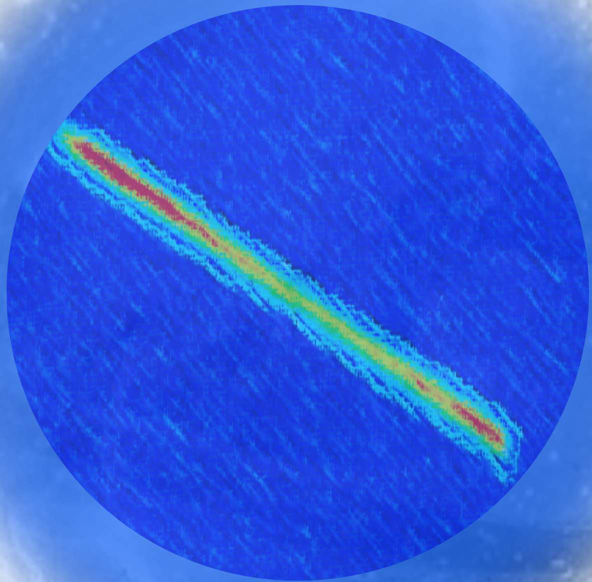
Trapless (^{8}Li) Beta Decay Study

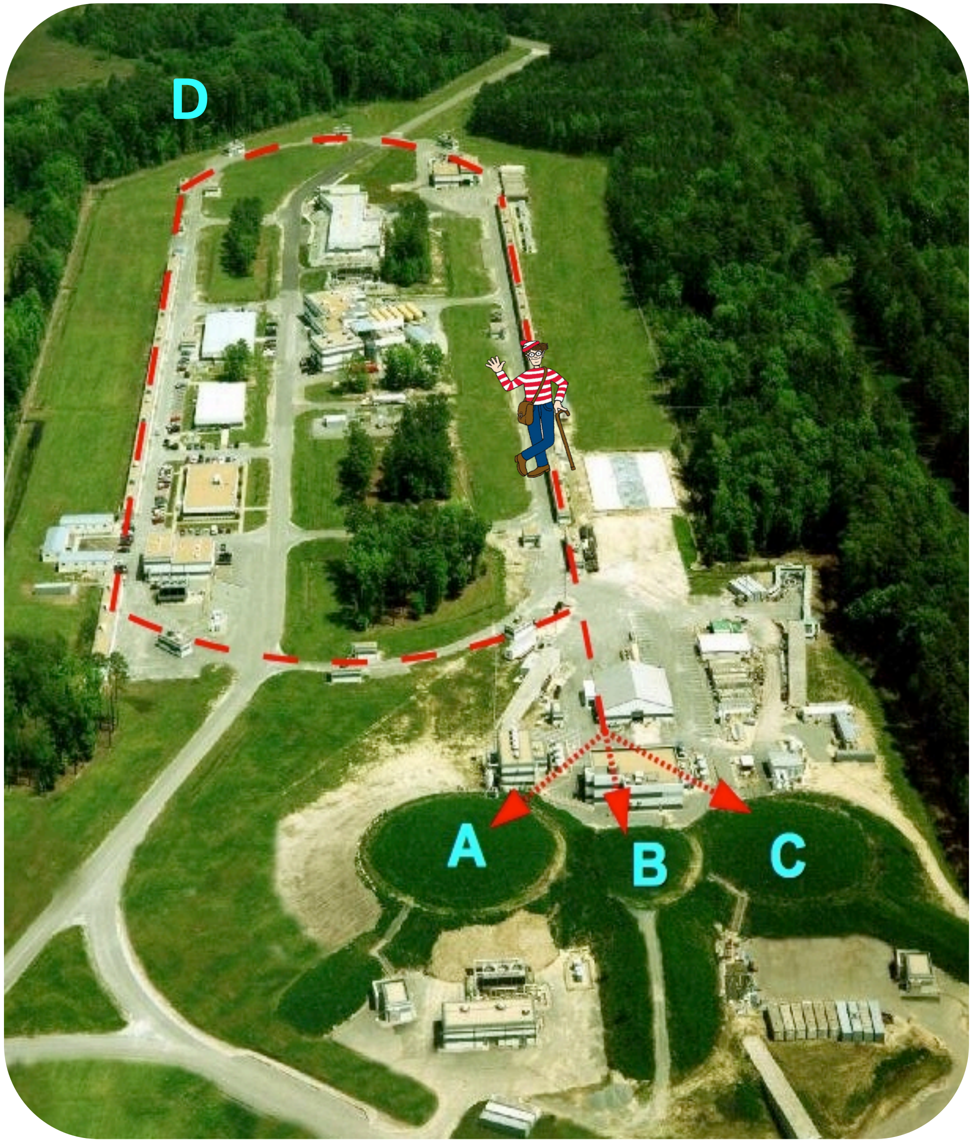
Or Hen – MIT



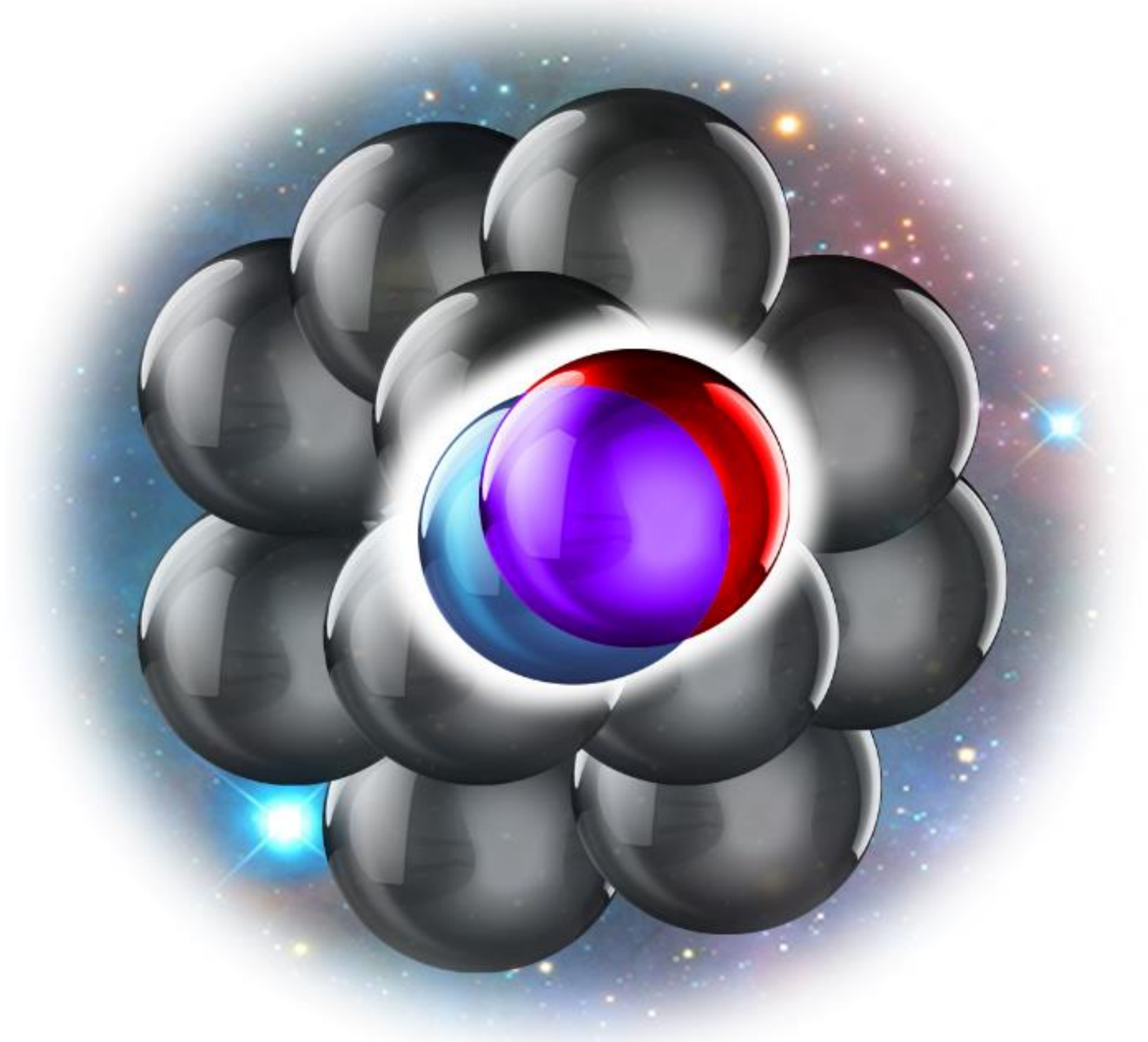
Hen Lab
Laboratory for Nuclear Science @ MIT

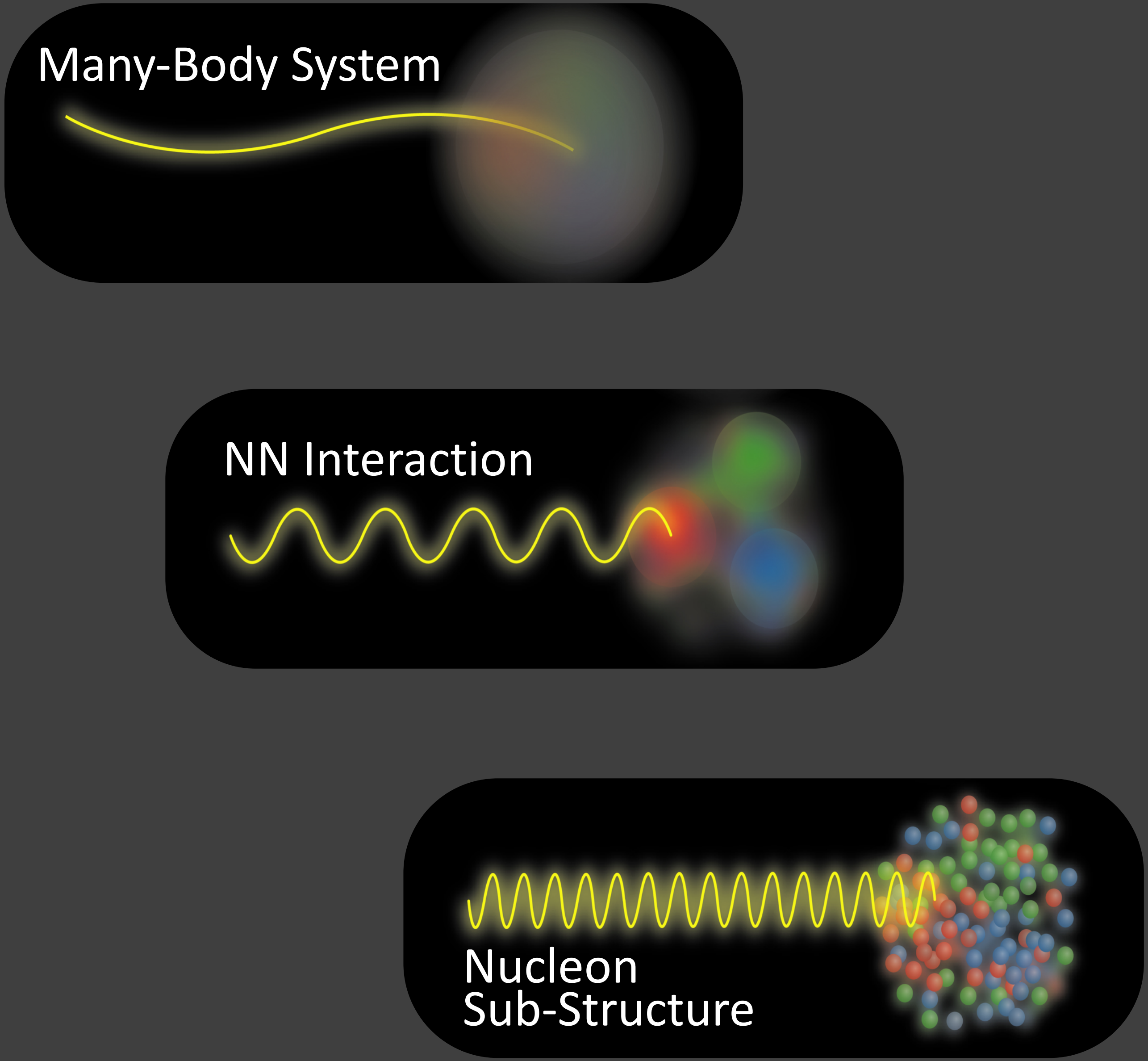
Jefferson-Lab National Accelerator Facility

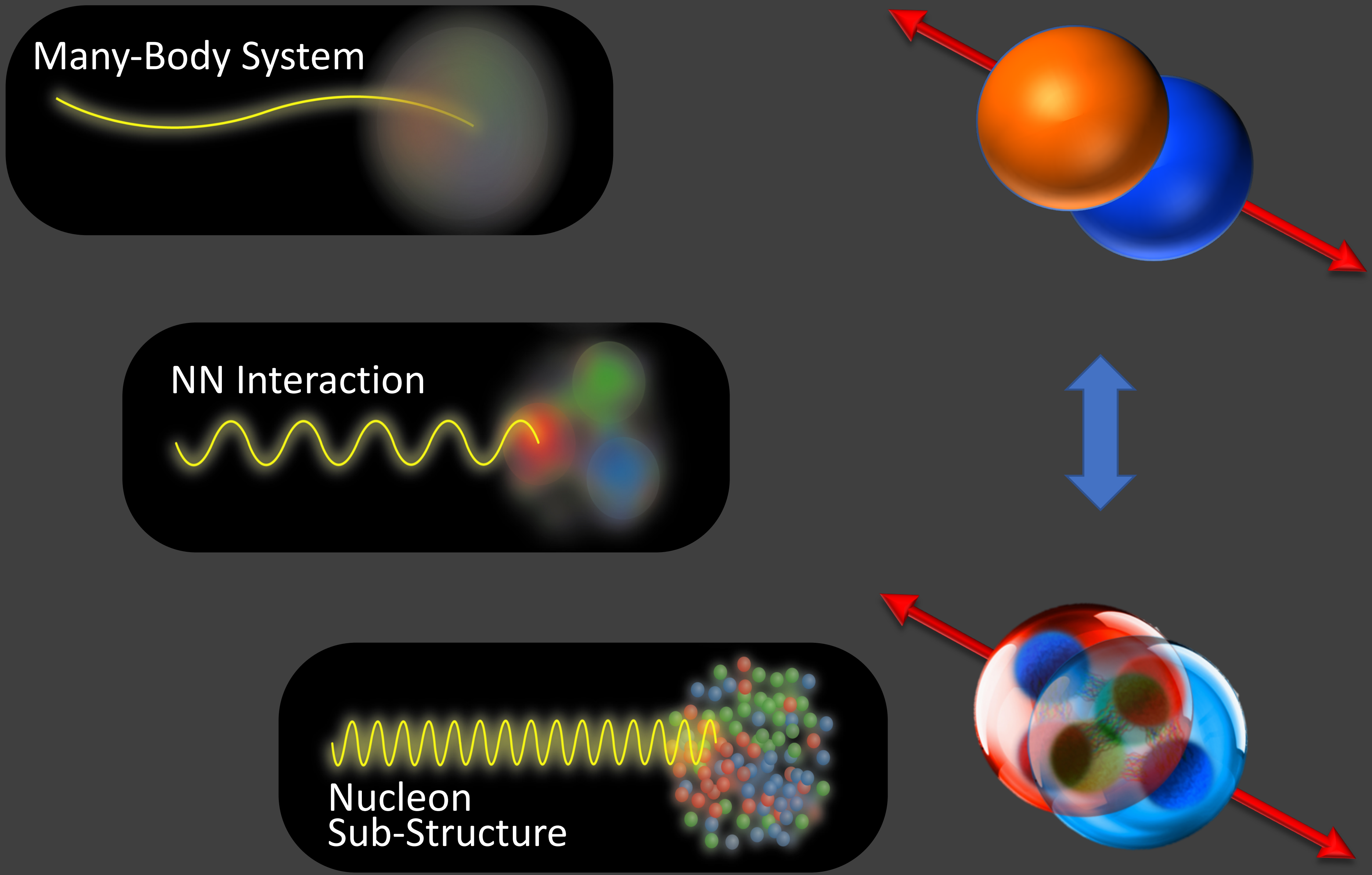
- Virginia, USA
- Electron beam
  [12 GeV; ~80 uA;
  high polarization]
- 4 experimental halls
- Approved program for coming ~decade
- Leading to EIC



Short-Range Correlations (SRC)




Many-Body System
NN Interaction
Nucleon
Sub-Structure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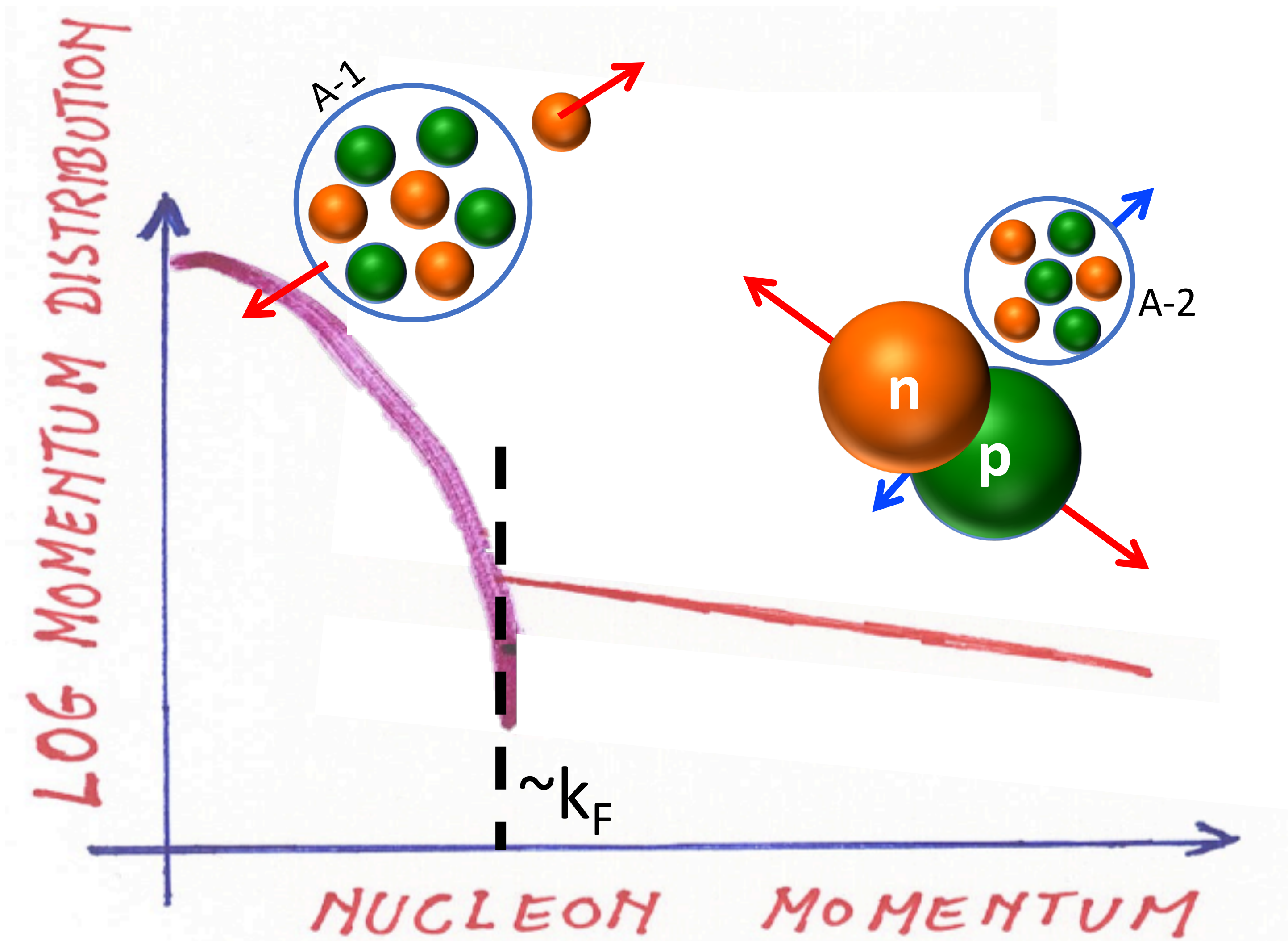
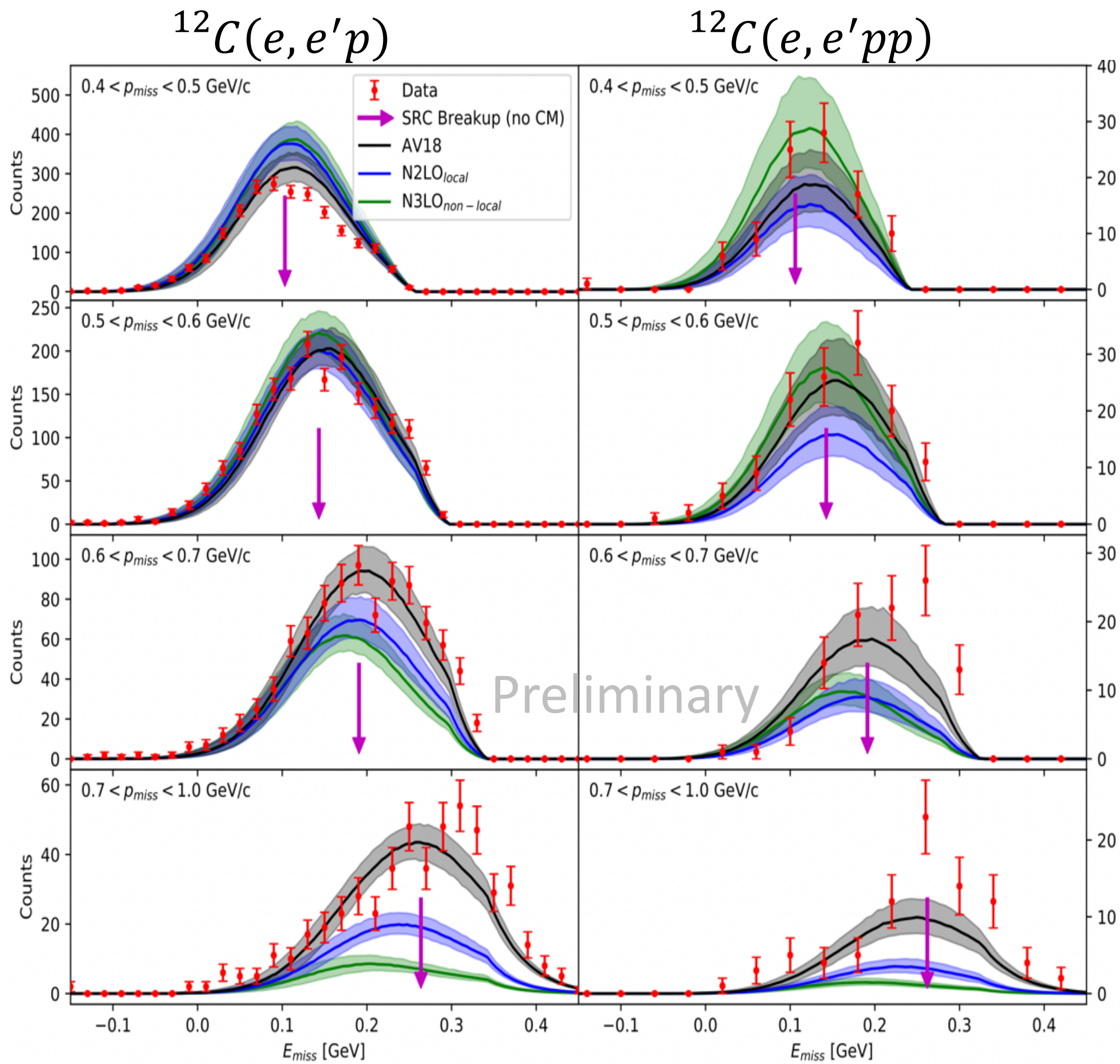


Duer, PRL (2019); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003); <u>Review:</u> Hen RMP (2017);

Mapping the nuclear spectral function

NEW!



Momentum

400 – 500 MeV/c

500 – 600 MeV/c

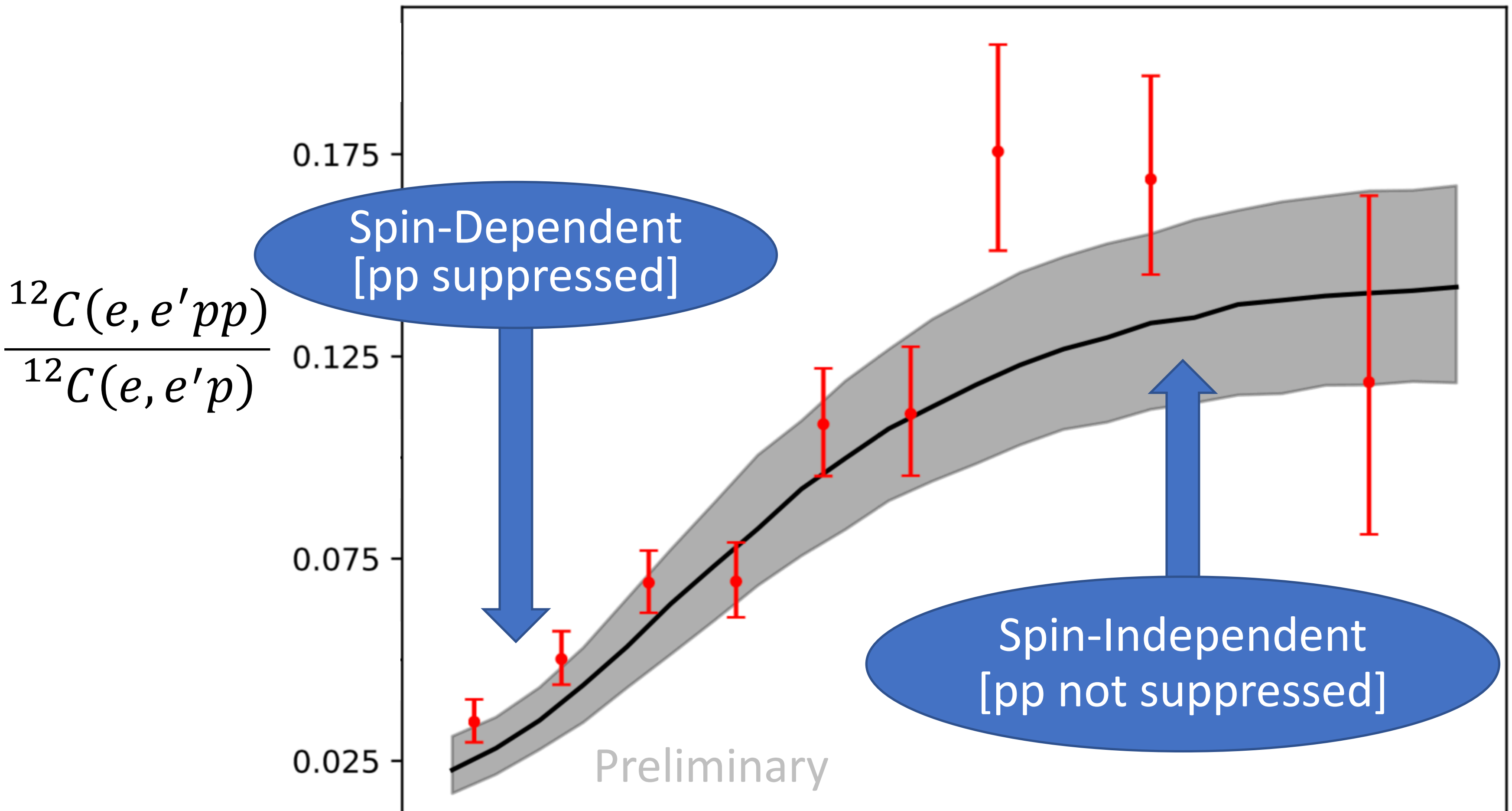
600 – 700 MeV/c

700 – 1000 MeV/c

Energy 0 400 MeV 0 400 MeV

A. Schmidt

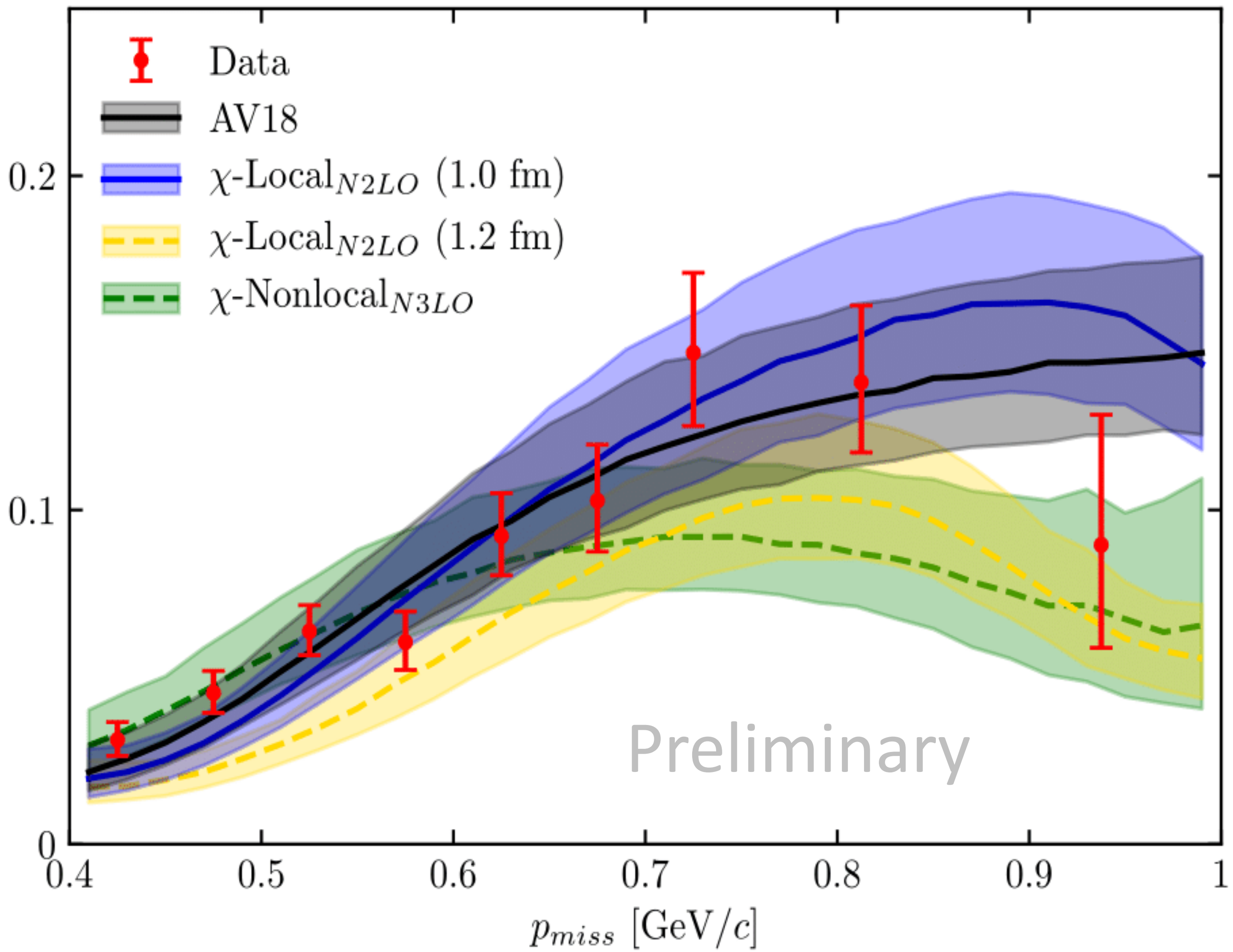
Probing the NN Interaction



A. Schmidt

Probing the NN Interaction

$$\frac{^{12}C(e,e'pp)}{^{12}C(e,e'p)}$$



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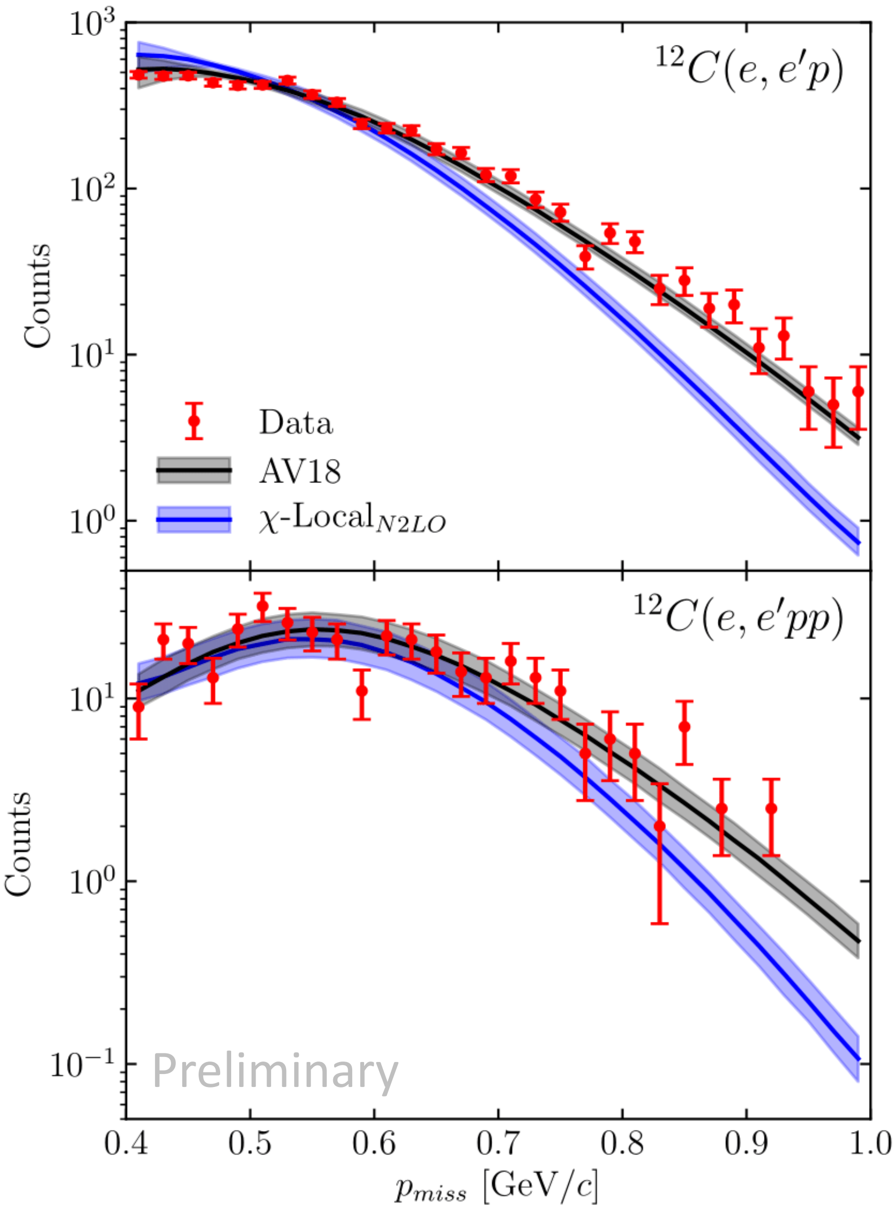

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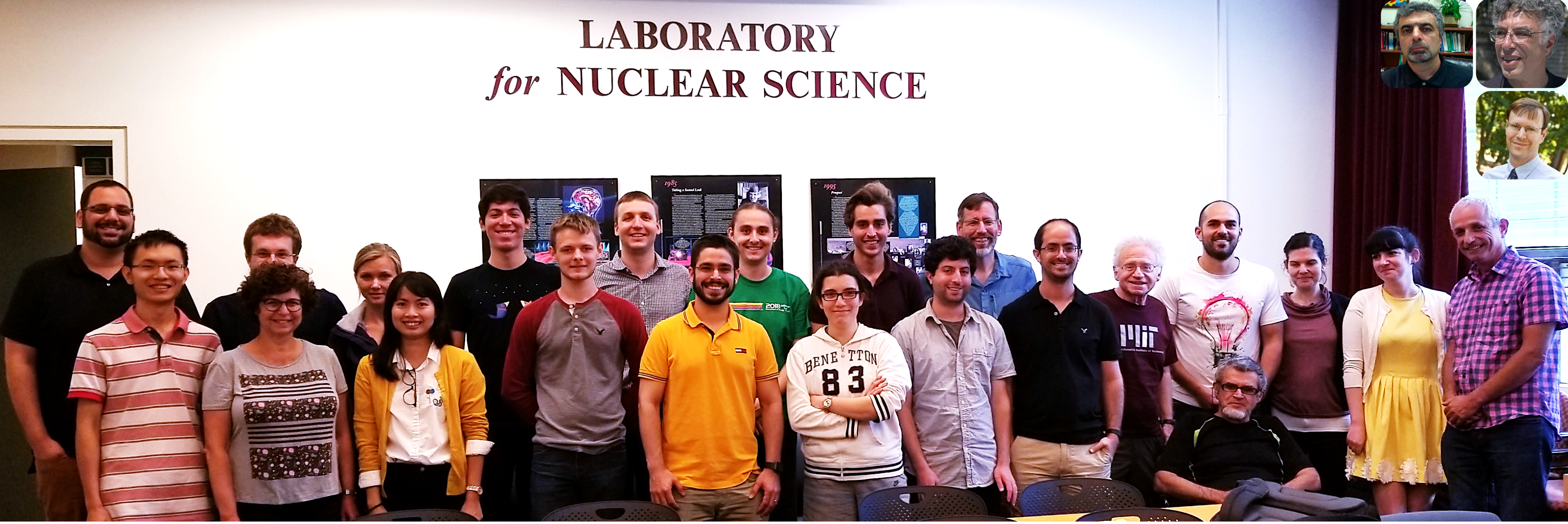
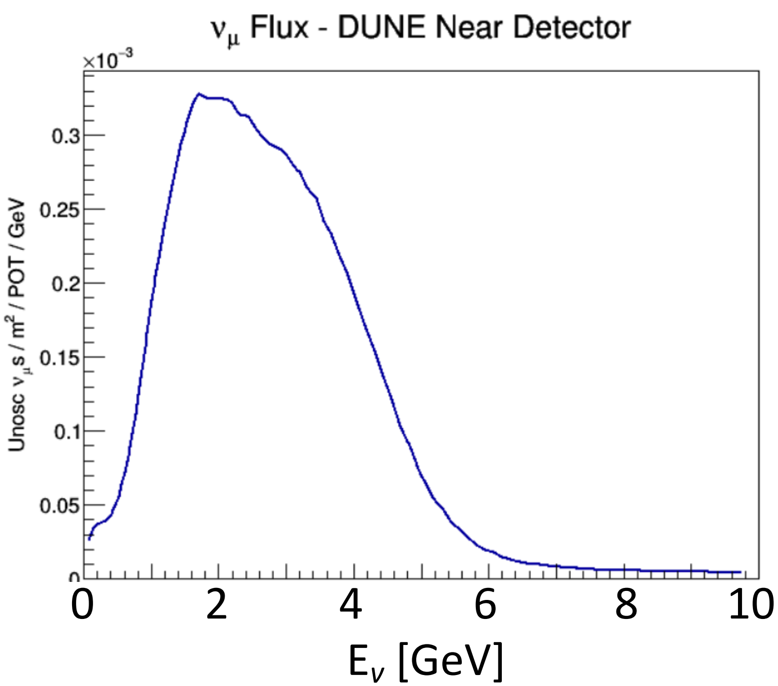


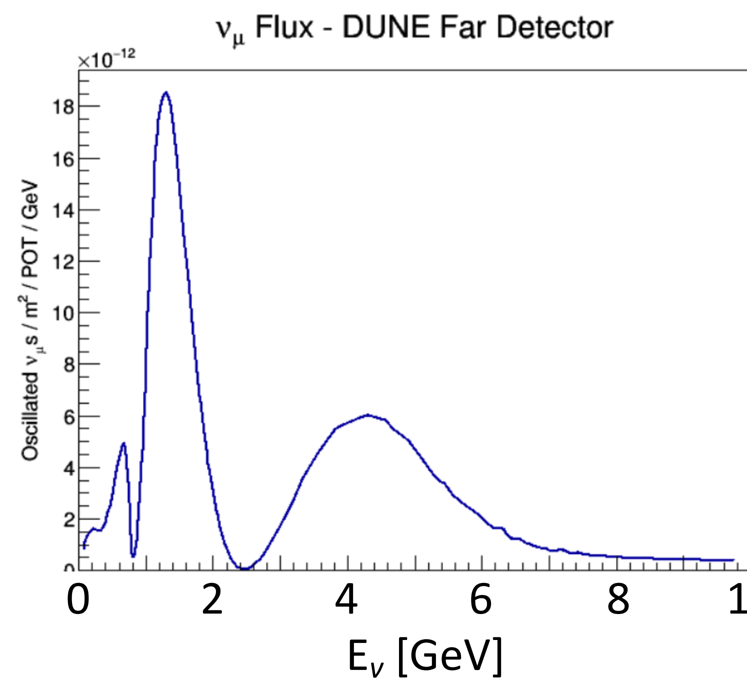
2018/19 Publications:

- Nature 566, 354 (2019)
- Nature, 560, 617 (2018)
- PRL, In-Print (2019)
- PRL 121, 092501 (2018)
- Physics Letters B 791, 242 (2019)
- Physics Letters B 785, 304 (2018)
- Physics Letters B 780, 211 (2018)
- CPC 42, 064105 (2018)

arXiv: 1811.01823; 1812.08051;
1902.06358; 1805.01981.

Nuclear Bias in Neutrino Oscillations





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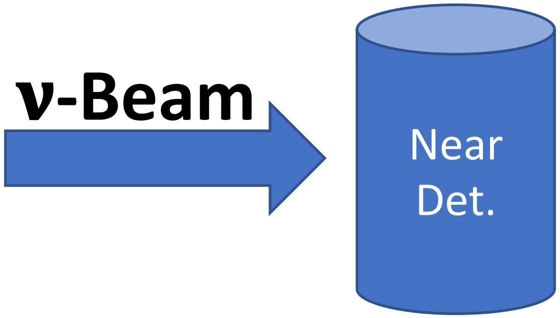
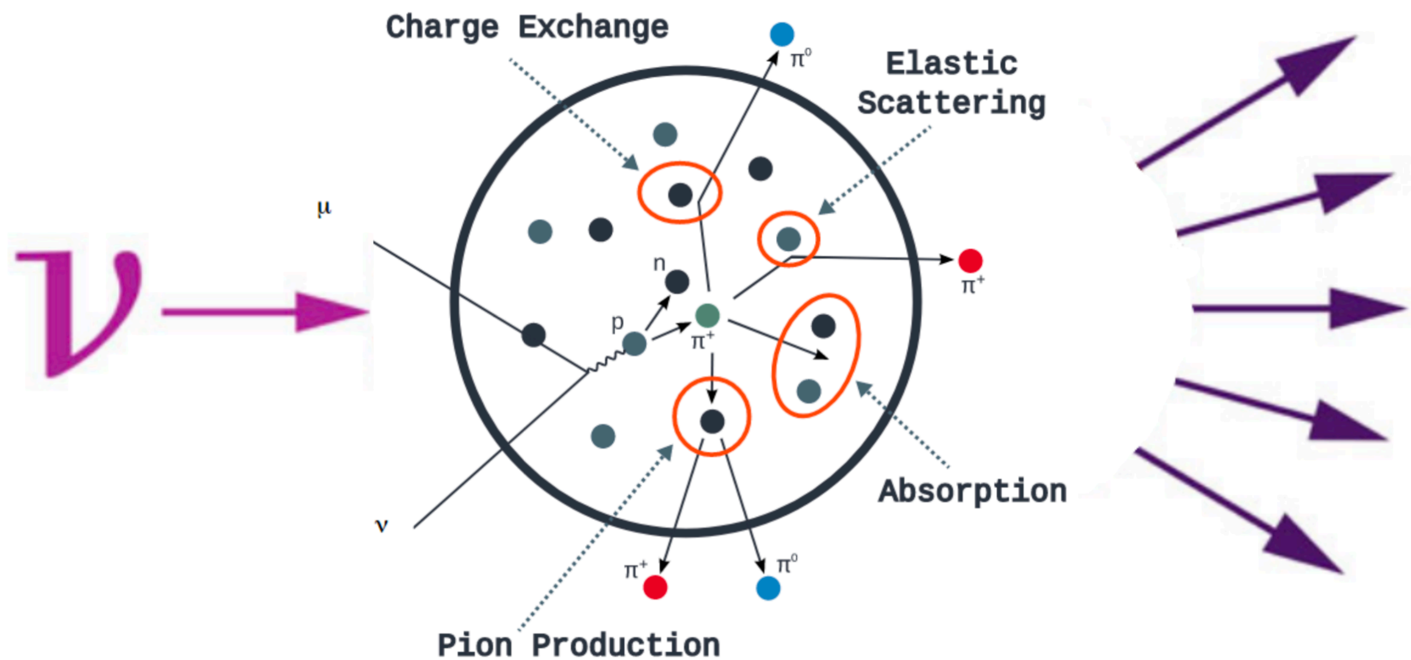




CLAS @ JLab

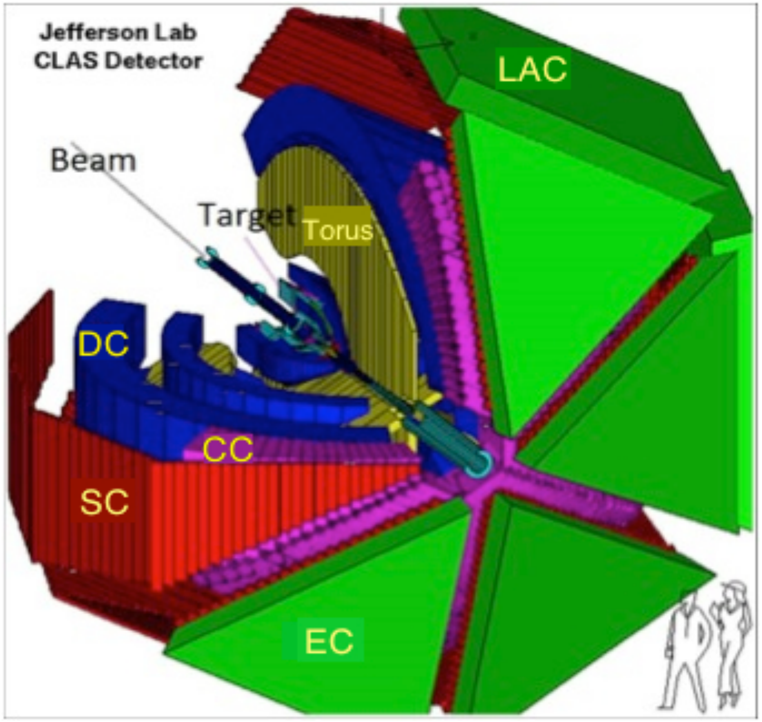
✧ 4π acceptance (almost).

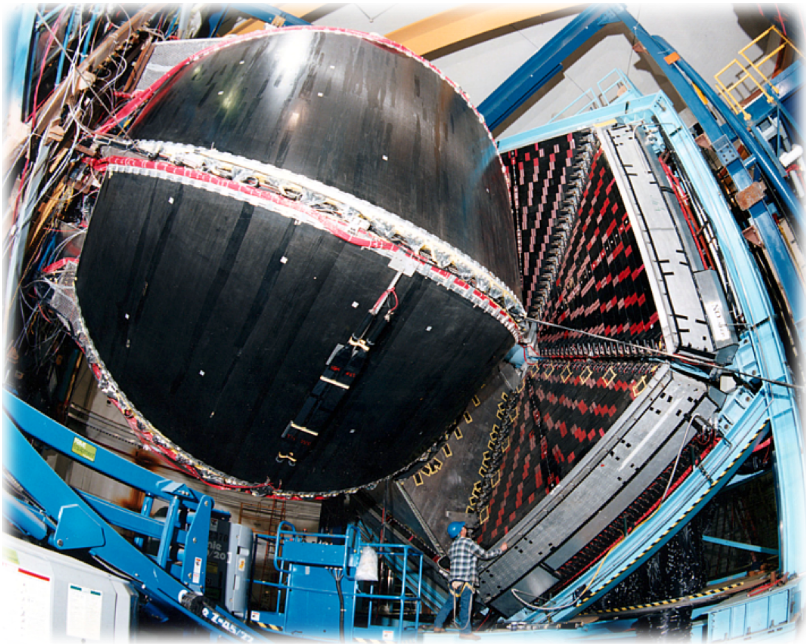
✧Charged particles (8-143°):

- $P_p > 300$ MeV/c
- $P_\pi > 150$ MeV/c

✧Neutral particles:

- EM calorimeter (8-75°)
- TOF (8-143°)





Playing the Neutrino Game

Goal: Use CLAS data to study E_{beam} reconstruction and vector-current cross-sections for different energies / nuclei.

Means (for QE study):

- Select clean (e,e'p) events (no pions, 2nd protons, ...),
- Reweight by *e-N* / ν*-N* cross-section ratio.
- Analyze as 'neutrino data' (assume unknown E_{beam}),
- Study beam energy reconstruction methods,
- Compare to GENIE predictions,
- Identify regions in phase-space where energy reconstruction and GENIE predictions agree well.

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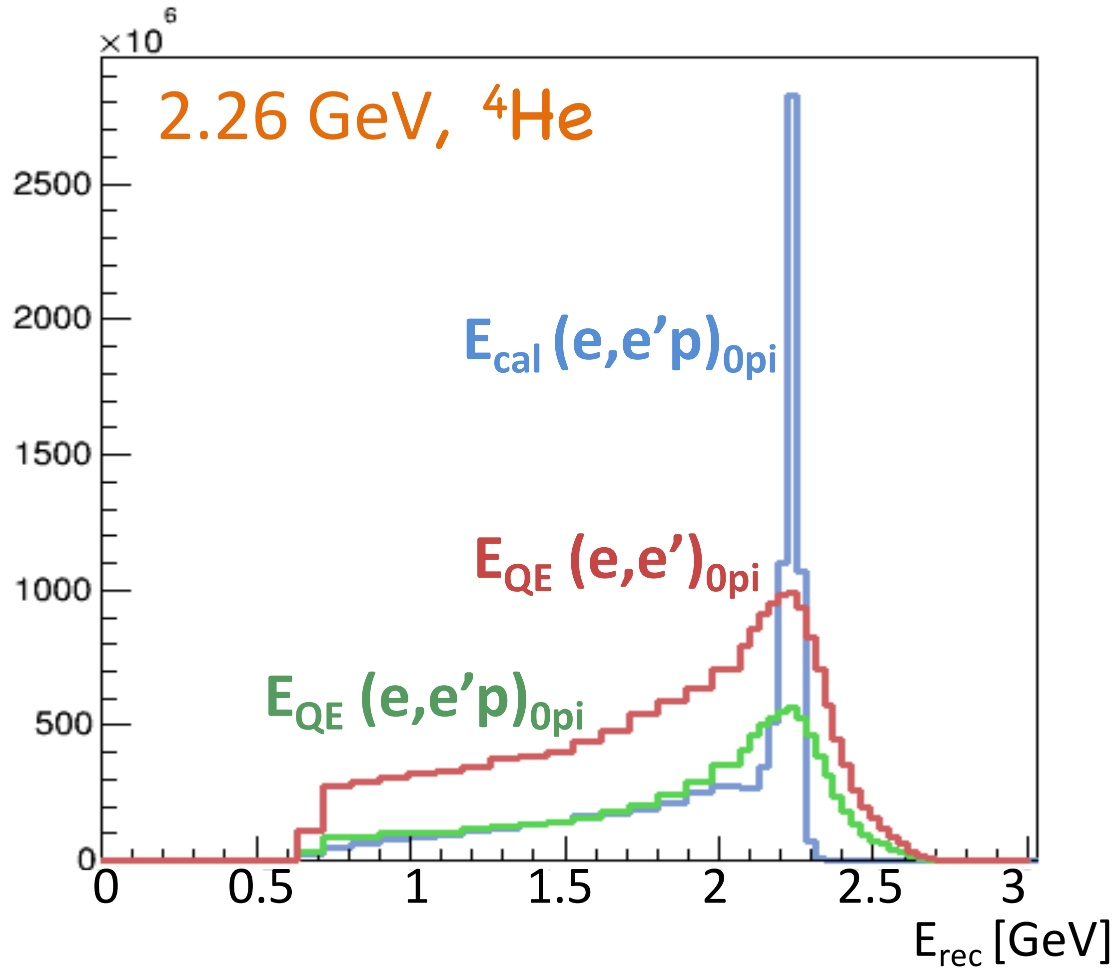
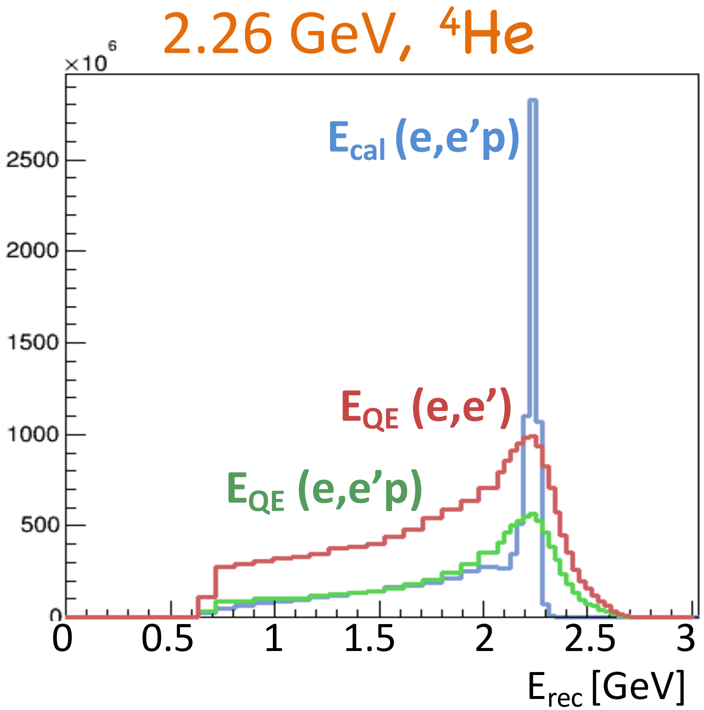
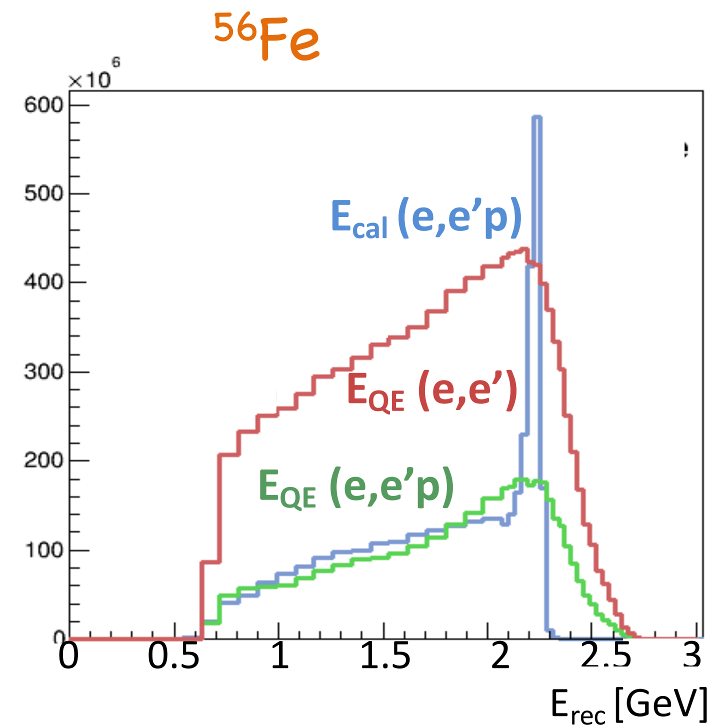
Energy Reconstruction



1. E_{QE} has worse peak resolution than E_{Cal}.
2. Same tail for E_{QE} & E_{Cal}.

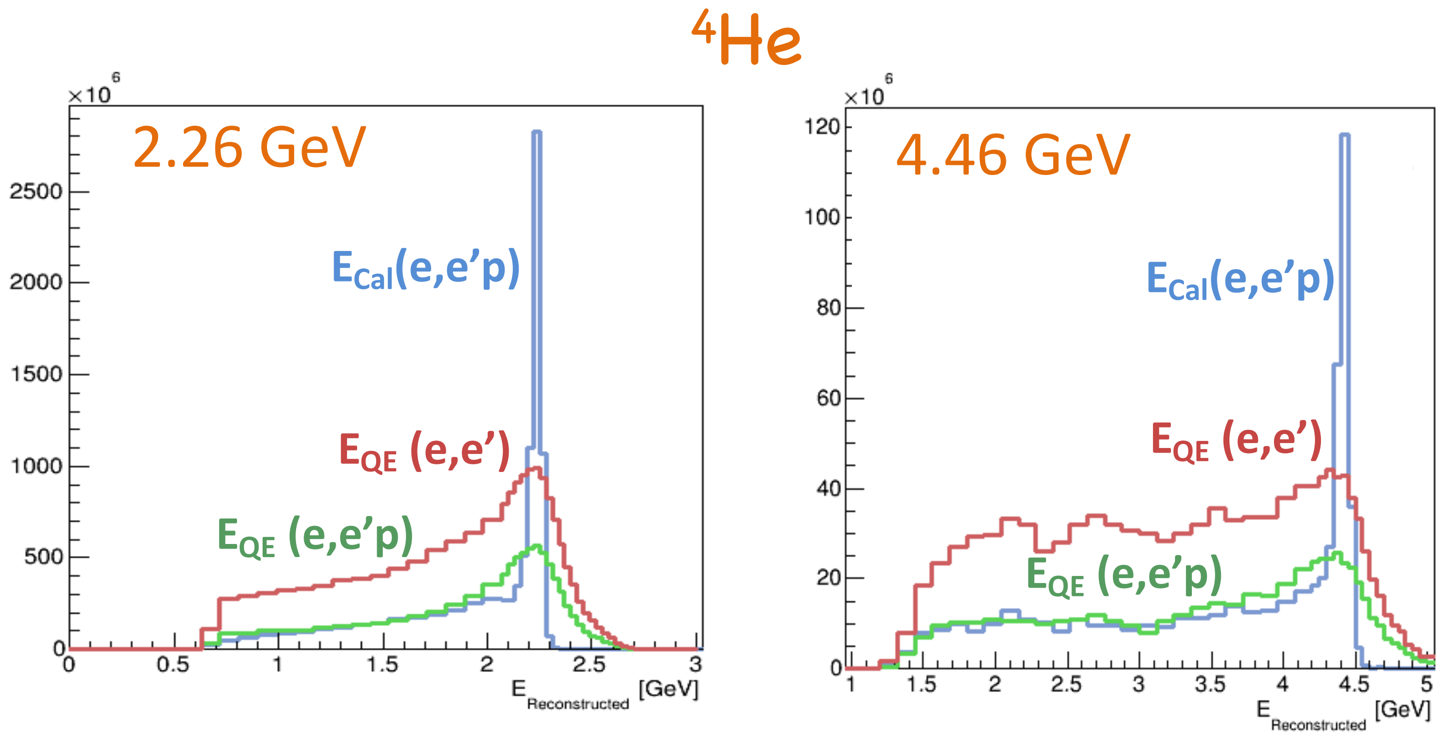
Large *A* Dependence





1. ^{56}Fe is predominantly tail.
2. ^{56}Fe is much worse than ^{4}He.

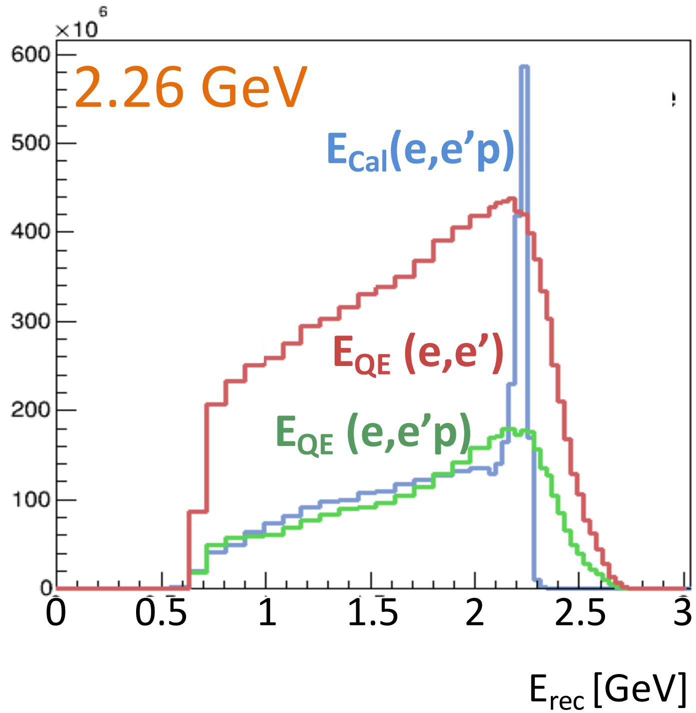
Large *E* Dependence

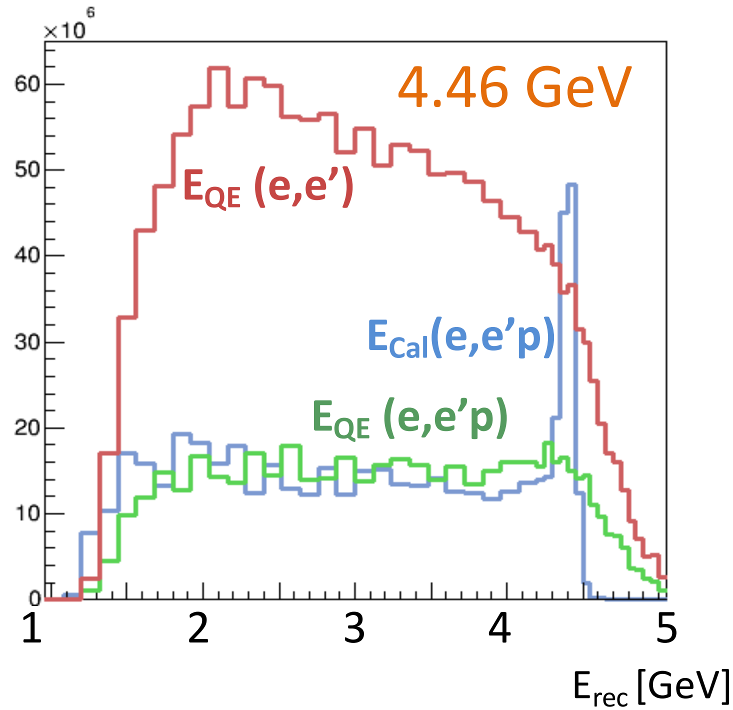


Better reconstruction at lower energies.

Large *E* Dependence

^{56}Fe





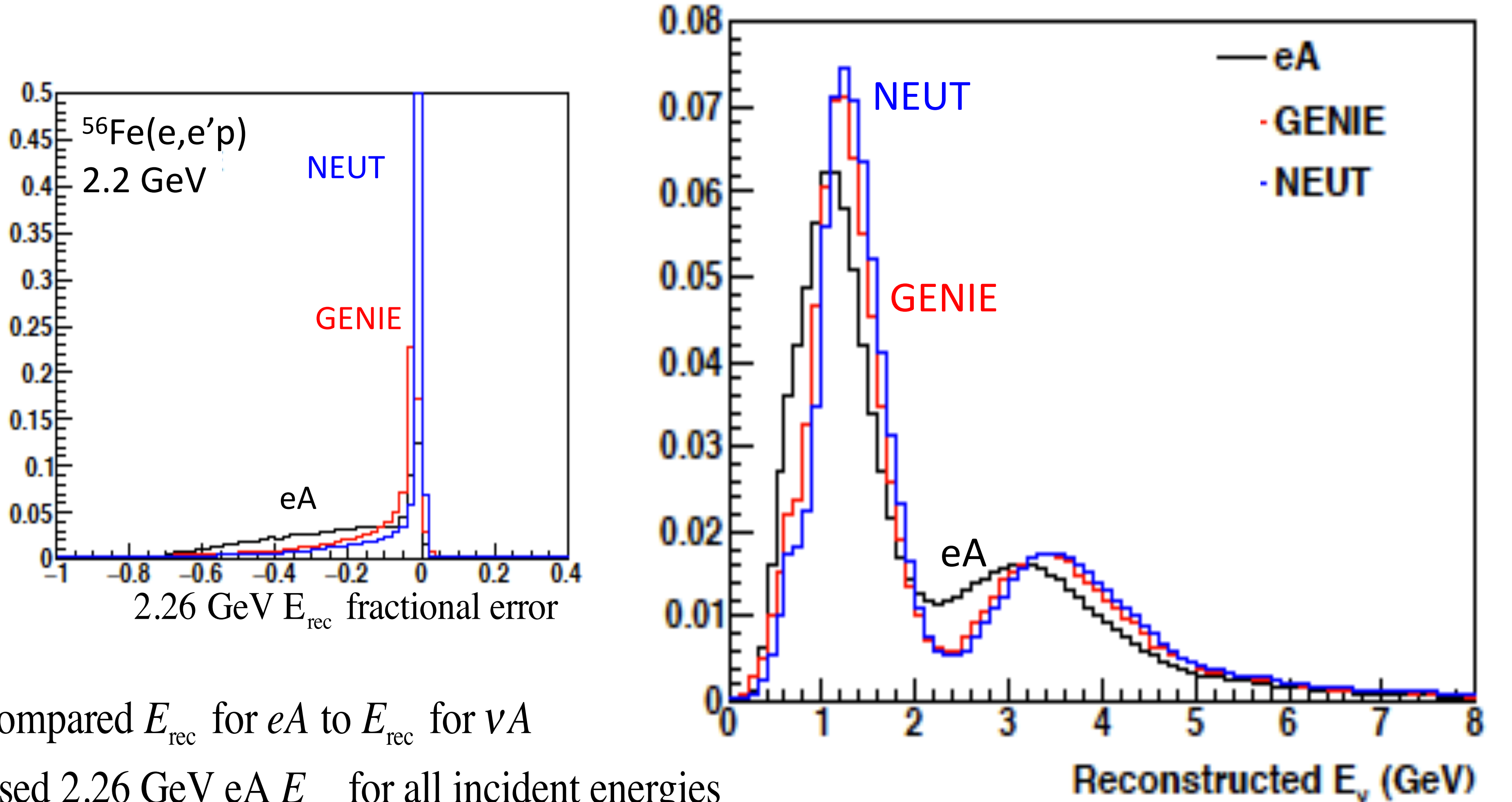
Better reconstruction at lower energies.

Data – Generator Comparisons

Fe	e^- Data	ν GENIE
2.2 GeV	26%	62%
4.4 GeV	14%	62%

Fraction of Fe$(e, e'p)$ and Fe$(\nu, \mu^- p)$ events with E_{Cal} within 5% of E_{beam}

Projected Implications to DUNE



- Compared E_{rec} for eA to E_{rec} for νA
- Used 2.26 GeV eA E_{rec} for all incident energies
- Threw events with νA Genie
- Reconstruct with νA Neut or eA data

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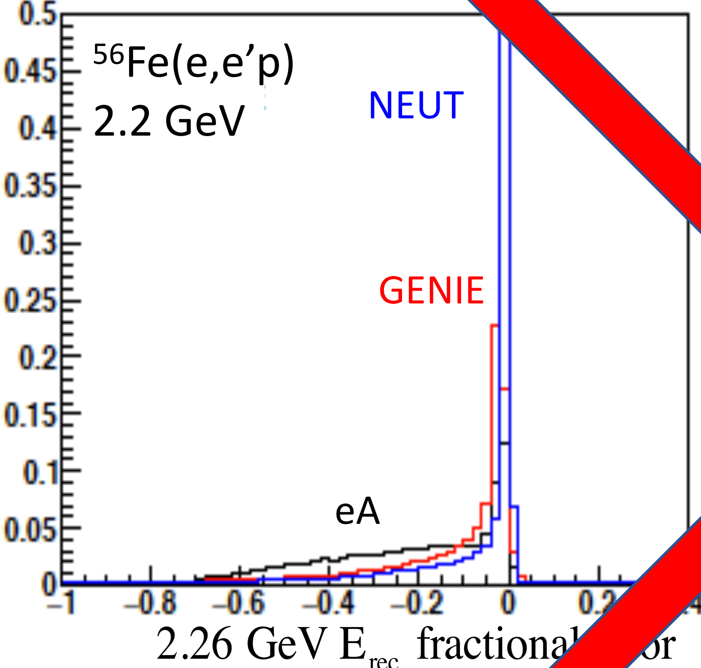

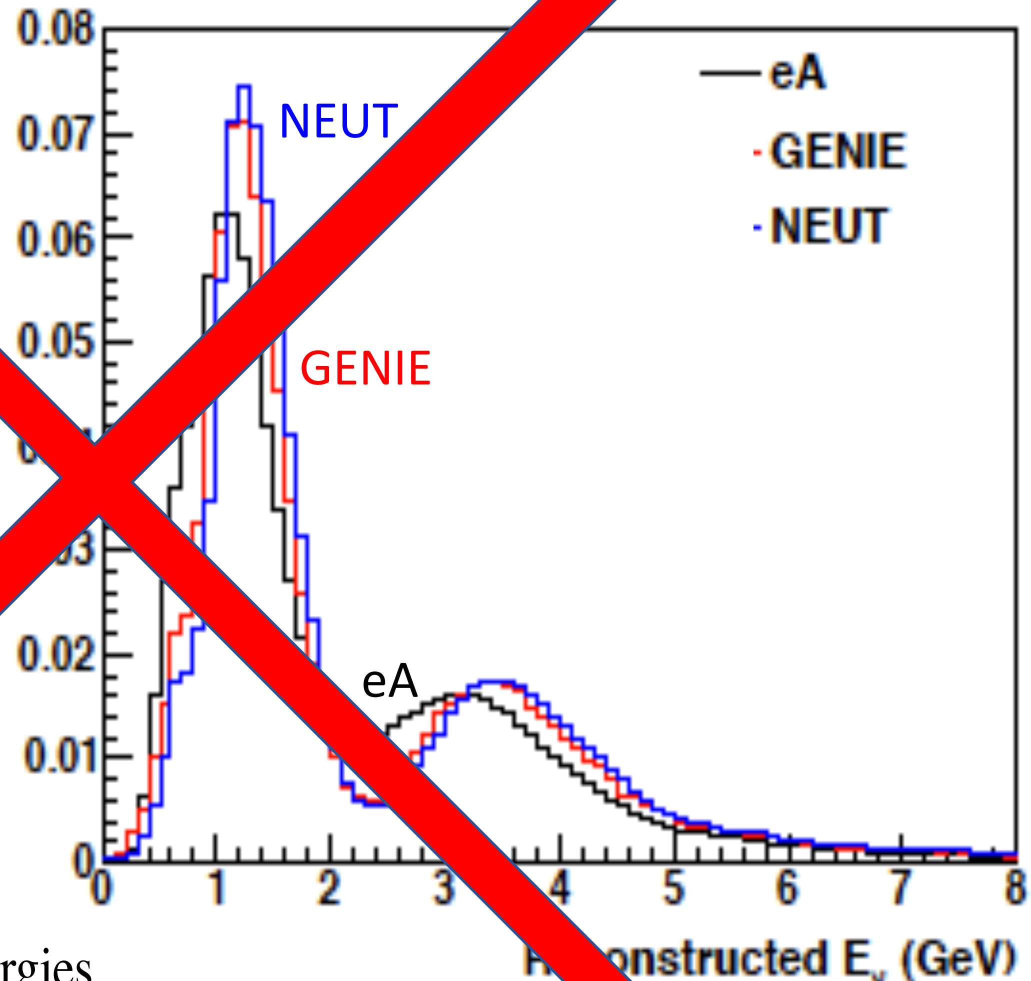

- Compared E_{rec} for eA to E_{rec} for νA
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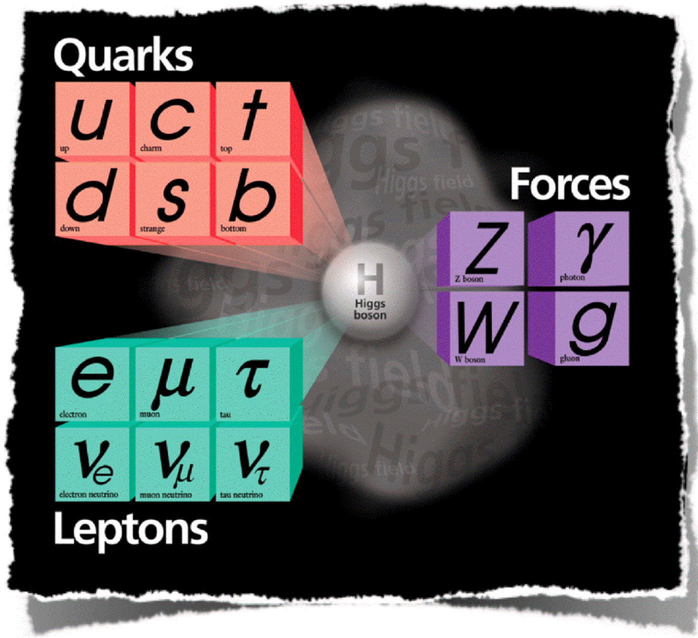
Today: The Standard Model



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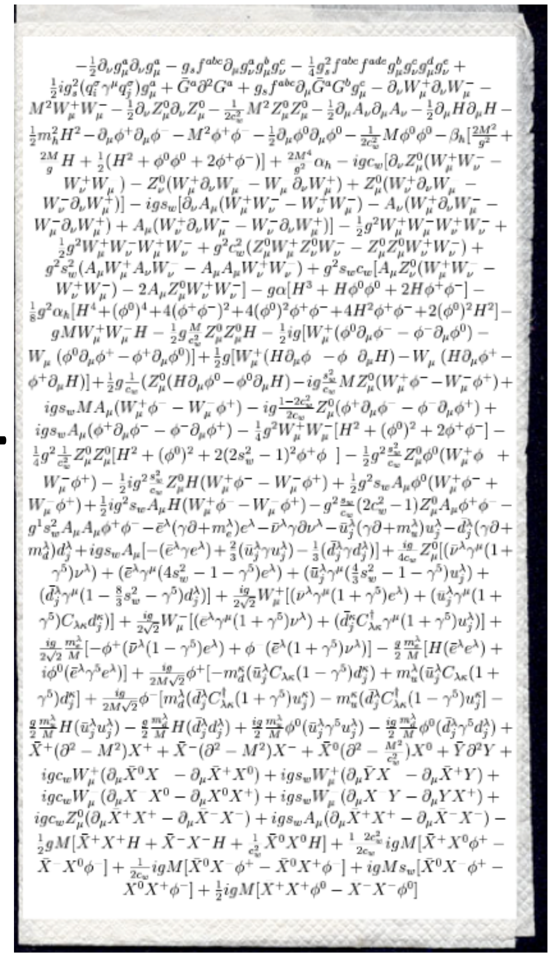

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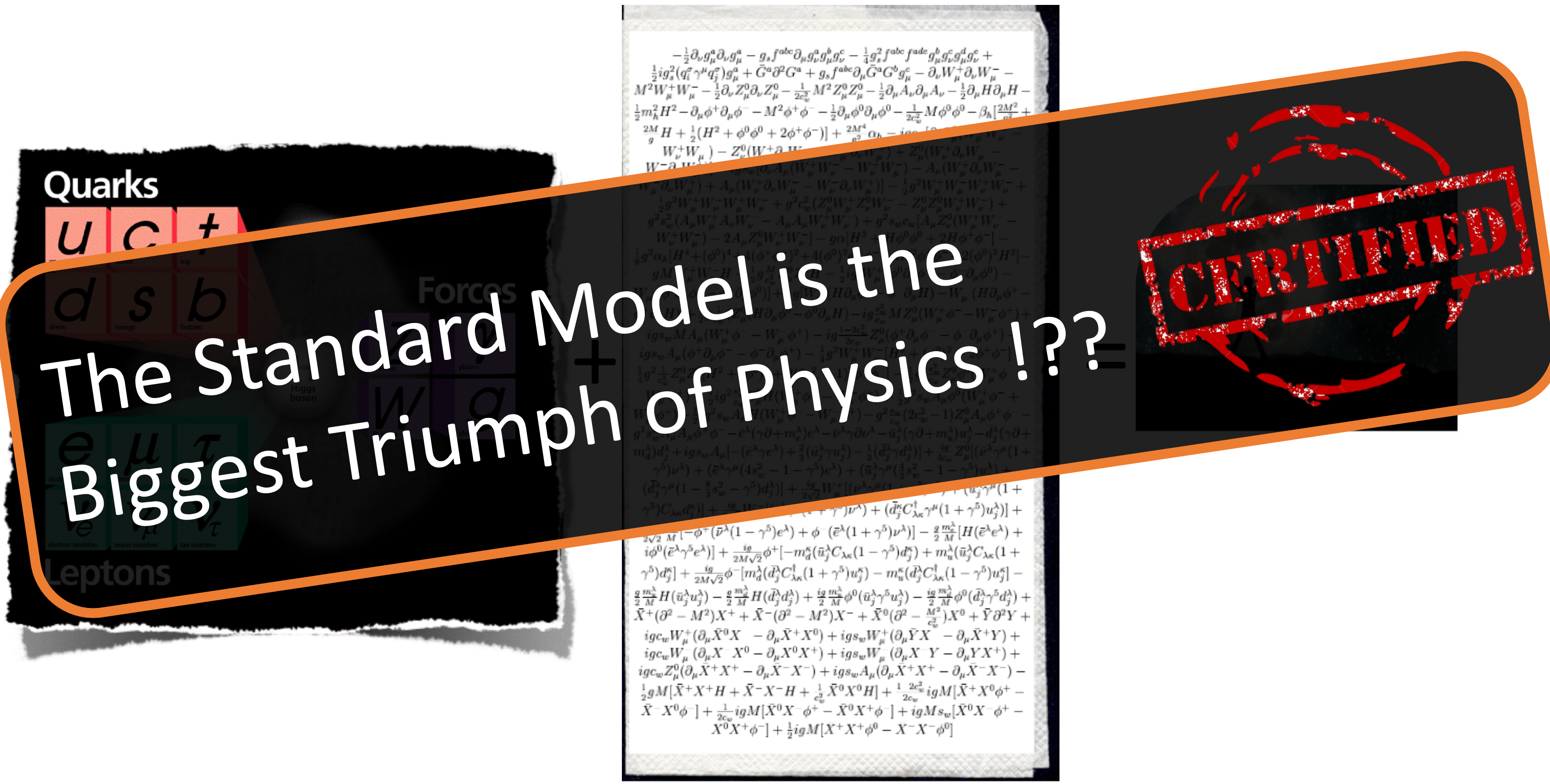
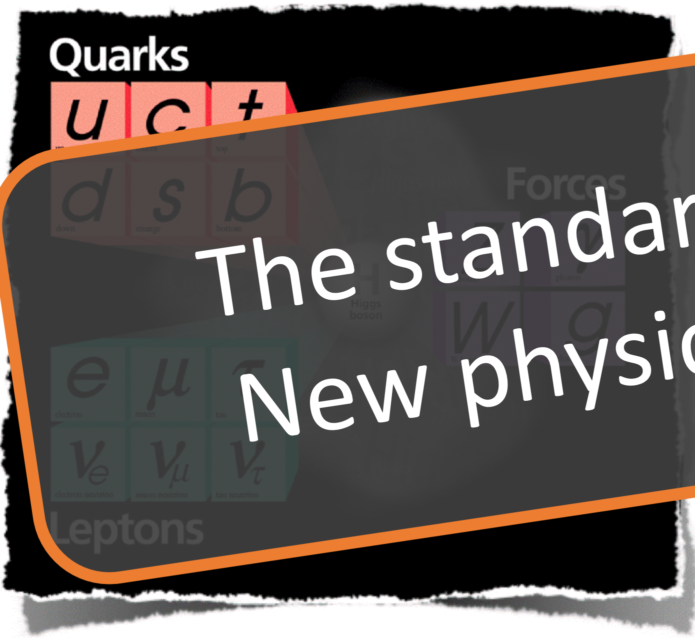
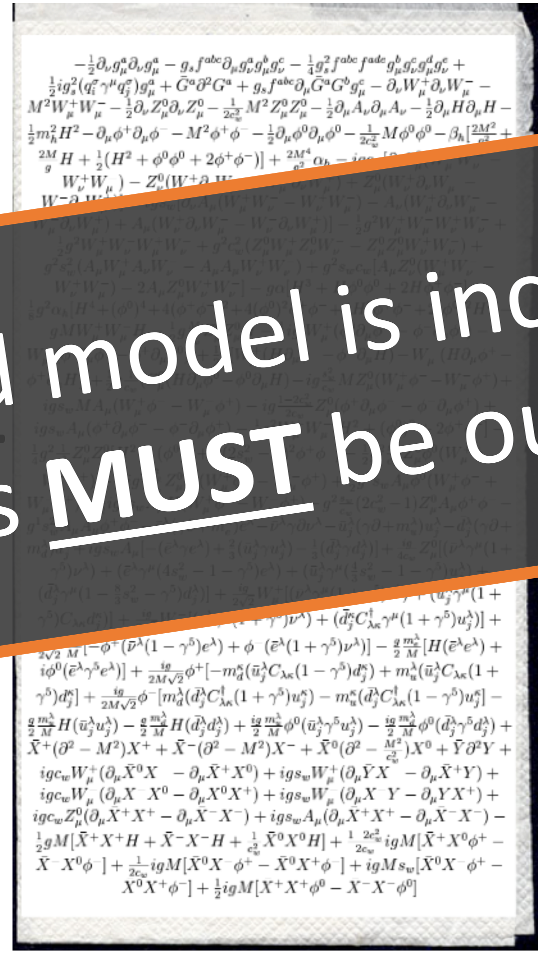
The Standard Model



But….. We still don't know Matter Anti-Matter Asymmetry, Dark Matter, Dark Energy, Black Holes, Gravity, ….

The Standard Model





The standard model is incomplete;
New physics **MUST** be out there…

But….. We still don't know Matter Anti-Matter Asymmetry, Dark Matter, Dark Energy, Black Holes, Gravity, ….

Tensor Currents in ^{8}Li Beta Decay

Searching Under the Lamppost …

Measuring Everything we can:

- Energy Spectra
- Angular Correlations
- Half-Lives
- Polarizations
- …

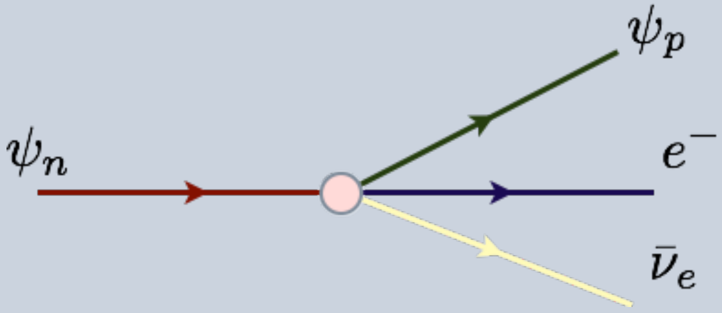
… Constraining New Physics

Comparing to Theory and Probing:

- Non V-A Contribution (S, ***T***, P).
- Right-handed Currents (V+A).
- Massive Neutrinos.
- CKM Unitary.
- ….

New Physics in β Decay

Standard Model:



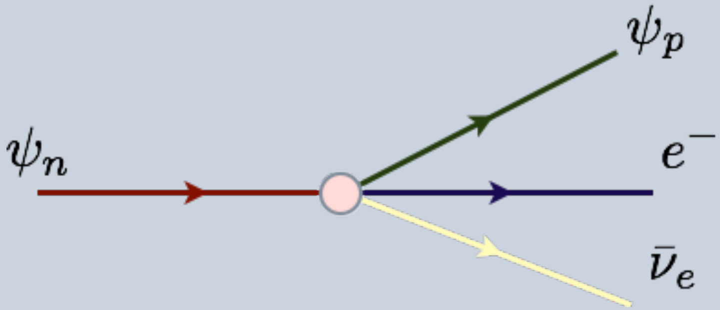
$$H_\beta = (\bar{\psi}_n \gamma_\mu \psi_p)(C_V \bar{\psi}_e \gamma^\mu \psi_\nu + C_V' \bar{\psi}_e \gamma^\mu \gamma_5 \psi_\nu) - (\bar{\psi}_n \gamma_\mu \gamma_5 \psi_p)(C_A \bar{\psi}_e \gamma^\mu \gamma_5 \psi_\nu + C_A' \bar{\psi}_e \gamma^\mu \psi_\nu)$$

$$C_V = C_V' = 1$$

$$C_A = C_A' = 1.26$$

New Physics in β Decay

Standard Model:

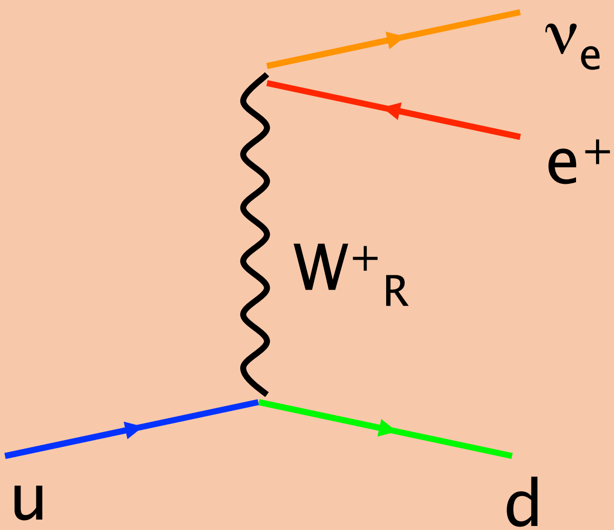


$$H_\beta = (\bar{\psi}_n \gamma_\mu \psi_p)(C_V \bar{\psi}_e \gamma^\mu \psi_\nu + C'_V \bar{\psi}_e \gamma^\mu \gamma_5 \psi_\nu) - (\bar{\psi}_n \gamma_\mu \gamma_5 \psi_p)(C_A \bar{\psi}_e \gamma^\mu \gamma_5 \psi_\nu + C'_A \bar{\psi}_e \gamma^\mu \psi_\nu)$$

$$C_V = C'_V = 1$$

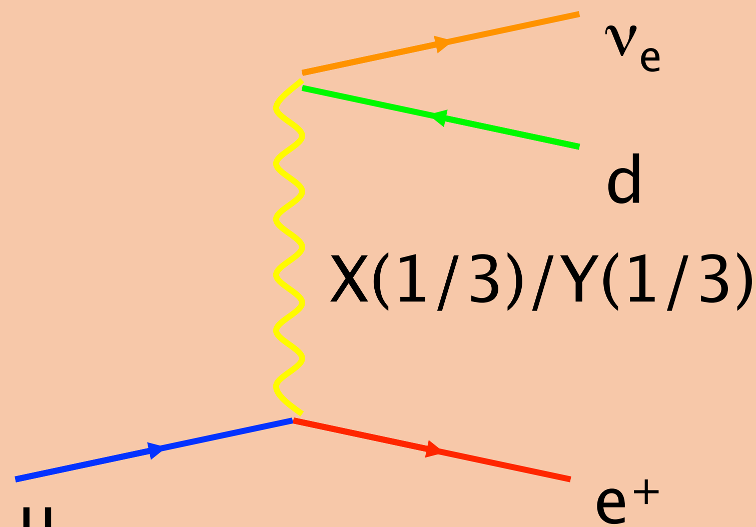
$$C_A = C'_A = 1.26$$

(Some) New Physics:



Right Handed Bosons

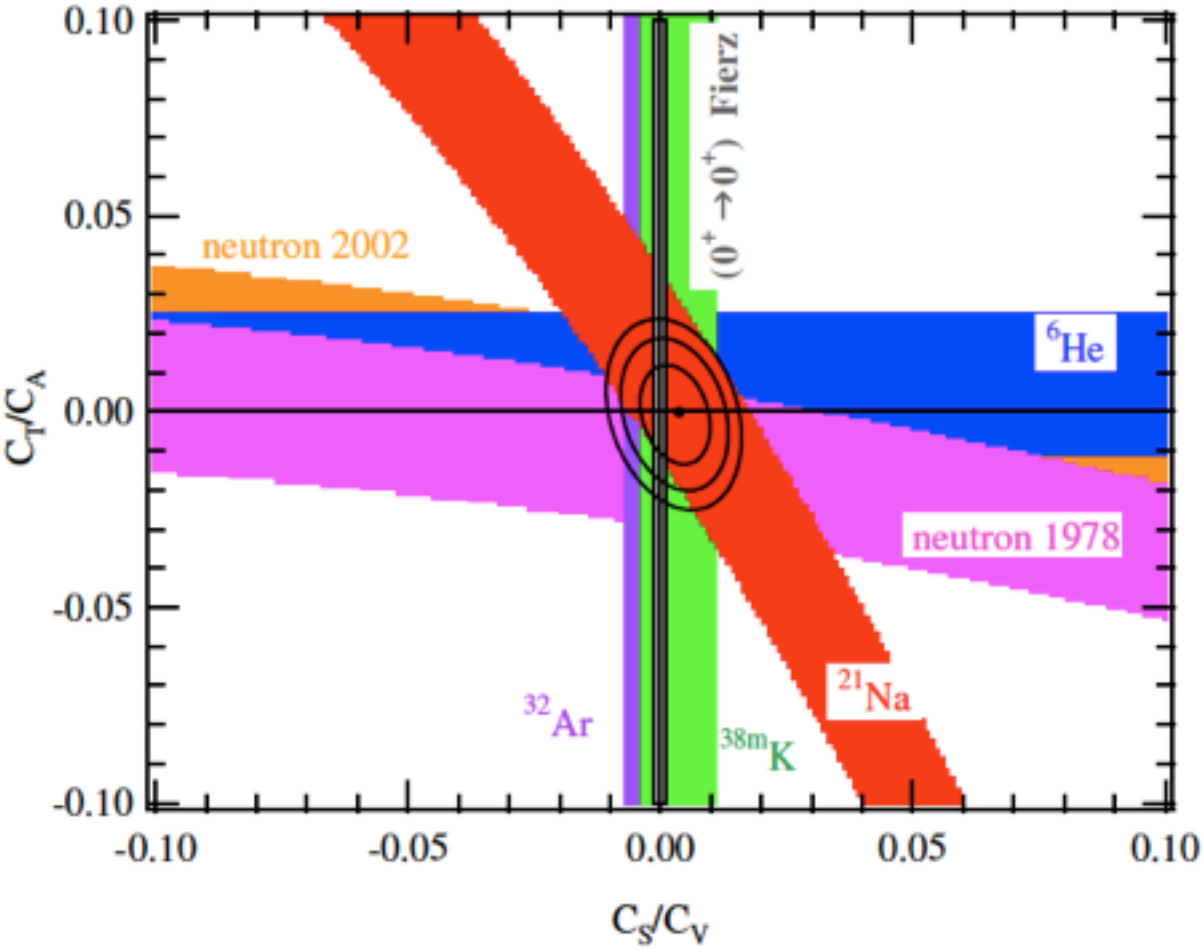
($C \neq C'$)

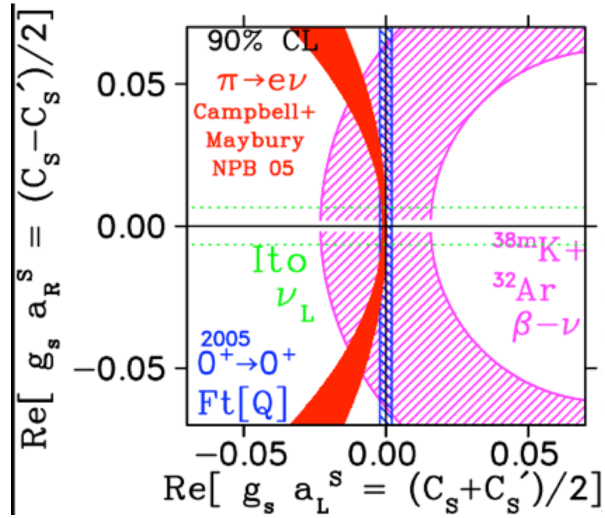


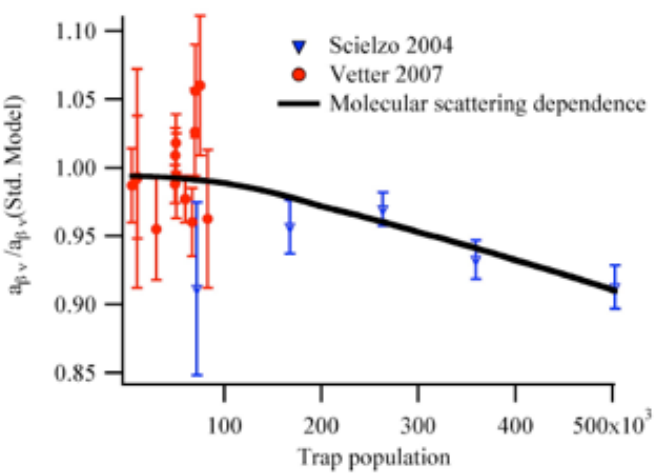
Scalar / Tensor Leptoquarks

($C_{S,T} \neq 0$)

A-V vs. Tensor Currents







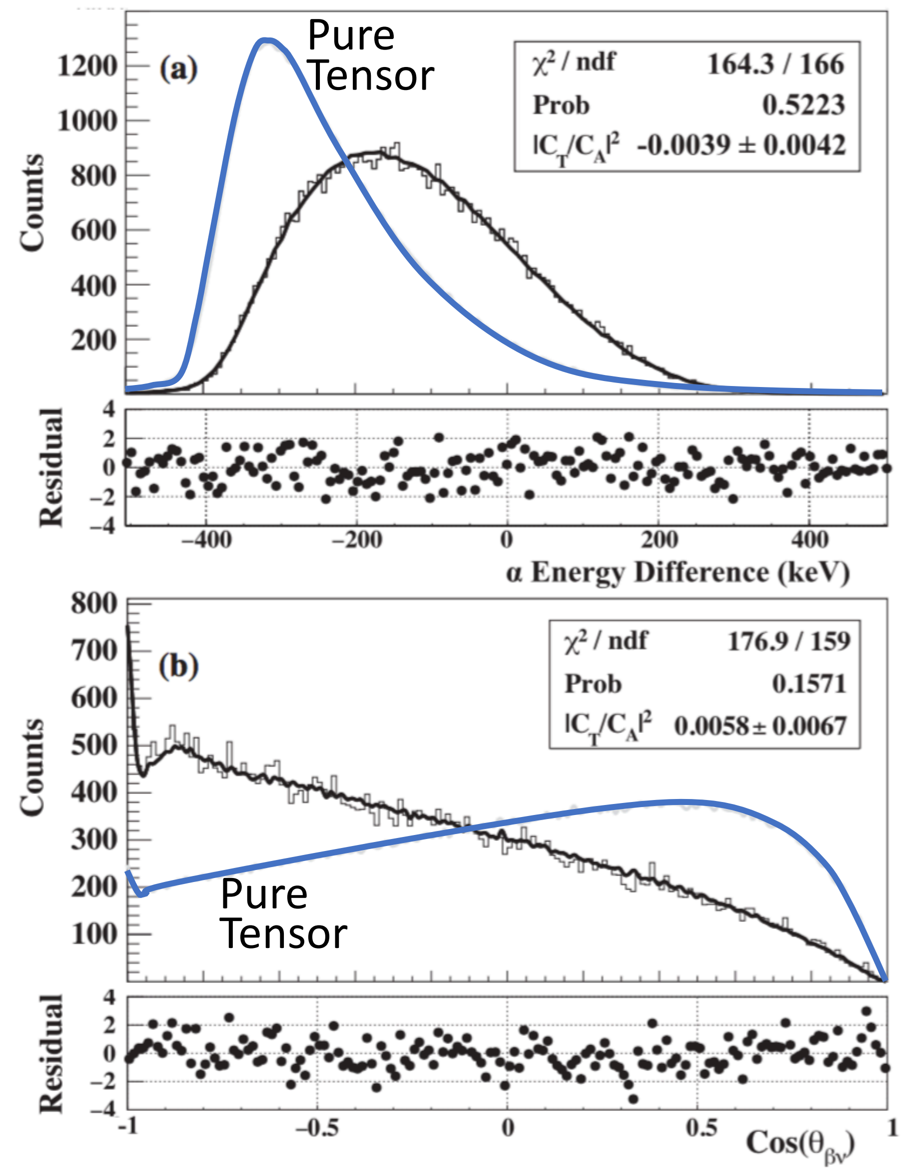
A-V vs. Tensor Currents in ^{8}Li

Kinematical distributions sensitive to the current:

- Energy distribution of recoiling ion (from two alpha measurement).
- Angle between neutrino and electron.

Resulting Constrain:

$C_T/C_A < 10\%$ (95% C.L.)



Sternberg et al., PRL 115, 182501 (2015)

Standard β Decay Experiment

Produce Radioactive Atoms
(Produce, Transport, Neutralize)

↓

Trap

↓

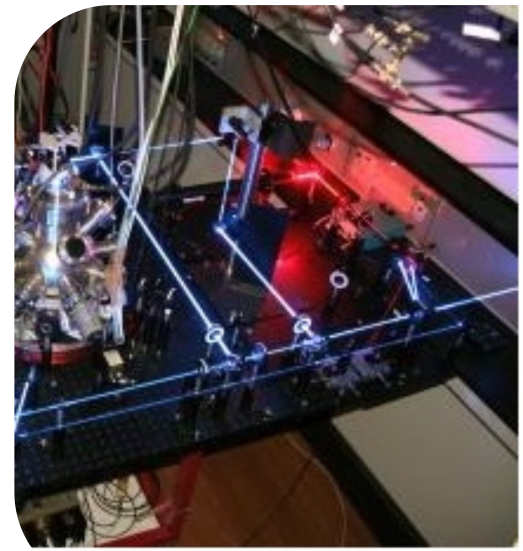
Wait for the decay…

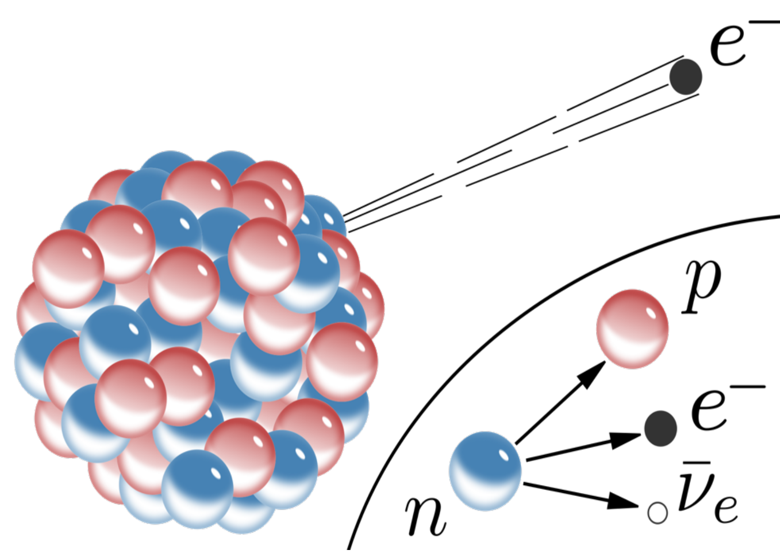
↓

Measure Decay Products

↓

Analyze the Data and Compare to SM Prediction





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Why Trap?

- Cold and Dilute:
  - No ‘smearing’
  - Less interactions
- Well localized vertex
- Isotope selectivity

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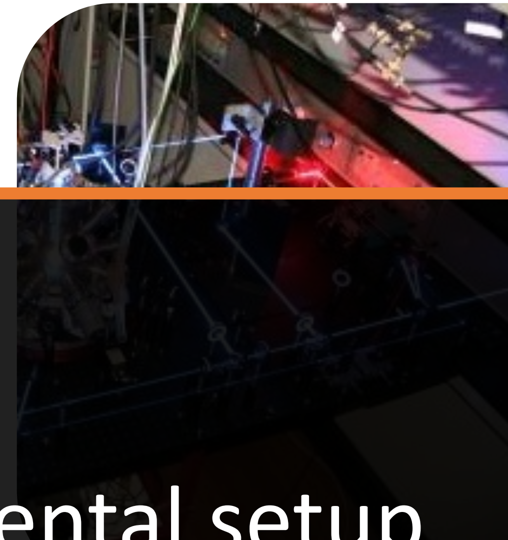

Why Trap?

- Cold and Dilute:
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Downside of Trapping:

- Complicated experimental setup.
- Limited number of Isotopes.
- Low Statistics.

Avoiding the Trap

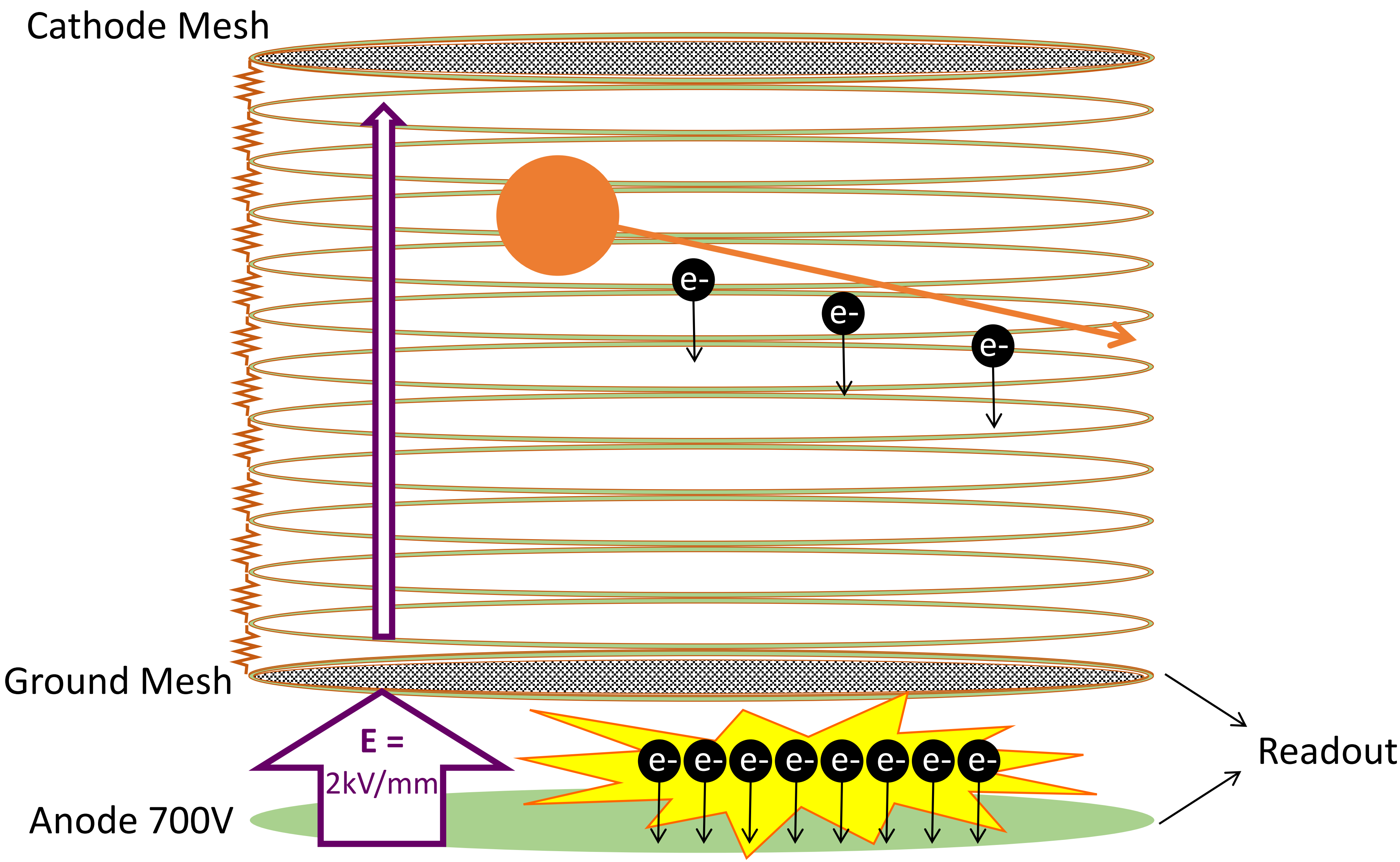
1. Use nucleus with ‘high energy’ decays.

   => $^{8}Li \rightarrow \boldsymbol{e^{-}} + \bar{\upsilon}_e + {}^{8}Be(\rightarrow \boldsymbol{\alpha} + \boldsymbol{\alpha})$

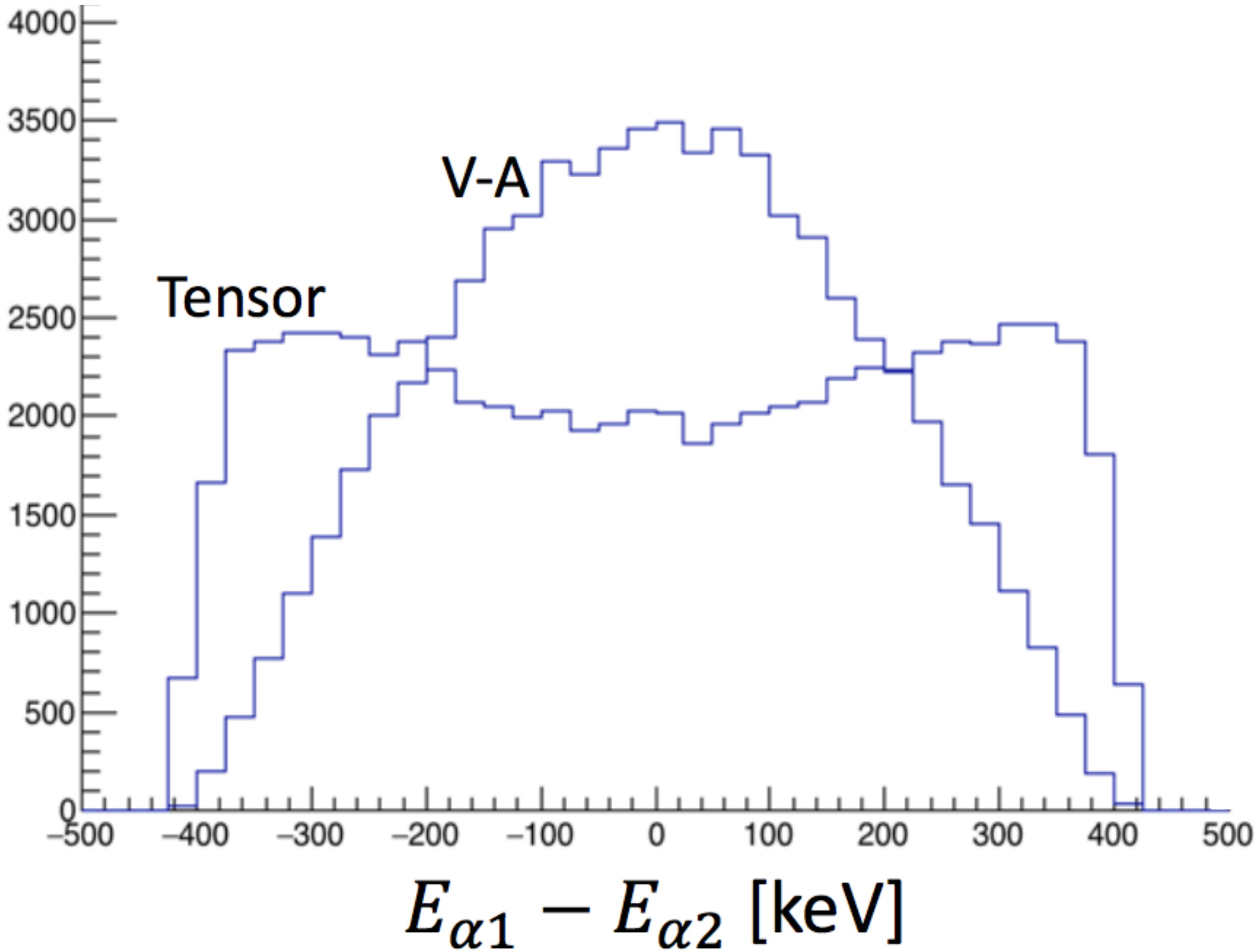
   - Easy to produce using conventional neutron sources.
   - **Two ~1.5 MeV alphas in the final state.**

2. Device a ‘trap-less’ measurement scheme

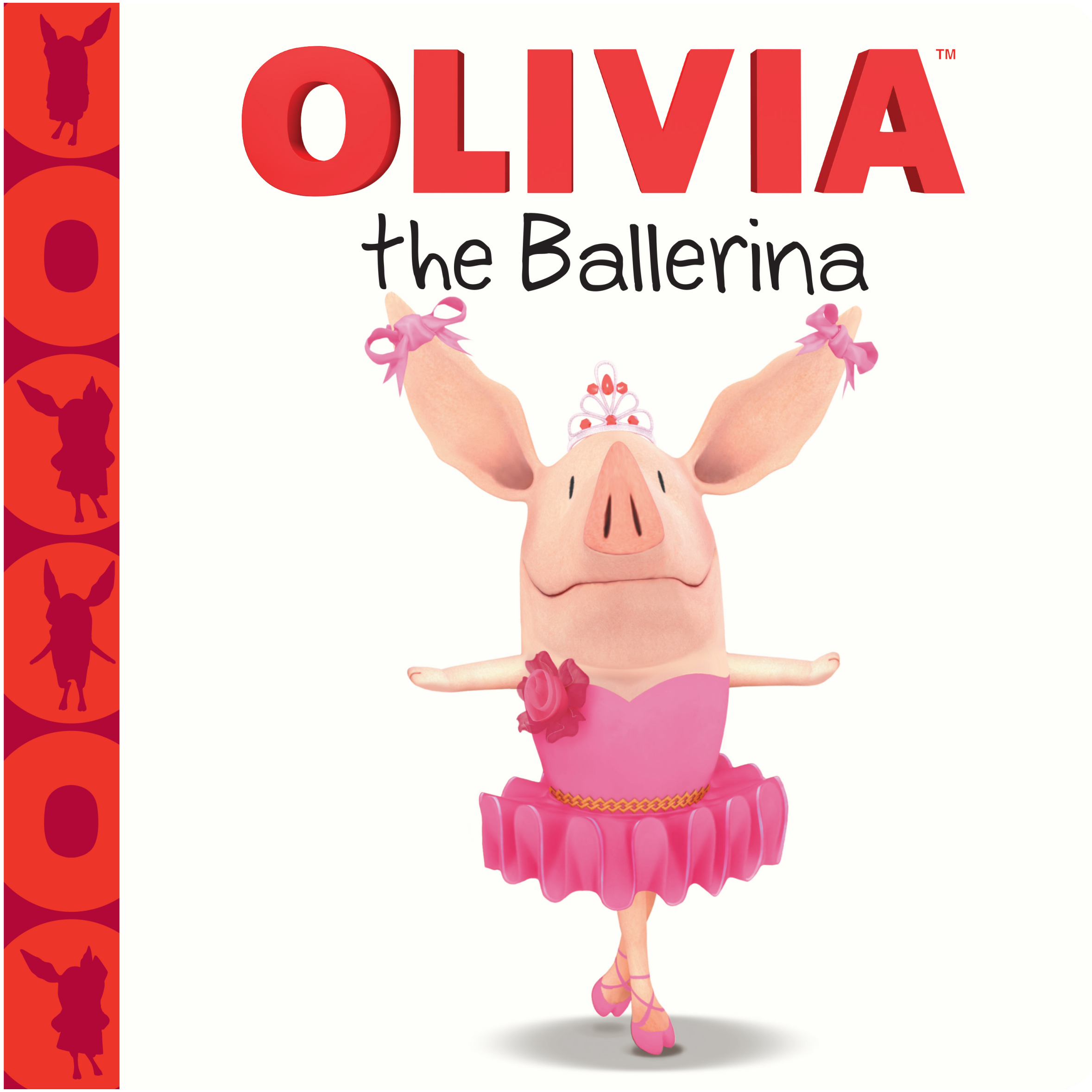
TPC


Cathode Mesh
e-
e-
e-
Ground Mesh
E =
2kV/mm
e- e- e- e- e- e- e- e-
Readout
Anode 700V

^{8}Li Physics (Tensor vs. V-A)



The OLIVIA Experiment



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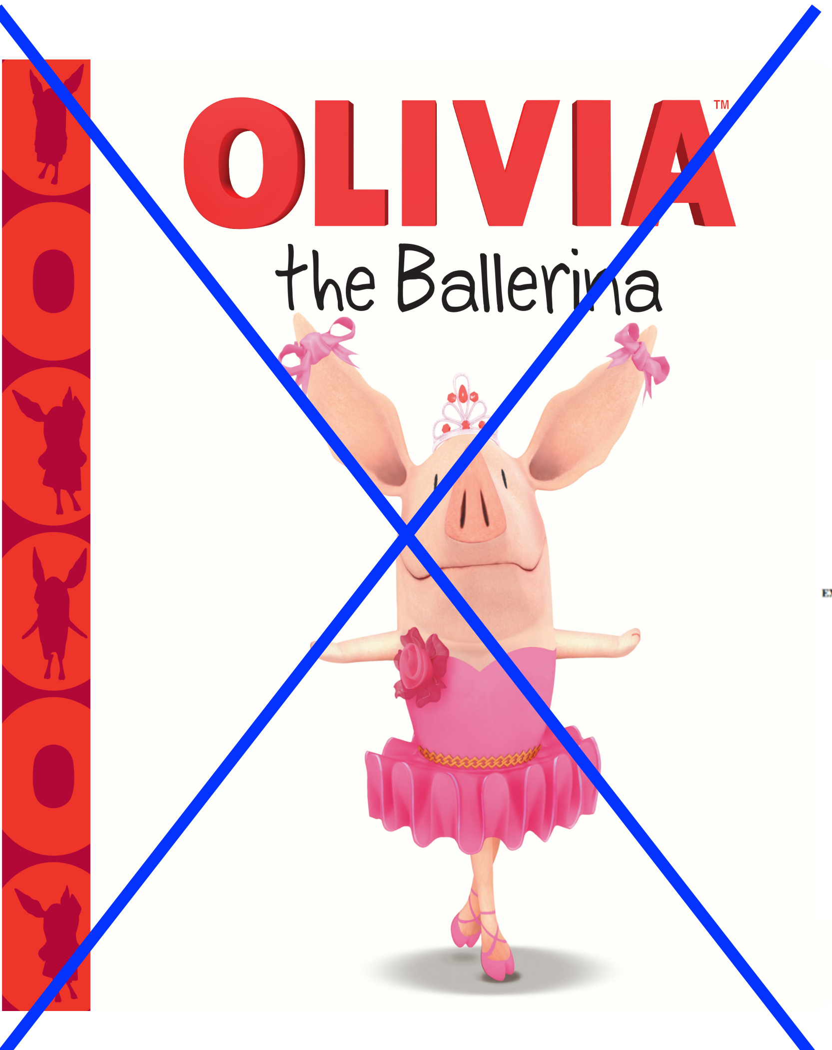
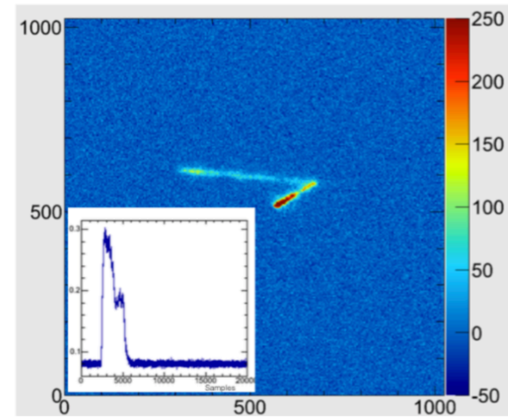
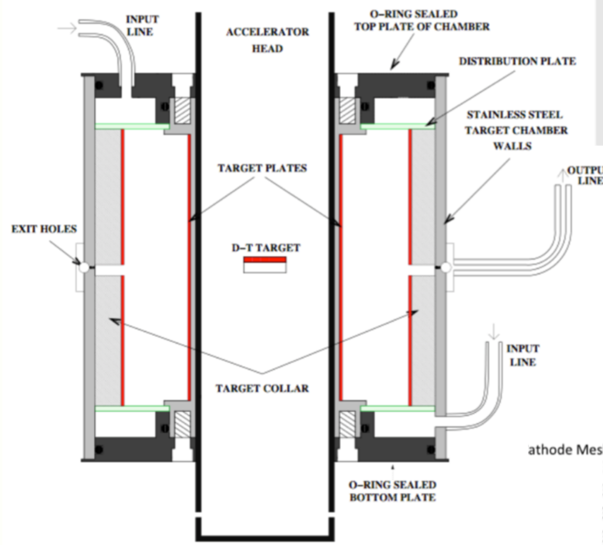
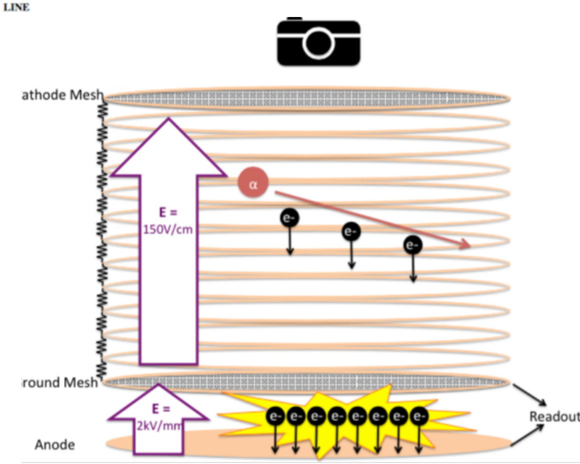


Optical LIthium V-mInus-A Experiment



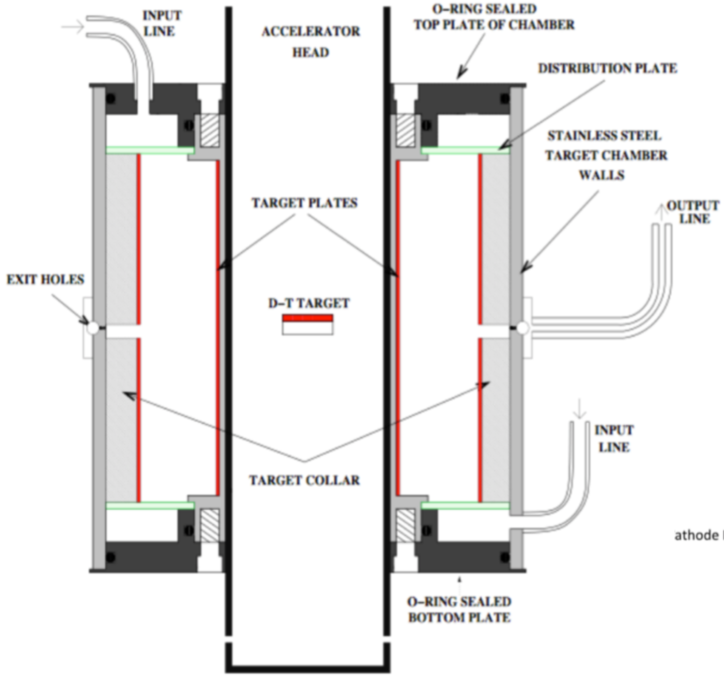




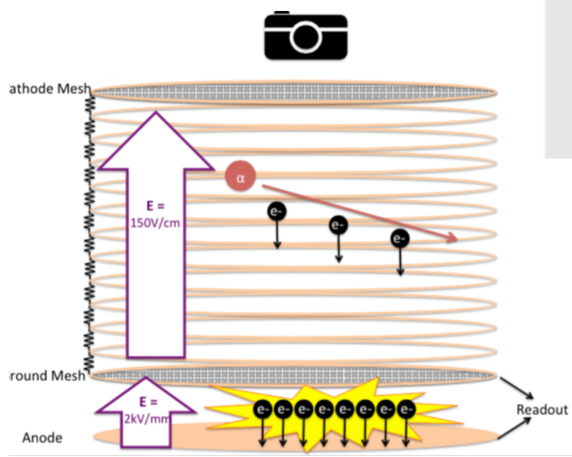
The OLIVIA Experiment (MIT/HUJI/UM)

Optical LIthium V-mInus-A Experiment

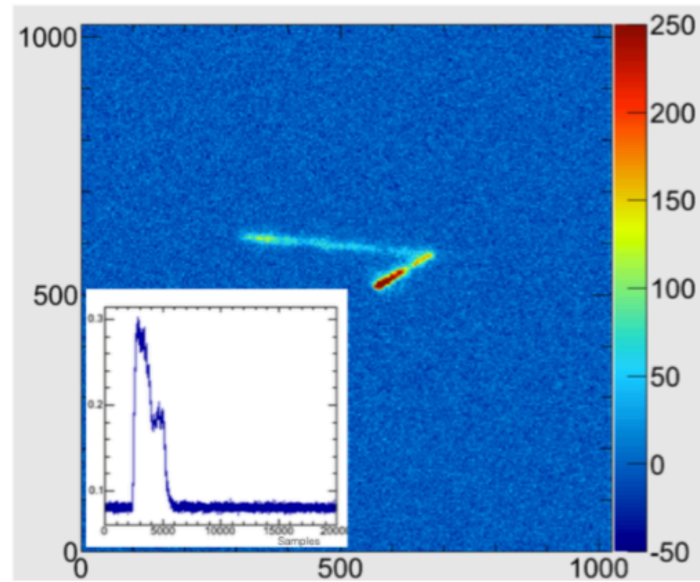
(1) Produce ^{8}Li



(2) Let it decay in our detector



(3) Measure the decay products



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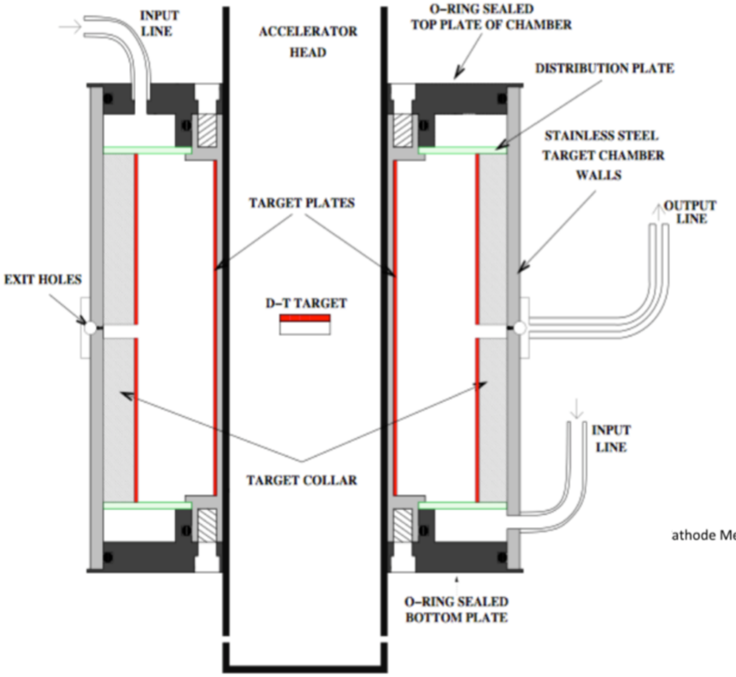

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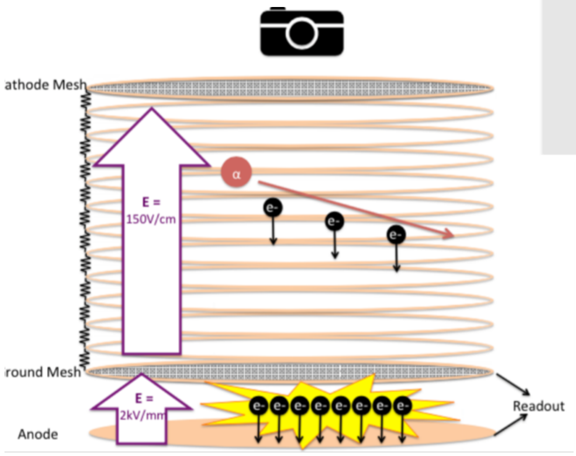

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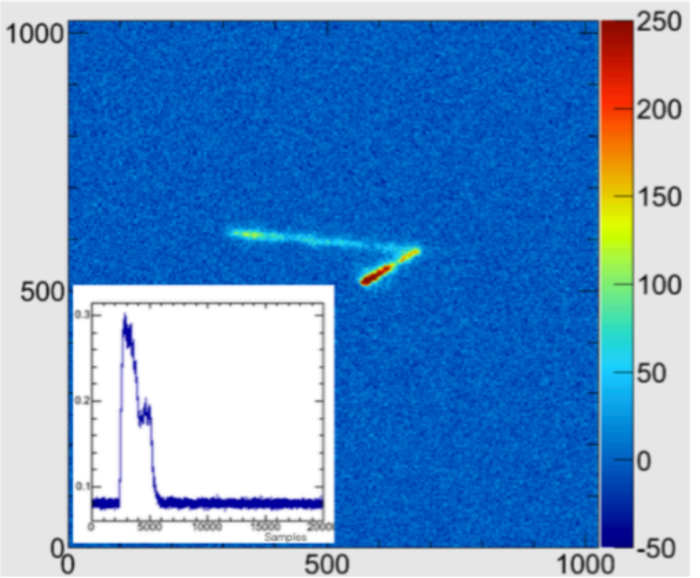

The OLIVIA Experiment (MIT/HUJI/UM)

Optical **LI**thium **V**-m**I**nus-**A** Experiment

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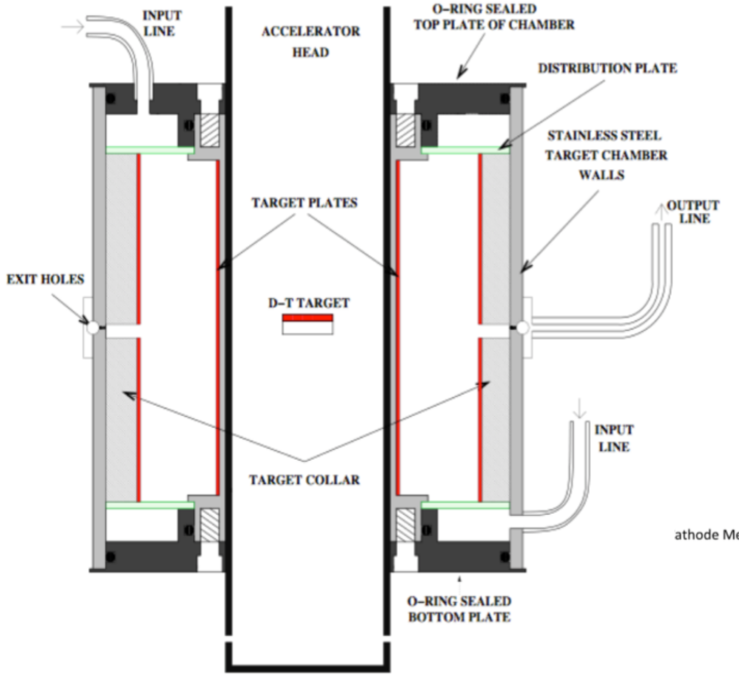

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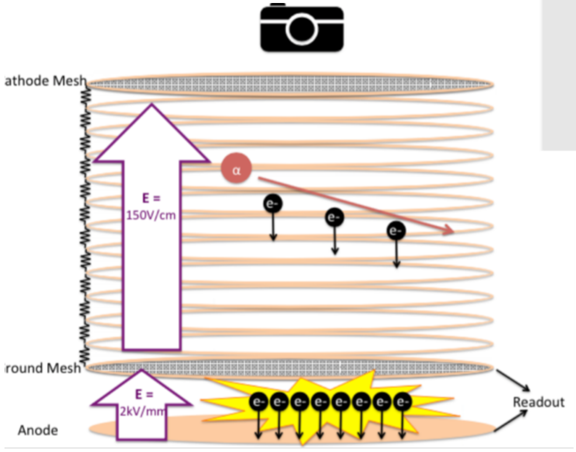

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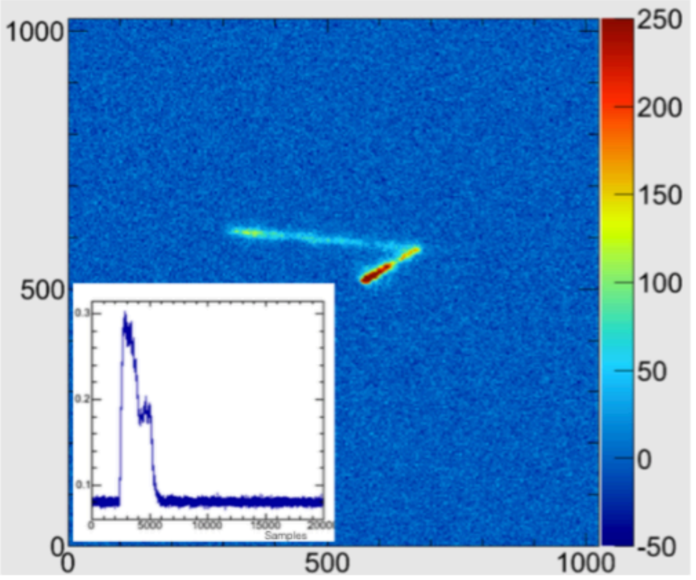
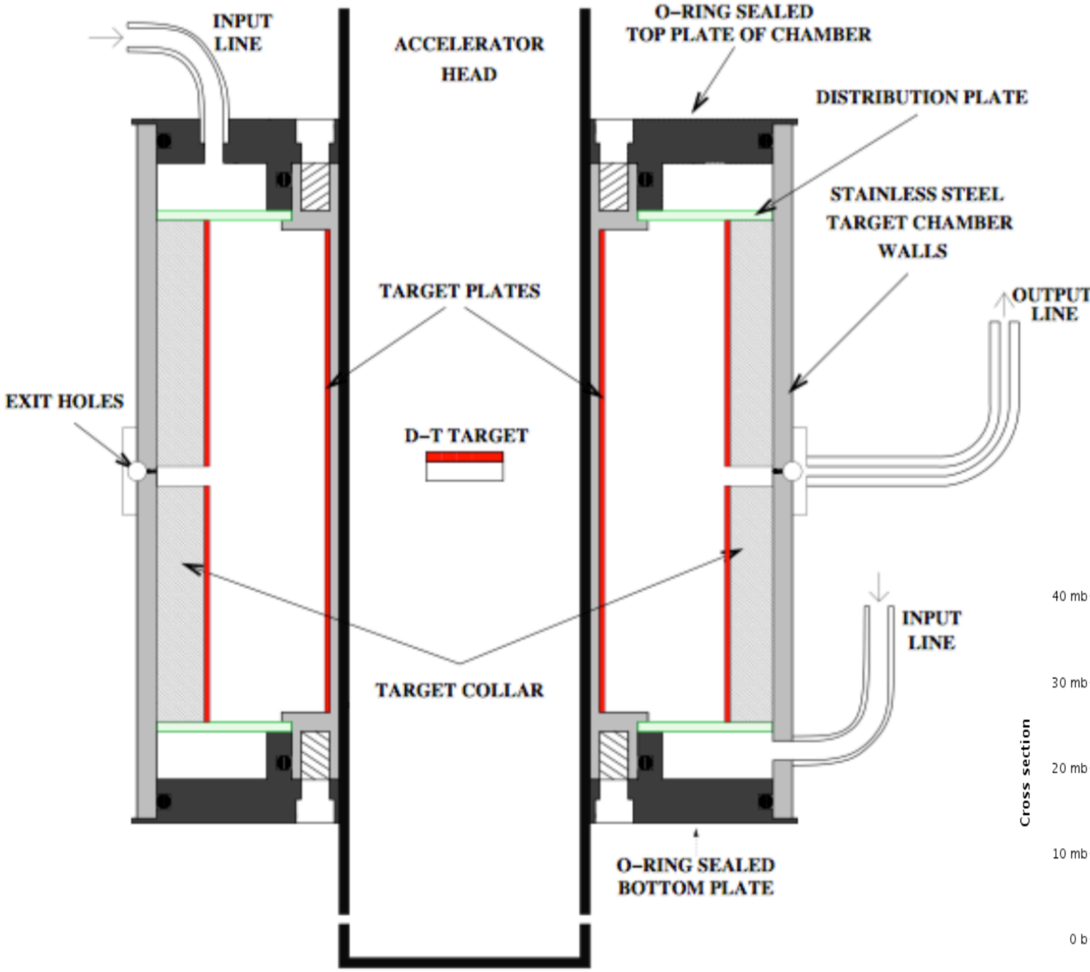
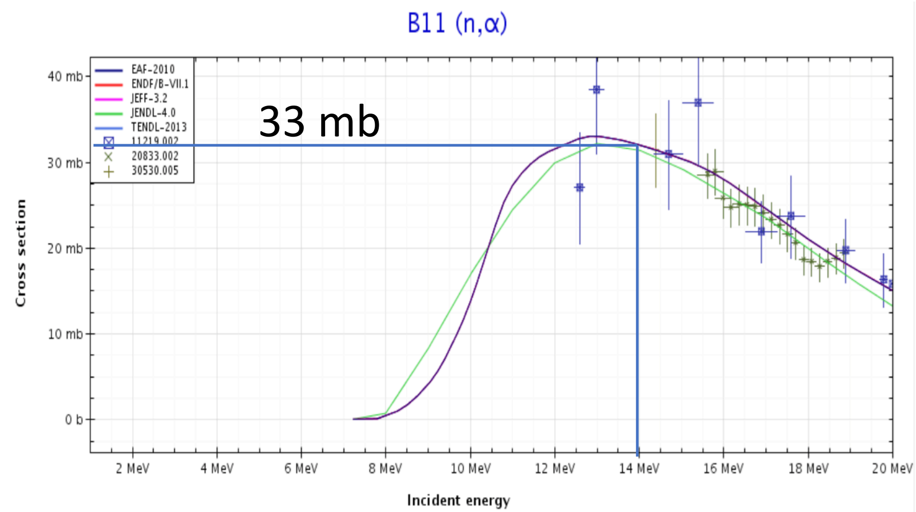


^{8}Li Production

Using a DT generator: $^{11}B(n,\alpha)^{8}Li$



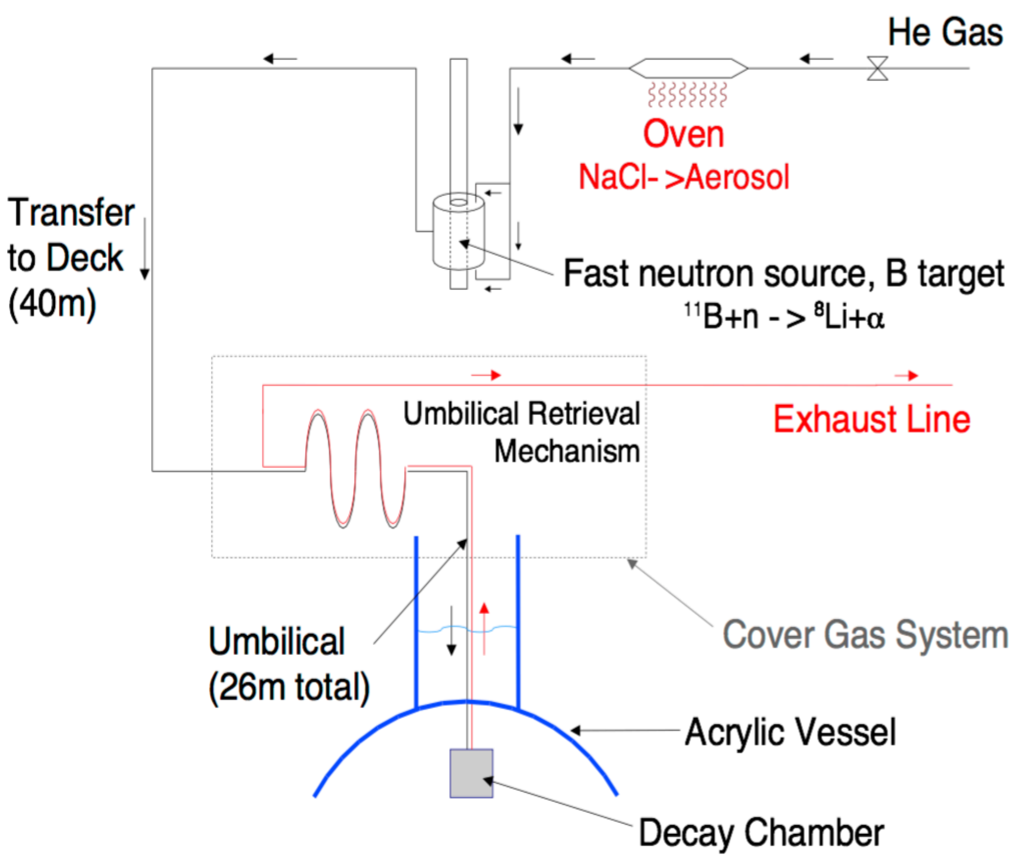
+ Transport ^{8}Li to the TPC using a gas flow system



Based on the SNO ^{8}Li calibration system
arXiv: 0202024 (2002)

^{8}Li Production

Using a DT generator: $^{11}B(n,\alpha)^{8}Li$



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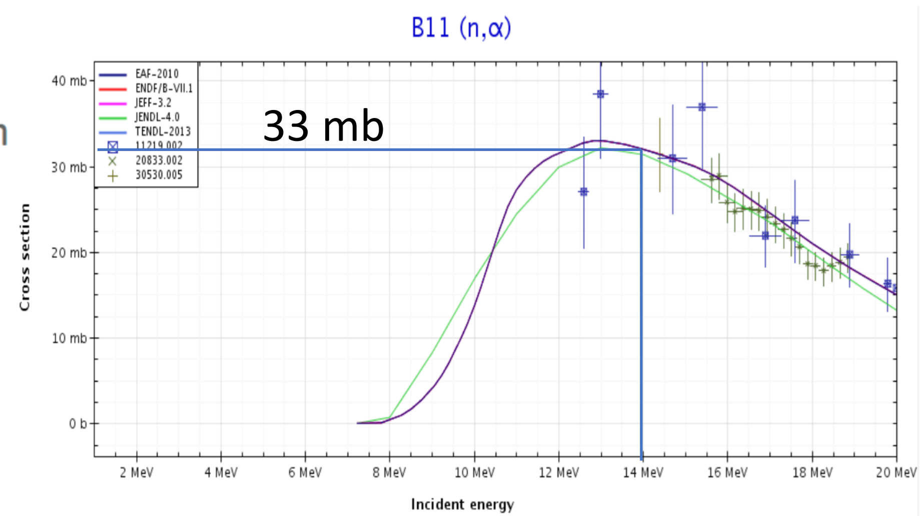

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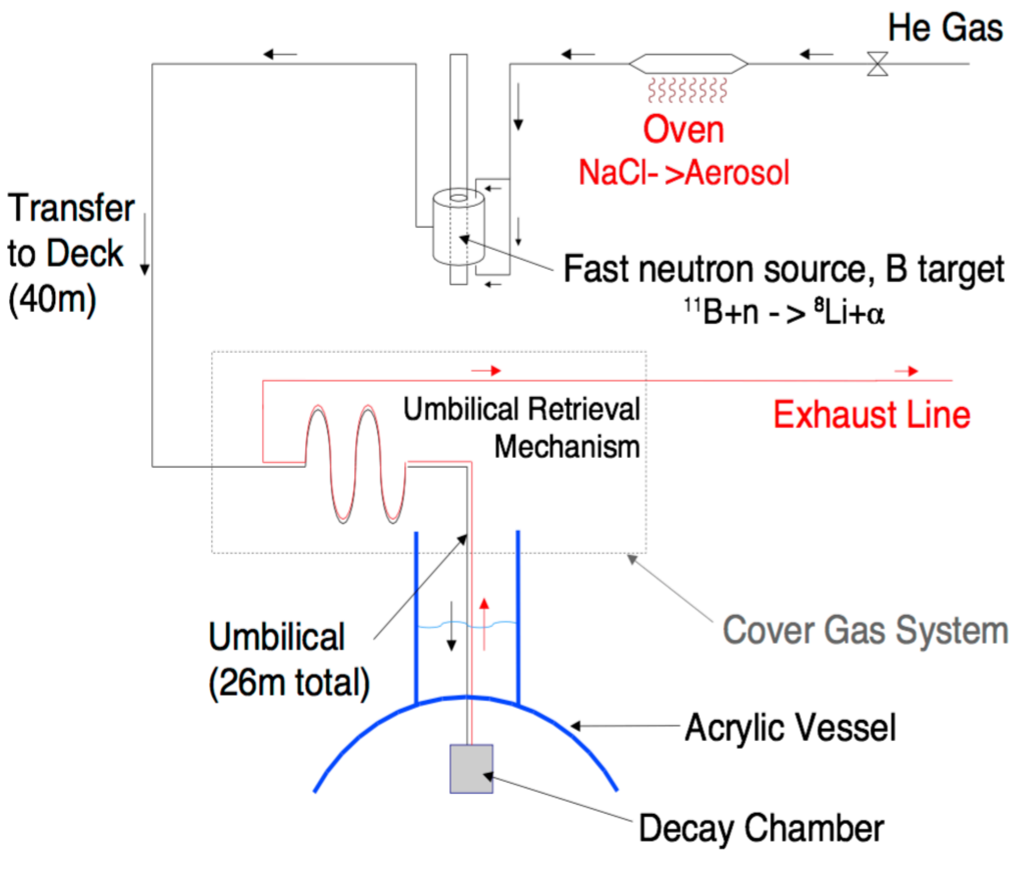
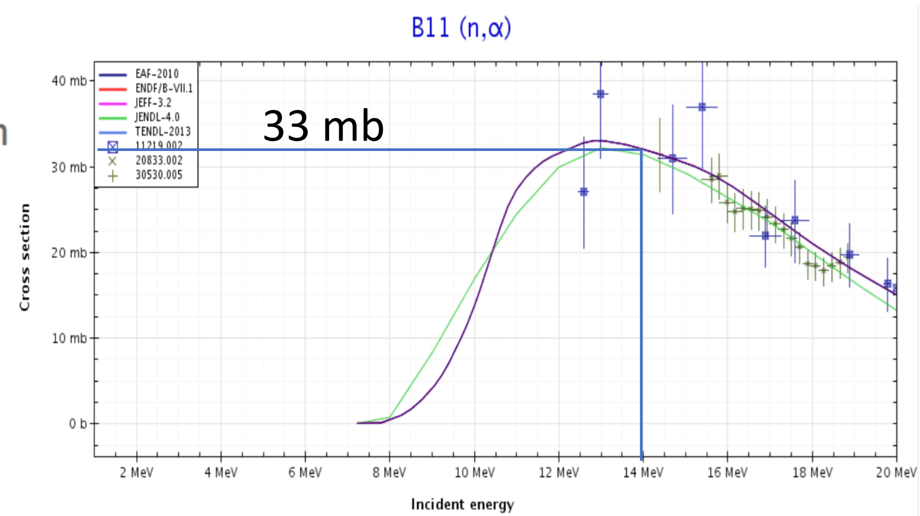


+ Transport ^{8}Li to the TPC using a gas flow system

Expected Statistics:

$3.6\text{x}10^{7}$



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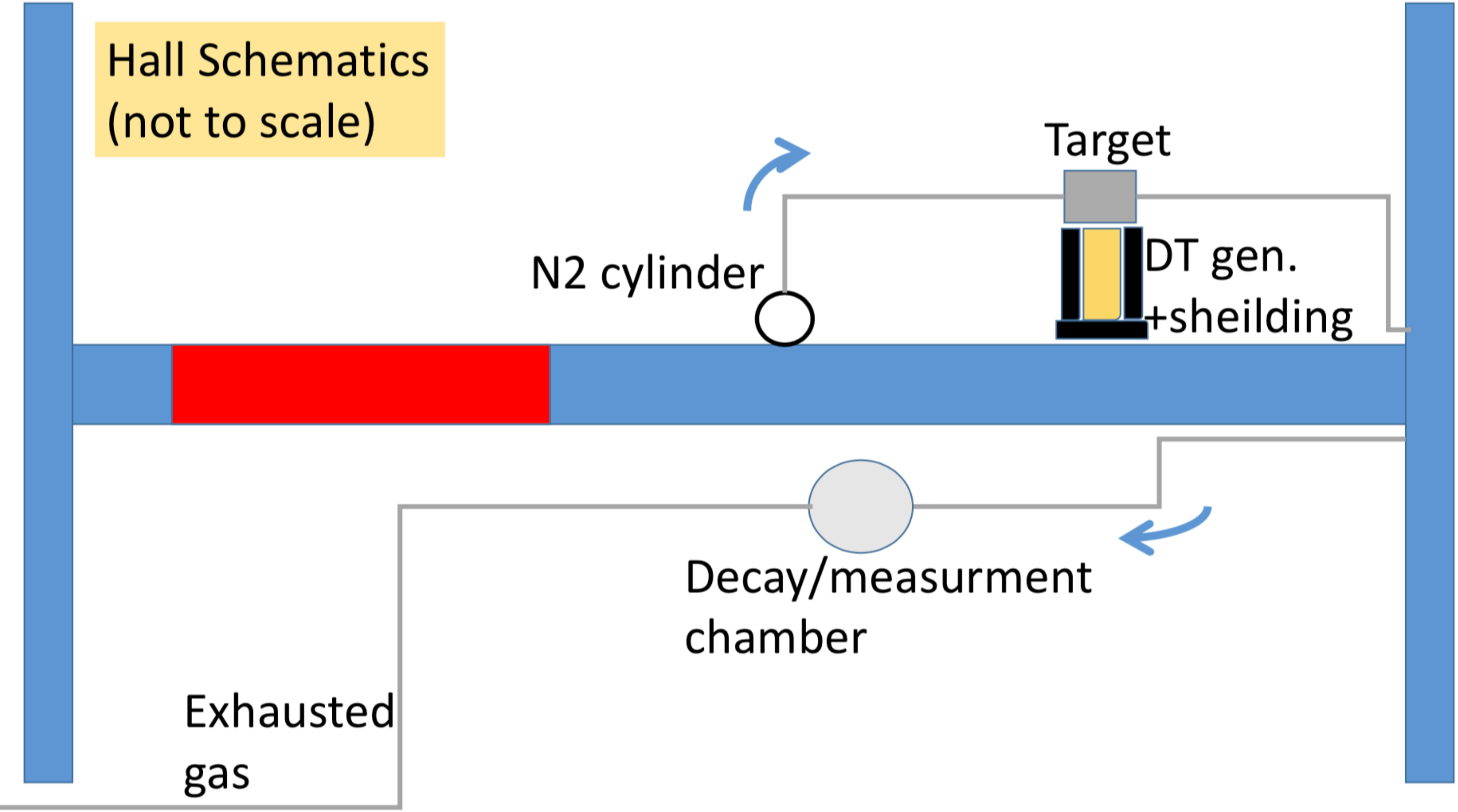
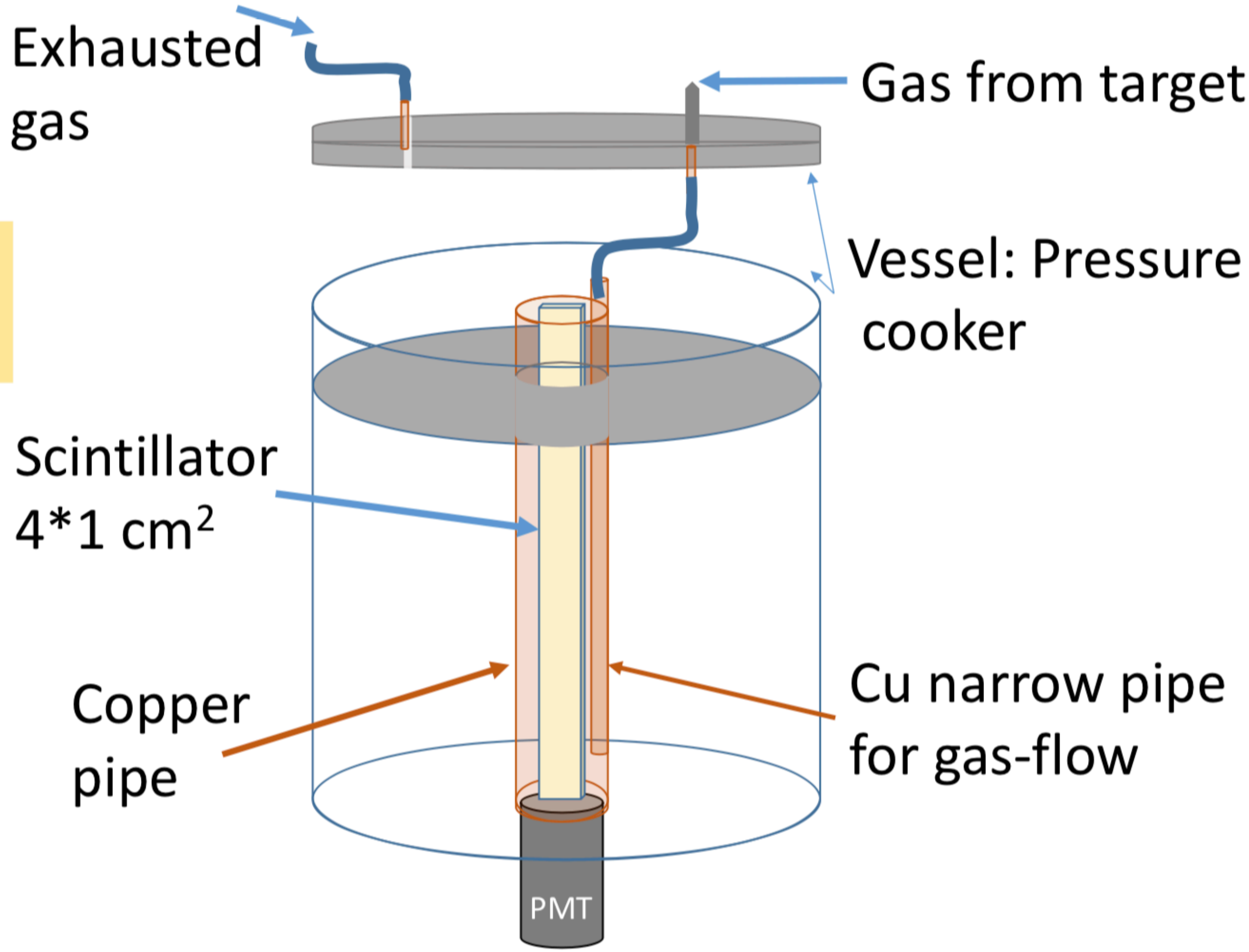
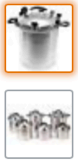

Hall Schematics
(not to scale)
Target
N2 cylinder
DT gen.
+sheilding
Decay/measurment
chamber
Exhausted
gas

Decay/Measurment Chamber





Roll over image to zoom in

All American 30-Quart Pressure Cooker Canner

by All American

2,921 customer reviews | 713 answered questions

Price: $343.00 prime

FREE Delivery **Tomorrow**

if you order within 9 hrs 45 mins. Details

Only 2 left in stock - order soon.

Sold by FastSavings and Fulfilled by Amazon. Gift-wrap available.

Eligible for amazonsmile donation.

Size: **30 qt**

10.5 qt
$232.80
prime

15.5 qt
used from $218.99

21.5 qt
$279.95
prime

25 qt
$299.95
prime

30 qt
$343.00
prime

41.5 qt
$494.95
prime

- The All American 30-quart pressure cooker and canner holds approximately 19 standard regular mouth pint jars or 14 standard regular mouth quart jars; Perfect Canner for all your canning needs!
- Made of durable, hand-cast aluminum with an attractive, easy to clean satin finish; Easy on-off cover; Positive action clamping wing nuts permit easy opening and closing
- Sturdy phenolic top handle; Exclusive "metal-to-metal" sealing system for a steam-tight seal; No gaskets to crack, burn, replace or clean
- Easy to read geared steam gauge; Automatic overpressure release; Settings of 5 psi, 10 psi, and 15 psi
- 19 inches high with 12-1/4-inch inside diameter; made in USA

All American 30-Quart Pressure Cooker Canner

by All American

★★★★★ 2,921 customer reviews | 713 answered questions

Price: $343.00 ✓prime

FREE Delivery **Tomorrow**

if you order within 9 hrs 45 mins. Details

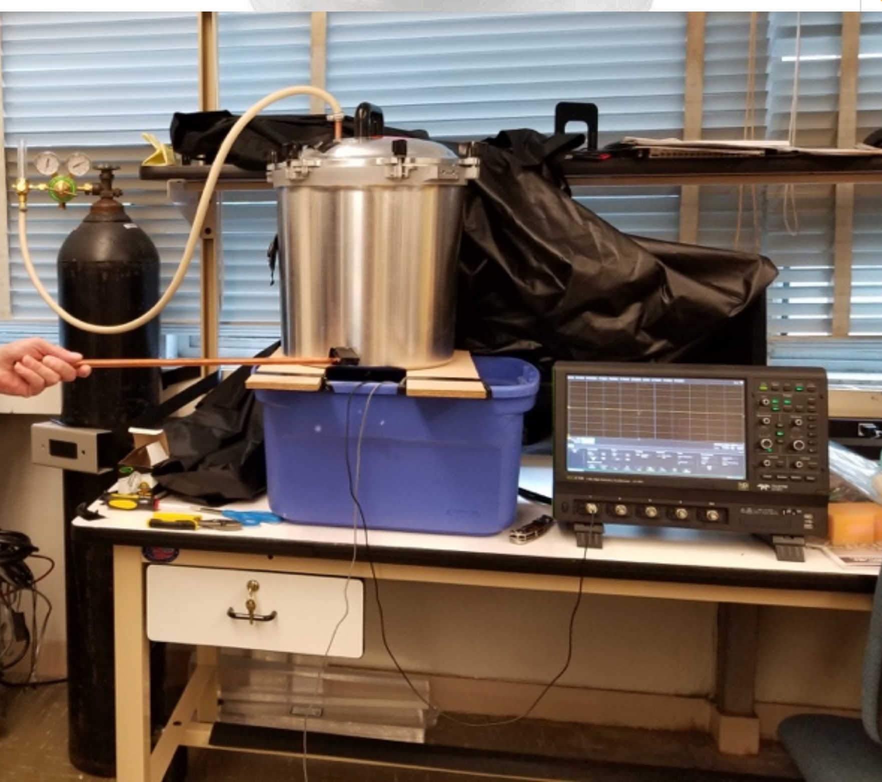
Only 2 left in stock - order soon.

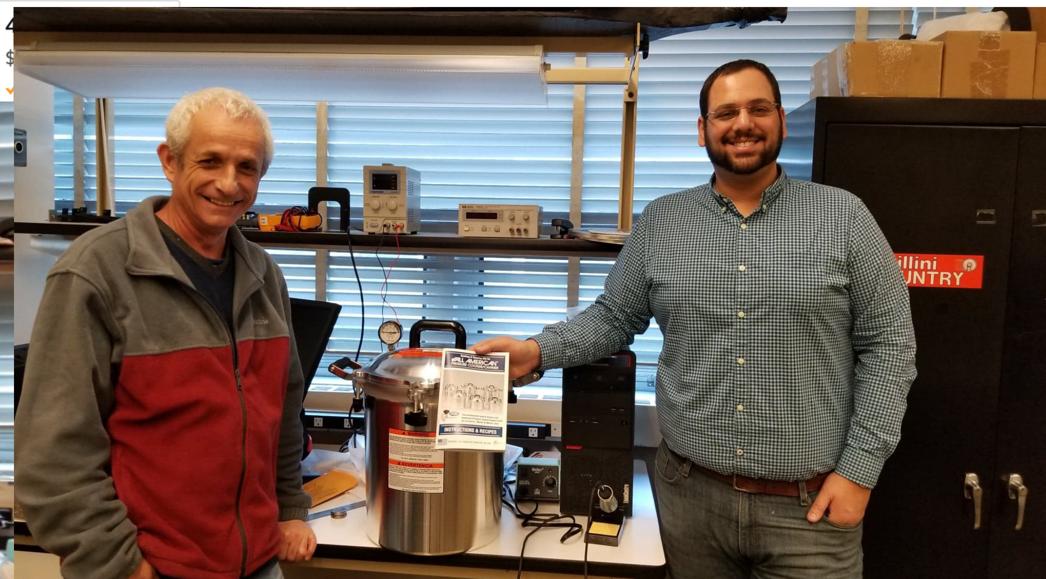
Sold by FastSavings and Fulfilled by Amazon. Gift-wrap available.

Eligible for amazonsmile donation.

Size: **30 qt**

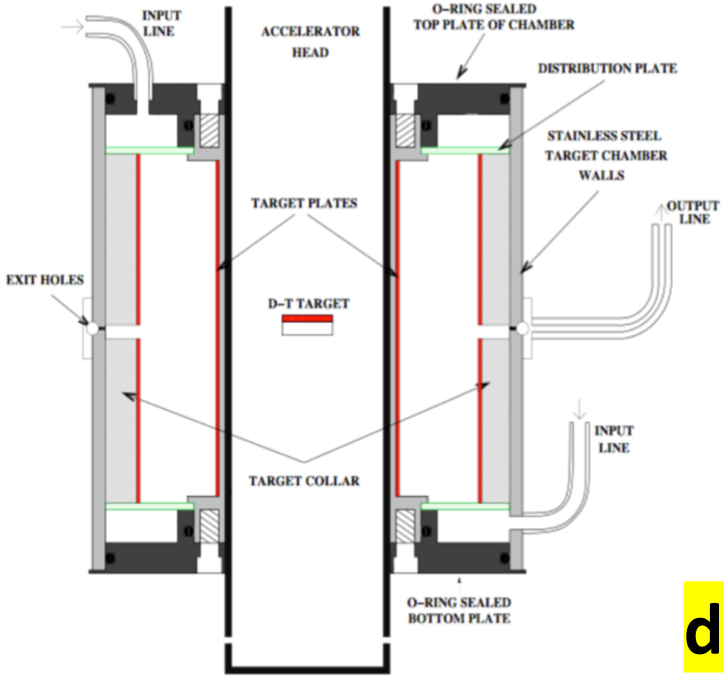
10.5 qt	15.5 qt	21.5 qt	25 qt	30 qt
$232.80	used from $218.99	$279.95	$299.95	$343.00
✓prime		✓prime	✓prime	✓prime



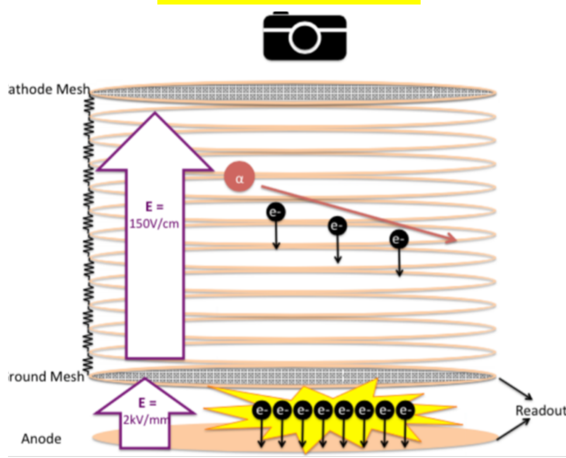


Currently working on production & transport rate measurements

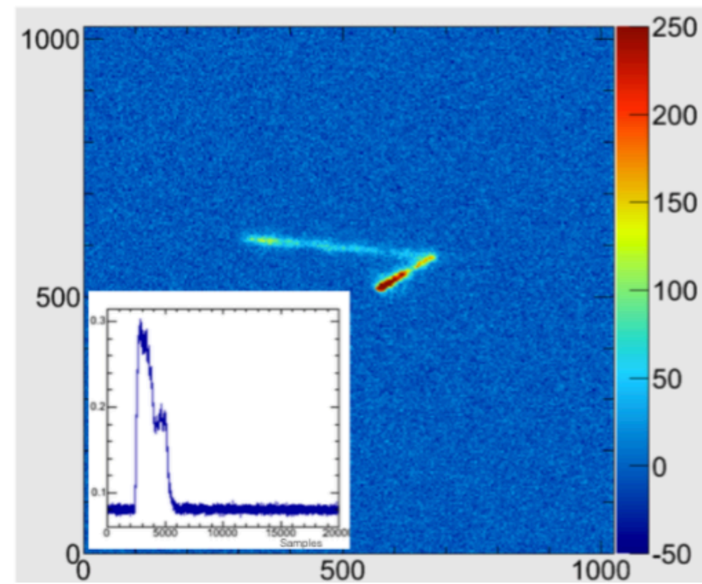
(1) Produce ^{8}Li



(2) Let it decay in our detector



(3) Measure the decay products



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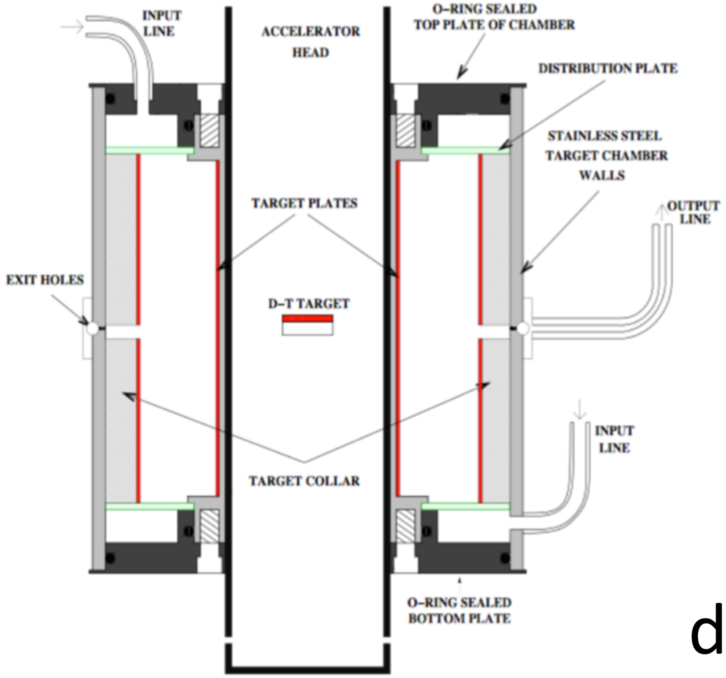

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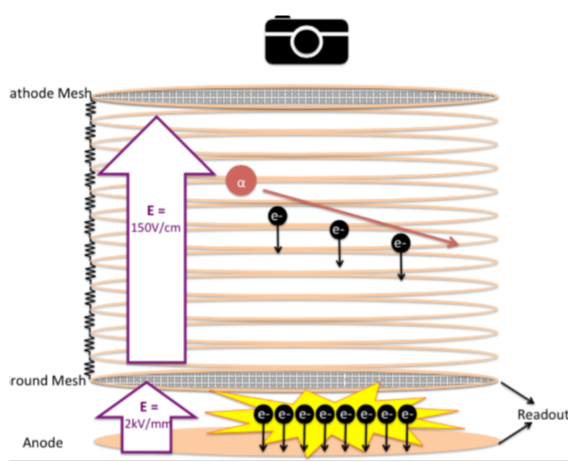

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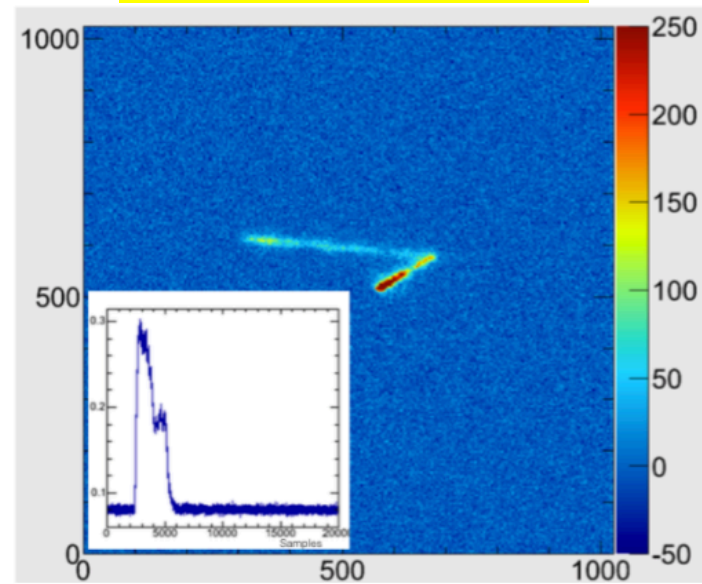
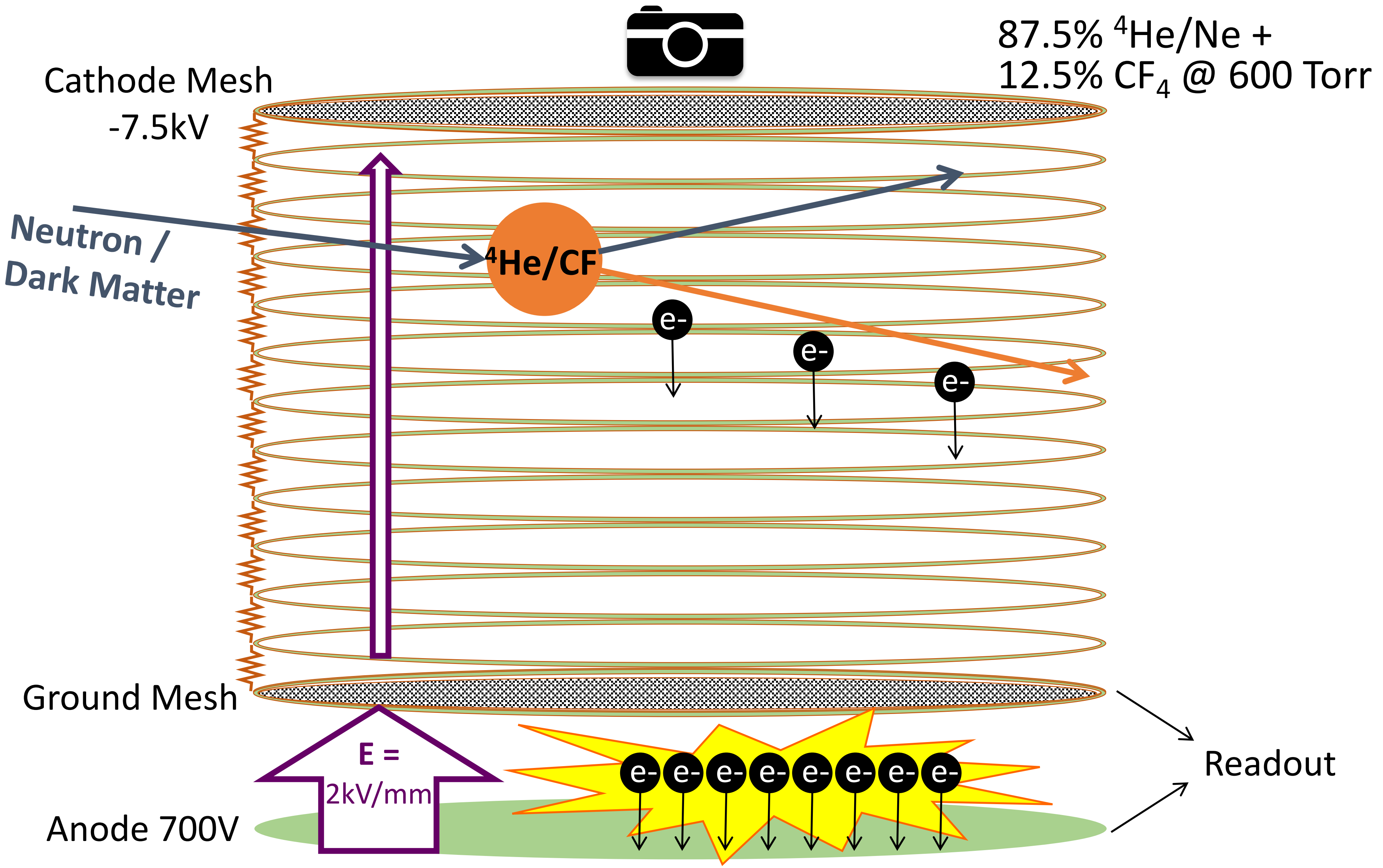
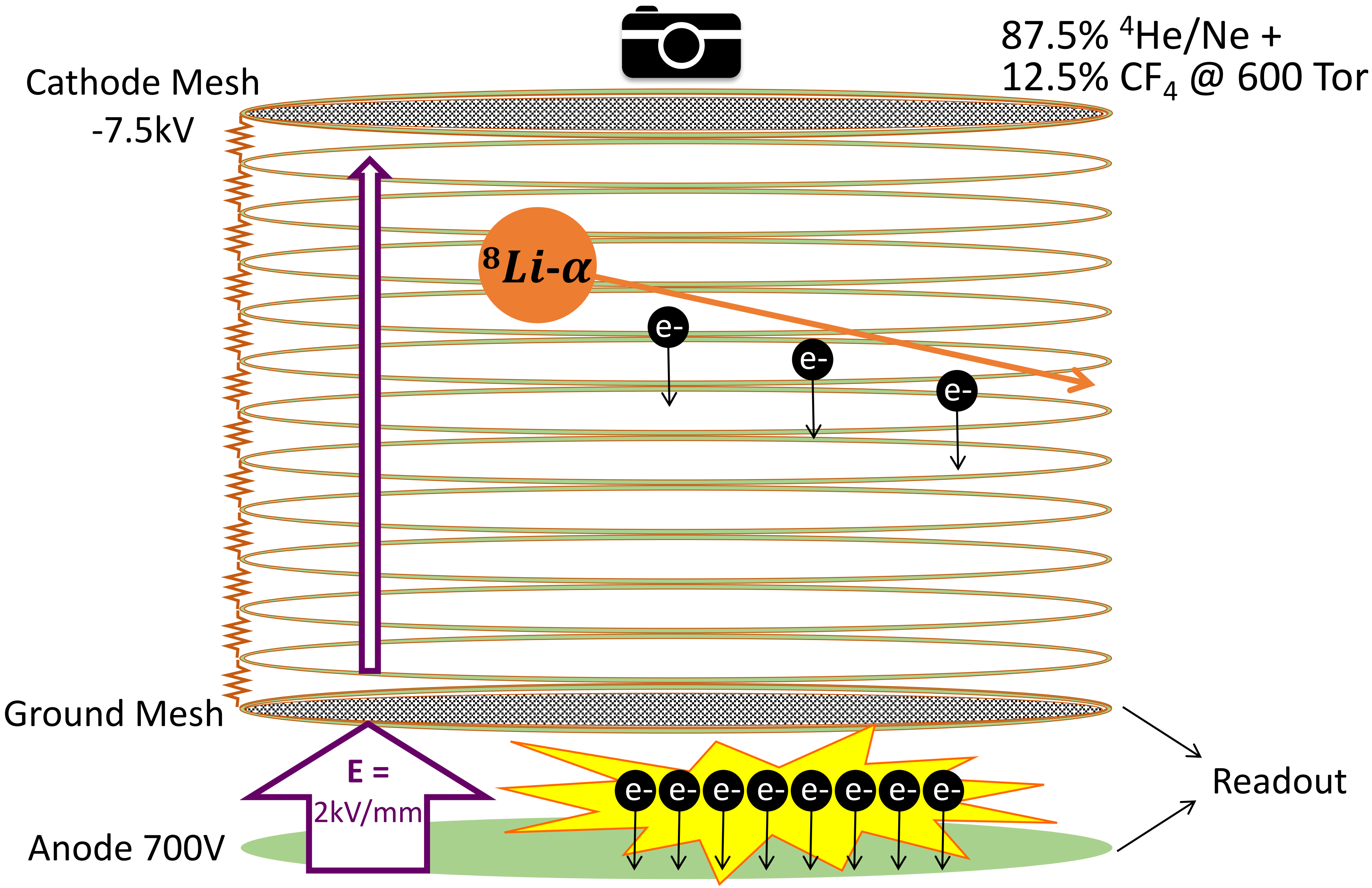


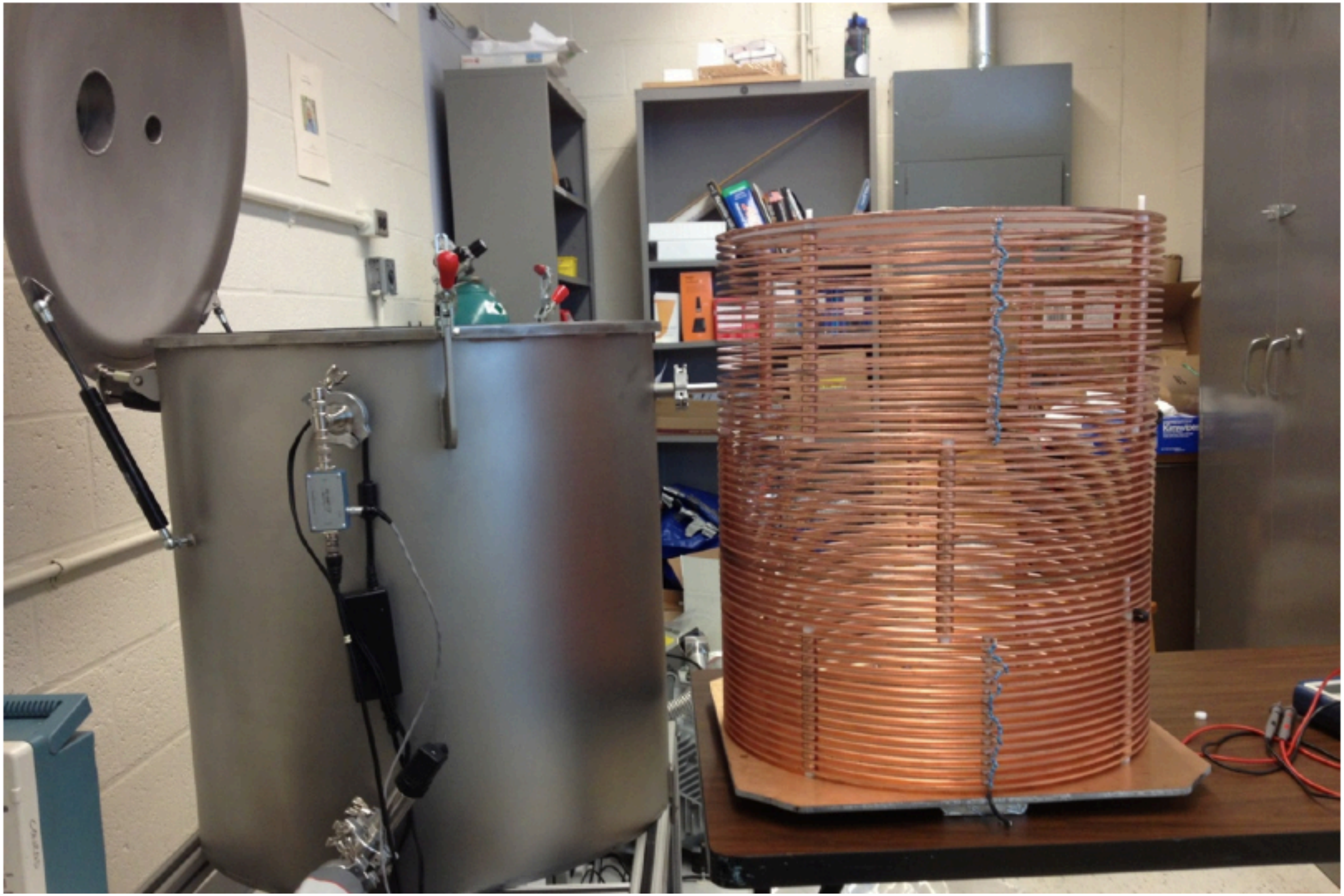
MITPC


87.5% 4He/Ne +
12.5% CF4 @ 600 Torr
Cathode Mesh
-7.5kV
Neutron /
Dark Matter
4He/CF
e-
Ground Mesh
E =
2kV/mm
Anode 700V
Readout

MITPC


87.5% $^4He/Ne$ +
12.5% CF_4 @ 600 Torr
Cathode Mesh
-7.5kV
^8Li-α
e-
e-
e-
Ground Mesh
E =
2kV/mm
e- e- e- e- e- e- e- e-
Readout
Anode 700V

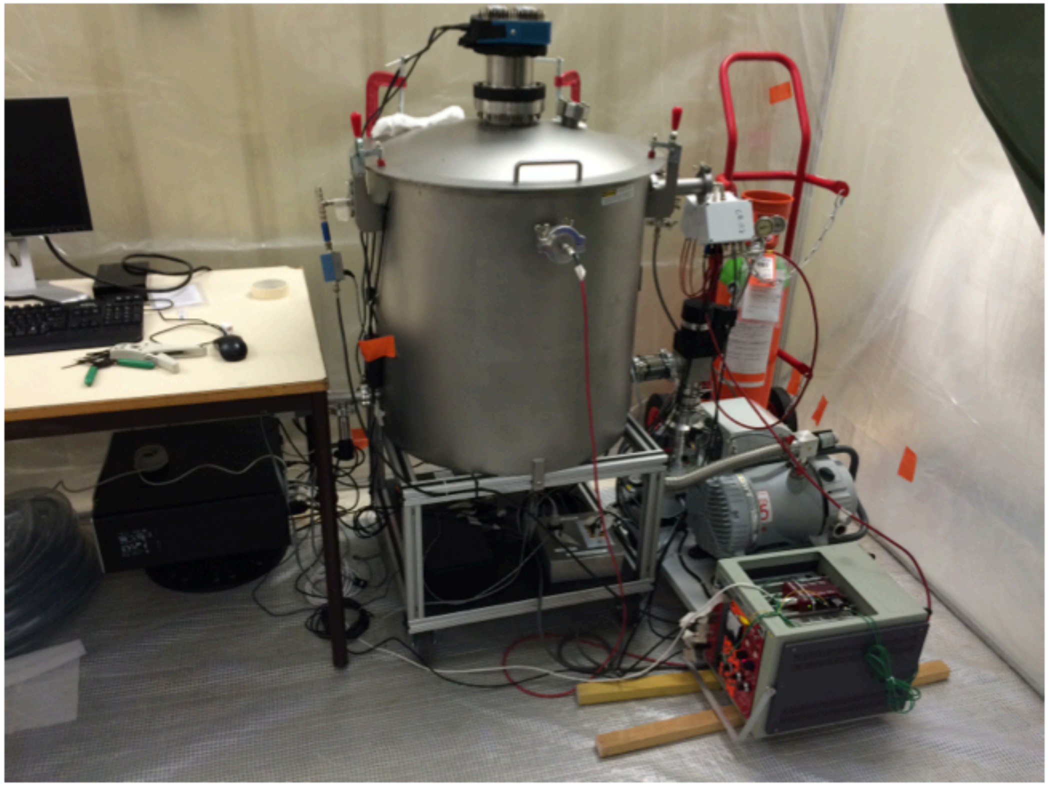
MITPC



MITPC

Little MITPC

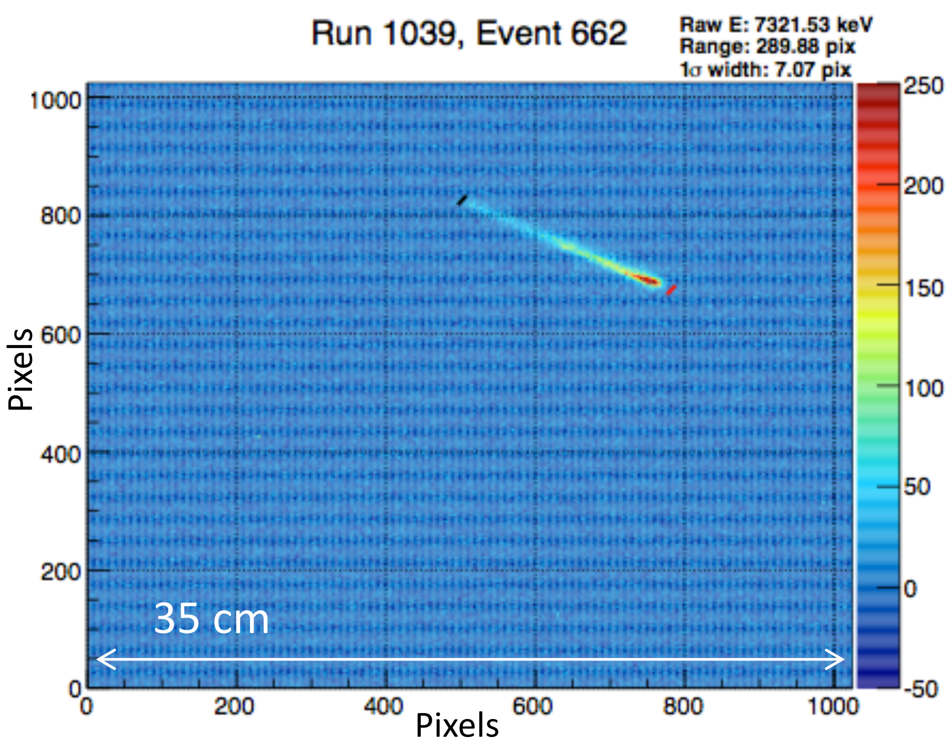
- 2.8L
- 0.2 – 10 MeV nuclear recoil
- 4 months of data at Double Chooz far hall
- Now at MIT for OLIVIA



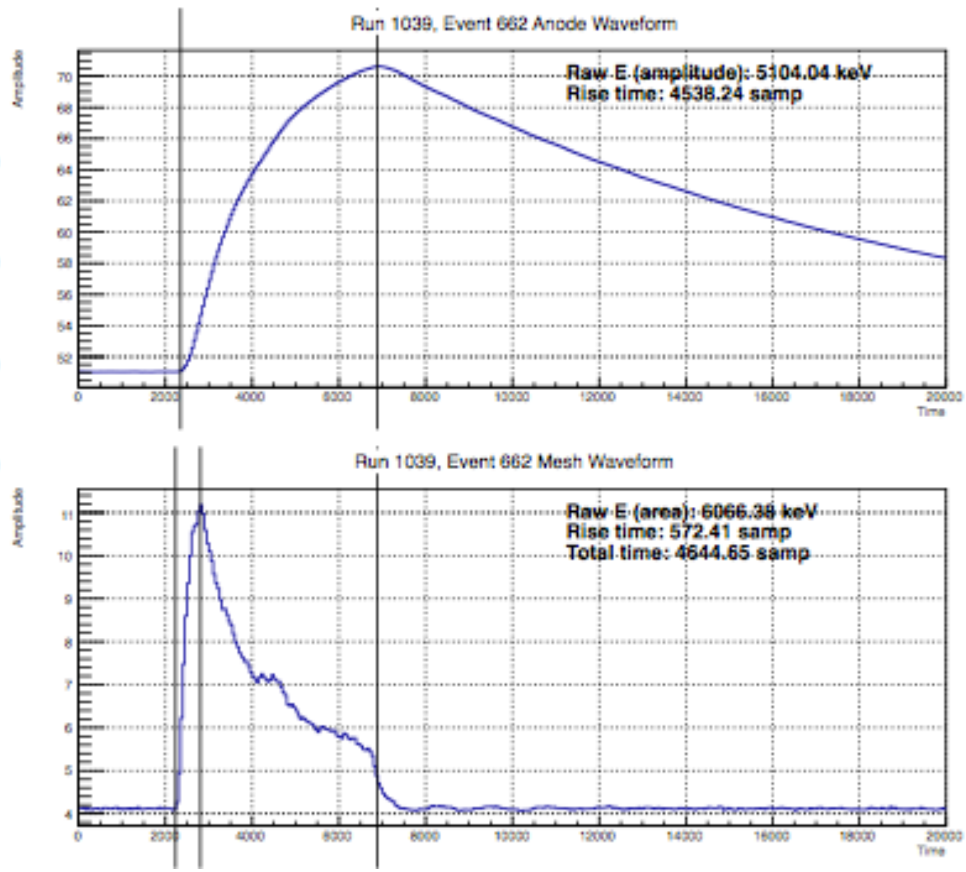
Big MITPC

- 60L
- 0.3 – 20 MeV nuclear recoil
- 7 months of data at Double Chooz near hall
- Now taking data at FNAL

Event Readout for Alpha Track



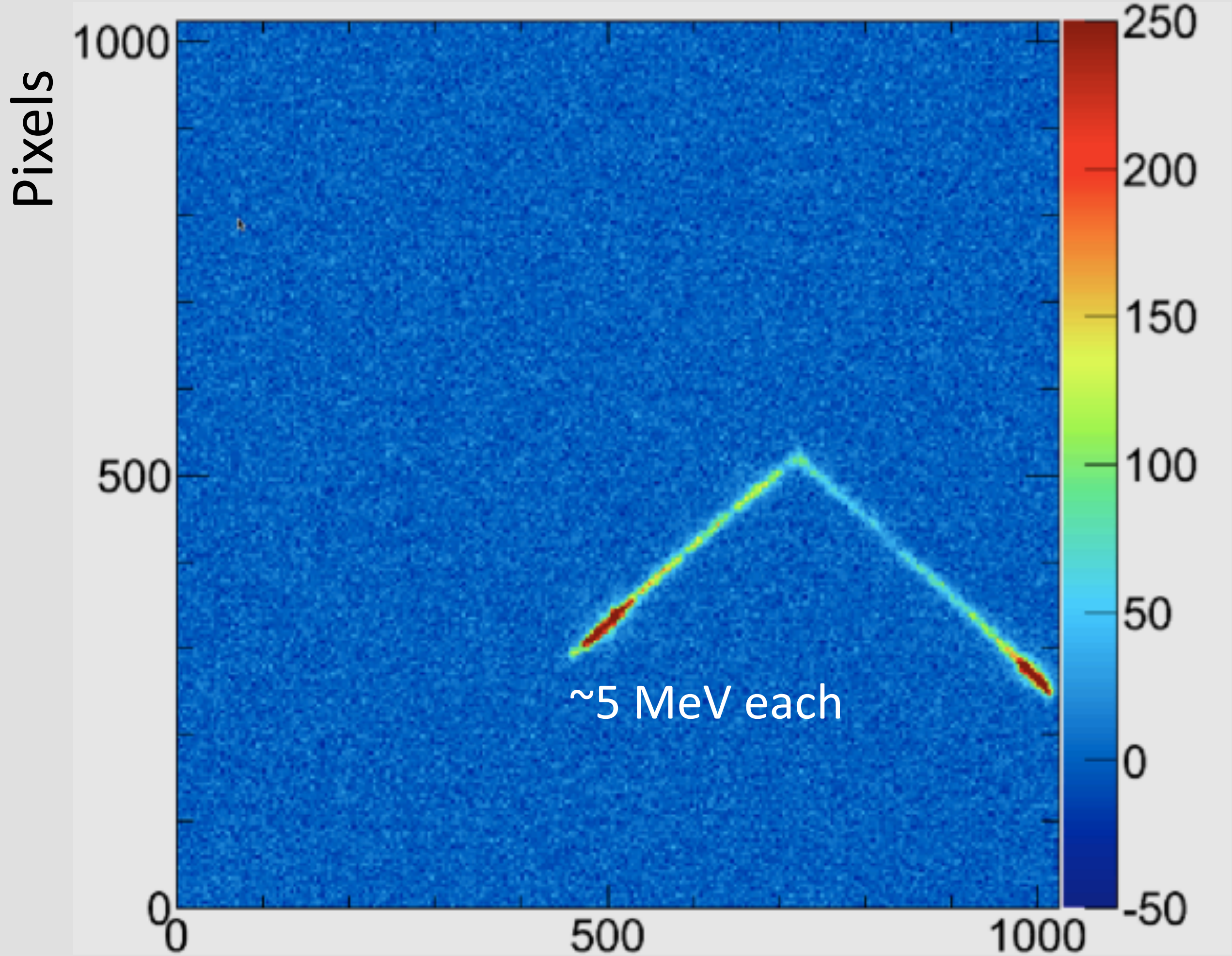
CCD readout



Waveform readouts: anode (top); mesh (bottom)

Two Alpha Event

$$^{220}\mathrm{Rn} \rightarrow {}^{216}\mathrm{Po} \rightarrow {}^{212}\mathrm{Pb}$$

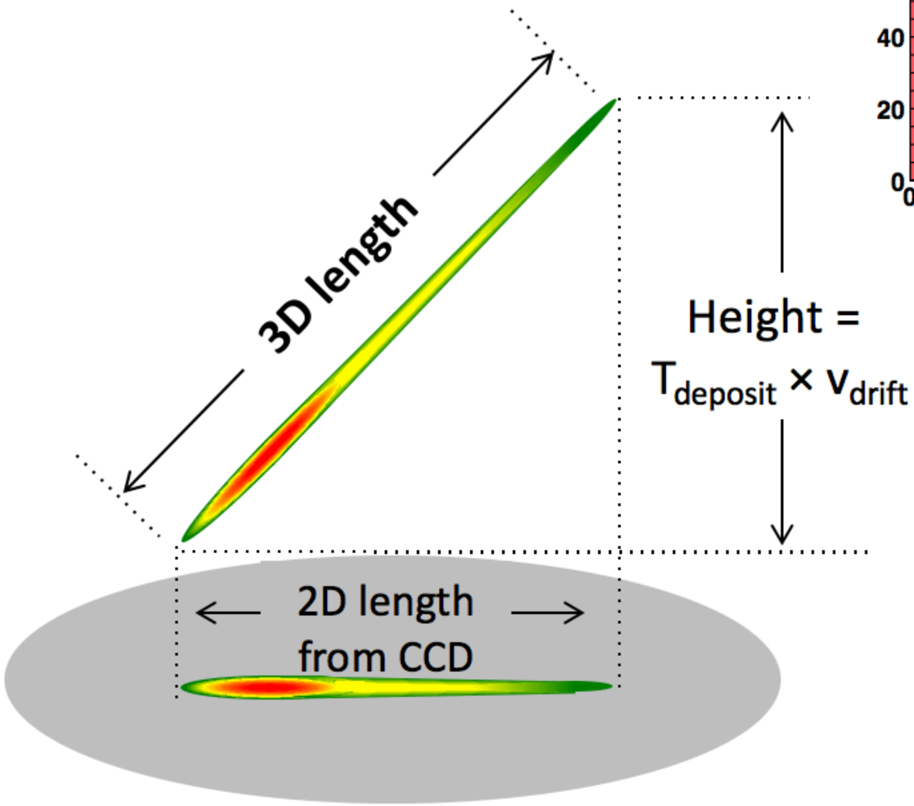


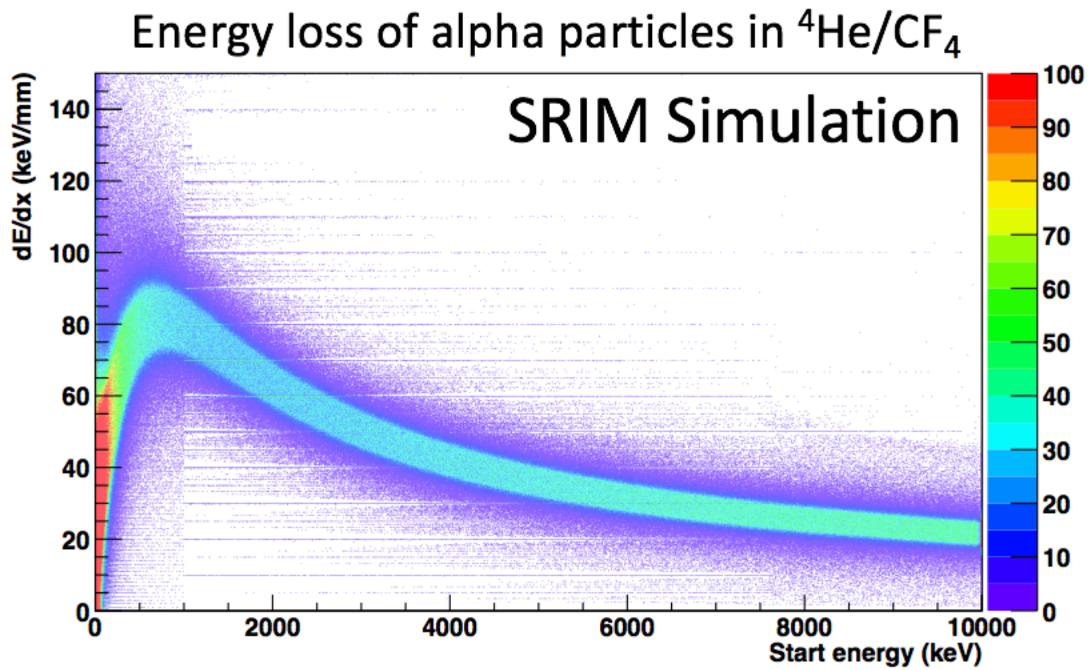
1024 pixels = 35.3 cm

Pixels

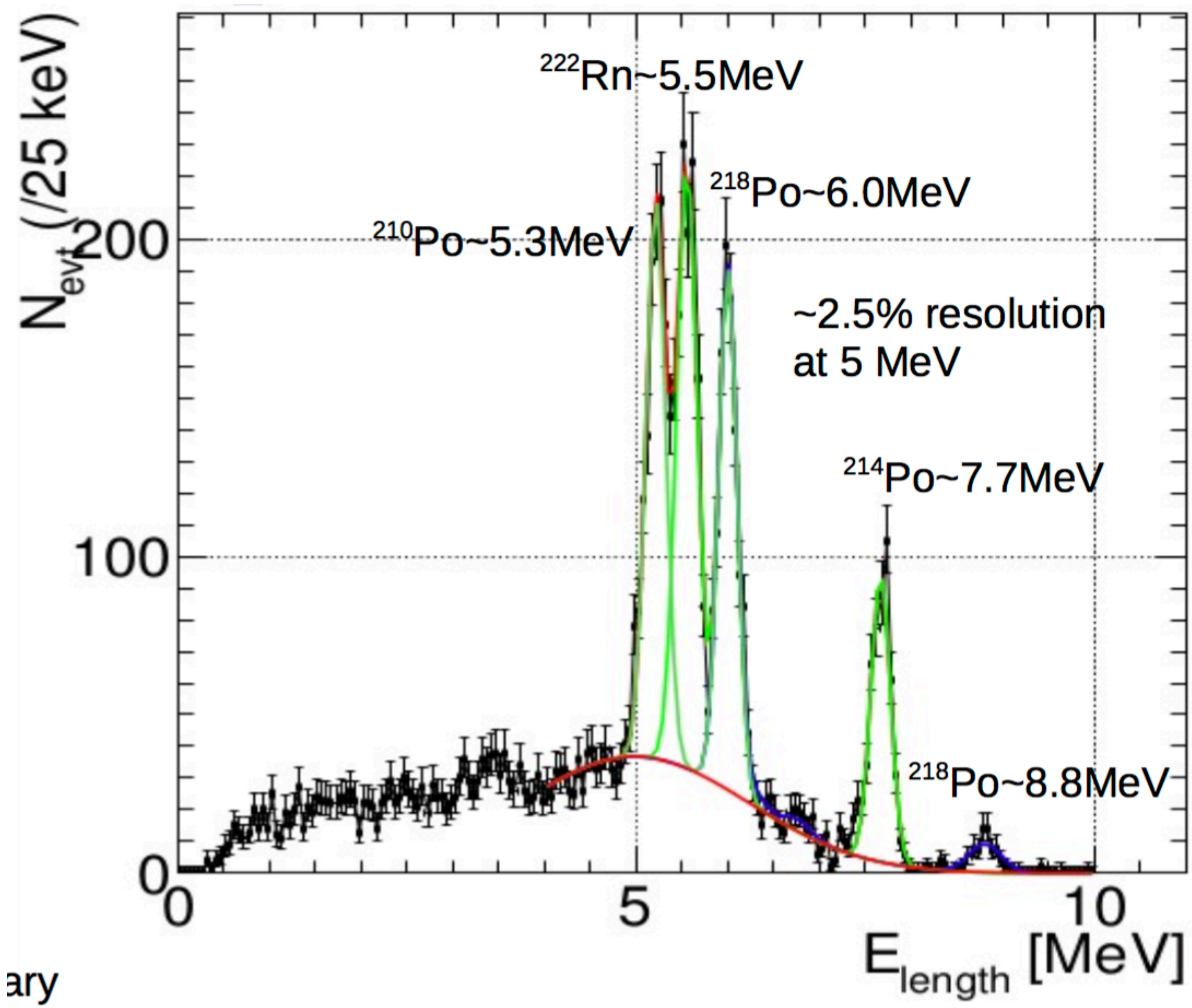
Energy Reconstruction

Energy Reconstruction from 3D track length

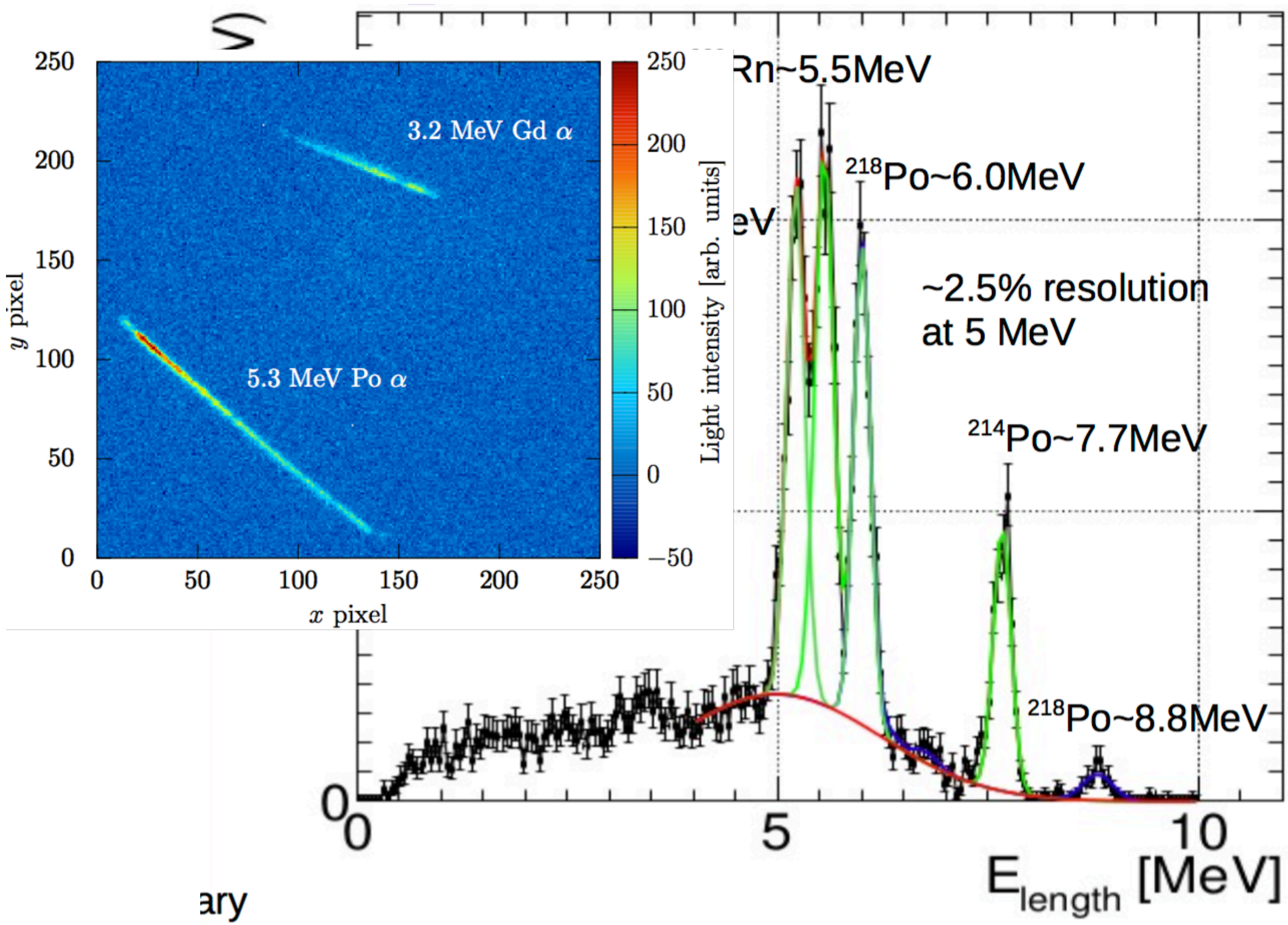




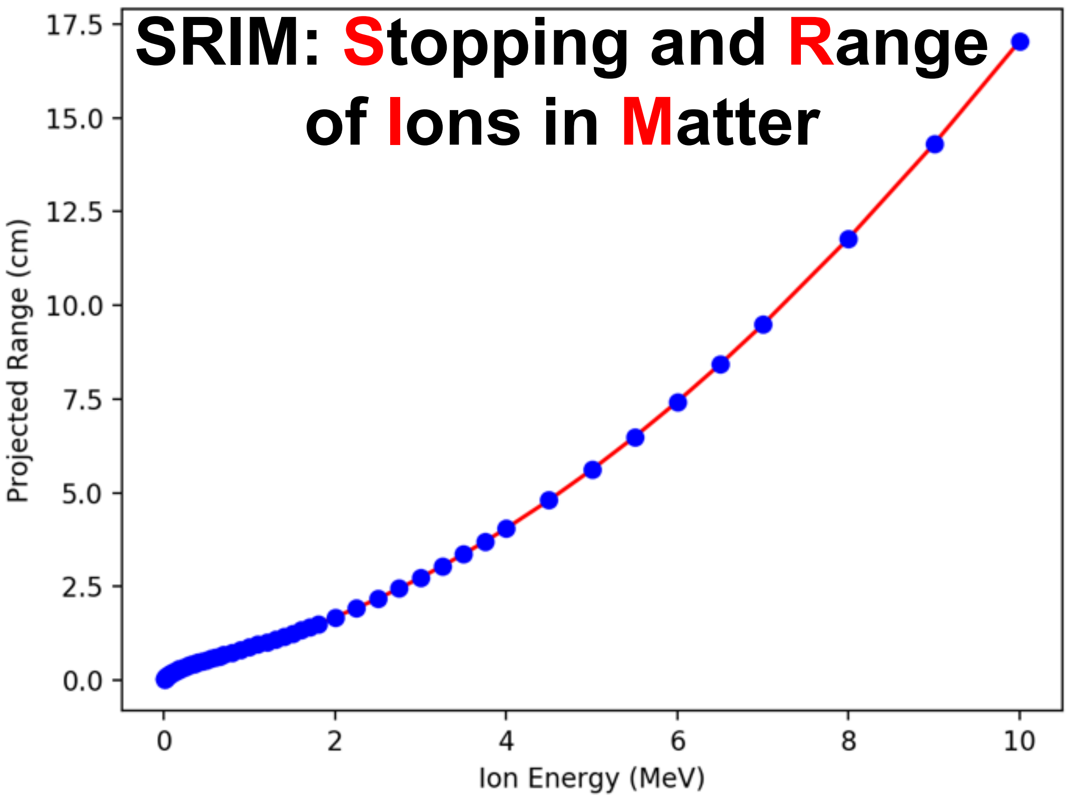
Energy Reconstruction

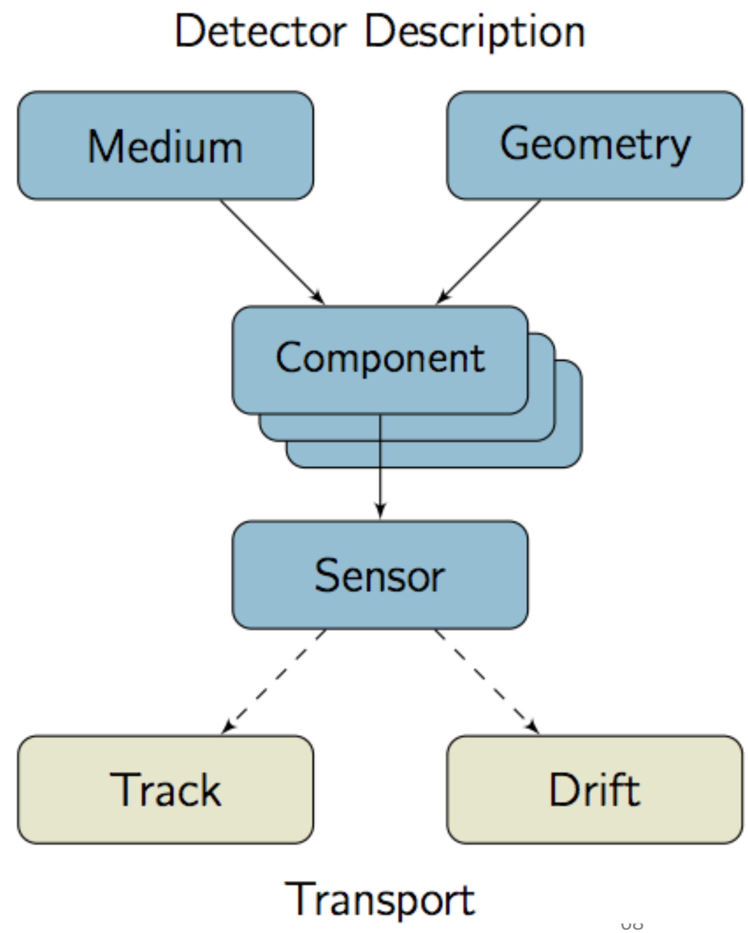


Energy Reconstruction

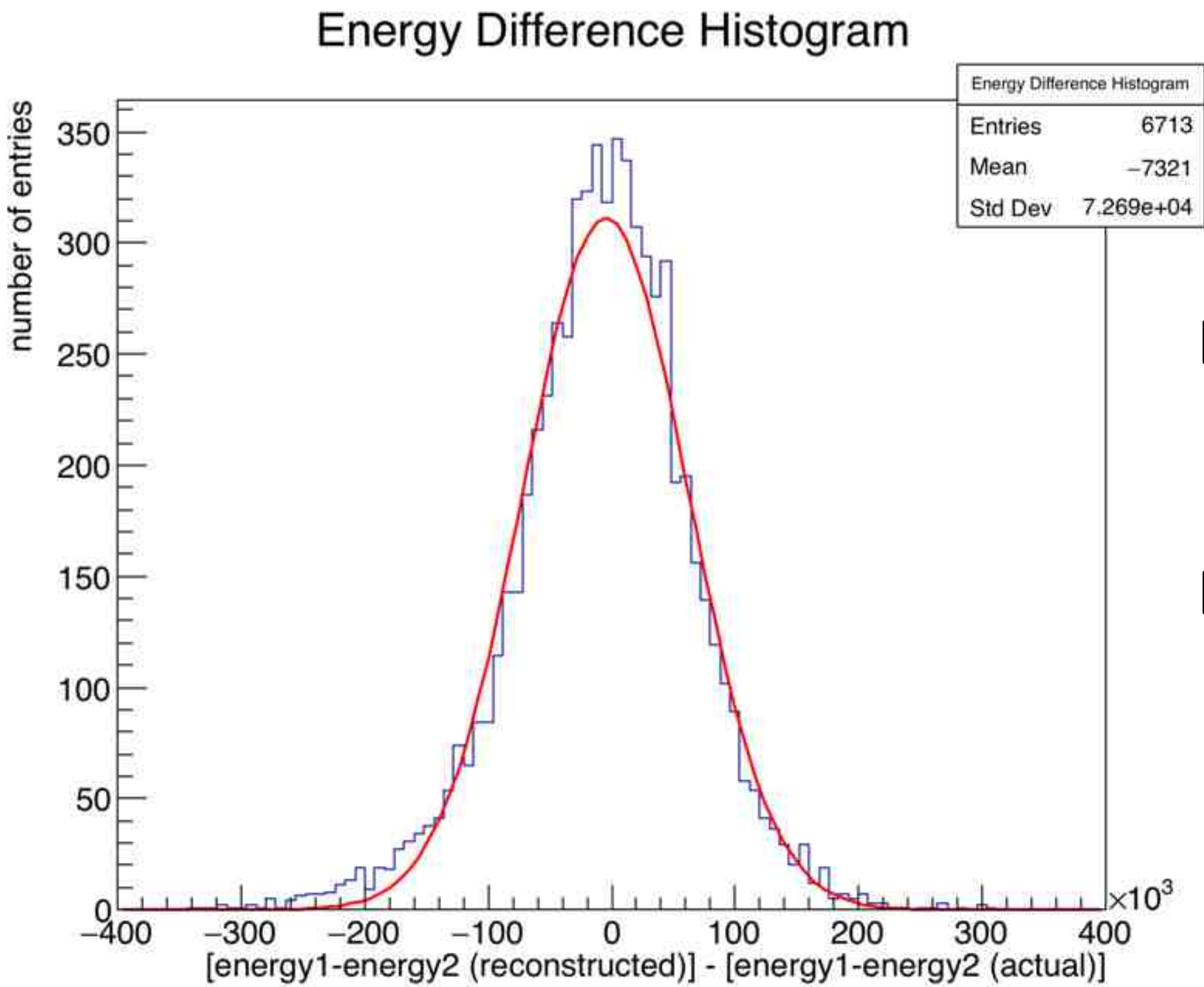


SRIM & Garfield Simulations





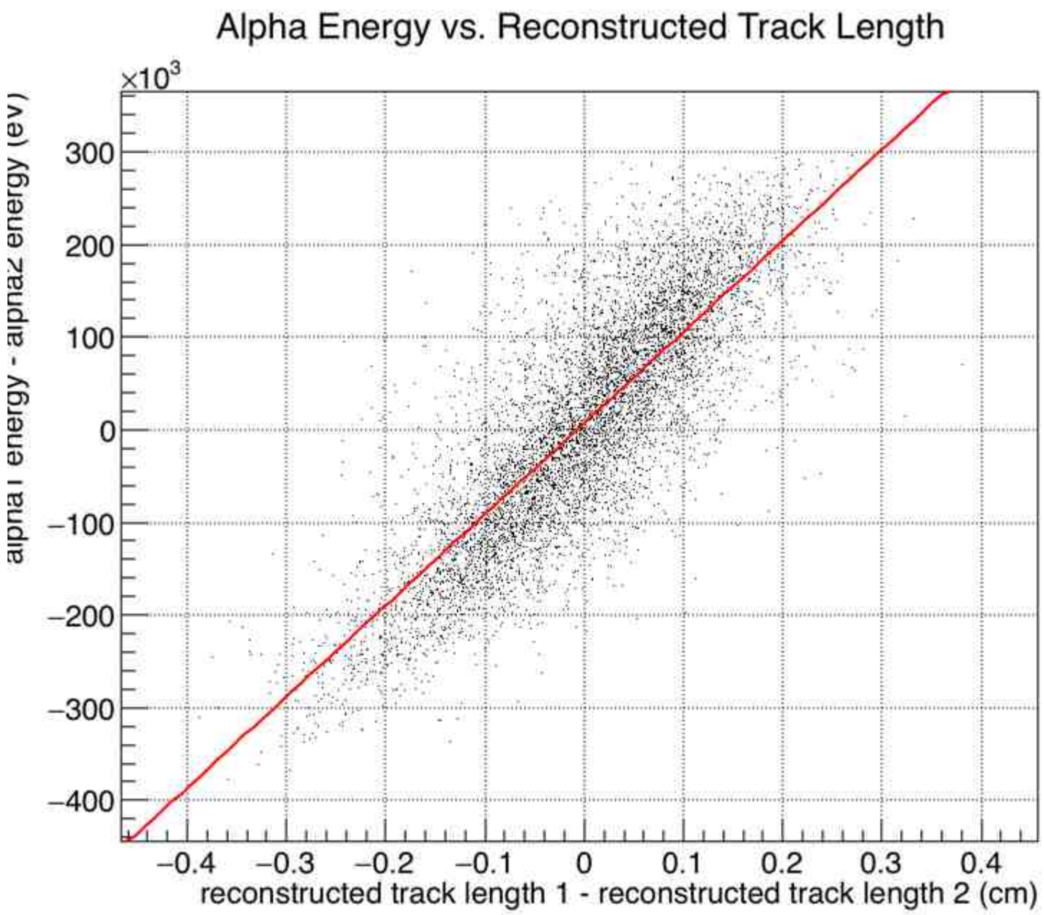
Goal: Reconstruct track length; correlate to alpha energy.



Energy Resolution of Data: 3.43%

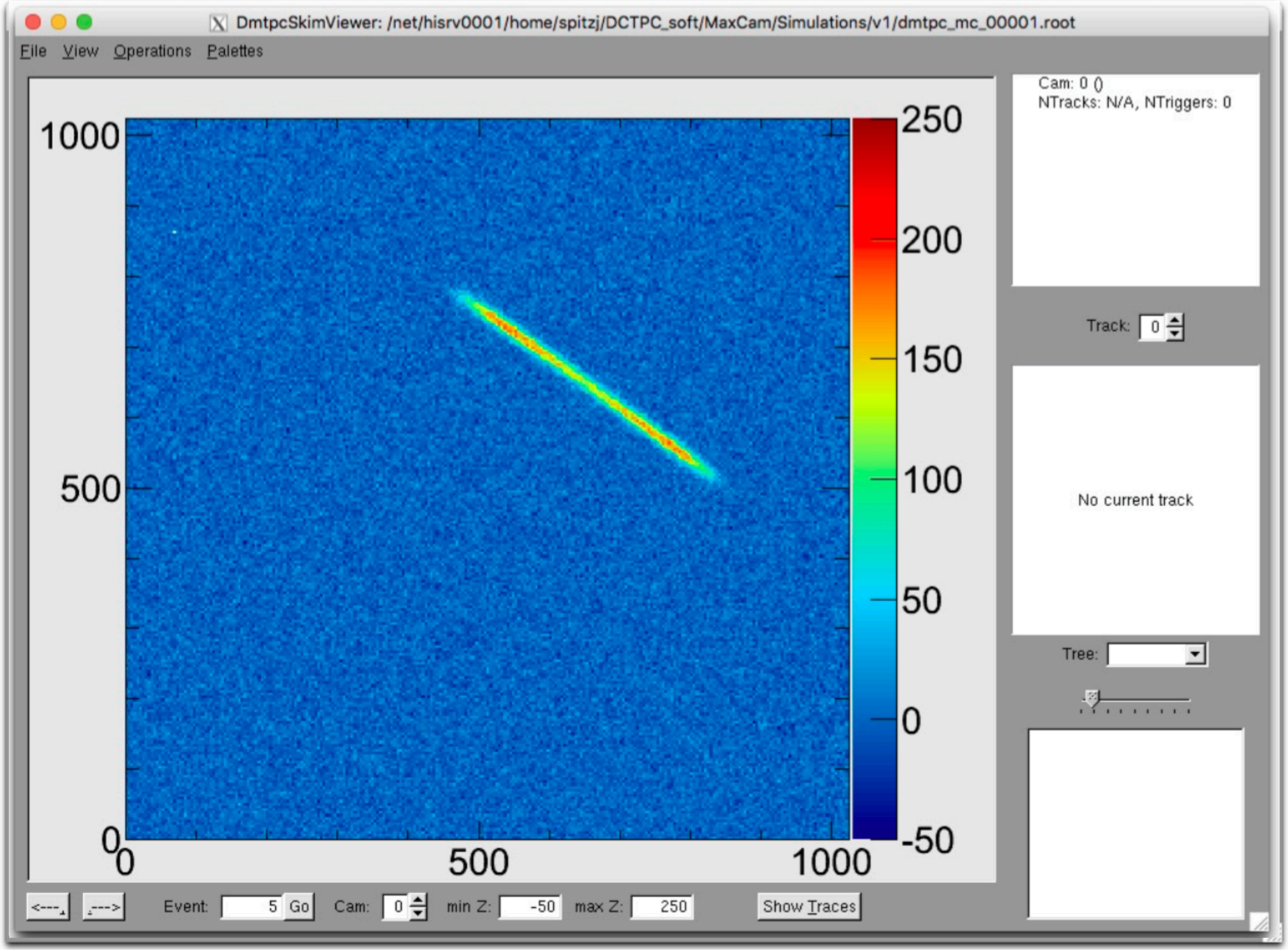
Energy Resolution of fit: 3.15 %

1. Find farthest endpoints along x and y directions.
2. Find $\theta_{reconstructed}$ using plot of cos(theta) vs. width.
3. Find z component of track length for each $z = \frac{1}{\tan(\theta_{reconstructed})*\sqrt{x^2+y^2}}$, where x, y, and z are the respective components of the track length (cm).
4. Find track length by taking $\sqrt{x^2 + y^2 + z^2}$



Sensitivity to ^{8}Li decay Alphas

'Typical' simulated events @ 200 Torr



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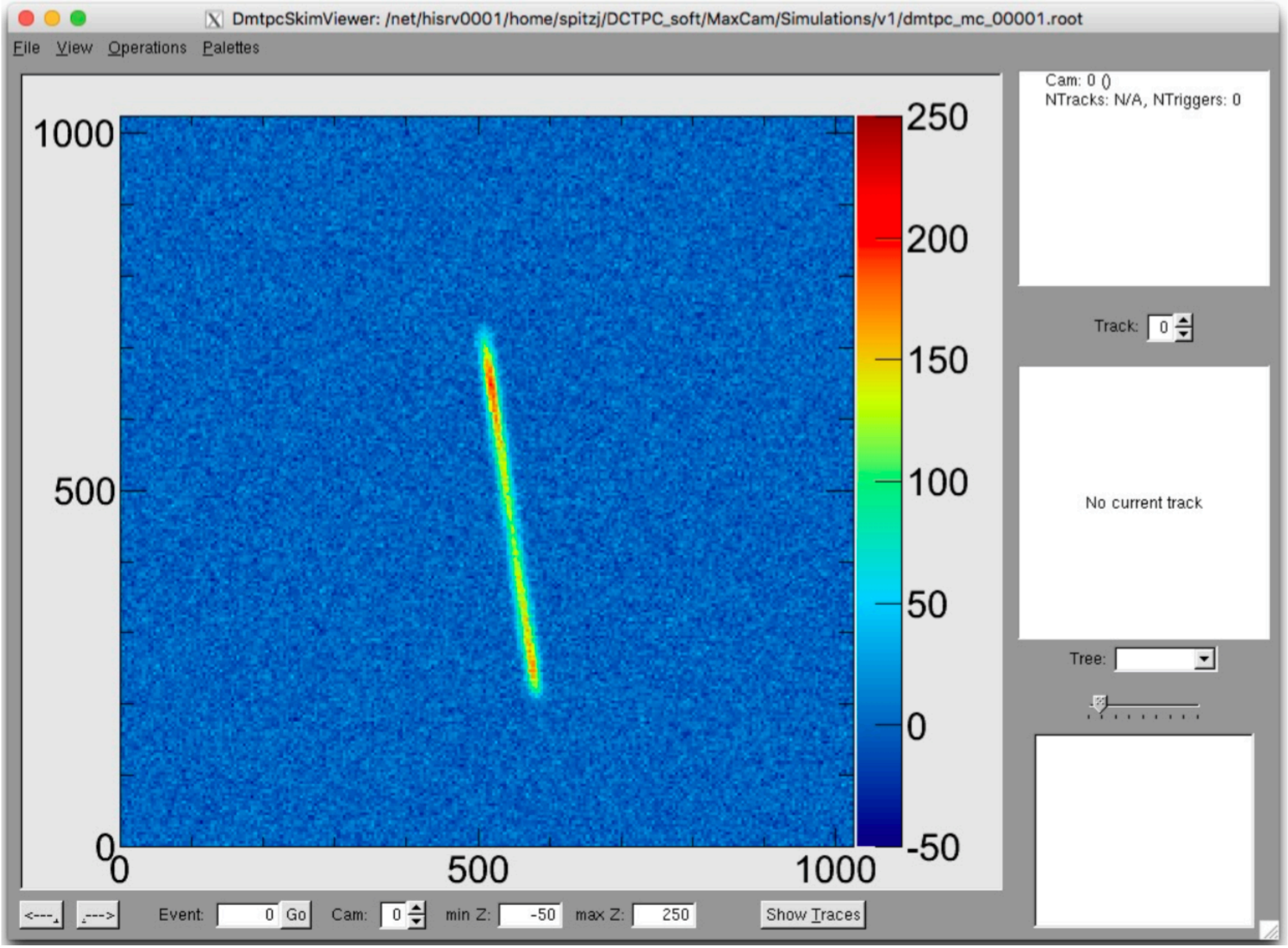

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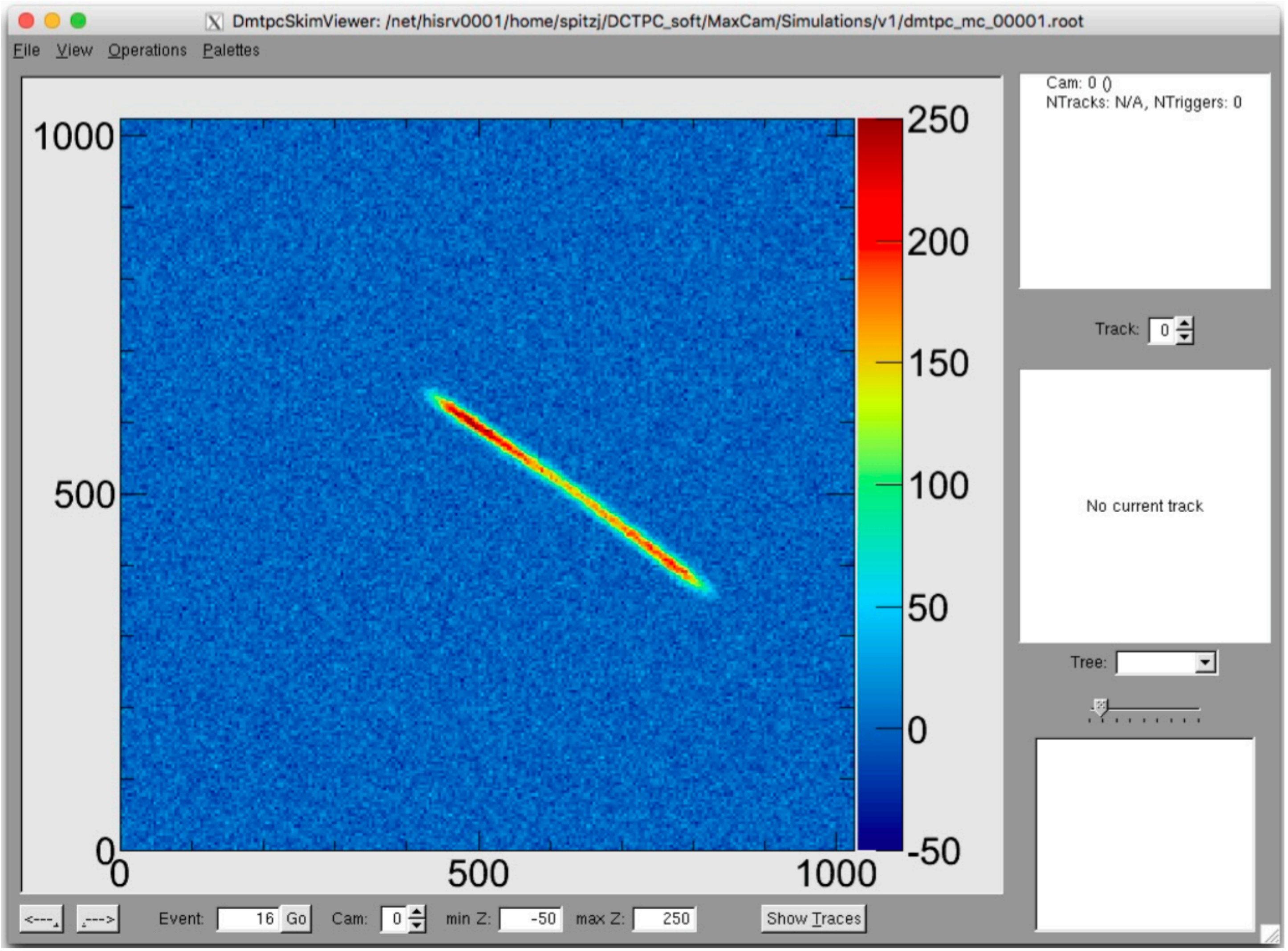

Sensitivity to ^{8}Li decay Alphas

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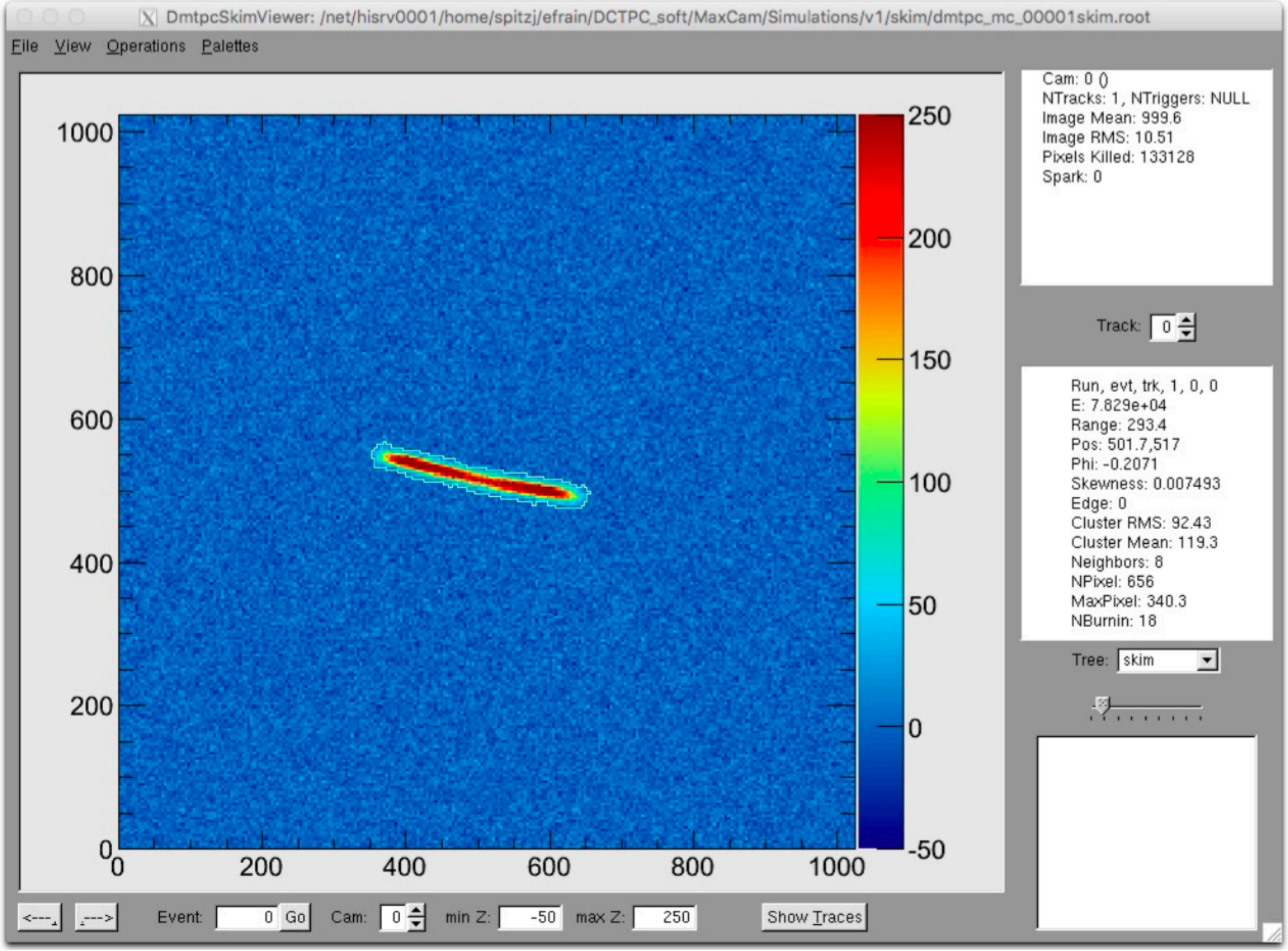

Sensitivity to ^{8}Li decay Alphas

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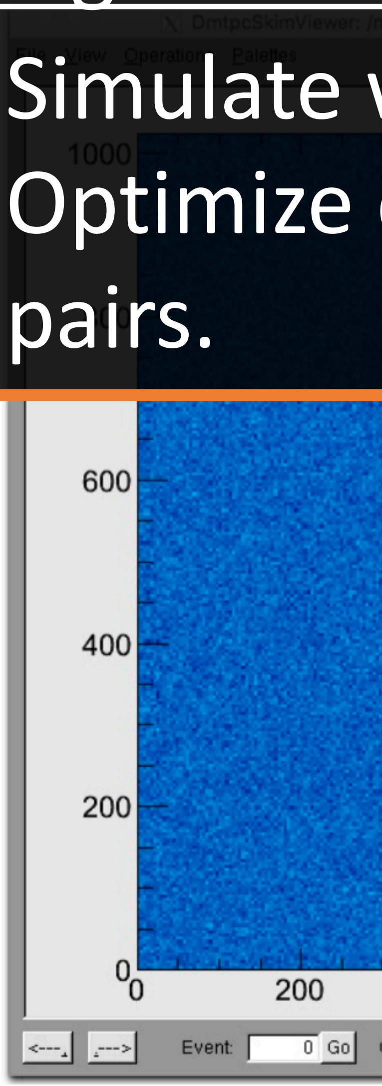
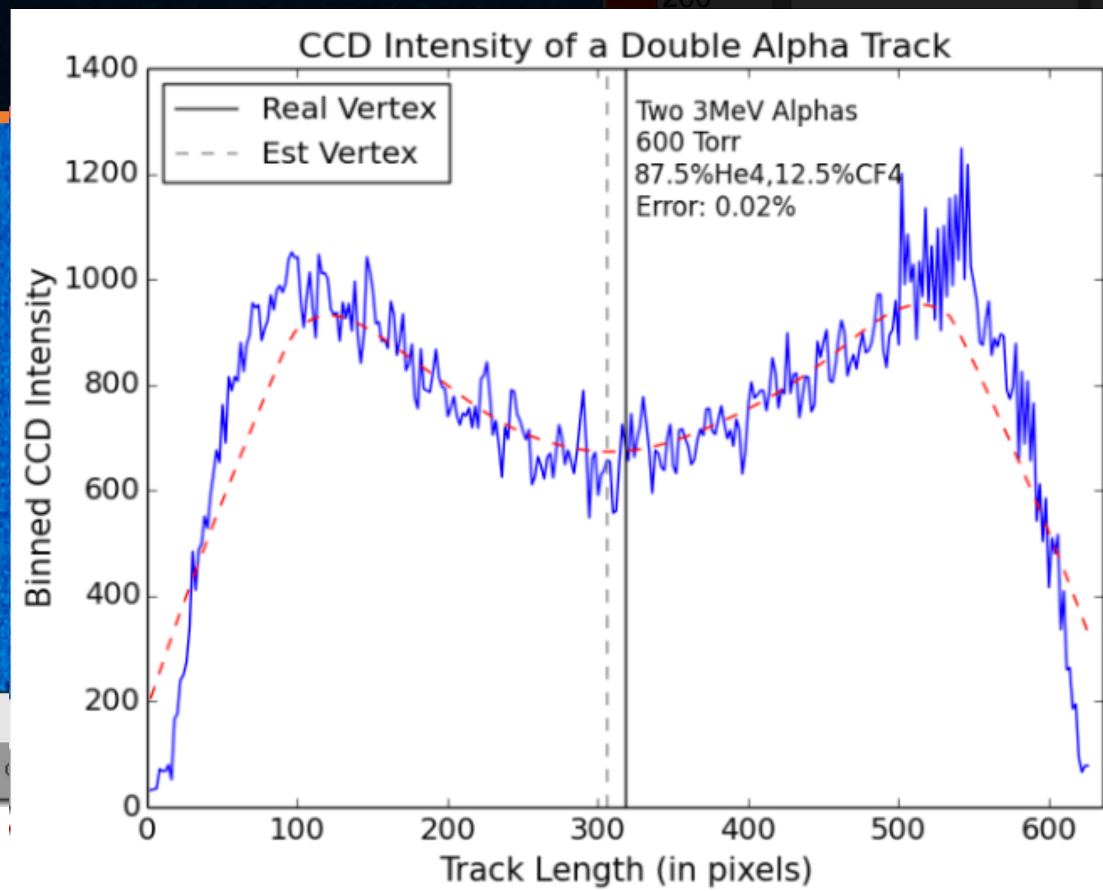


Ongoing Simulation Development:

- Simulate waveforms.
- Optimize clustering algorithm for alpha pairs.



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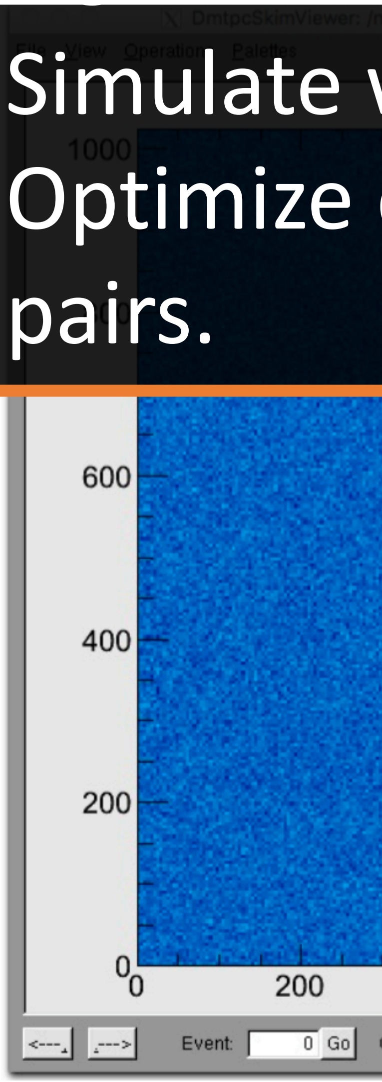
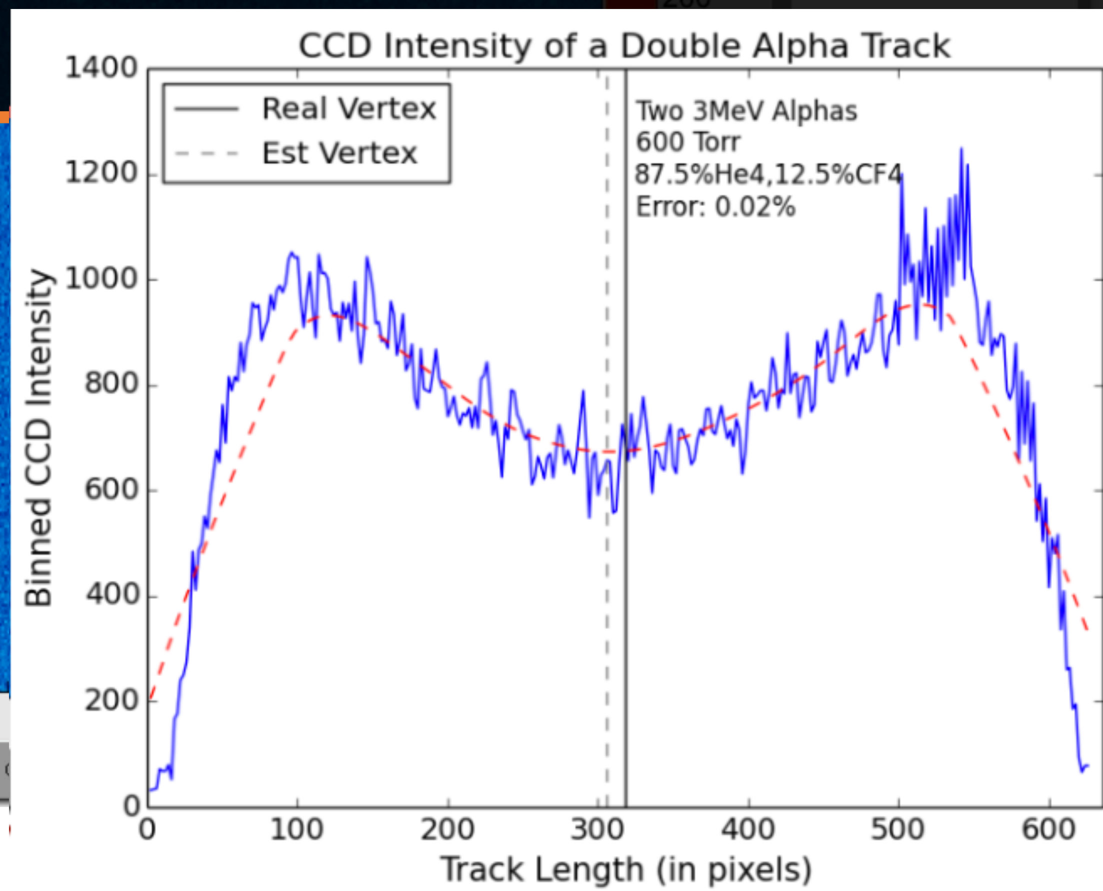
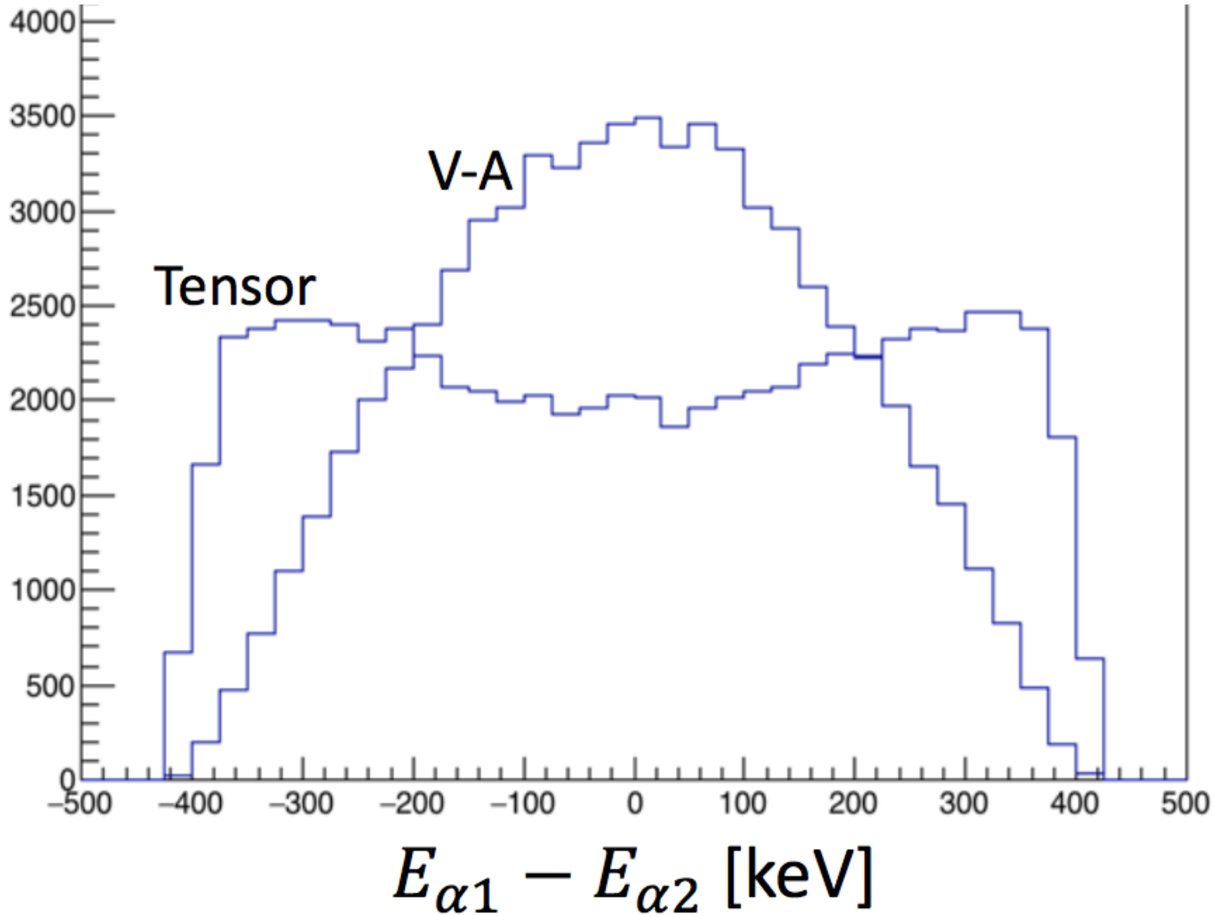
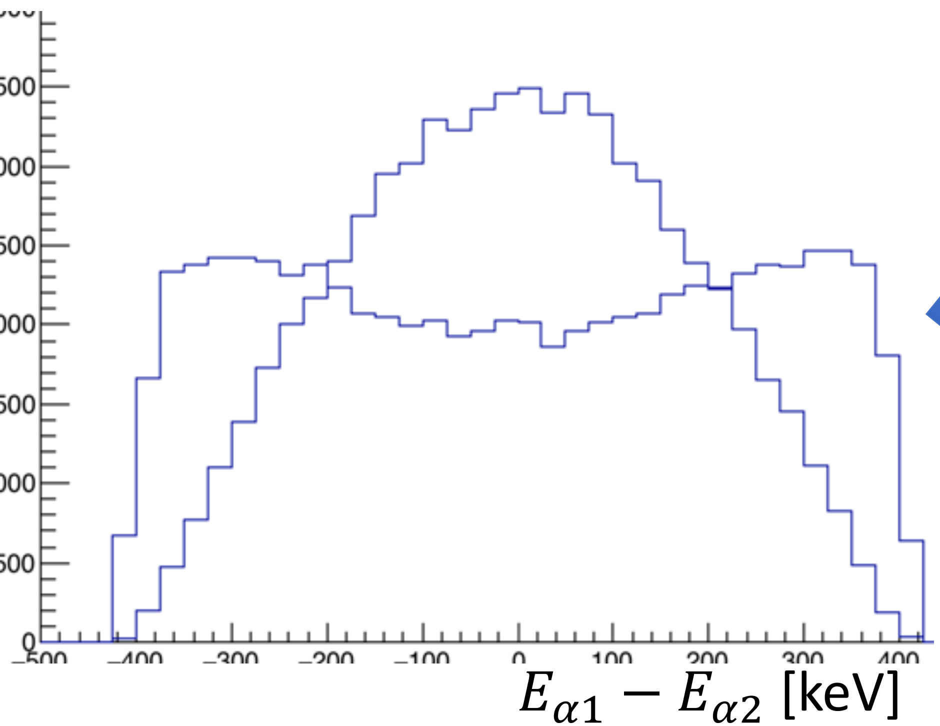




^{8}Li Physics (Tensor vs. V-A)



Resolution Effects

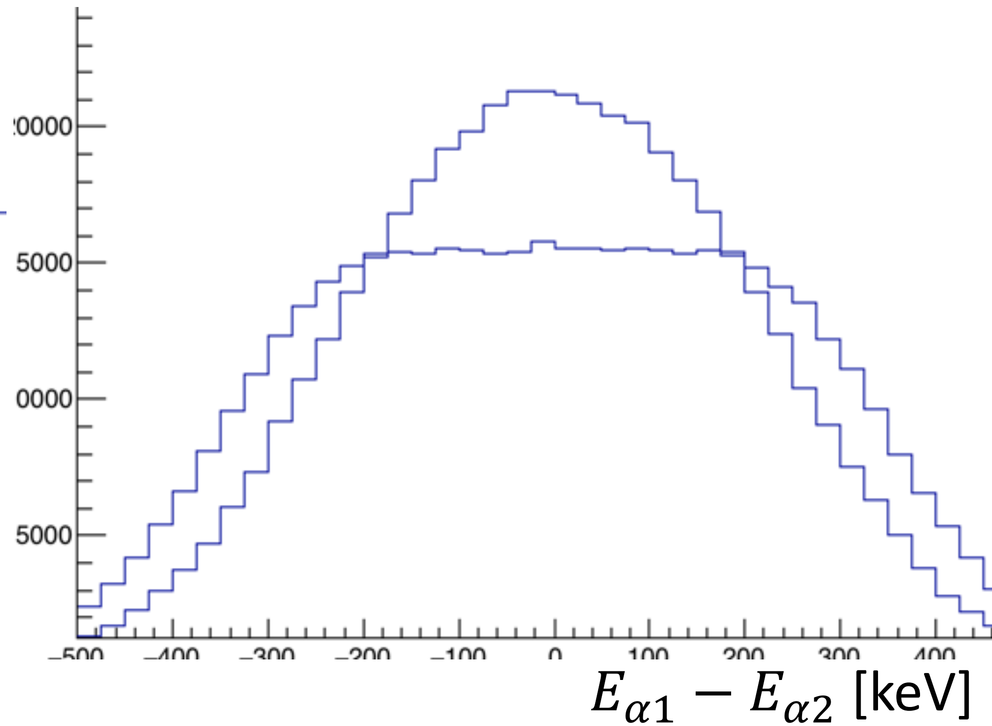


Nominal resolutions:

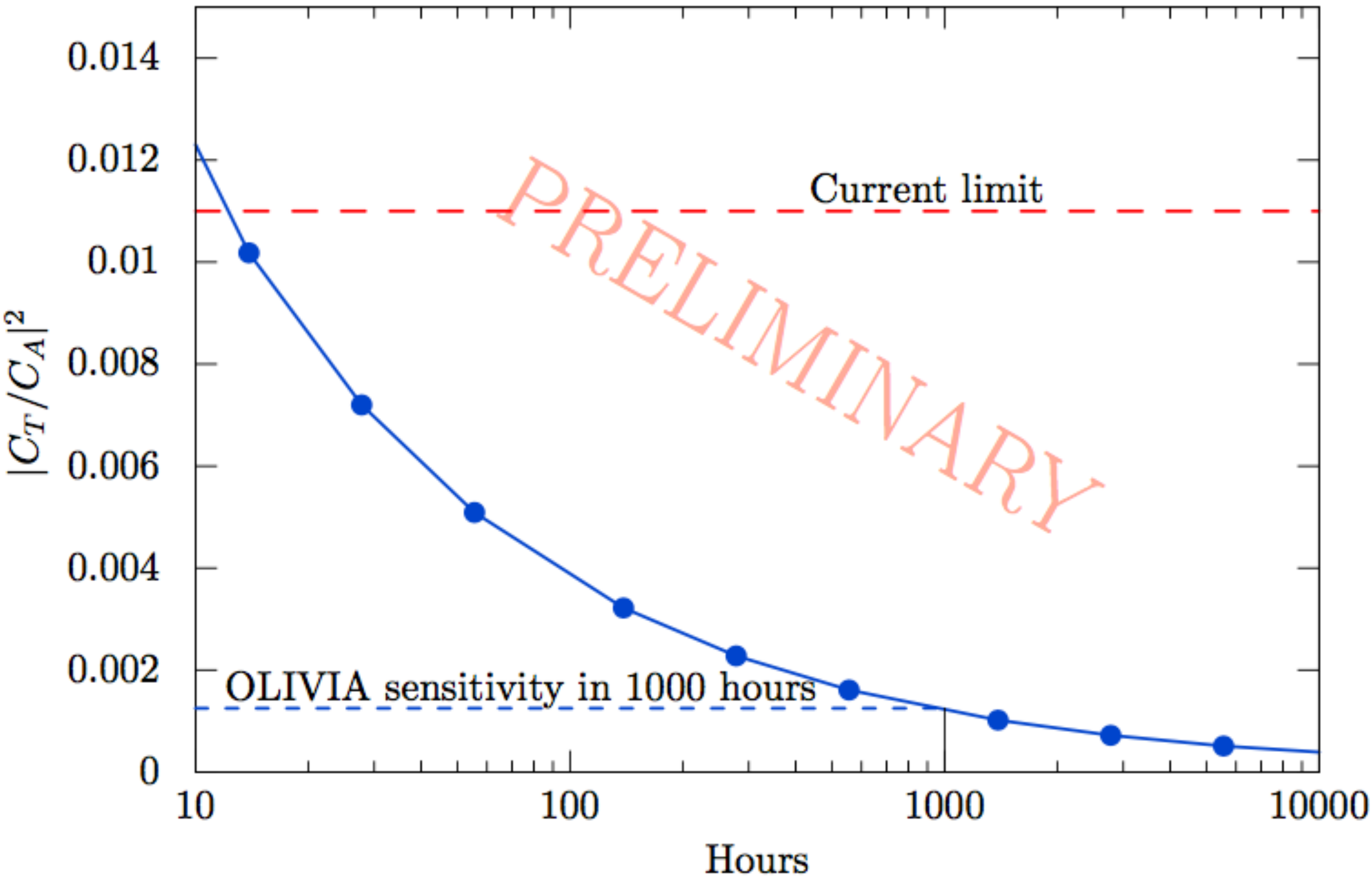
2% - Energy,

1^{o} – In-Plane angle,

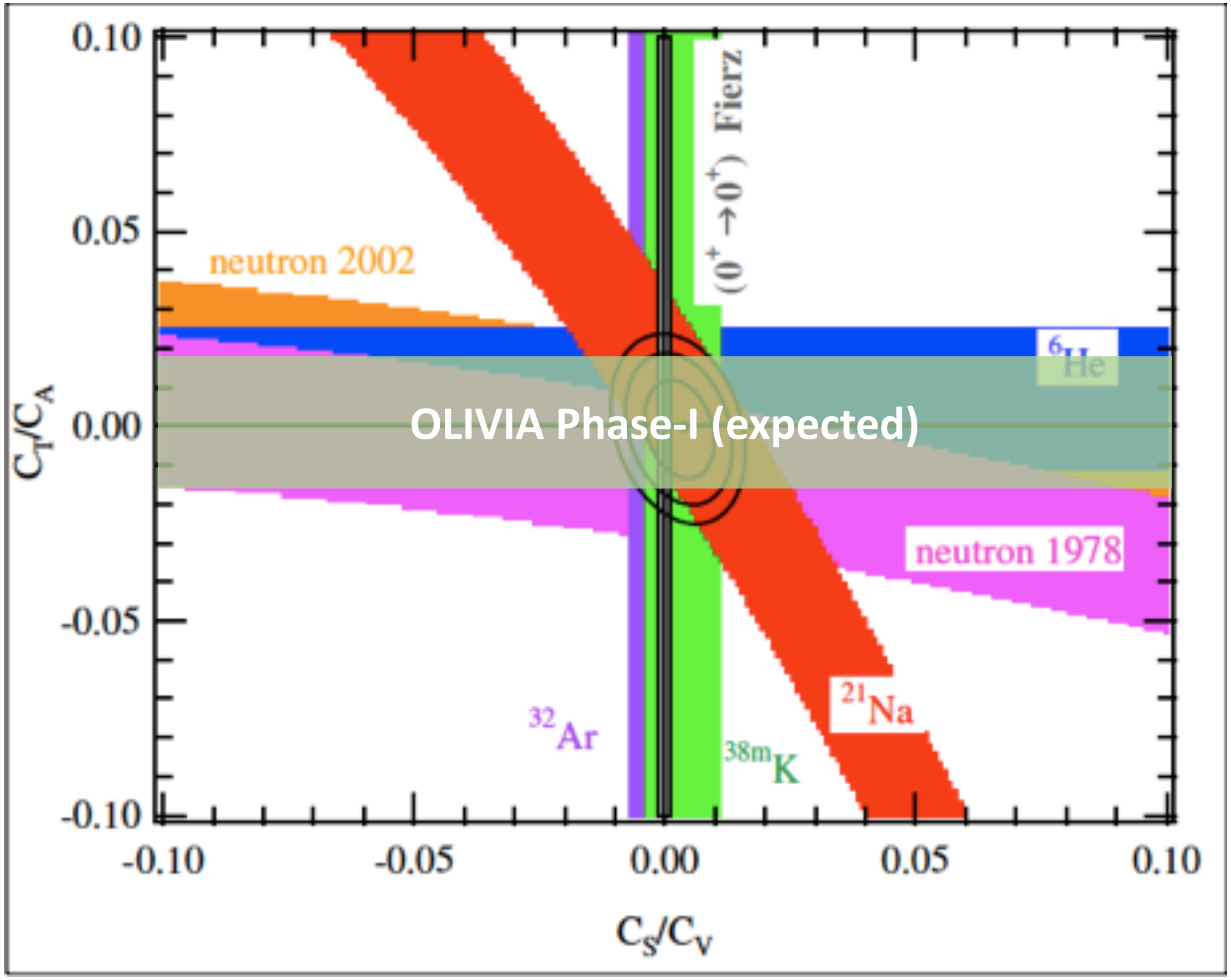
2^{o} – out-of-plane angle.



Status and Outlook



Status and Outlook



Status and Outlook

- MITPC is a great, proven, 3D alpha detector!
- Based on the reported SNO rates we can measure 10^7 decays in 2 - 3 months of data taking.
- Finalizing simulations to optimize the resolutions and extract the expected C_T/C_A sensitivity.
- Initial DT feasibility runs planed for the summer.

HAPPY TO COLLABORATE !