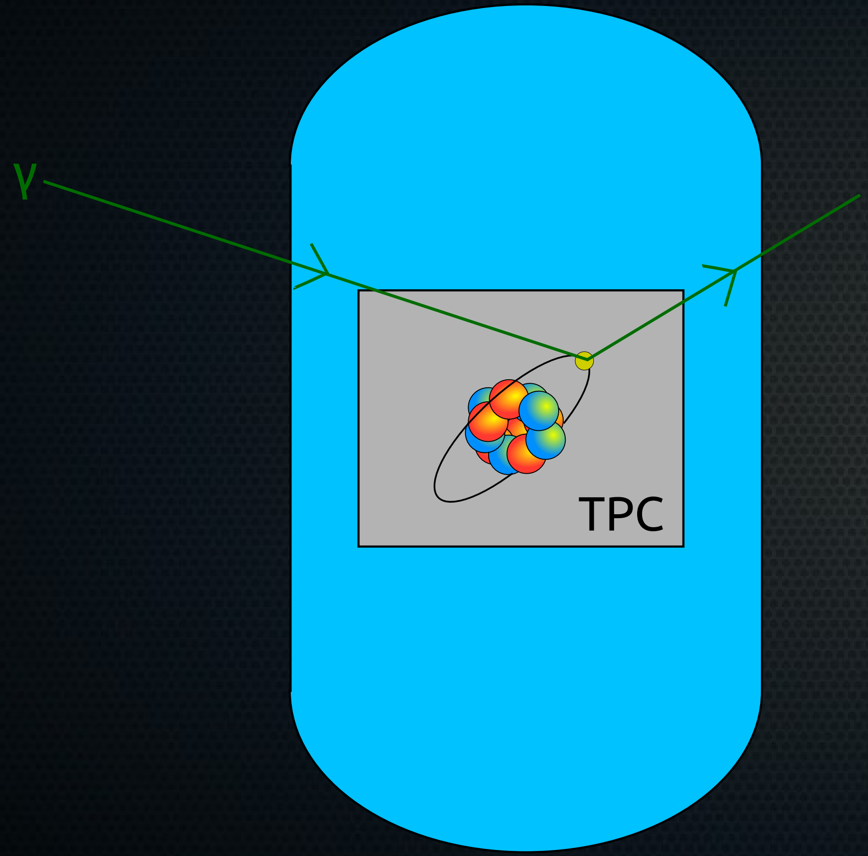
WIMP events are rare

Any backgrounds can easily hide a WIMP if we are not careful

Backgrounds: 2 Types

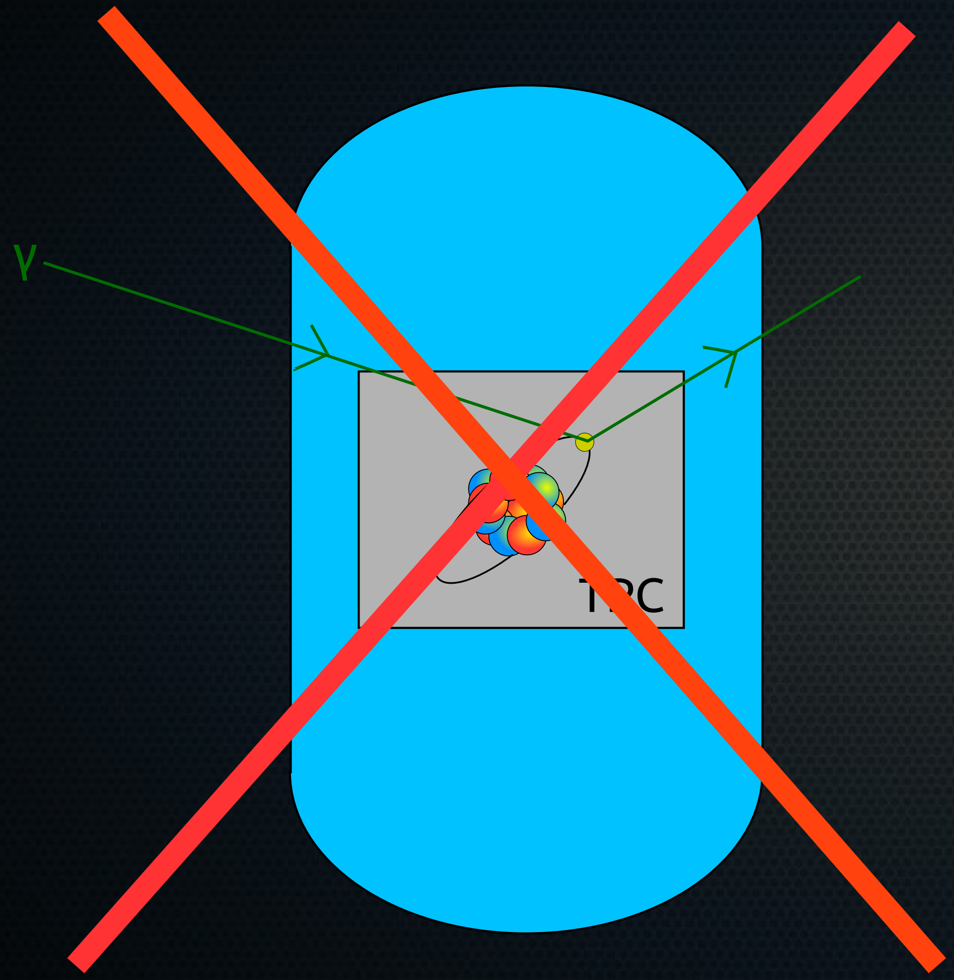


Electron Recoils



- Produced by β decay of ^{39}Ar or from incident γ rays
- Eliminate with pulse shape discrimination in LAr
- Ionization/scintillation signal ratio offers suppression

Electron Recoils



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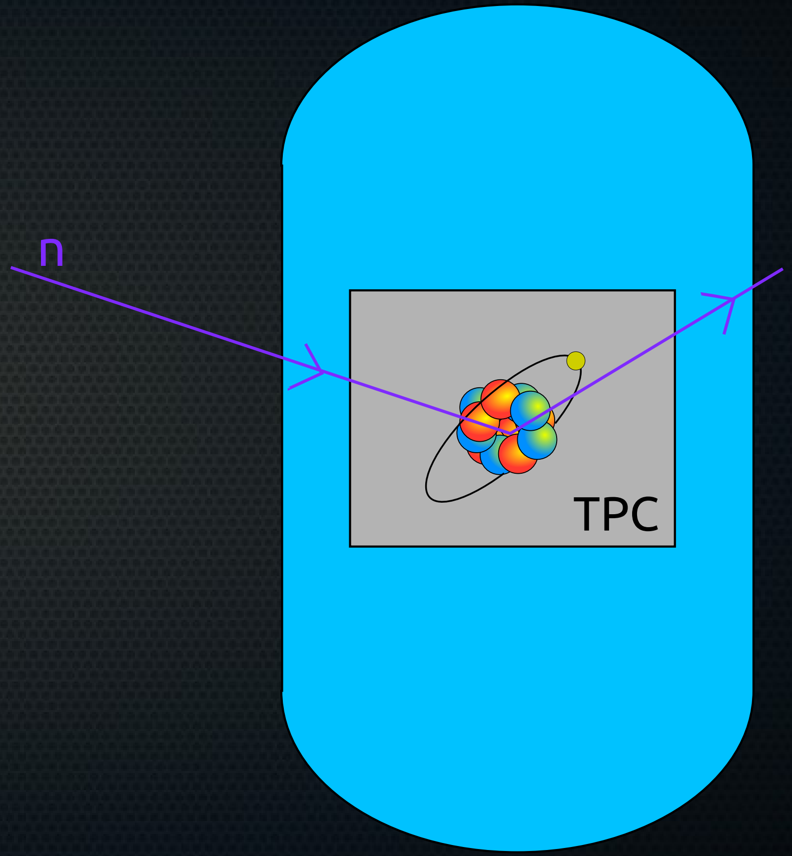
Nuclear Recoils

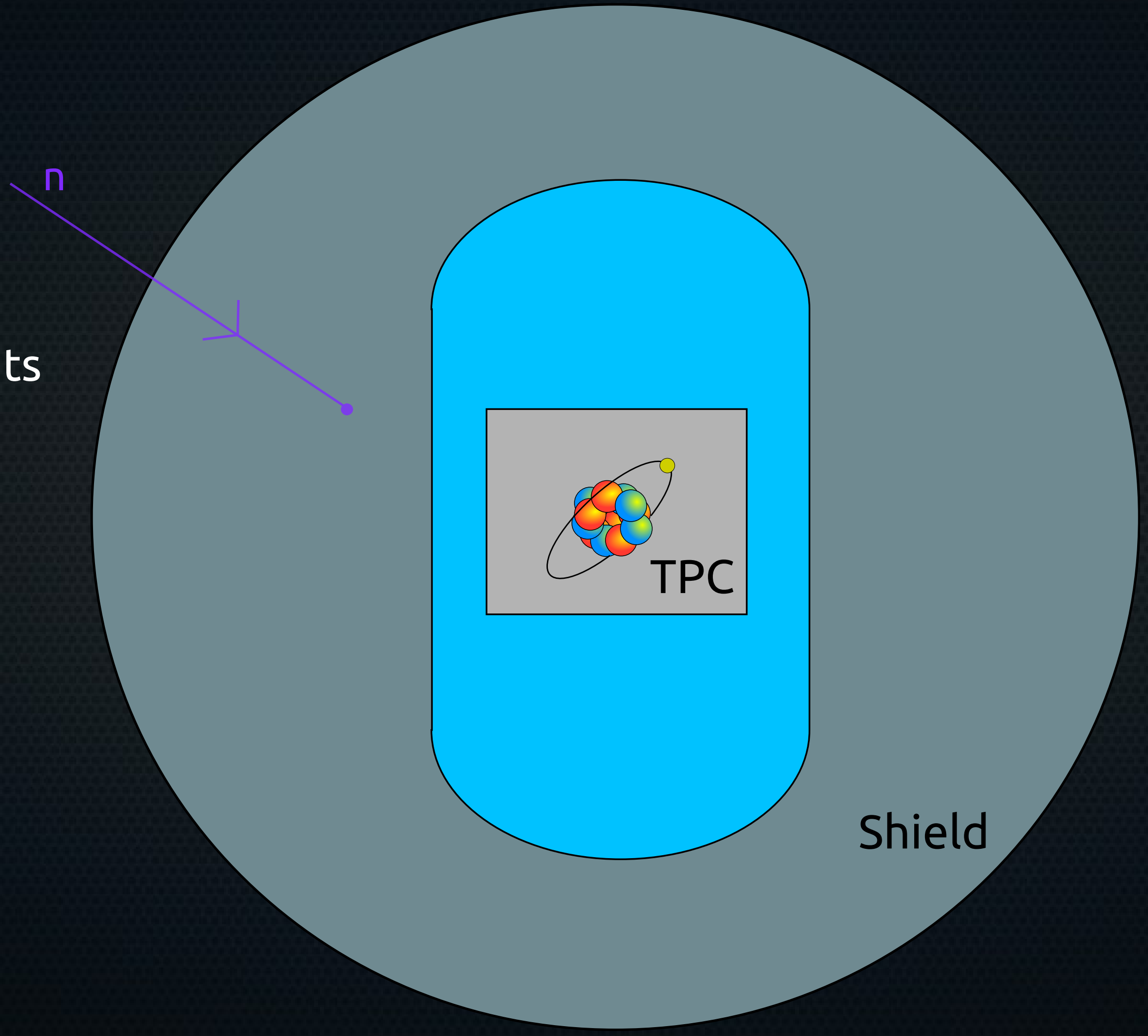
- From surface background α decays
  - Eliminated with fiducial cuts
- Neutron scatters
  - Radiogenic (fission and (α,n) reactions)
    - From surrounding environent
    - In detector components
  - Cosmogenic (muon spallation)
- Cannot be rejected with pulse shape discrimination



So how can we remove neutron backgrounds?

Passive Shielding?

- Radiogenic (fission and (α,n) reactions)
  - From surrounding environent
  - In detector components
- Cosmogenic (muon spallation)



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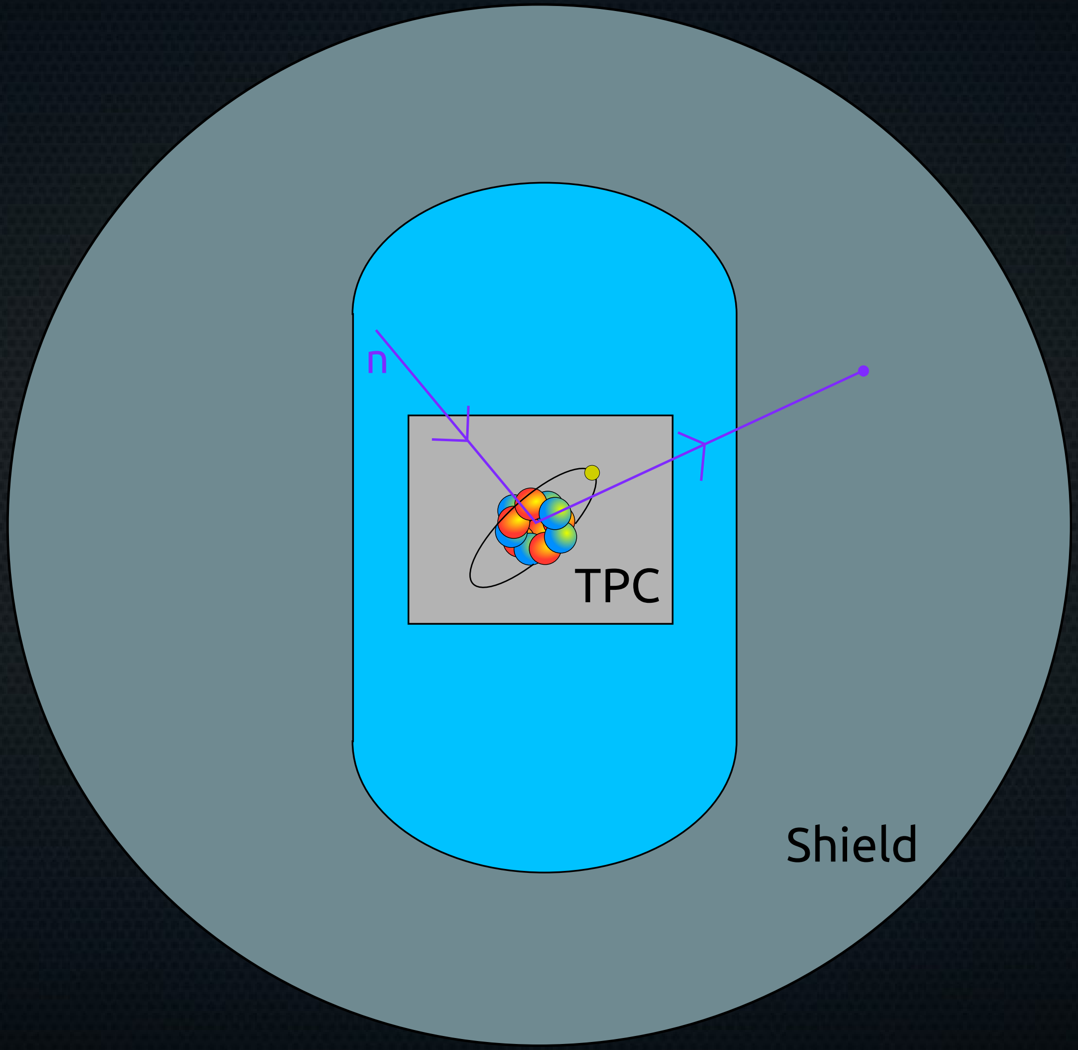

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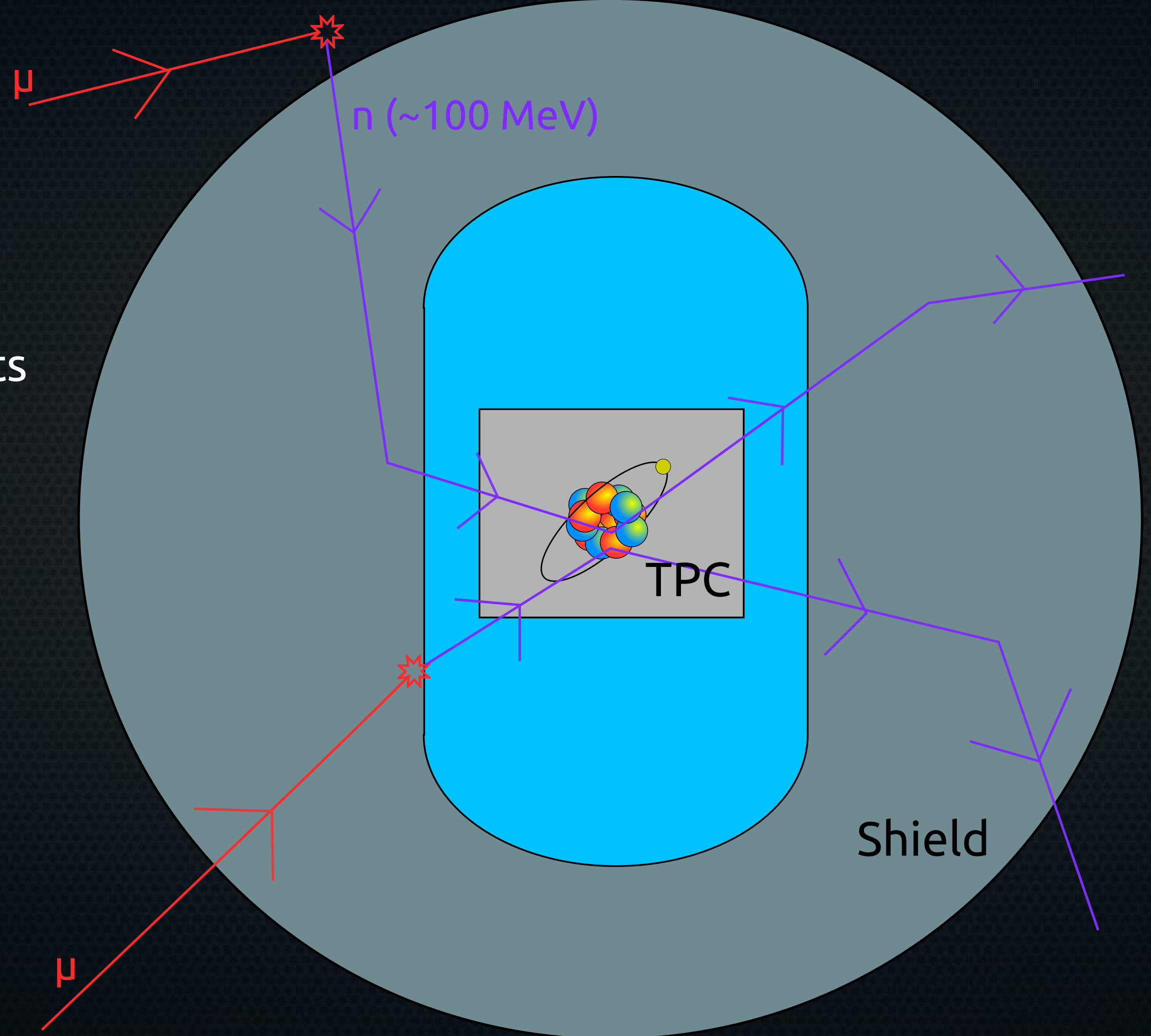
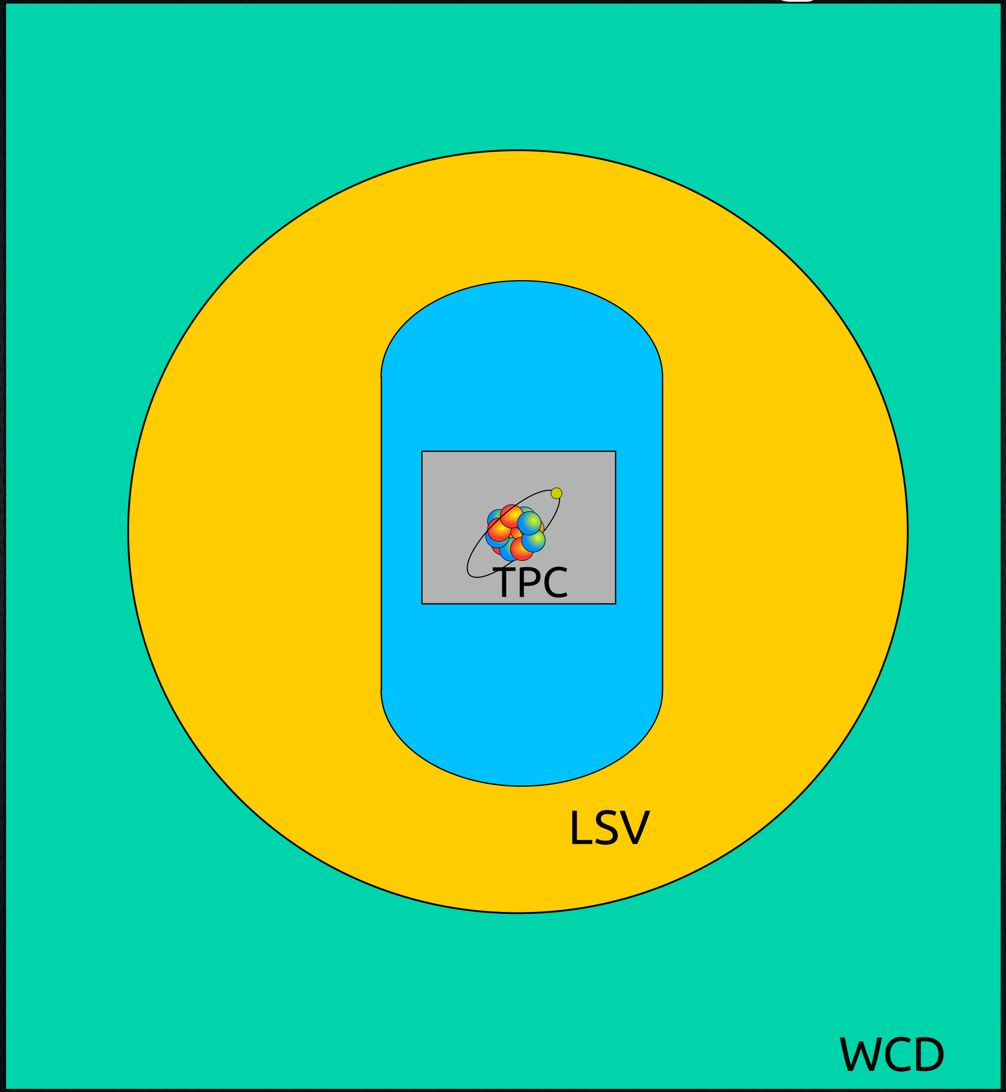


Active Shielding

Water Cherenkov Detector

- Provides shielding to the LSV
- Can detect passing muons that may produce a cosmogenic neutron



Liquid Scintillator Vessel

- Boron-loaded to improve neutron capture cross section
- Detects neutrons and γ rays in coincidence with TPC
- Provides shielding and *vetoing* of backgrounds
- Allows for *in situ* background measurements

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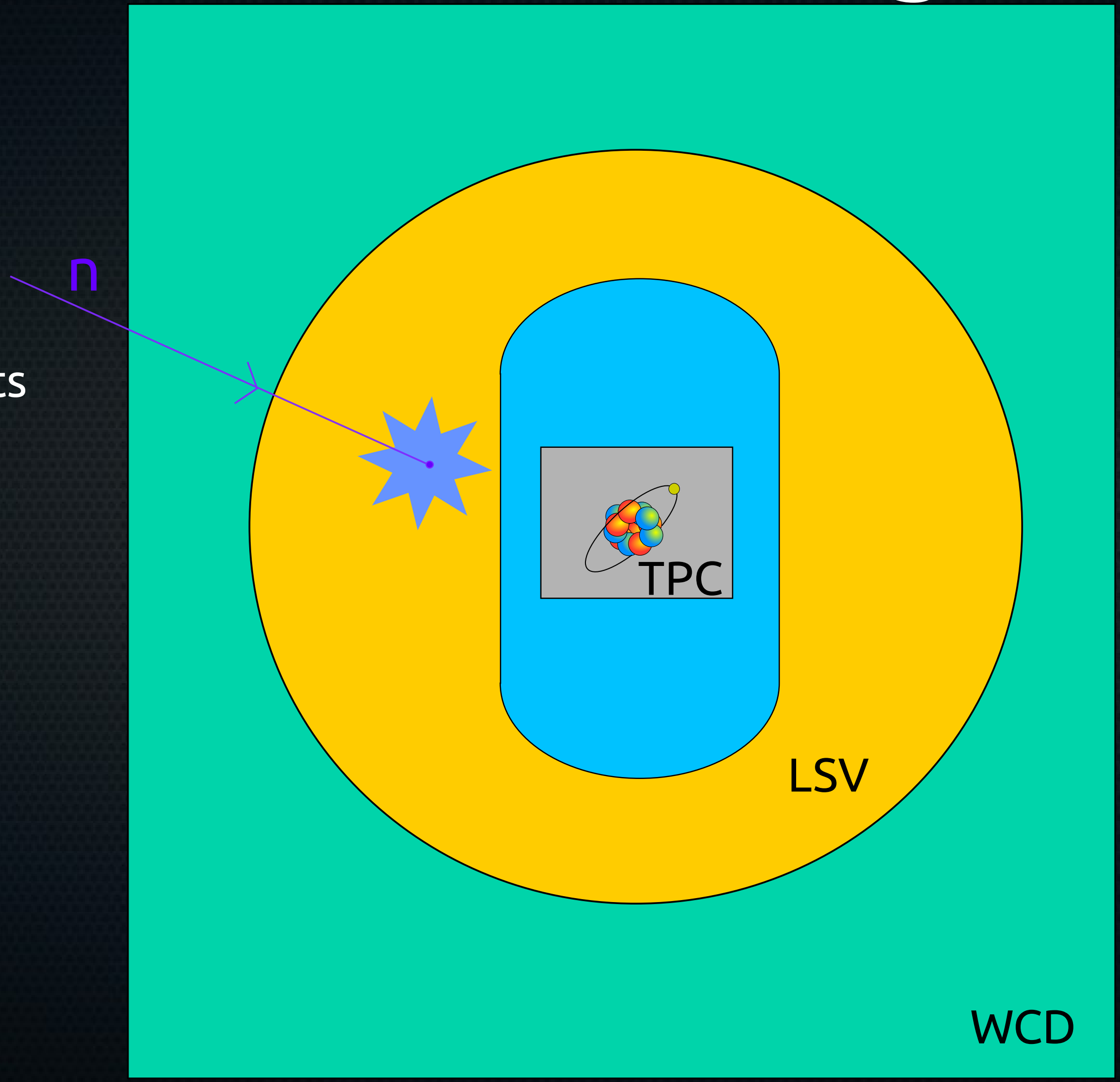

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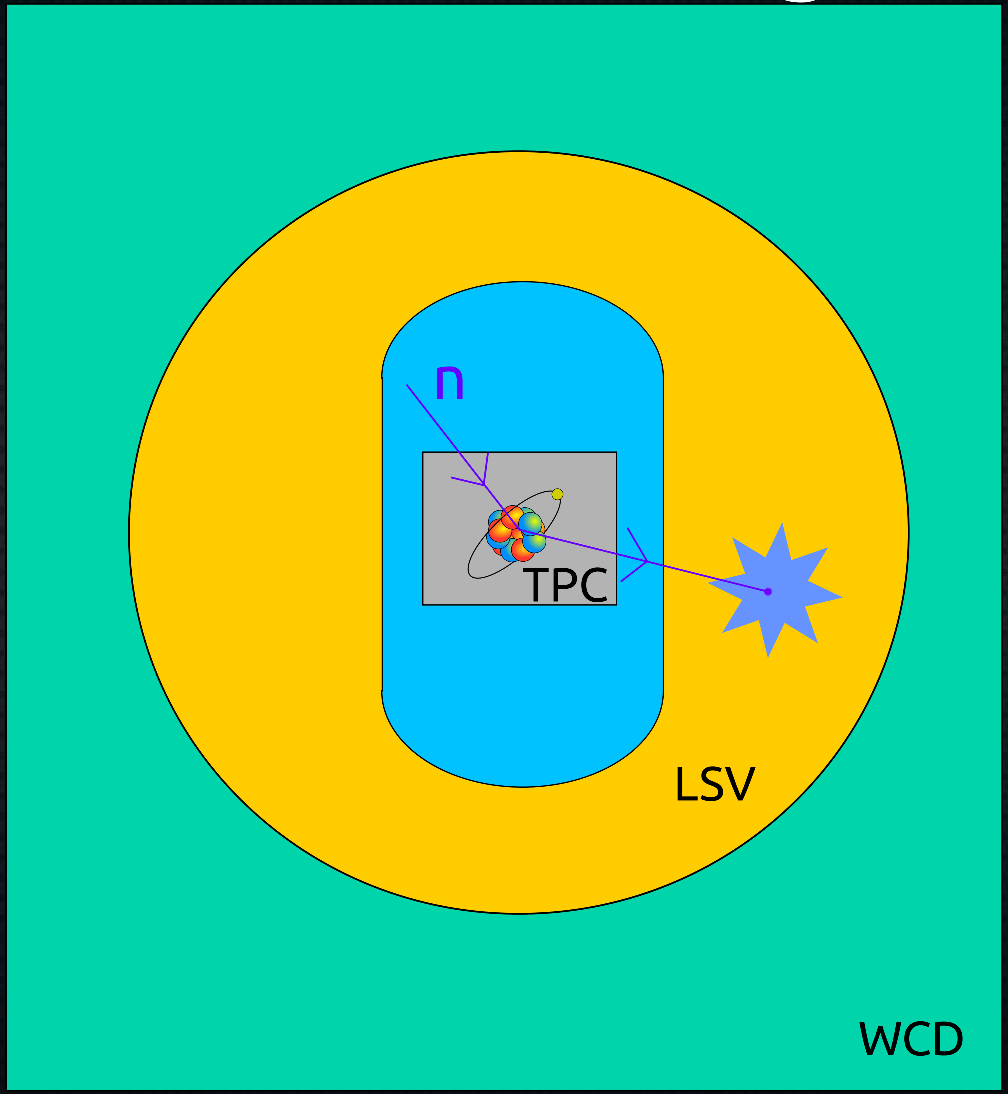
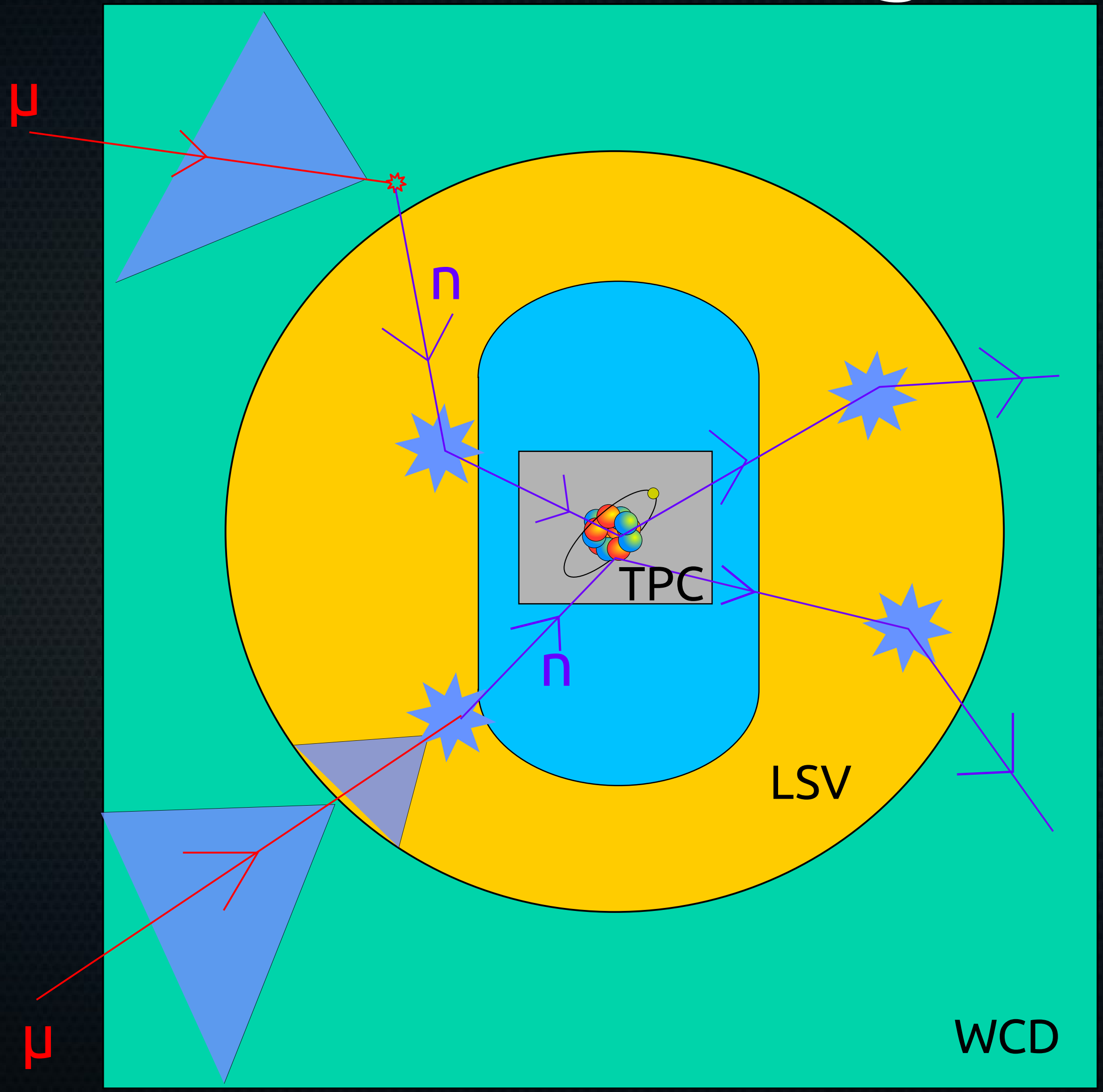
  - In detector components
- Cosmogenic (muon spallation)



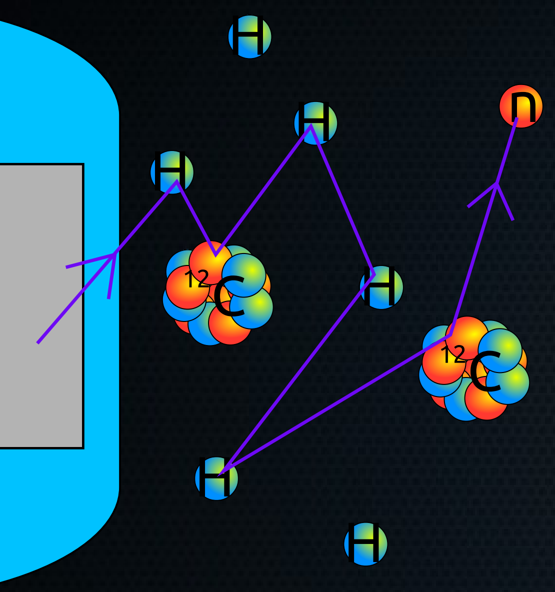
Active Shielding

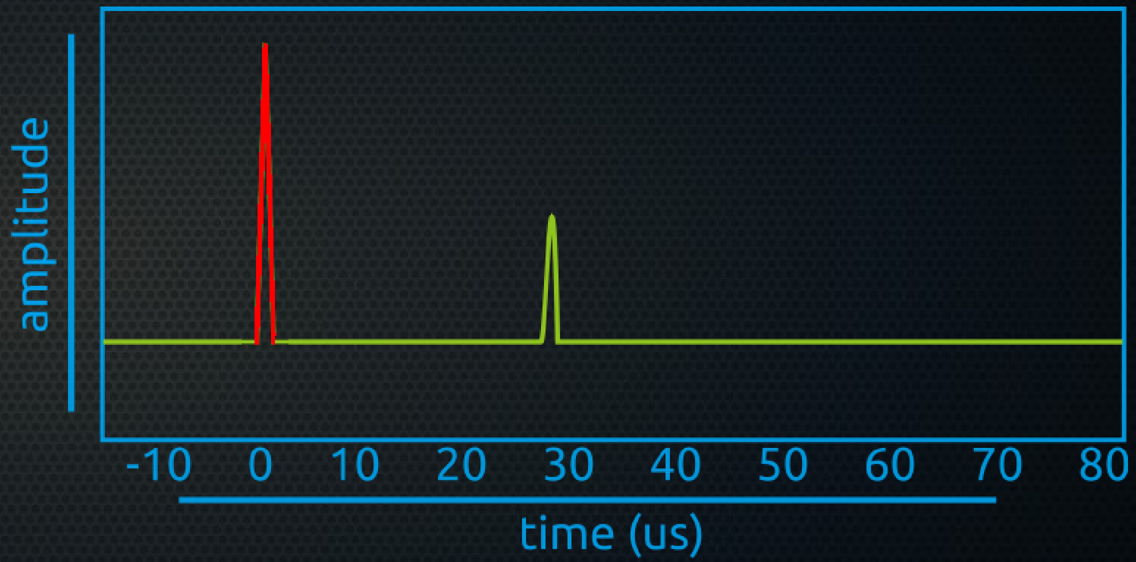
- Radiogenic (fission and (α,n) reactions)
  - From surrounding environent
  - In detector components
- Cosmogenic (muon spallation)



Vetoing Neutrons with the LSV

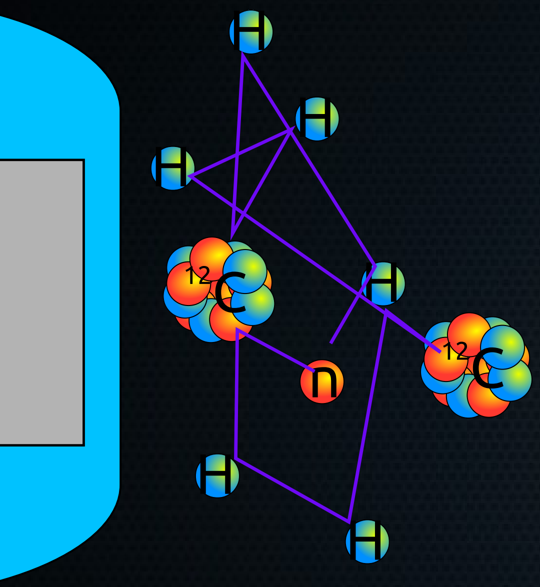
Neutron Detection: Prompt Signal

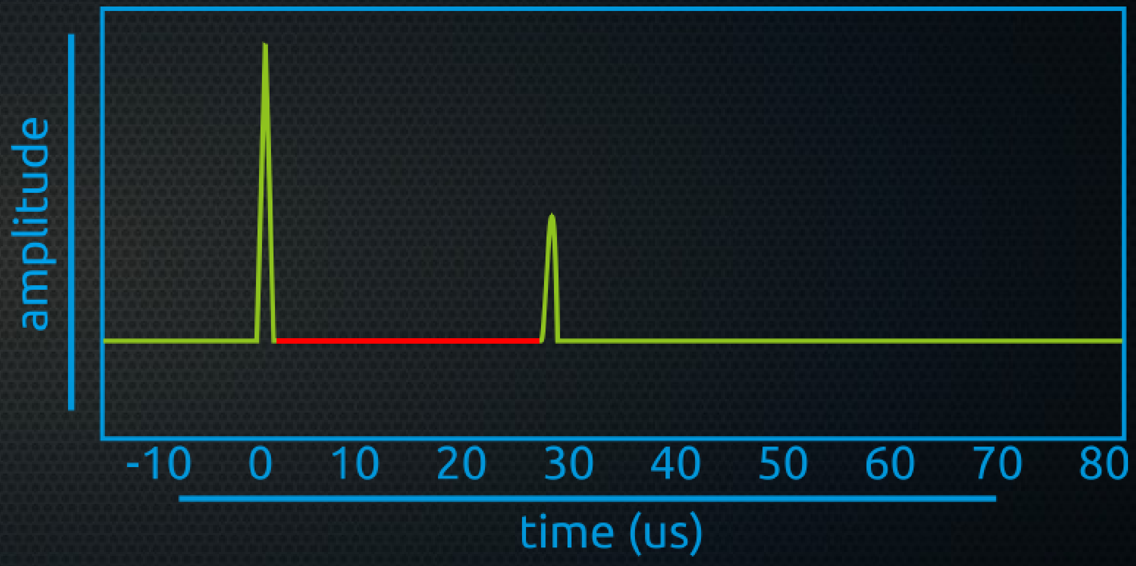




- Neutron thermalization
  - Very fast (< 100 ns)
  - Prompt time cut → low background
    → can cut with low threshold
  - Signal size depends on neutron energy

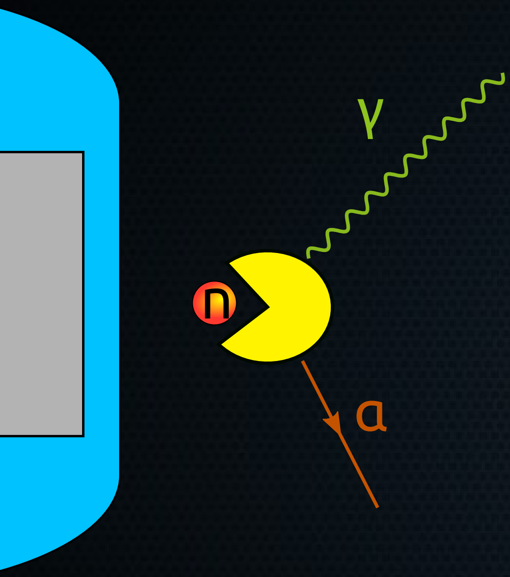
Neutron Detection: Quiet Time

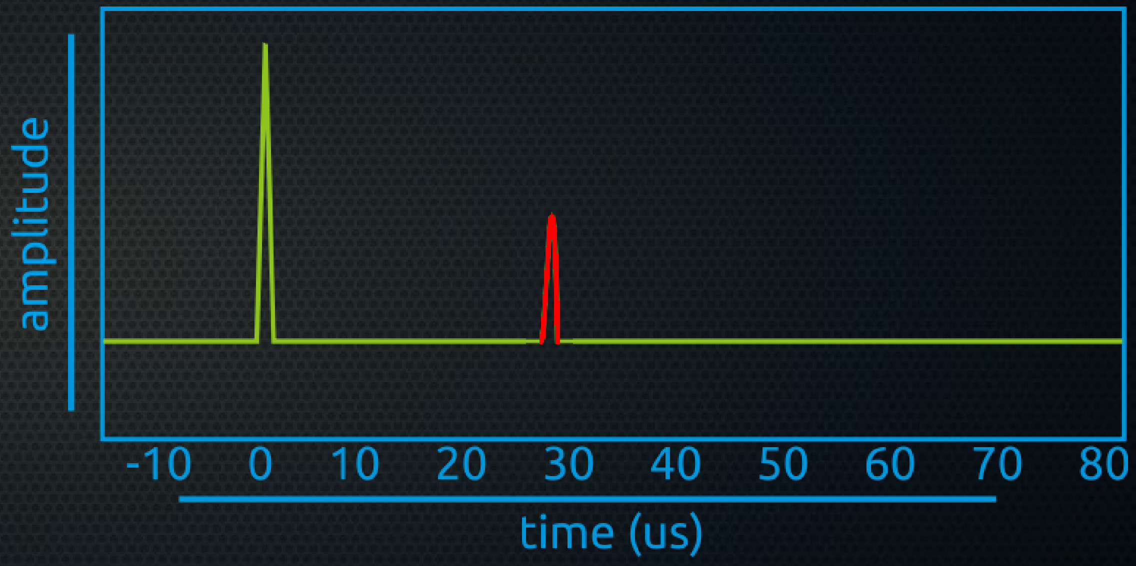




- Neutron random walk
  - No signal produced
  - Neutron random walks at thermal energies

Neutron Detection: Capture Signal





- Neutron capture
  - Neutron captures on
    - ^{10}B: σ = 3837 b
    - ^{1}H: σ = 0.33 b
      - Produces 2.2 MeV γ

Neutron Capture on ^{10}B

$$^{10}\mathrm{B} + n \rightarrow \ ^7\mathrm{Li}^*(839\ \mathrm{keV}) + \alpha\ (1471\ \mathrm{keV}) \qquad (93.7\%)$$

$$^7\mathrm{Li}^* \rightarrow ^7\mathrm{Li} + \gamma\ (478\ \mathrm{keV})$$

$$\rightarrow \ ^7\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) \qquad (6.4\%)$$

Neutron Capture on ^{10}B

$$^{10}\mathrm{B} + n \rightarrow \ ^{7}\mathrm{Li}^{*}(839 \text{ keV}) + \alpha \ (1471 \text{ keV}) \qquad (93.7\%)$$

$$^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li} + \gamma \ (478 \text{ keV})$$

$$\rightarrow \ ^{7}\mathrm{Li} \ (1015 \text{ keV}) + \alpha \ (1775 \text{ keV}) \qquad (6.4\%)$$

Relatively high energy, easy to see
But ~8% chance it will go back into cryostat unseen

Neutron Capture on ^{10}B

$$^{10}\mathrm{B} + n \rightarrow \ ^{7}\mathrm{Li}^{*}(839\ \mathrm{keV}) + \alpha\ (1471\ \mathrm{keV}) \qquad (93.7\%)$$

$$^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li} + \gamma\ (478\ \mathrm{keV})$$

$$\rightarrow \ ^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) \qquad (6.4\%)$$

Highly quenched to a total signal equivalent to an electron energy of ~50-60 keVee
Will always deposit all energy into the scintillator
If we can reliably see these, we can see neutrons

Target vetoing efficiency: > 99.5%

Target vetoing efficiency: > 99.5%

The key to high efficiency is to efficiently detect the α + Li

Target vetoing efficiency: > 99.5%

The key to high efficiency is to efficiently detect the α + Li

The key to detecting the α+Li is a high light yield

Designing the LSV

Designing the LSV

Designing the LSV

Scintillator Cocktail:

- Pseudocuemene [PC] (50%)
- Trimethyl borate [TMB] (50%)
- PPO (3 g/L)

Reflector: Lumirror E6SR

Designing the LSV

Primary scintillator

Scintillator Cocktail:

- Pseudocuemene [PC] (50%)
- Trimethyl borate [TMB] (50%)
- PPO (3 g/L)

Reflector: Lumirror E6SR

Designing the LSV

Scintillator Cocktail:

- Pseudocuemene [PC] (50%)
- Trimethyl borate [TMB] (50%)
- PPO (3 g/L)

Boron-loading agent
Mixes well with PC

Reflector: Lumirror E6SR

Designing the LSV

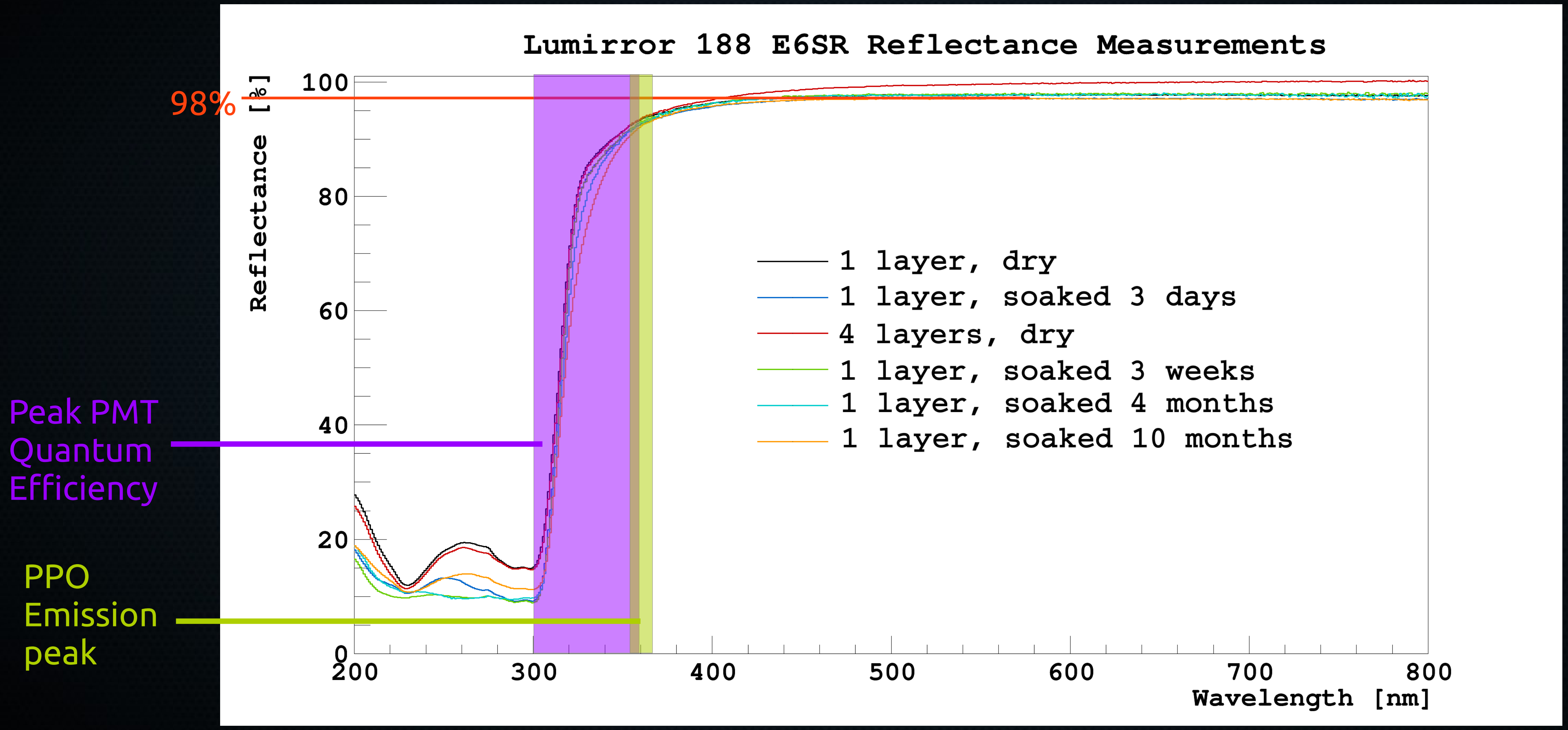
Scintillator Cocktail:

- Pseudocuemene [PC] (50%)
- Trimethyl borate [PC] (50%)
- PPO (3 g/L)

Wavelength shifter
Shifts scintillation light to visible
Improves scintillator response

Reflector: Lumirror E6SR

Designing the LSV



Designing the LSV

Prototype Tests

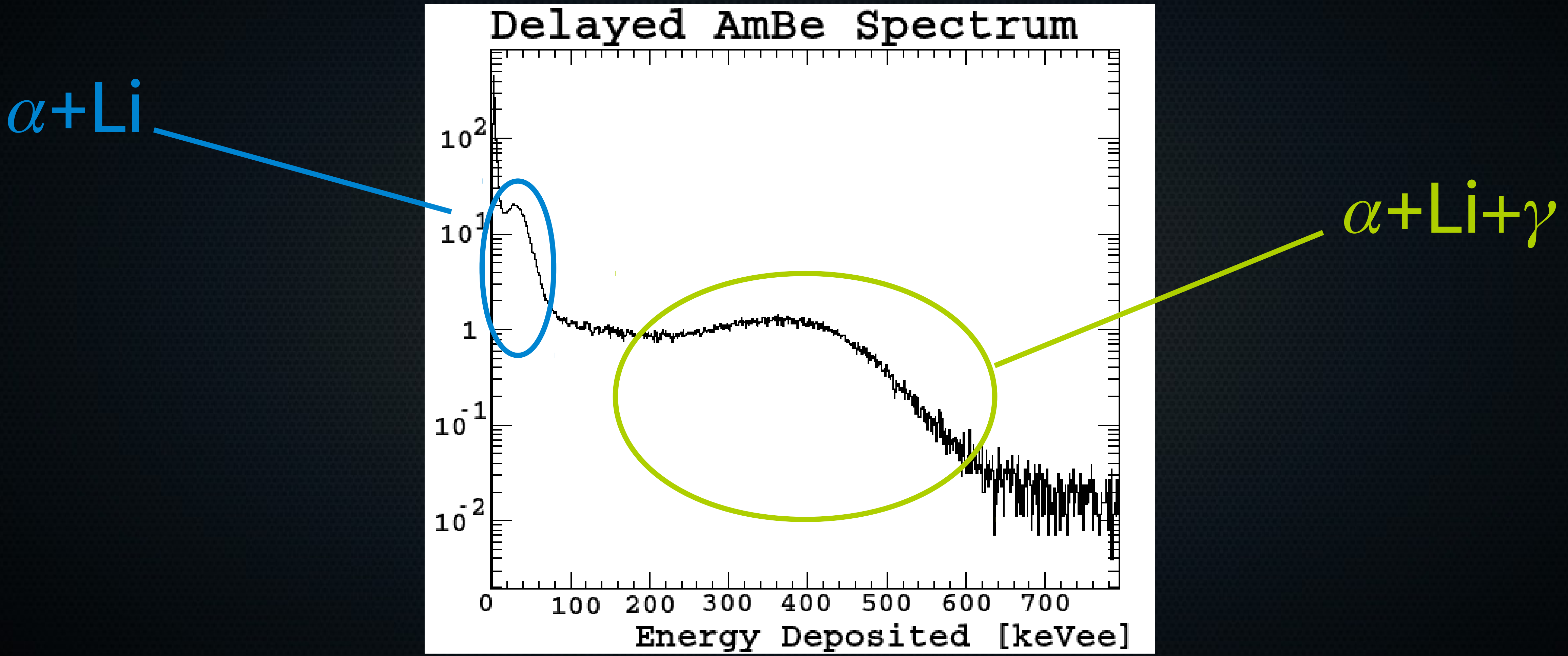
Measurements

- Light yield: 0.47 PE/keV
- Decreased by 0.52%/week

Optical Monte Carlo

- Light yield: 0.46 PE/keV
- Scaled to DS-50 geometry
  - Light yield: 0.48 PE/keV
  - High enough to detect α+Li

Prototype Tests



See arXiv:1509.02782

- [x] Neutron capture producsts are detectable
- [ ] Prompt signal is detectable

Testing Prompt Response

$$F = E \cdot LY \cdot QF(E)$$

Testing Prompt Response

$$F = E \cdot LY \cdot QF(E)$$

Light output by scintillation event

Testing Prompt Response

$$F = E \cdot LY \cdot QF(E)$$

Incident particle energy

Testing Prompt Response

$$F = E \cdot LY \cdot QF(E)$$

High energy electron recoil light yield

Testing Prompt Response

$$F = E \cdot LY \cdot QF(E)$$

Quenching factor
(depends on particle type and kinetic energy)

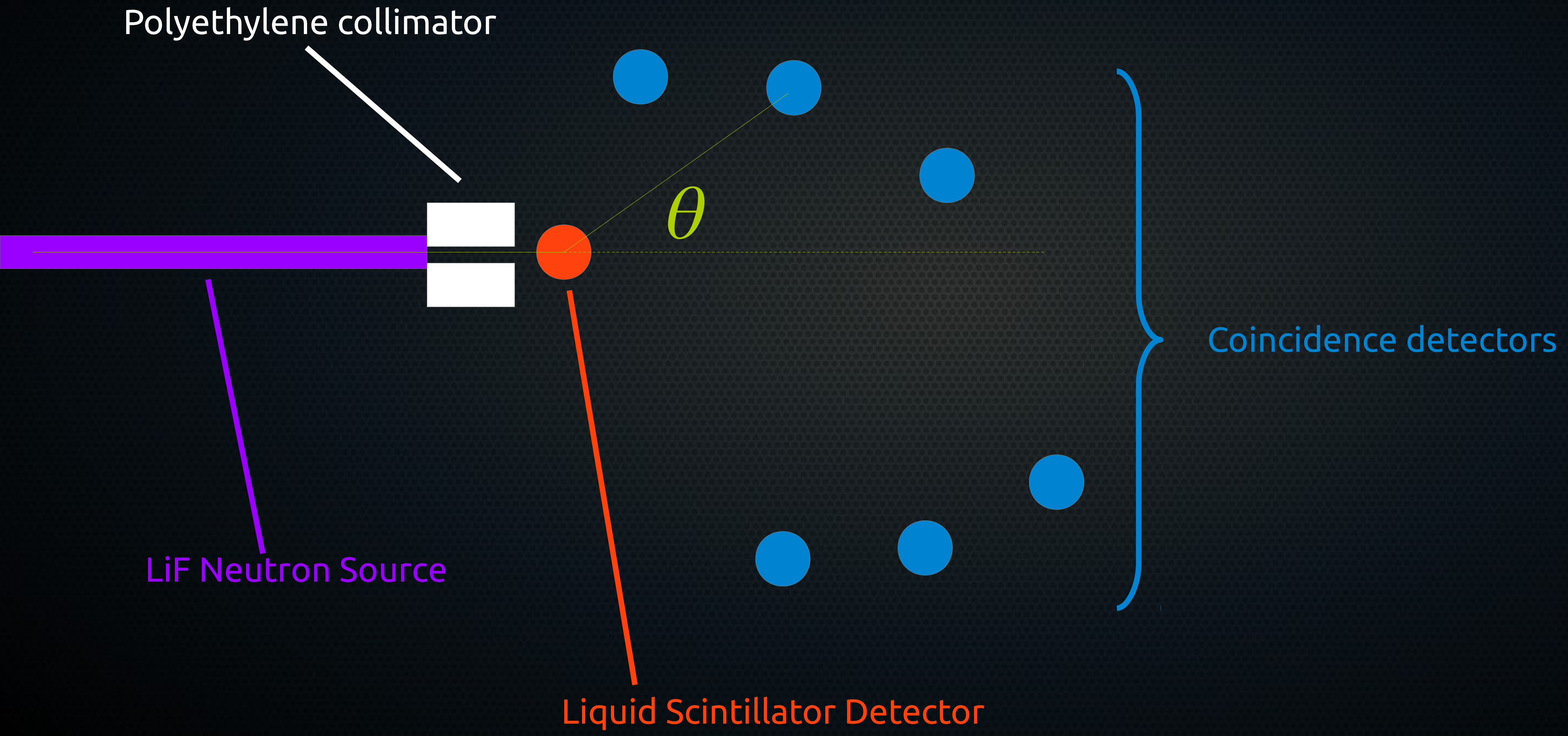
Testing Prompt Response

$$F = E \cdot LY \cdot \frac{1}{1 + kb \cdot \frac{dE}{dx}}$$

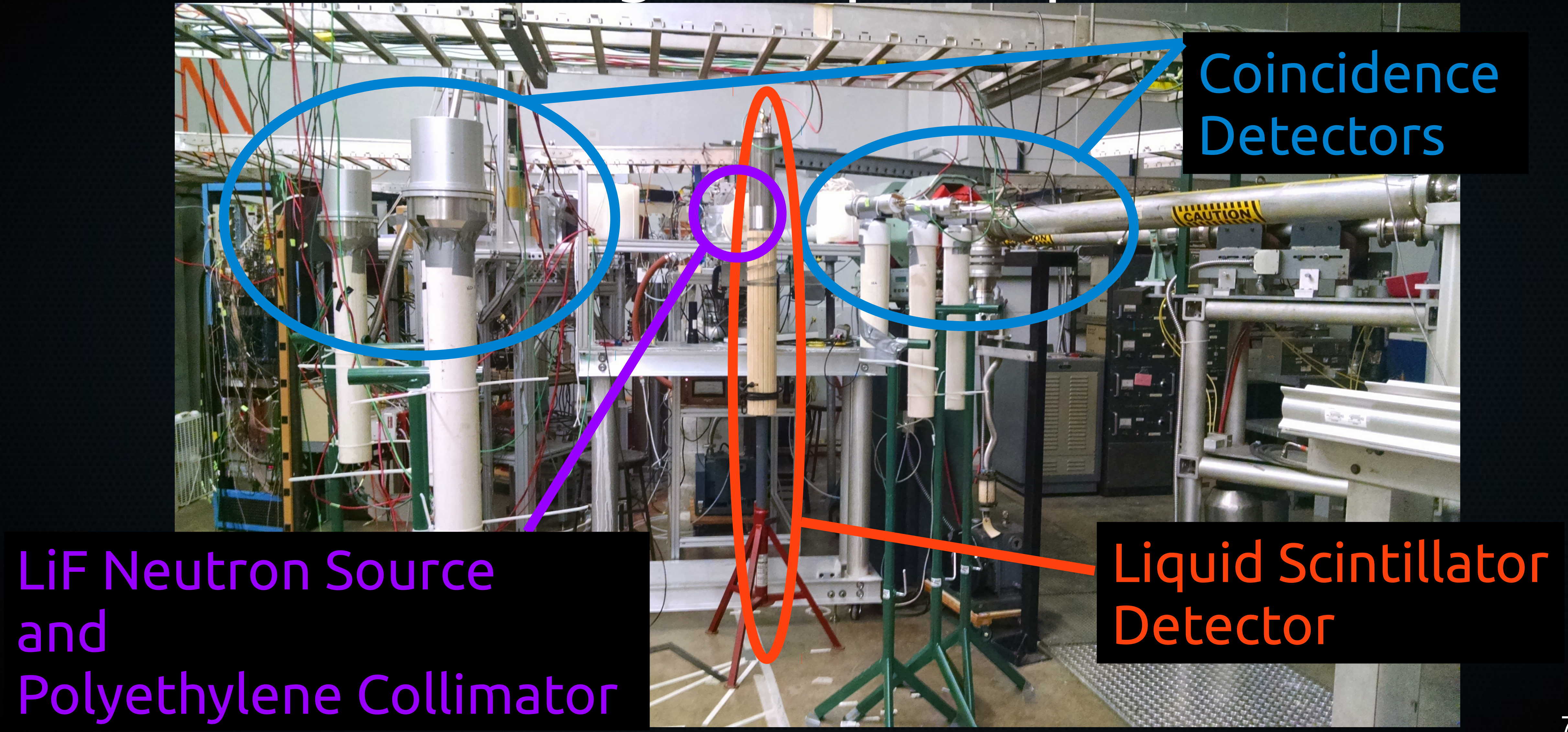
Quenching factor

Introduces substantial non-linearity for nuclear recoils

Testing Prompt Response

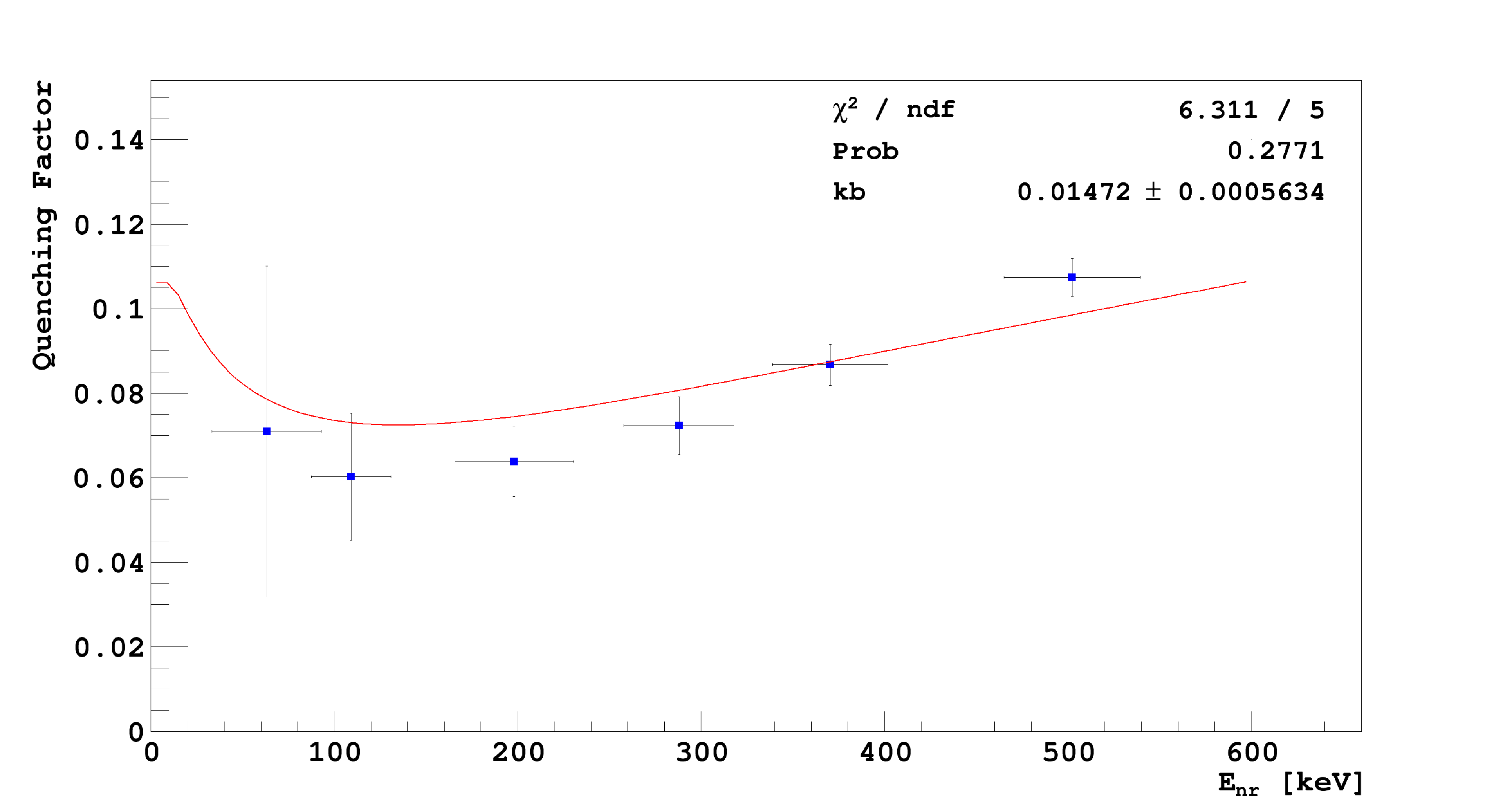


Testing Prompt Response



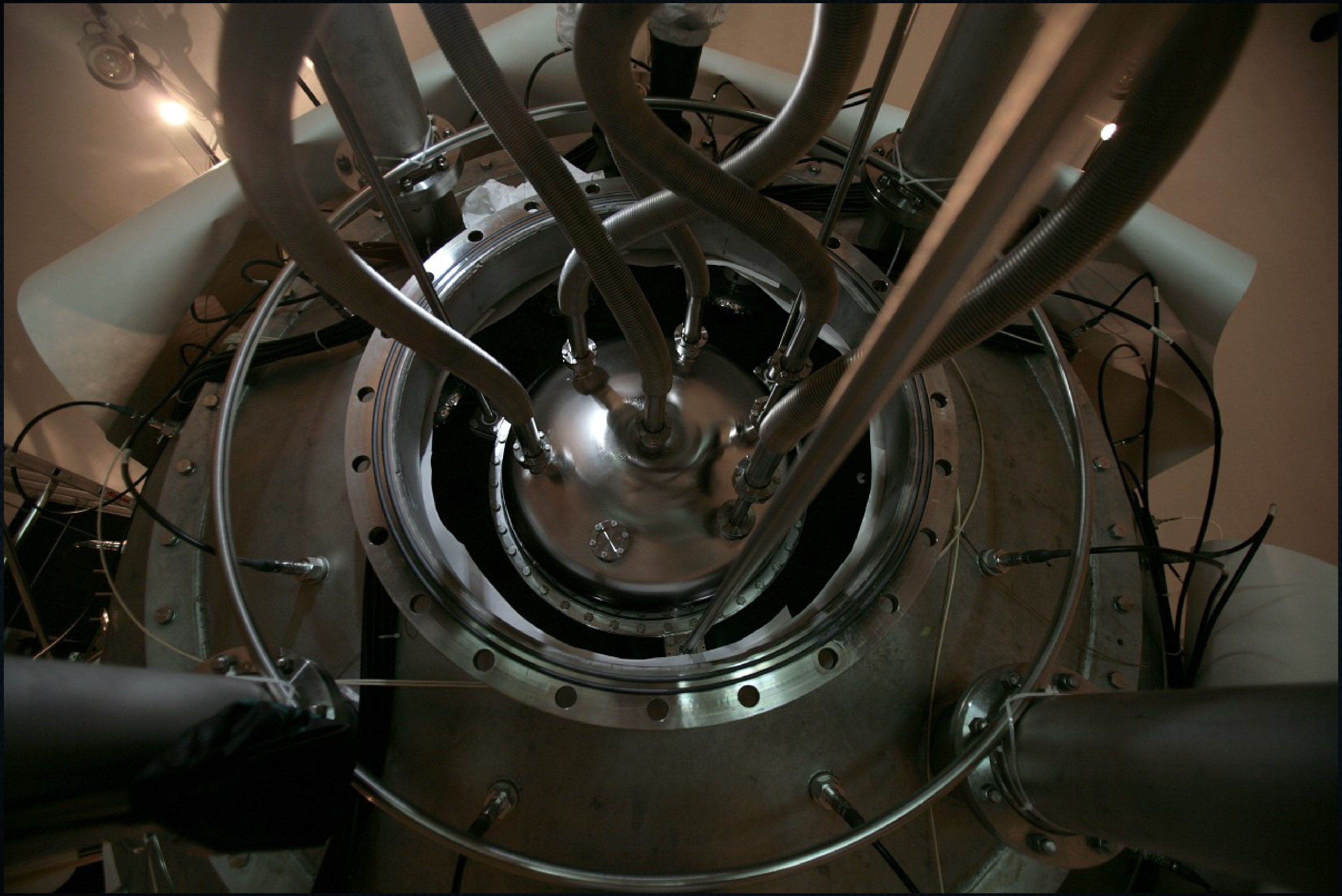
At University of Notre Dame

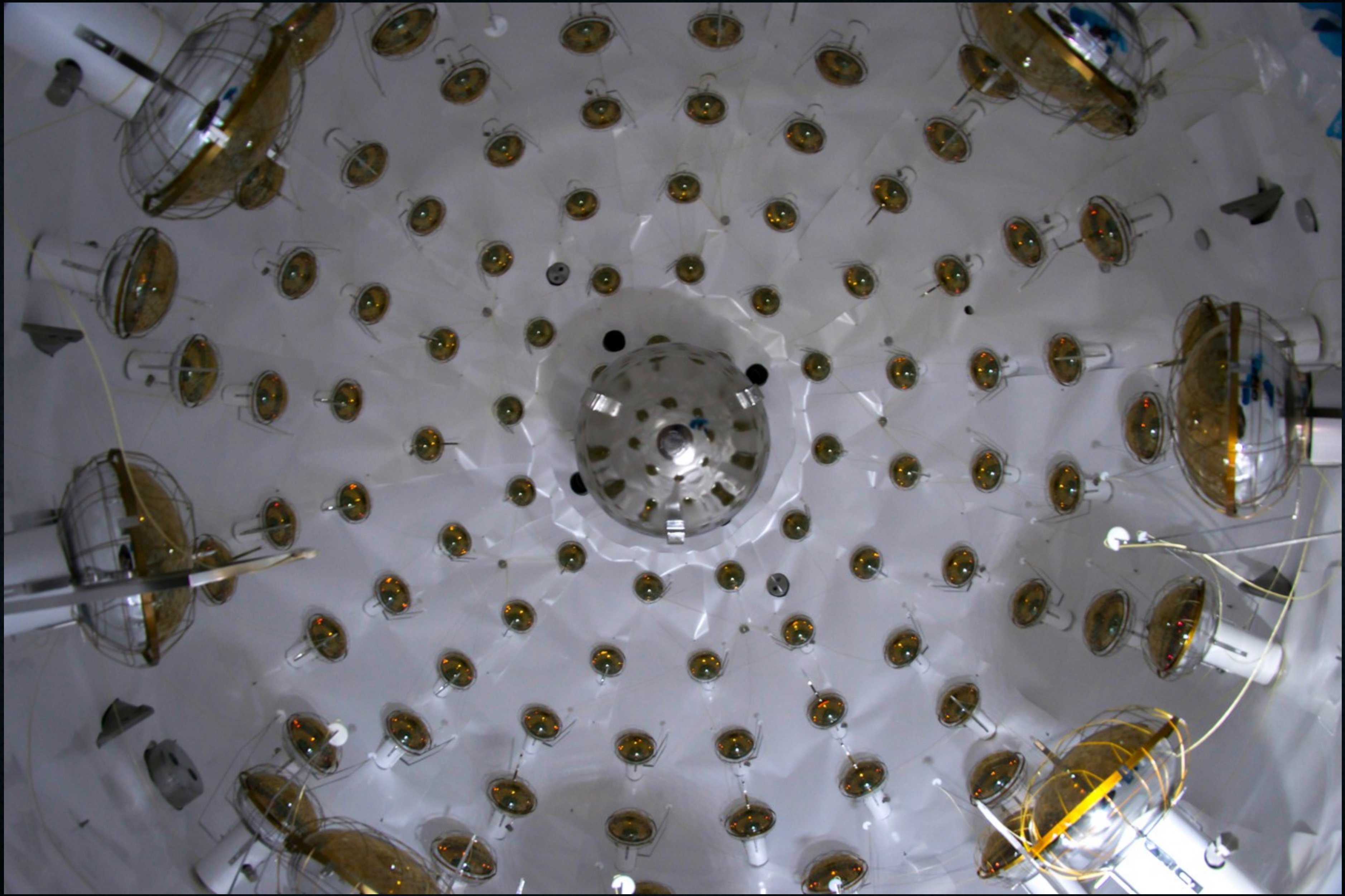
Testing Prompt Response



- ☑ Neutron capture producsts are detectable
- ☑ Prompt signal is detectable

Begin: The DarkSide

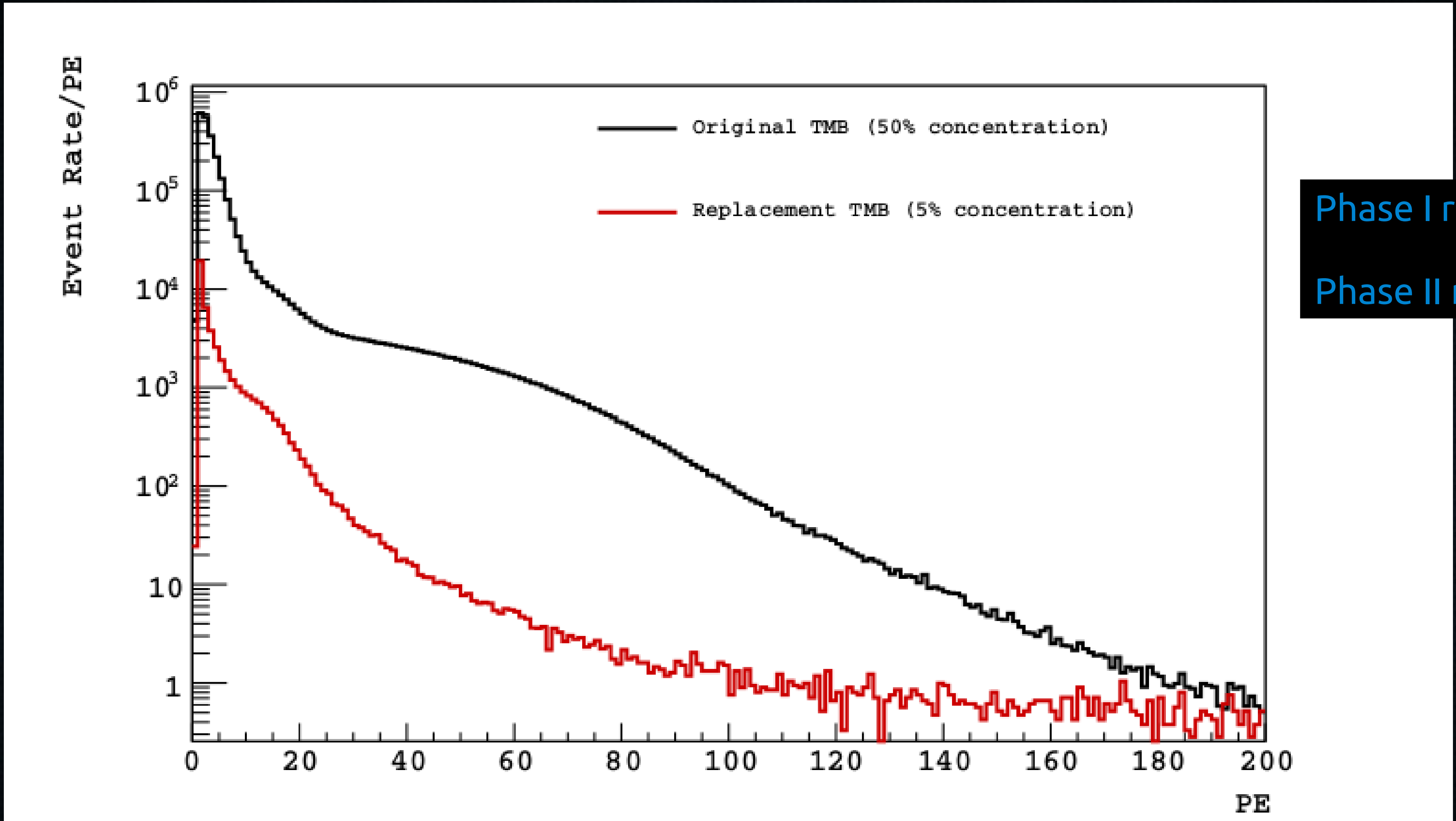




The LSV: A Tale of Two Cocktails

- Phase I
  - Nov 2013 – Jun 2014
  - 50% PC, 50% TMB
  - 2.5 g/L PPO
  - Overwhelming ^{14}C contamination from TMB ~200 kBq from atmospheric ^{14}C
  - Neutron capture time ~2.2 us
  - High light yield >0.5 PE/keV

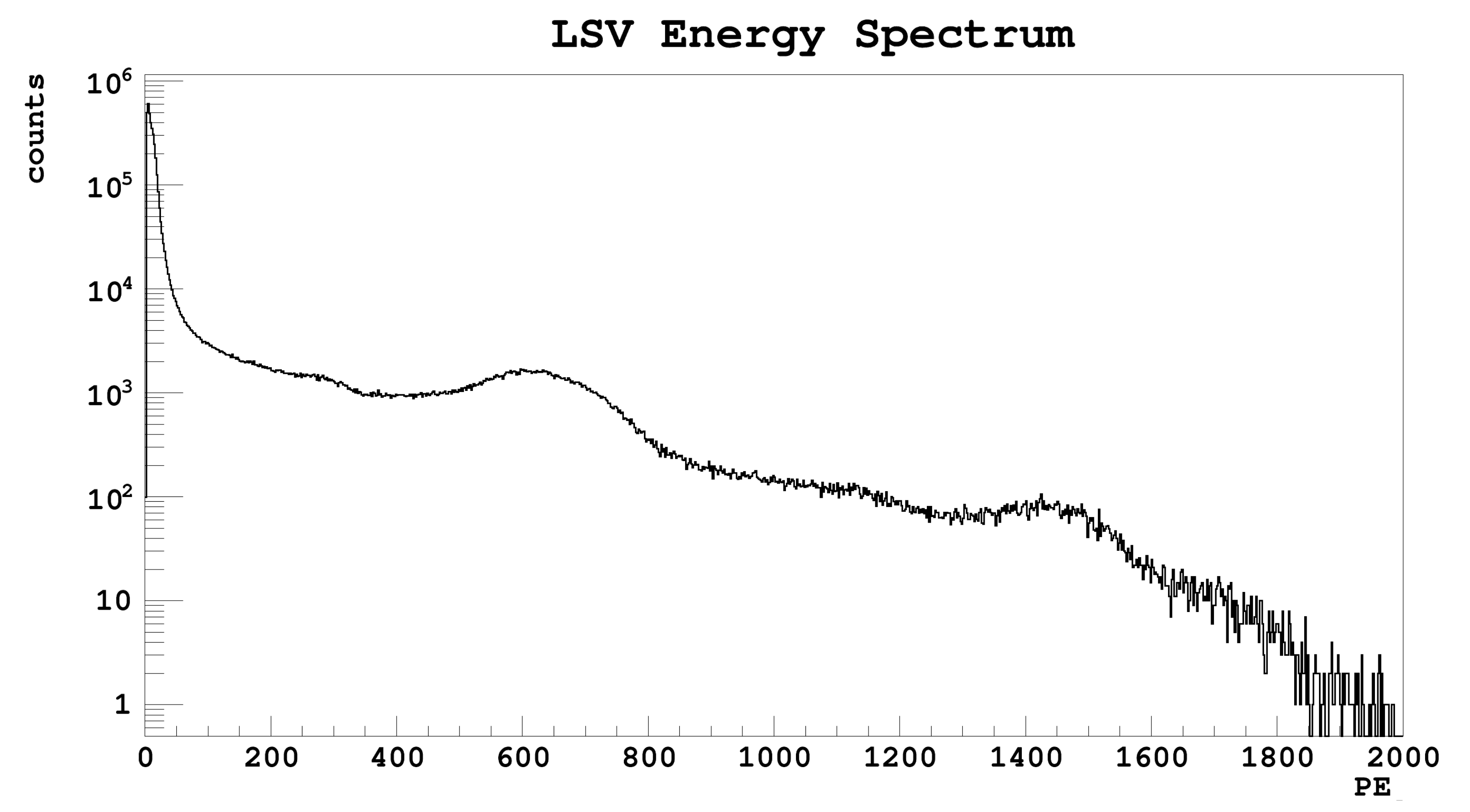
- Phase II
  - Apr 2015 – Present
  - 95% PC, 5% TMB
  - 1.4 g/L PPO
  - New TMB made from petroleum – much lower ^{14}C rate ~250 Bq (measured ^{14}C contamination of new TMB at the LLNL accelerator mass spectrometer to be below background)
  - Neutron capture time ~22 us
  - High light yield > 0.5 PE/keV



Phase I rate: ~200 kBq

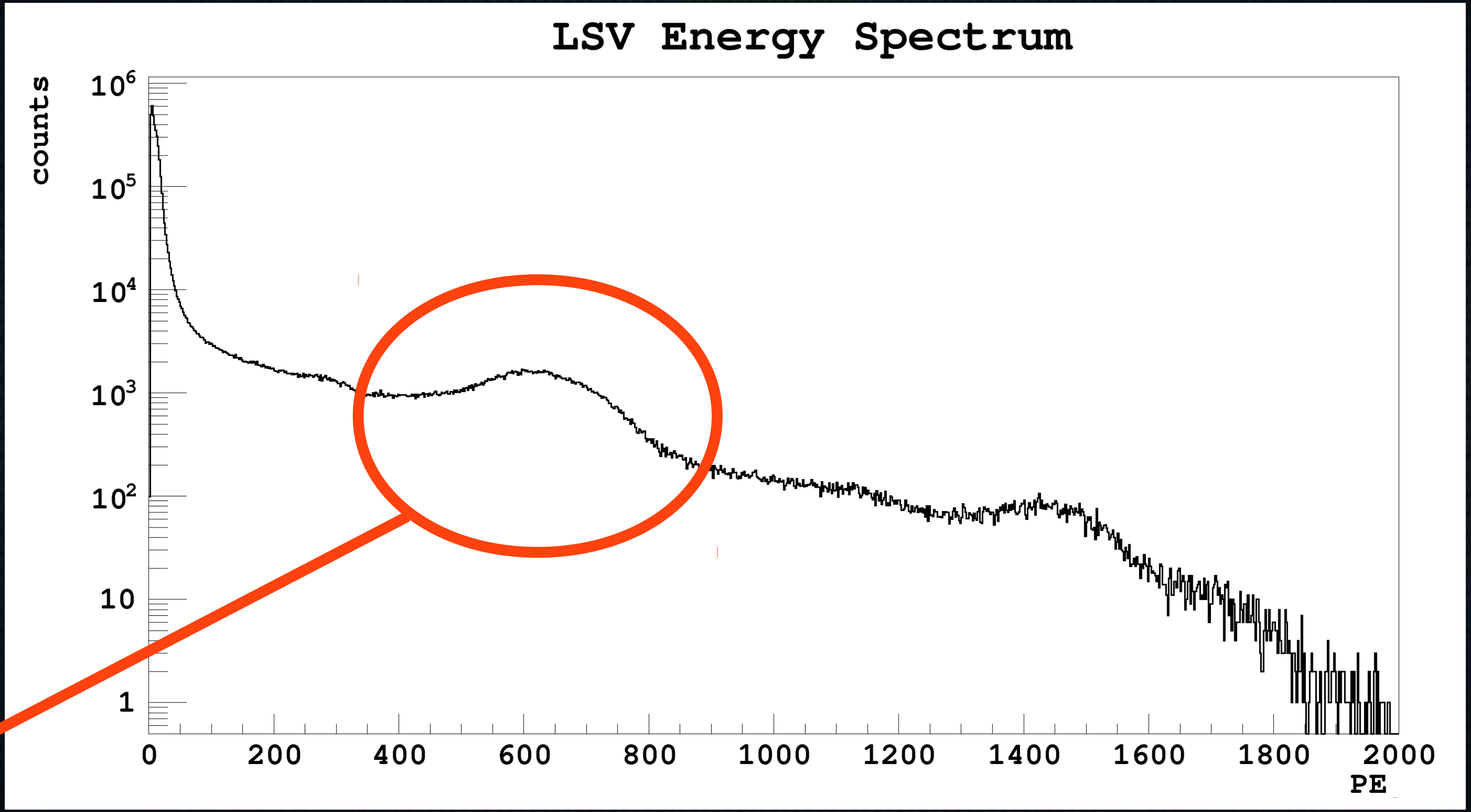
Phase II rate: 245 Bq

Prompt LSV-TPC Coincidence



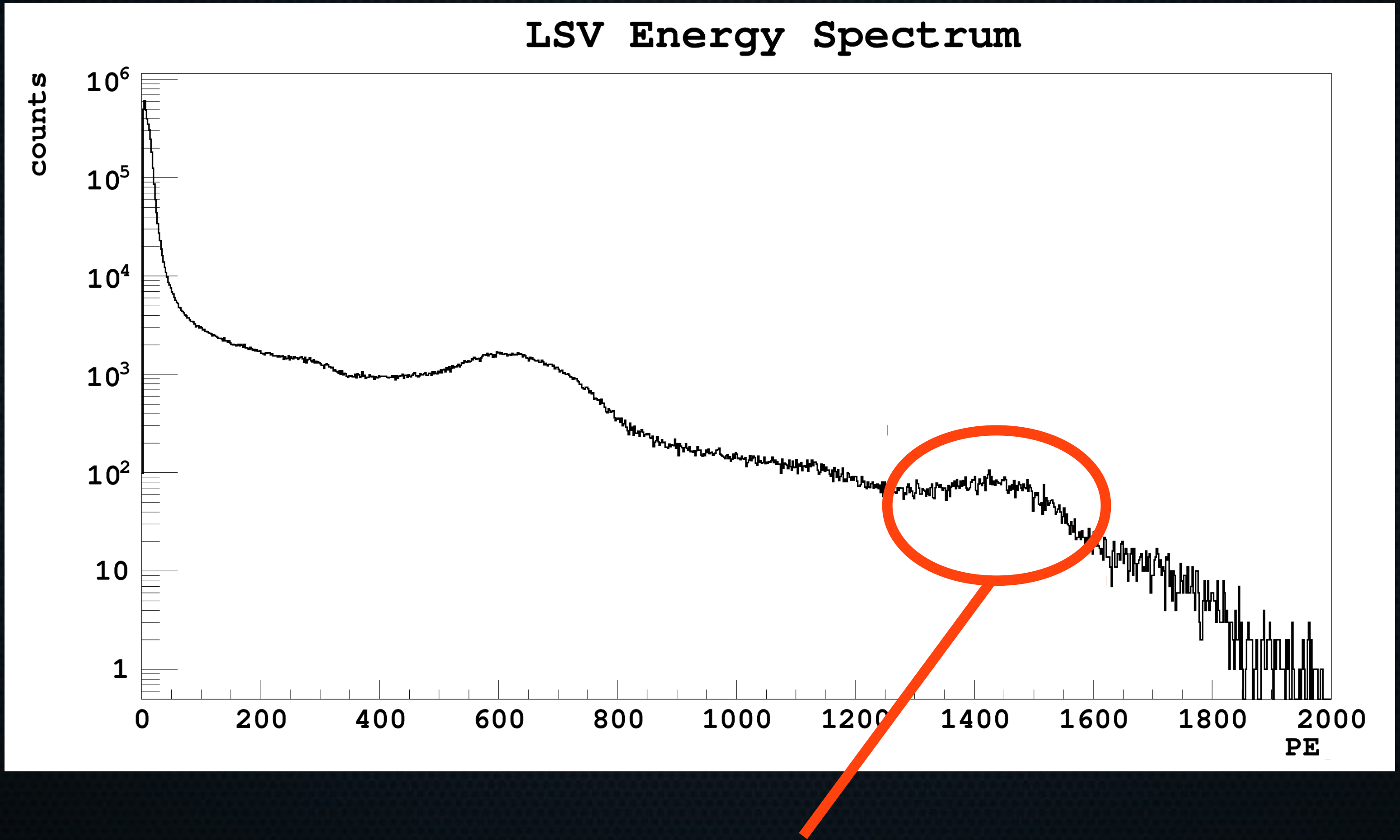
Note: these are mostly γ rays

Prompt LSV-TPC Coincidence



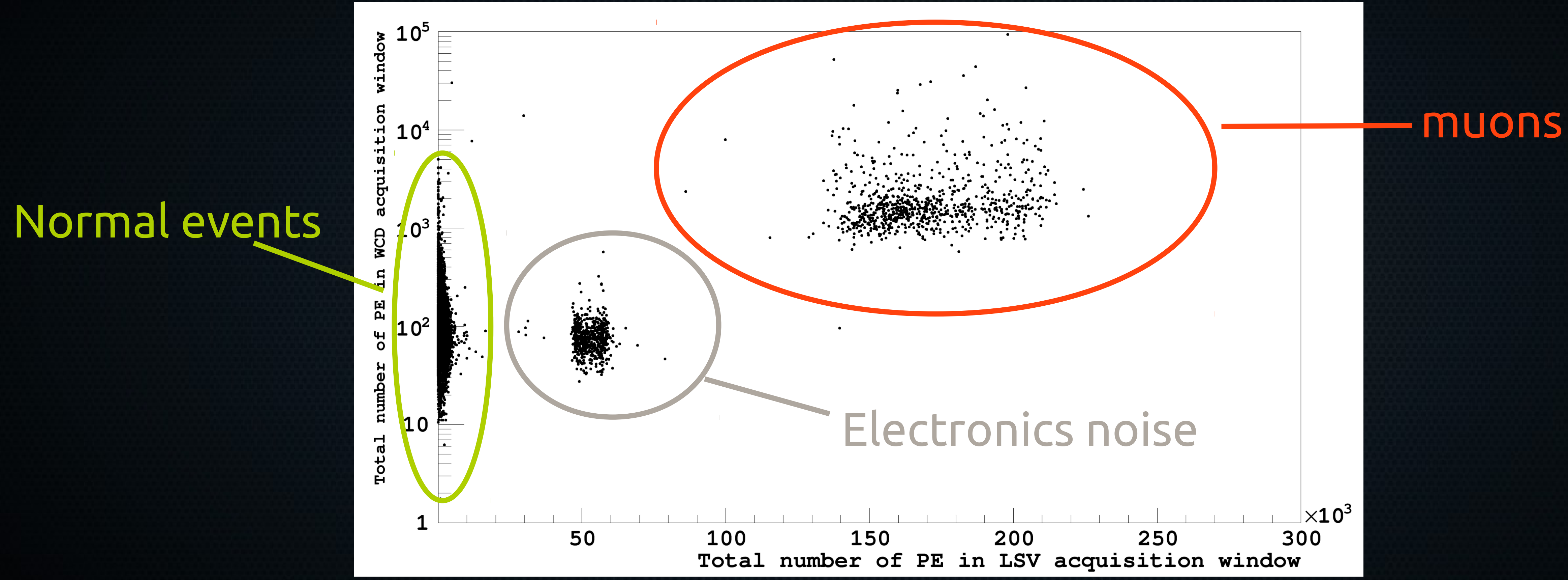
^{60}Co: γ (1.17 MeV, 1.33 MeV) → 0.59 PE/keV

Prompt LSV-TPC Coincidence



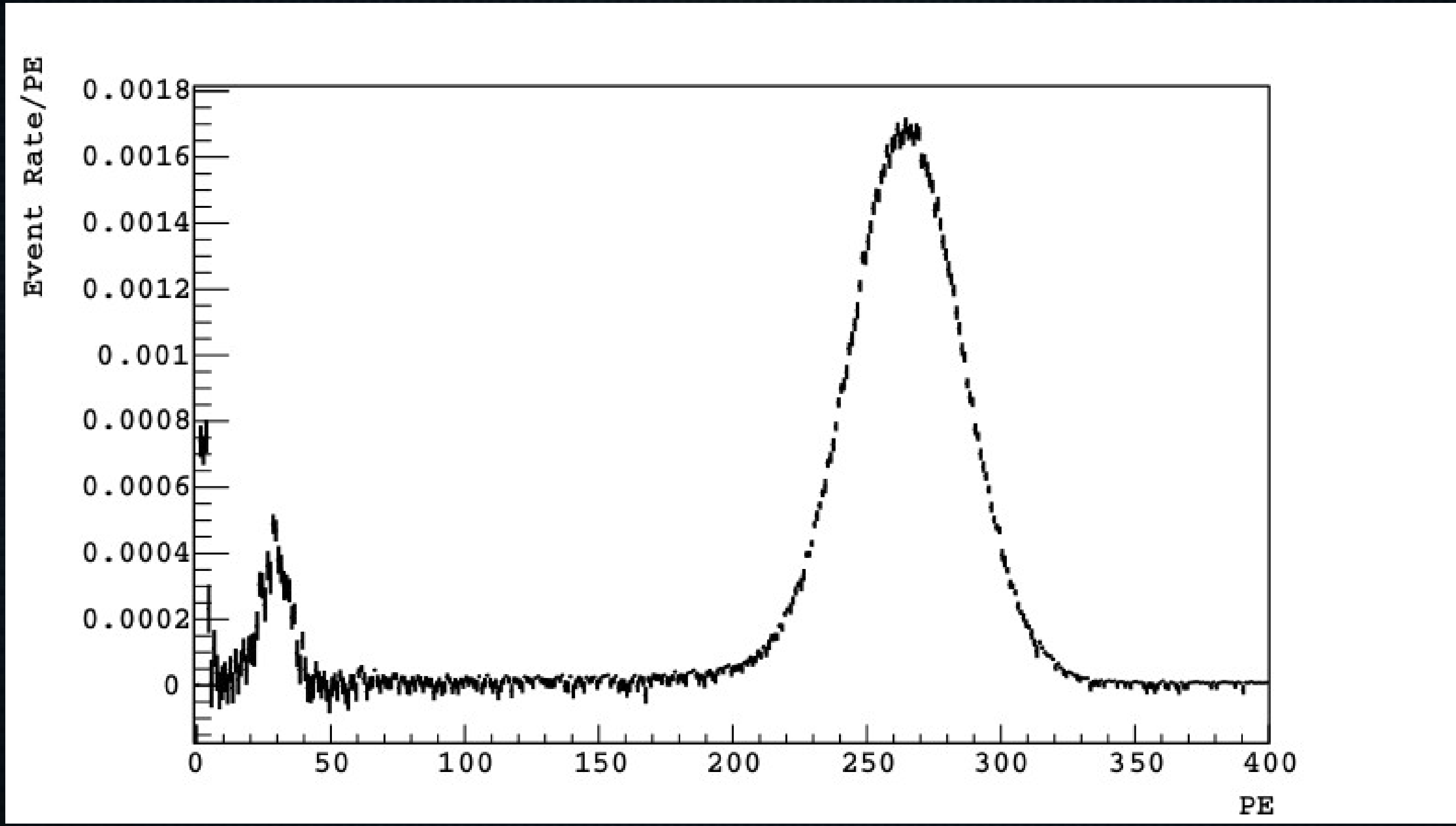
^{208}Tl: γ (2.6 MeV) $\rightarrow$ 0.55 PE/keV

Muons



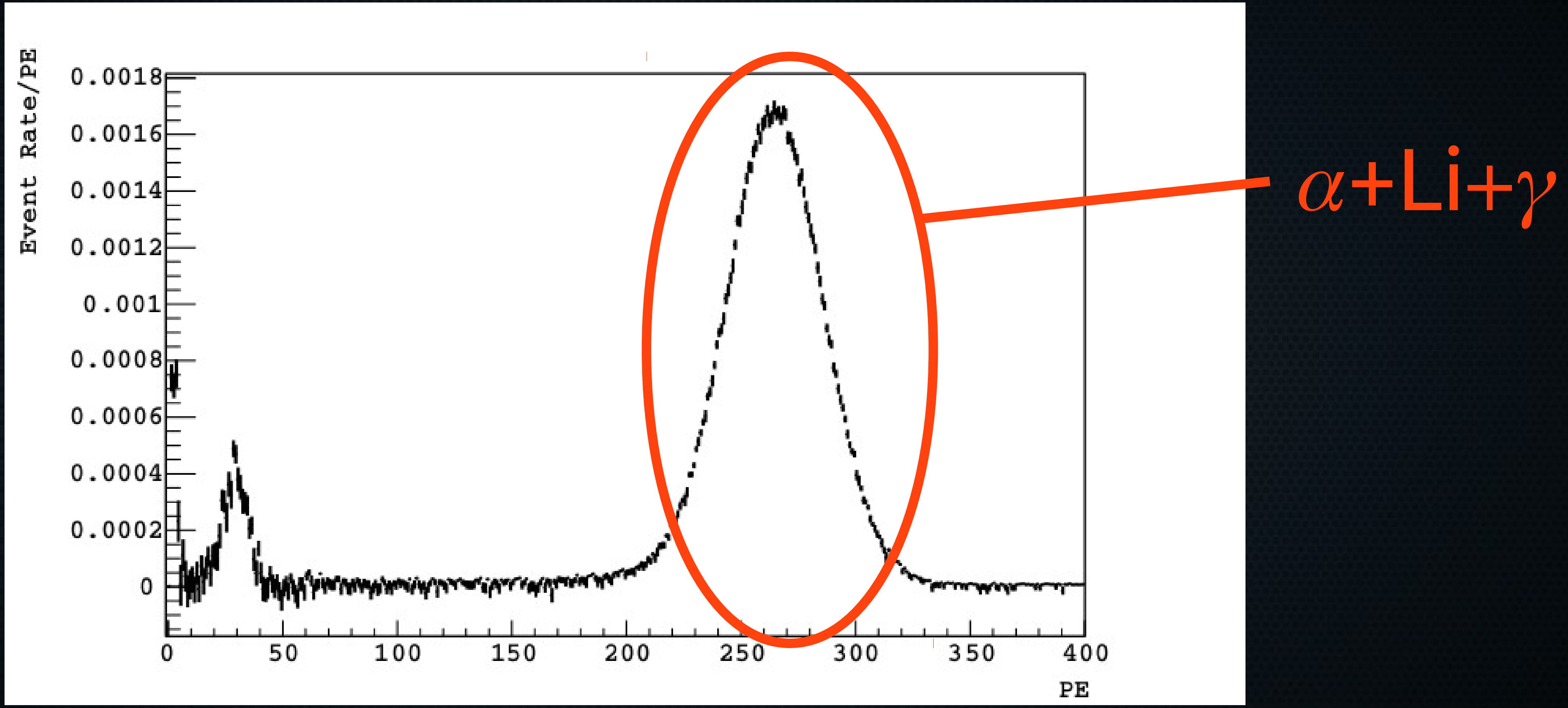
Normal events
muons
Electronics noise
Total number of PE in WCD acquisition window
Total number of PE in LSV acquisition window
1
10
10^2
10^3
10^4
10^5
50
100
150
200
250
300
$\times10^3$

Neutron Capture Signal



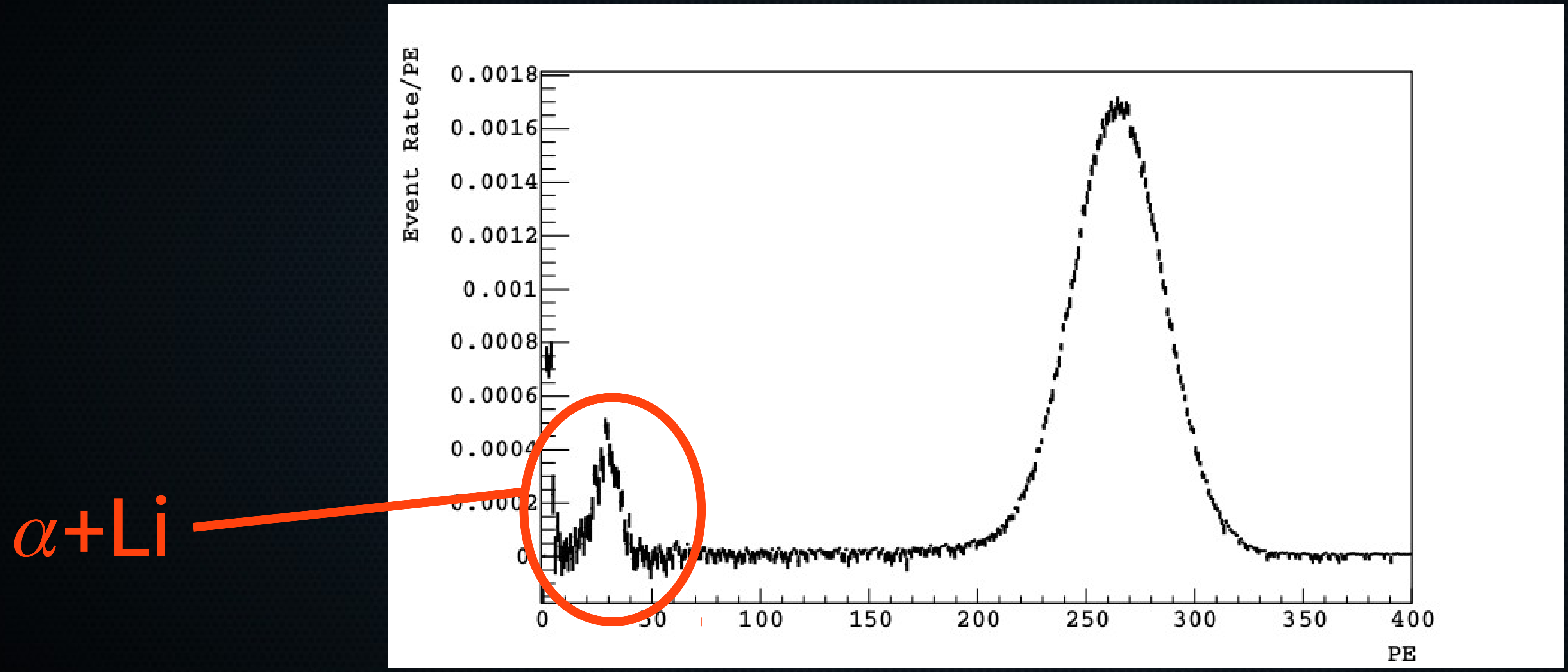
$^{241}Am^{9}Be$ Calibration Run

Neutron Capture Signal



^{241}Am^{9}Be Calibration Run

Neutron Capture Signal



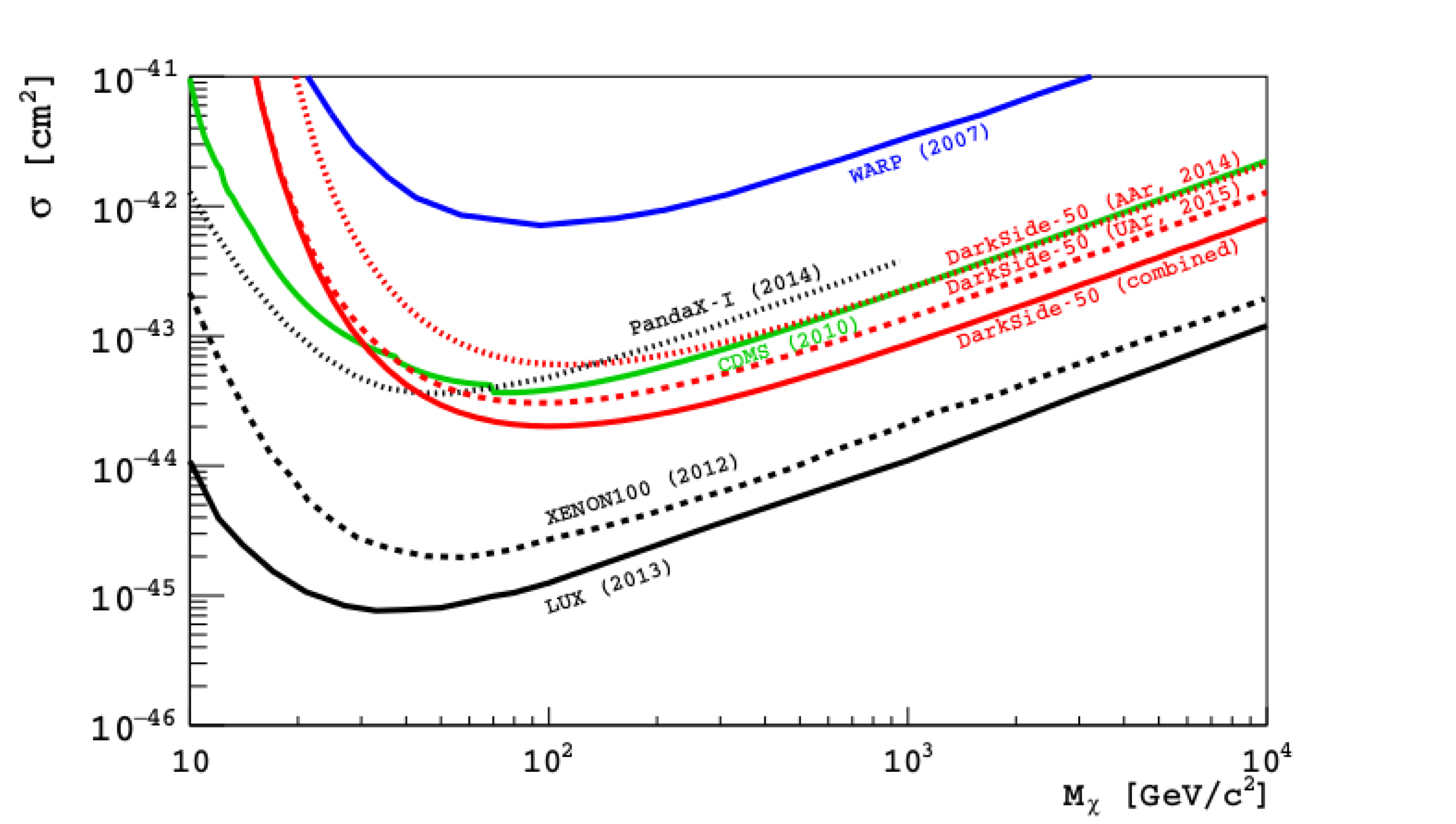
$^{241}Am^{9}Be$ Calibration Run

Neutron Vetoing Efficiency

- Calibrations and simulations: vetoing efficiency from capture signal alone is > 99.1%
  - ~7.7% of neutrons capture on ^{1}H; 2.2 MeV γ lost ~8% of the time
    - 0.62% loss from this channel
  - ~0.23% capture after the LSV acquisition window has closed
  - ~0.05% leave no signal in LSV at all
- Total efficiency is even larger due to thermalization signal
  - Low background → cut with 1 PE threshold (~0.9% acceptance loss)
  - Will evaluate using $^{241}Am^{13}C$ source

Results

- 118 live days of running
  - "First Results from the DarkSide-50 Dark Matter Experiment at Laboratori Nazionali del Gran Sasso"
  - "Low radioactivity argon dark matter search results from the DarkSide-50 experiment"
- 2 neutrons vetoed that otherwise passed all cuts
  - 1 radiogenic
  - 1 cosmogenic
- 0 remaining backgrounds!



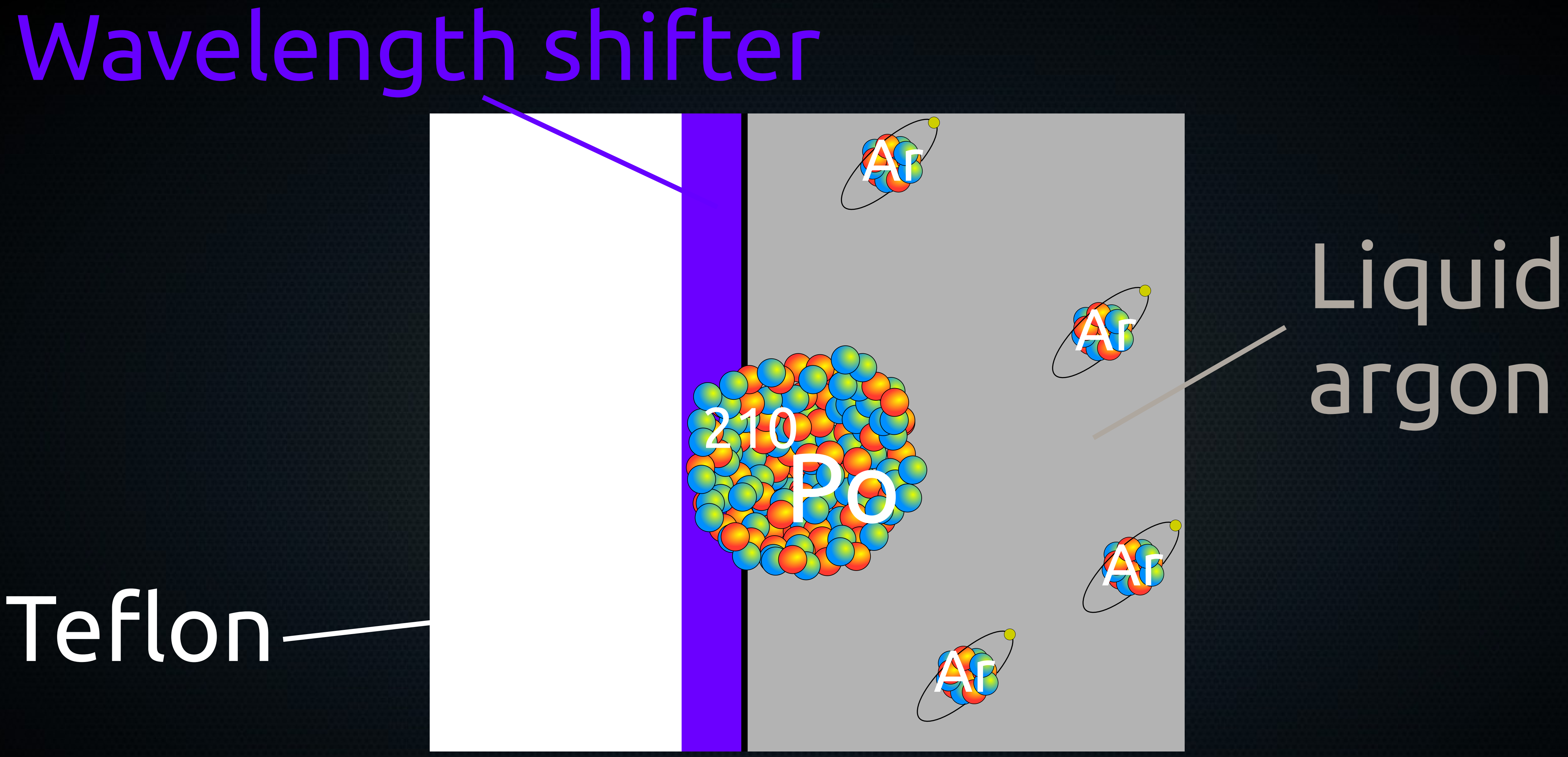
σ [cm^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10
10^2
10^3
10^4
M_χ [GeV/c^2]
WARP (2007)
DarkSide-50 (AAr, 2014)
DarkSide-50 (UAr, 2015)
DarkSide-50 (combined)
PandaX-I (2014)
CDMS (2010)
XENON100 (2012)
LUX (2013)

Summary

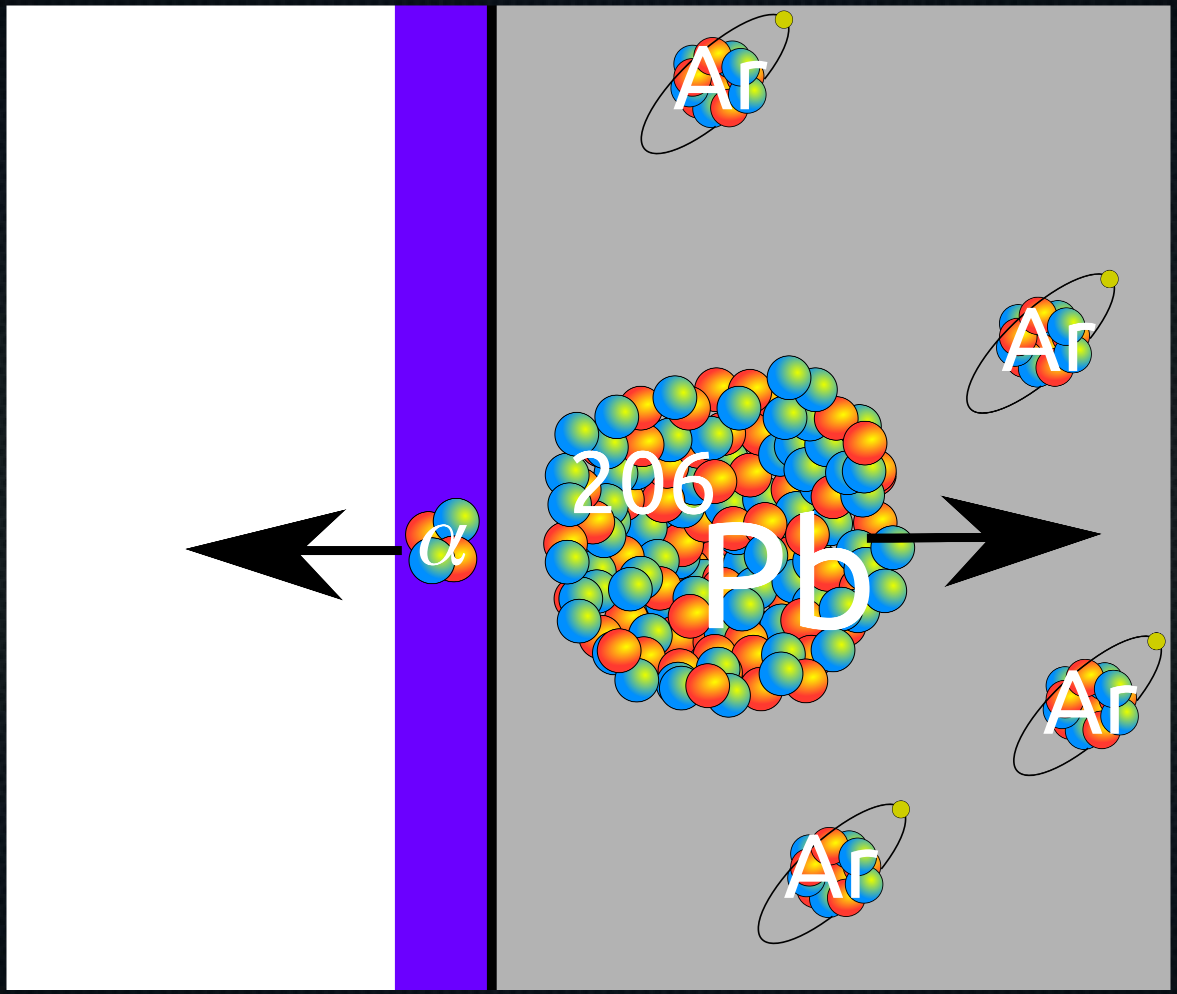
- Detecting WIMPs requires extraordinarily low backgrounds
- Electron recoil backgrounds can be effectively removed using pulse shape discrimination
- Nuclear recoil backgrounds from surface radioactivity can be removed with position cuts
- Nuclear recoil backgrounds from neutrons can be removed with our highly efficient neutron veto
- DarkSide has collected 118 days of data background free

Further R&D

Surface backgrounds: The other nuclear recoil


Wavelength shifter
Liquid argon
Teflon
Ar
Ar
Ar
Ar
210
Po

- $T^{1/22}{}_{Po\text{-}210}$ = 138 d
- $E(\alpha)$ = 5.304 MeV
- $E(^{206}Po)$ = 103 keV



- $T^{1/22}_{Po\text{-}210}$ = 138 d
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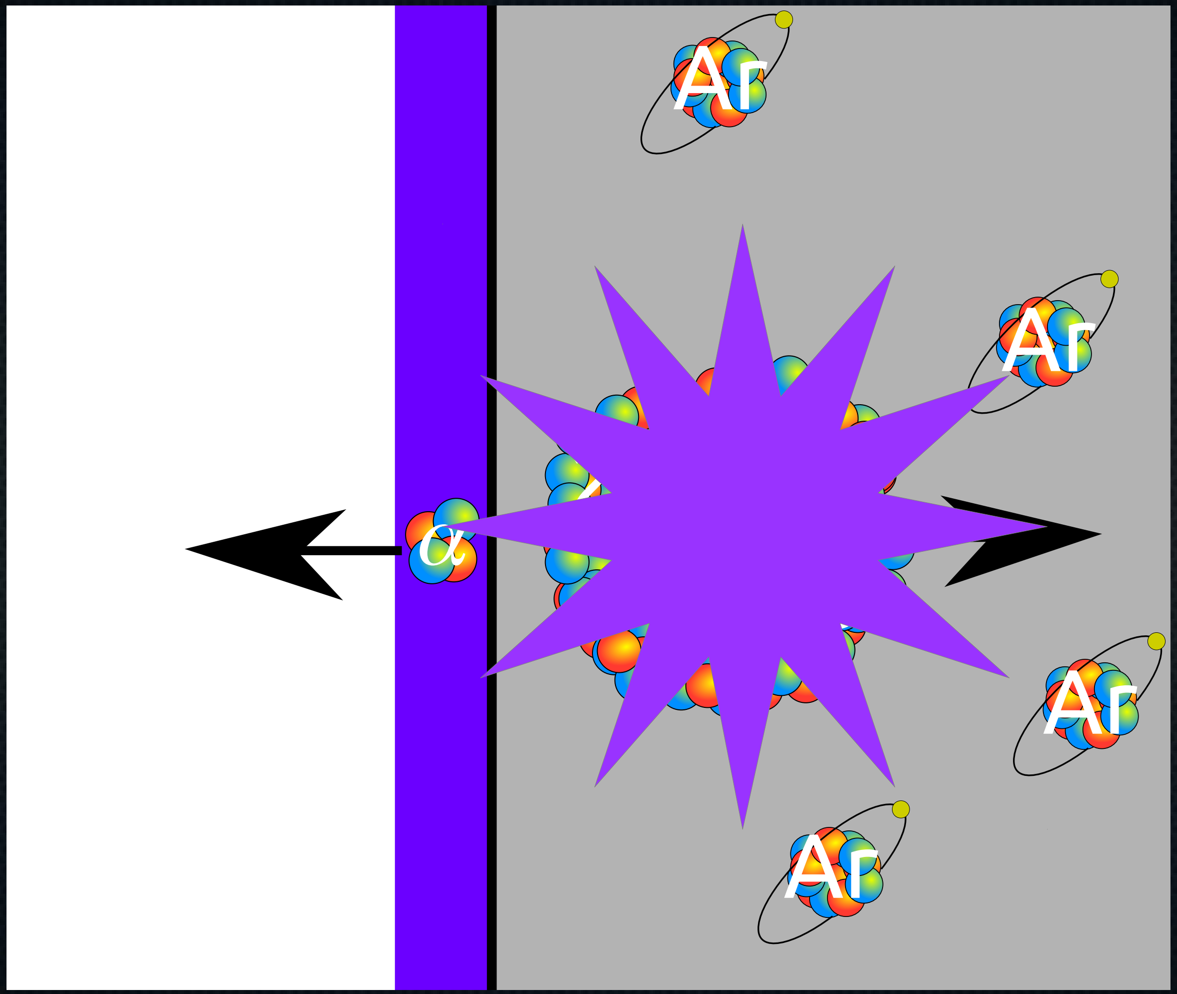
- $E(^{206}Po)$ = 103 keV

Nuclear recoil!



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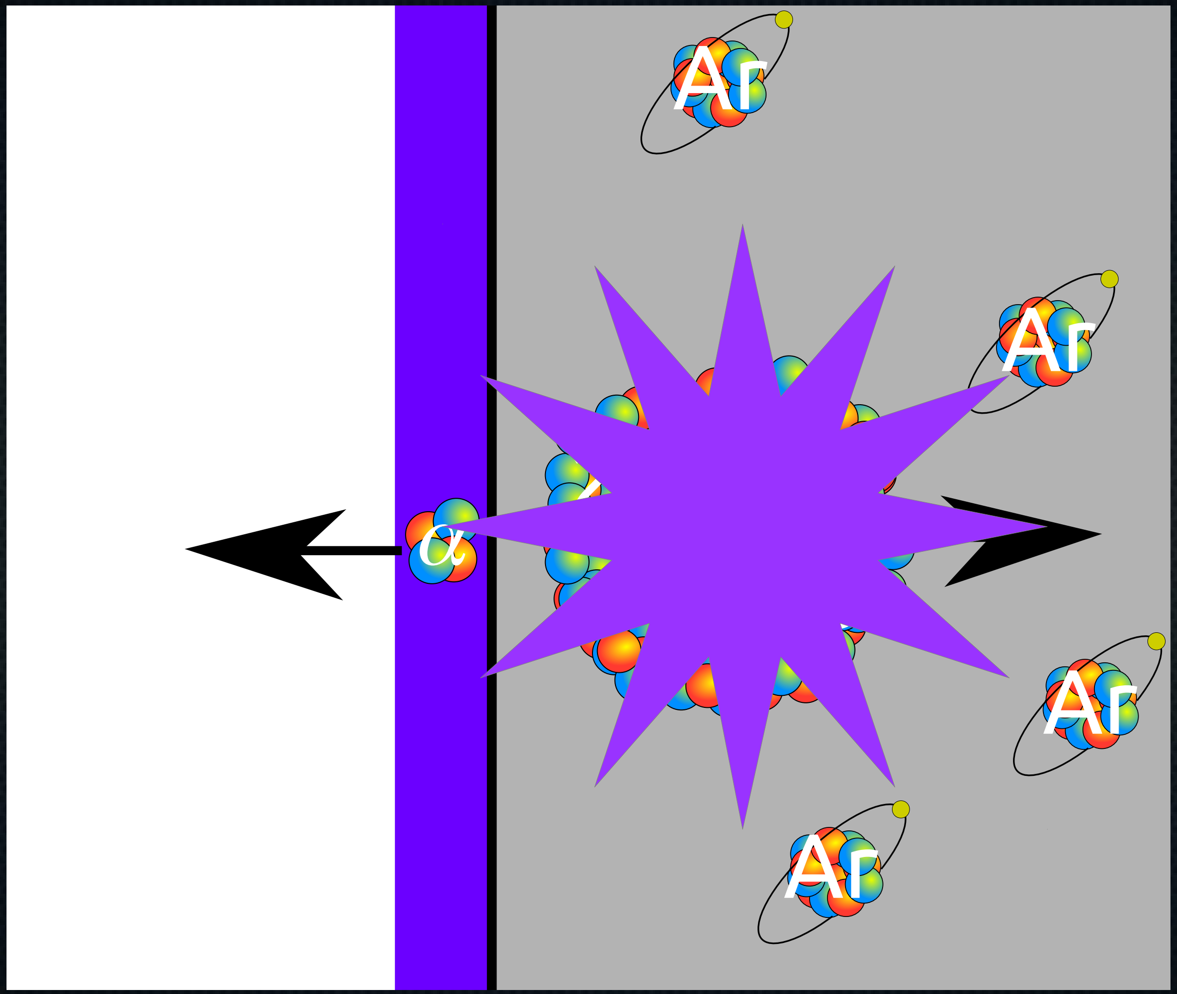
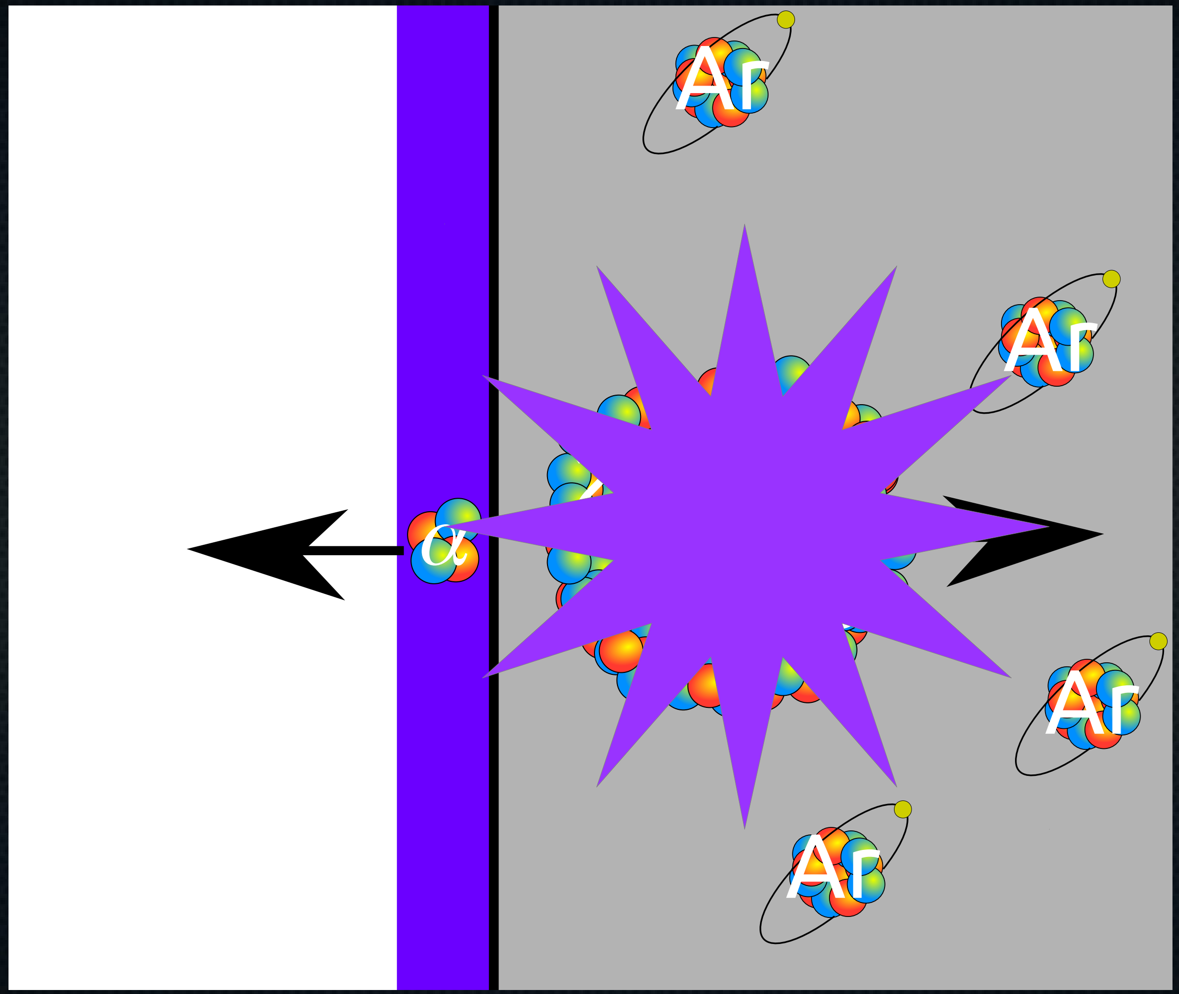


Usual strategy: Position cuts

- $T^{1/22}_{Po\text{-}210}$ = 138 d
- $E(\alpha)$ = 5.304 MeV
- $E(^{206}Po)$ = 103 keV

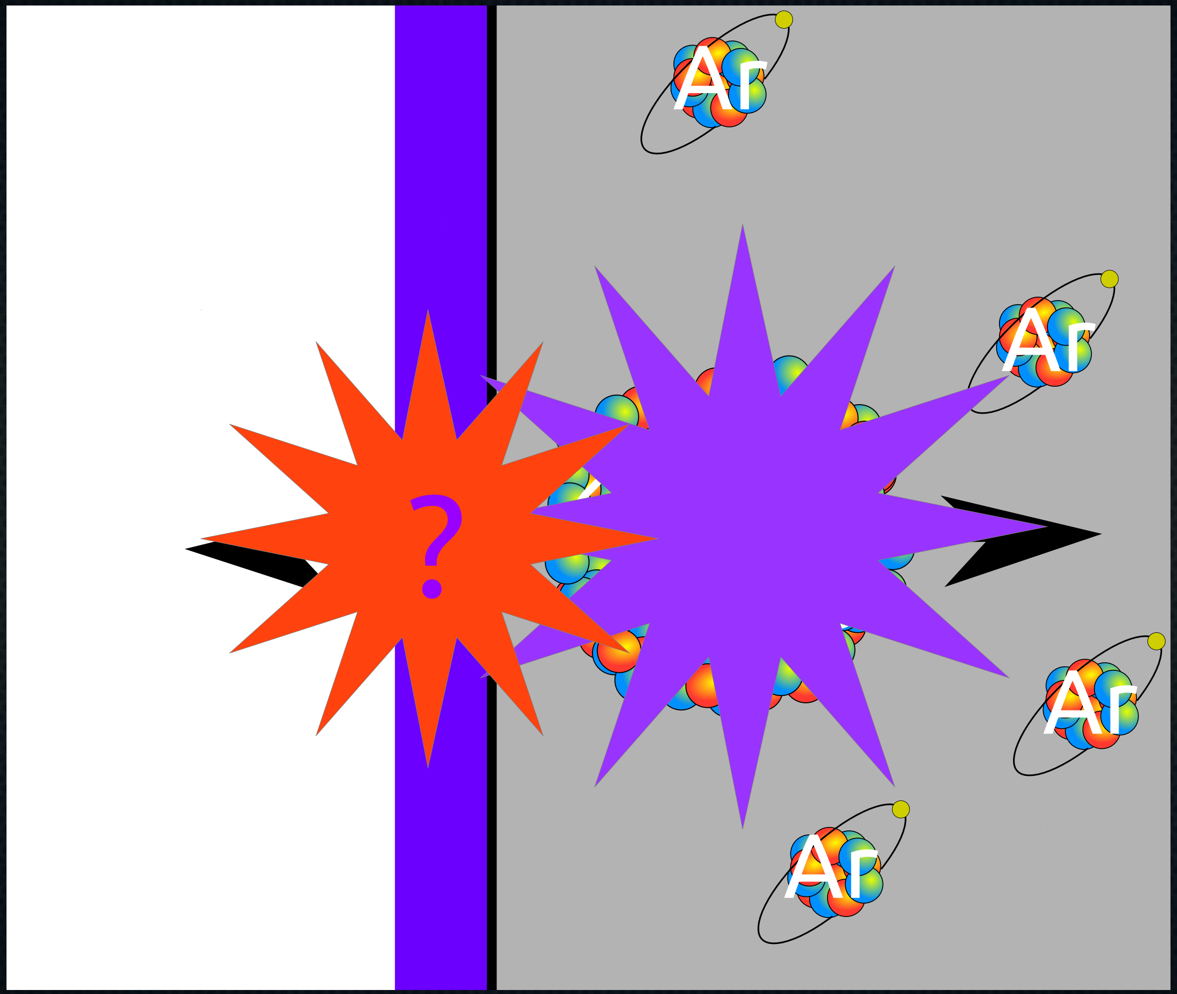
Nuclear recoil!



Usual strategy:
Position cuts

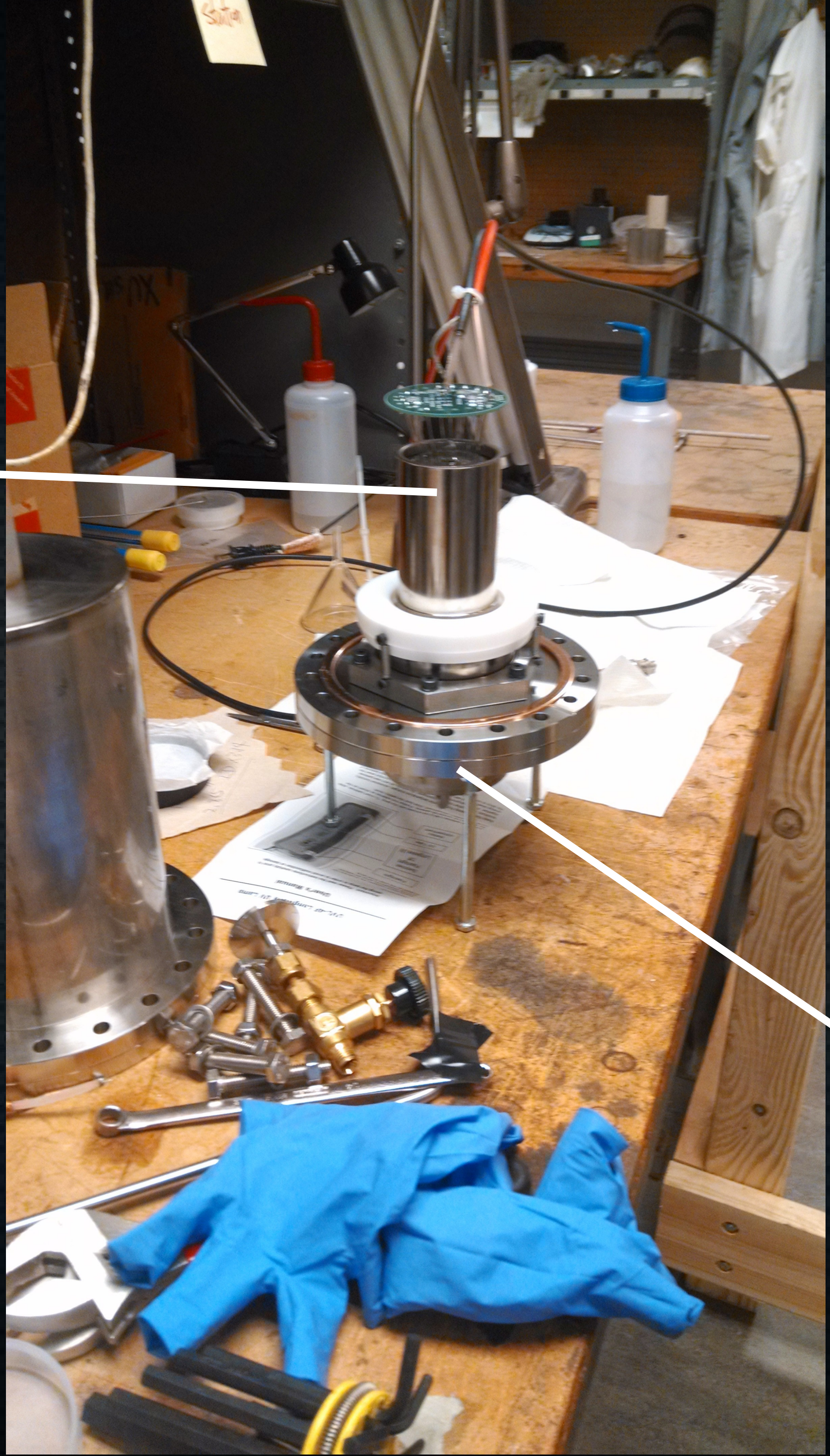
The problem:
- (x,y) reconstruction is hard
- Reduces exposure

Our solution:




OMEGA

PMT



Contains spectralon cup

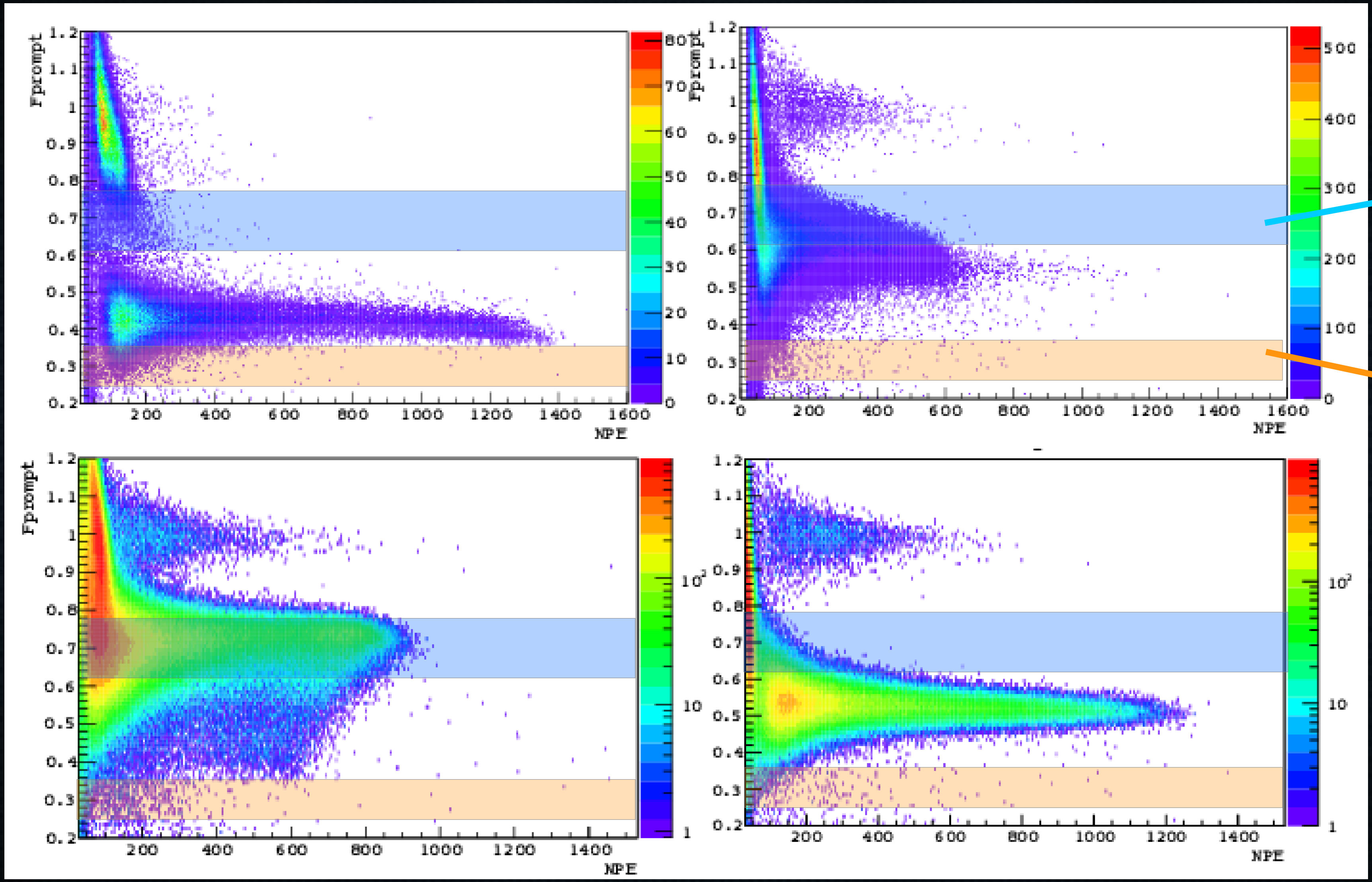
Tested wavelength shifters:

- Tetraphenyl butadiene (TPB)
- P-Terphenyl (pTP)

20°C -190°C

TPB

pTP



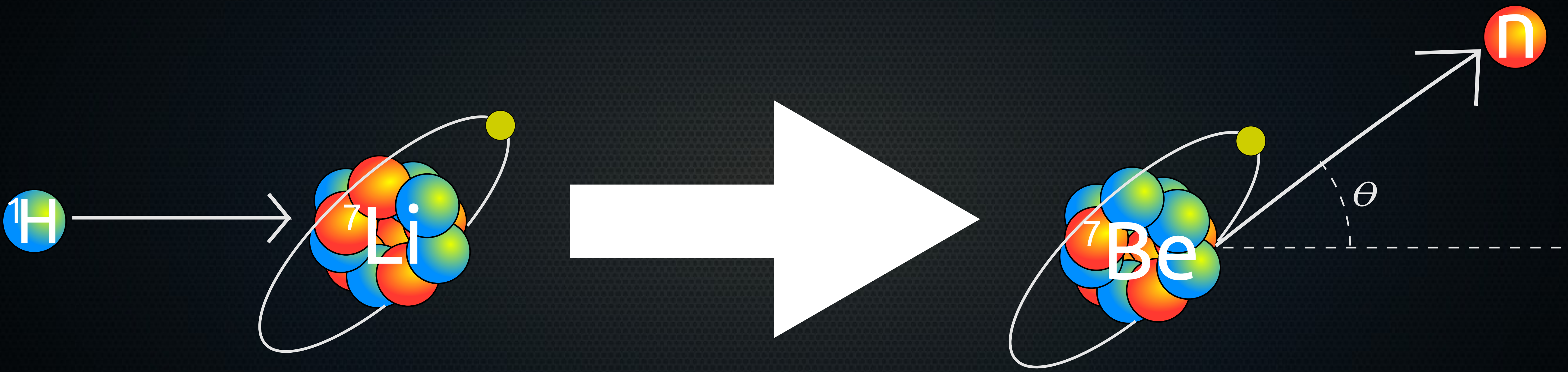
Using a ^{210}Po needle source


THE END

Neutron Rates

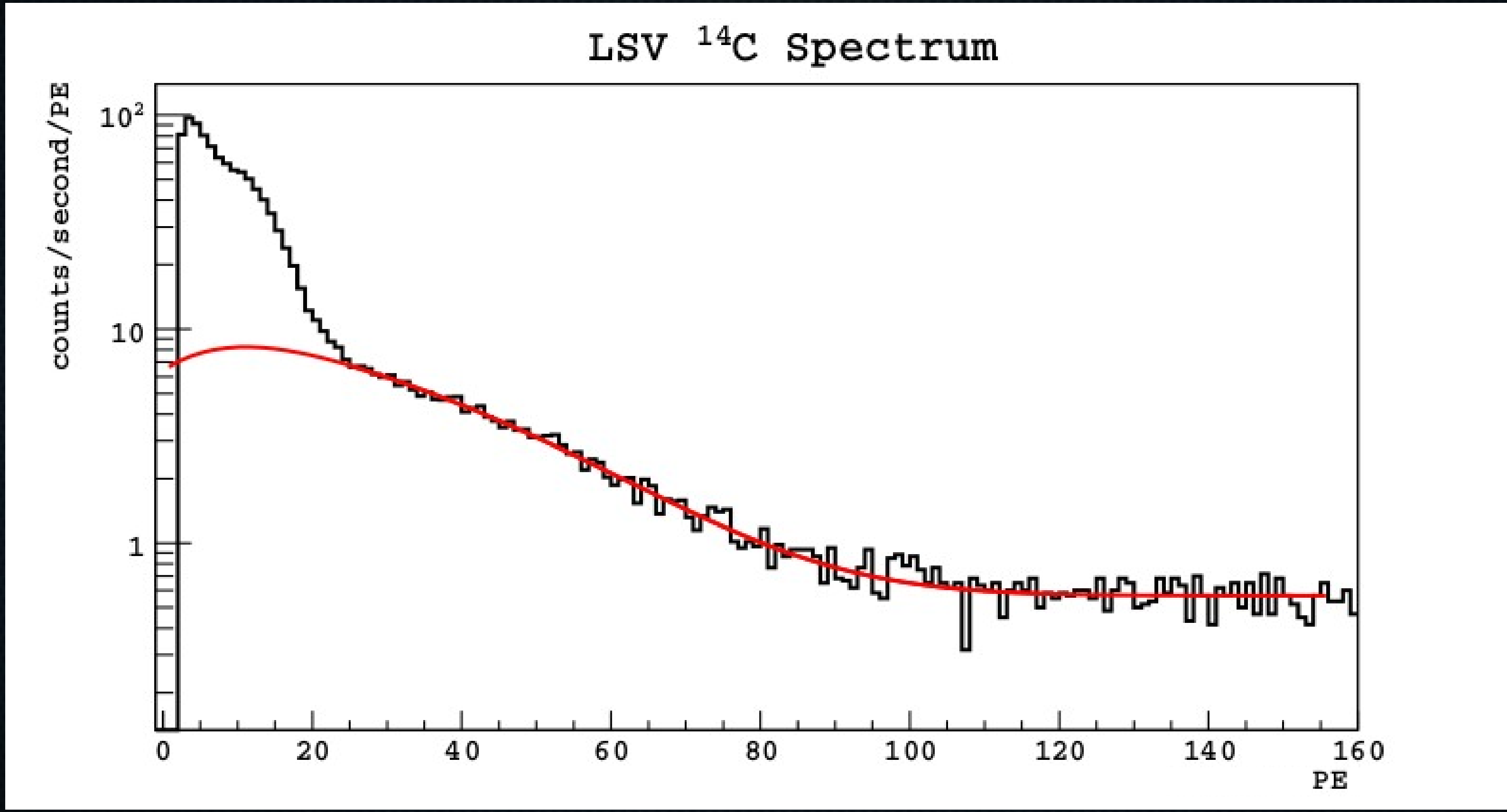
- Expect ~10 radiogenic neutron single scatters in the TPC per year
- Expect ~581 cosmogenic neutrons to enter the TPC per year (far fewer will produce single scatters in the WIMP search region)
  - FLUKA simulations show no events in 34 years where a cosmogenic neutron reaches the TPC and the LSV or WCD fails to trigger
  - A. Empl et al. *A Fluka study of undergroundcosmogenic neutron production*. JCAP, Aug. 2014.

Testing Prompt Response: Li(p,n)Be reaction



14C Measurement

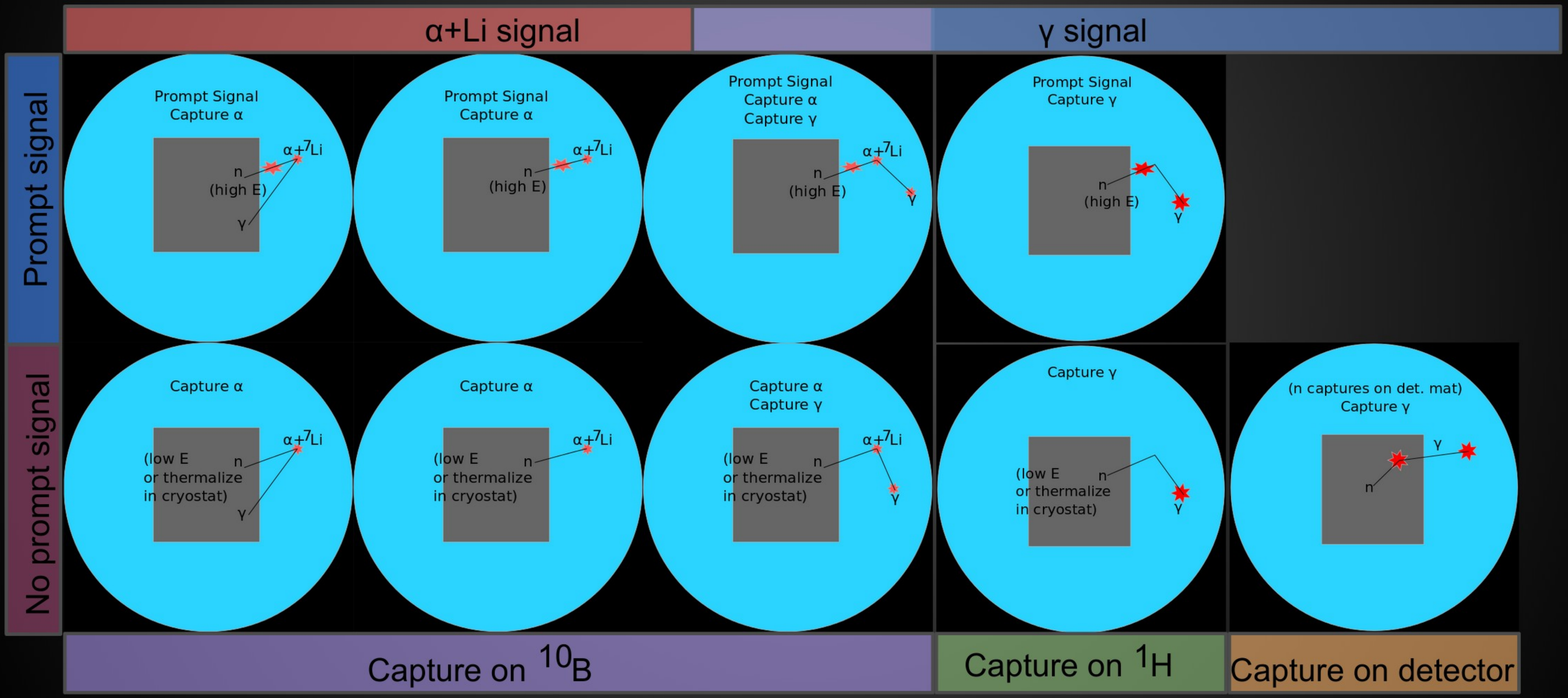
Phase II

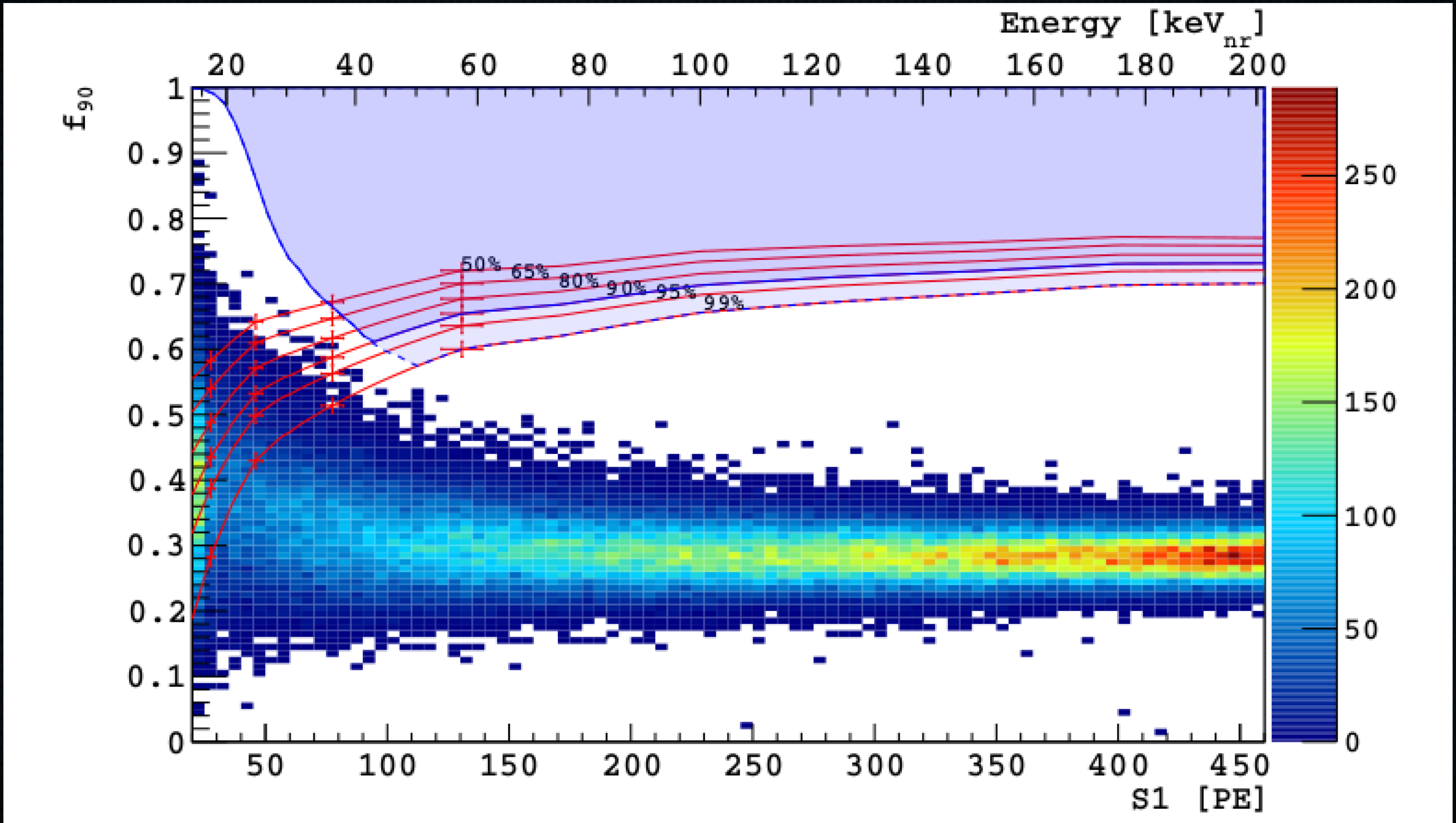


Assumed:
kB = 0.012 cm/MeV

Measured:
LY = 0.56(1) PE/keV
Rate = 245±27 Bq

Detection Mechanisms




Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f_{90}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
250
200
150
100
50
0