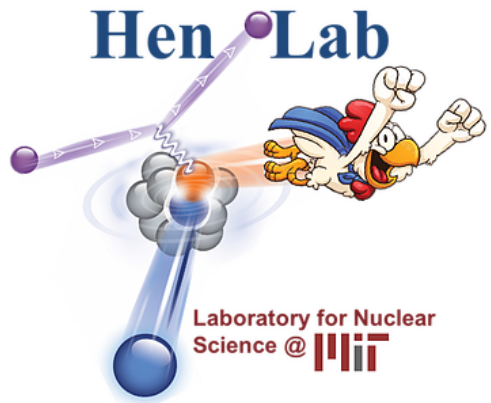
OLIVIA:
TPC-based ^{8}Li beta decay measurement

Axel Schmidt

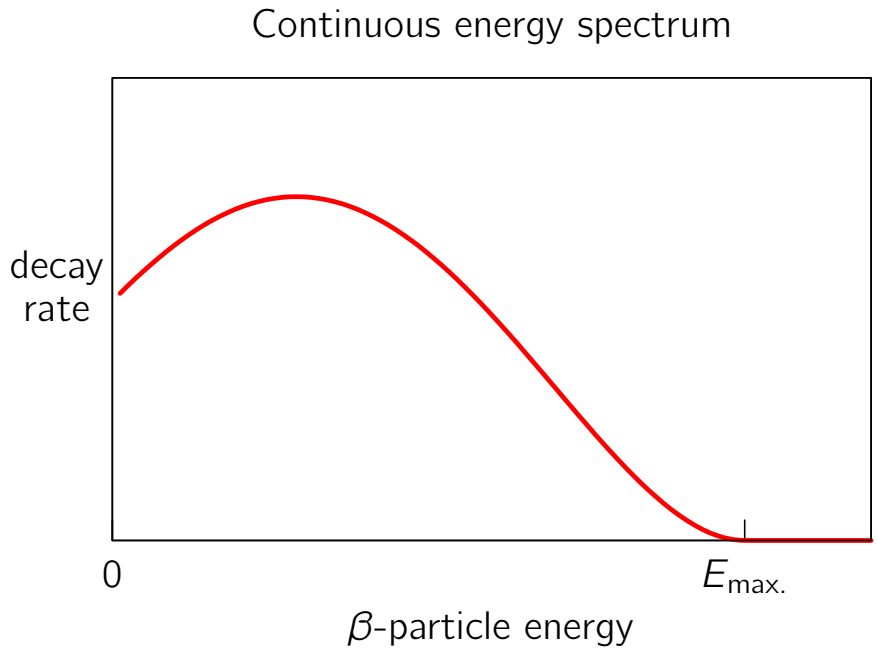
MIT

August 10, 2017

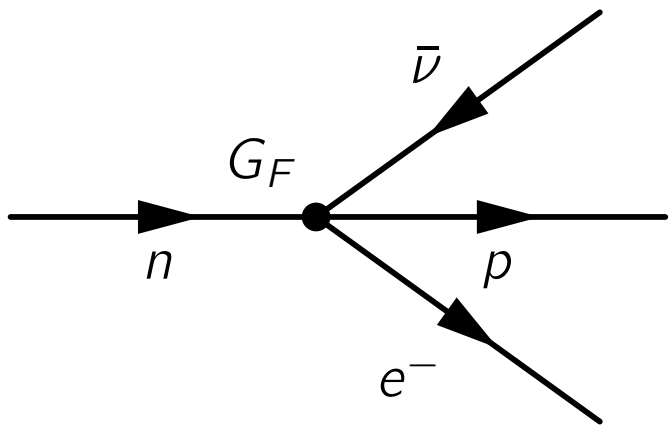


β-decay has led to the discovery of two particles.

Continuous energy spectrum
$\longrightarrow$ neutrino

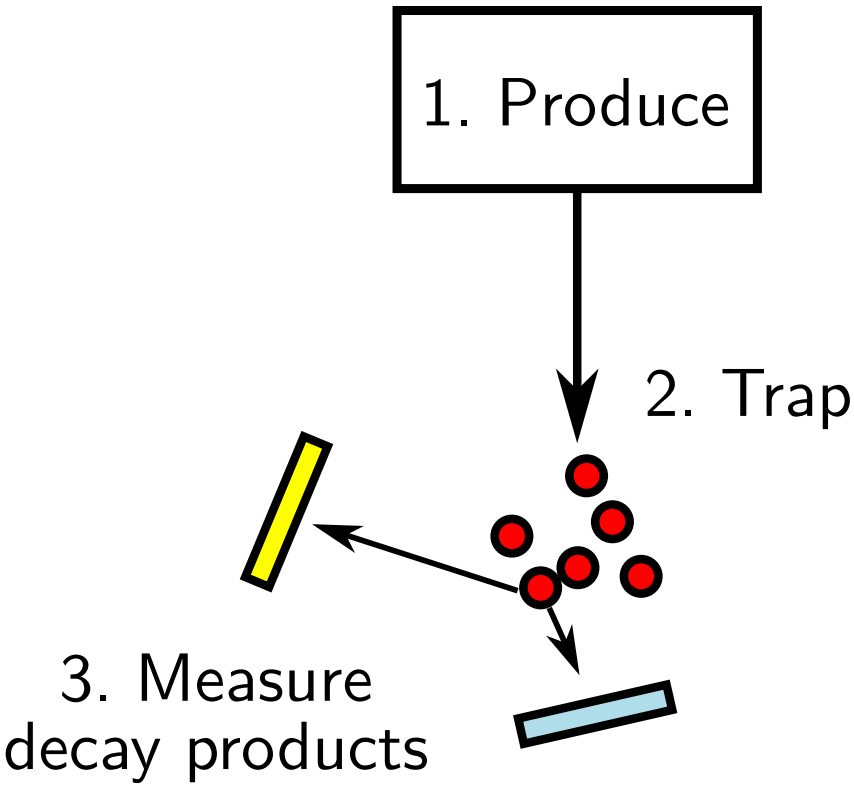


UV divergence of 4-point vertex
$\longrightarrow$ weak boson



$$\Gamma \sim G_F^2 E^2$$

Typical β-decay measurements use atom traps.



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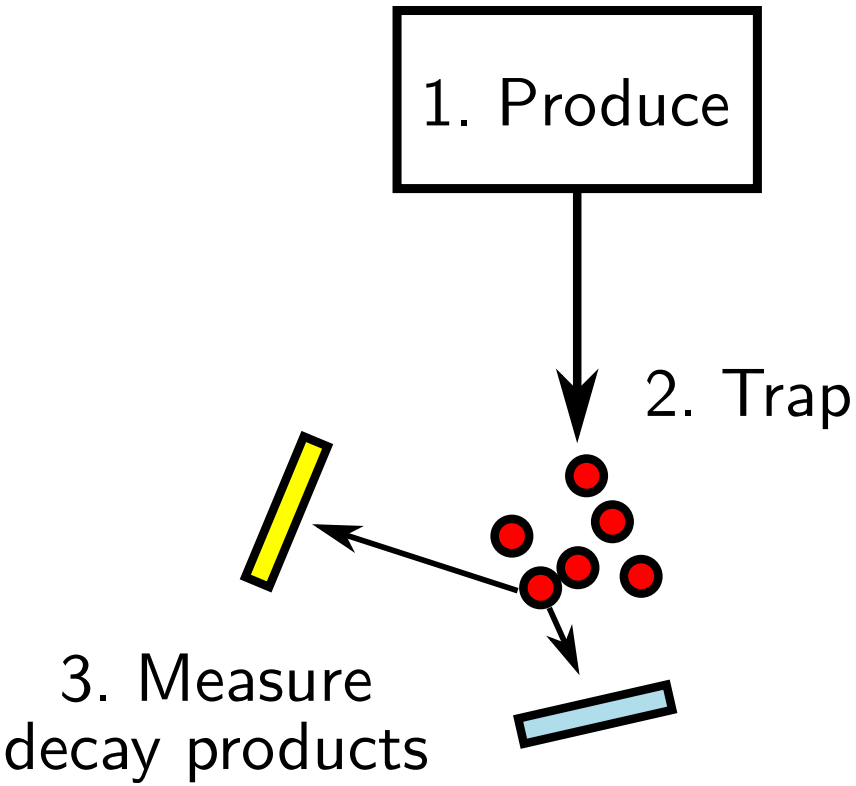
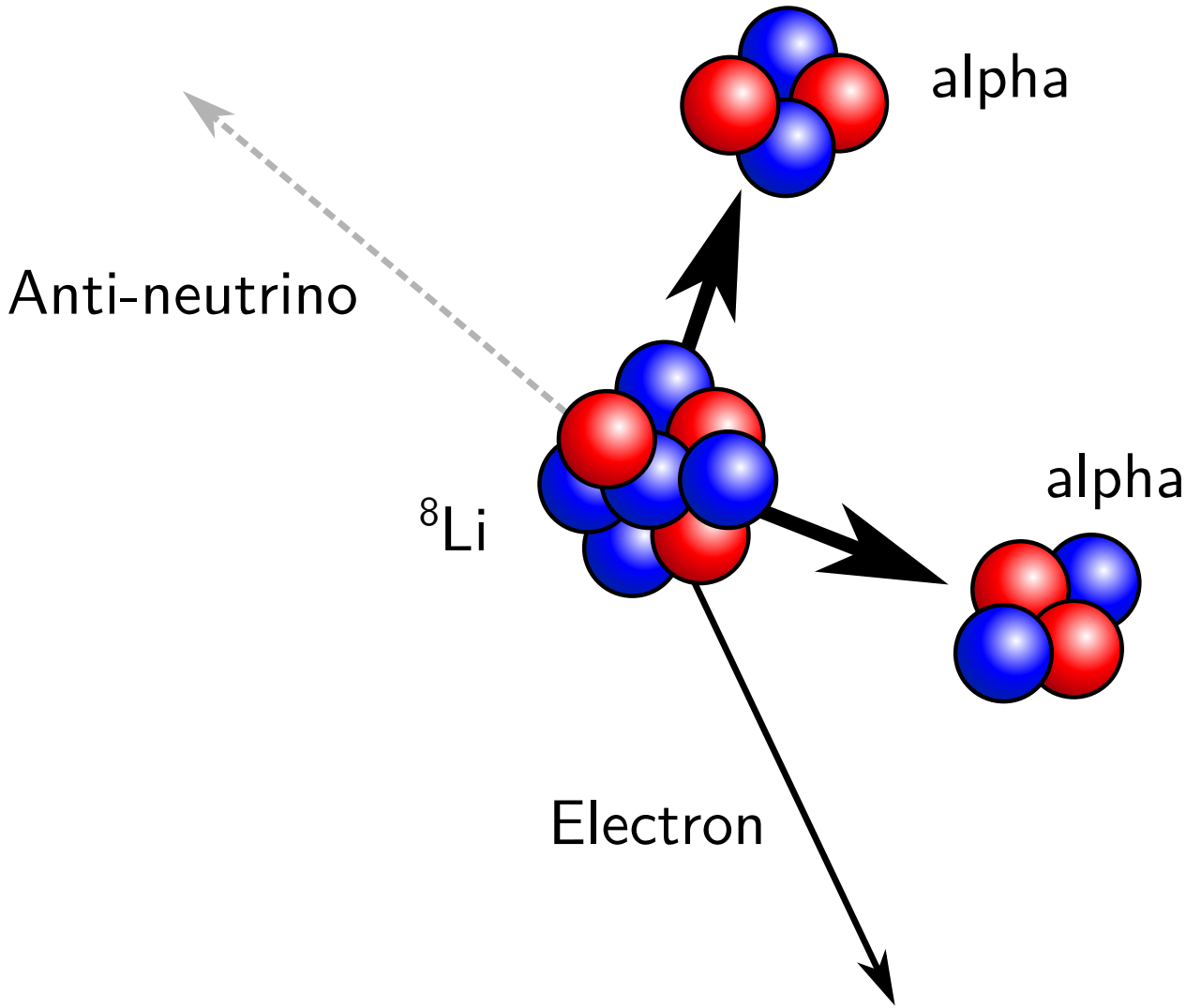


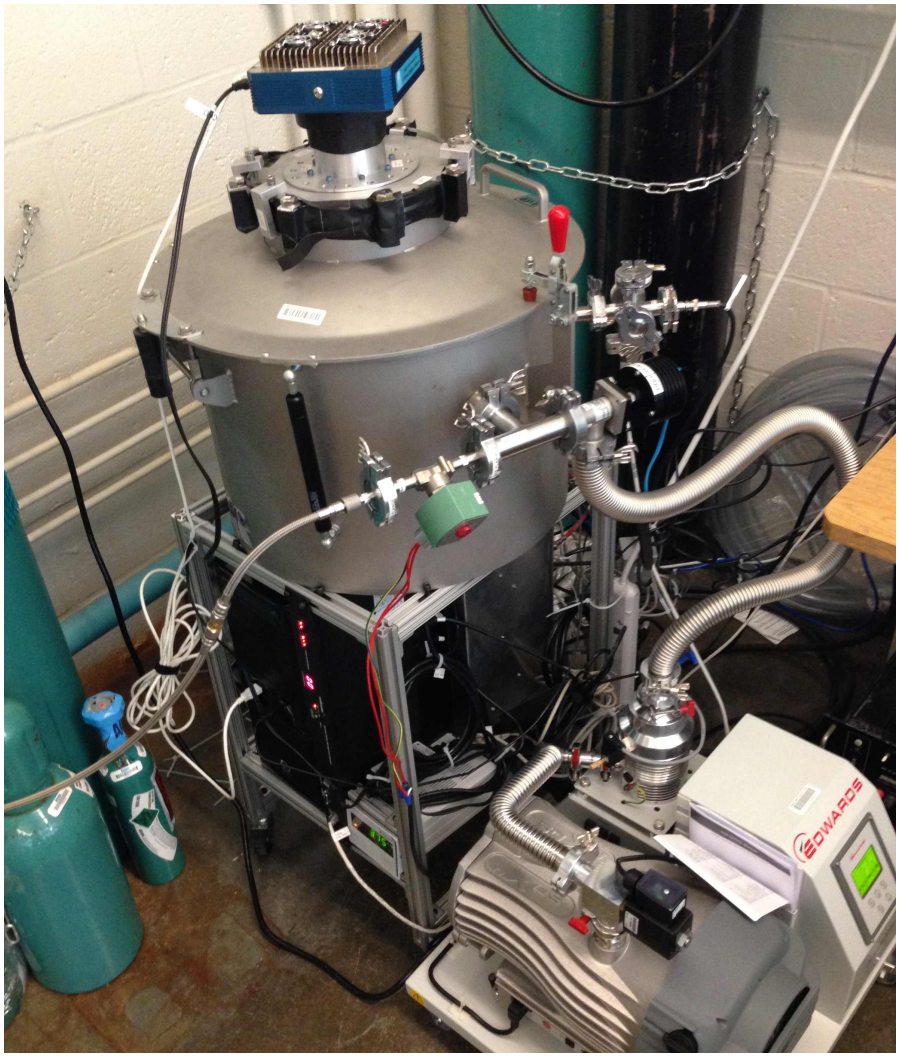
Obstacles

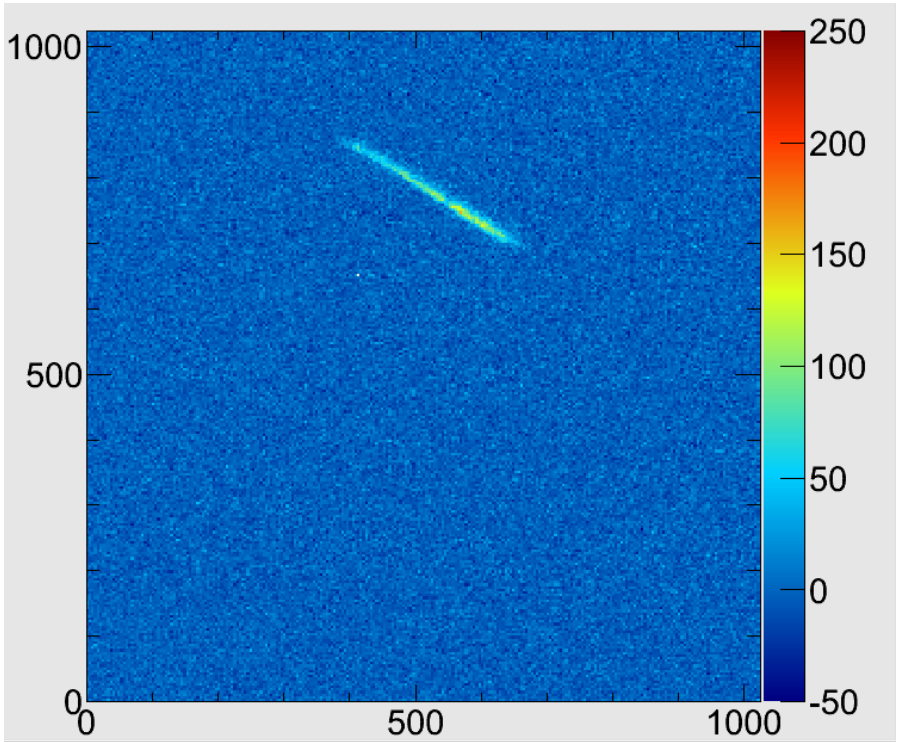
- Need to reconstruct full kinematics
  - undetectable neutrino
  - few 100s of keV nucleus
- Low rates
- Limited detector acceptance

^{8}Be breaks apart into two α-particles.



OLIVIA: a TPC for nuclear recoils.



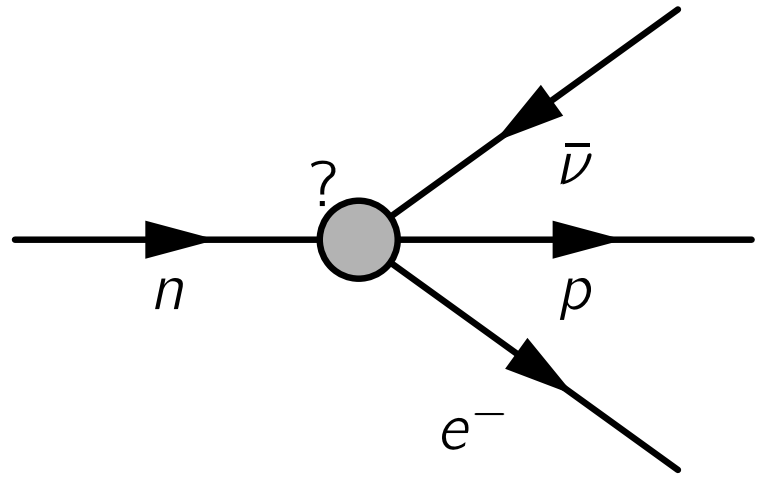


The important points

1. BSM searches with β-decay
   - ^{8}Li β-decay is fertile ground for finding hints of BSM physics.

2. The OLIVIA Experiment
   - A TPC experiment has advantages over tranditional atom-traps.

β-decay need not have $V - A$ structure.



$$
\begin{aligned}
H_{\text{eff.}} = & \left(\bar{\psi}_p \psi_n\right)\left(C_S \bar{\psi}_e \psi_\nu + C'_S \bar{\psi} \gamma_5 \psi_e\right) \\
& + \left(\bar{\psi}_p \gamma_\mu \psi_n\right)\left(C_V \bar{\psi}_e \gamma^\mu \psi_\nu + C'_V \bar{\psi} \gamma^\mu \gamma_5 \psi_e\right) \\
& + \frac{1}{2}\left(\bar{\psi}_p \sigma_{\lambda\mu} \psi_n\right)\left(C_T \bar{\psi}_e \sigma^{\lambda\mu} \psi_\nu + C'_T \bar{\psi} \sigma^{\lambda\mu} \gamma_5 \psi_e\right) \\
& - \left(\bar{\psi}_p \gamma_\mu \gamma_5 \psi_n\right)\left(C_A \bar{\psi}_e \gamma^\mu \gamma_5 \psi_\nu + C'_A \bar{\psi} \gamma^\mu \psi_e\right) \\
& + \left(\bar{\psi}_p \gamma_5 \psi_n\right)\left(C_P \bar{\psi}_e \gamma_5 \psi_\nu + C'_P \bar{\psi} \psi_e\right) \qquad + \text{h.c.}
\end{aligned}
$$

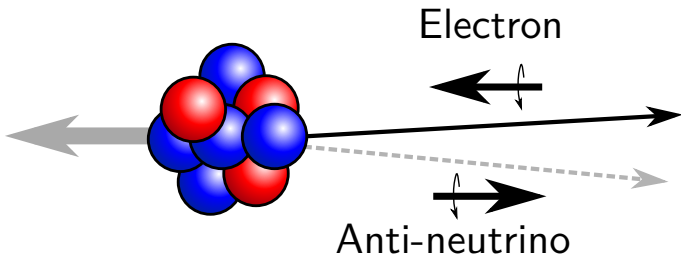
The decay rate has several correlation terms.

$$\Gamma \propto 1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} - c\left[\frac{\vec{p}_e \cdot \vec{p}_\nu}{3E_e E_\nu} - \frac{(\vec{p}_e \cdot \vec{j})(\vec{p}_\nu \cdot \vec{j})}{E_e E_\nu}\right]\left[\frac{J(J+1) - 3\langle(\vec{J}\cdot\vec{j})^2\rangle}{J(2J-1)}\right] + \frac{\langle\vec{J}\rangle}{J}\cdot\left[A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}\right]$$

$$a \propto |M_F|^2\left(|C_V|^2 - |C_S|^2 + |C_V'|^2 - |C_S'|^2\right) \frac{1}{3}|M_{GT}|^2\left(|C_T|^2 - |C_A|^2 + |C_T'|^2 - |C_A'|^2\right)$$

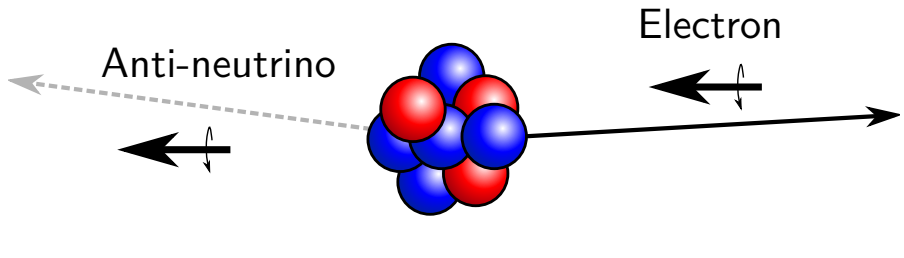
Decays can be "Fermi" or "Gamow-Teller."

Fermi Decay ($S_{e\nu} = 0$)



- $\Delta J = 0$
- $\Delta T = 0$

Gamow-Teller Decay ($S_{e\nu} = 1$)

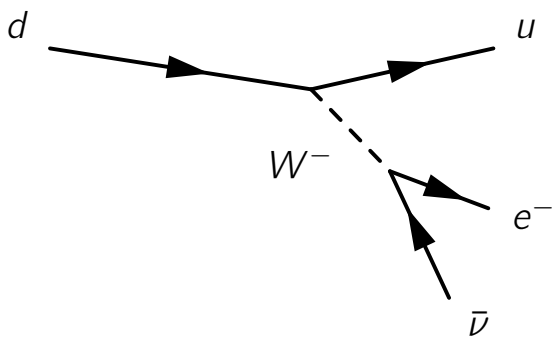


- $\Delta J = \pm 1, 0$
- $0^+ \rightarrow 0^+$ forbidden

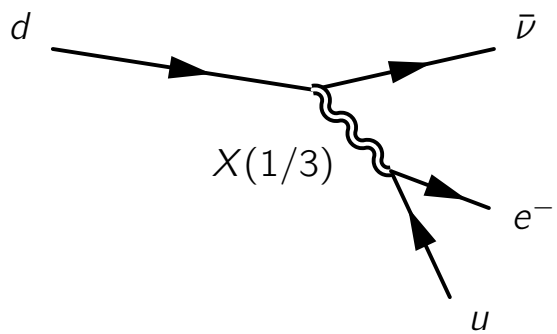
Scalar/tensor currents may come from BSM particles.

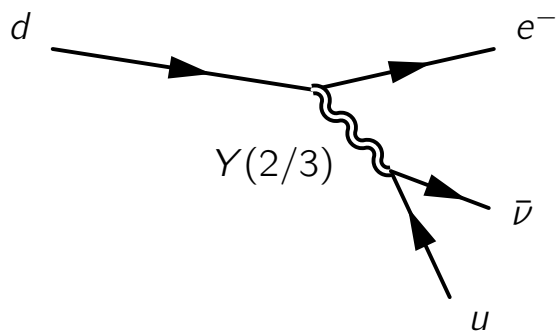
- Lepto-quarks
- Right-handed bosons

SM β-decay



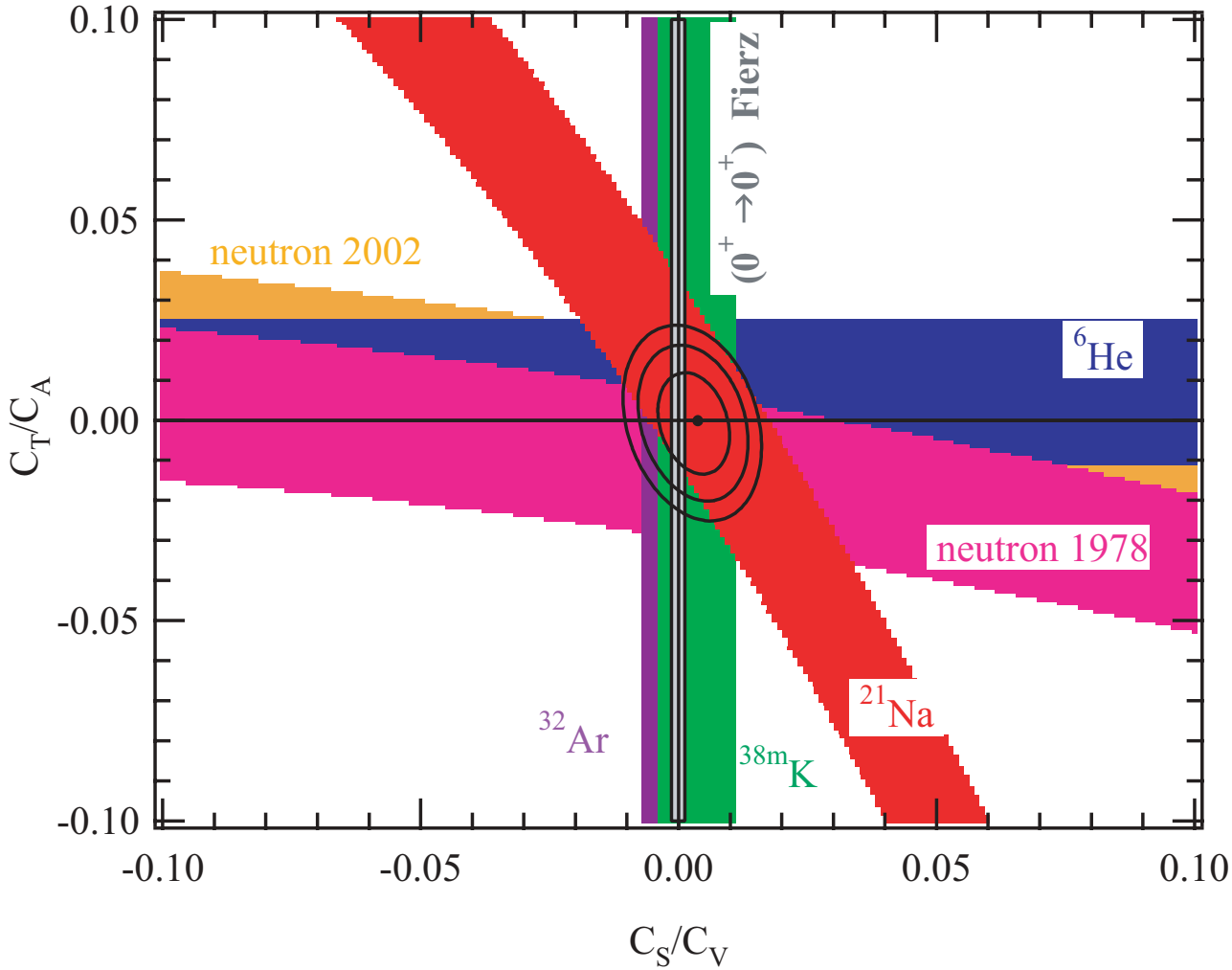
New tree-level diagrams





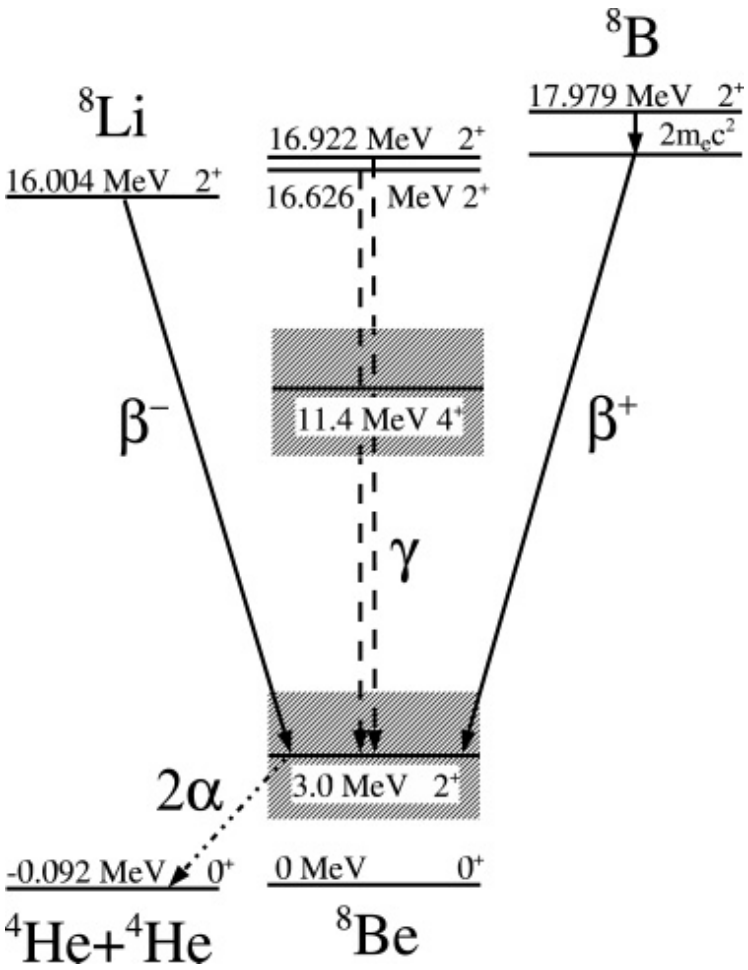
Only C_V and C_A are macroscopic.

$C_V = -C'_V = 1$ $\qquad$ $C_A = -C'_A \approx -1.27$



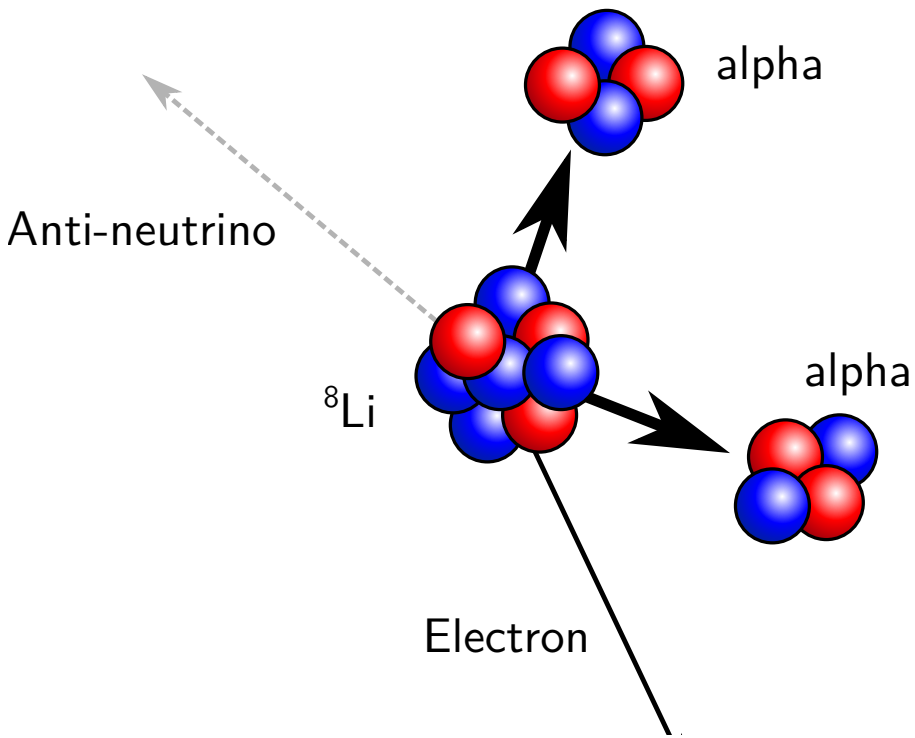
PRC 77, 035502 (2008)

Properties of ^{8}Li decay



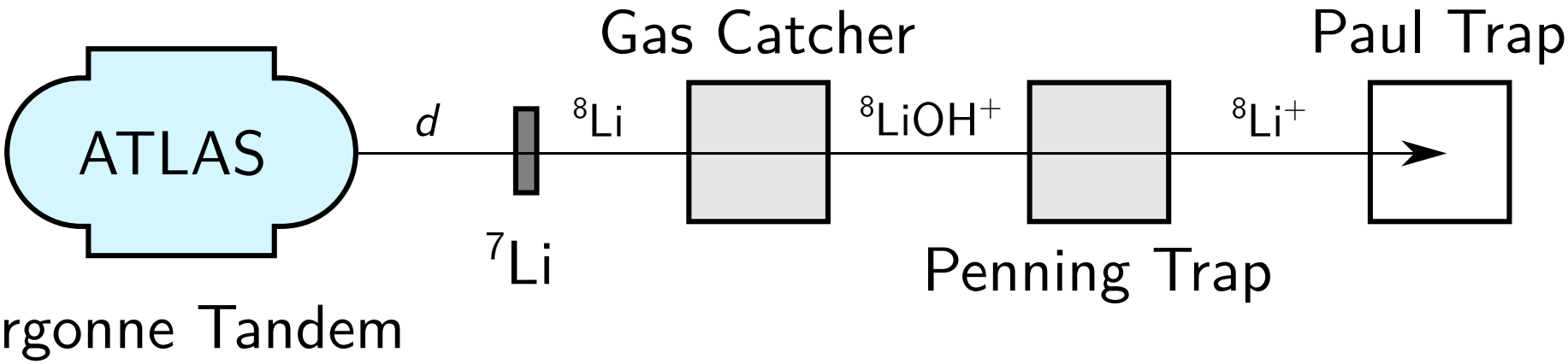
PRC 73, 025503 (2006)

- Nearly pure Gamow-Teller
- $Q = 13$ MeV
- $t_{1/2} = 839$ ms
- Immediate break-up
  - $^8\mathrm{Be} \rightarrow \alpha + \alpha + 3.09$ MeV



Previous ^{8}Li measurement was performed using atom traps.

Argonne ^{8}Li experiment:



PRL 110, 092502 (2013), PRL 115, 182501 (2015)

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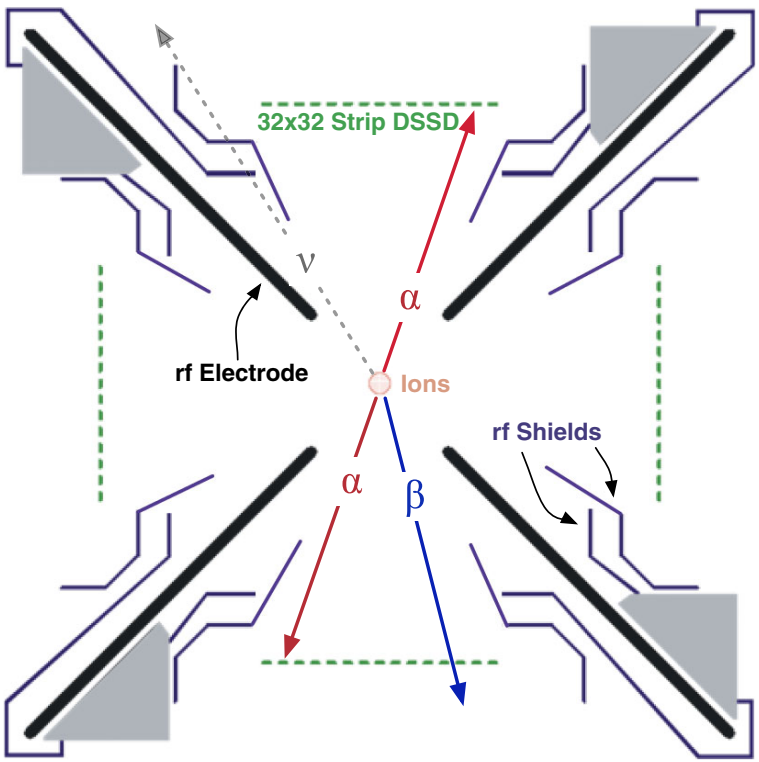

$$|\frac{C_T}{C_A}|^2 = .0013 \pm .0038_{\text{stat}} \pm .0043_{\text{sys}}$$

Figure from PRL 115, 182501 (2015)

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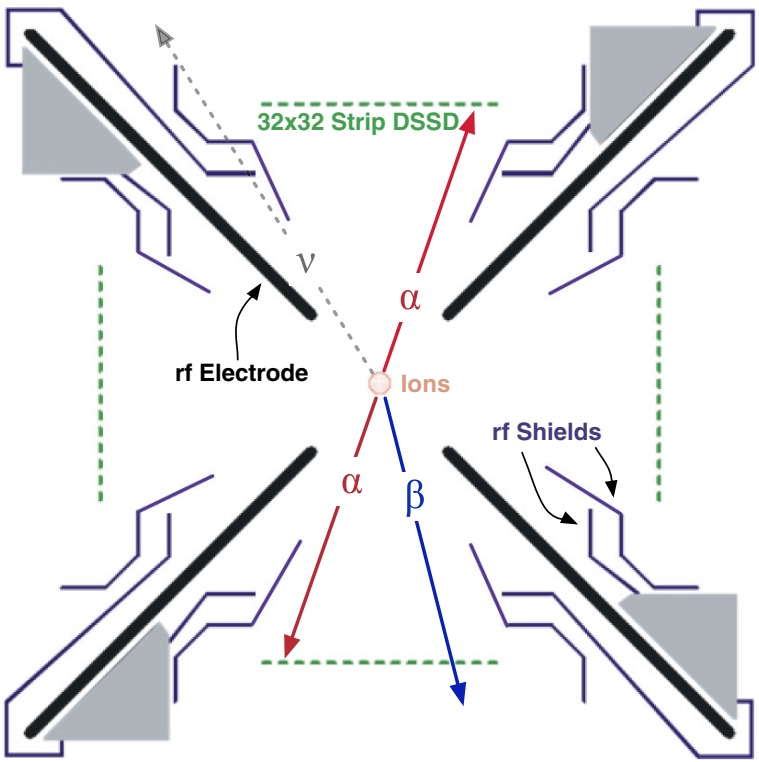

Figure from PRL 115, 182501 (2015)

$$|\frac{C_T}{C_A}|^2 = .0013 \pm .0038_{\text{stat}} \pm .0043_{\text{sys}}$$

Pros:

- Well-localized vertex
- Isotope selectivity

Cons:

- Low statistics
- Limited coverage
- Detector systematics

No precision measurements performed without traps!

The important points

1. BSM searches with β-decay
   - ^{8}Li β-decay is fertile ground for finding hints of BSM physics.

2. **The OLIVIA Experiment**
   - **A TPC experiment has advantages over tranditional atom-traps.**

OLIVIA is a TPC-based ^{8}Li β-decay experiment.

Optical LIthium V-mInus-A

- Gas-filled TPC for ≈MeV recoils
- Scintillation at amplification plane
- Events read out by CCD camera

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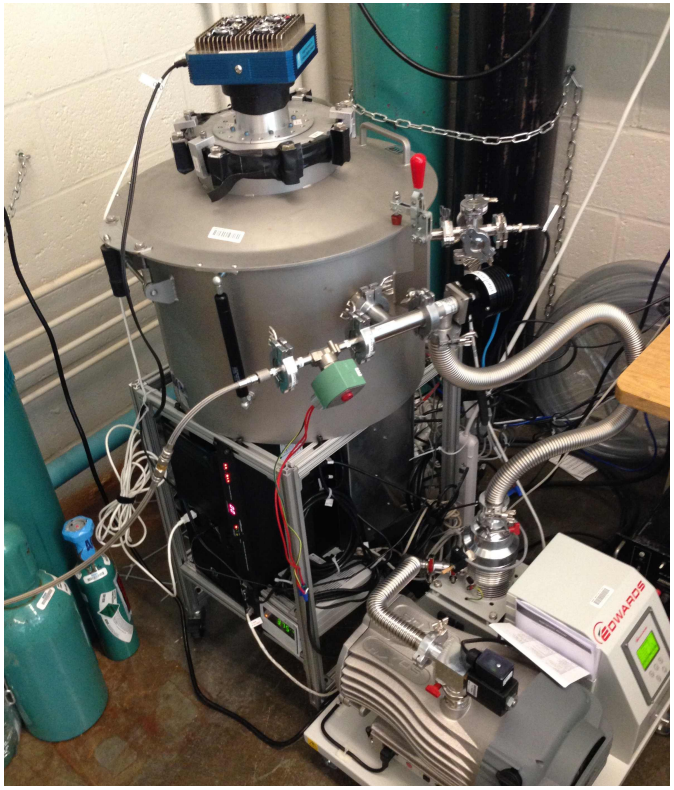

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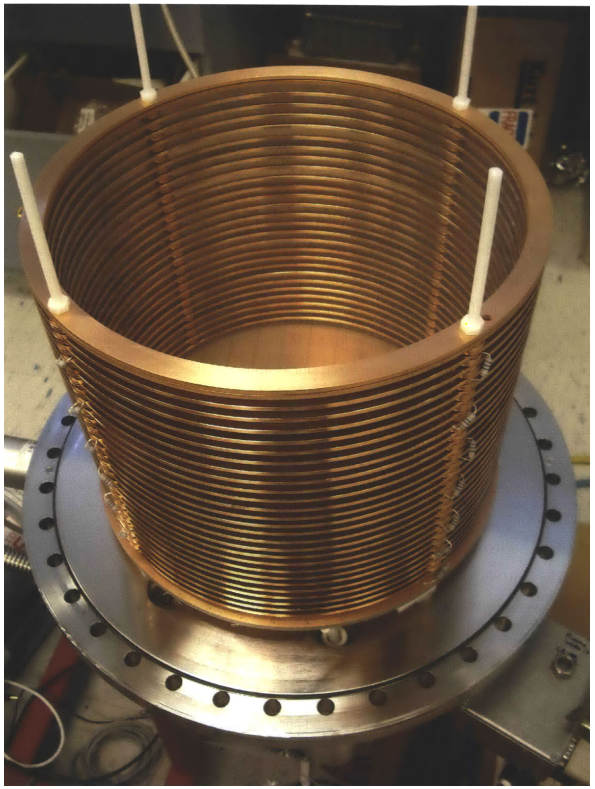

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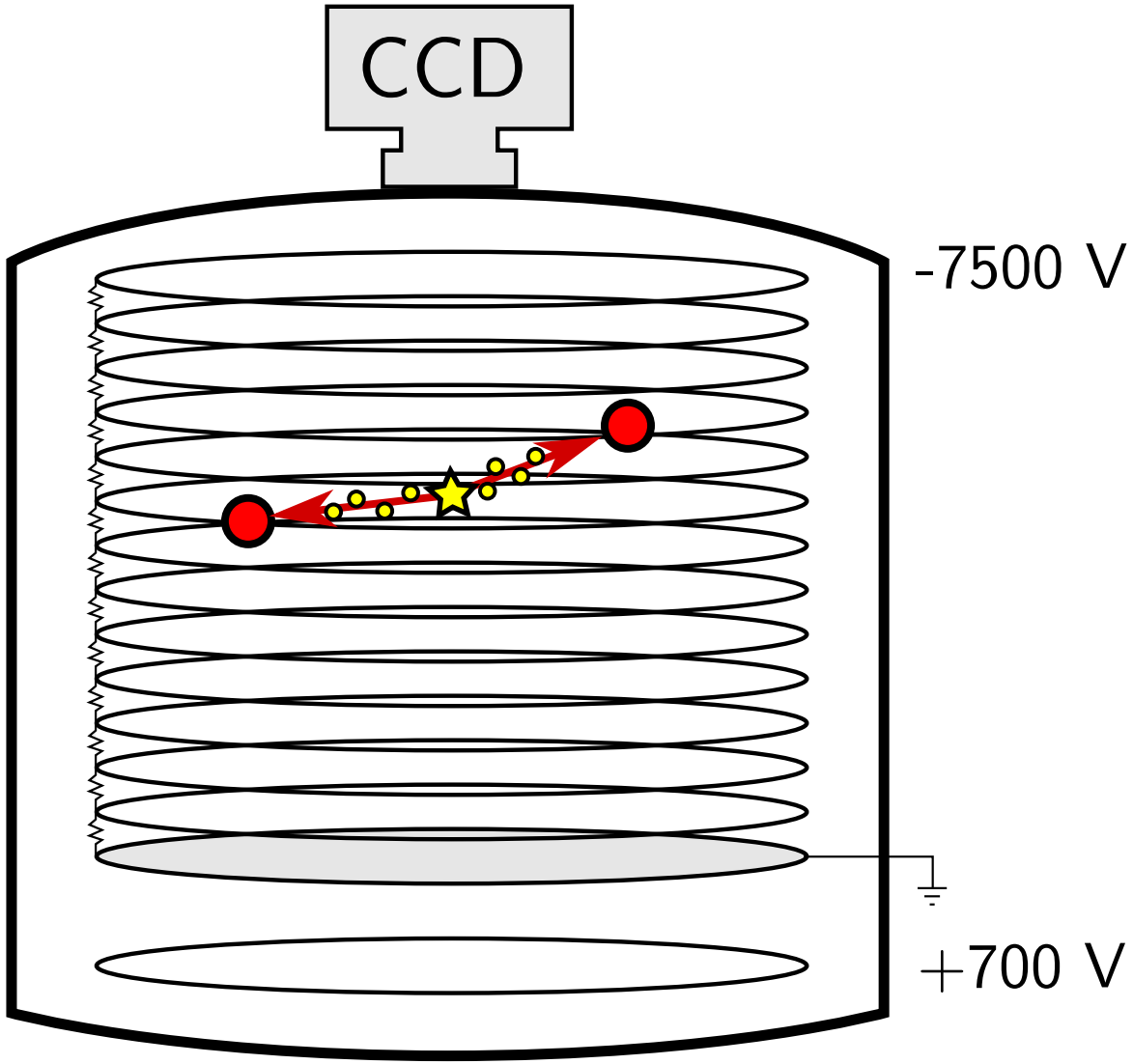

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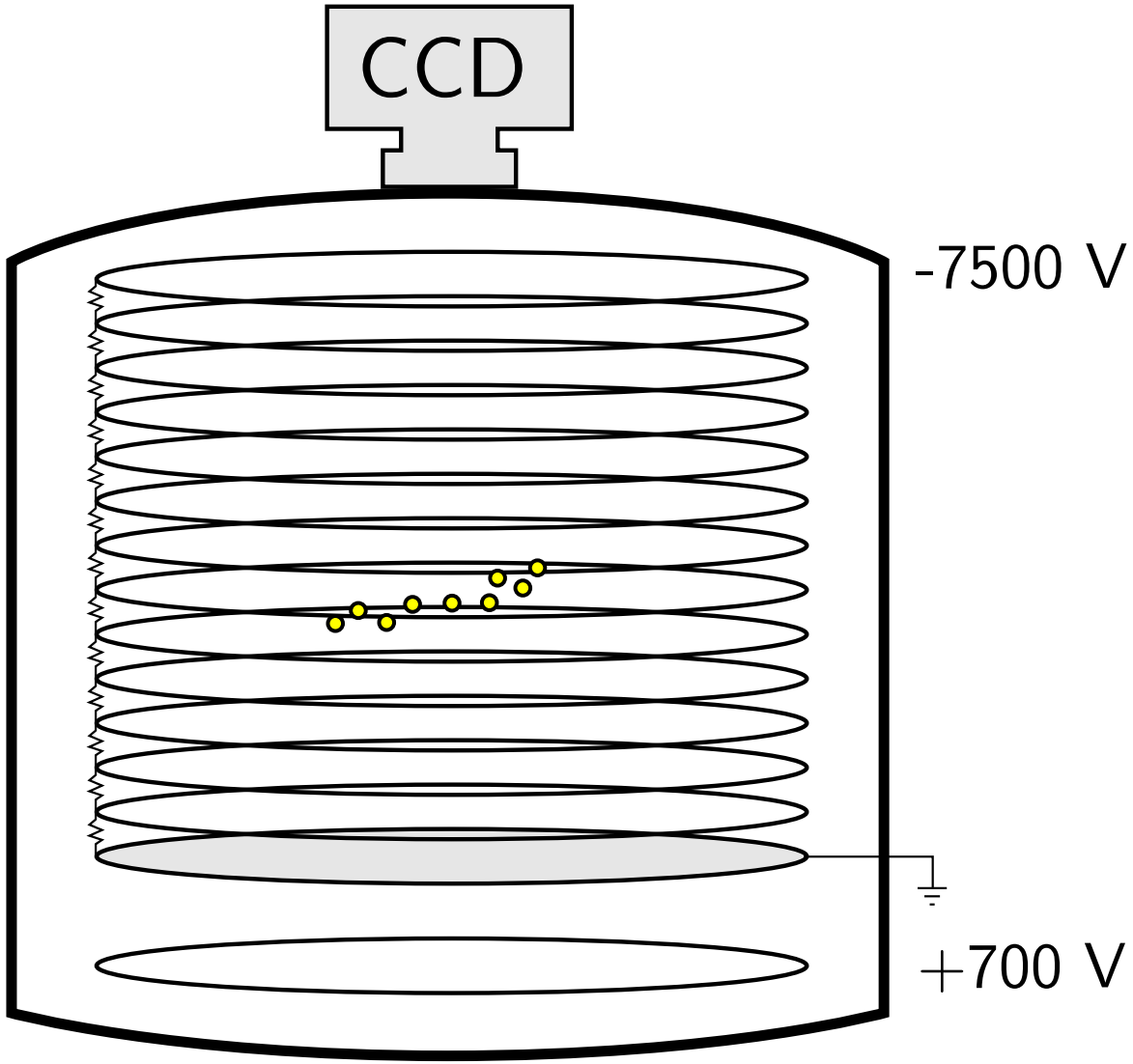

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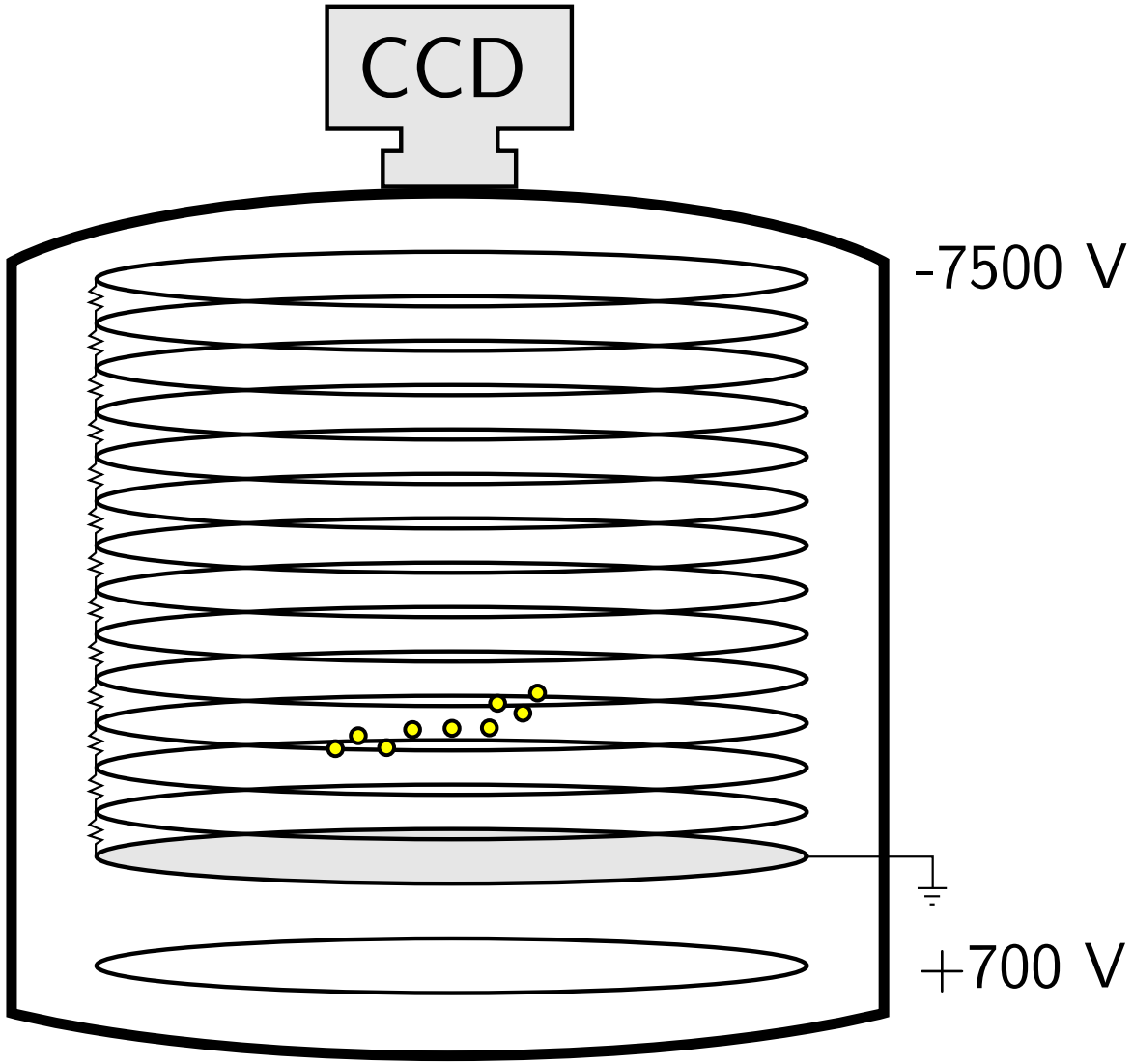

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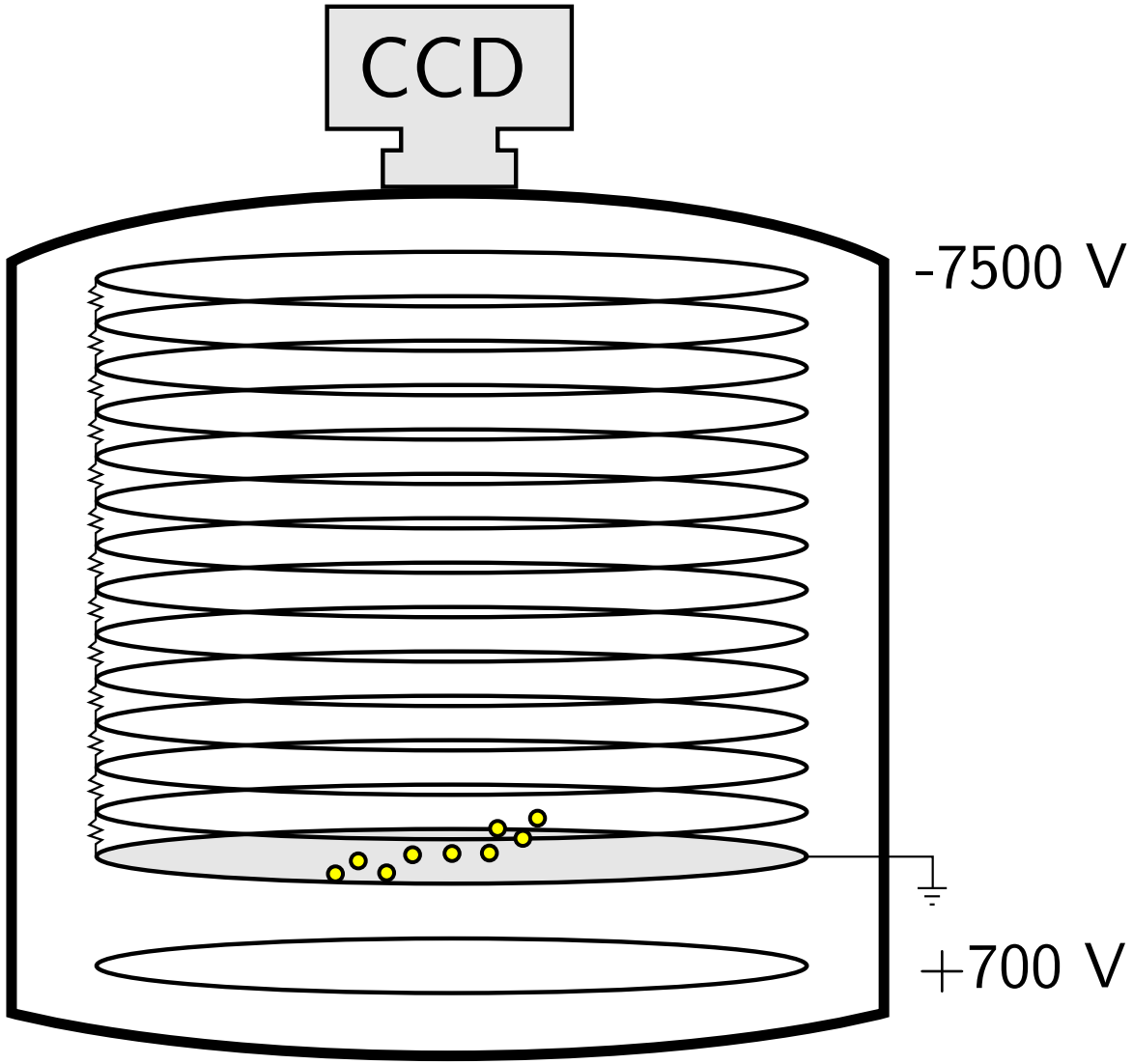

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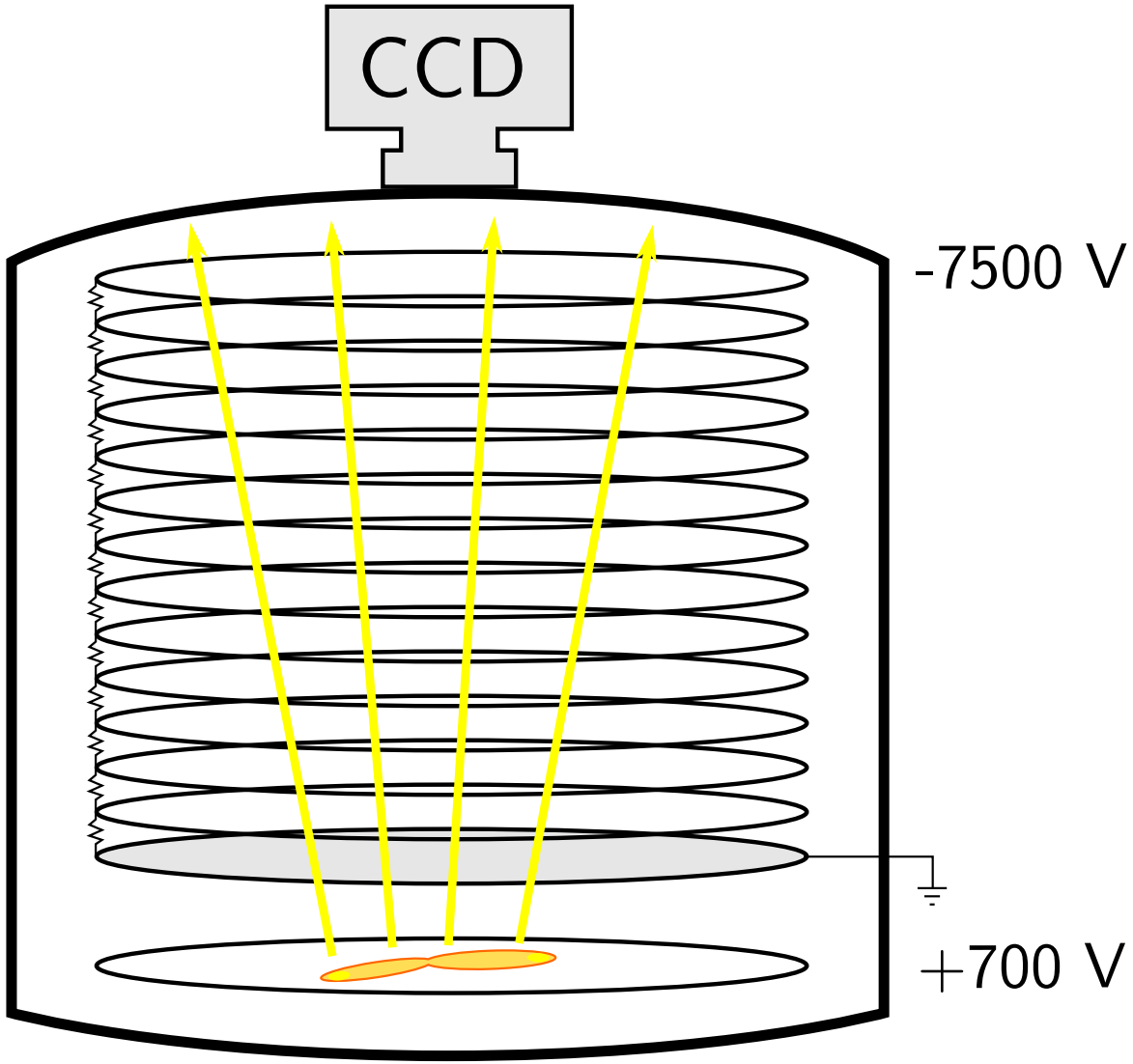
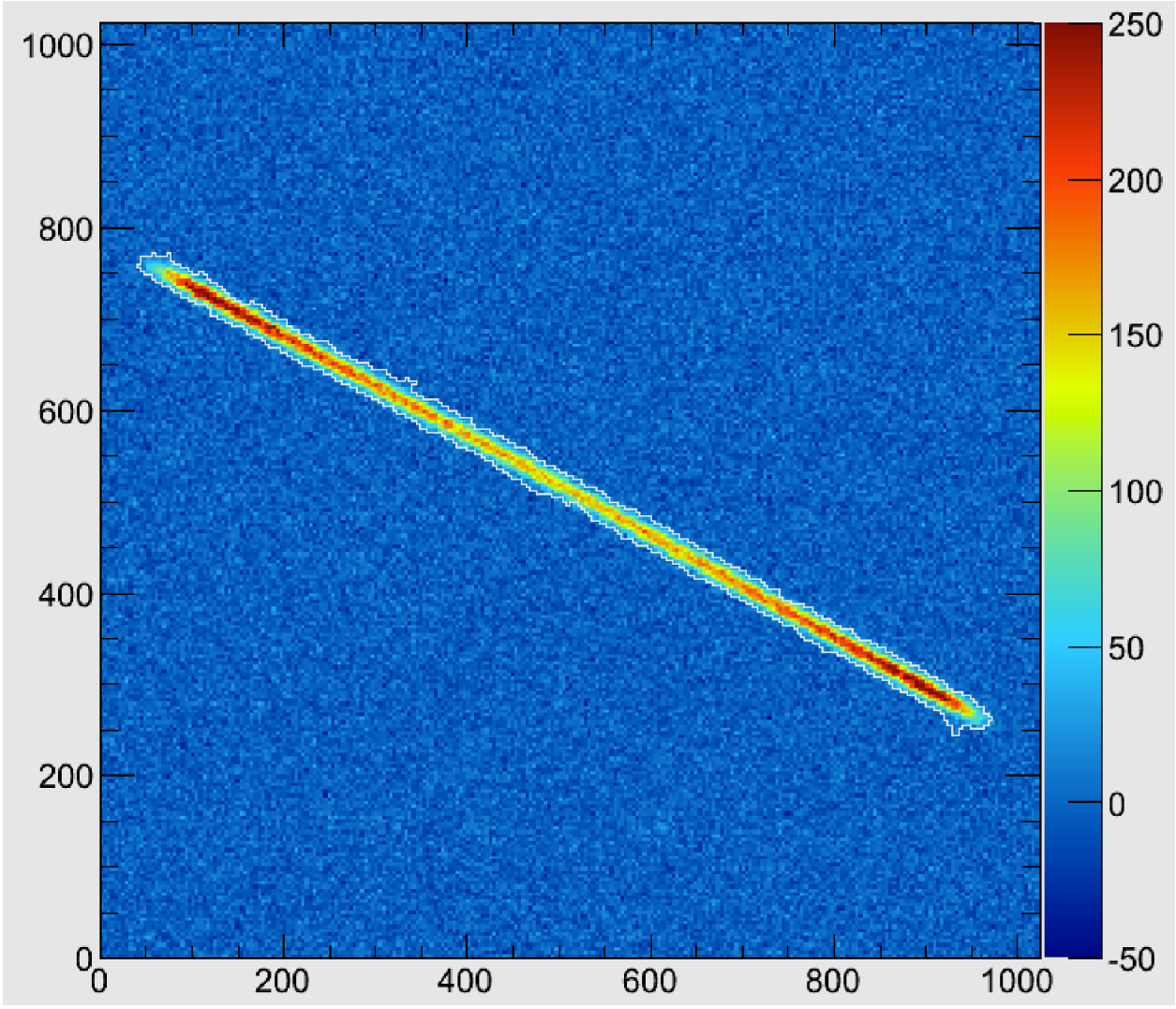
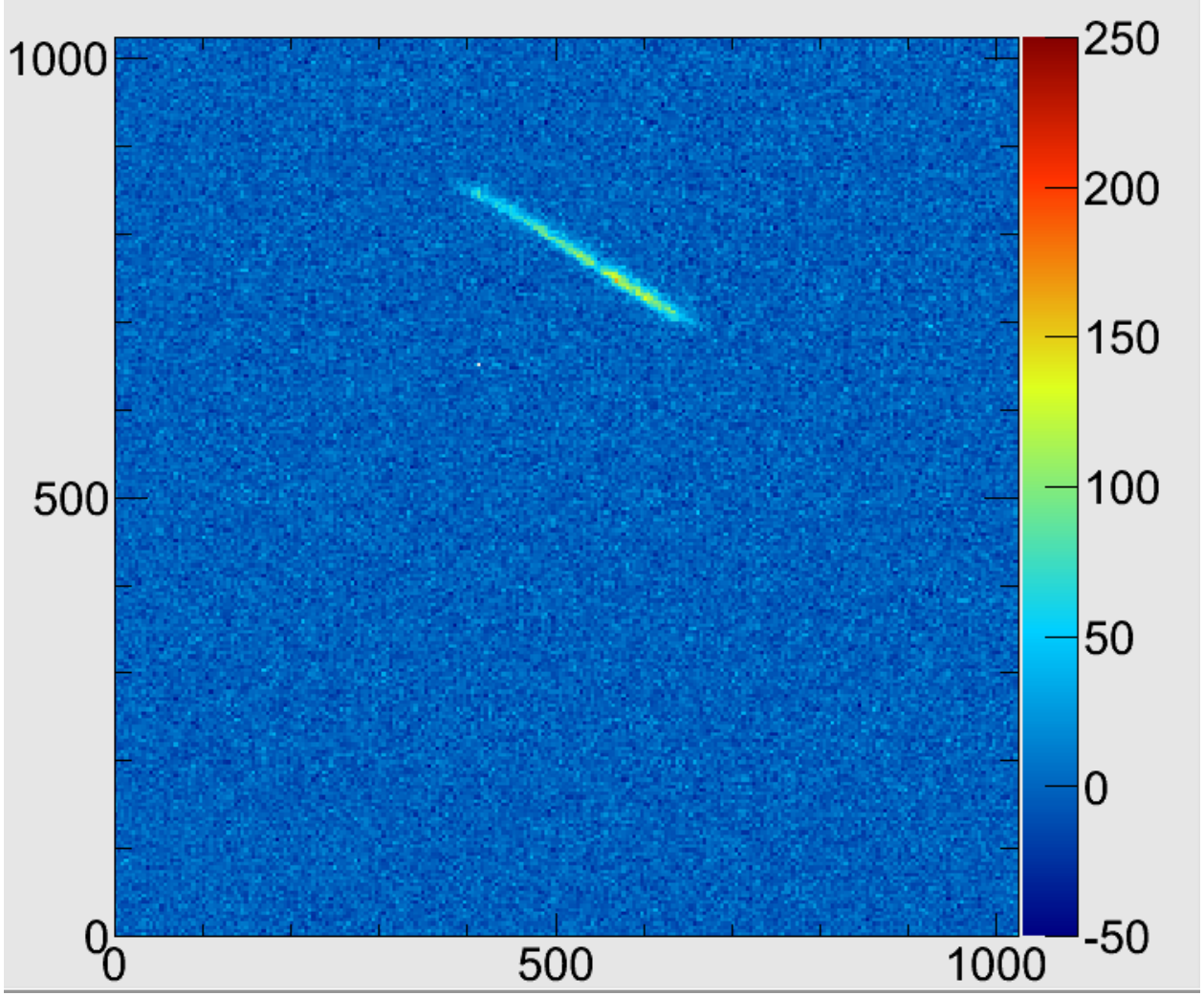


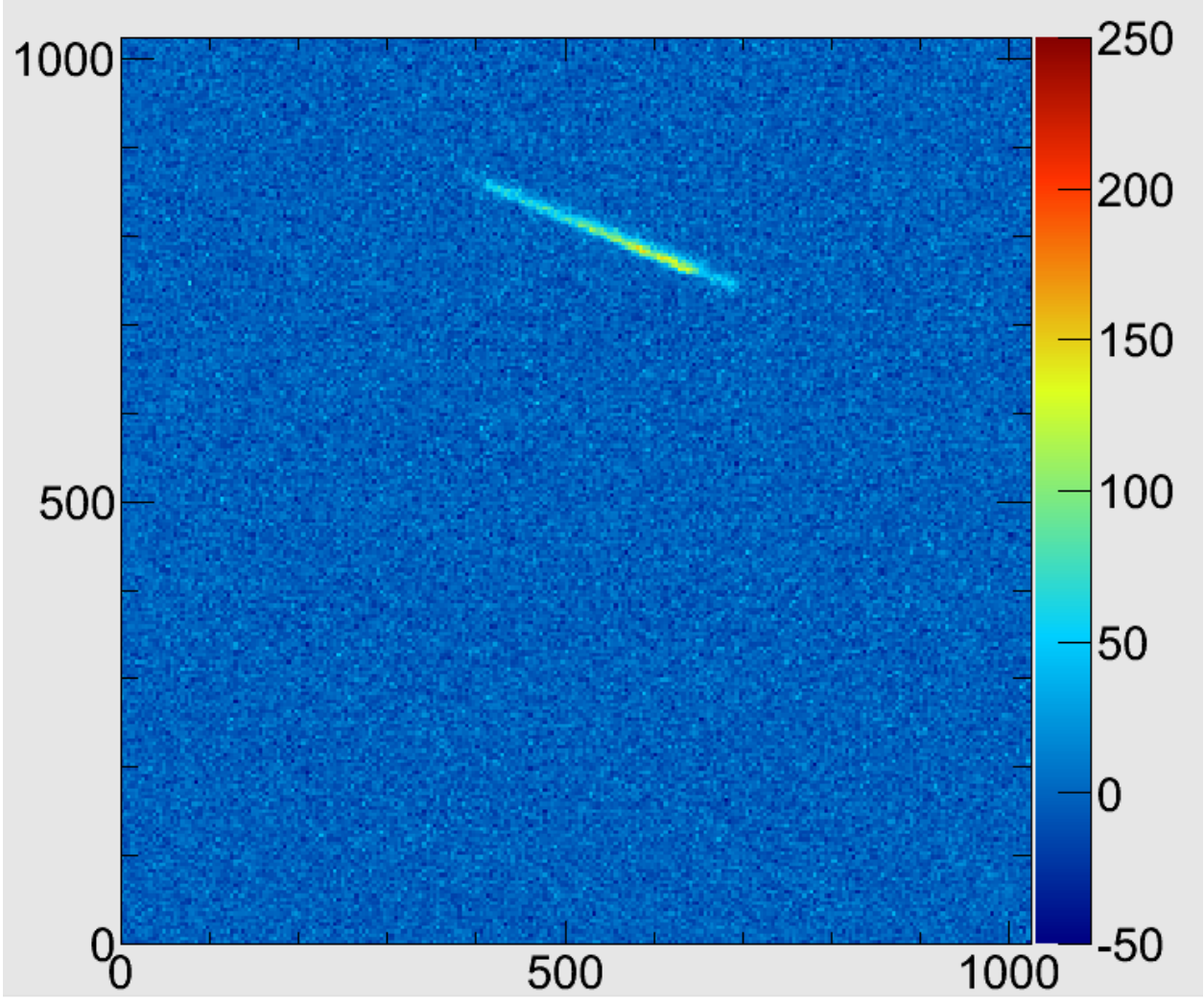
Simulated event



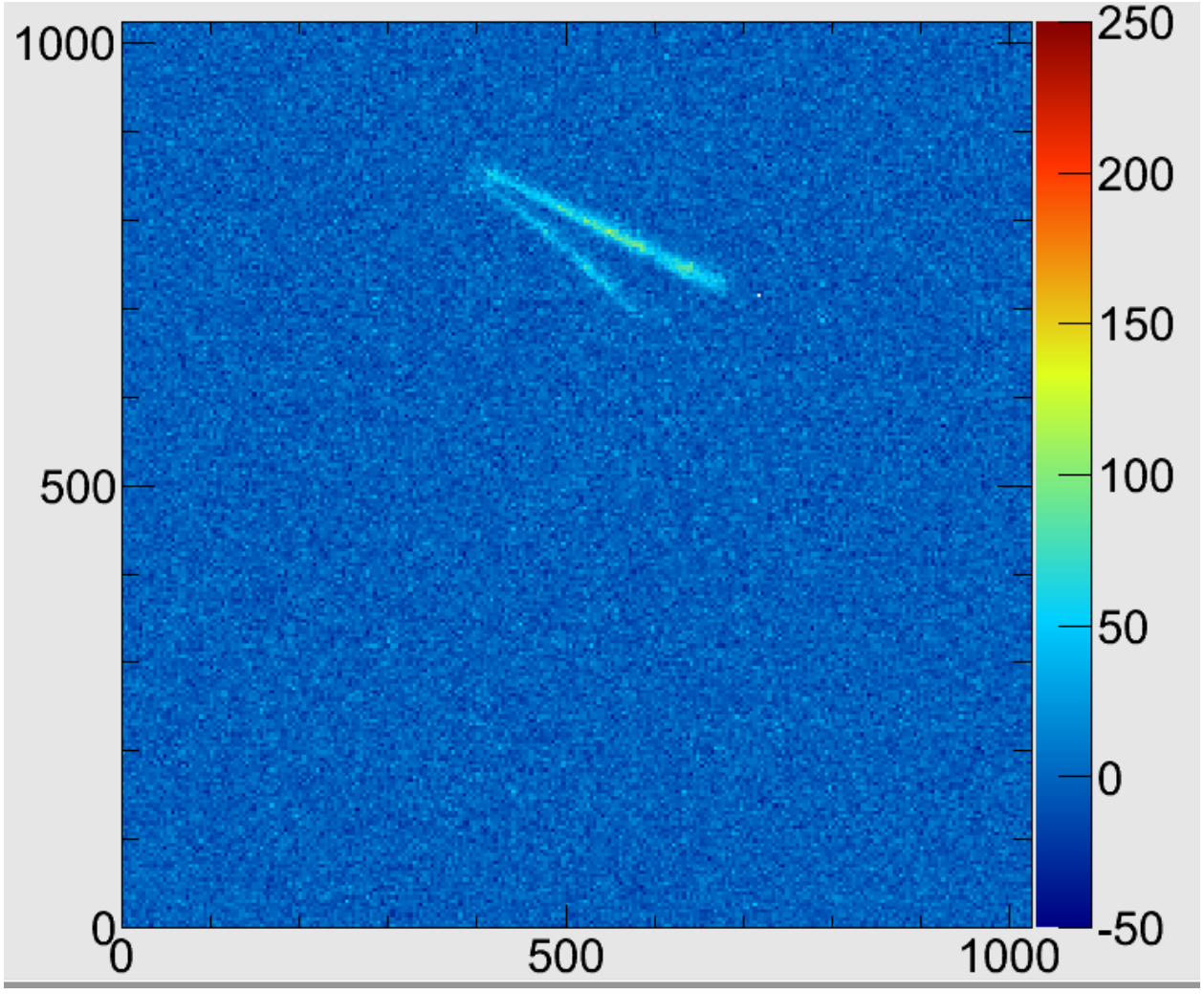
Real α-event from ^{148}Gd source



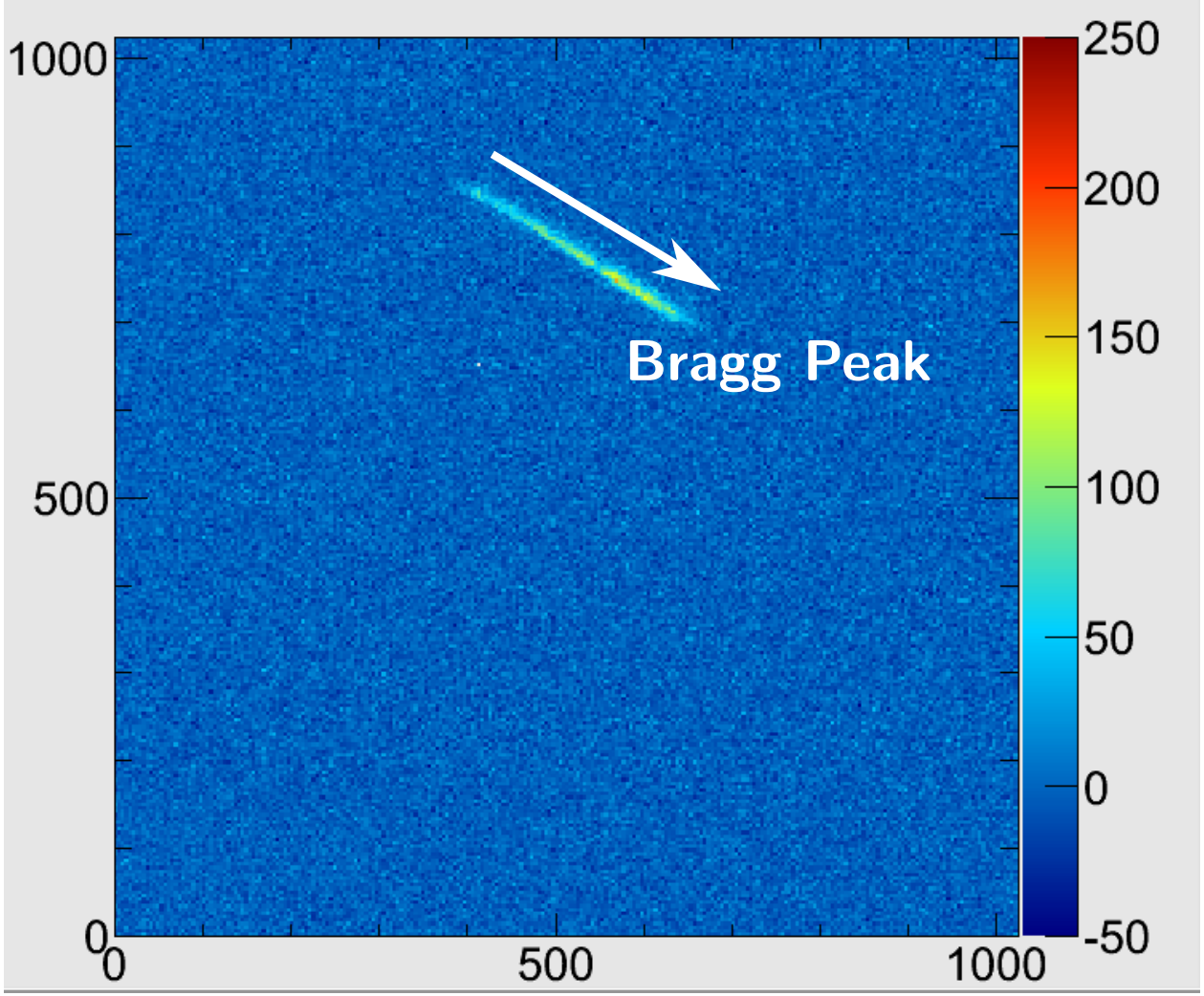
Real α-event from ^{148}Gd source



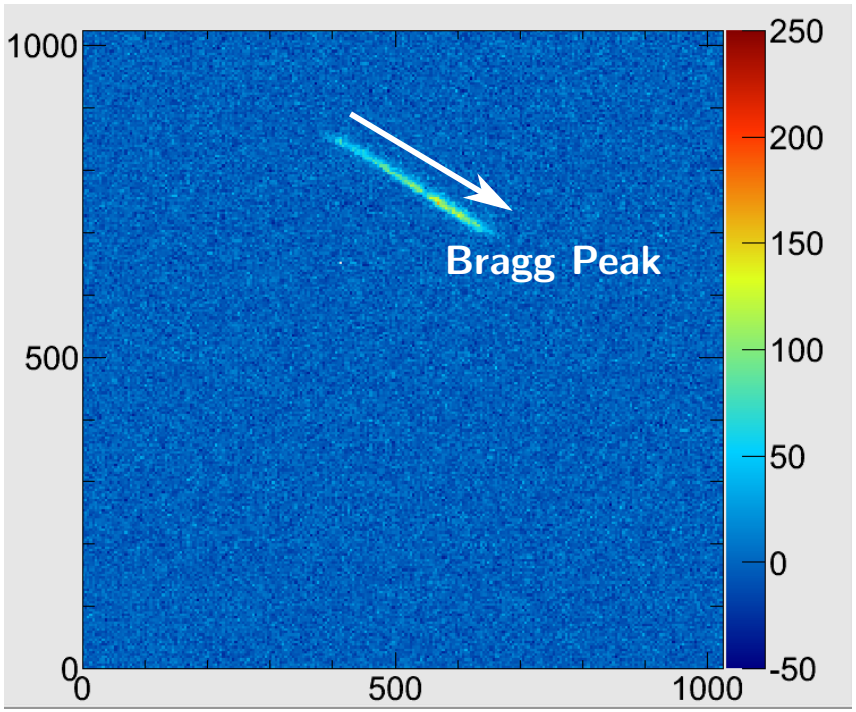
Real α-event from ^{148}Gd source

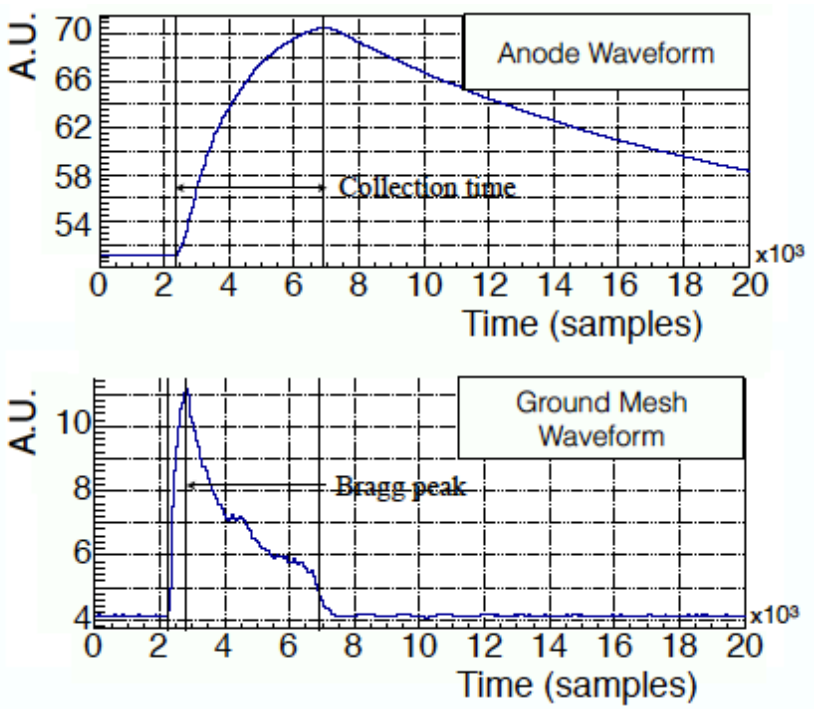


The Bragg peak tells us the track direction.

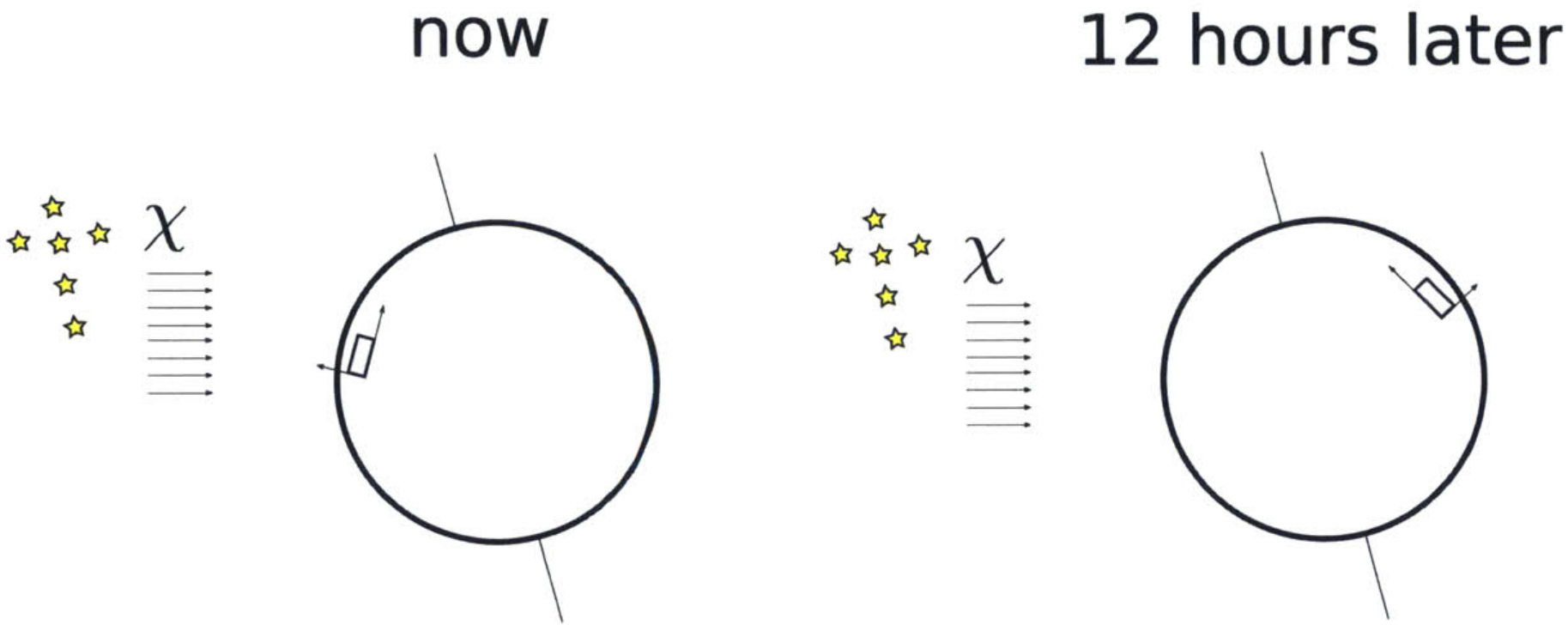


Time structure of ground mesh wave form gives us a 3-dimensional picture.





OLIVIA was originally DMTPC, a directional DM detector.



Cosmin Deaconu thesis, MIT 2015

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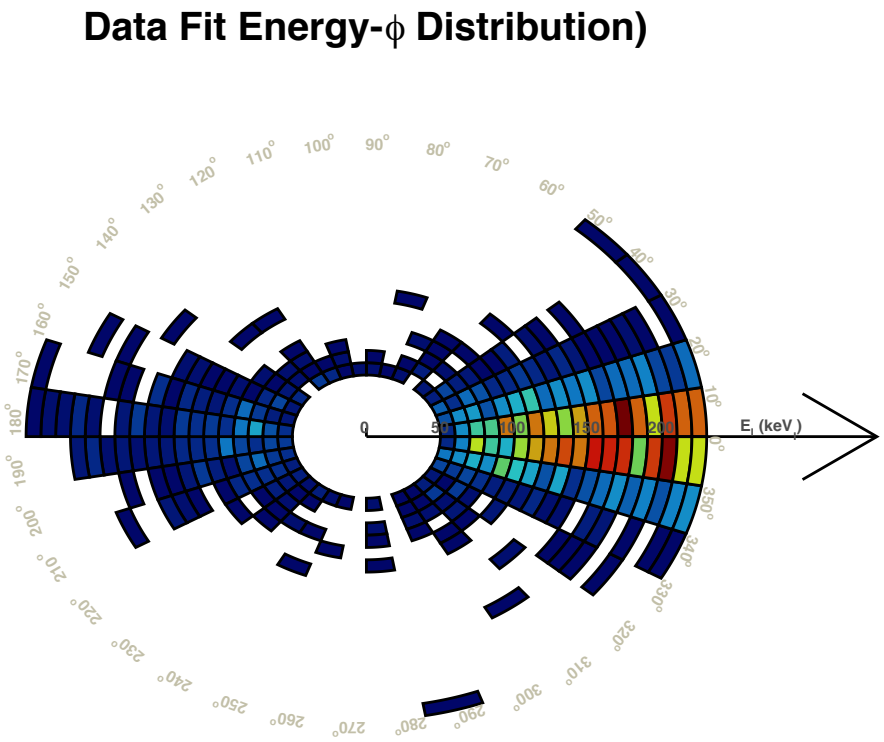
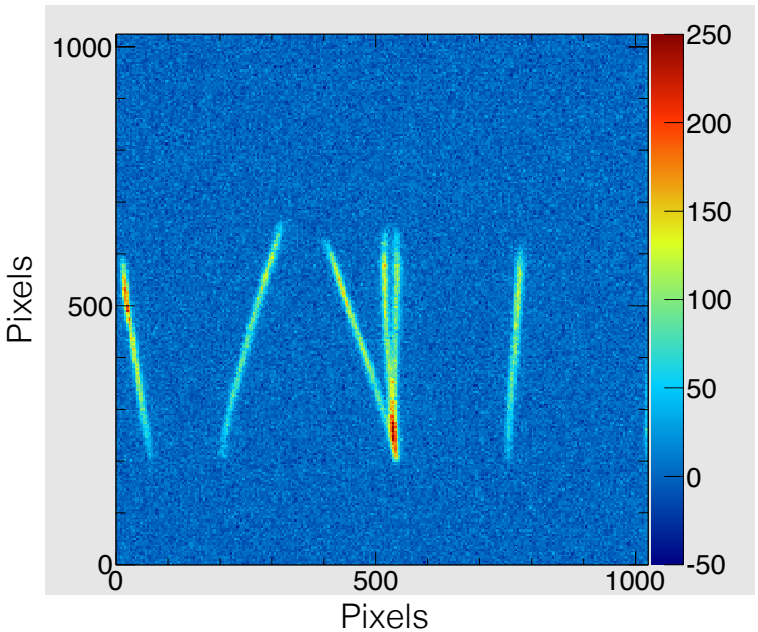


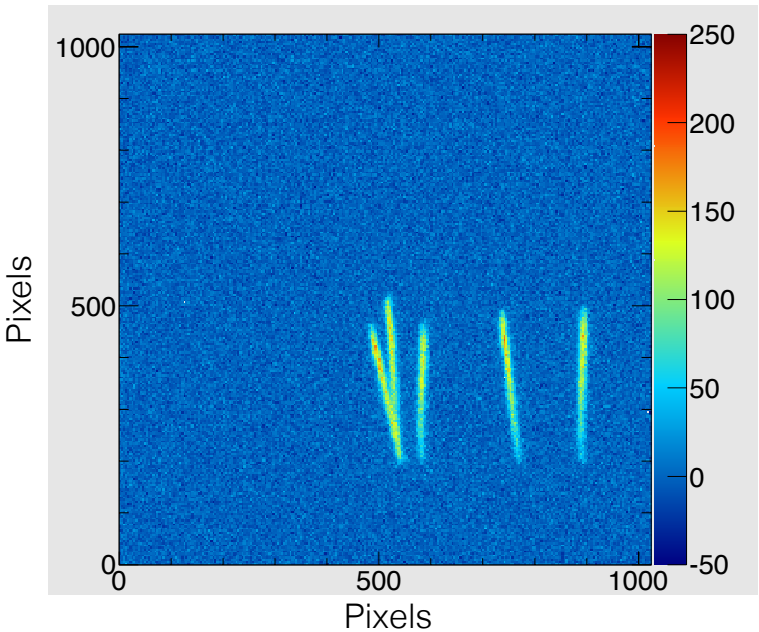
Deaconu et al., PRD 95, 122002 (2017)

DCTPC/MITPC: a neutron background detector for neutrino experiments

- 1-year run at Double-Chooz, then Booster Beamline at Fermilab
- Experiment with different gas mixtures: He, Ne, + CF_4



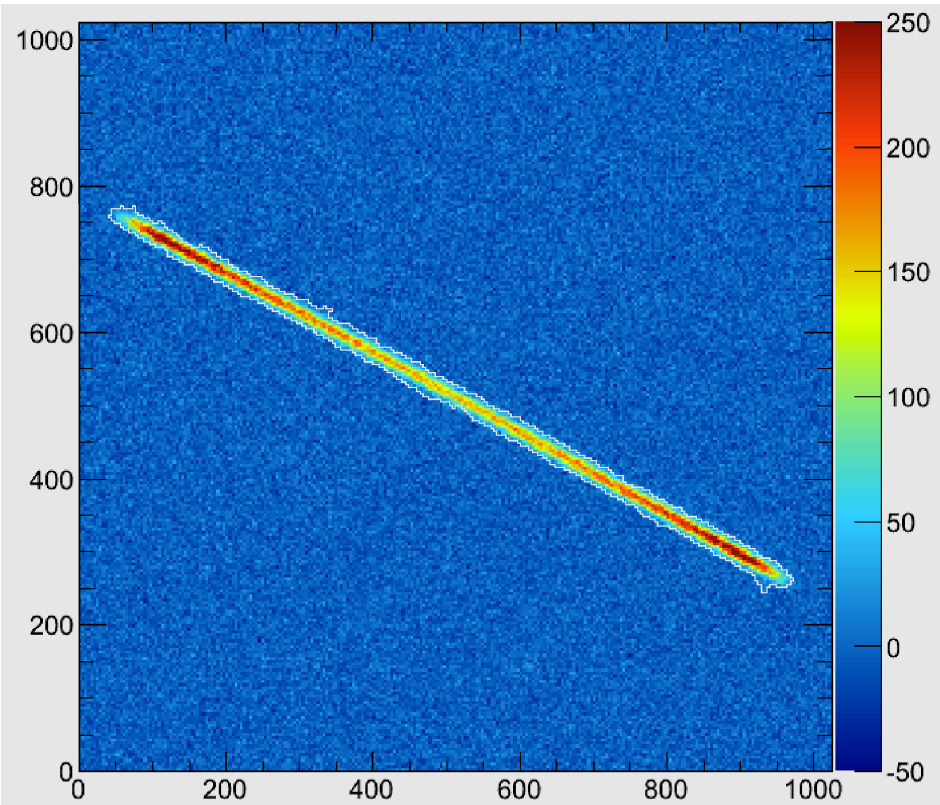
He mixture

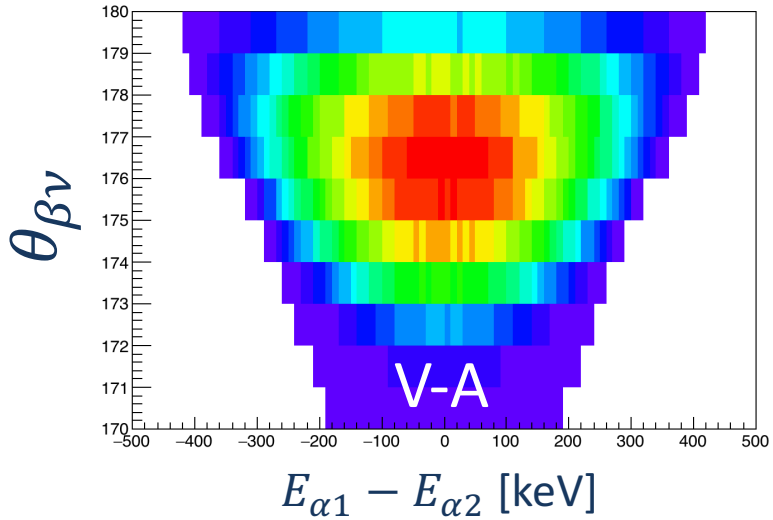


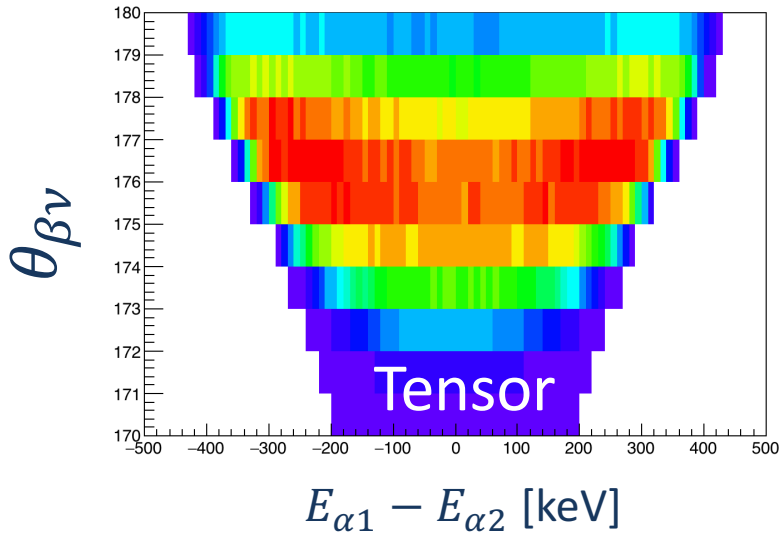
Ne mixture

A. Hexley et al., J. Instr. 10 P11010 (2015)

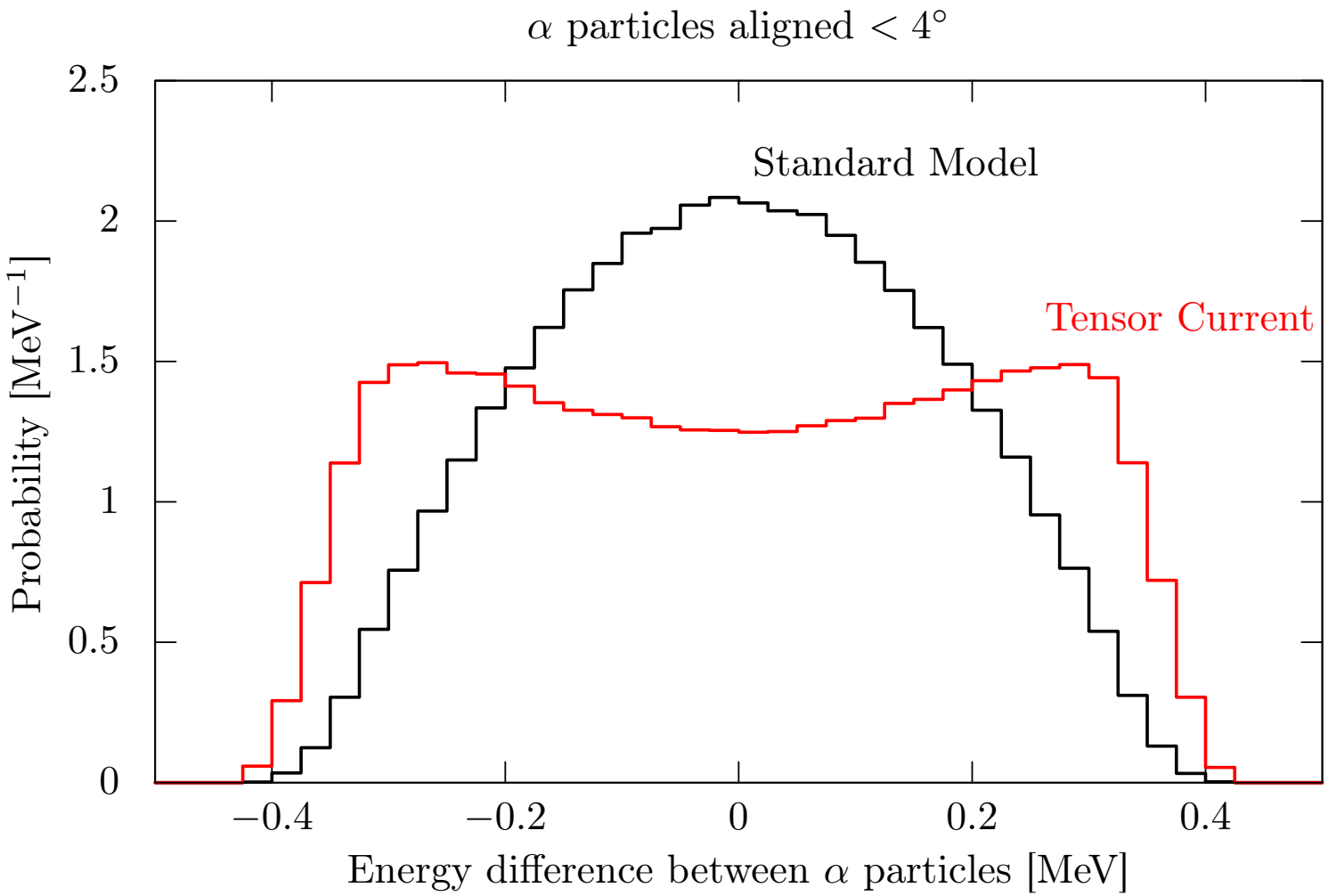
OLIVIA must reconstruct the energy and angles of two back-to-back 1.5 MeV α-particles.







Tensor contributions show up in the energy difference between α's.



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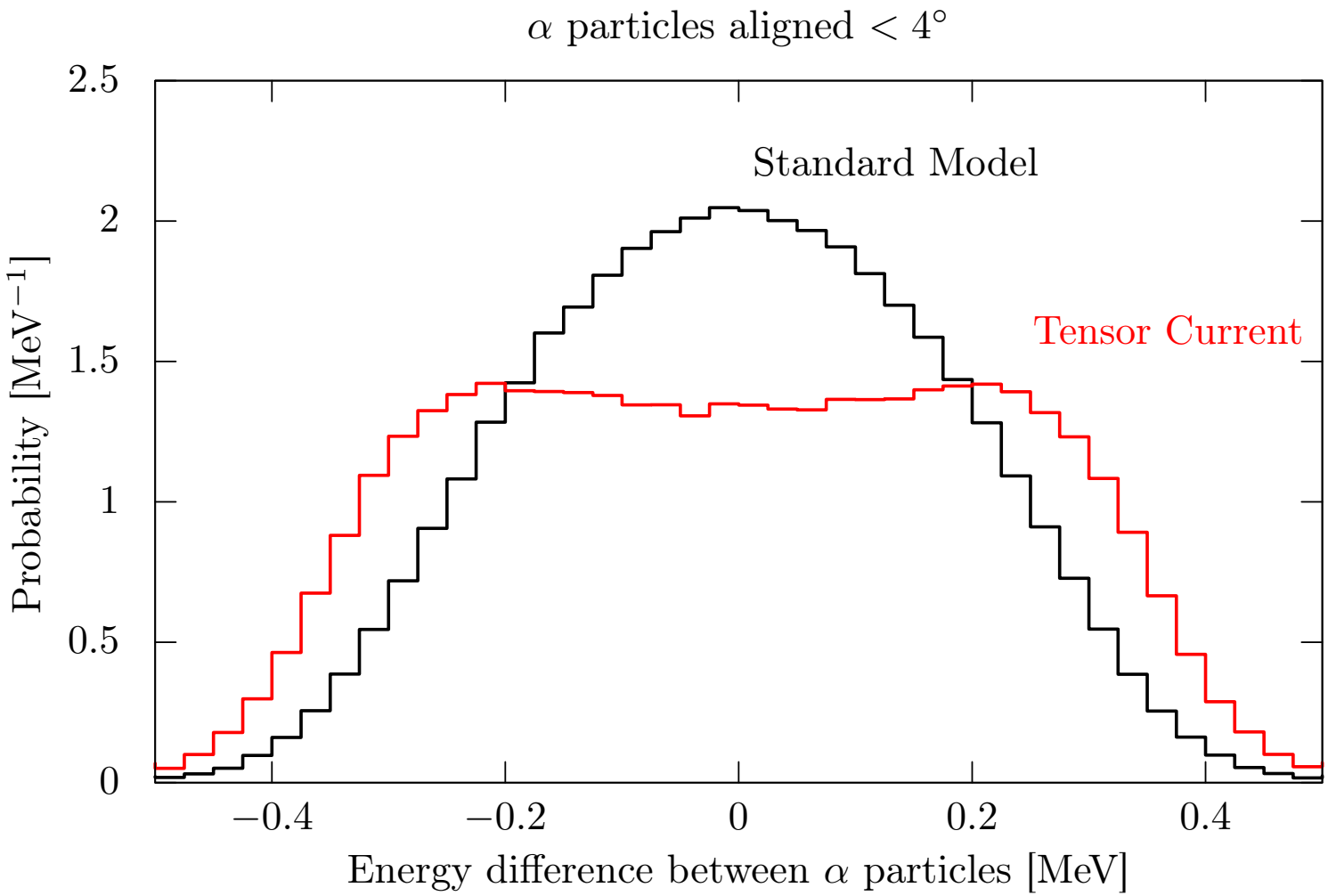
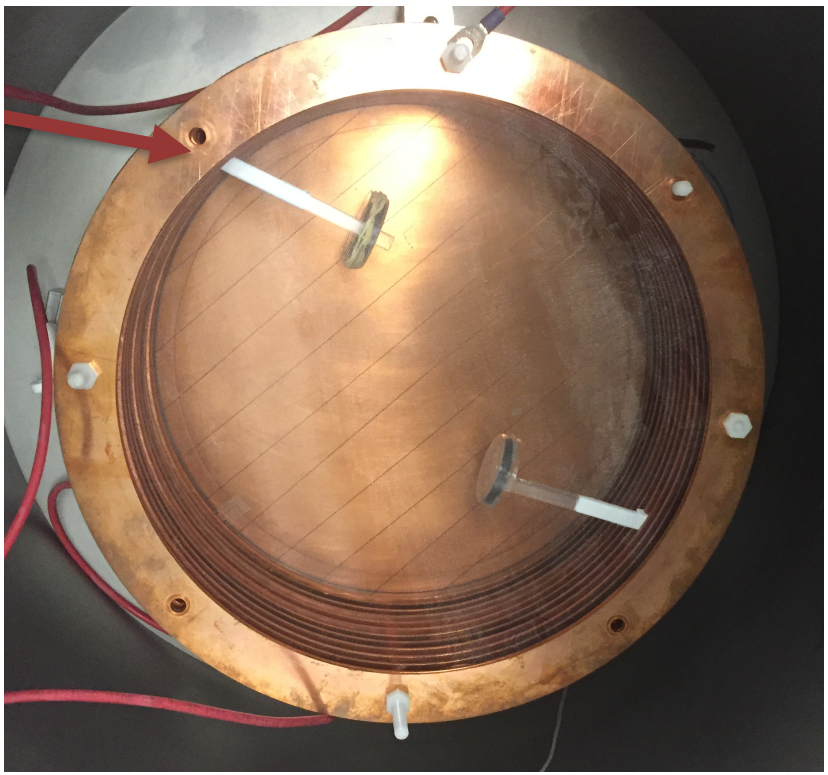
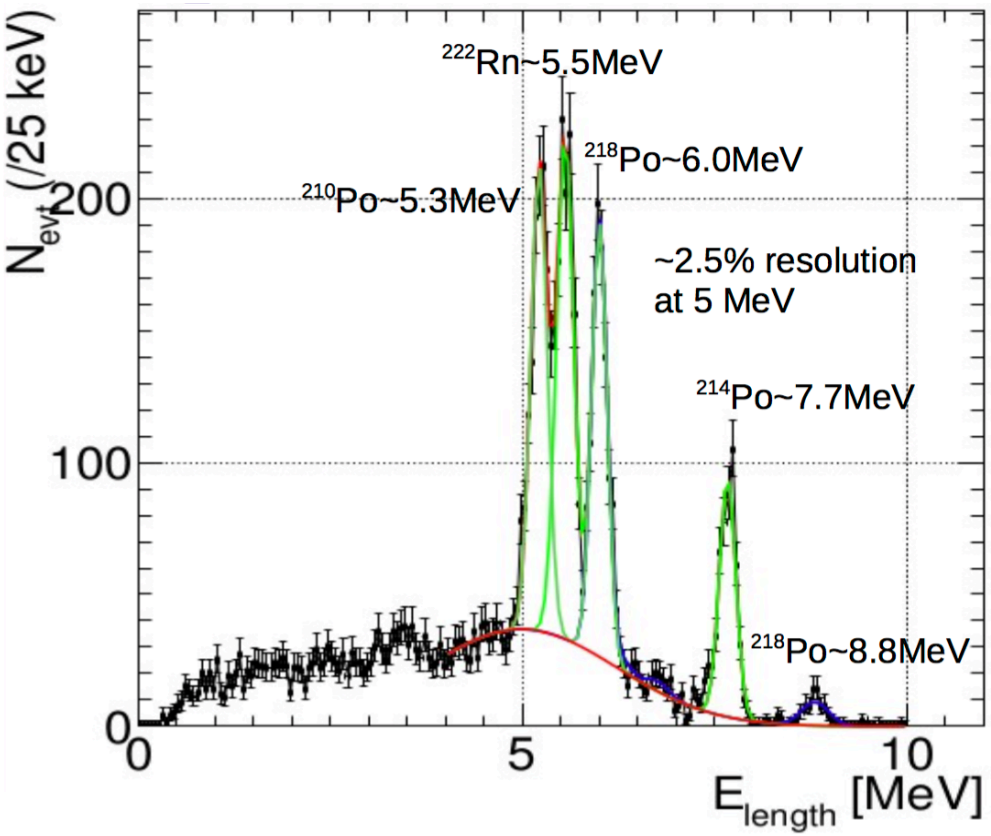


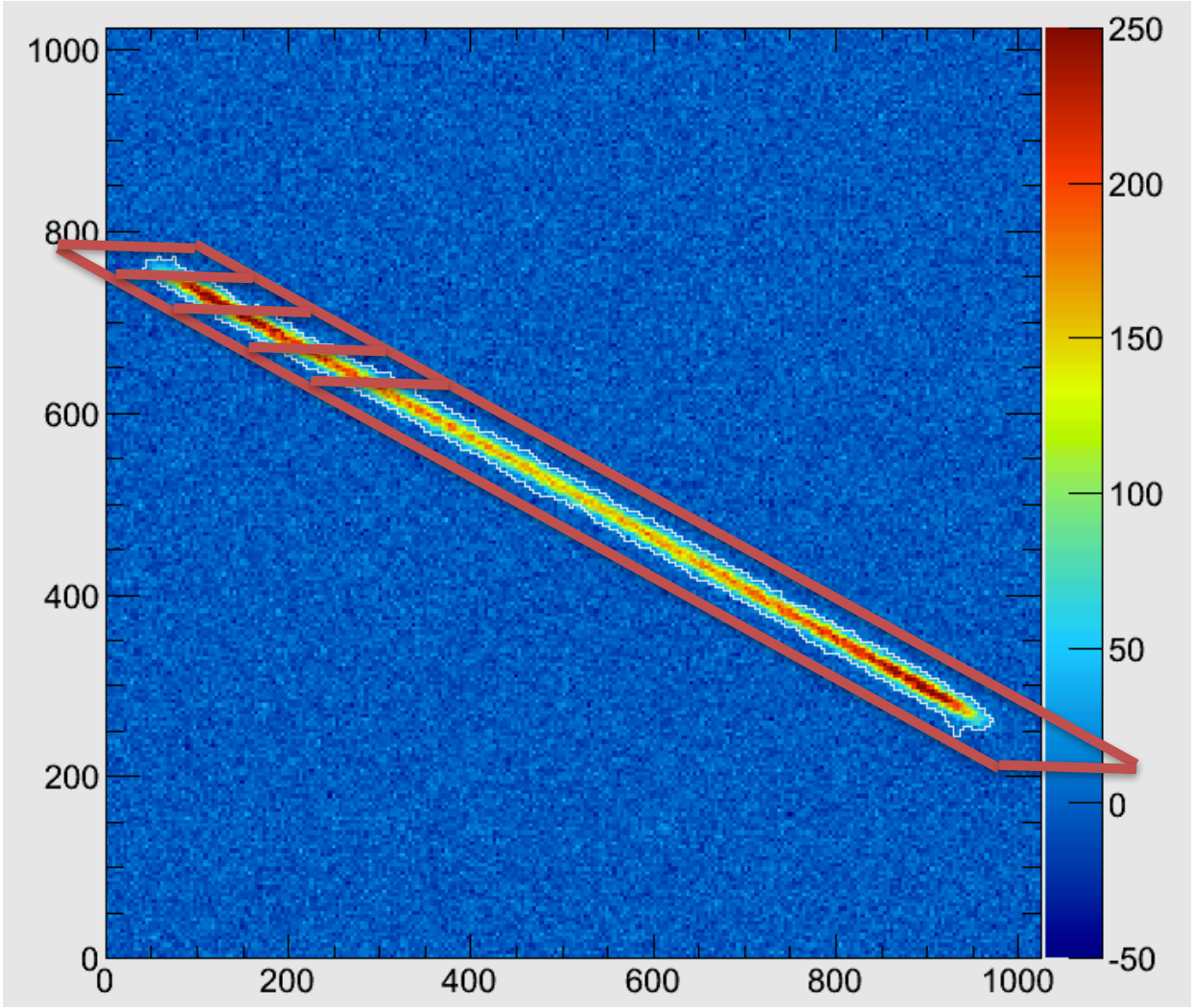
We are optimizing resolutions using α-sources.



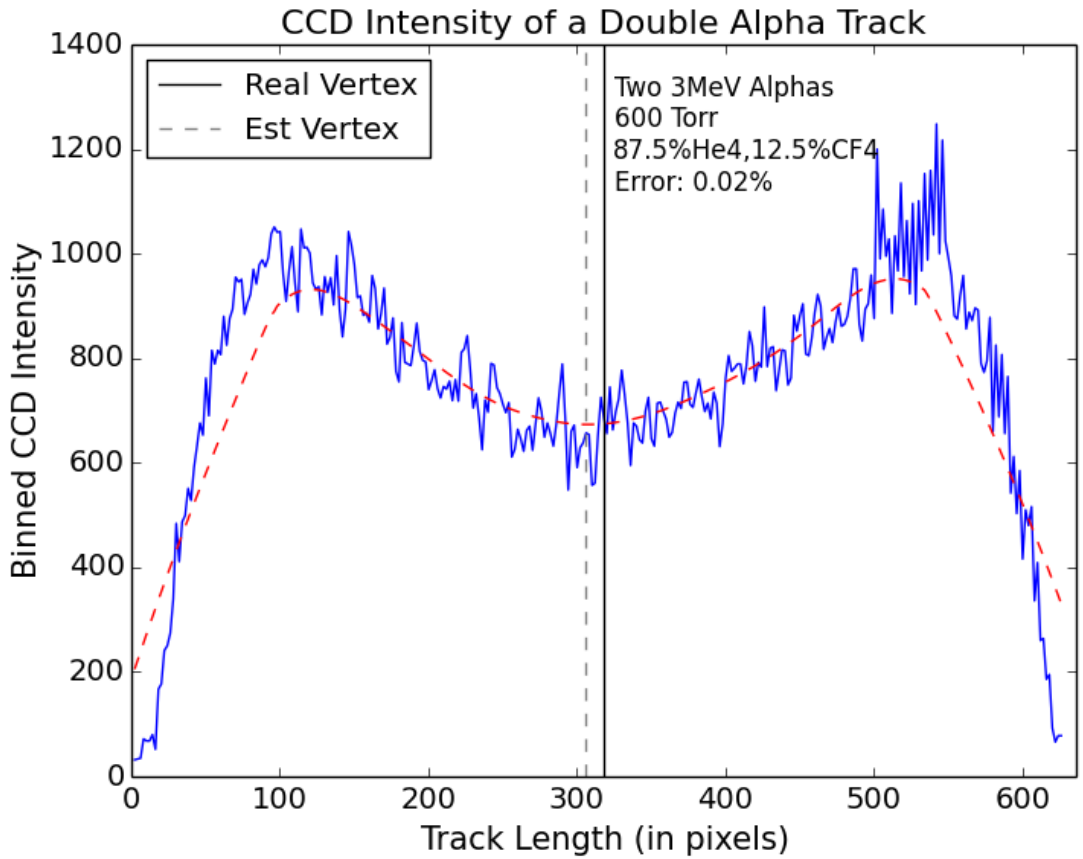


Achieved 2.5% resolution at 5 MeV.
Goal is 2% at 1.5 MeV.

We have developed algorithms that identify the decay vertex.



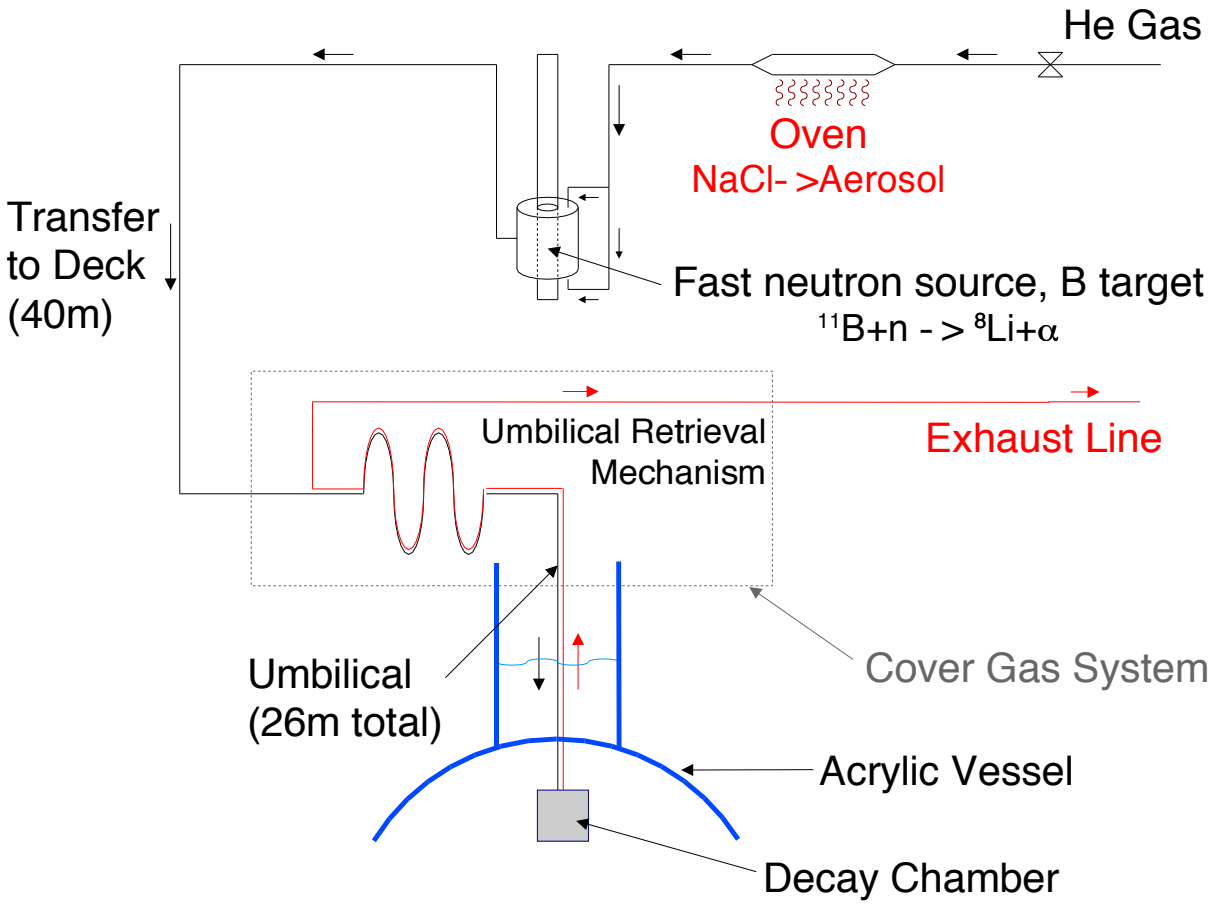
We have developed algorithms that identify the decay vertex.



Analysis by graduate student Efrain Segarra

We still need to figure out how to make the ^{8}Li.

SNO had a ^{8}Li calibration source.



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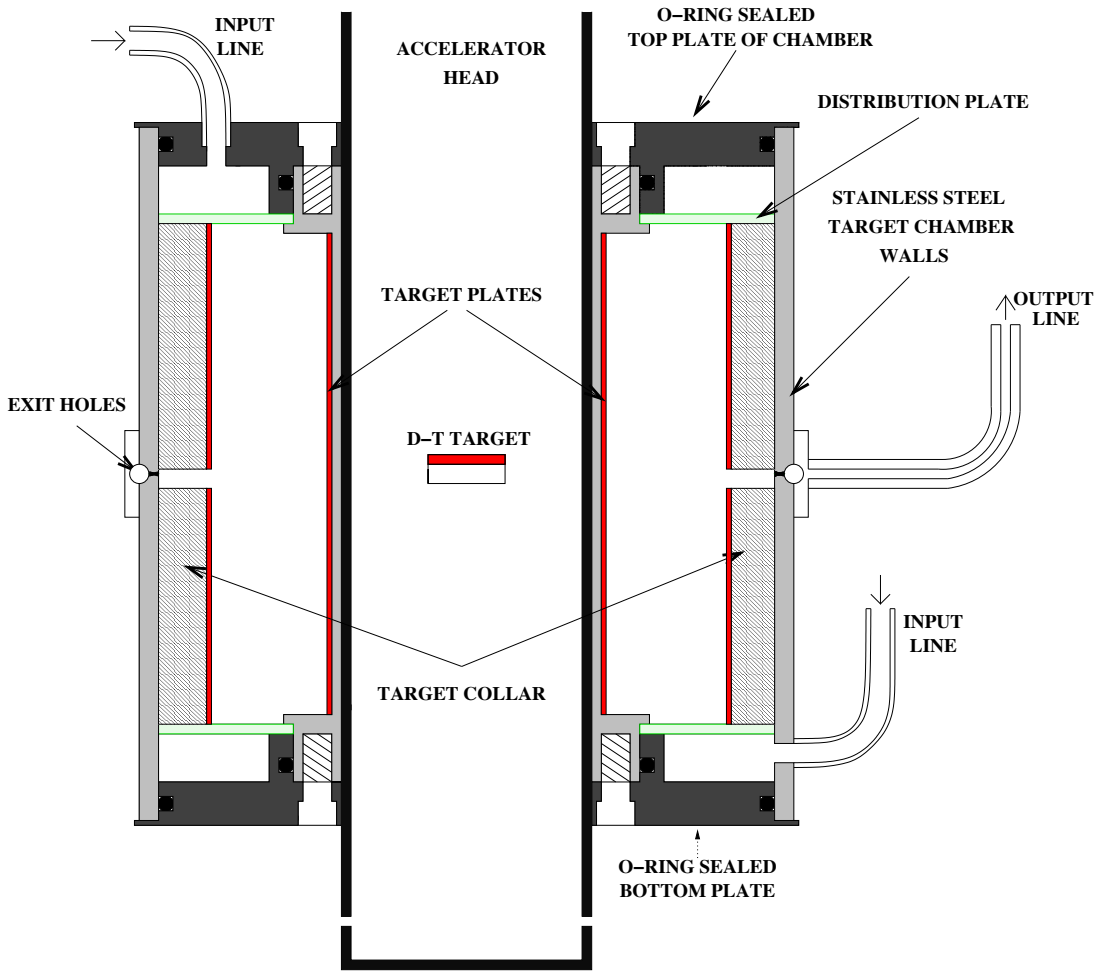
SNO used a *dt*-fusion generator for $^{11}B(n,\alpha)^{8}Li$.



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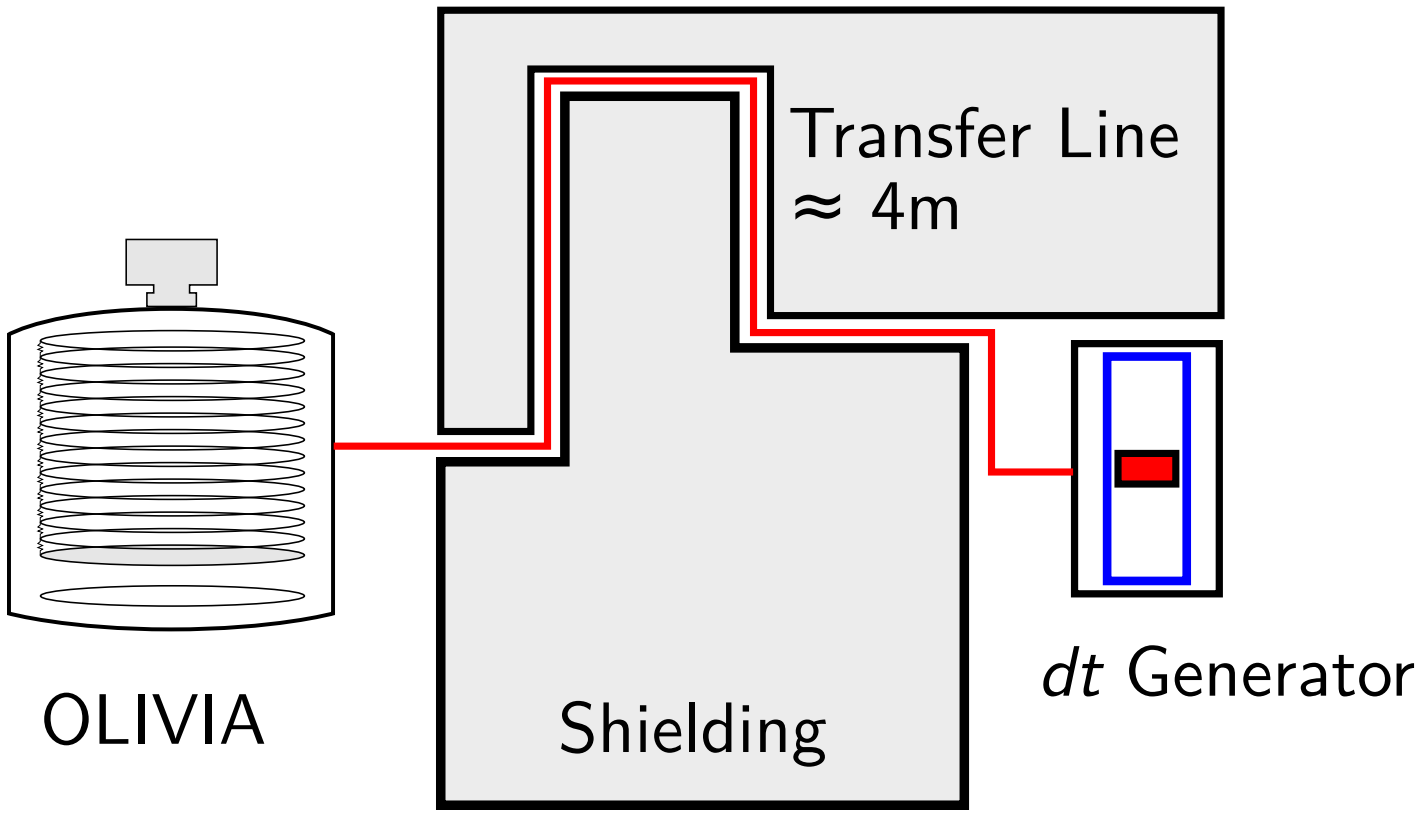
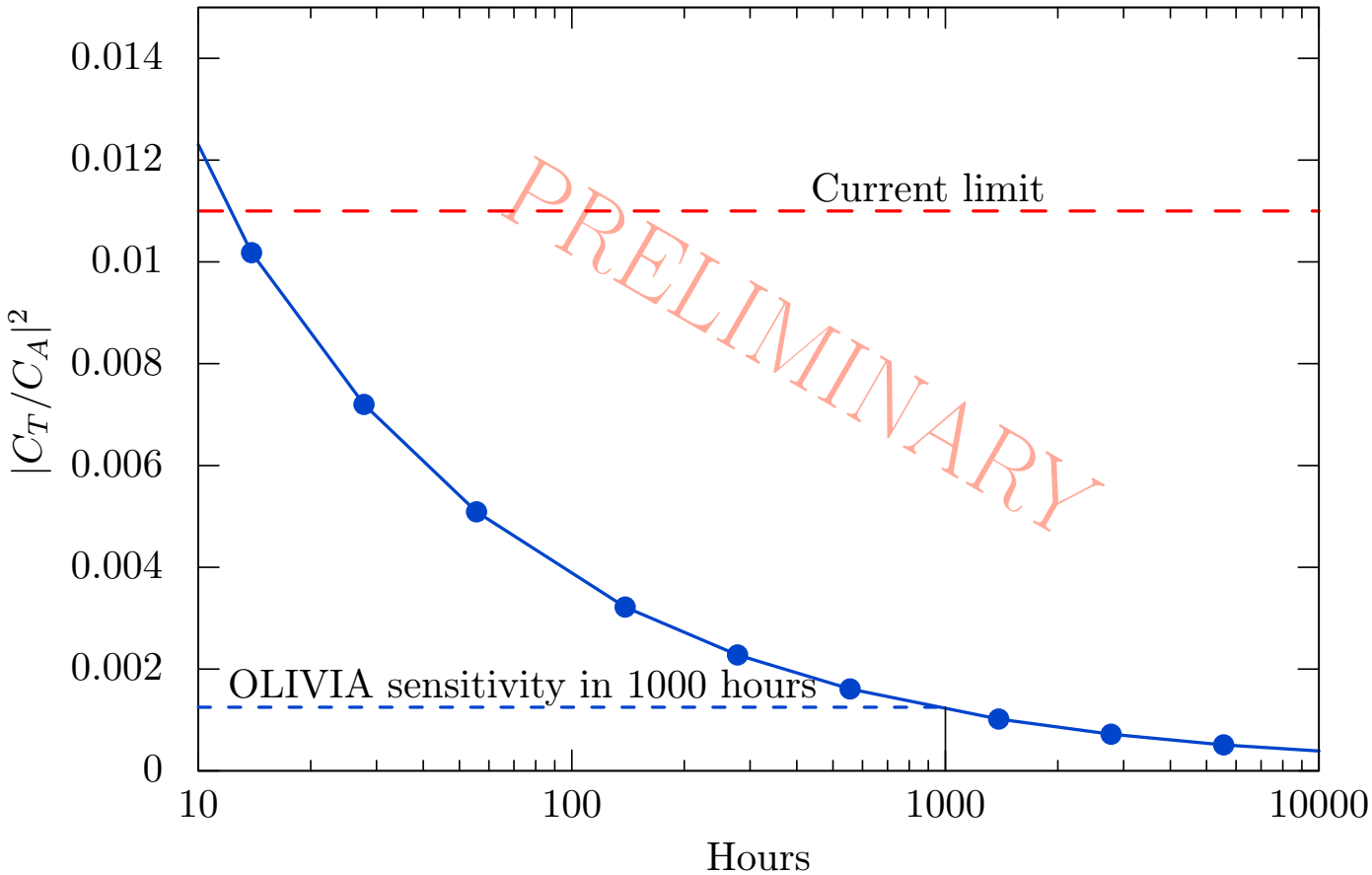
Possible OLIVIA set-up



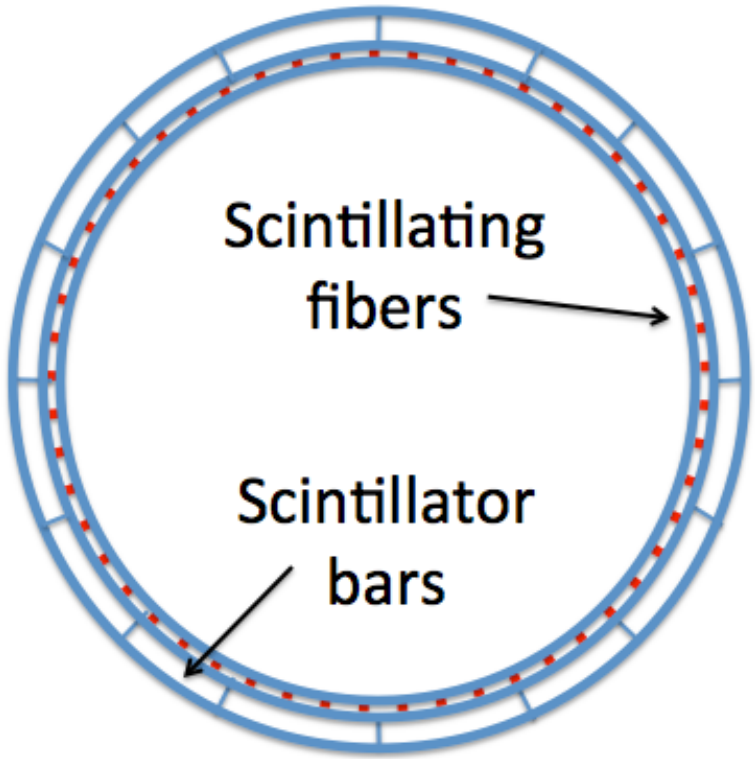
Our goal is 10^7 decays in OLIVIA in one month.

OLIVIA would have tremendous reach from increased statistics.



Incl. reasonable estimates for achievable resolutions, ^{8}Li production rates

Potential upgrade of β-detectors



Add scintillator array for detecting electrons inside the TPC volume.
$\longrightarrow$ additional correlations

Summary

- ^{8}Li has great potential for probing BSM physics
- Previous best measurement used an ion trap $\longrightarrow$ limited statistics
- OLIVIA
  - Use existing TPC technology
  - Factor 10$\times$ increase in statistics
  - Full 4π detector coverage
  - Follow SNO design for ^{8}Li production
  - Drastic improvement in reach!
- We are just getting started!

β-decay has already led us to two new particles.
OLIVIA can help us look for another!