The Selena Neutrino Experiment

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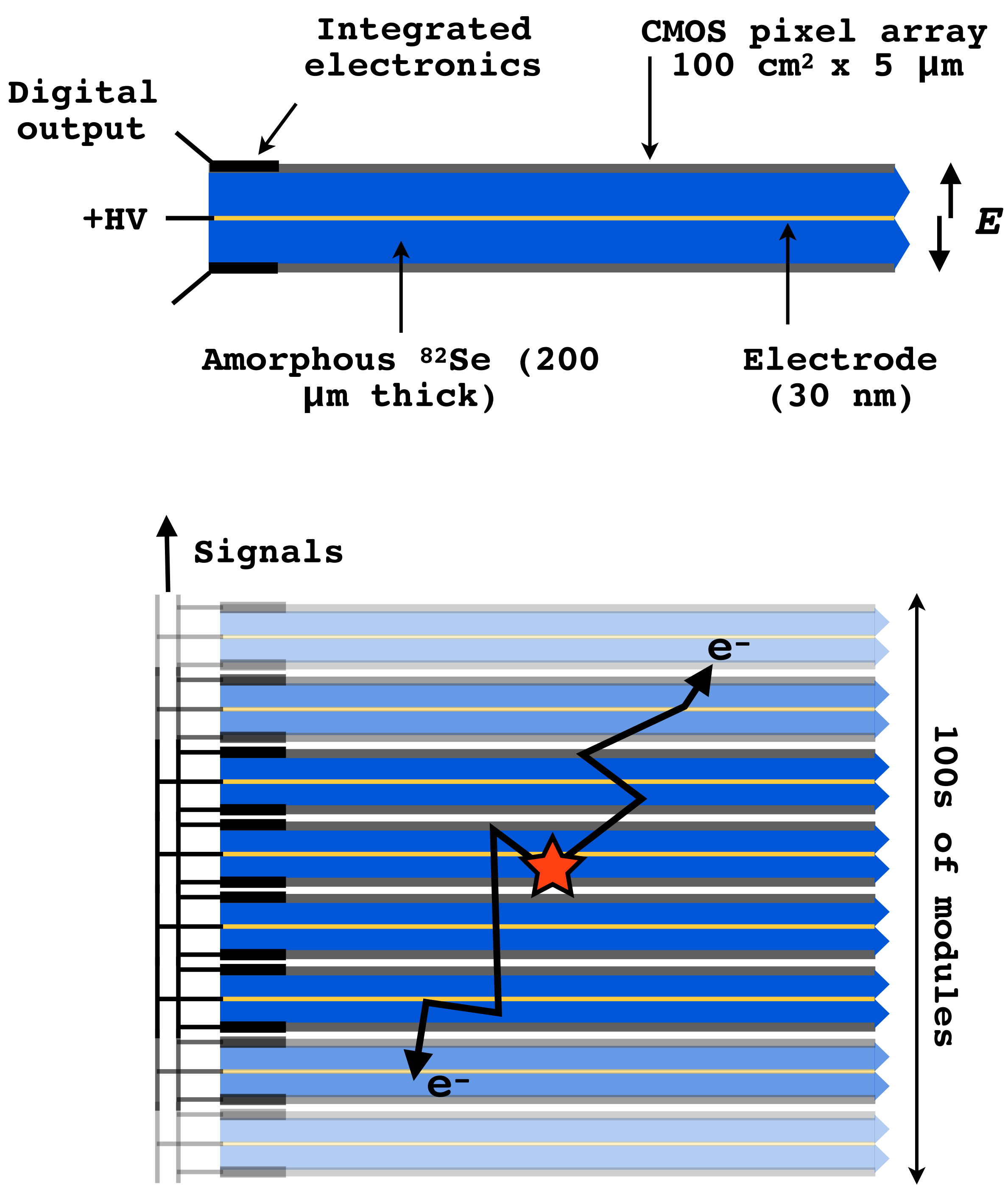
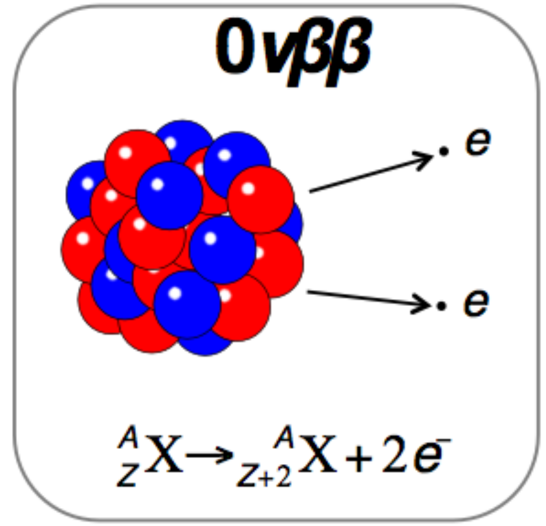
Outline

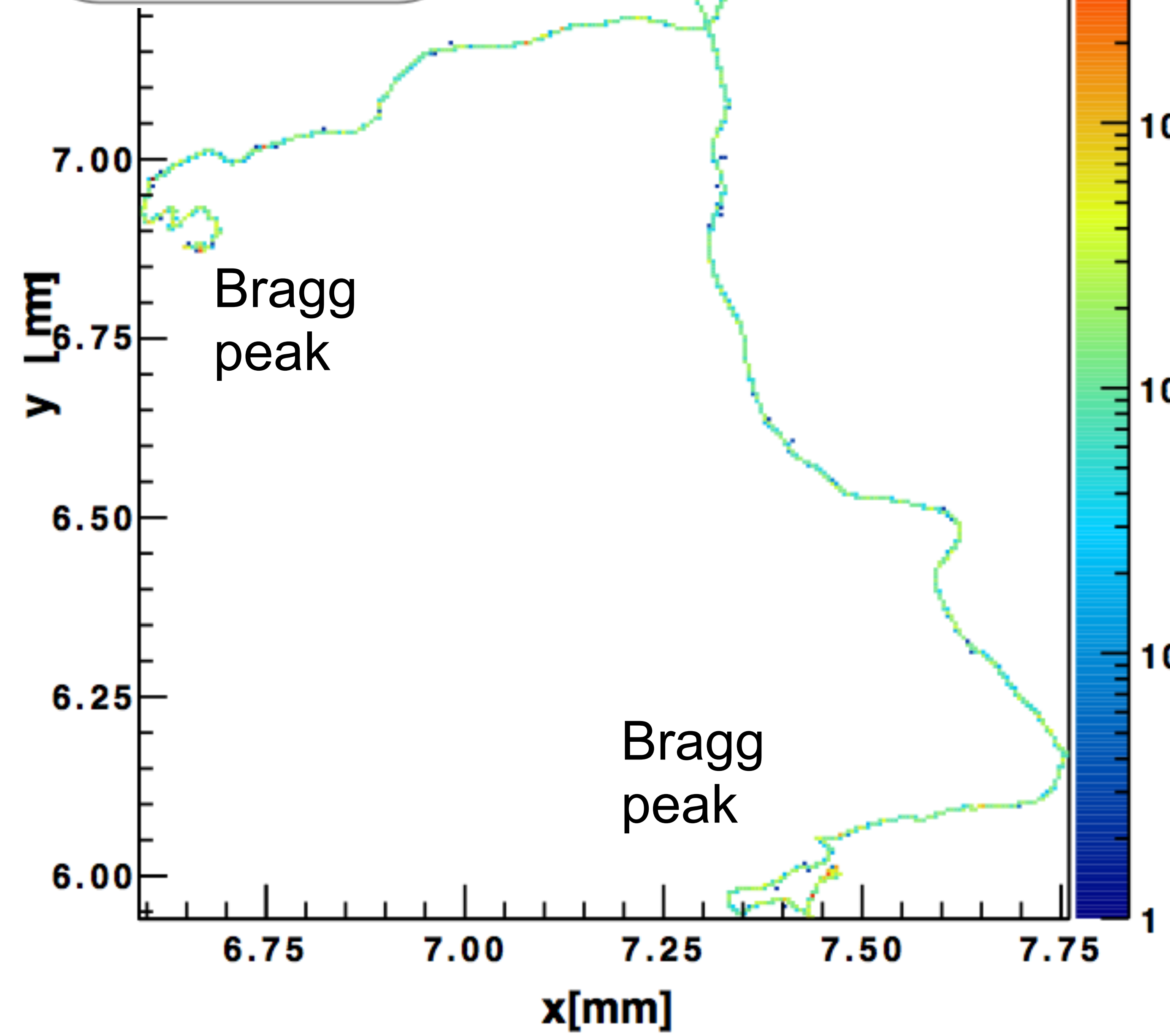
- Selena detector concept.
- R&D progress and status.
- Prospects for neutrinoless $\beta\beta$ decay.
- Prospects for a zero-background solar ν experiment.
- Solar ν spectroscopy with Selena.

Selena detector concept

JINST12(2017)P03022



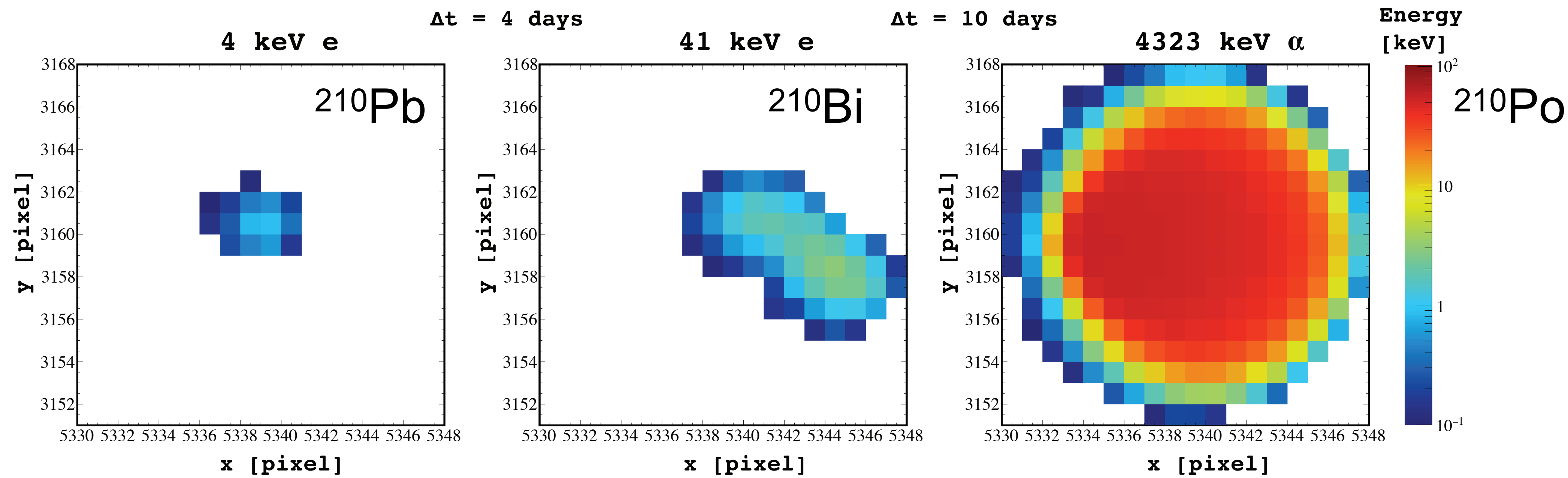




Spatial correlations

Data from DAMIC: UW's other imaging solid state detector.

- **^{210}Pb surface background:**

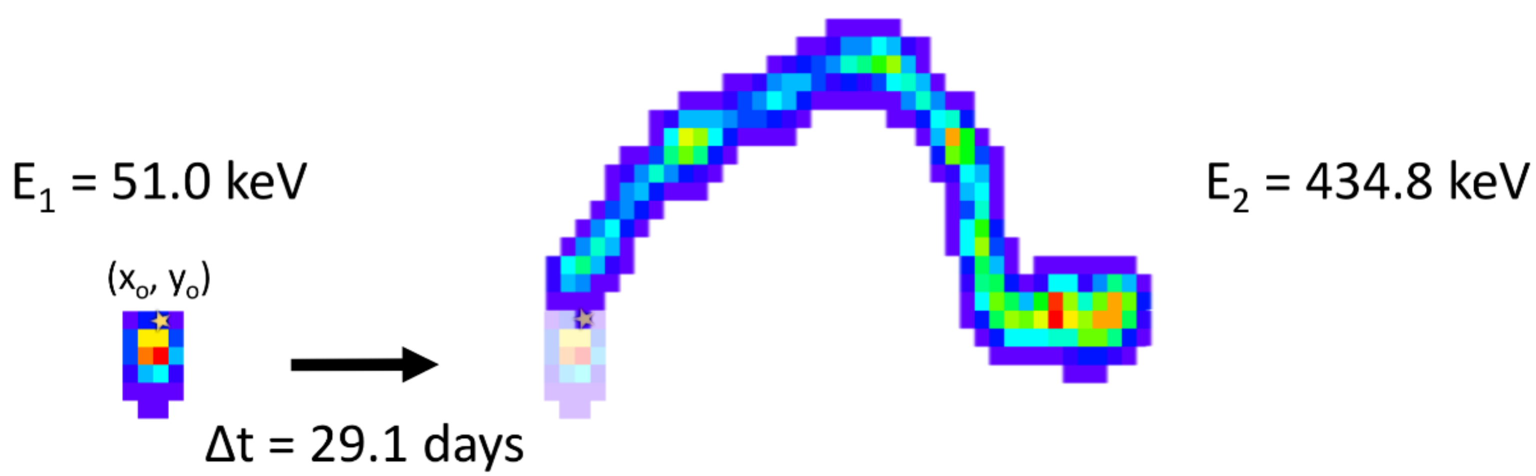


- **Cosmogenic ^{32}Si:**

Search for spatially correlated beta decays. Sensitivity with current data is few Bq/kg.

JINST16(2021)P06019

^{32}Si ($T_{1/2}$= 150 y, β) → ^{32}P ($T_{1/2}$= 14 days, β)



Detector goals

- Excellent *energy resolution* to perform precision spectroscopy, i.e., distinguish 0ν signal from $2\nu\ \beta\beta$ decay background.

- Excellent *spatial resolution* to suppress backgrounds by event topology, e.g., number of Bragg peaks, decay sequences, etc.

- *Easy to build*: room temperature operation, not very stringent radio purity requirements or fiducialization, etc.

- *Scalable*: standard CMOS foundry process (300 mm diameter wafers) and industrial aSe deposition.

2021 → **2024** → **2029** → **2040**

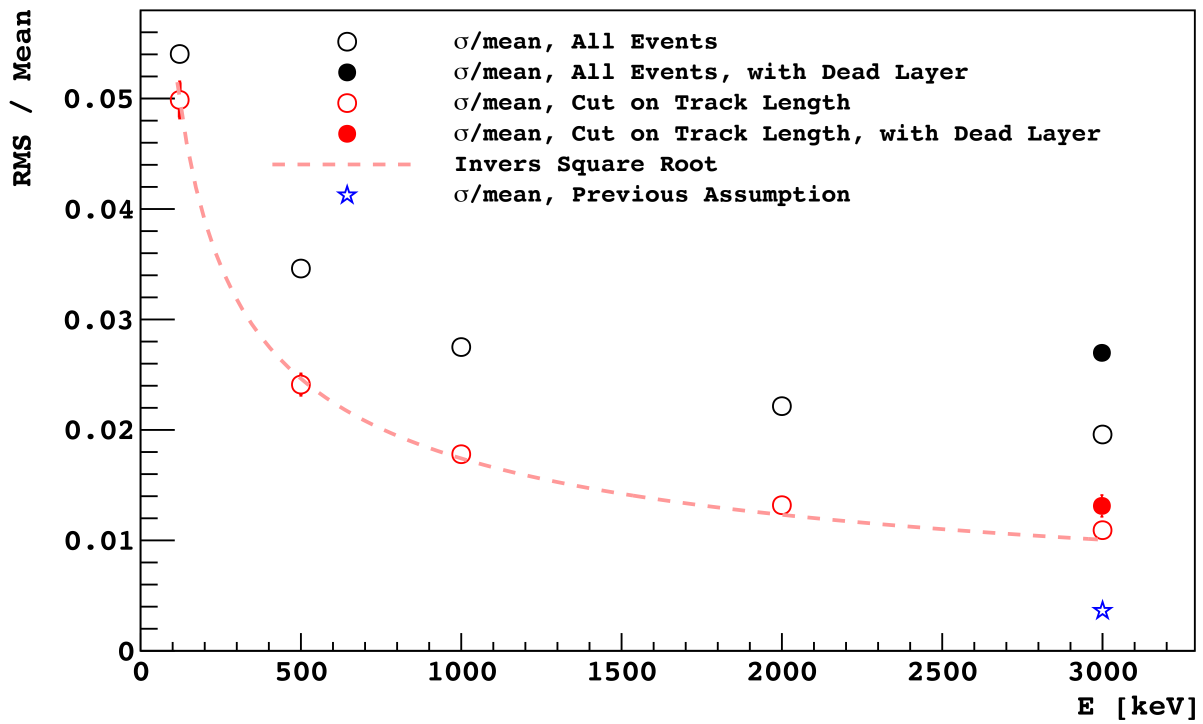
2021	2024	2029	2040
Small prototypes	Large detector module (0.25 kg)	100 kg (400 modules) demonstrator	10-ton detector underground

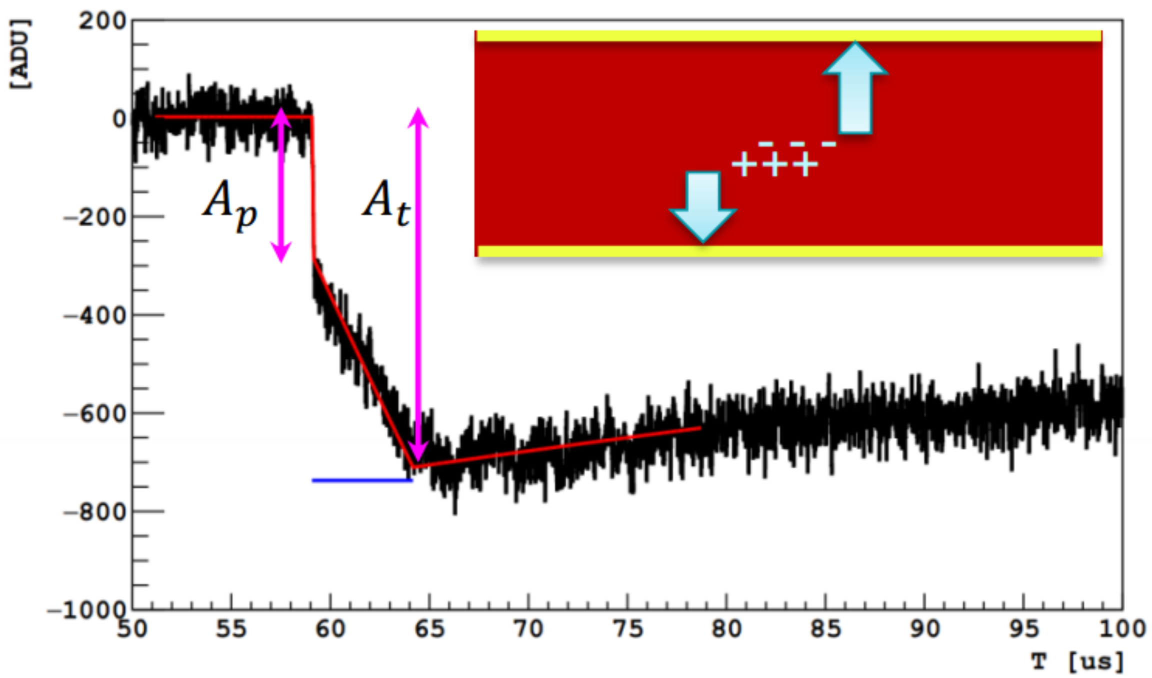
R&D: Single pixel

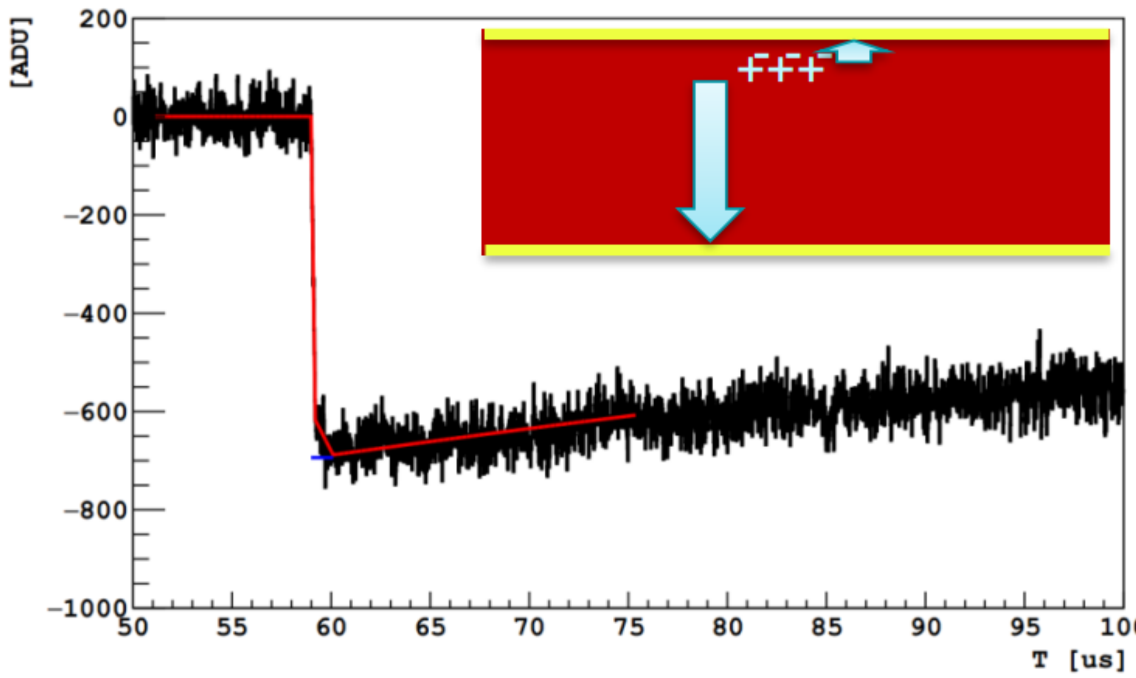
JINST16(2021)P06018

^{57}Co
122 keV

Source from above

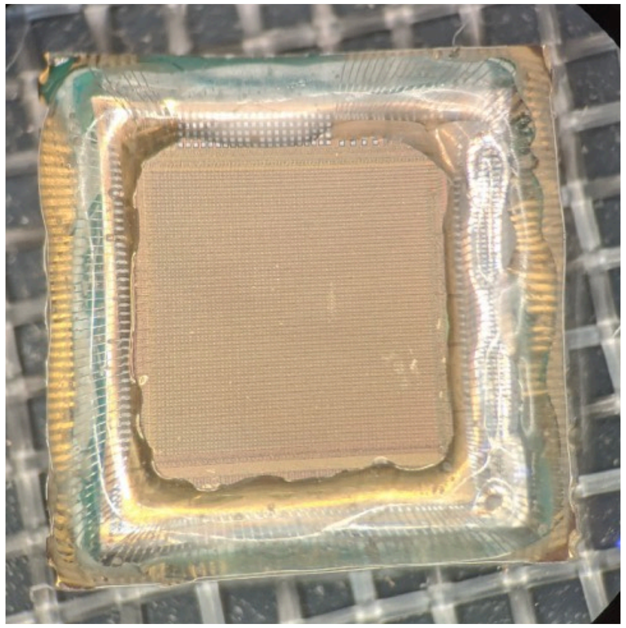




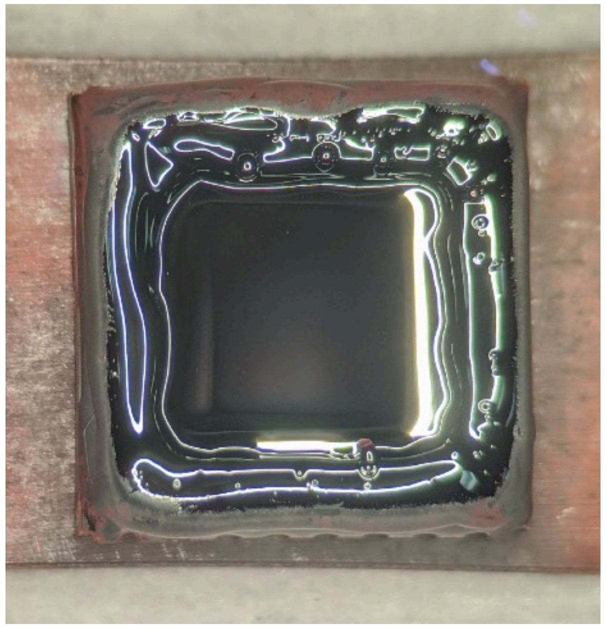


R&D: Topmetal-II⁻

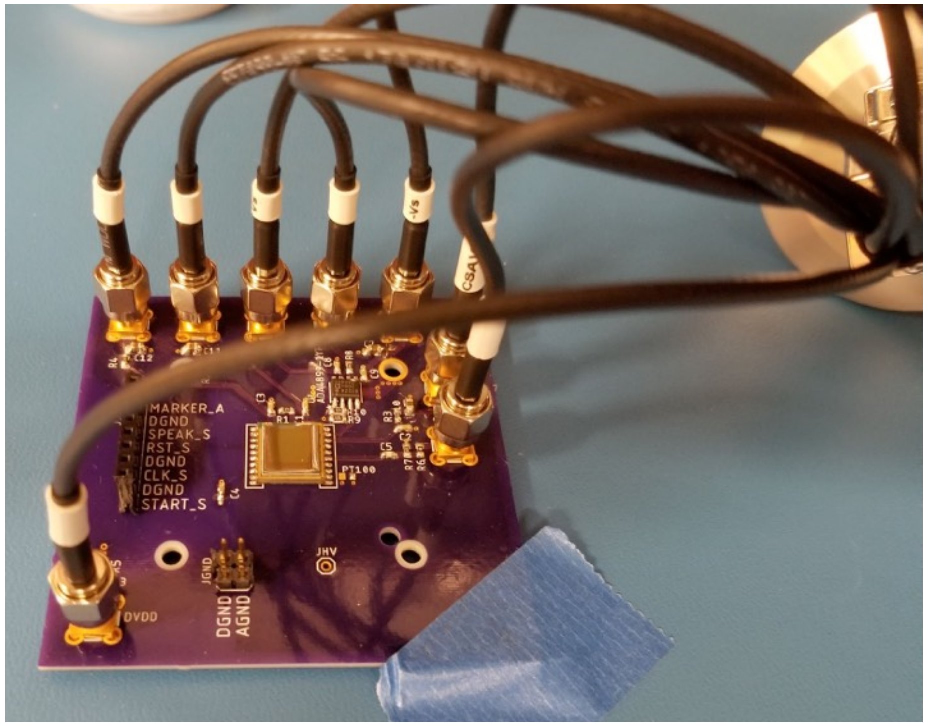
Before aSe



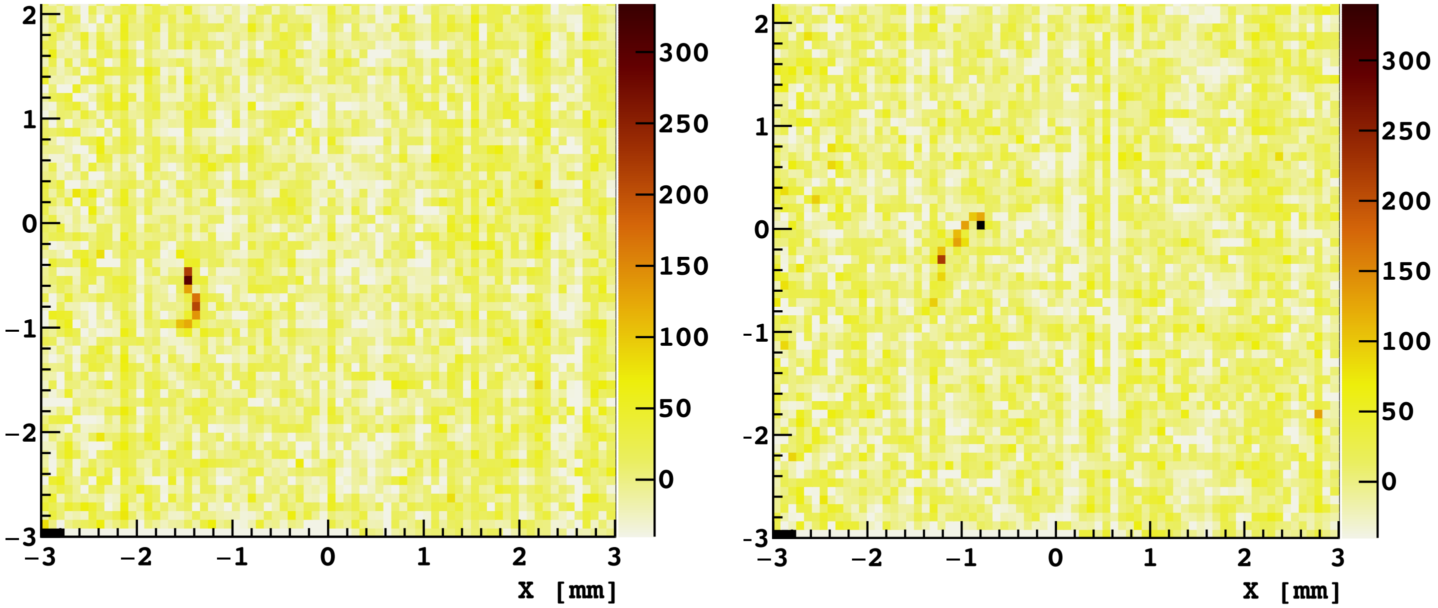
After aSe



Test board



Electron tracks from ^{90}Sr-Y!



- From Y. Mei at LBNL.

  NIMA810(2016)144

- CMOS pixel array with exposed metal electrodes.
- (83 μm)^2 pixels
- 15 e^- pixel noise.

Status

Milestones achieved:

- We measured the energy response of aSe.
- We coupled aSe to a CMOS pixel array.

We are already characterizing the response of our first aSe/CMOS image sensors!

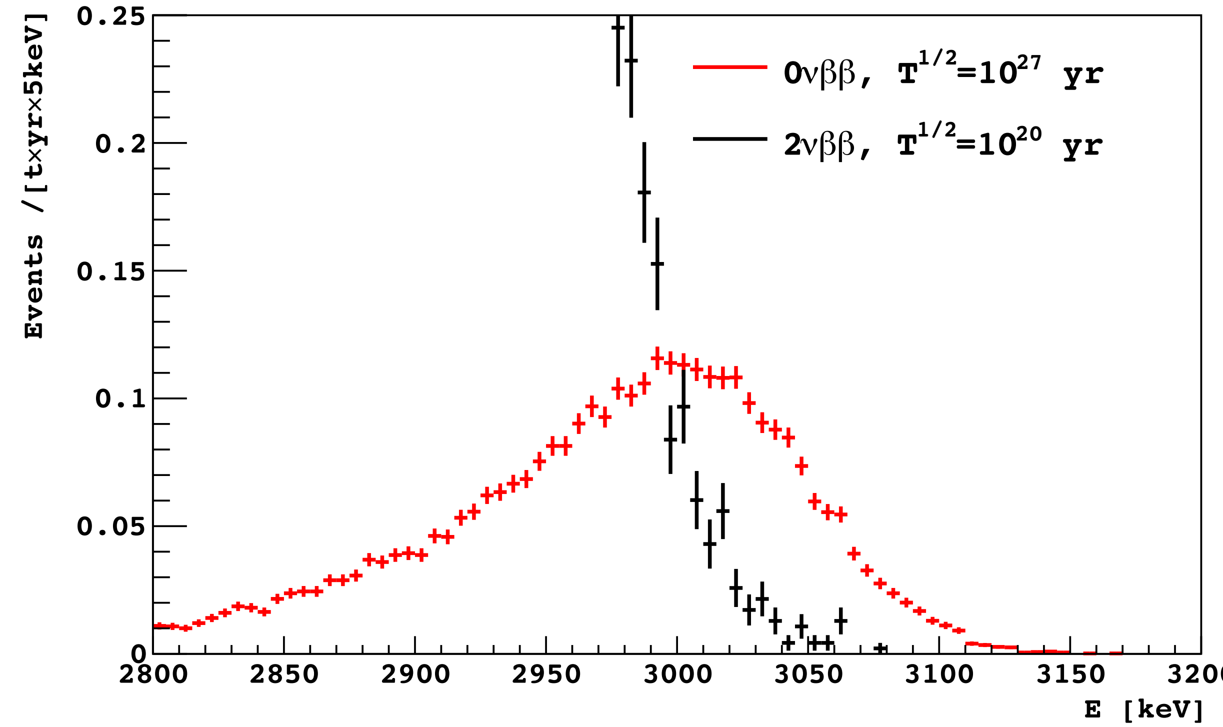
Publication in the coming months.

We present prospects for $0\nu\beta\beta$ decay search and solar ν spectroscopy assuming *experimentally informed* expected detector performance for an exposure of 100 ton-year

- **Many opportunities** to improve energy and spatial resolution: thinner dead layer, smarter energy reconstruction, smaller pixel size…

$0\nu\beta\beta$ decay

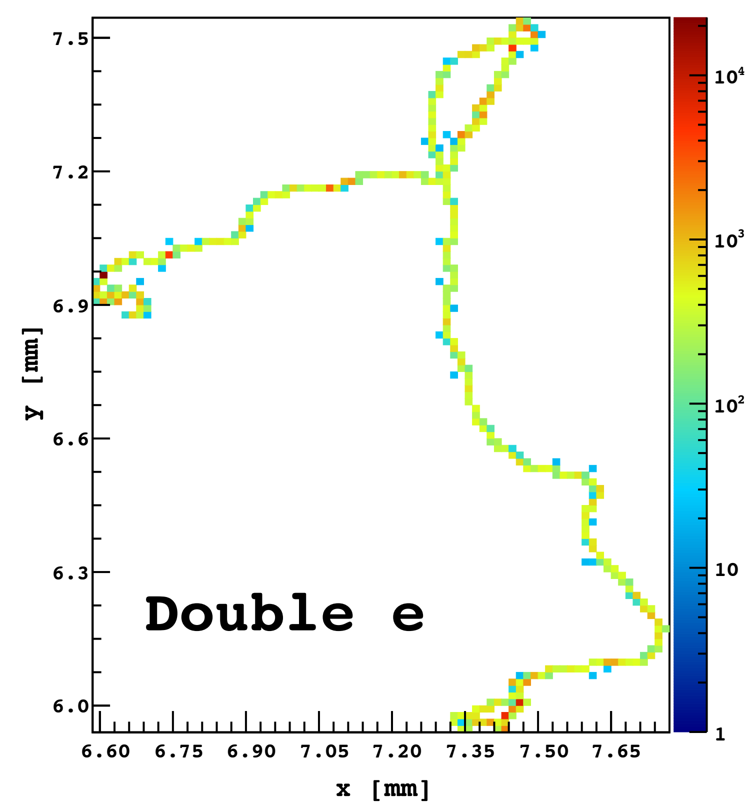
- By identification of Bragg peak we can achieve 10^{-3} suppression of single electron background, with 50% signal acceptance.
- Bulk backgrounds suppressed by α/β particle ID, spatial correlations.

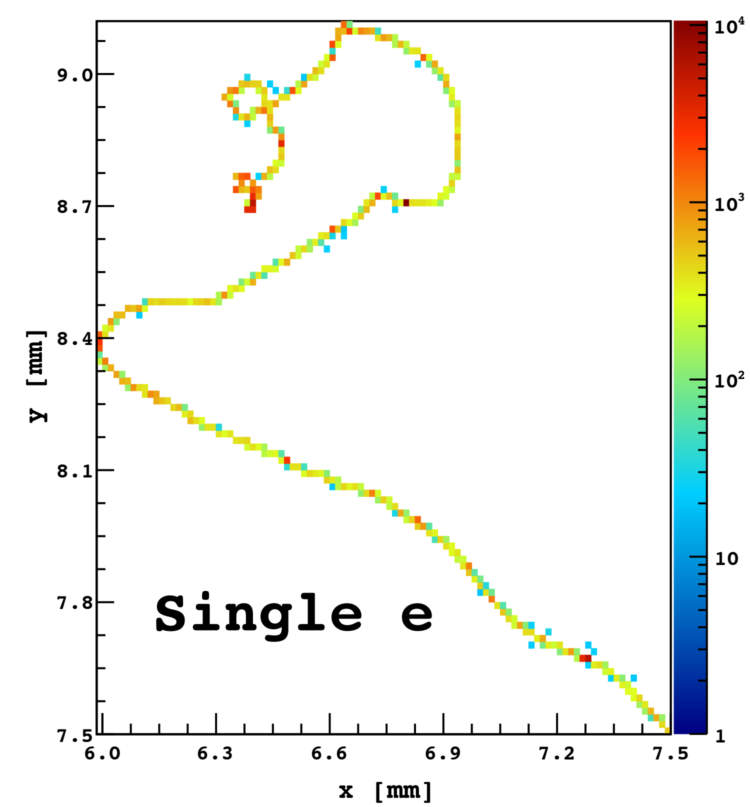


Background rate <6 x 10^{-5} /keV/ton/year!

JINST12(2017)P03022

$T_{1/2}$ > **10^{28} years** limit on ^{82}Se $0\nu\beta\beta$





- Pixel size would need to be improved to (15 μm)^2 and dead layers to ~10 μm.

Solar ν

- Solar νs have been identified as a background for searches for $0\nu\ \beta\beta$ in ^{82}Se.

PHYSICAL REVIEW C **95**, 055501 (2017)

Solar neutrino interactions with the double-β decay nuclei ^{82}Se, ^{100}Mo, and ^{150}Nd

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[1]*Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*

[2]*Los Alamos National Laboratory, Los Alamos, New Mexico, USA*

(Received 8 February 2017; published 2 May 2017)

Solar neutrinos interact within double-beta decay ($\beta\beta$) detectors and contribute to backgrounds for $\beta\beta$ experiments. Background contributions due to solar neutrino interactions with $\beta\beta$ nuclei of ^{82}Se, ^{100}Mo, and ^{150}Nd are evaluated. They are shown to be significant for future high-sensitivity $\beta\beta$ experiments that may search for Majorana neutrino masses in the inverted-hierarchy mass region. The impact of solar neutrino backgrounds and their reduction are discussed for future $\beta\beta$ experiments.

- This is not a problem for our $0\nu\beta\beta$ search because the capture product ^{82}Br is a β emitter, which leads to a decay sequence that we can tag and discard.

Triple sequence:

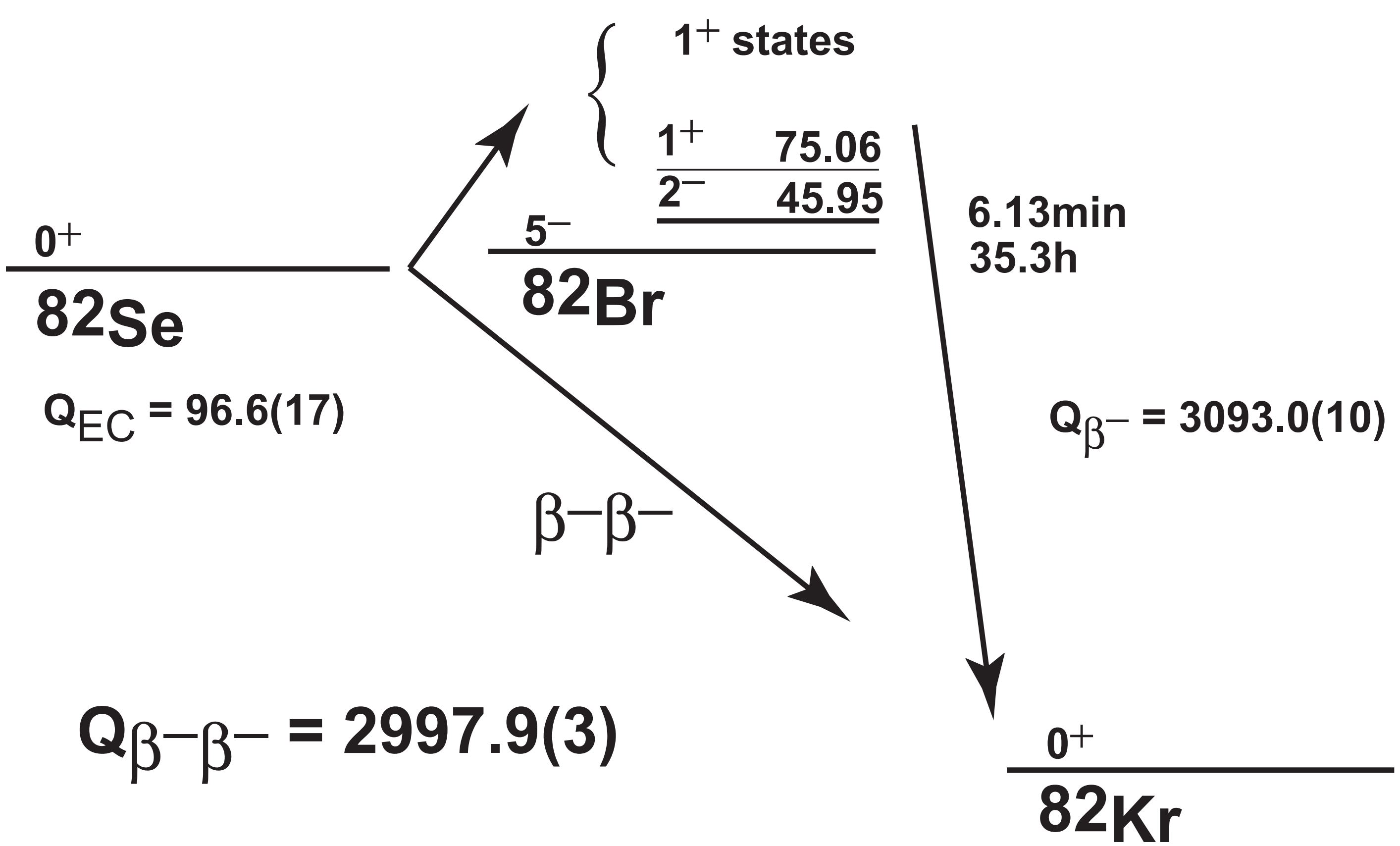
E_ν – 172 keV

$\nu_e + {}^{82}Se \longrightarrow {}^{82}Br^* + e^- +$ C.E. (29 keV) "prompt"

${}^{82}Br^* \longrightarrow {}^{82}Br +$ C.E. (46 keV) $\tau_{1/2}$ = 6.1 min

${}^{82}Br \longrightarrow {}^{82}Kr + \gamma + \beta^-$ $\tau_{1/2}$ = 35 hours

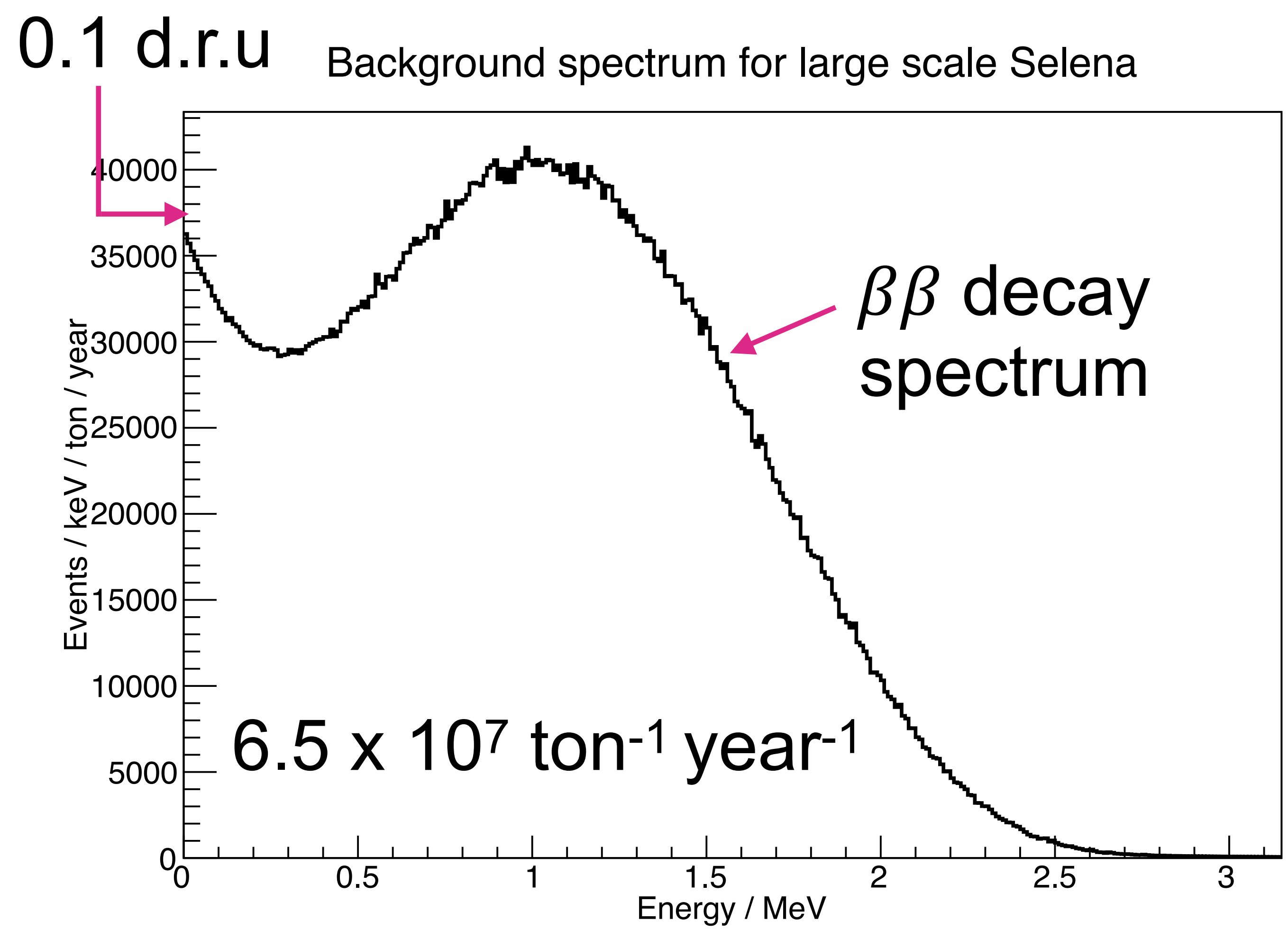
445 keV end-point



We can also use the prompt events to perform solar ν spectroscopy!

Backgrounds

- Expected number of three accidental events in a (100 μm)^2 pixel (22 μg) is **<10^{-4} in 100 ton year**.
- Other α, p, or n reactions that make ^{82}Br* have a different prompt event topology.
- No cosmogenic isotope starts a decay chain that mimics the triple coincidence.



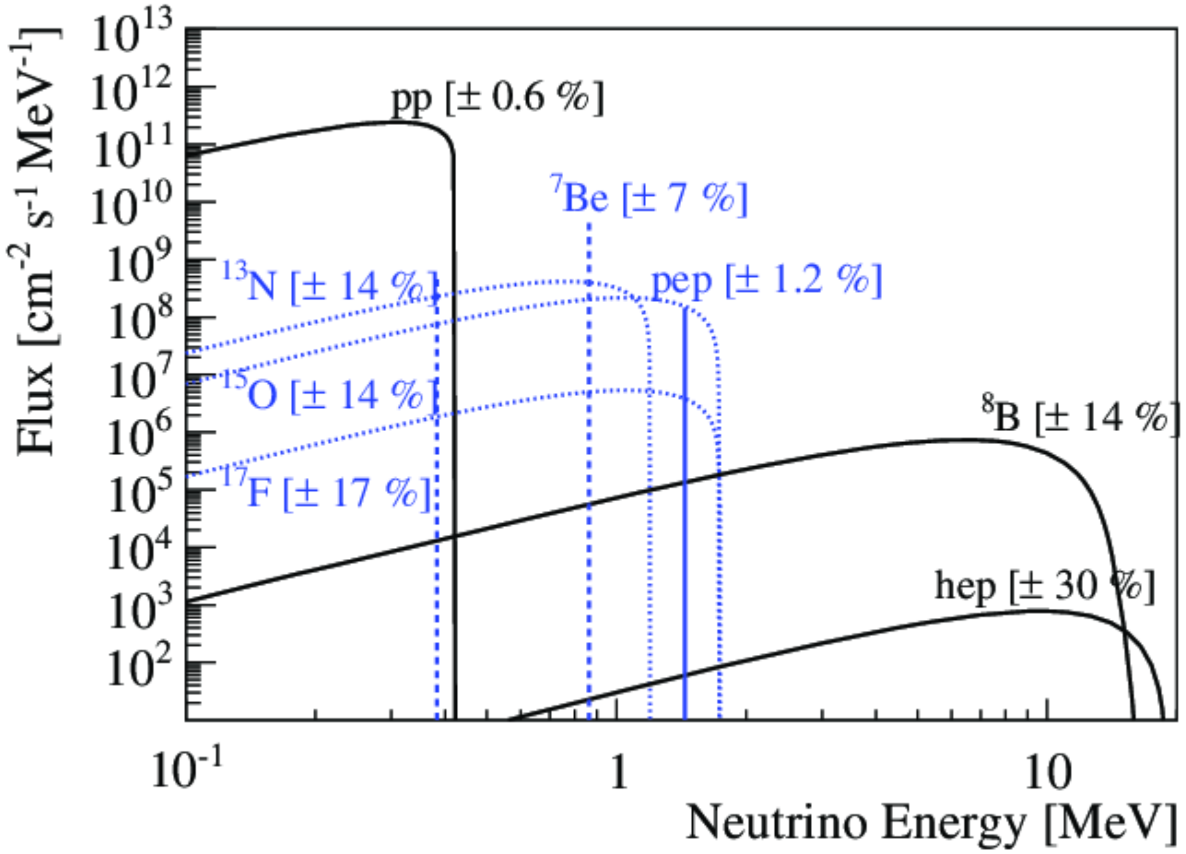
- Some neutron captures on Se isotopes can give triple coincidences but their event topologies are also very different.

No identified background to mimic the triple coincidence.
Possibility of zero background ν spectroscopy!

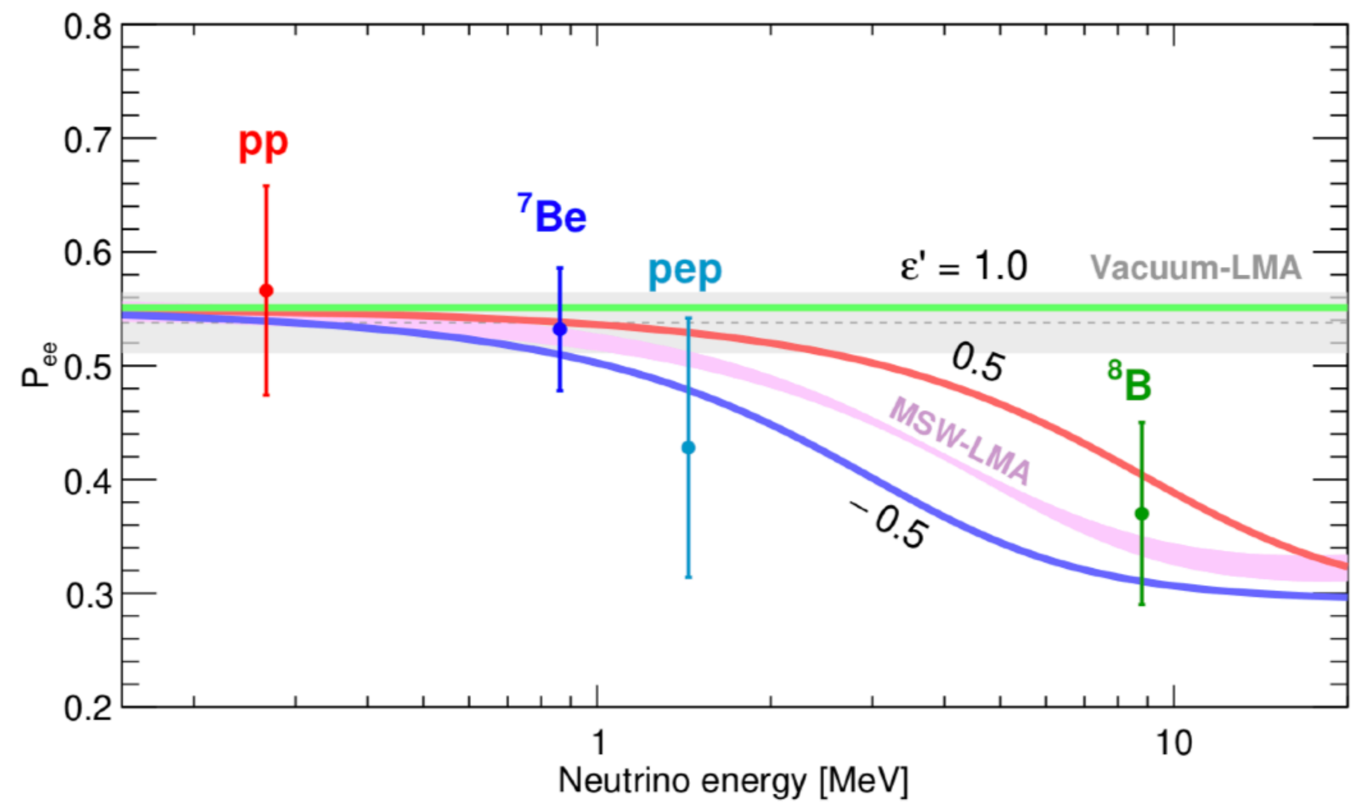
Solar ν measurements

Solar neutrinos

Solar fluxes



Survival probability



- Nuclear reactions in the sun.
- *pp* + CNO cycles.
- Predicted by solar models.

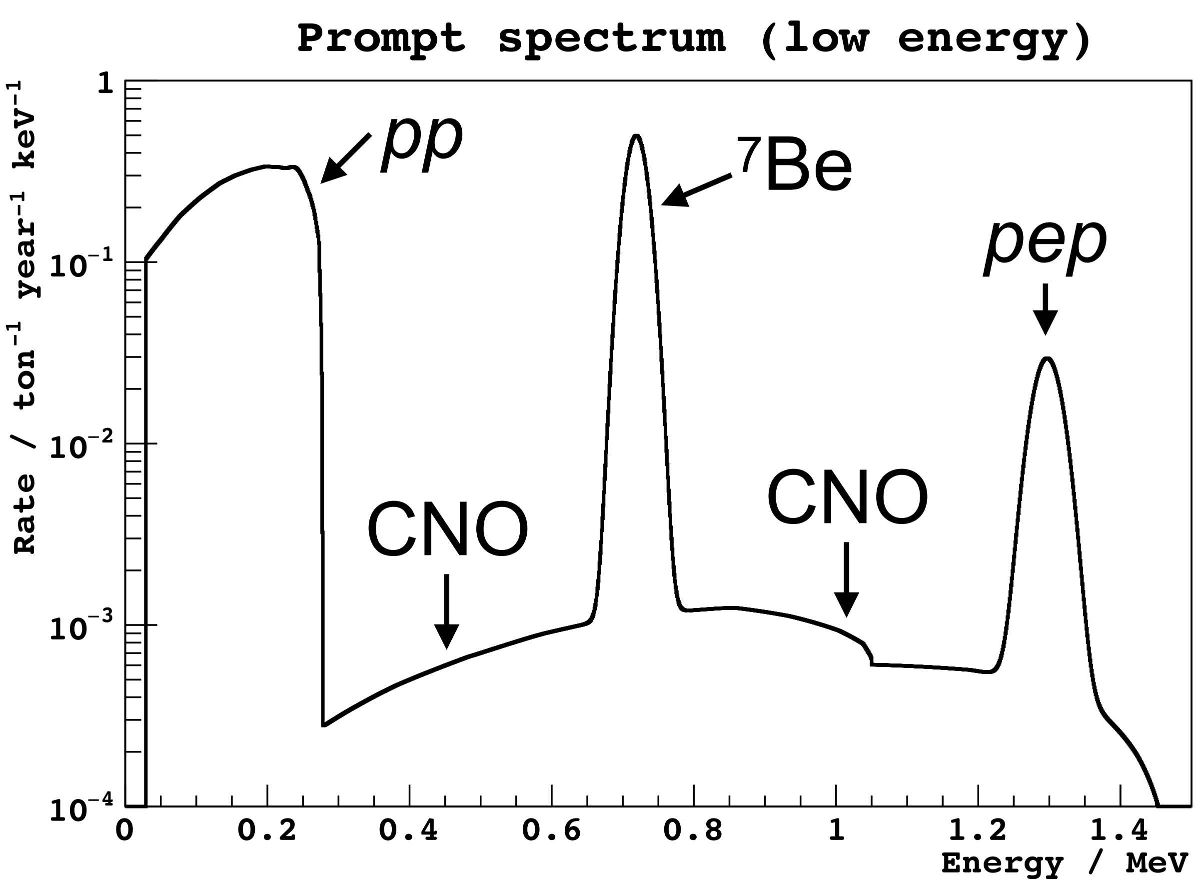
- Vacuum oscillations, matter effects.
- Precise prediction by MSW-LMA (parameters from PMNS matrix).

Prompt spectrum

$$\nu_e + {}^{82}\text{Se} \longrightarrow {}^{82}\text{Br}^* + e^- + \text{C.E. (29 keV)}$$

Capture $\sigma(E)$ from
PRC 94, 014614 (2016)

E_ν – 172 keV



100 ton-year

Species	E range (keV)	N	1/√N
pp	29 - 278	6170	**1.3%**
^{7}Be	665 - 775	1850	**2.3%**
pep	1230 - 1360	151	**8.1%**
CNO	278 - 655 785 - 1220	63	**12.6%**
^{8}B	(1.5 - 15) x 10^3	209	**6.9%**

Solar Physics

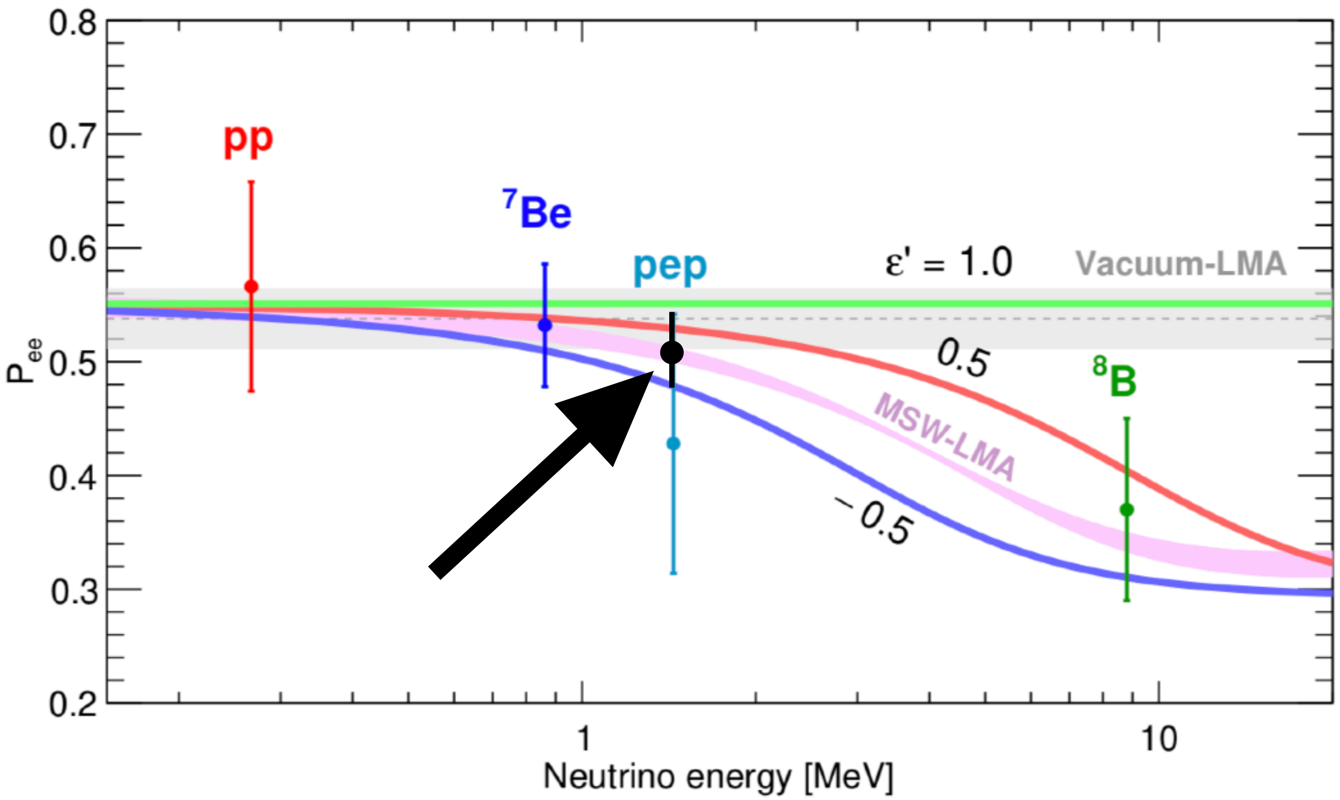
- **Solar luminosity:** *pp* rate unc. improved to **1.3%** (currently ~10% by BX). Flux measurement uncertainty depends on uncertainty on ν_e capture σ. If calibrated to ν-*e* scattering σ by comparing measured ^{7}Be rate with BX, sys. unc. = **3.5%**.
- **Solar metallicity:** CNO flux measured to **13%**. Difference between high- and low-metallicity solar model predictions: **28%**.
- **Solar core temperature:**

PRD 49, 3923 (1994)

Species	RMS width (keV)	Mean unc. (keV)	Line diff. (keV)	Fraction
^{7}Be	14.8	0.34	1.29	26%
pep	19.8	1.60	7.59	21%

Neutrino physics

- **Onset of matter effects in ν oscillations:** *pep/pp* rate ratio measured to **8%**. Flux ratio very well predicted by SSM, MSW effect should suppress *pep* ν_e flux by **7%**. NSI could increase this.



Sensitive probe for neutrino transport in the Sun

Conclusion

- A large Selena detector has the potential for *background-free* search for $0\nu\beta\beta$ decay and solar ν spectroscopy.
- Could place a limit on **$T_{1/2}$ > 10^{28} years** on ^{82}Se $0\nu\beta\beta$ ($m_{\beta\beta}$ < 10 meV).
- Measure basic properties of the Sun to validate our solar / stellar models.
- We already *fabricated and operated* **the lowest noise single-pixel aSe sensor** ever!
- We *demonstrated* that aSe can be coupled to a CMOS pixel array to **image electron tracks**!
- Our R&D program continues to characterize and optimize the CMOS/aSe sensor toward a large-area module for Selena.

Thank you!

- University of **Washington**: Alvaro E. Chavarria, Alex Piers, Harry Ni.
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- **Hologic** Coporation: Brad Polischuk, Snezana Bogdanovich.

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