Updated measurements of ^{32}Si and ^{208}Pb background rates in DAMIC CCDs

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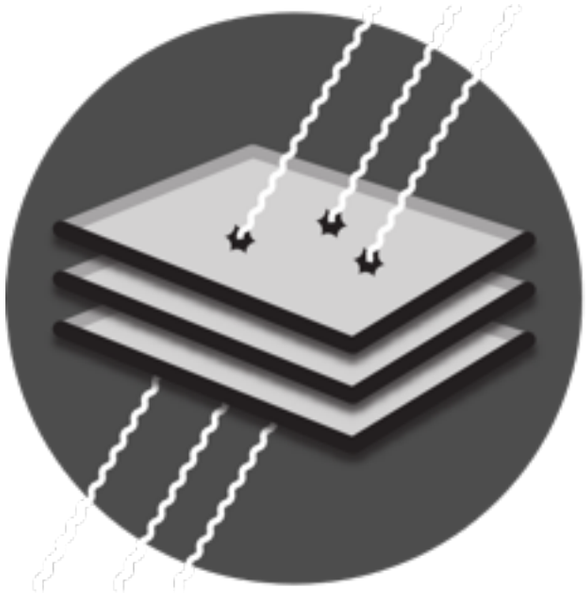

DAMIC
DARK MATTER
IN CCDS

DAMIC-M kickoff meeting
Paris
2018 Jun 12

ENRICO FERMI INSTITUTE

Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

Understanding of backgrounds is pretty important

- Several review articles have been written on the subject of background mitigation [1,2]

- Without an understanding of backgrounds, a DM experiment absolutely cannot claim a discovery

- The CCD technology in DAMIC presents unique opportunities in background measurement and rejection

LOW-RADIOACTIVITY
BACKGROUND TECHNIQUES

G. Heusser

BACKGROUNDS TO SENSITIVE EXPERIMENTS
UNDERGROUND

Joseph A. Formaggio[1] and C.J. Martoff[2]

[1] G. Heusser, Annu. Rev. Nucl. Part. Sci 45 (1995)
[2] J.A. Formaggio & C.J. Martoff, Rev. Nucl. Part. Sci 54 (2004)

Previous effort within DAMIC

- Earlier measurement by DAMIC in 2015 [1]
- Established stringent limits on U/Th bulk contamination, 208Pb, and 32Si
- Used 85.5 live days of data and a mixture of 500 um and 675 um thick CCDs

JINST

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Measurement of radioactive contamination in the high-resistivity silicon CCDs of the DAMIC experiment

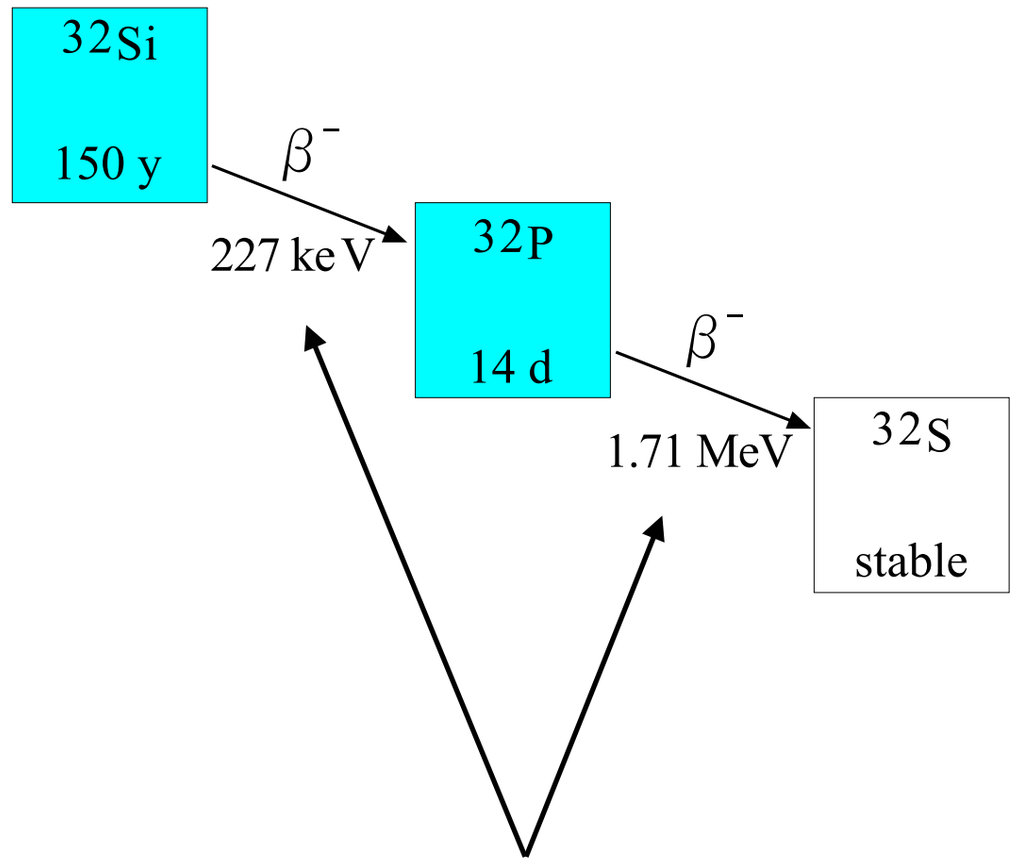
The DAMIC collaboration

DAMIC DARK MATTER IN CCDS

[1] A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562

^{32}Si contamination

- ^{32}Si is produced in cosmic ray interactions with ^{40}Ar in the atmosphere; falls to earth in precipitation
  - Isotope enrichment can be difficult and expensive
  - Even with enriched silicon, would need an understanding of the remaining ^{32}Si abundance
- Decay sequence from ^{32}Si can be exploited with CCDs to search for decays
- Understanding efficiency of our search, we can back out an abundance for ^{32}Si



Expect spatially coincident β^- pair in separate images

DAMIC DARK MATTER IN CCDS

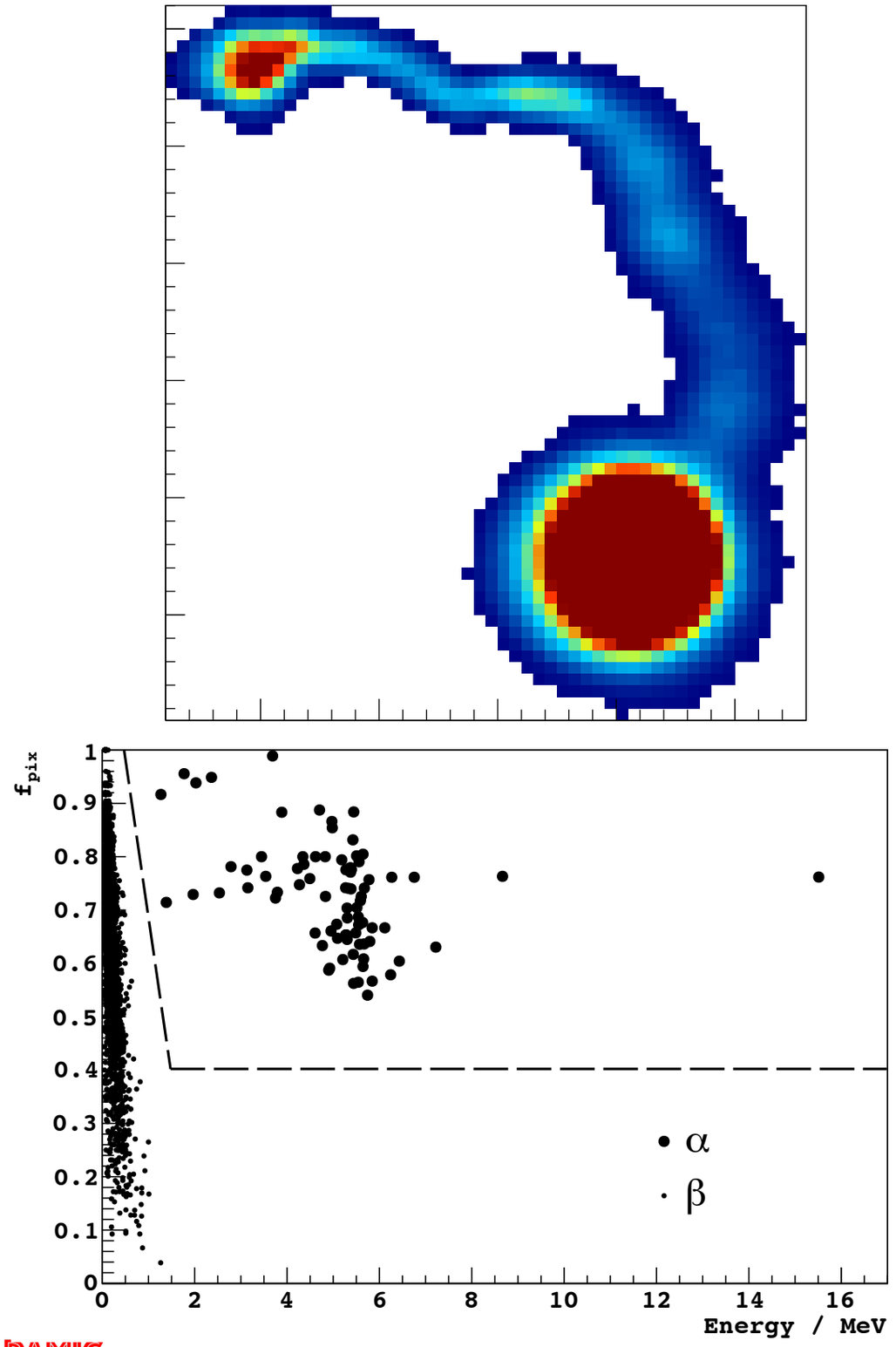
[1] A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562

α/β selection

- Alphas and betas show very different track characteristics in the CCD [1]

- Metric “fpix” can be used to discriminate with reasonable effectiveness

  - Size of smallest box that fully contains event



DAMIC DARK MATTER IN CCDS

[1] A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562
Figures from [1]

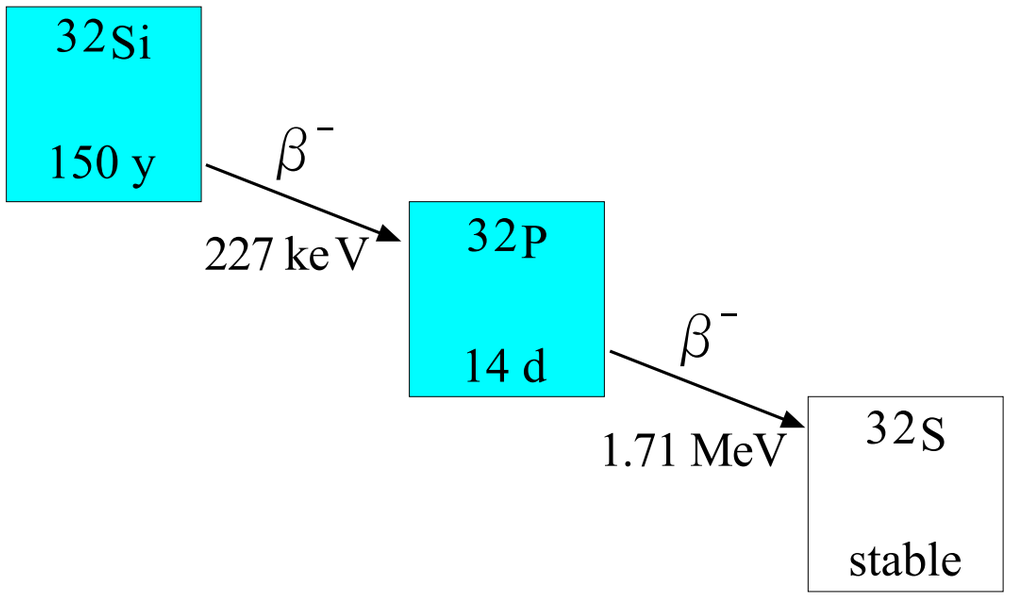
Search for 32Si decay sequences

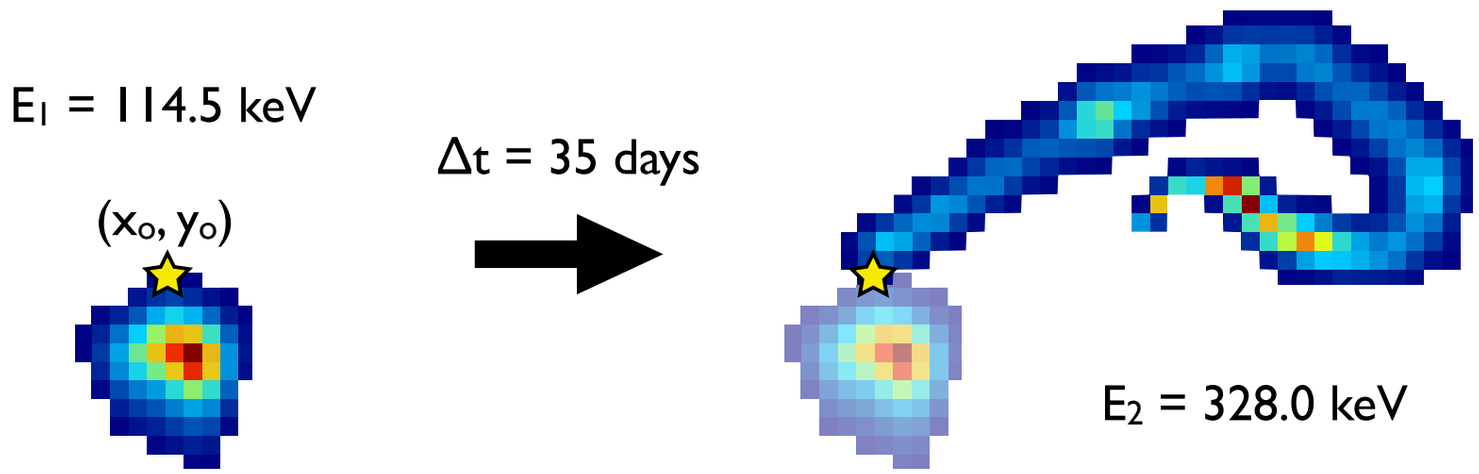
- Perform two search types using cluster data

    1. Parent-decay energy [70, 230 keV]; separation of events < 70 days
    2. Parent-decay energy < 70 keV; separation of events (25, 70 days)

- Require all clusters to be *not* alpha-like

- Calculate time-cut efficiency with toy MC

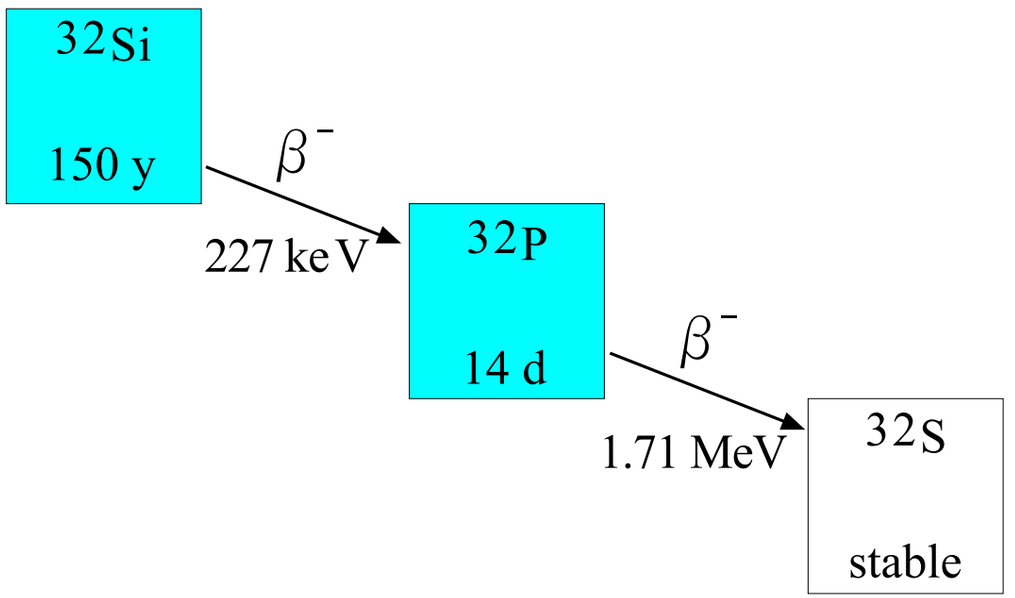


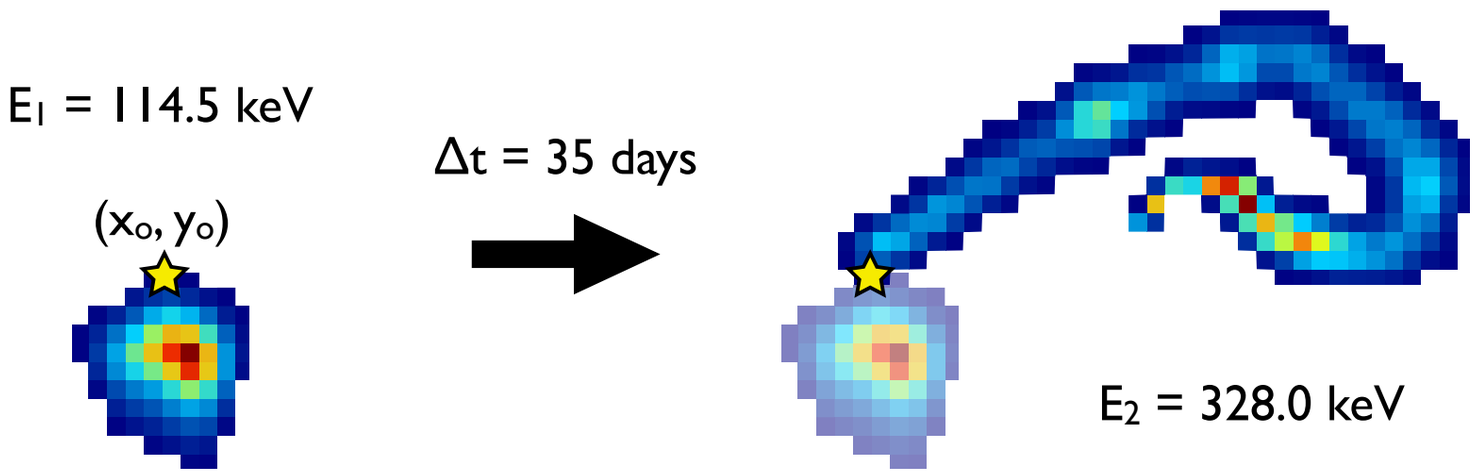


From A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562

Search for 32Si decay sequences

- Results from search types
  1. 22, expect 6.2 accidental events
  2. 11, expect 3.5 accidental events
- Translated into decay rates
  1. 9.2 ± 2.8 /kg/day
  2. 14.4 ± 6.4 /kg/day
- Weighted average of searches gives 10.0 ± 2.5 /kg/day
- Previous result: 80 (+110, -65) /kg/day [1]

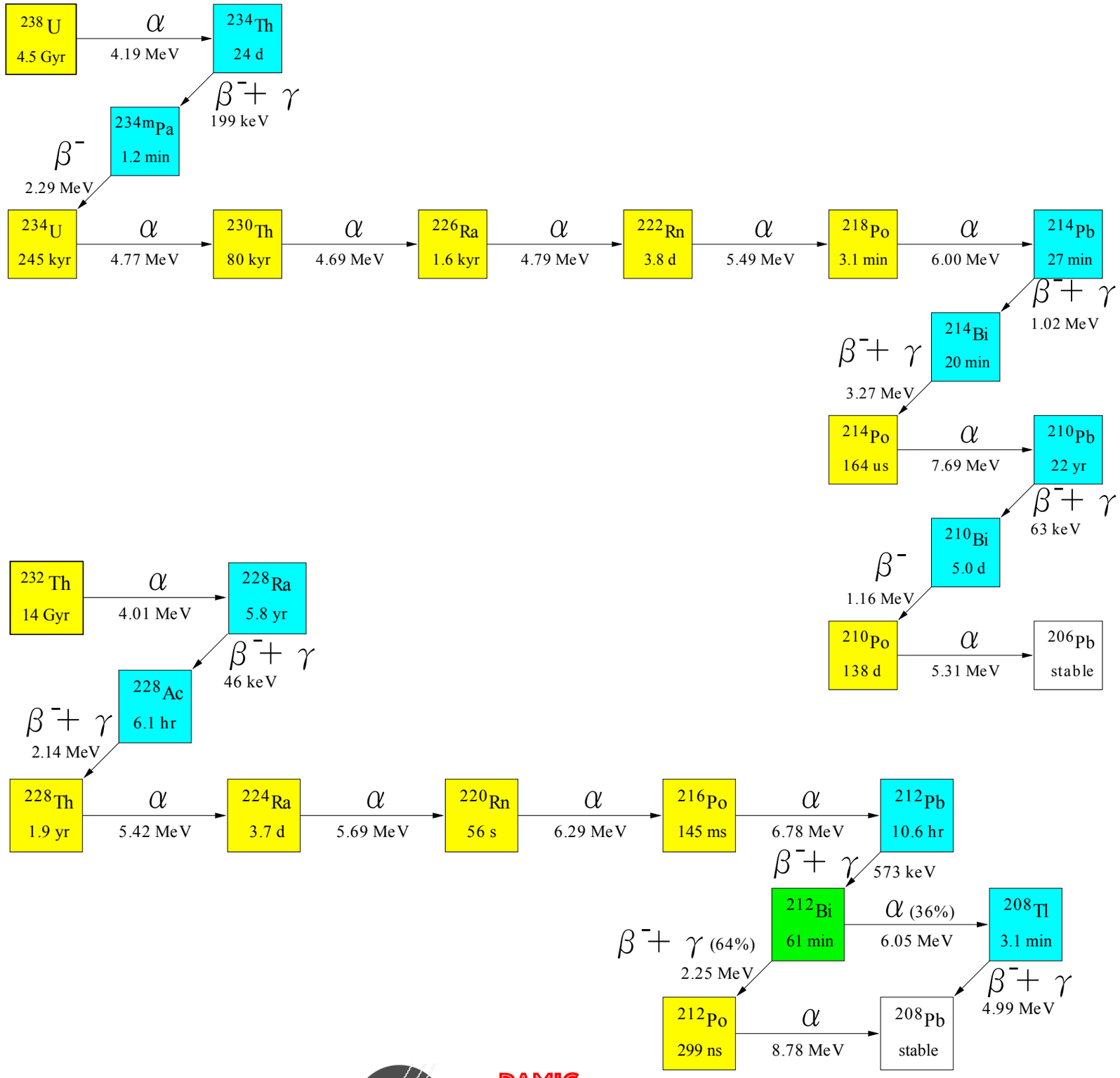




From [1]

[1] A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562

U and Th decay chains

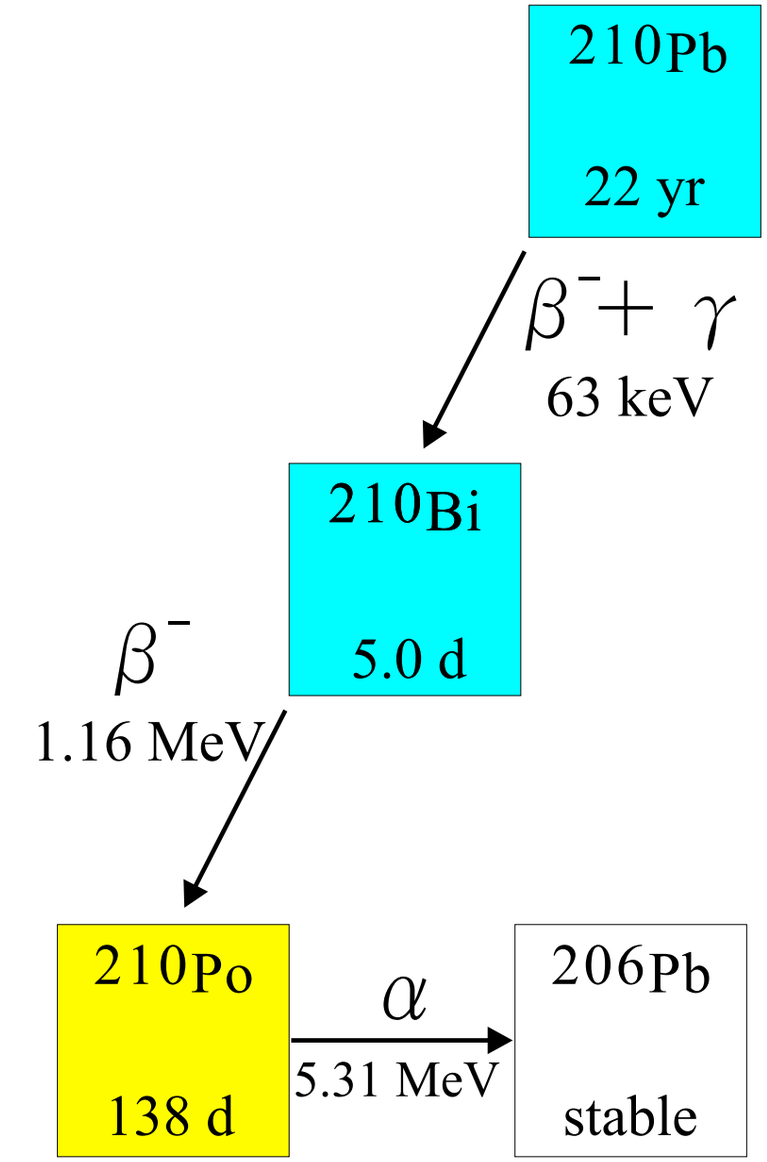


DAMIC DARK MATTER IN CCDS

[1] A. Aguilar-Arevalo *et al.*, J. Inst 10 (2015) arXiv:1506.02562
Figure adapted from [1]

^{208}Pb decays

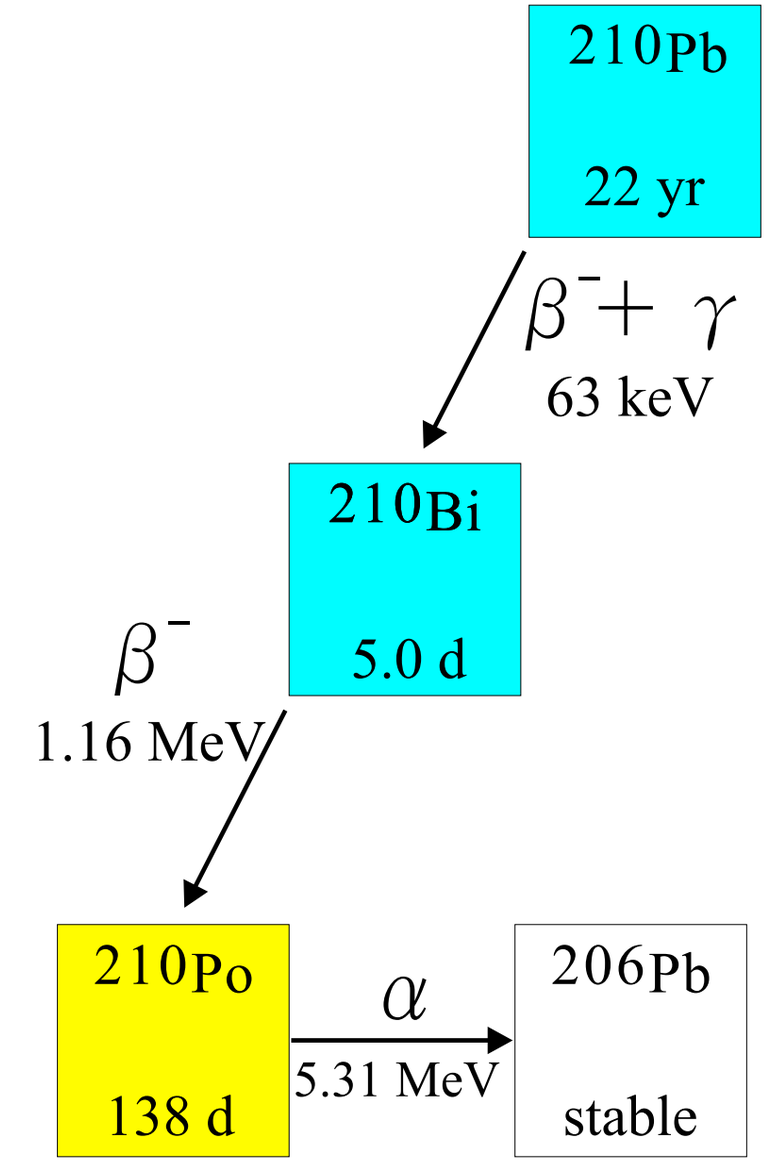
- 210Pb is a radon daughter (part of 238U chain)
  - May reasonably expect it to be a surface contaminant
- As with ^{32}Si, can search for spatially correlated series of events
  - Should observe some combination of the two β and the α
  - Can perform search in different ways (looking for two betas, beta-alpha, or all 3 events)
- Need to account for possibility of ^{32}Si decay sequence mimicking β-β observation from 210Pb



DAMIC DARK MATTER IN CCDS

^{208}Pb decays

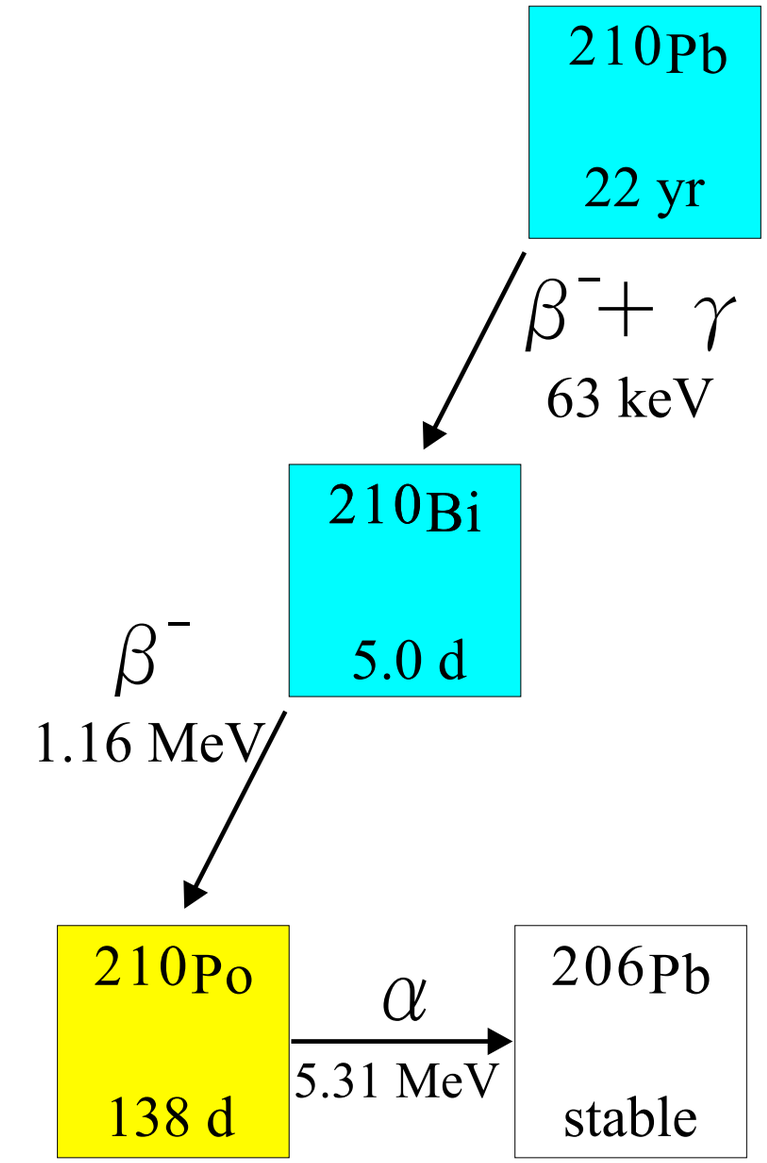
- Again determine time selection efficiency from toy MC
  - β-β: 0.788
  - β1-α: 0.242
  - β2-α: 0.242
  - β1-β2-α: 0.2198
- Can use results from ^{32}Si search to determine the accidental contribution of ^{32}Si-related βs in the ^{208}Pb sample
  - Expect 17.2 leakage events in β-β search



DAMIC DARK MATTER IN CCDS

^{208}Pb decays

- Number of decays inferred from beta-beta search
  - 551
- Number inferred from beta-alpha
  - 594
- Search methods in reasonable agreement (uncertainties to be finalized)
- Rate per unit area: 7.7e-3 /cm2/day
- Previous rate(s)
  - 0.012 +/- 0.004 (back)
  - 0.078 +/- 0.010 (front)



DAMIC DARK MATTER IN CCDS

Alpha event characteristics

- Beyond discriminating betas from alphas, can further subdivide alpha events

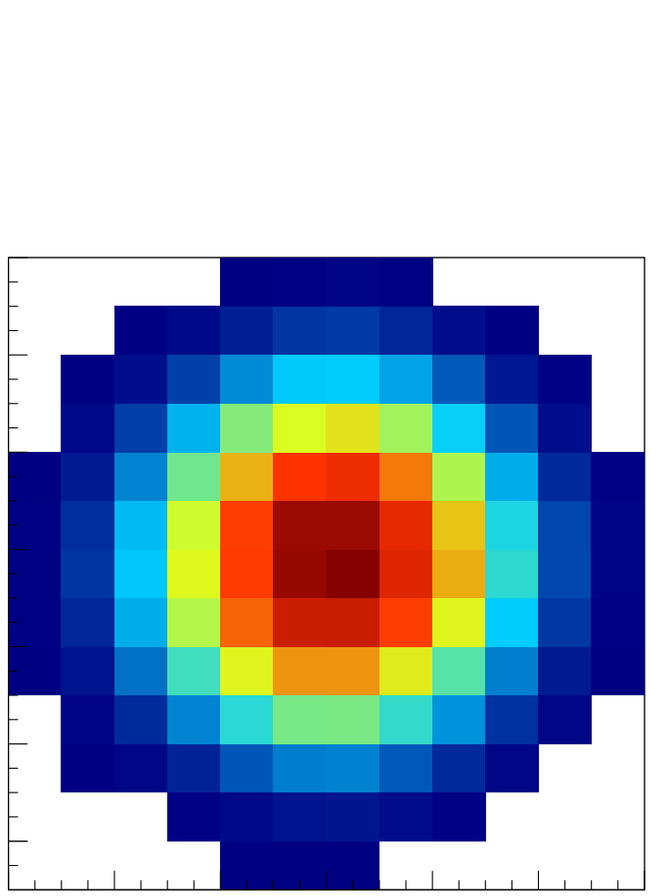
- Possible to separate those occurring on front vs back surfaces

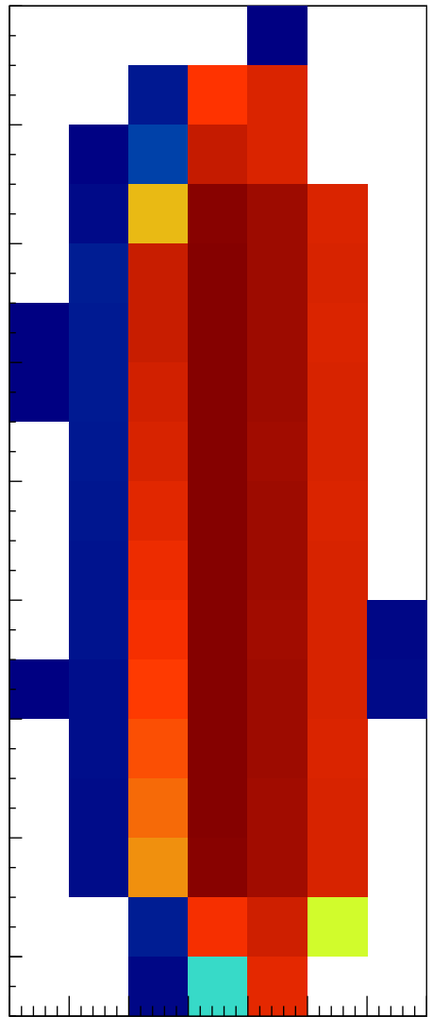
  - Plasma alphas (L) originate in bulk or on back surface of CCD

  - “Bloomed” events (R) originate on front surface

- Front vs back events have *slightly* different efficiencies (not currently accounted for)

- Can divide population and determine front vs back rate as done in [1]





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Limits of U and Th bulk contaminants

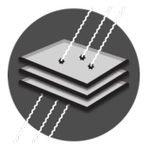
- Characteristic sequences of decays can identify presence of U and Th in bulk silicon

- *Absence* of these sequences are informative too

  - Absence of ~18 MeV, alpha-like signals: upper limit of 0.4 /kg/day for 232Th

  - Absence of plasma alpha followed by beta: upper limit of 0.6 /kg/day for 238U

- These limits appear consistent with [1]



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Conclusions

- Spatial resolution of CCDs allows awesome feats of background rejection using “coincidences” with time scales on the order of months
- Bulk U/Th contaminants extremely low - ppt level
- ^{32}Si rate is factor of 10 lower than earlier measurements
  - Great news! But… does it suggest variability from boule to boule?
  - All of this information is of interest for SuperCDMS
- ^{208}Pb rate is well understood
- CCDs provide information-rich datasets that we can continue to explore for additional cross checks or handles on backgrounds

Much credit goes to Paolo and Ariel Matalon (UofC grad student)