Background in the Dark Matter Experiment DEAP-3600

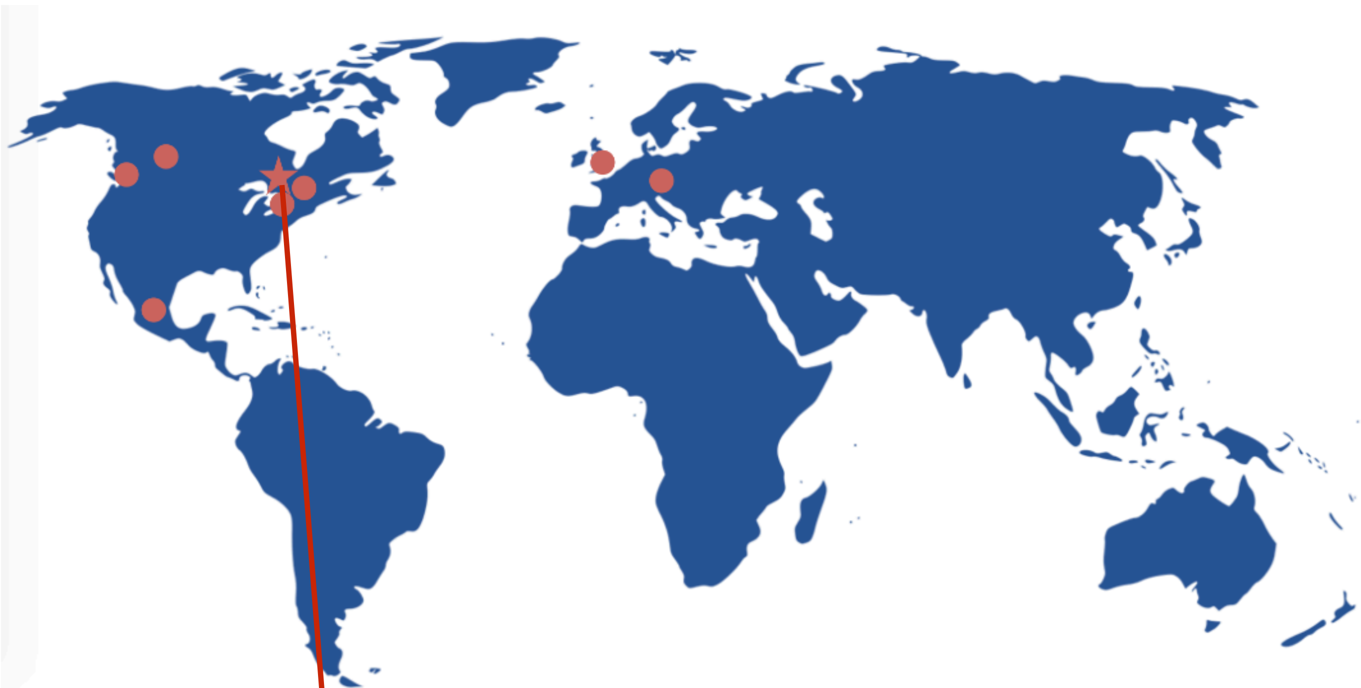
Björn Lehnert

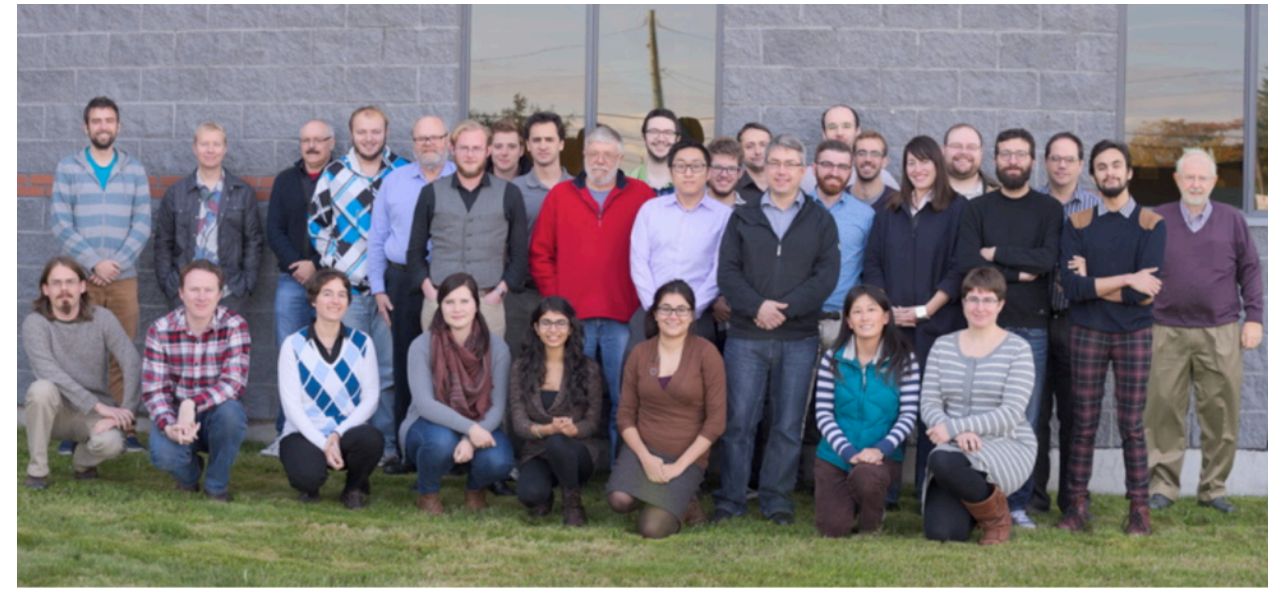
on behalf of the DEAP-3600 Collaboration

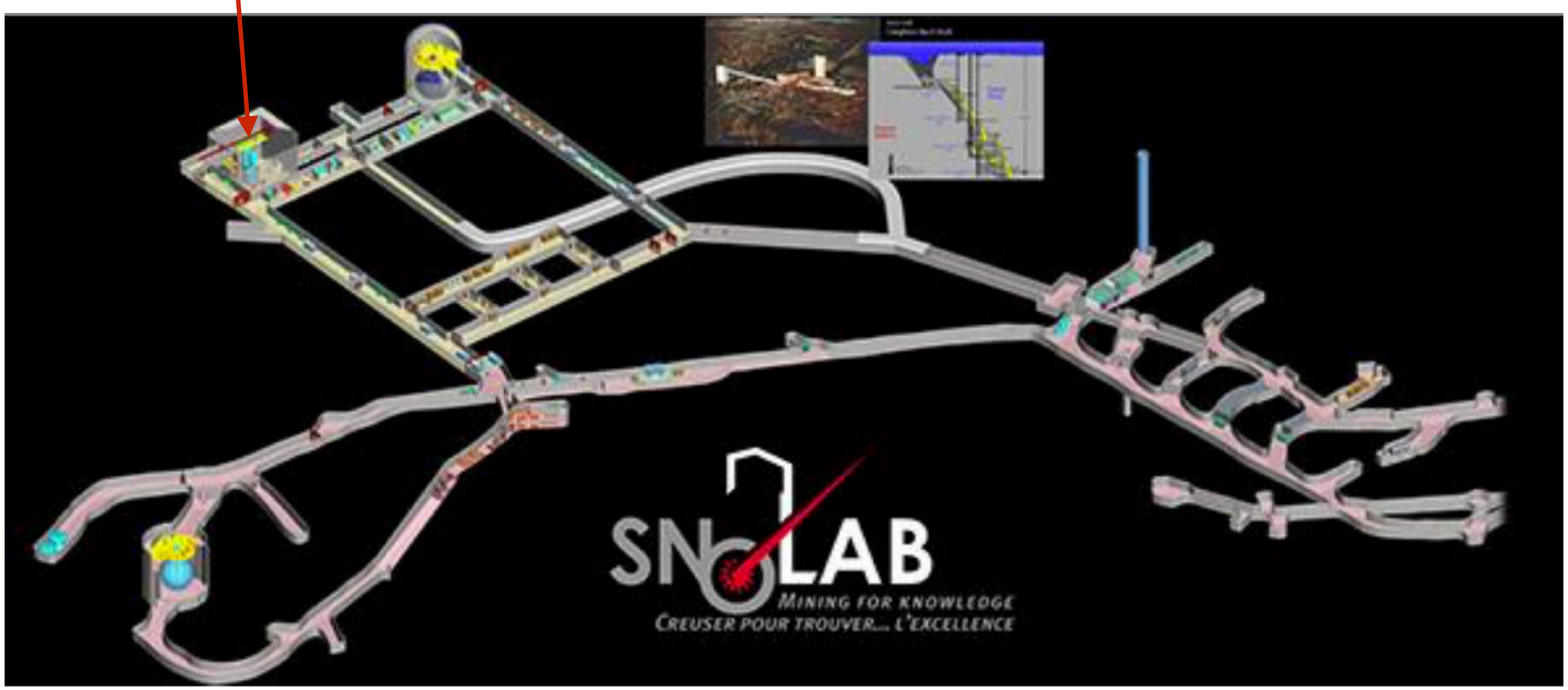
Carleton University

CAP Conference
Kingston 01/06/17

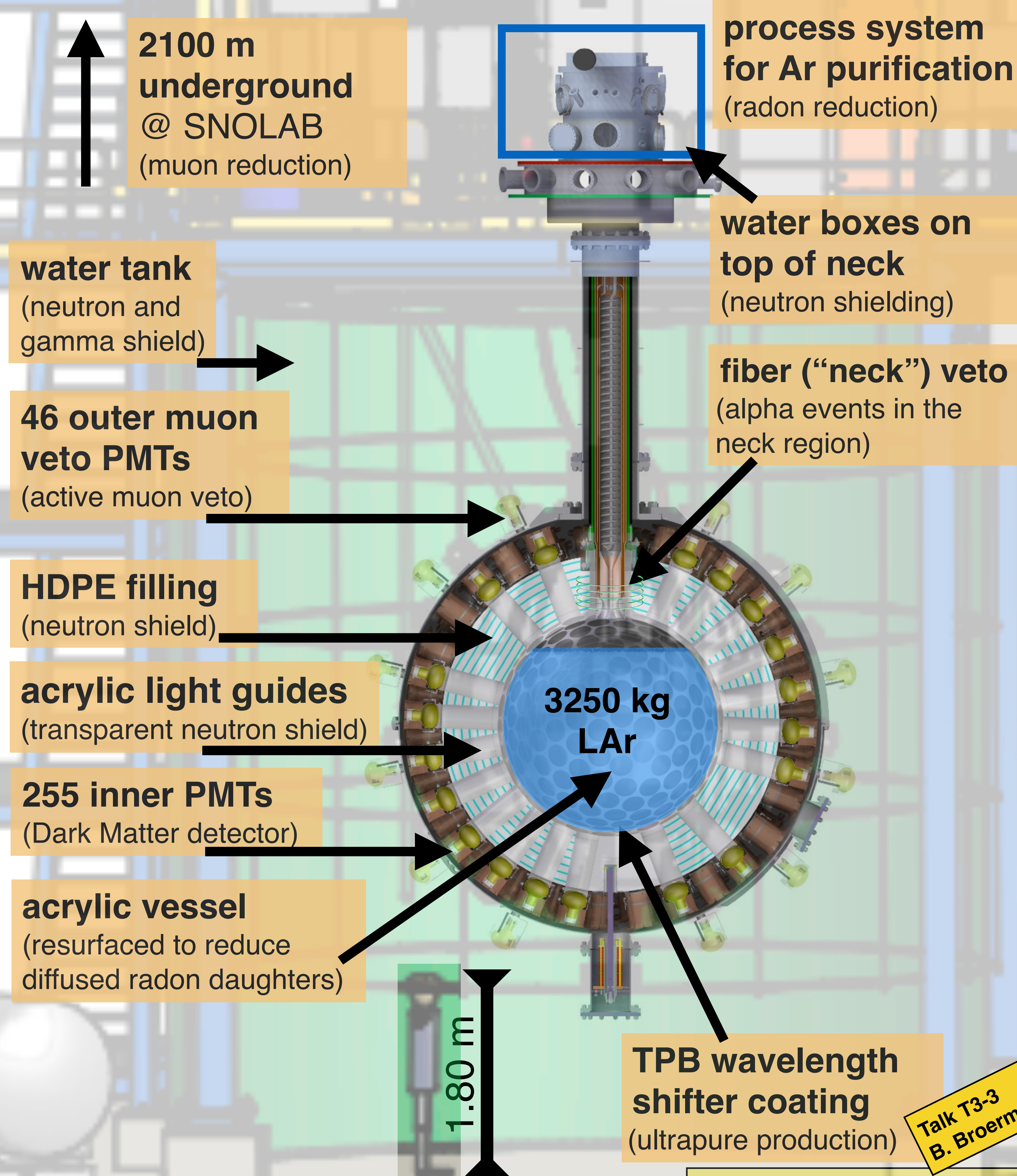
DEAP-3600







- 75 members
- Canada, UK, Mexico, Germany
- Stable running since November 2016



DEAP-3600

IPP talk M. Boulay

- **Single phase** liquid argon (**LAr**) target (new concept)
- Detection of **scintillation** light

- Low background experiment
- Goal: **< 1 background event** in 3000 kg x yr fiducial exposure

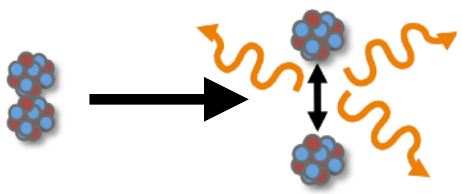
- Sensitivity for spin-independent WIMP-nucleon cross-selection: **10^{-46} cm^2 (@100 GeV)**

Hardware design concepts for background mitigation:

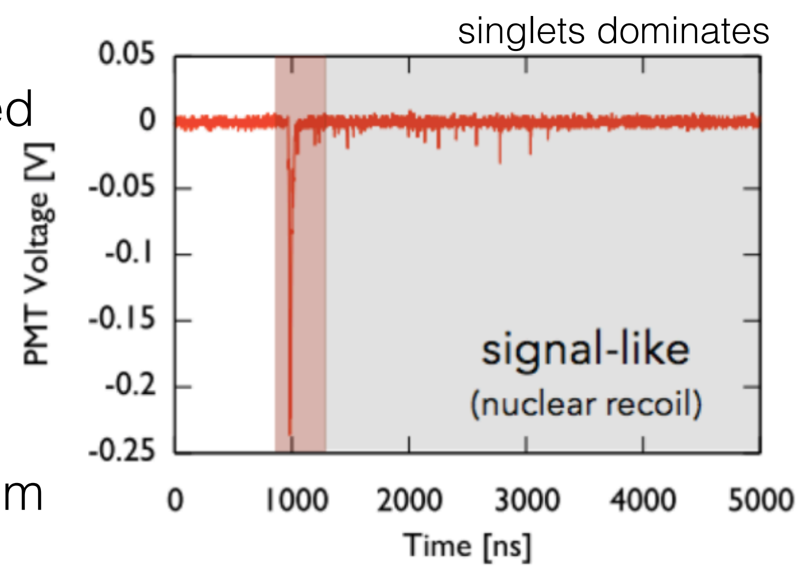
- Deep underground
- Active muon veto
- Onion-layer passive shielding
- Resurfacing of acrylic vessel to remove diffused radon
- Neutrons from PMTs shielded by long transparent acrylic light guides

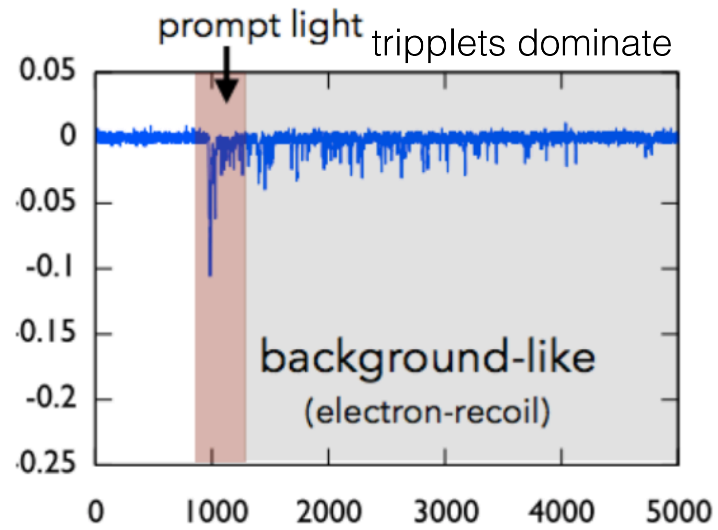
Experimental Signatures

Ar scintillation:
- excimers are created



- singlet: 6 ns
- tripplet: 1500 ns
- wavelength: 128 nm



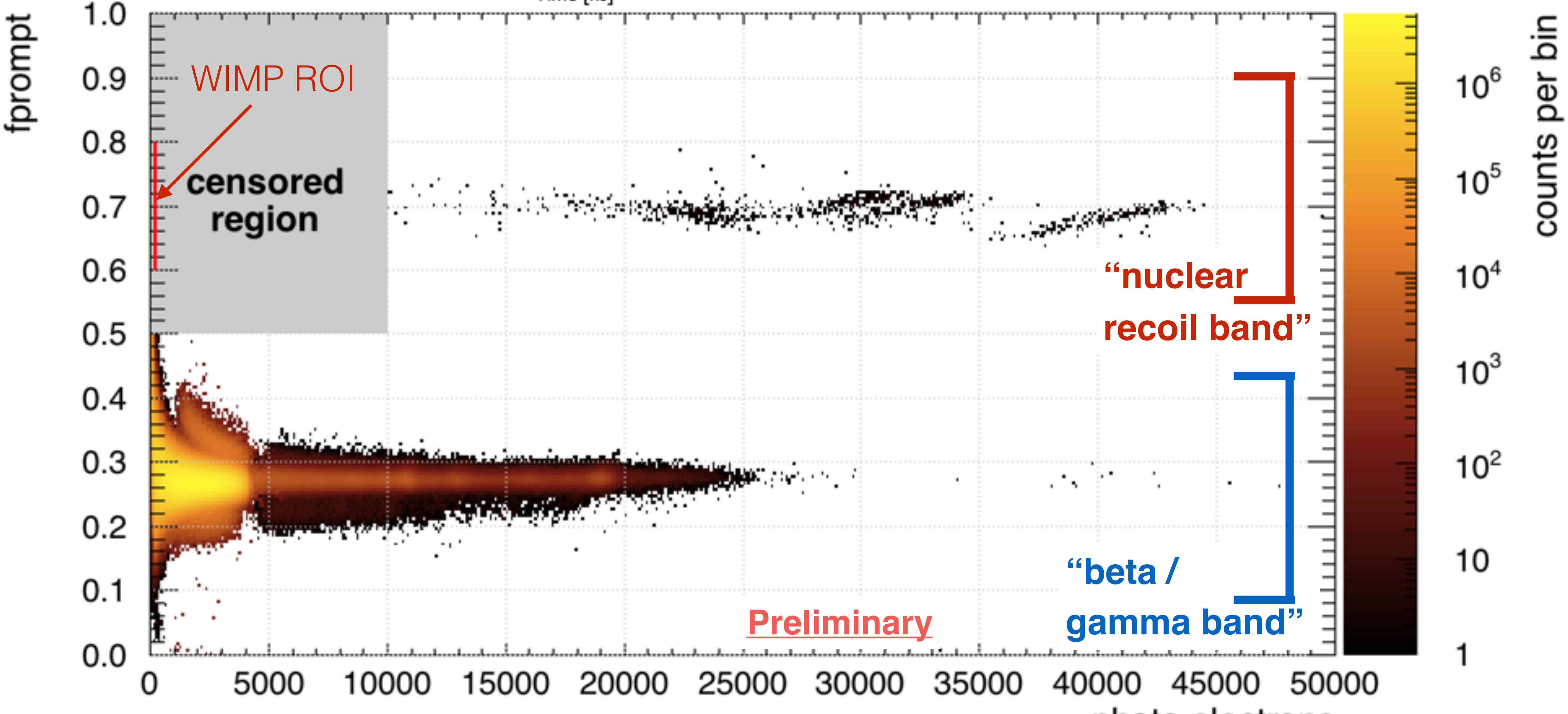


Pulse shape discrimination (PSD) parameter:

fprompt =

$$\frac{\textbf{prompt light (150 ns)}}{\textbf{total light (10000 ns)}}$$

factor 10^{10} separation



DEAP 3600 commissioning data

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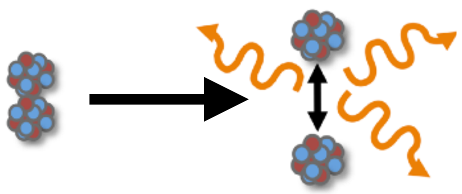

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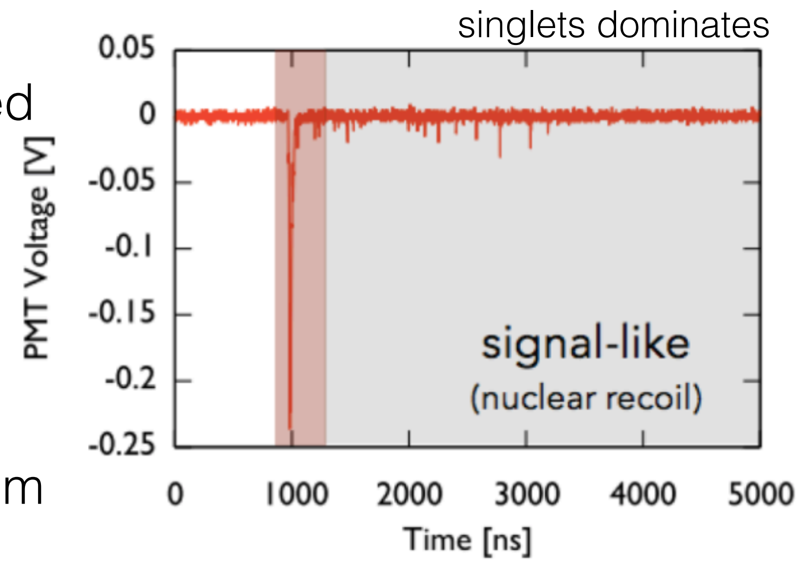

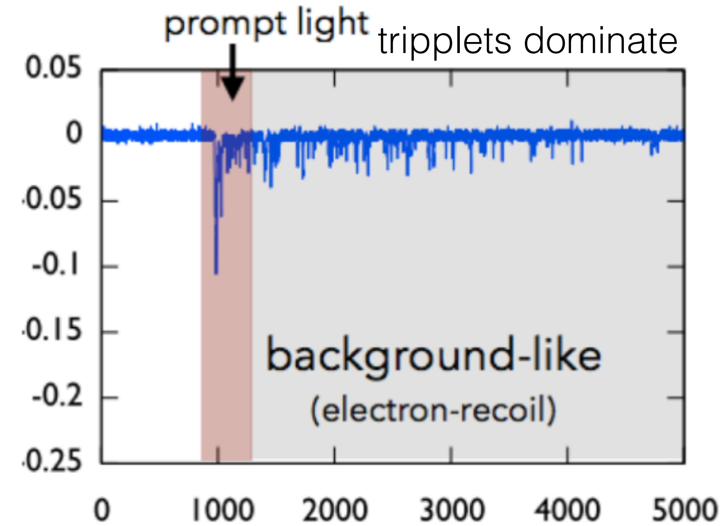

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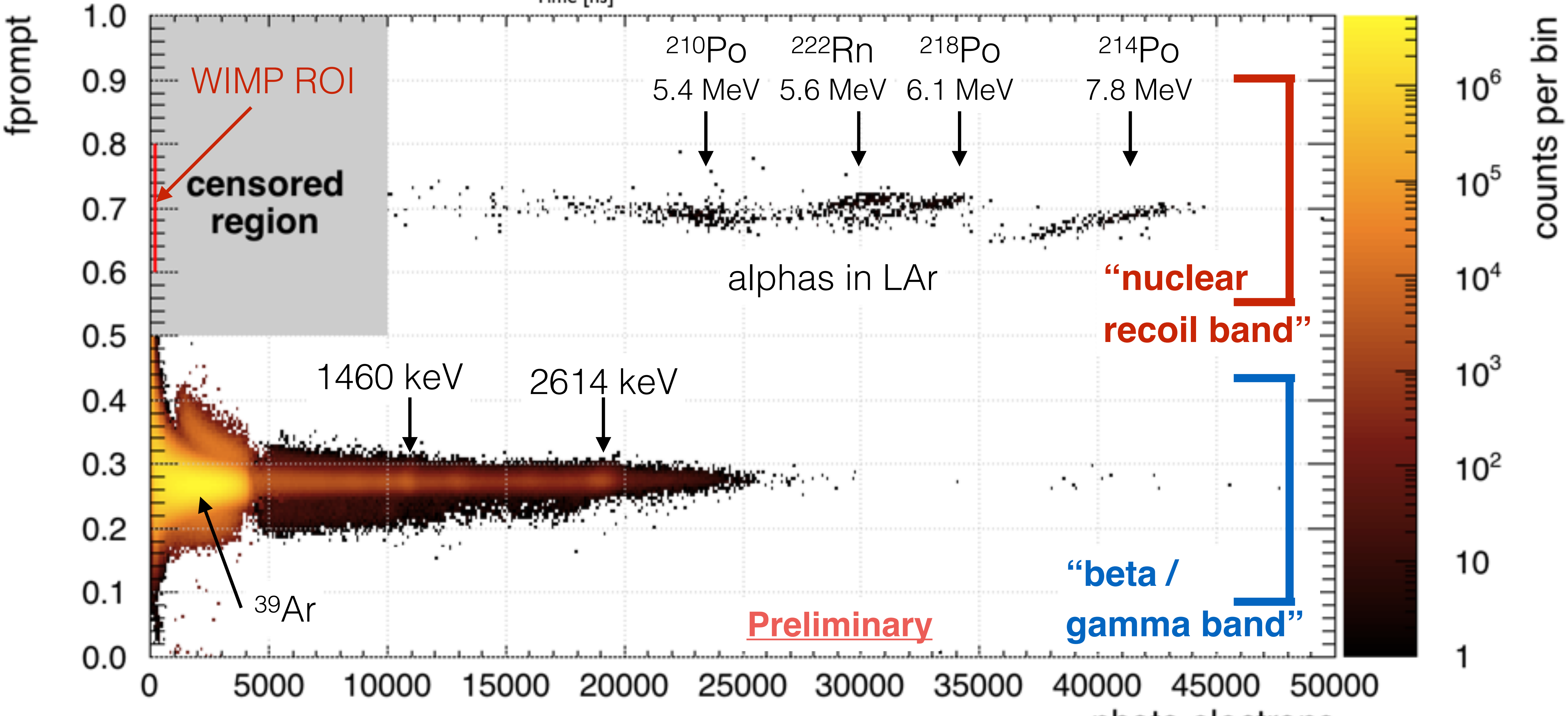


DEAP 3600 commissioning data

Major Backgrounds In WIMP Region of Interest

Potential background sources:

- Alphas: Energy degraded or shadowed
- Recoil of nuclei in alpha decays
- PSD leakage from ^{39}Ar and ER background
- Neutron interactions
- Other light sources in the detector

Talk W3-5 S. Westerdale

Talk W3-5 C. Moore

Poster Pos-37 A. Erlandson

Talk R2-3 R. Stainforth

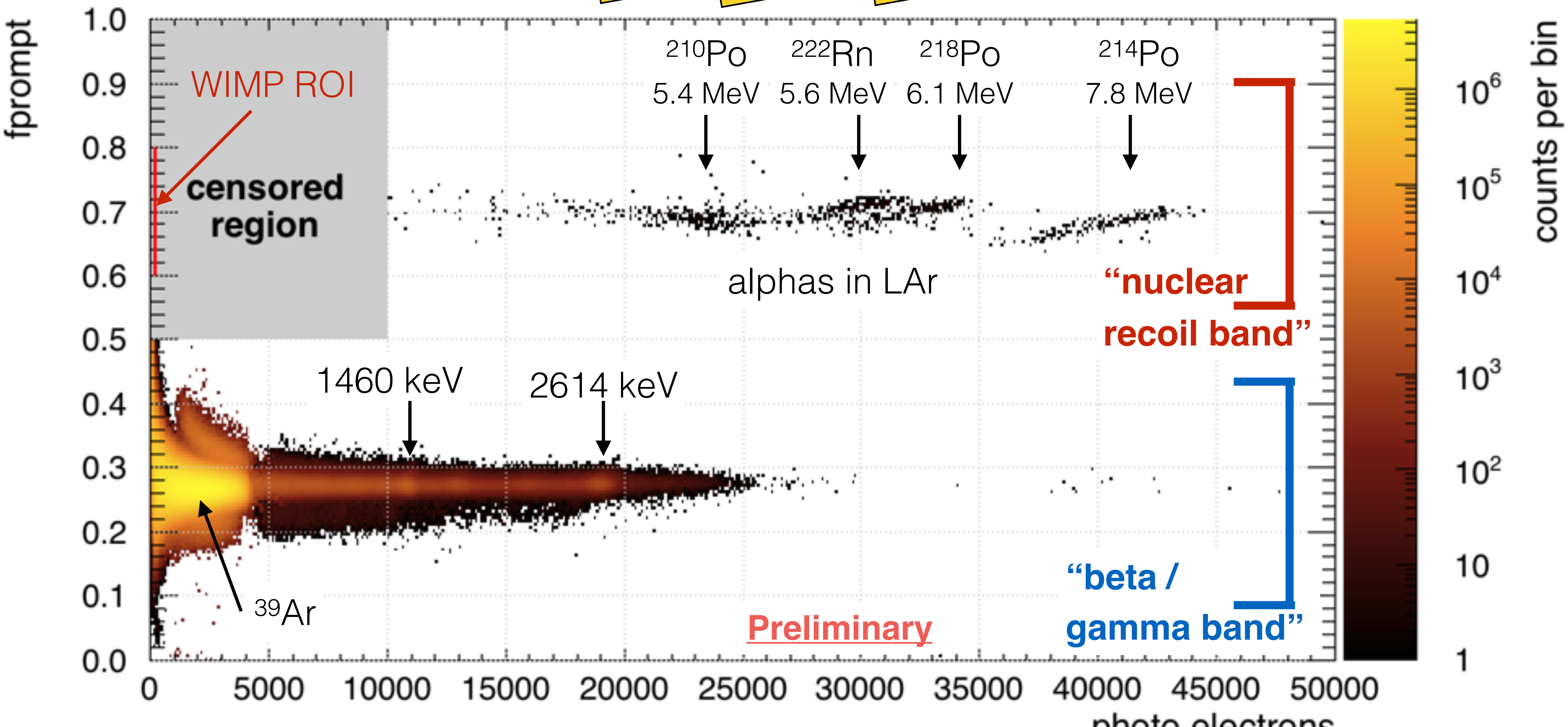
≈ 120 - 240 photo electrons

≈ 16 - 32 keVee (electron equivalent)

≈ 60 - 120 keVr (recoil)

Design goals:

background component	alphas	neutrons	^{39}Ar
event in ROI	0.2	0.2	0.2



DEAP 3600 commissioning data

Alpha Background Topologies

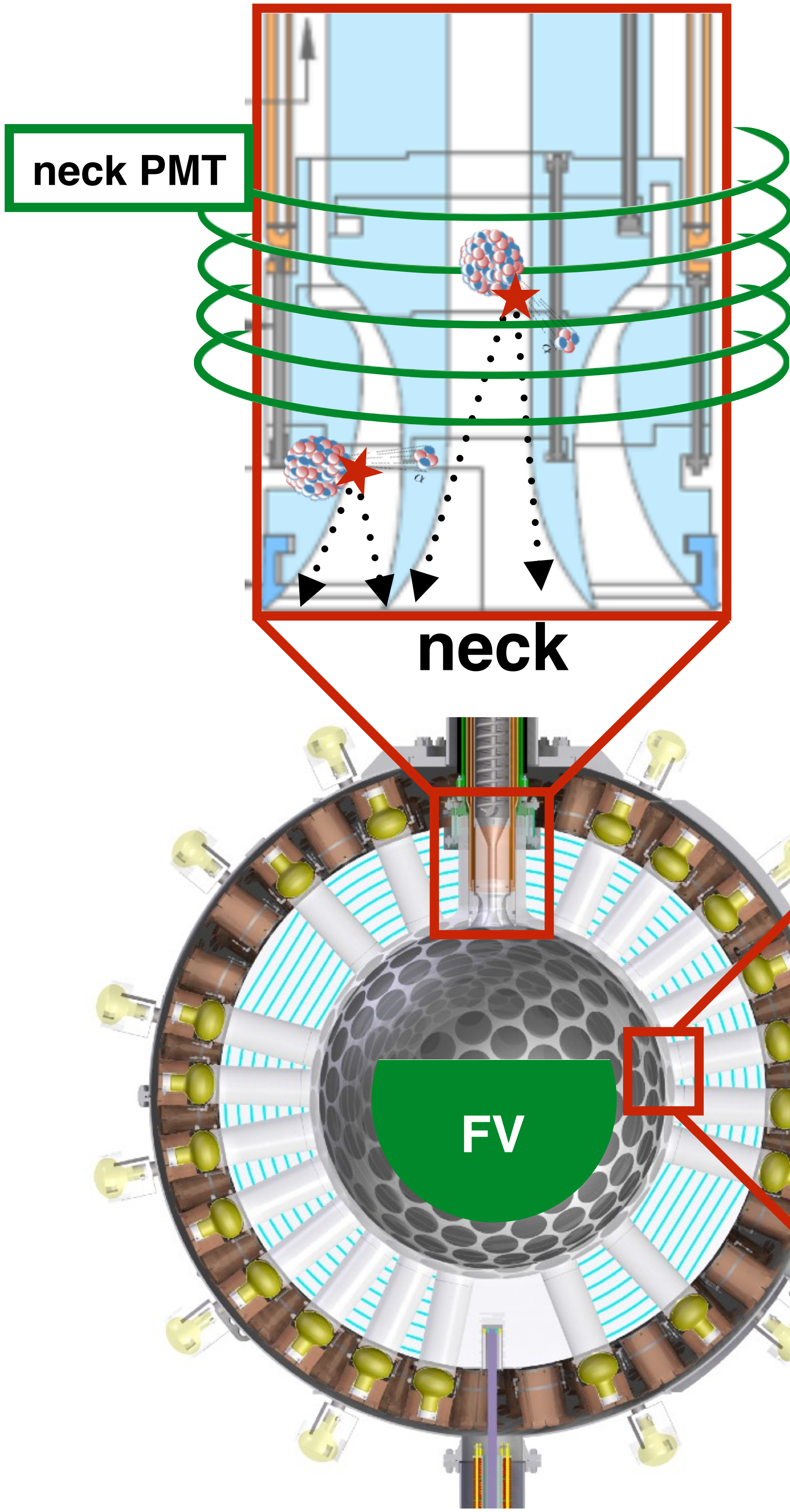
- Alphas result in a low energy detector response if:
  - Part of energy is deposited in a dead surface (e.g. acrylic)
  - Energy is deposited in medium with less scintillation (TPB)
  - Scintillation light is lost due to shadowing

- Mitigation in analysis:
  - Fiber ("neck") veto
  - Fiducial volume (FV) cut

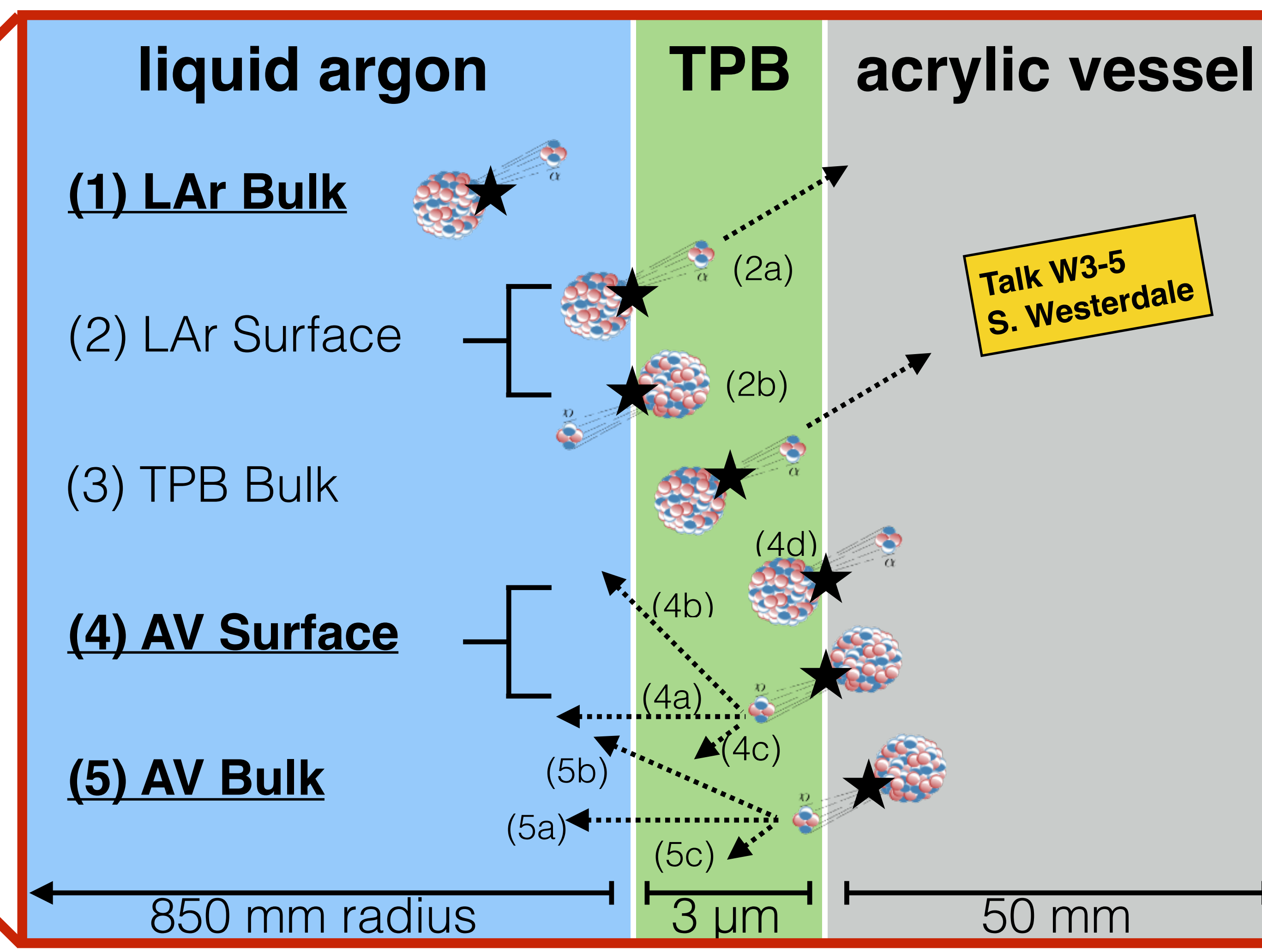
Talk R1-5 S. Langrock

Talk T3-3 C. Stone

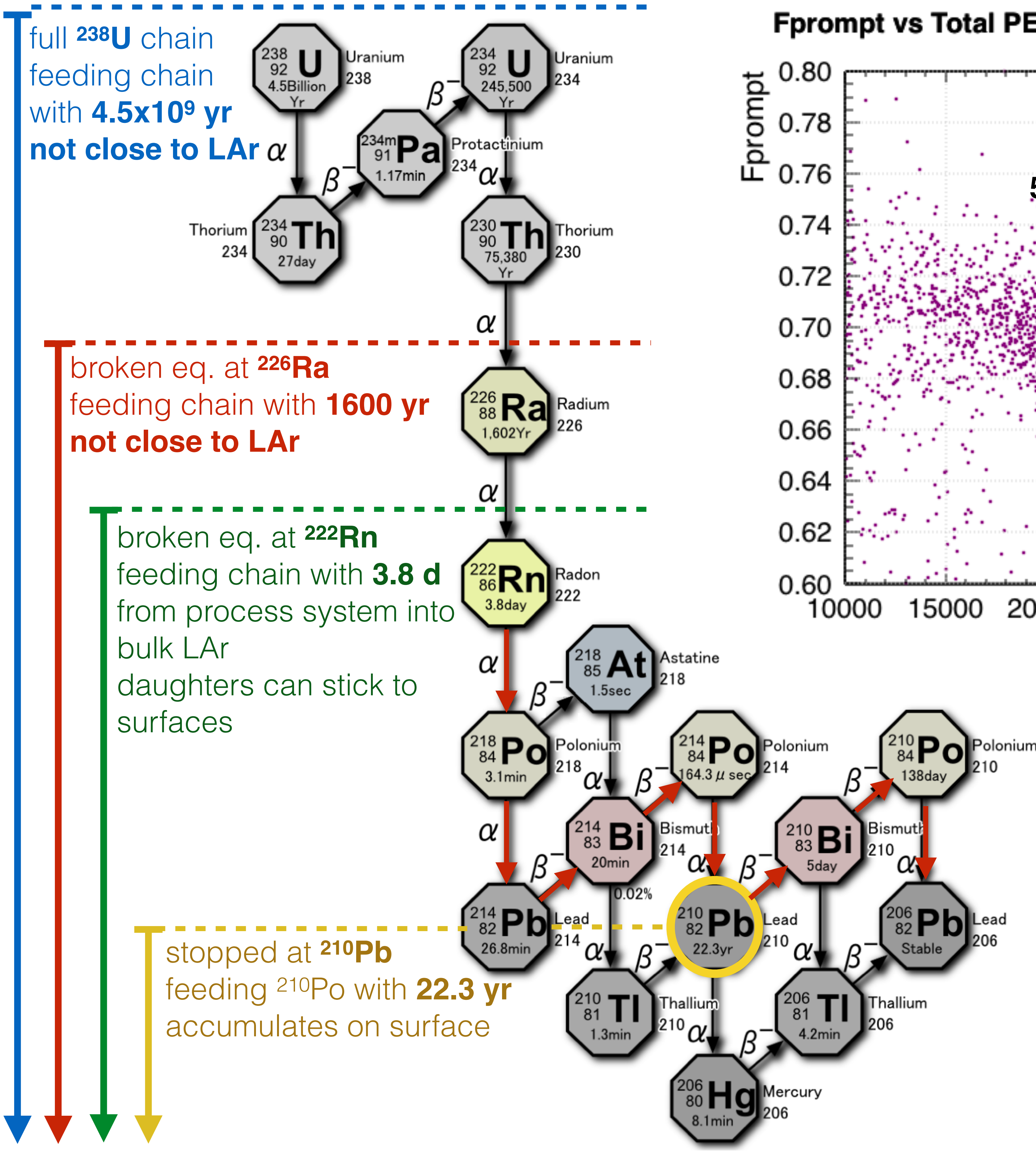
Poster Pos-40 C. Rethmeier

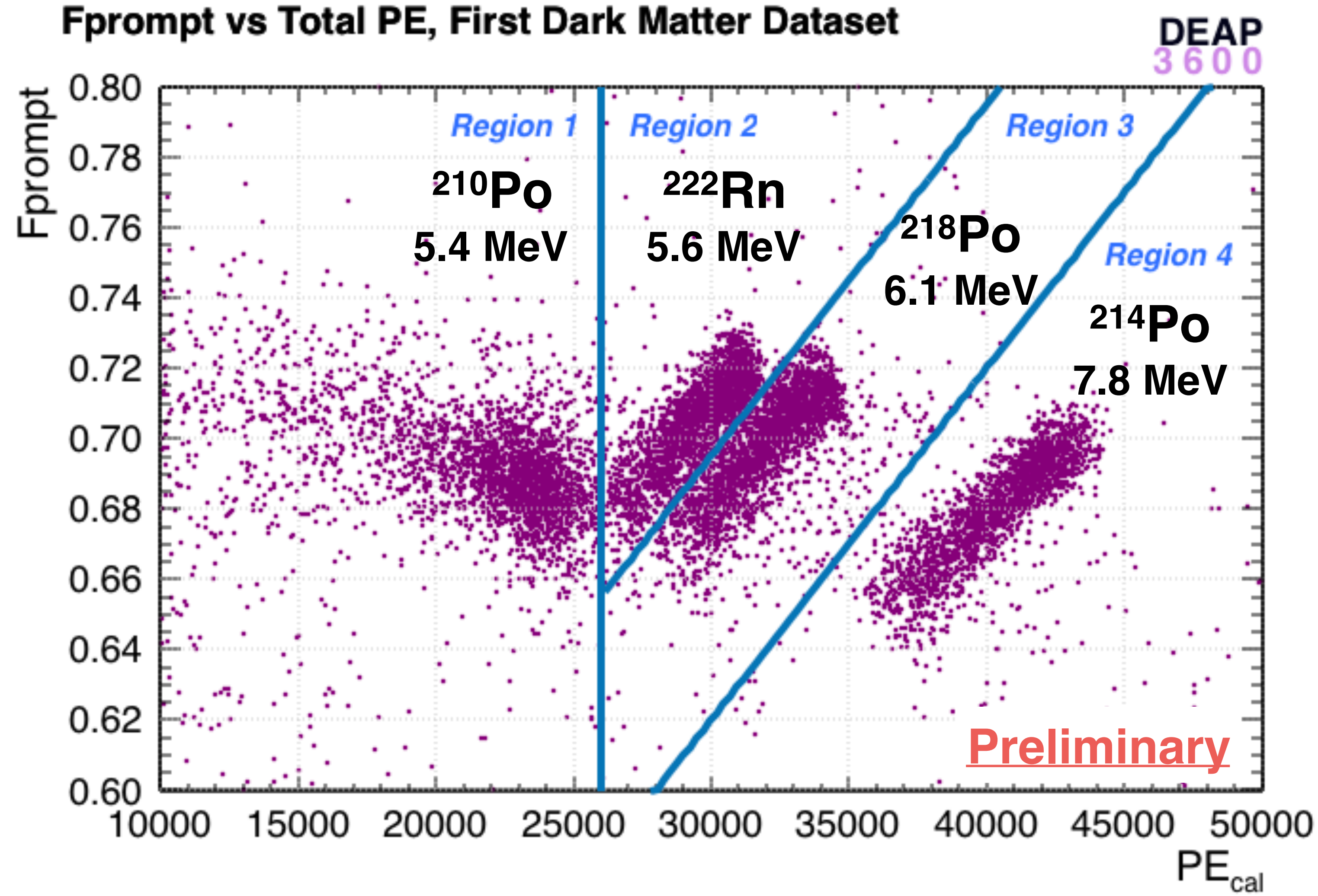


detector surface



^{238}U Decay Chain





- DEAP DAQ is designed for low energy WIMP interactions. Events at alpha energies saturate DAQ

Talk M4-3
J. McLaughlin

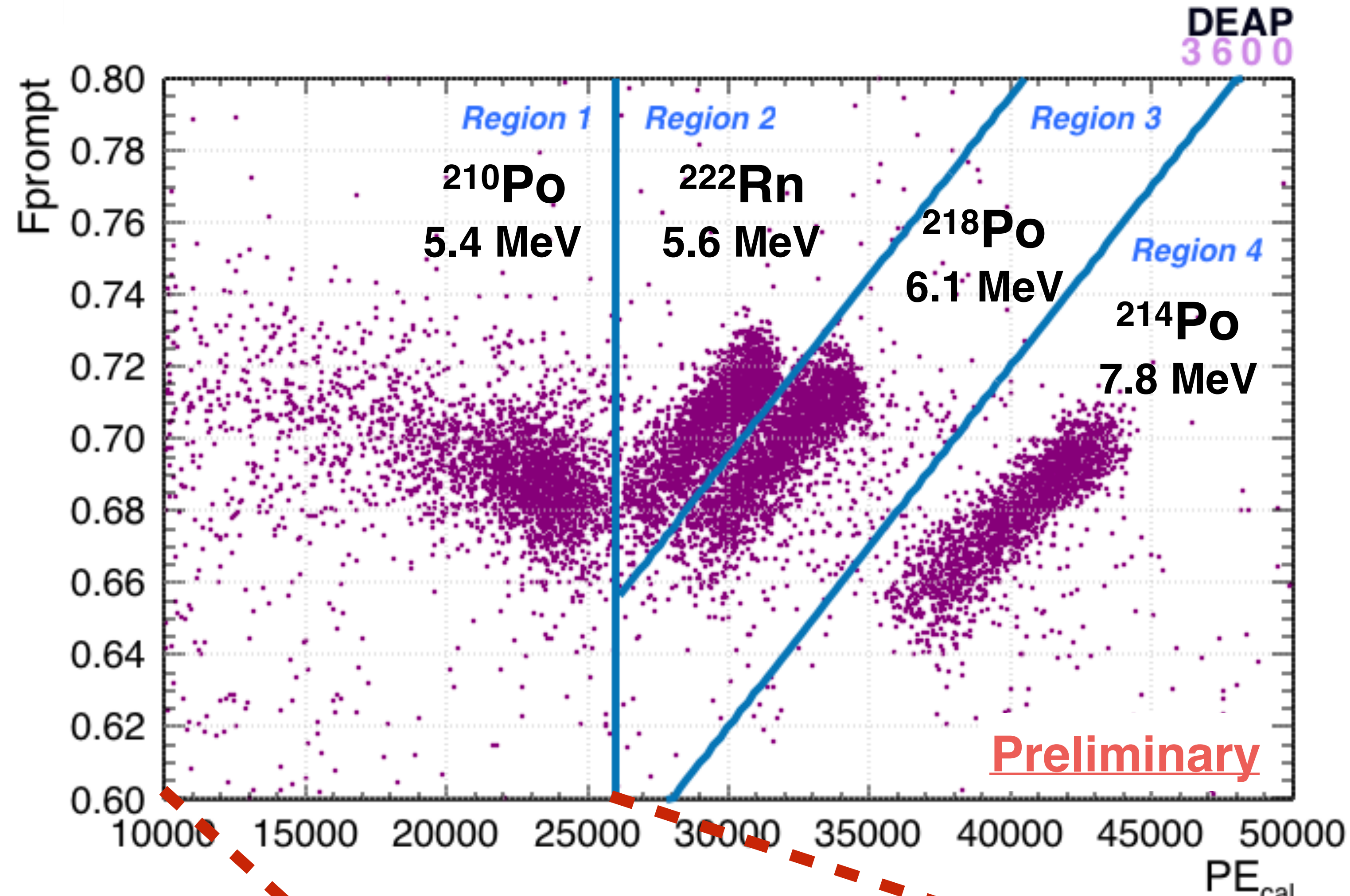
- ^{222}Rn, ^{218}Po, ^{214}Po in LAr bulk:
  - Detector response depends on radius
- ^{210}Po on surface:
  - Equal detector response

Alpha Background

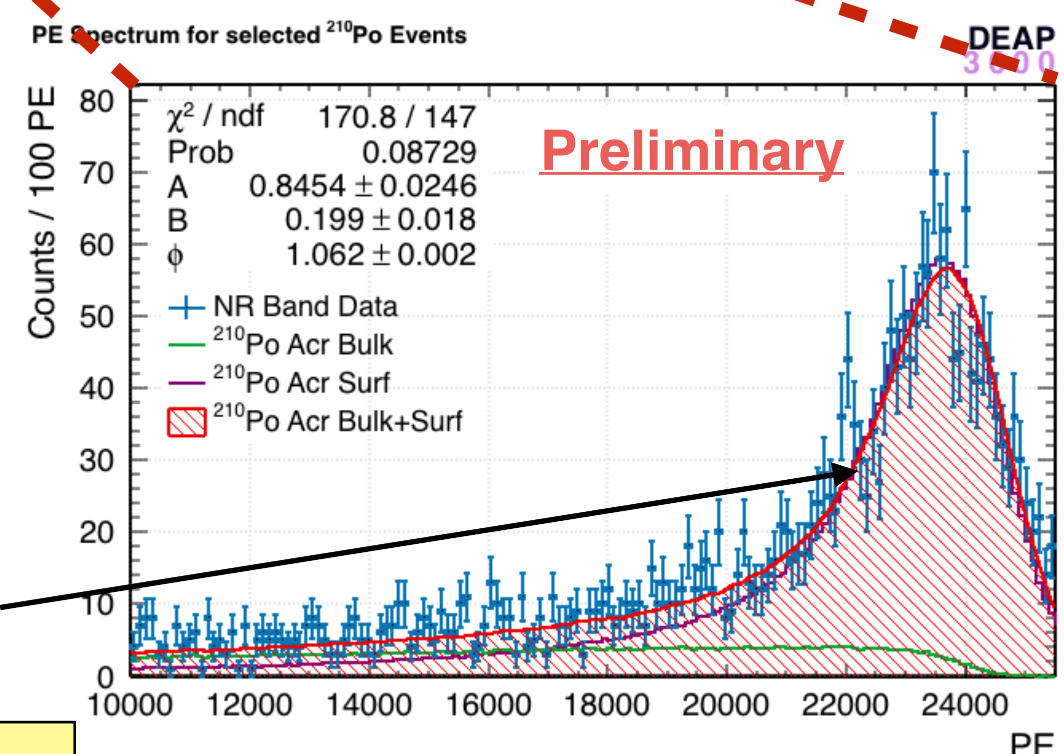
- Measuring the ^{222}Rn content in the bulk LAr shows the well very competitive results
- **Preliminary conclusion:** ^{222}Rn induced background within expectations

^{222}Rn in Dark Matter experiments:

Target	Experiment	Activity [mBq]
LAr	DEAP-3600	≈0.5
LXe	Xenon1T	5.7
LXe	PandaX	3.9
LXe	LUX	17.9



- https://indico.cern.ch/event/432527/contributions/1071738/attachments/1321292/1981557/ICHEP2016_EthanBrown_v1.pdf
- "Krypton and radon background in the PandaX-i dark matter experiment," JINST 2, 2017.
- "Radon-related backgrounds in the LUX dark matter search," Phys. Procedia, vol. 658, 2015.

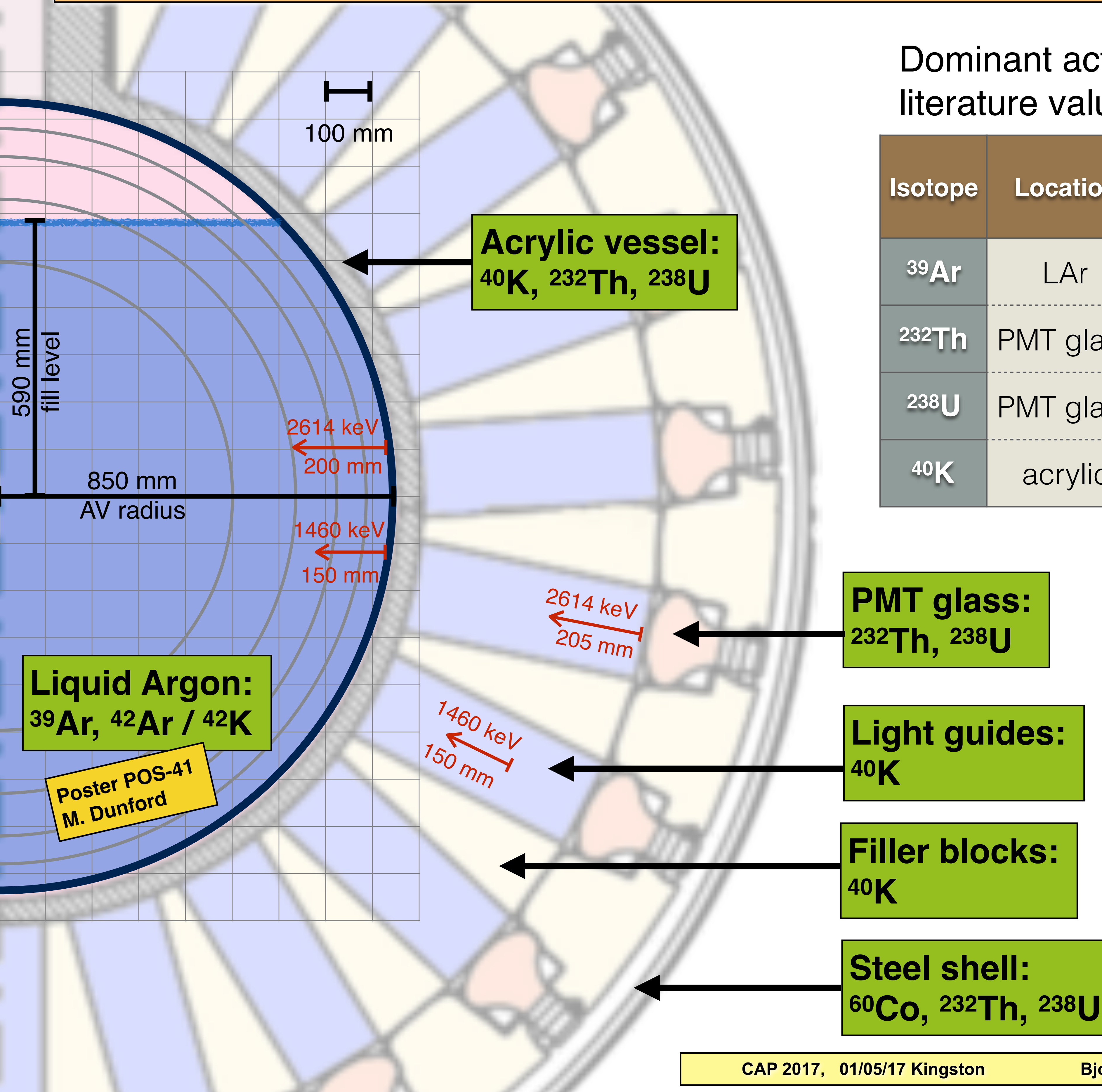


Majority of ^{210}Po decays on TPB - acrylic interface (red)

Gamma and Beta Background

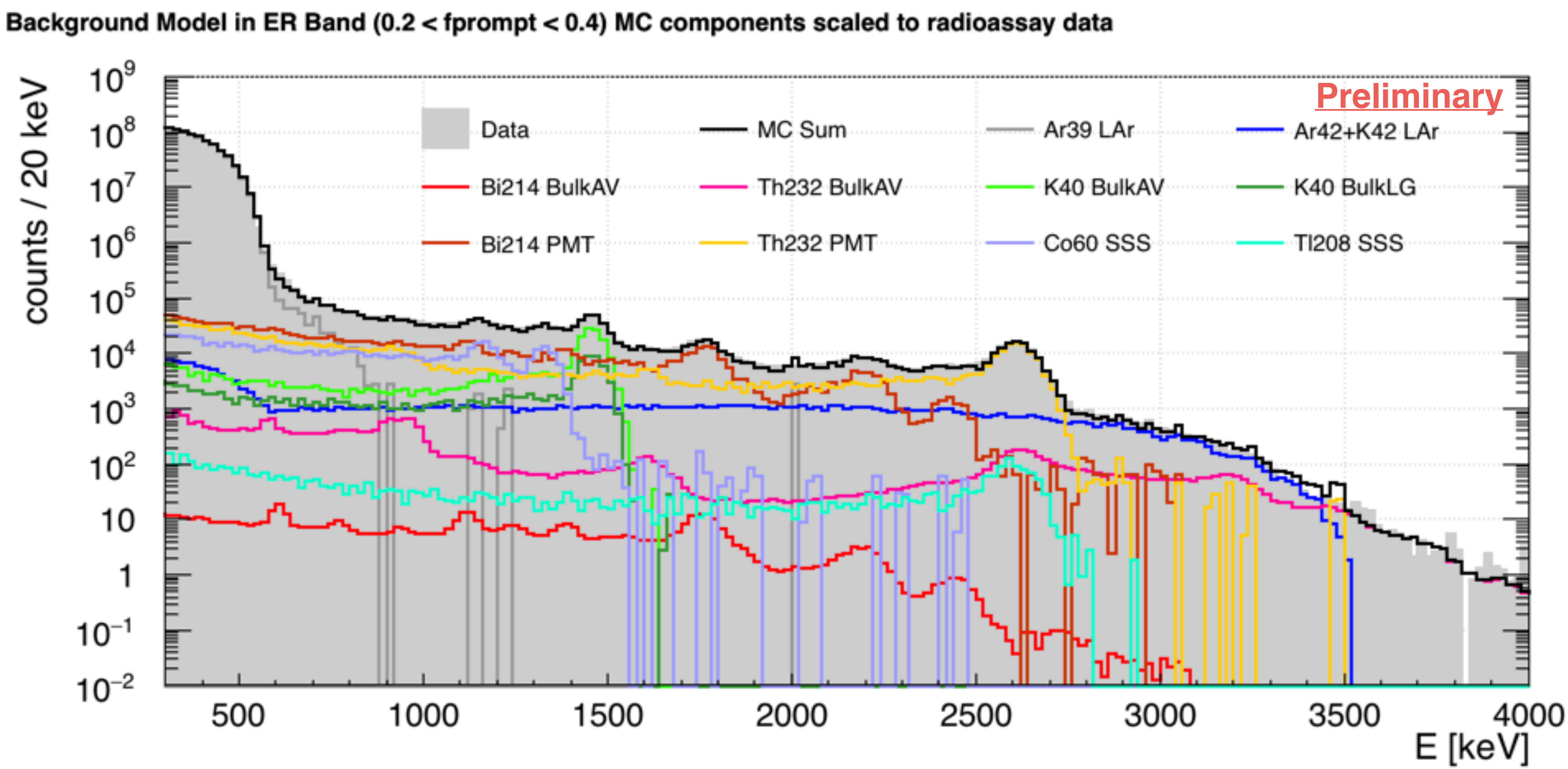
Dominant activities from screening or literature values (approximate)

Isotope	Location	Activity [Bq]	specific activity [mBq/kg]	Concentration [ppb]
^{39}Ar	LAr	3300	1010	
^{232}Th	PMT glass	26	139	34
^{238}U	PMT glass	169	921	75
^{40}K	acrylic	7.5	≈2	70



simulated background components

Electron Recoil Band Background Model



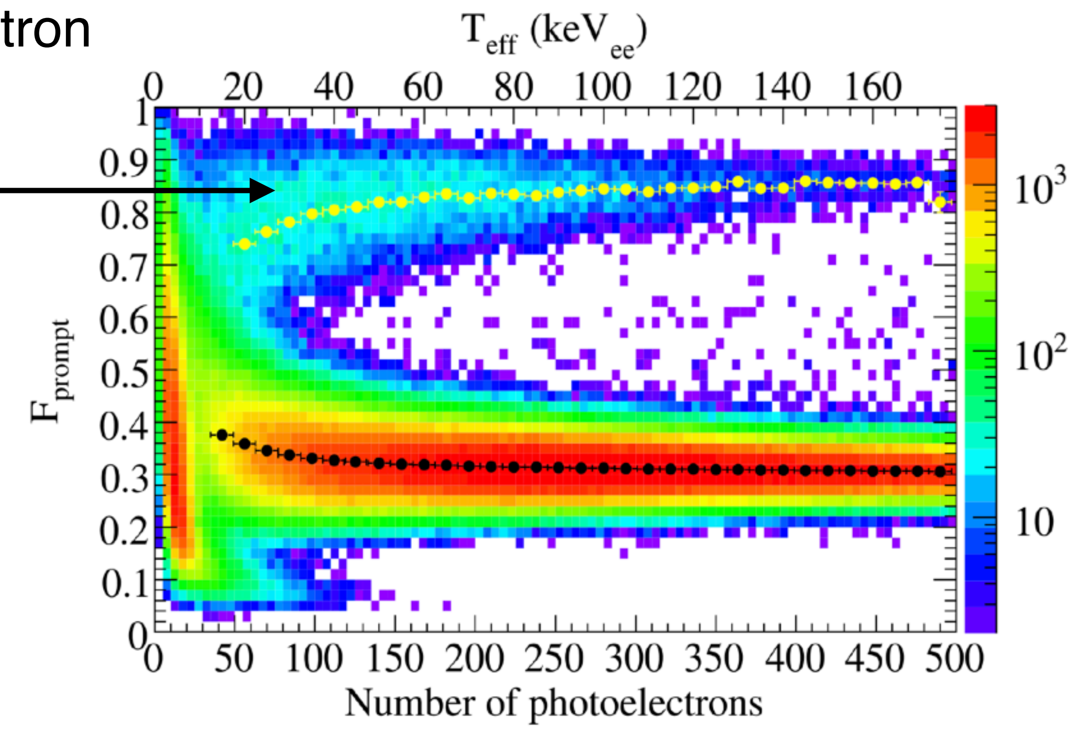
- Empiric energy calibration based on 1460 keV (^{40}K) and 2614 keV (^{208}Tl) peak
- Scaling of MC simulations to known screening / literature values (this is not a fit)
- Low energy region (< 0.5 MeV) dominated by ^{39}Ar
- Mid energy region (0.5 - 2.6 MeV) dominated by gamma from outside components (mainly PMT glass)
- High energy region (> 2.6 MeV) dominated by ^{42}K and beta components from very close ^{208}Tl sources

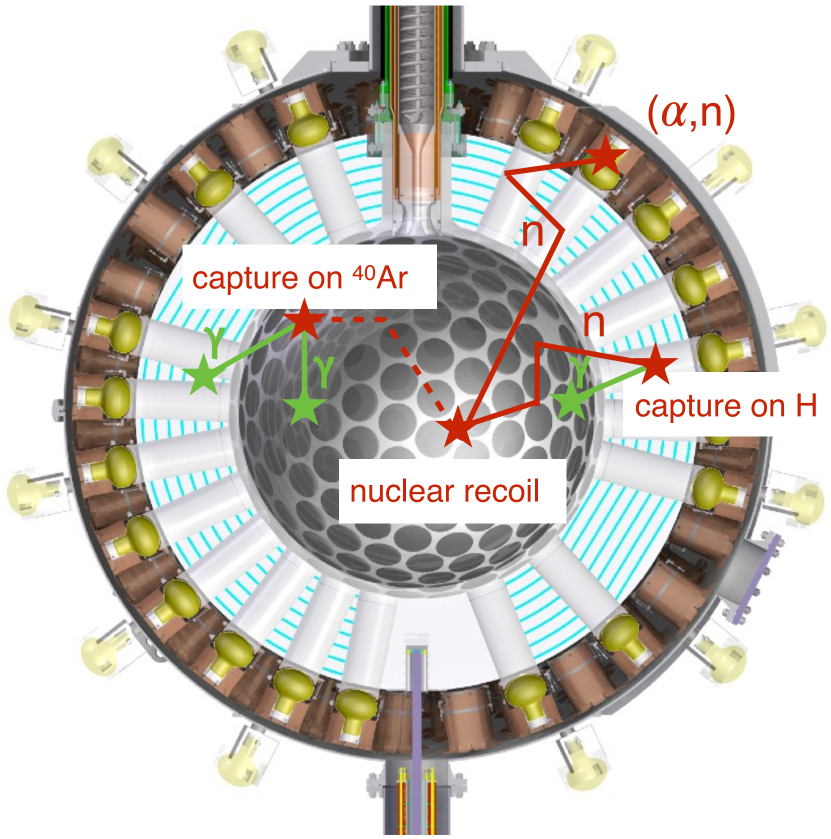
- **Gamma line measurements can be used to constrain (α,n) neutron production**

Neutron Background

- Neutrons produced by
  - (α,n) reactions in close and far material
  - fission
  - muon induced
- Extensive neutron MC campaign using radio-purity assays and (α,n) yields from SOURCES-4C
  - Dominant source is (α,n) in PMT glass (≈70%)
  - Well constrained from γ-background and consistent with target values

AmBe neutron calibration in DEAP-1





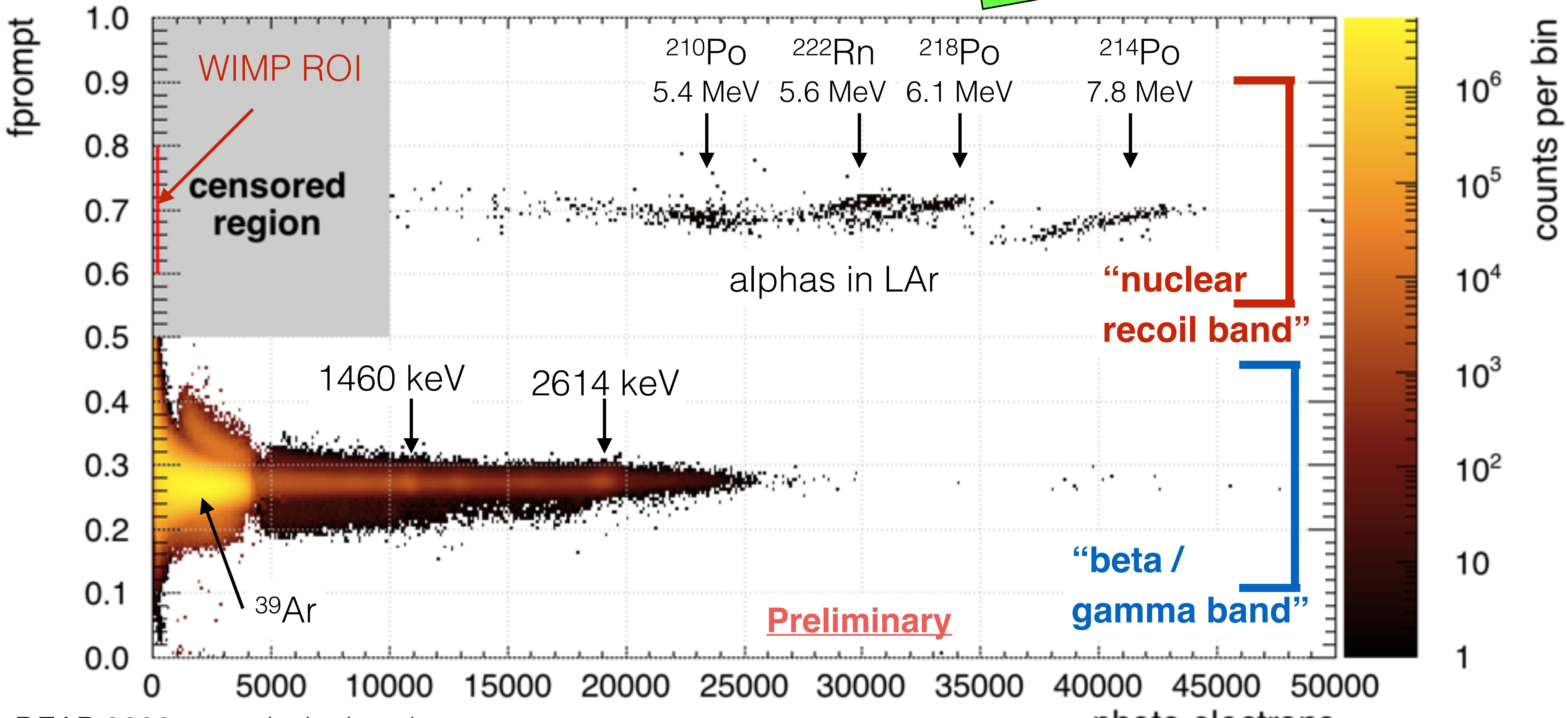
Data driven limit on neutron interactions:

- **Idea:** Eventually all neutrons capture and leave gamma signature
  - 2.2 MeV γ form ^{1}H in acrylic
  - 6.1 MeV γ-cascade from ^{40}Ar in LAr
  - Search for n - γ coincidences
- **Preliminary result:**
  - No coincidence found above expected random background
  - Limit on neutron interactions consistent with target value

Conclusion

- DEAP-3600 design goal is: < 1 bg event in 3000 kg x yr fiducial exposure
- Major expected background components: alphas, neutrons, ^{39}Ar
    - High energy alphas well understood
    - Neutron background constrained with data
    - Electronic recoil background well understood
- Other background sources under investigation
- Detailed background model is being constructed

Stay tuned to see more @TAUP (July 2017 in Sudbury)



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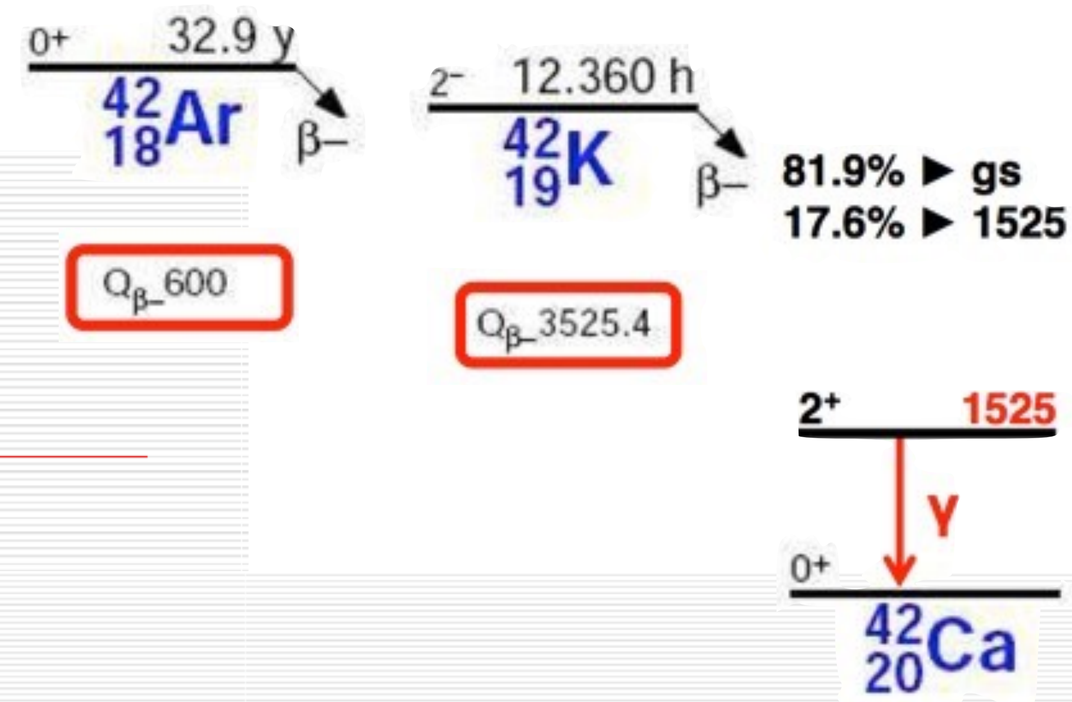
Backup

^{42}Ar - ^{42}K Decay Chain

- With about 100 muBq, 0.33 decays / s are expected in DEAP-3600



Short history of ^{42}Ar problem

1979 – **R. Davis** (possible background for **ICARUS**; ^{42}Ar as a result o nuclear bomb tests)

1992 – **C. Arpesella et al. [1]** (first experimental limit, **< 10^{-18} ^{42}Ar/^{40}Ar**)

1995 – first estimations using information about nuclear tests in atmosphere, **< 10^{-22}–10^{-23} ^{42}Ar/^{40}Ar** (**P. Cennini et al. [2]** and **A.S. Barabash et al. [3])**

1997 – **A.J. Peurrung et al. [4] -** new source of ^{42}Ar has been discussed: ^{40}Ar(α,2p)^{42}Ar (cosmic-ray interactions in the upper atmosphere; **~ 10^{-20} ^{42}Ar/^{40}Ar**)

1998 – **V.D. Ashitkov et al. [5]** – new experimental limit from **DBA** experiment, **< $6\cdot10^{-21}$ ^{42}Ar/^{40}Ar**

2003 - **V.D. Ashitkov et al. [6]** – final experimental limit from **DBA** experiment, **< $4.3\cdot10^{-21}$ ^{42}Ar/^{40}Ar (90% CL)**

2011 – **LArGe (GERDA) [7], (2.2 ±1.0)·10^{-21} ^{42}Ar/^{40}Ar**

2014 – **GERDA-I [8], (7-12)·10^{-21} ^{42}Ar/^{40}Ar**

List of references

[1] C. Arpesella et al., Preprint INFN-LNGS 92/27, 1992.

[2] P. Cennini et al., NIMA, 356 (1995) 526.

[3] A.S. Barabash et al., NIMA, 385 (1997) 530; preprint ITEP 18-95, 1995.

[4] A.J. Peurrung et al., NIMA, 396 (1997) 425.

[5] V.D. Ashitkov et al., NIMA, 416 (1998) 179.

[6] V. D. Ashitkov et al., Inst. Exp. Tech. 46 (2003) 153.

[7] M. Heisel, thesis, Heidelberg, 2011.

[8] M. Agostini et al., Eur. Phys. J. C 74 (2014) 2764.

(Ref:TAUP 2015 presentation http://www.taup-conference.to.infn.it/2015/day2/parallel/nub/5_barabash.pdf)