Title: The DEAP Dark-Matter Search Program

Date: Jun 13, 2009 09:00 AM

URL: http://pirsa.org/09060049

Abstract: The DEAP/CLEAN collaboration will be constructing a 3600-kg single-phase liquid-argon dark matter detector at SNOLAB with sensitivity to 10-46 cm2 for a 100 GeV WIMP. We are currently operating a 7-kg liquid-argon detector (DEAP-1) at SNOLAB. Using DEAP-1 we have made measurements of alpha surface activity and radon levels in the detector. We have also performed studies of pulse-shape discrimination to separate electromagnetic interactions in the liquid argon from nuclear recoils. Recently published data from surface at Queen’s University showed no contamination in the WIMP signal region from 16.7 Million tagged gamma events in WIMP the region of interest. A further 22 M events have been accumulated at SNOLAB with no contamination. The design of the DEAP-3600 detector will be presented with emphasis on reduction of backgrounds, including design of a resurfacer to remove radon daughters which plate out on acrylic and the design of the acrylic container to plate shield against neutron activity from the PMTs and steel outer vessel.

Introduction

- Introduction and the Detector
  - Tonne scale and argon
  - Sensitivity and background requirements
  - Detector Design
  - DEAP-1
- ^{39}Ar background
  - Separation of EM and nuclear-recoil events
  - Depleted argon
- Nuclear-Recoil backgrounds
  - External neutrons
  - PMT (α,n)
  - Acrylic surface contamination

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DEAP/CLEAN Collaboration

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DEAP & CLEAN

microCLEAN: Yale

- 4 kg prototype run with LAr and LNe at Yale
- PSD and quenching factors measured. (arXiv:0801:1531)

DEAP-1: SNOLAB

- 7 kg prototype experiment
- Run at Queen's for demonstration of PSD (arXiv:0904:2930)
- Now at SNOLAB for continued PSD, background studies, DM search

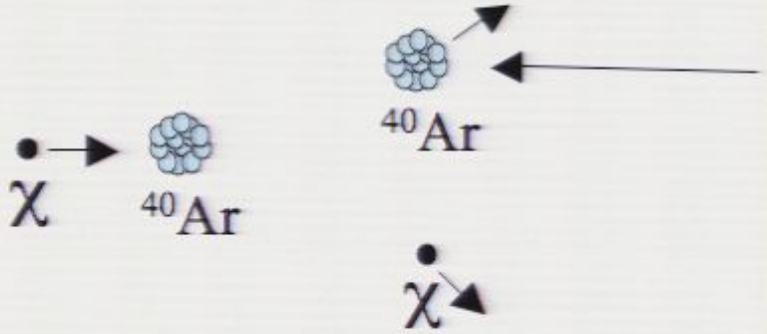
miniCLEAN-360: SNOLAB

- 360 kg liquid argon for dark matter and prototyping neon for particle astrophysics
- primary emphasis of US collaborators in short term

DEAP/CLEAN-3600: SNOLAB

- 3600 kg liquid argon for dark matter
- primary emphasis of Canadian collaborators in short term

Direct WIMP detection with liquid argon



Scattered nucleus (with several 10's of keV) is detected via scintillation in liquid argon.

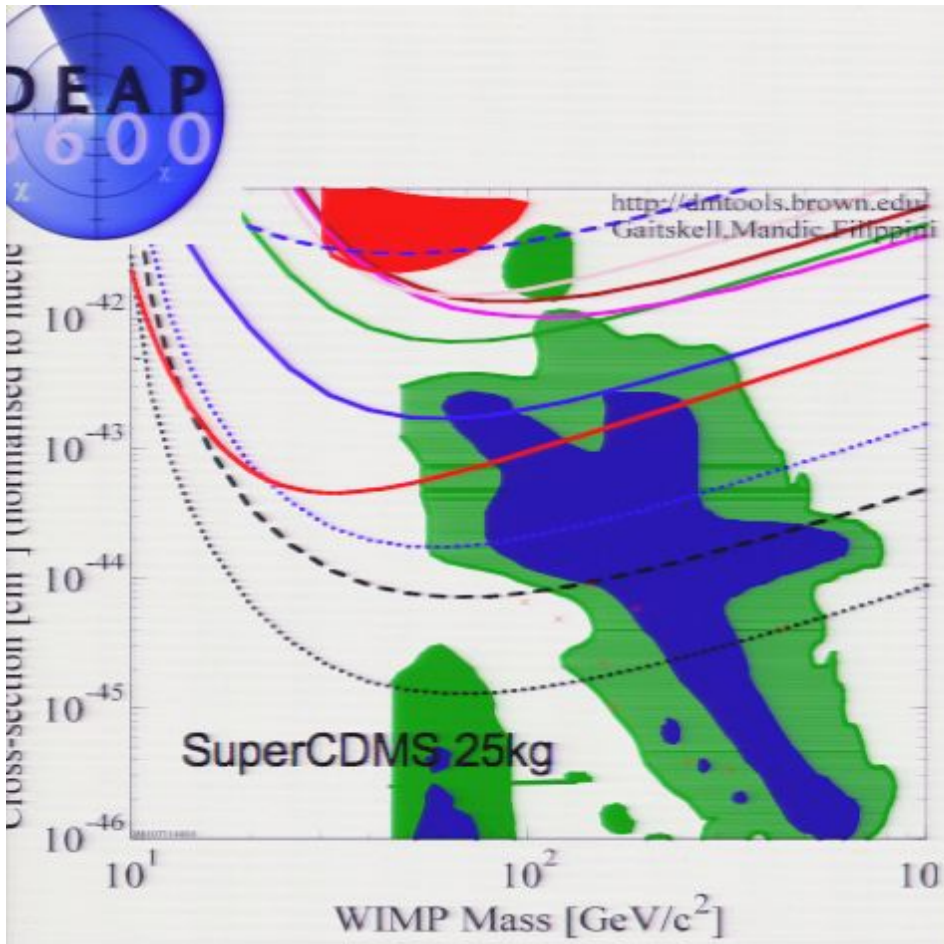
Pulse-shape discrimination (PSD) is very powerful in argon, allows for suppression of background β/γ events.

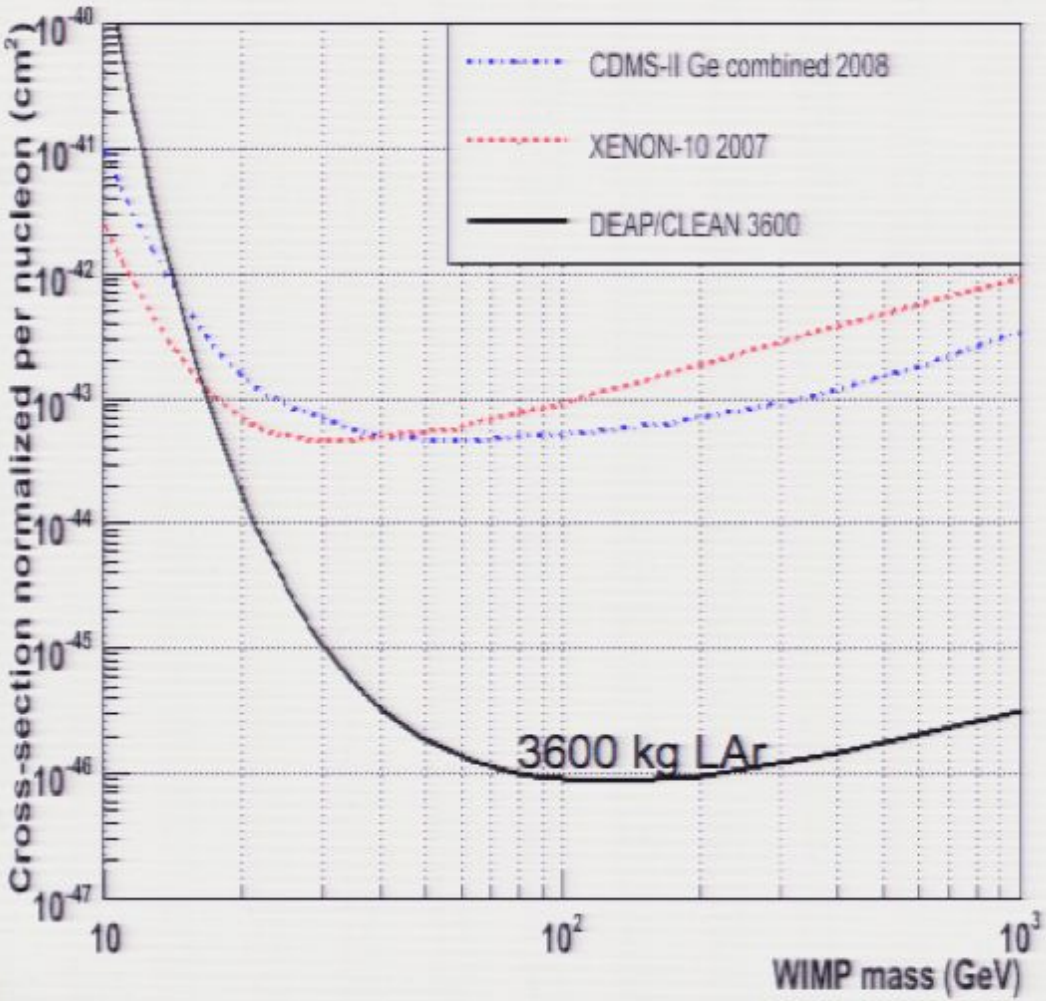
Projected pulse shape discrimination (PSD) in argon allows threshold of approx. 20 keV_{ee} (60 keV_r)

1000 kg argon target allows 10^{-46} cm^2 sensitivity (spin-independent) with ~20 keV_{ee} threshold (60 keVr) threshold.

Liquid argon
- is easily purified
- has a high light yield
- is inexpensive
- has an easily accessible temperature (85K)
- allows a very large detector mass (~tonne)

DEAP-1 (7 kg)
DEAP-3600 (3600 kg)





DATA listed top to bottom on plot
CDMS (Soudan) 2005 Si (7 keV threshold)
DAMA 2000 58k kg-days NaI Ann.Mod. 3sigma,w/o DAMA 19
CRESST 2004 10.7 kg-day CaWO4
Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
WARP 2.3L, 96.5 kg-days 55 keV threshold
ZEPLIN II (Jan 2007) result
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
XENON10 2007 (Net 136 kg-d)
CDMS Soudan 2007 projected
SuperCDMS (Projected) 2-ST@Soudan
SuperCDMS (Projected) 25kg (7-ST@Snolab)
Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (1
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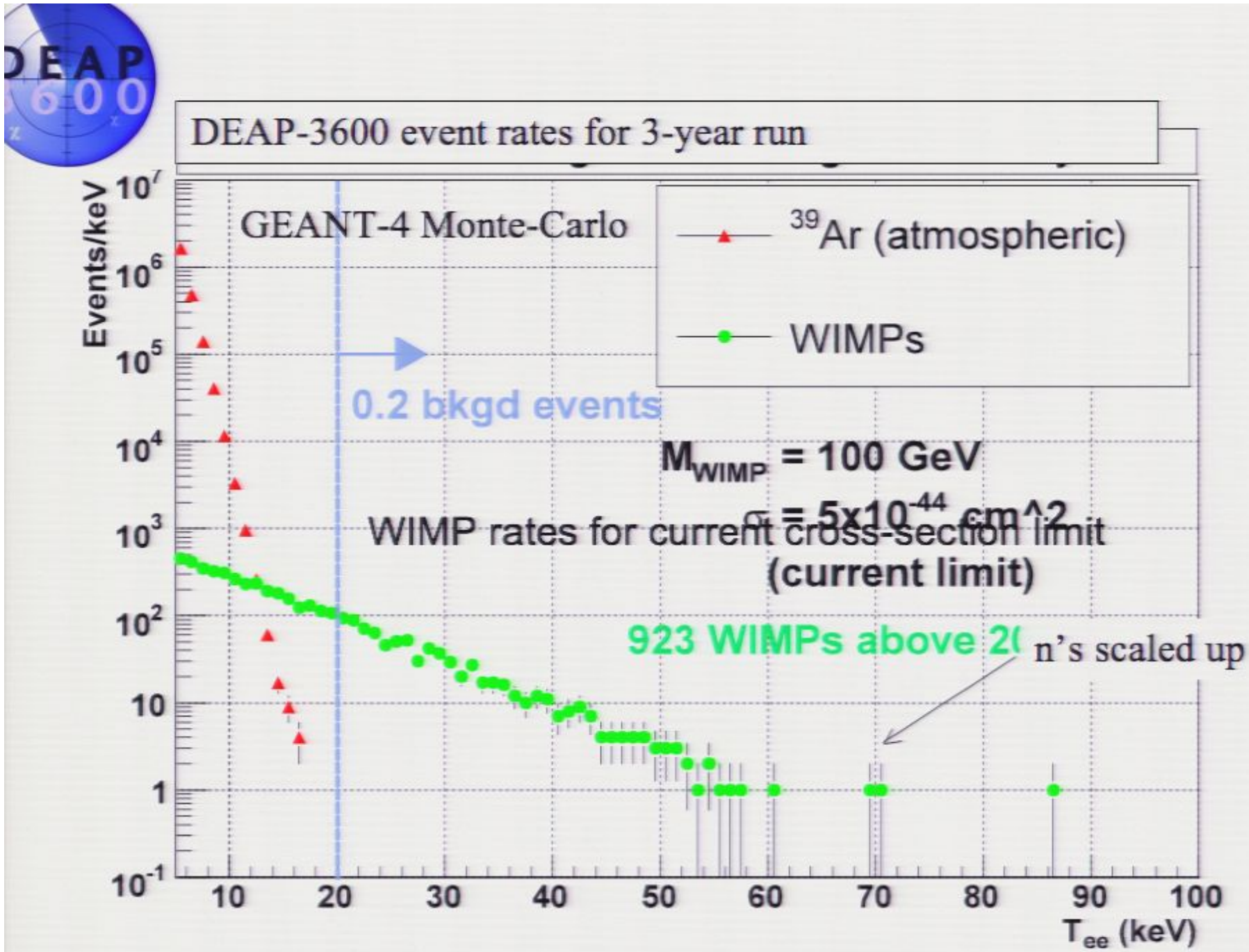
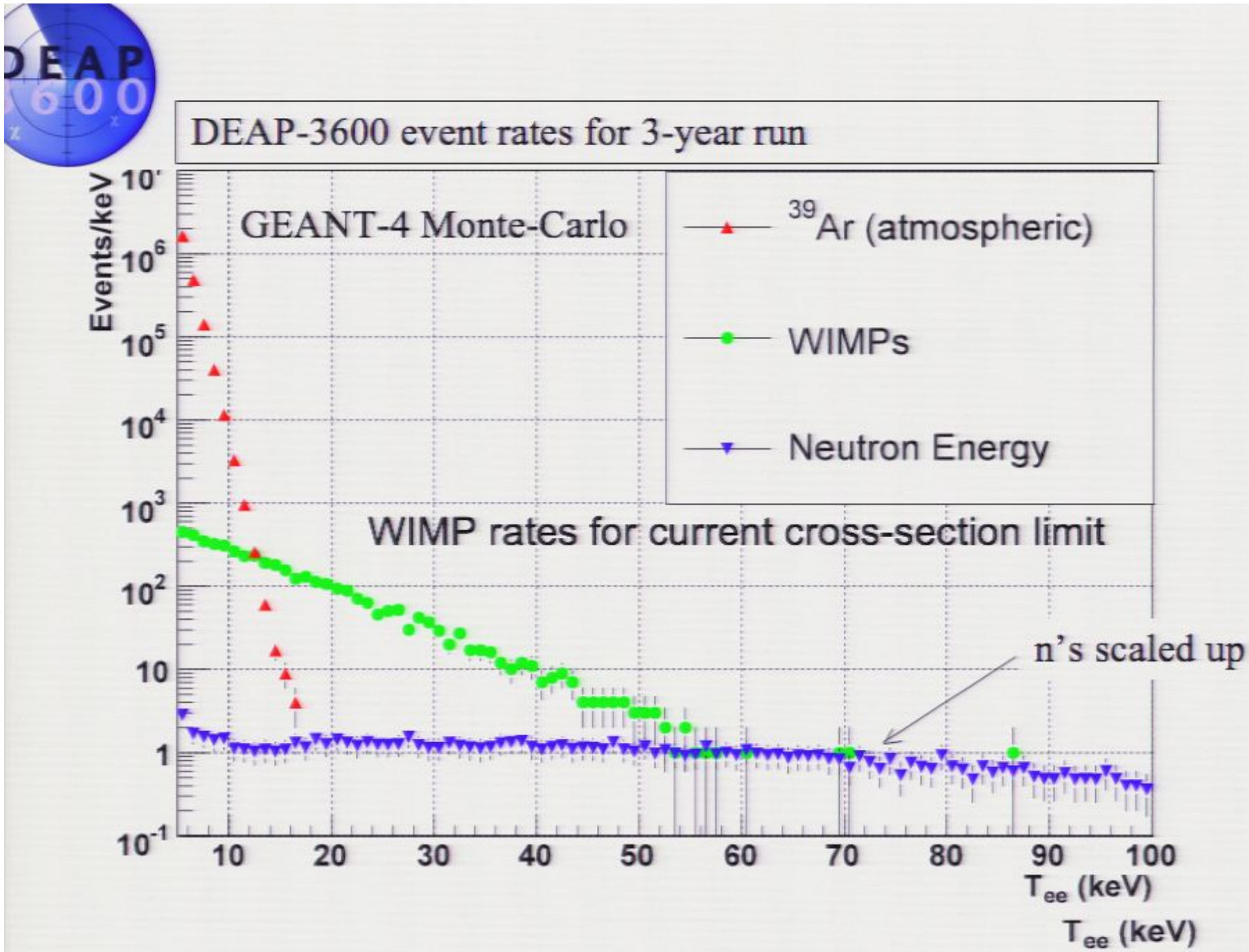
Ellis et. al Theory region post-LEP benchmark points

60 keVr threshold,
1 000 000 kg-day exposure

ts on Dark Matter


DEAP-3600 event rates for 3-year run
GEANT-4 Monte-Carlo
^{39}Ar (atmospheric)
WIMPs
0.2 bkgd events
M_{WIMP} = 100 GeV
σ = 5x10^{-44} cm^2
WIMP rates for current cross-section limit
(current limit)
923 WIMPs above 2(
n's scaled up
Events/keV
T_{ee} (keV)


DEAP-3600 event rates for 3-year run
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WIMP rates for current cross-section limit
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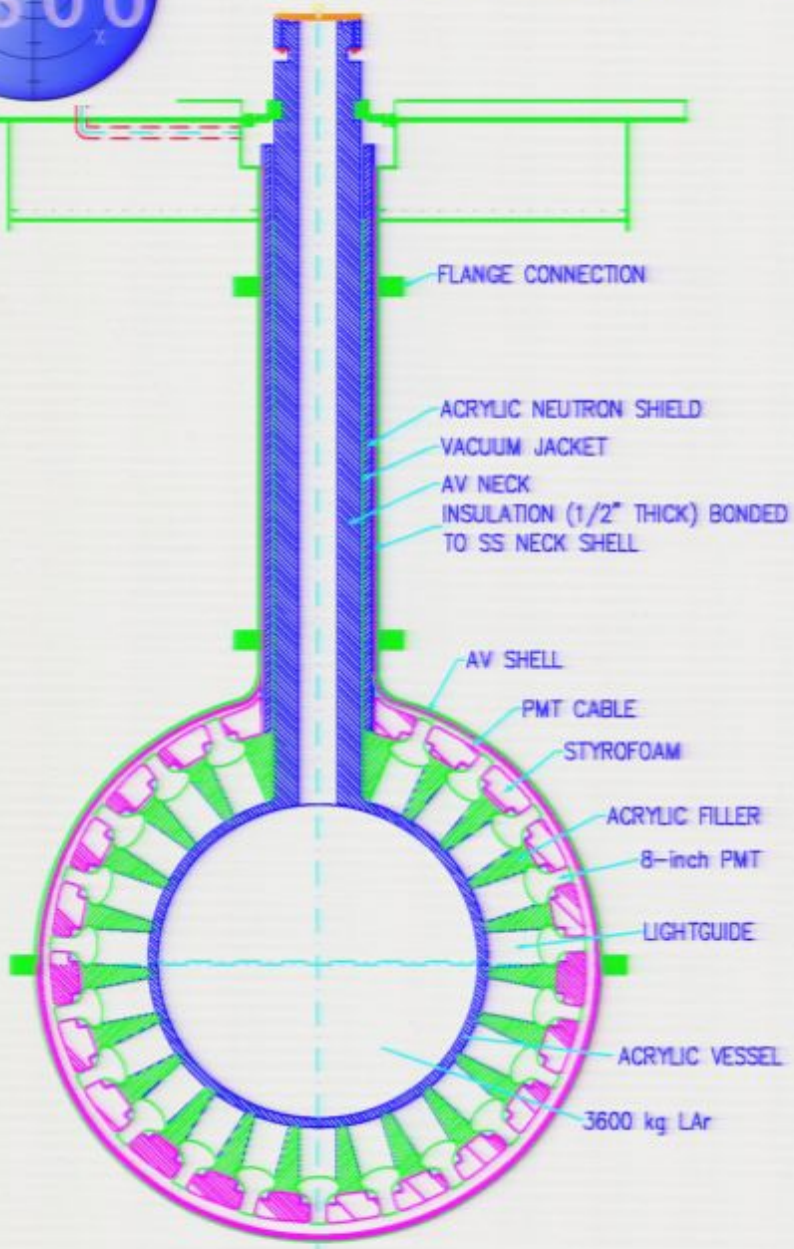
Events/keV
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10
20
30
40
50
60
70
80
90
100
T_{ee} (keV)

DEAP-3600 Design



Driven by background requirements

85 cm radius acrylic sphere: 3600 kg LAr
(55 cm, 1000 kg fiducial)

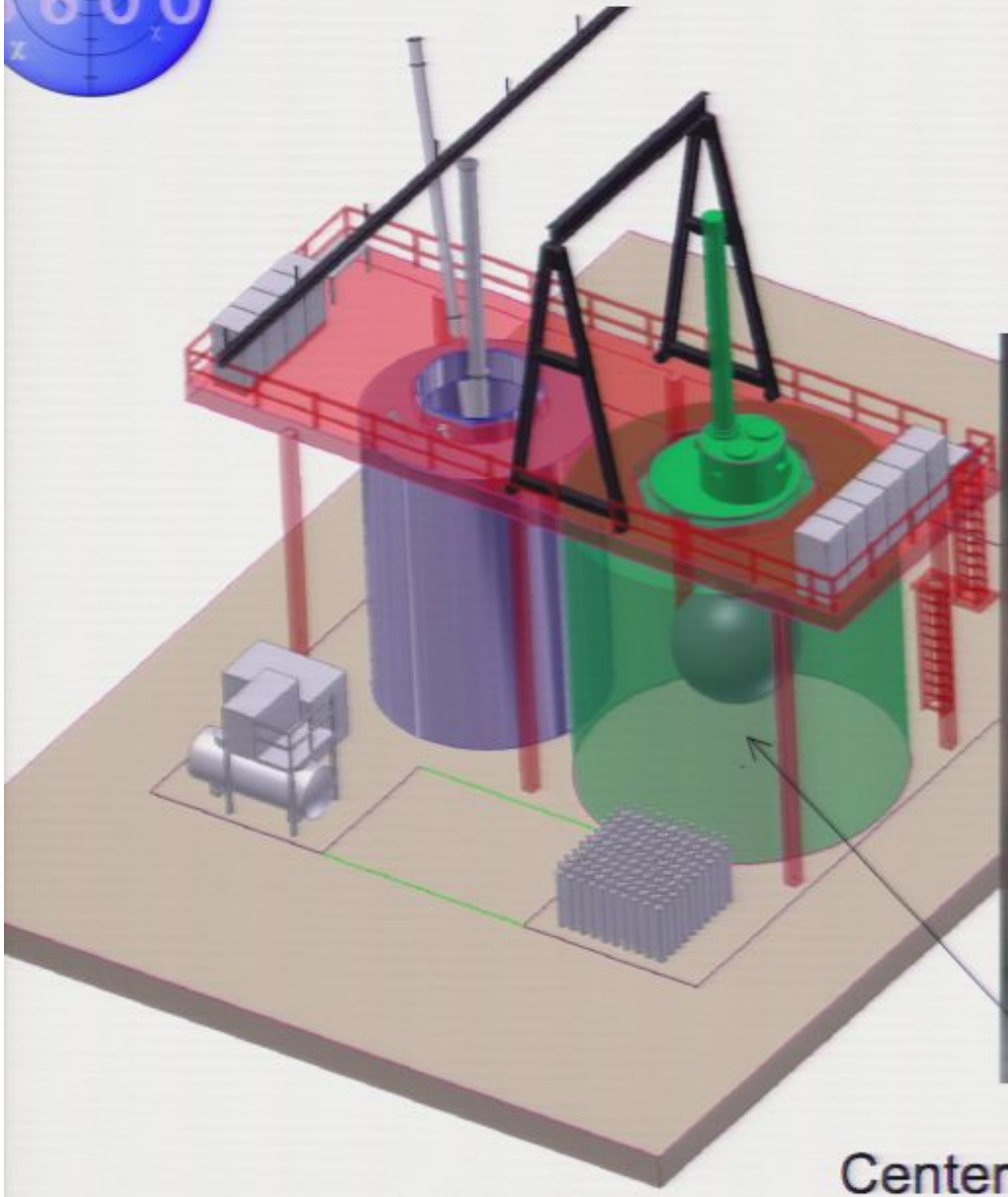
255 8" PMTs (warm)

50 cm acrylic light guides and fillers for neutron shielding (from PMTs)

Steel shell for safety to prevent cryogen/water mixing (AV failure)

Only LAr, acrylic, and WLS (10 g) inside of neutron shield (minimizes Rn emanation)

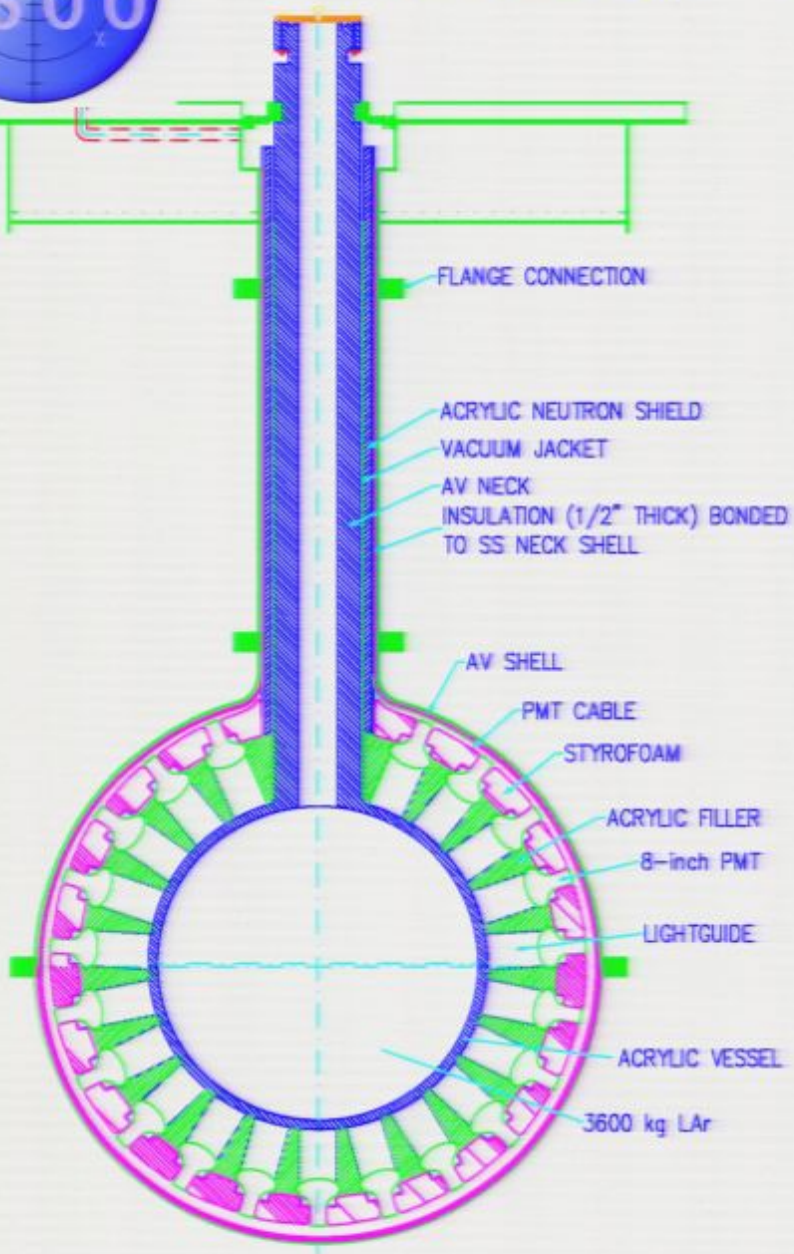
DEAP-3600 in SNOLAB Cube Hall



8.5 meter diameter tank shield
external neutrons and γ's

Center of DEAP-3600 shield tank;
deck installation by fall 2009

DEAP-3600 Design



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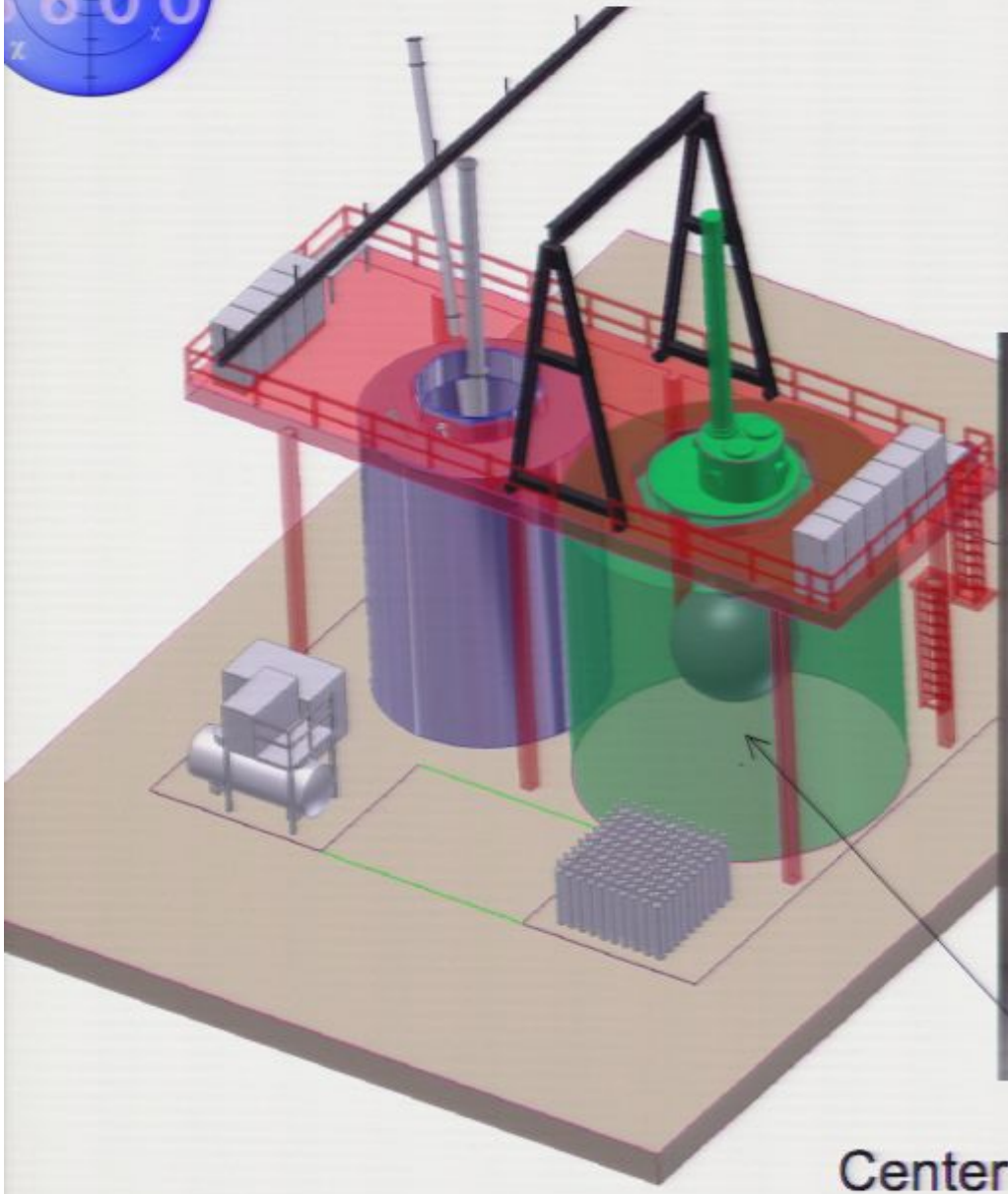

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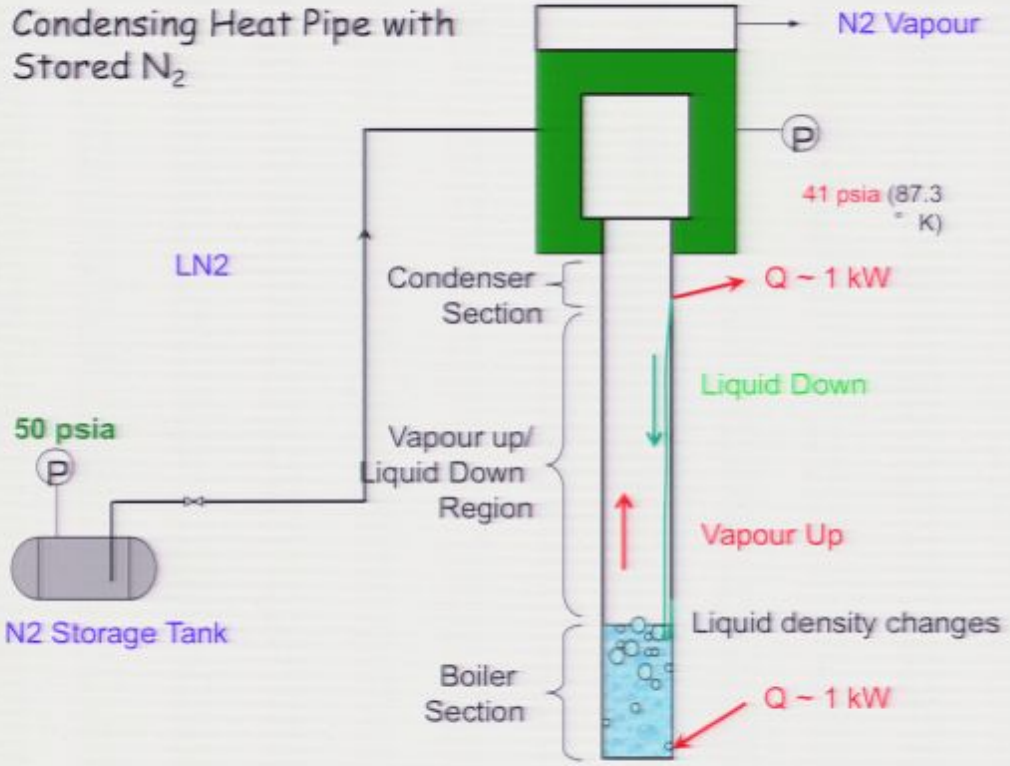
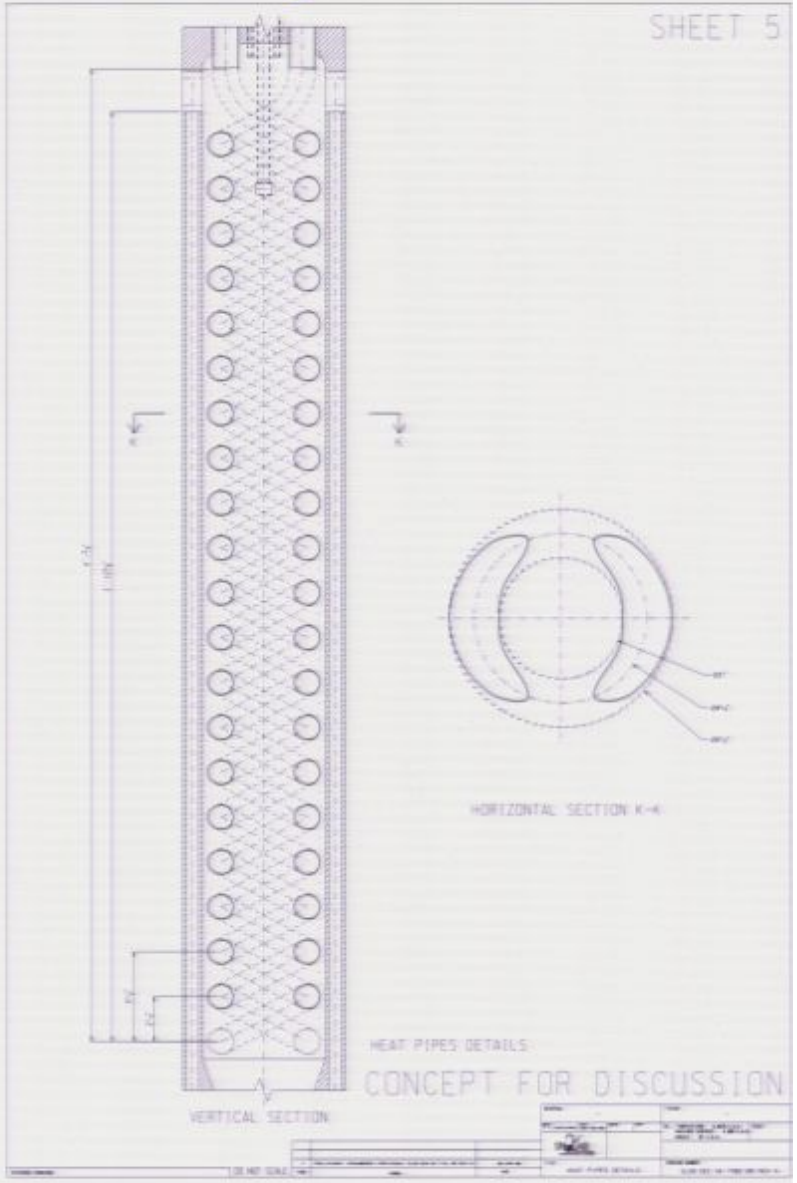
Neck/Cooling Concept

Two helical coils charged with LN_2.





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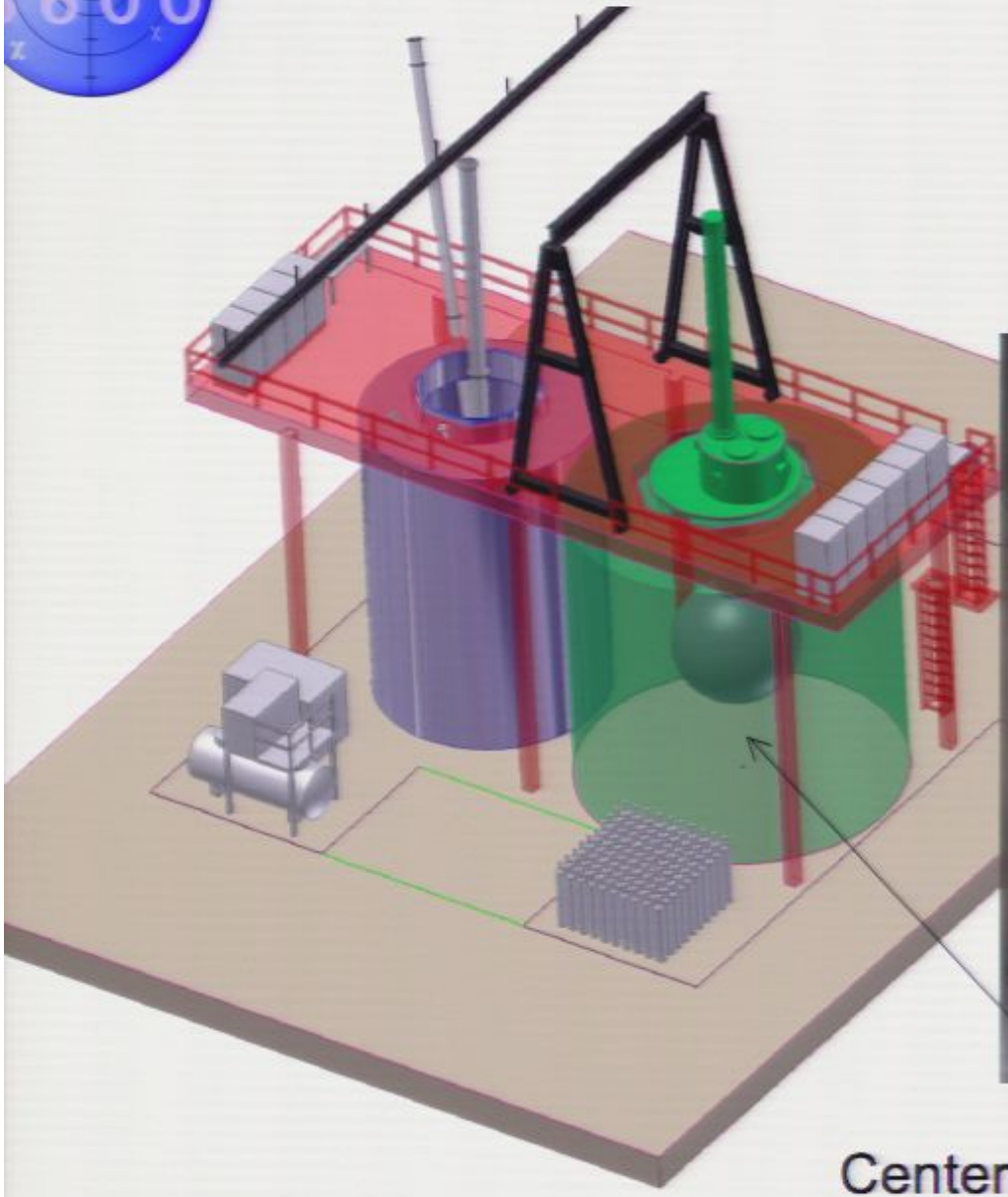

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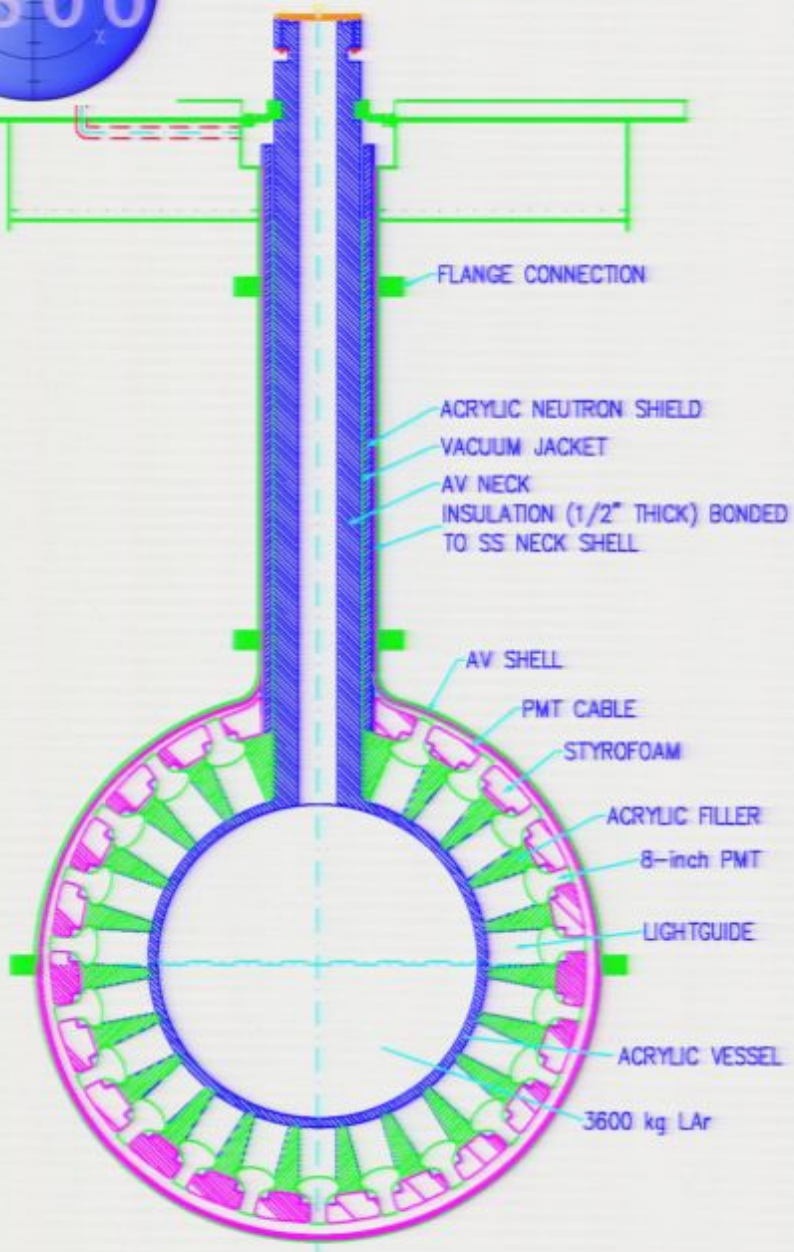

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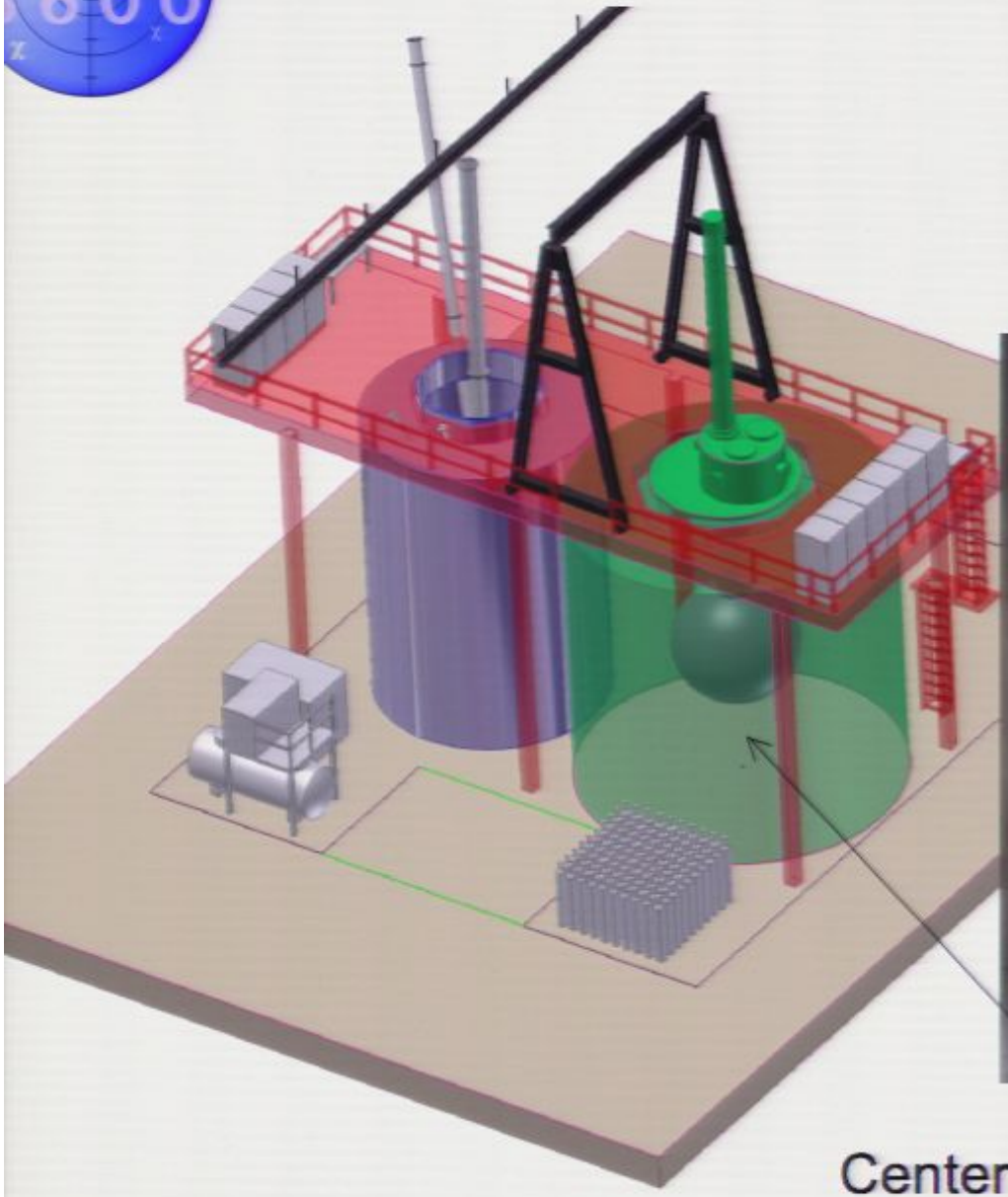

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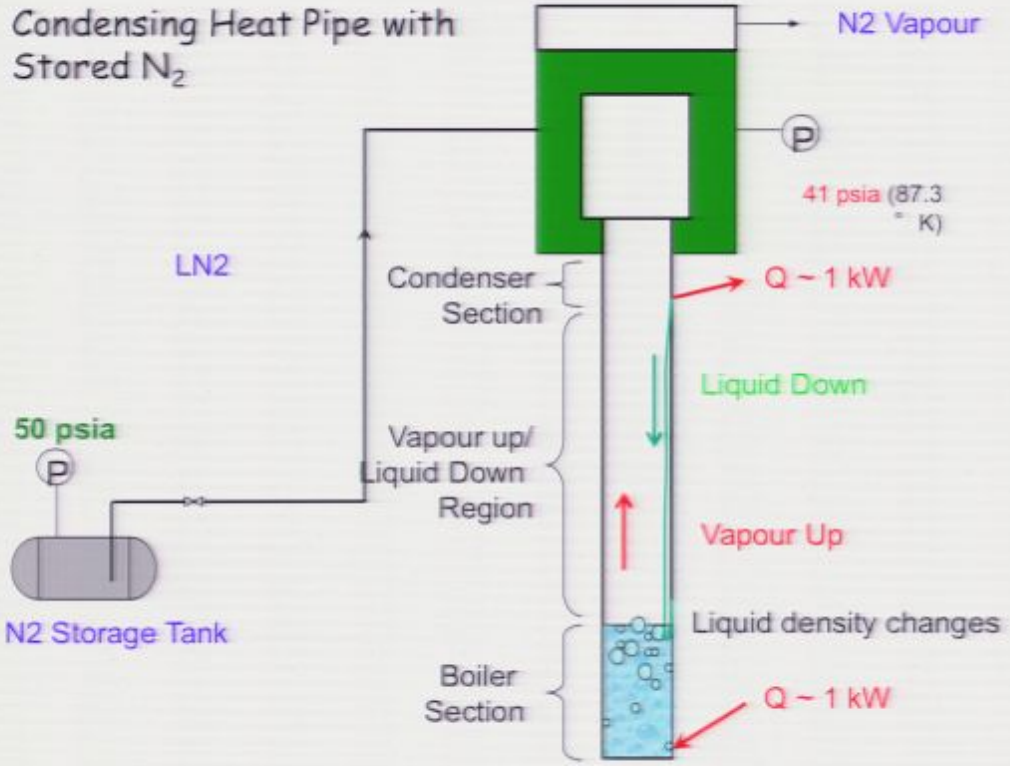
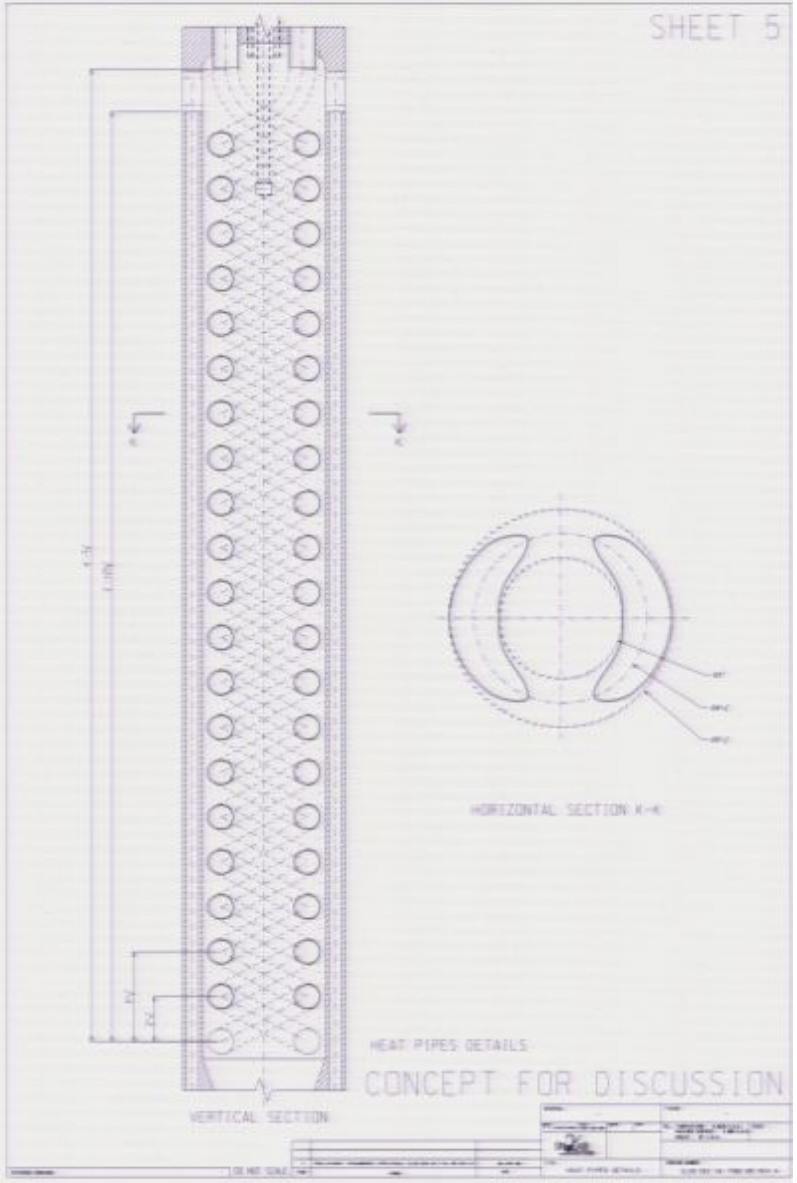




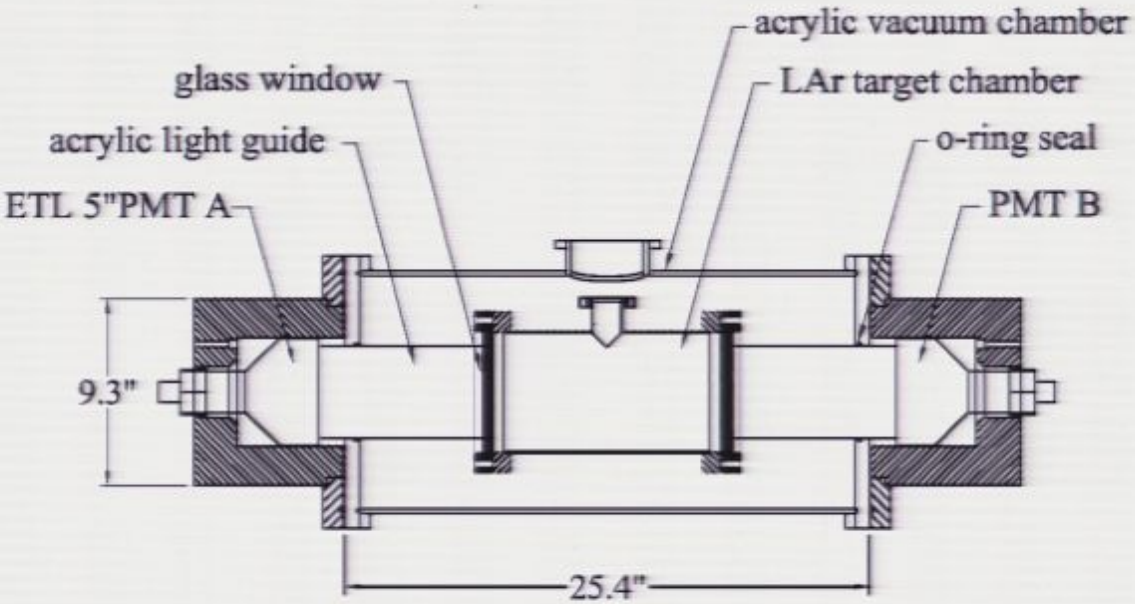
WIMPs and Backgrounds

- Sensitive to 1 WIMP/tonne/year
- Background Rate = ~0.1/tonne/year

1. EM Backgrounds
    1. Pulse-shape discrimination
    2. Istopically-improved Argon
2. Neutron/Alpha Backgrounds
    1. Radon
    2. PMT (α,n)
    3. Surface activity

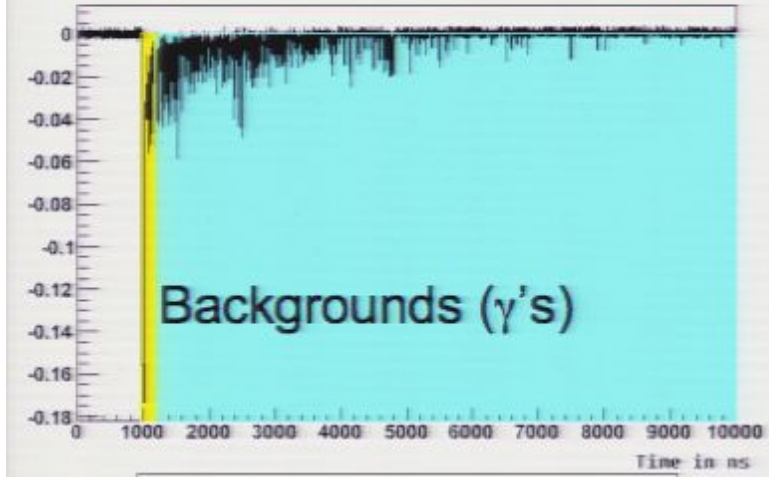
DEAP-1

A 7 kg single-phase
iquid-argon detector

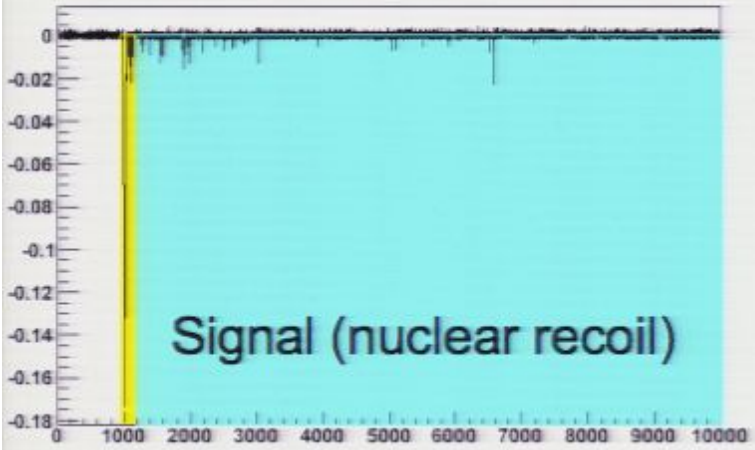


- Development of liquid-argon methods
- Prove pulse-shape discrimination
- Develop background-reduction techniques
- Dark Matter sens. to ~10^{-44} cm^2 at 100 GeV

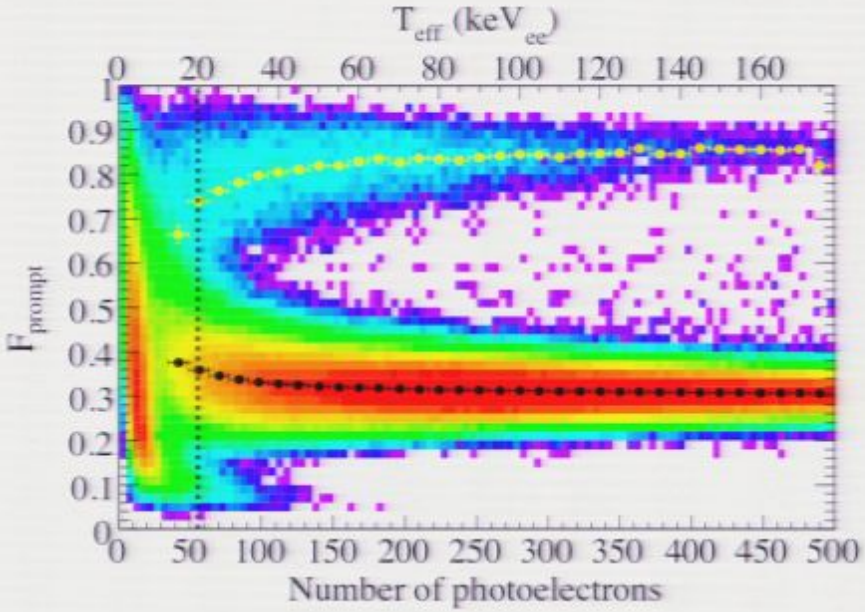
DEAP-1 Pulse-Shape Discrimination



Yellow: Prompt light region
Blue: Late light region



DEAP-1 data using
AmBe calibration source.



Data (at Queen's U./surface)
submitted
to Phys. Rev. C
arXiv.org: 0904:2930

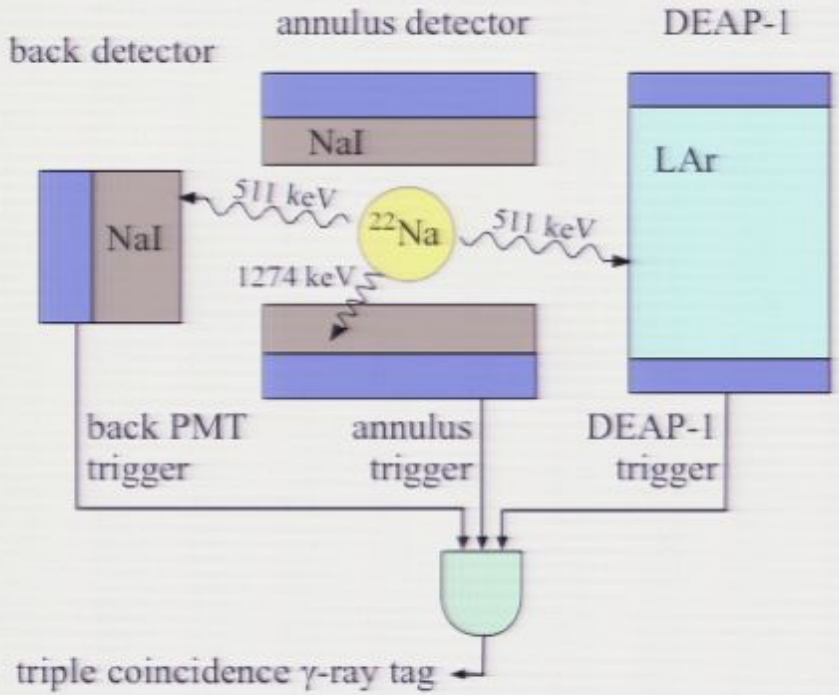
$$F_{prompt} = \frac{\text{PromptPE}\,(150ns)}{\text{TotalPE}\,(9\mu s)}$$

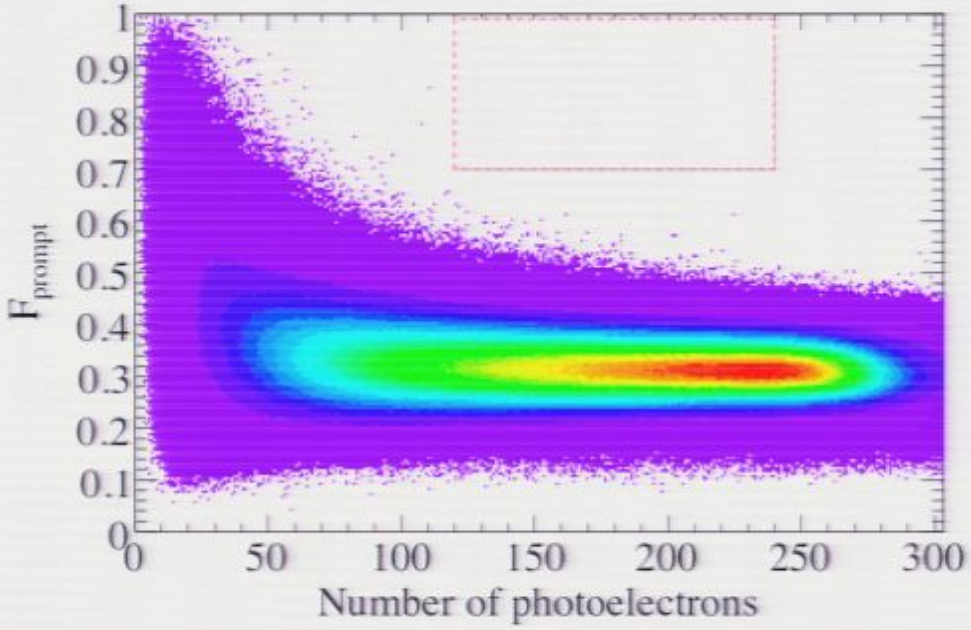
(Light yield = 2.8 pe/keV and stable.)

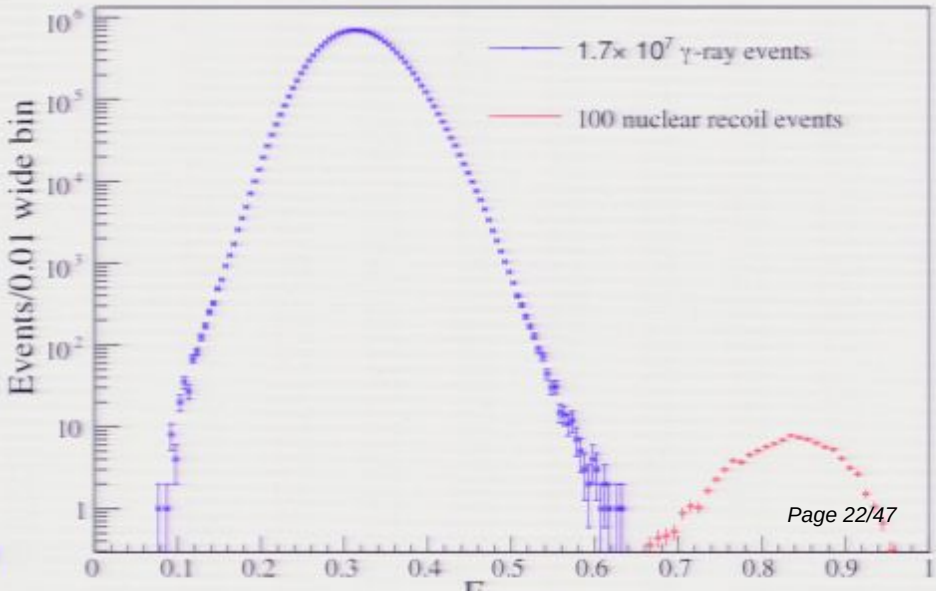
DEAP-1

Tagged γ Calibration

Triple-coincidence Na-22 calibration







120-240 pe: 17 Million events

Queen's Run (surface)

β/γ leakage (statistics limited) <6x10^{-8}

arXiv.org: 0904.2930

DEAP-1

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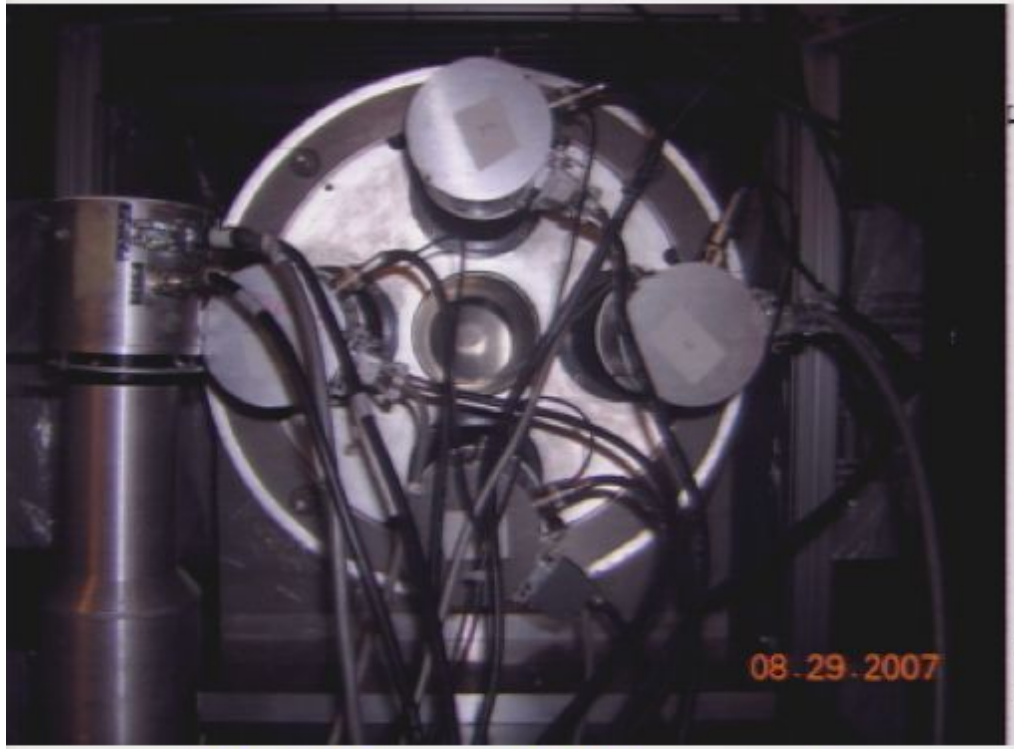

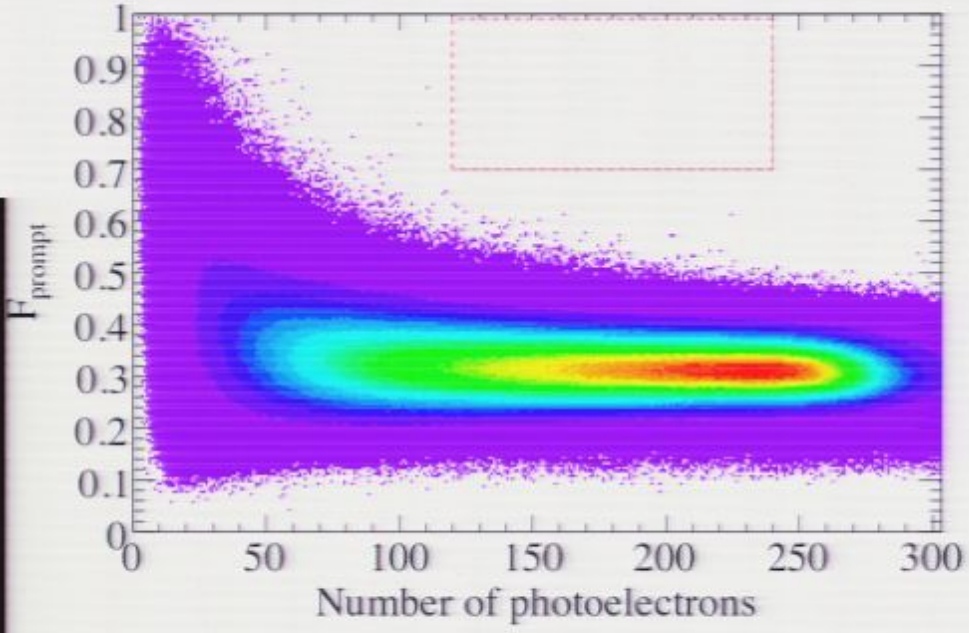

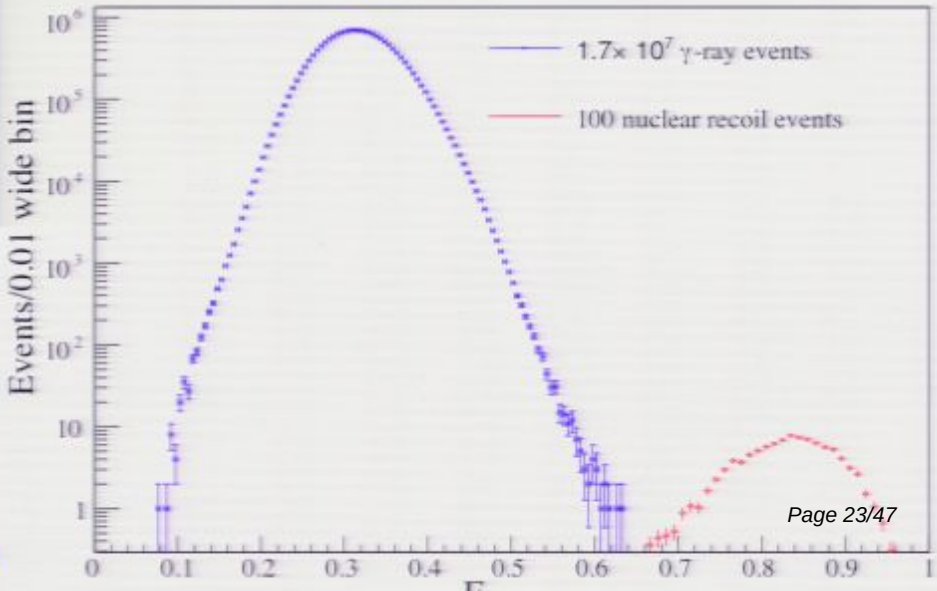

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Queen's Run (surface)
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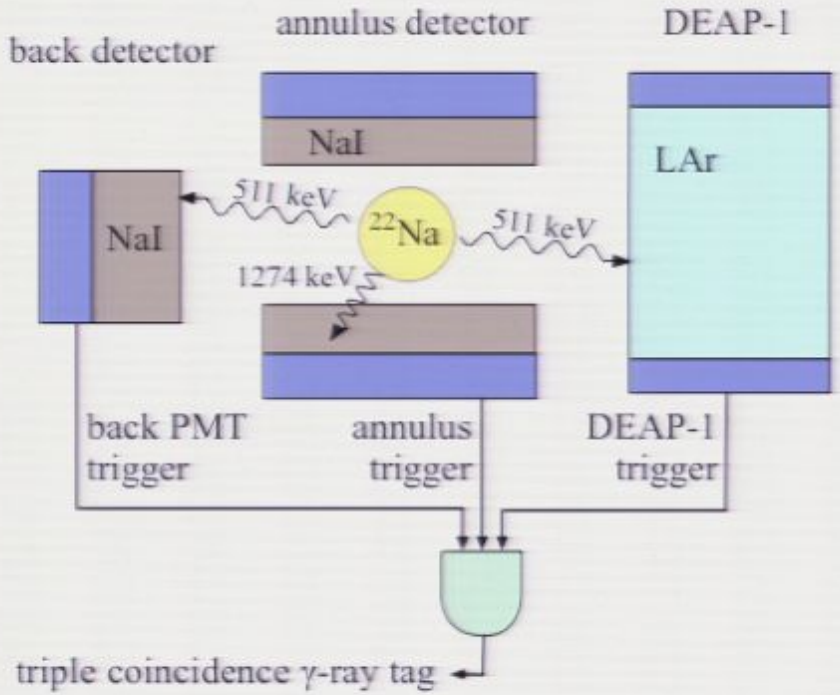

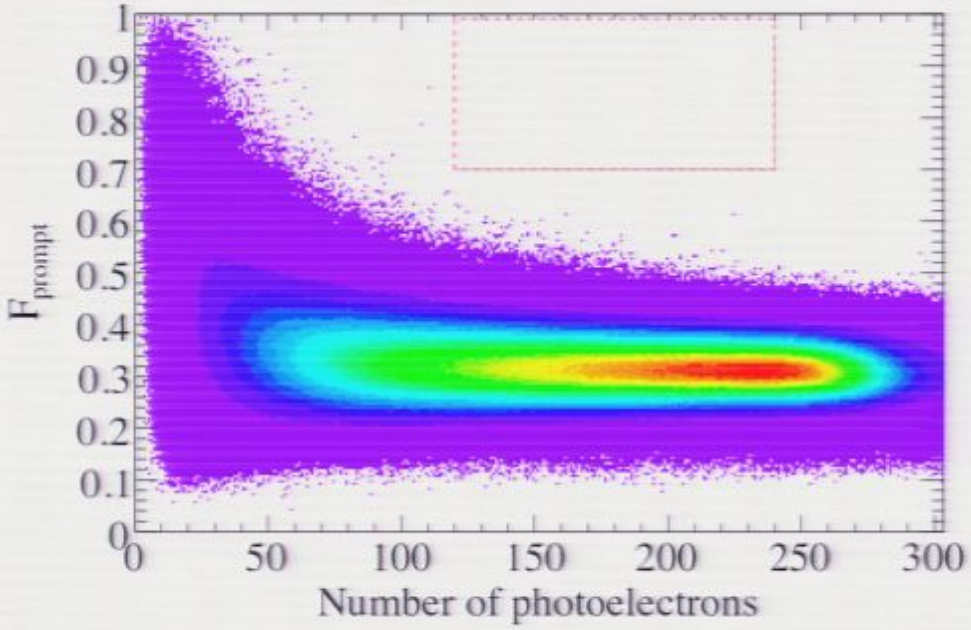

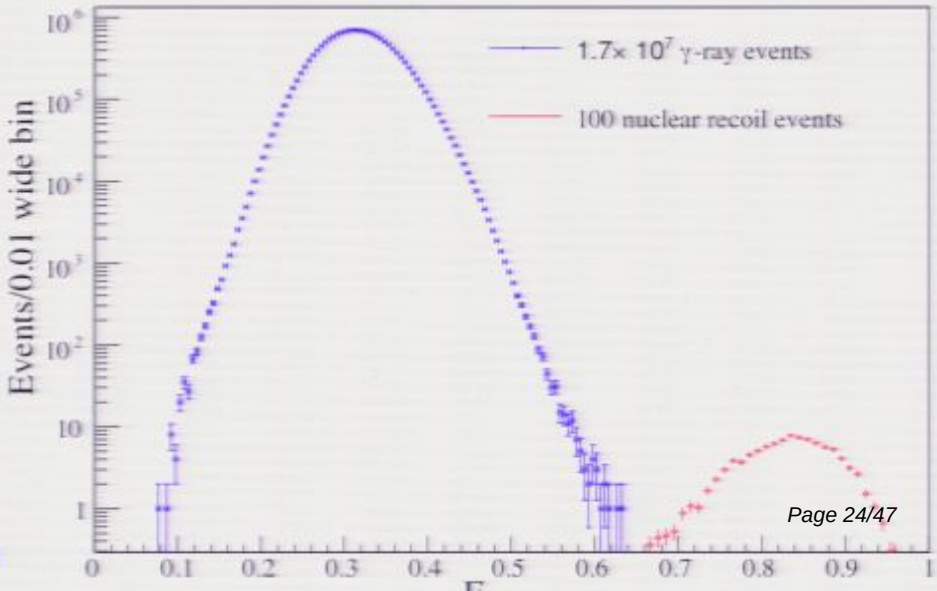

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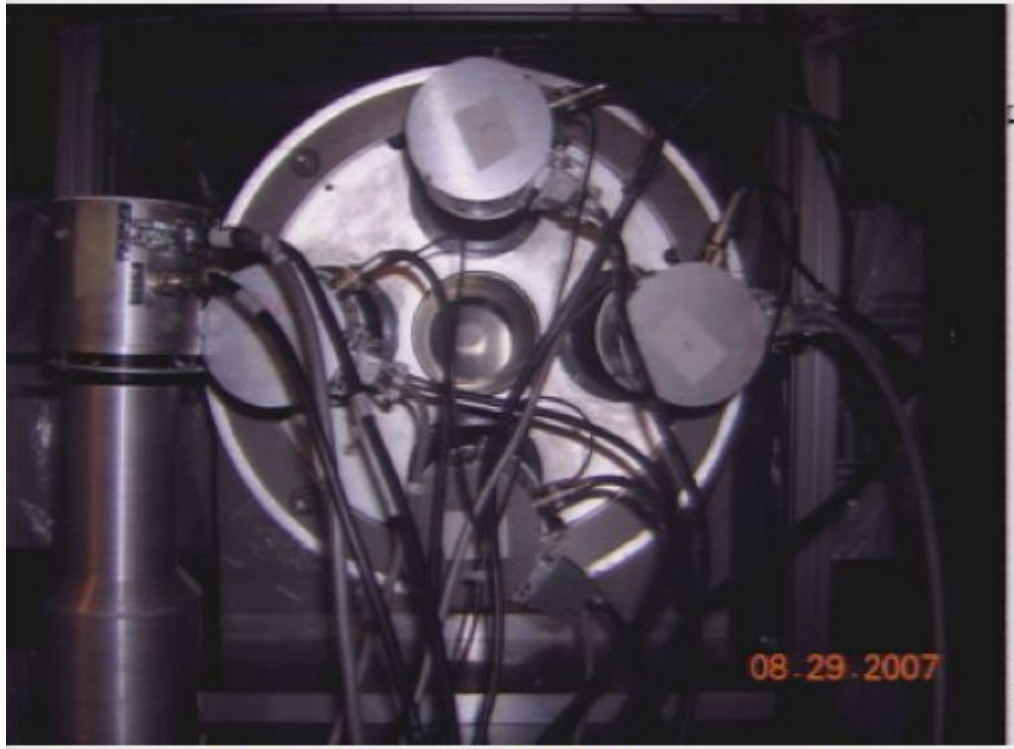

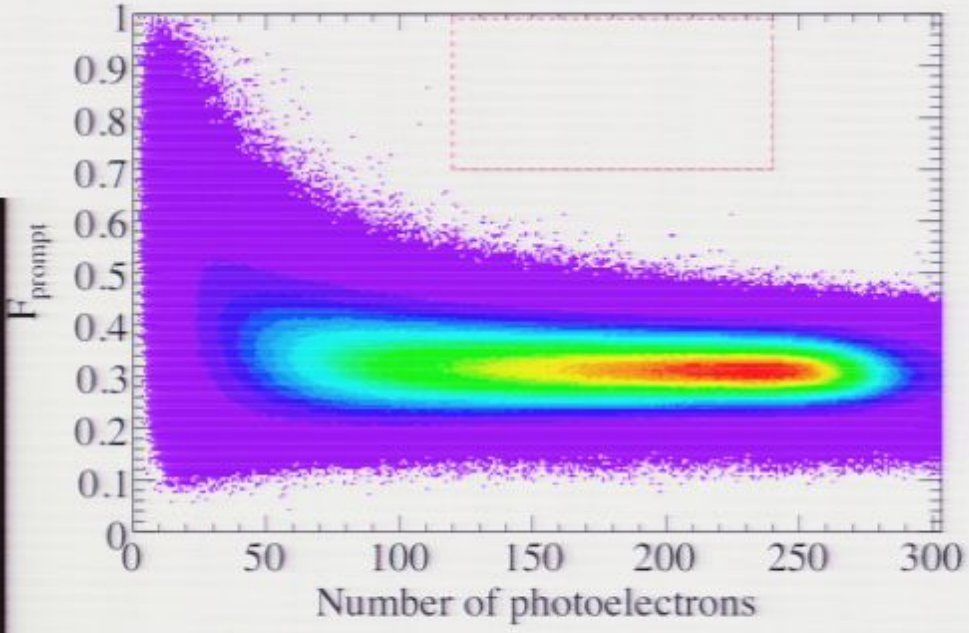

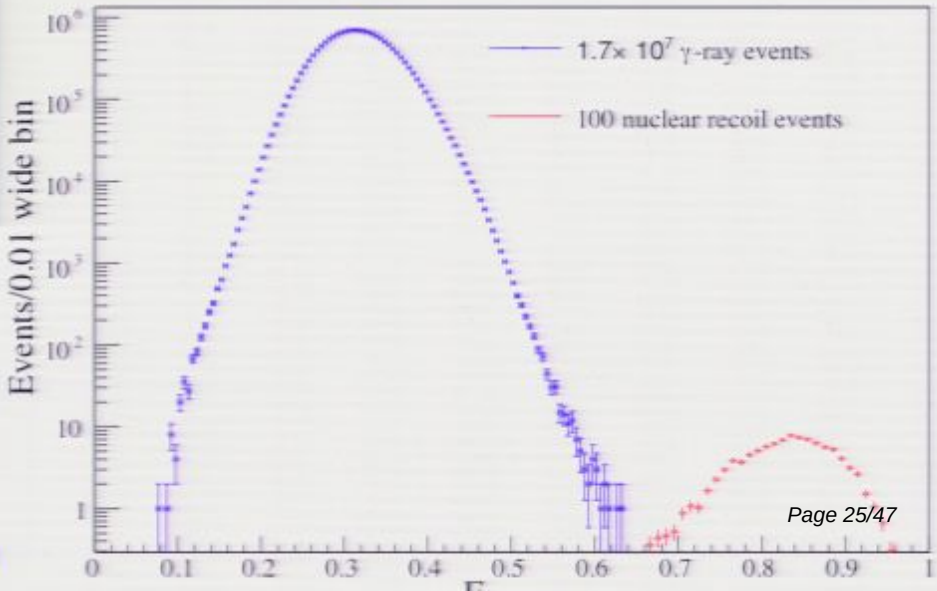

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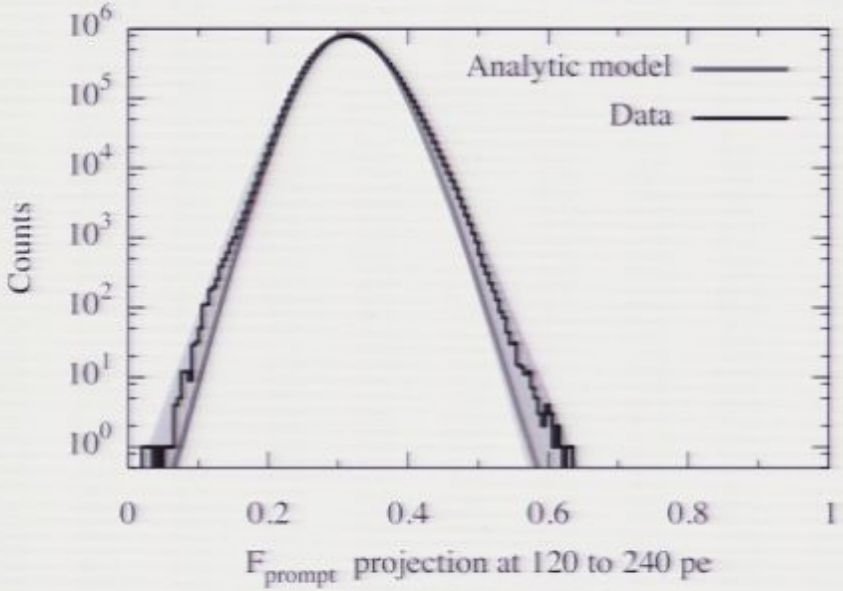
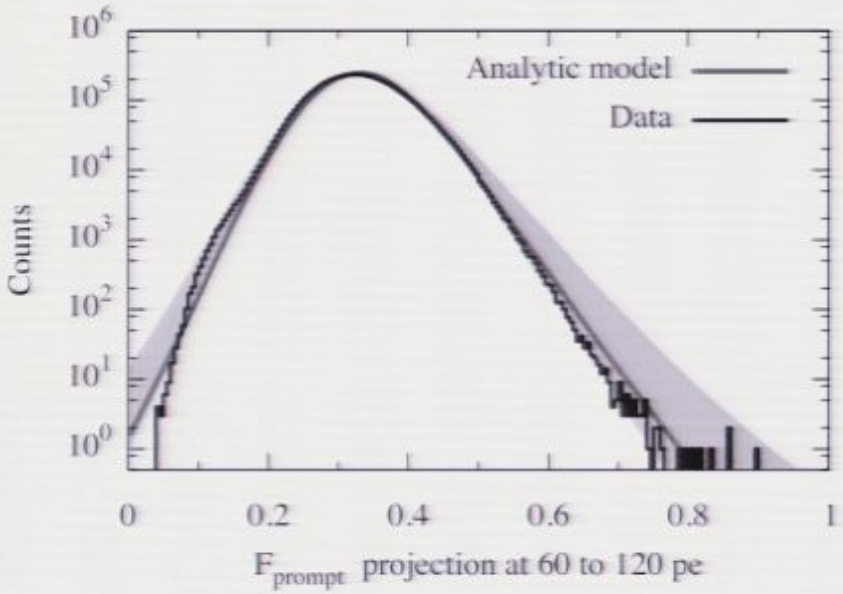
DEAP-1

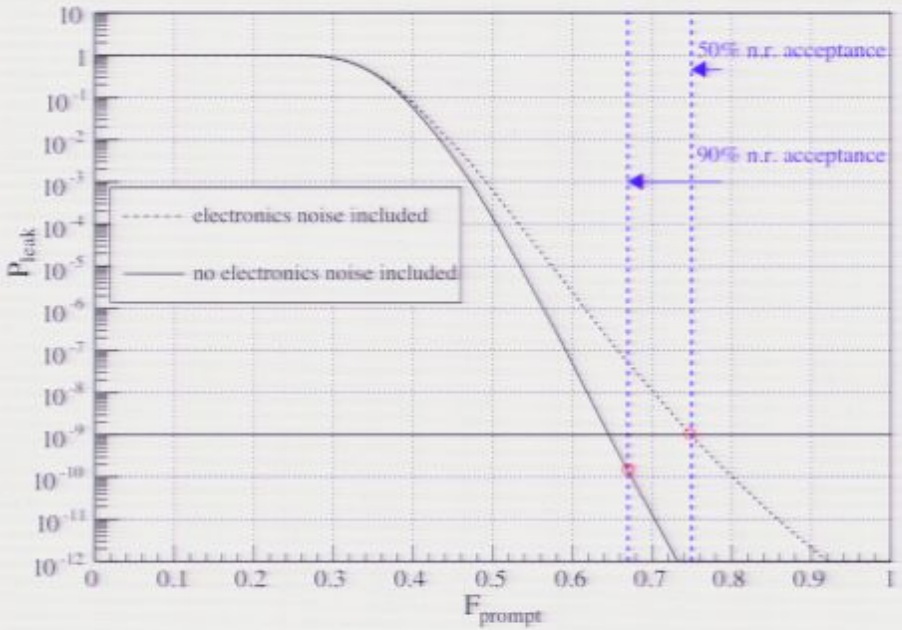
Analytic Model of PSD





An analytic model fits the data well. The uncertainty in the model is due to the absolute spe calibration.

Using the analytic model and assuming 20-40 keVee WIMP acceptance and 6 pe/keV we obtain the following leakage probabilities.



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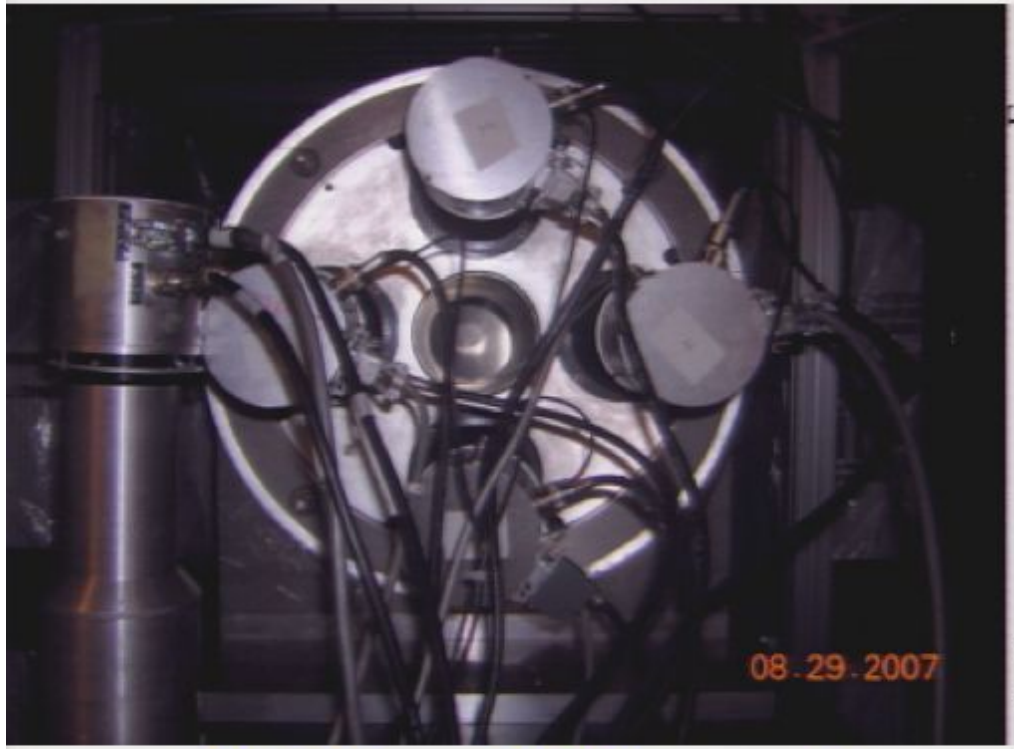

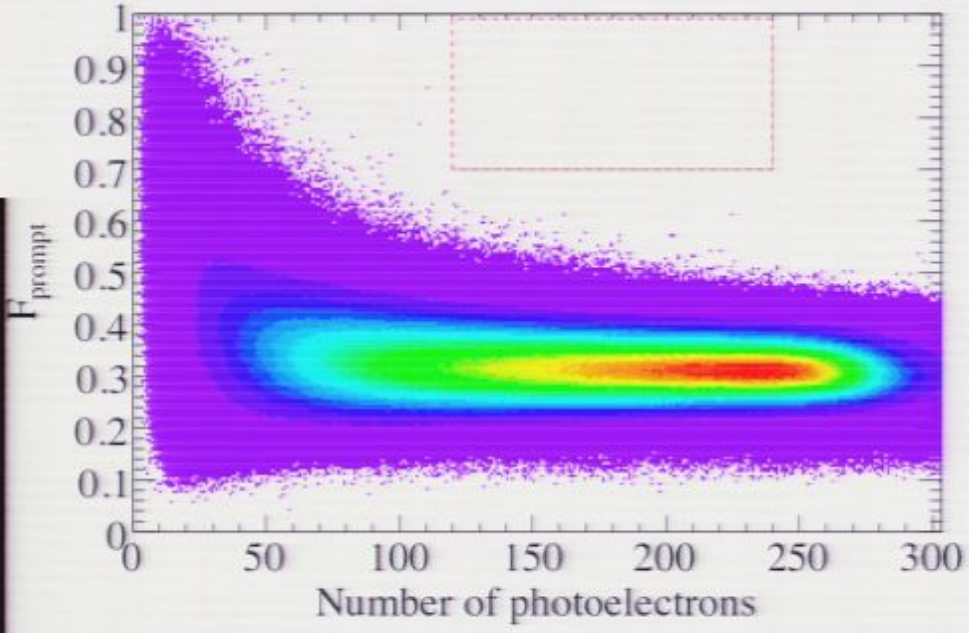

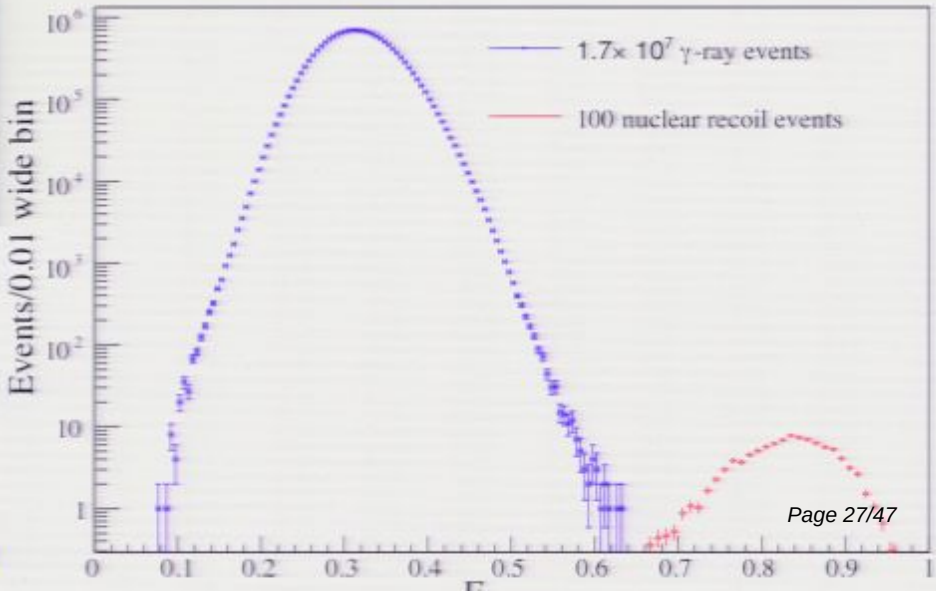

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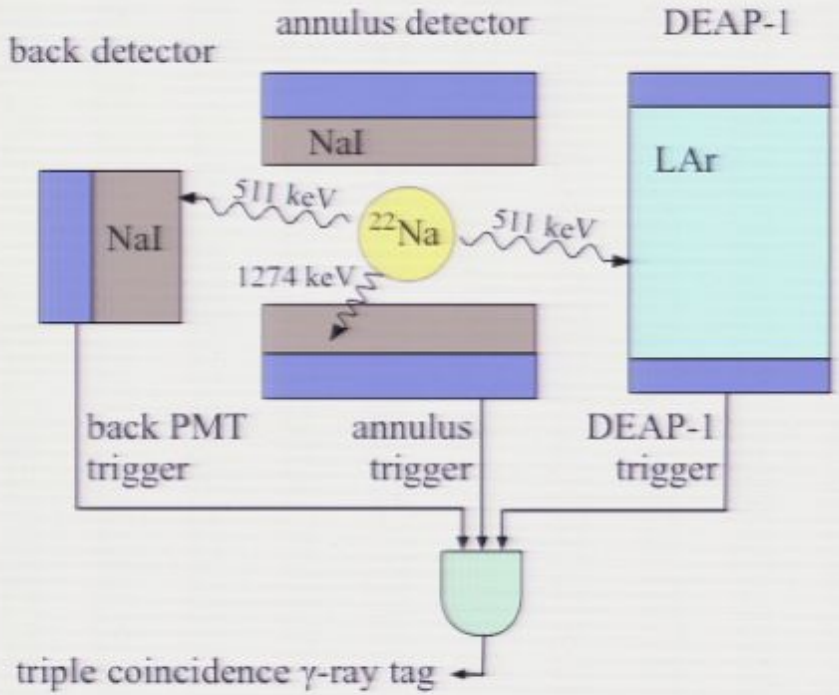
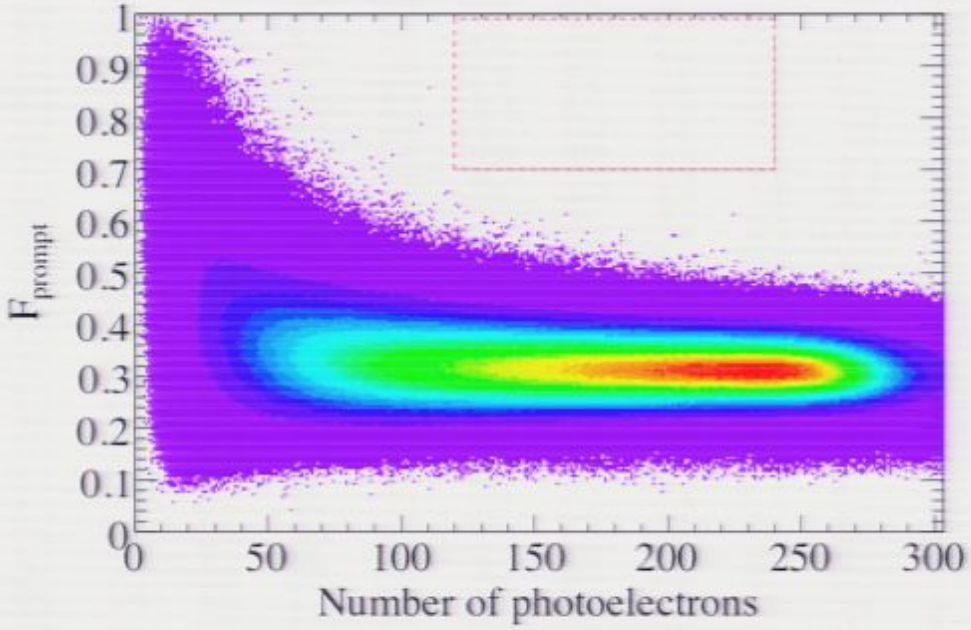
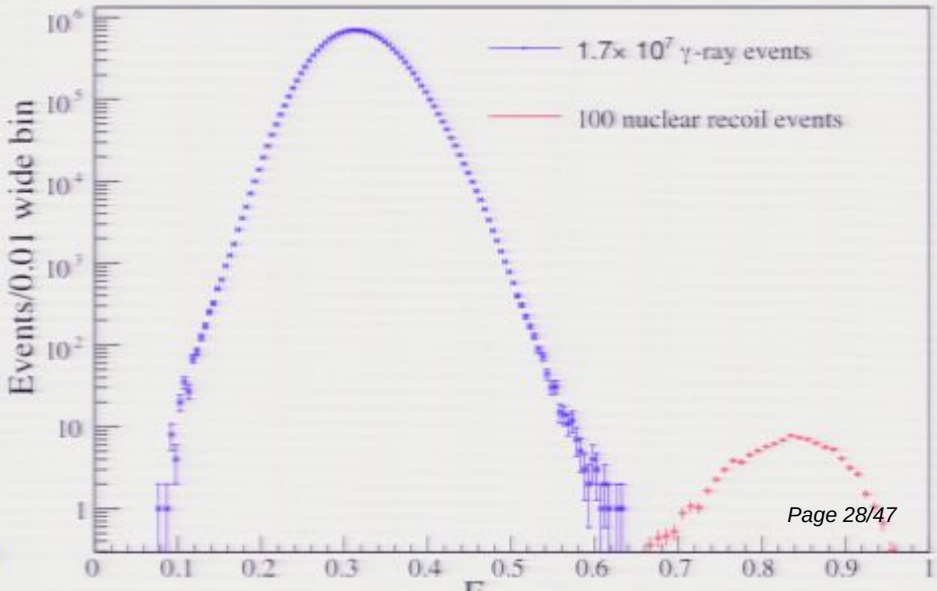
Tagged γ Calibration

Triple-coincidence Na-22 calibration

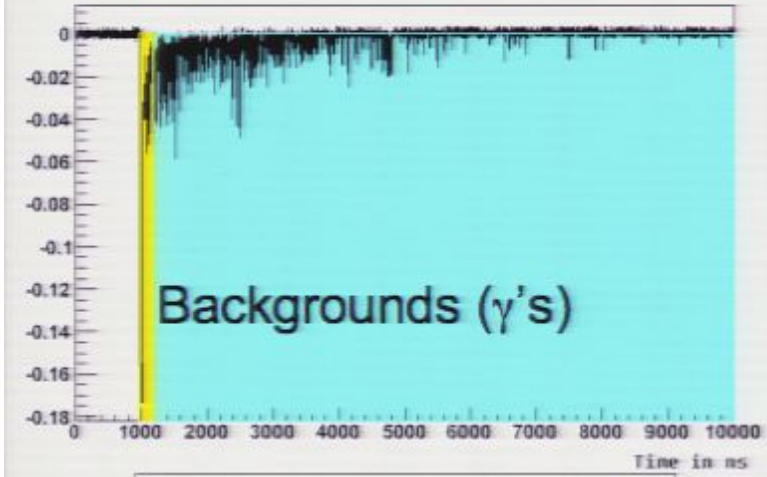




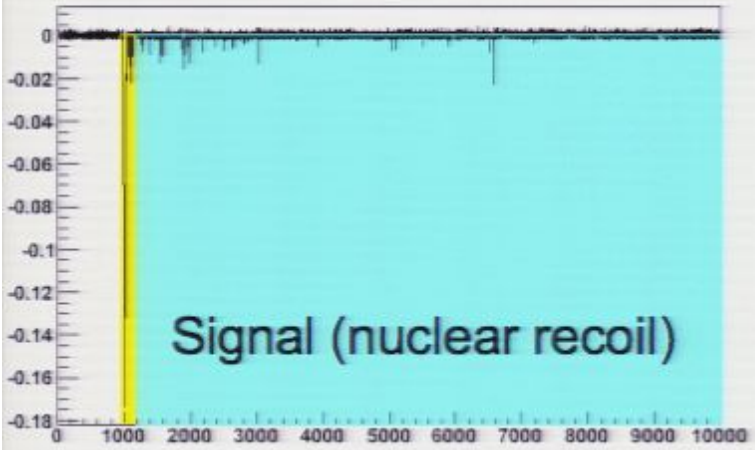


120-240 pe: 17 Million events
Queen's Run (surface)
β/γ leakage (statistics limited) <6x10^{-8}
arXiv.org: 0904.2930

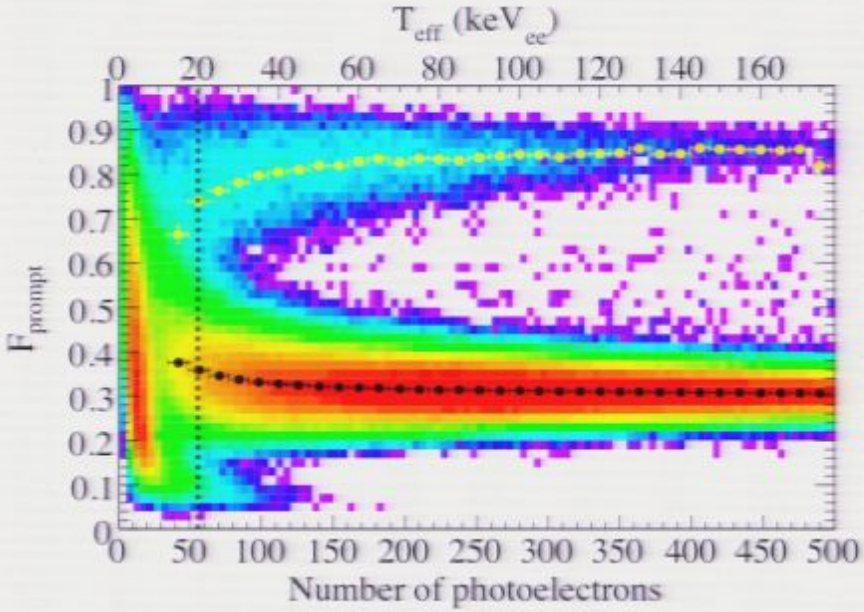
DEAP-1 Pulse-Shape Discrimination



Yellow: Prompt light region
Blue: Late light region



DEAP-1 data using
AmBe calibration source.



Data (at Queen's U./surface)
submitted
to Phys. Rev. C
arXiv.org: 0904:2930

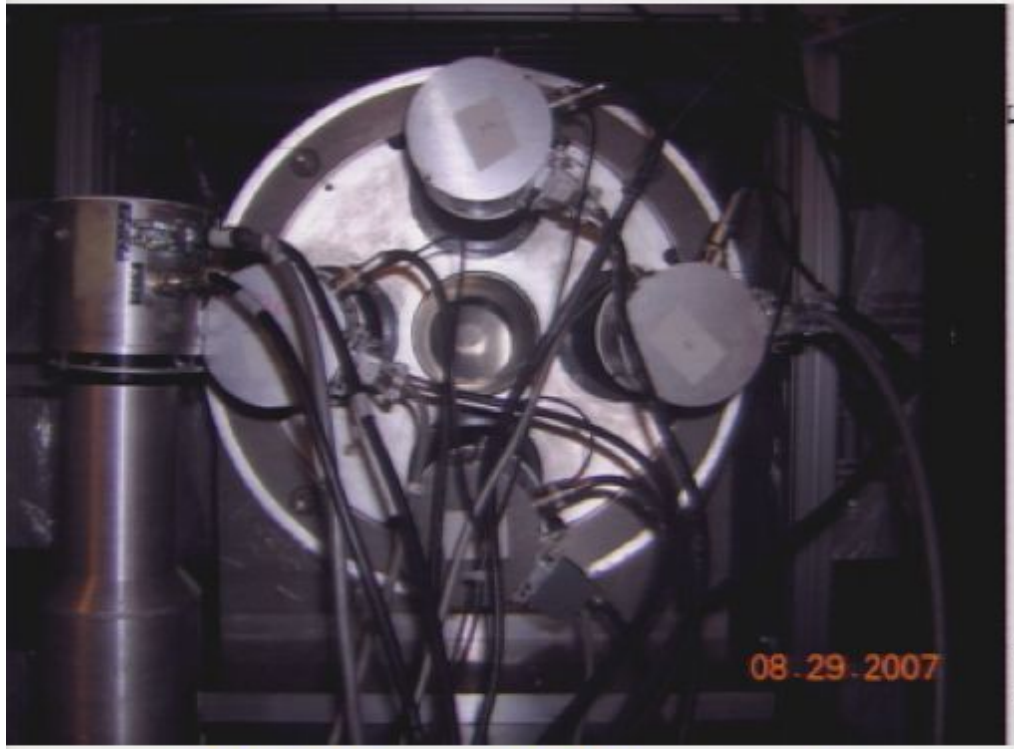
$$F_{prompt} = \frac{\text{PromptPE}\,(150ns)}{\text{TotalPE}\,(9\mu s)}$$

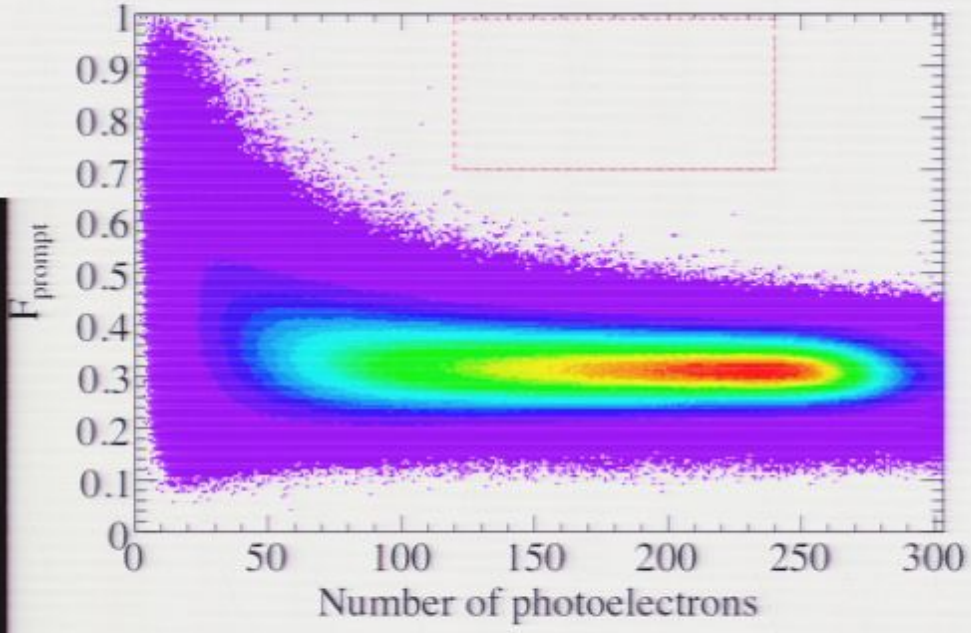
(Light yield = 2.8 pe/keV and stable.)

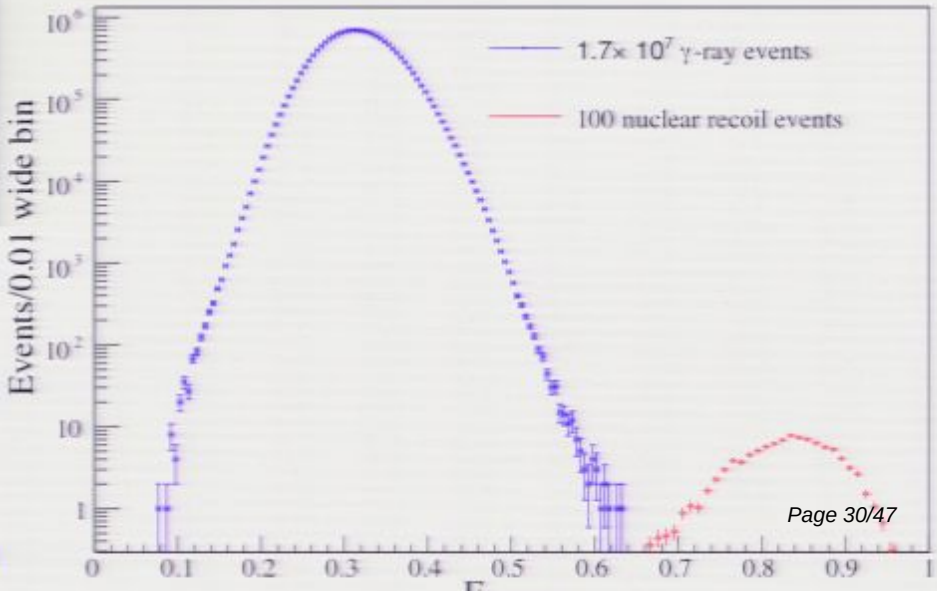
DEAP-1

Tagged γ Calibration

Triple-coincidence Na-22 calibration



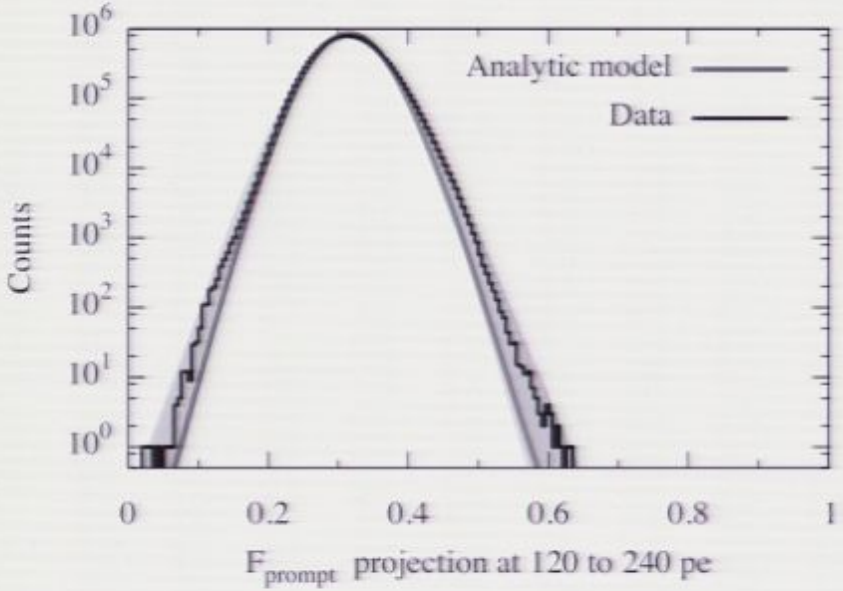


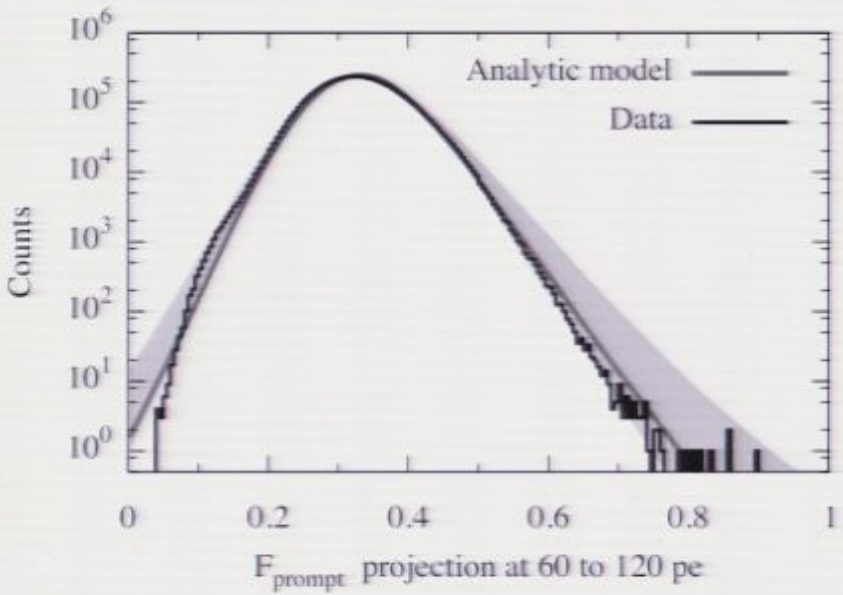


120-240 pe: 17 Million events
Queen's Run (surface)
β/γ **leakage (statistics limited) <6x10^{-8}**
arXiv.org: 0904.2930

DEAP-1

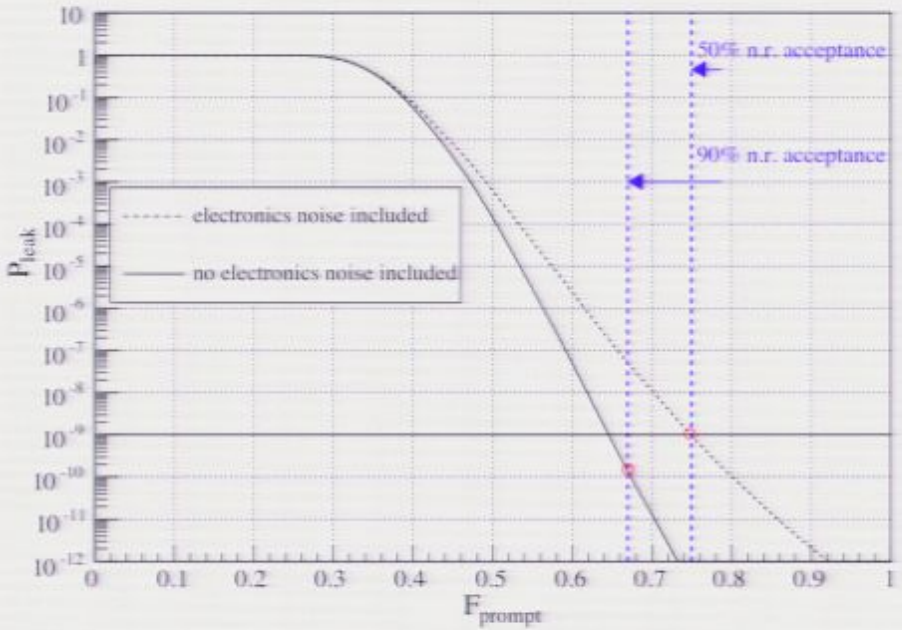
Analytic Model of PSD





An analytic model fits the data well. The uncertainty in the model is due to the absolute spe calibration.

Using the analytic model and assuming 20-40 keVee WIMP acceptance and 6 pe/keV we obtain the following leakage probabilities.



Depleted Argon

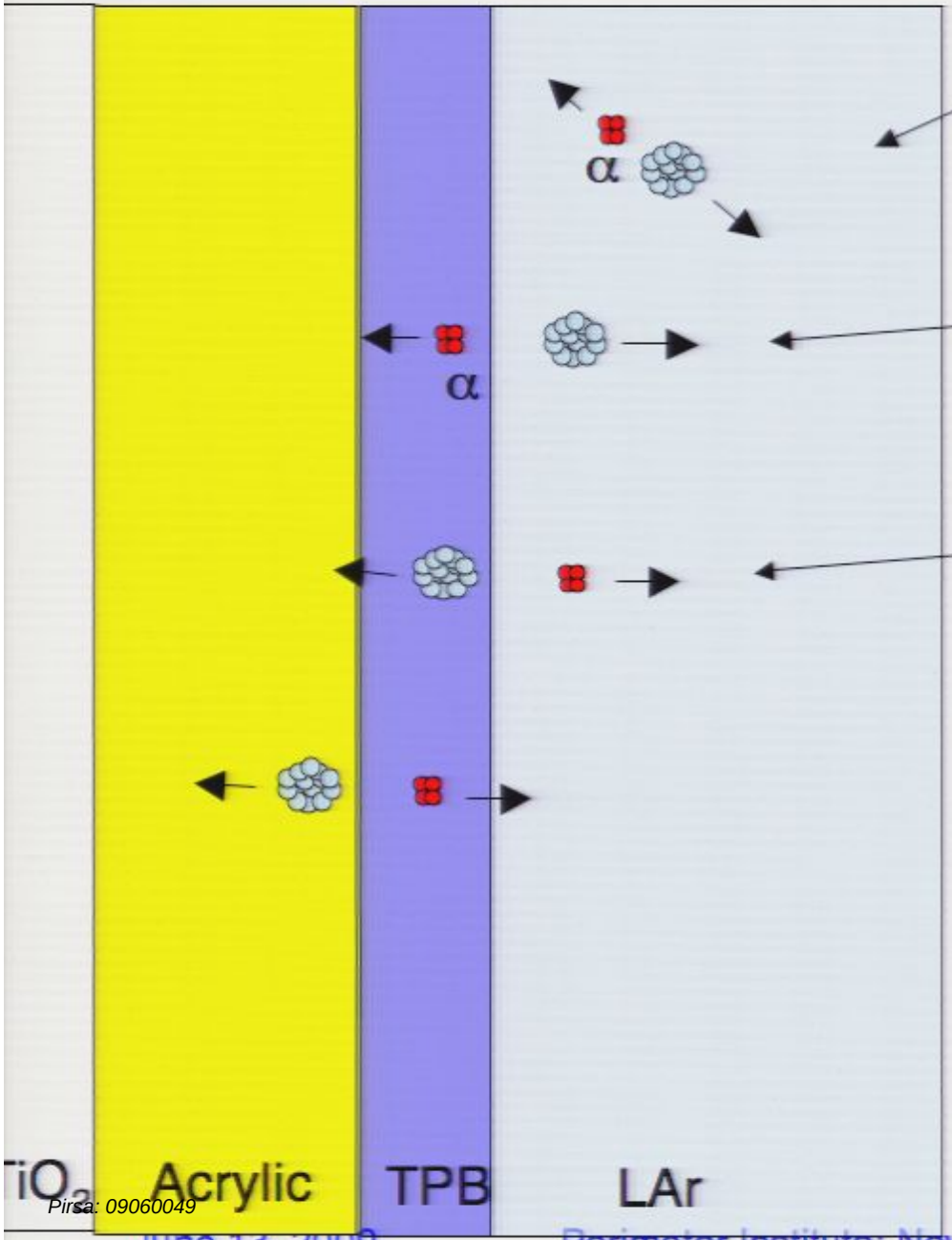
- $^{nat}Ar \sim 1$ Bq kg^{-1}
- A collaboration has been formed with Princeton to search for sources of depleted Argon.
- Engineering to put a proportional counter in a SNOLAB 60-tonne tank. (Tank was part of SNO water system.)
- Looking for depletions > factor 20.

Radon and Surfaces

- Radon has a long-lived radioactive daughter: ^{210}Pb (22-year half life)
- Admitting radon = admitting a "permanent" contamination.

- Radon studies in DEAP-1 and design to avoid radon problems in DEAP-3600…

Surface α events in DEAP for WIMP search



Decay in bulk detector tagged by α-particle energy

Decay from surface releases untagged recoiling nucleus and α in TPB (see both, low energy)

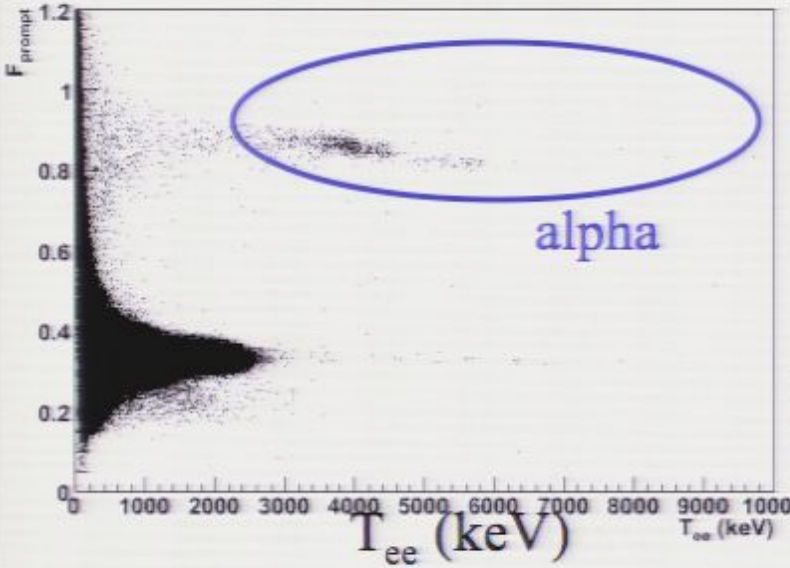
Decay from surface releases untagged recoiling nucleus and α in TPB (see mostly α-particle, high energy)

LE:HE Ratio 1:1 for events on TPB surface

Decay from inside TPB or acrylic releases α which may also enter LAr. Could see
(a) Light from TPB only (prompt) or
(b) Light from LAr (range of energies)

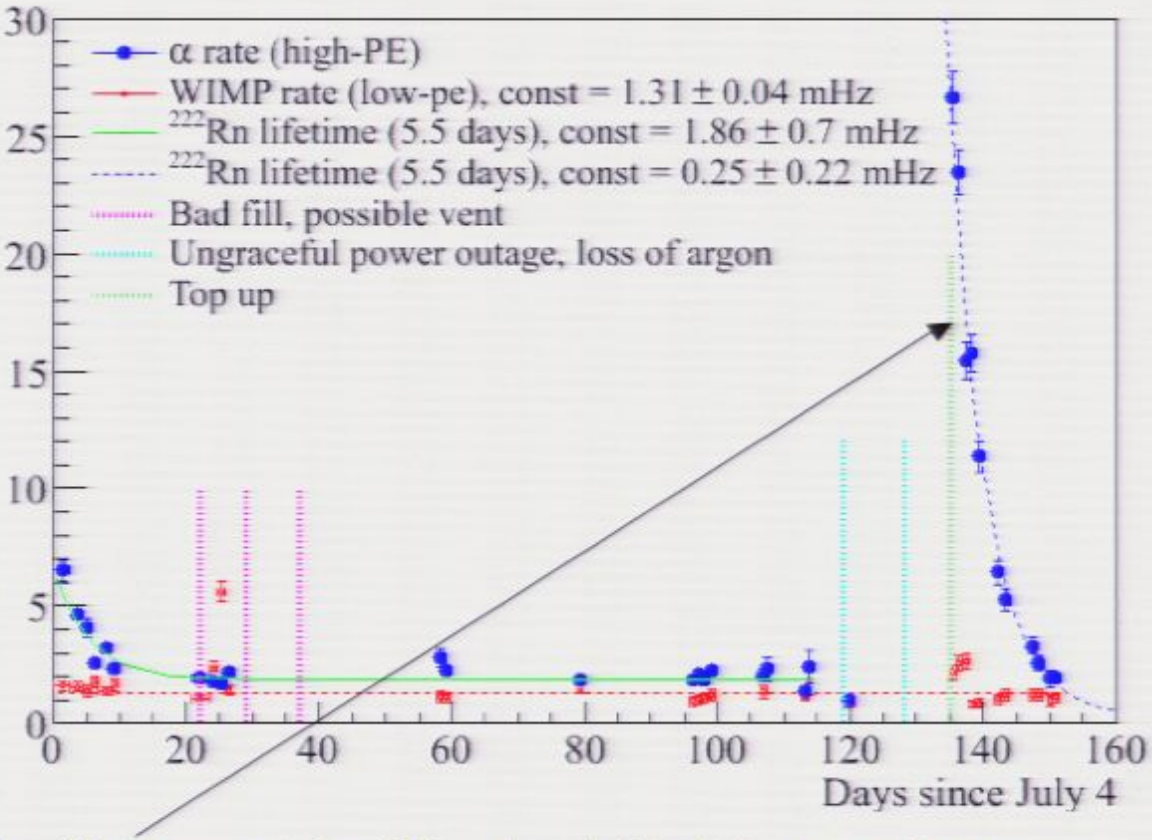
NOTE: Light yield measured for a's in TPB is Y=40 pe/MeV

^{222}Rn in DEAP-1 (data from SNOLAB)

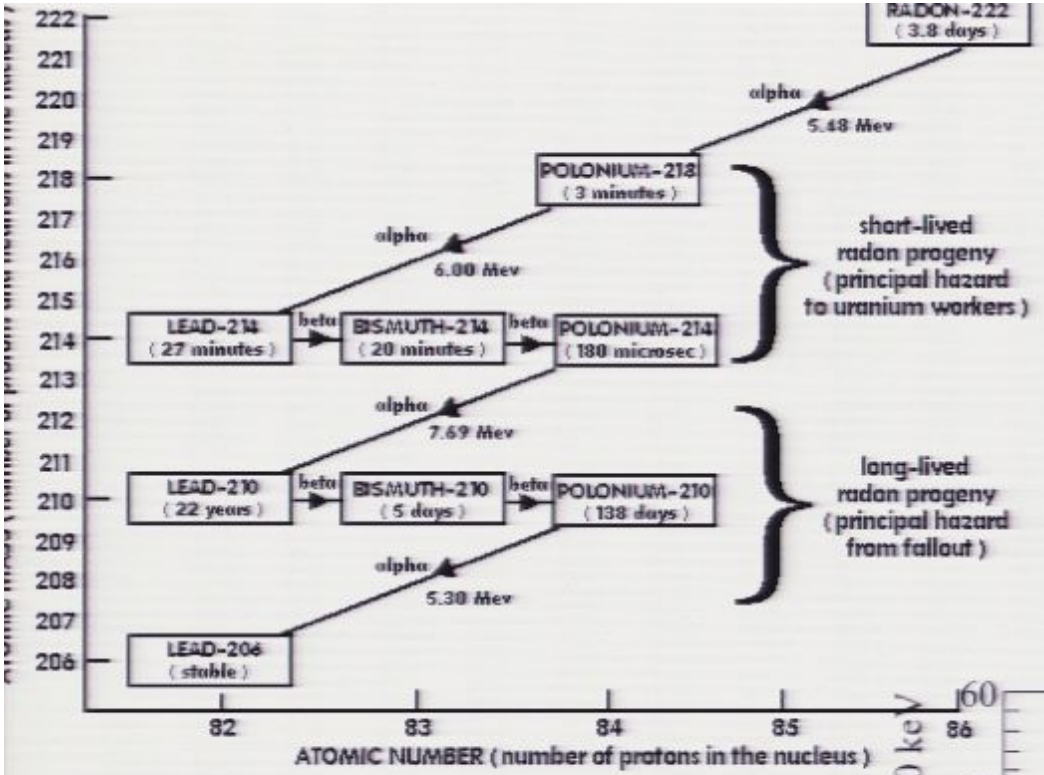


Low-PMT voltage runs to sample high-energy alpha events

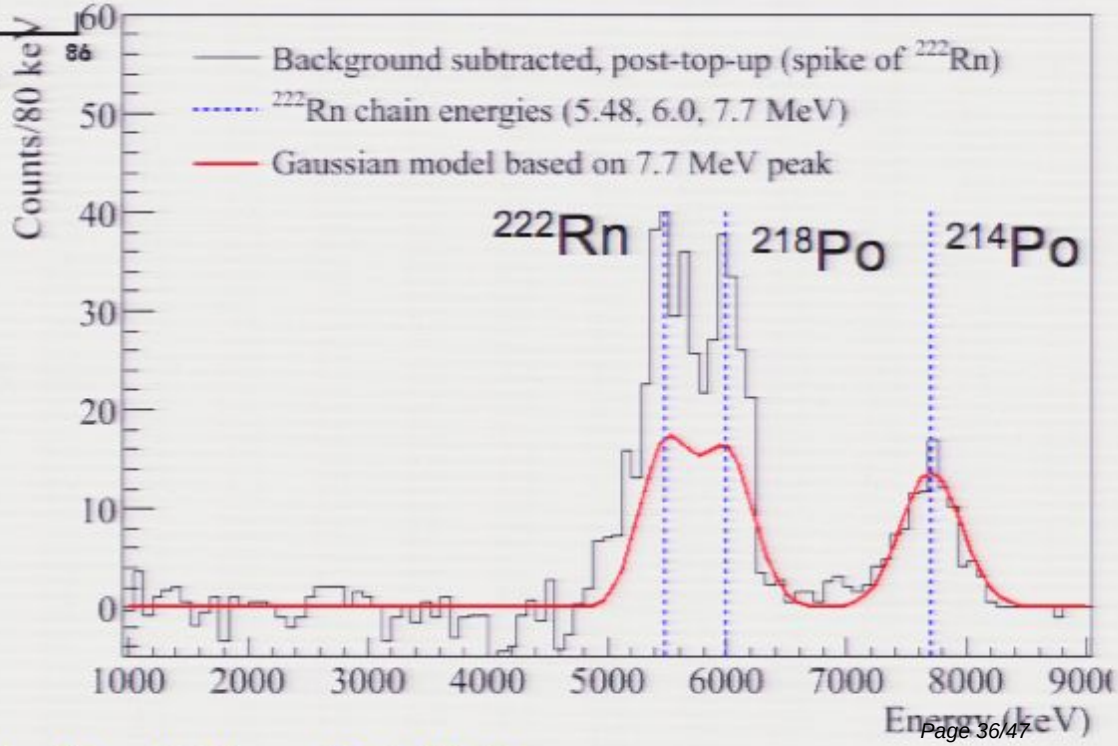
Decay of ^{222}Rn after detector fill



Rn introduced from gas bottle, new Rn filter installed for next run



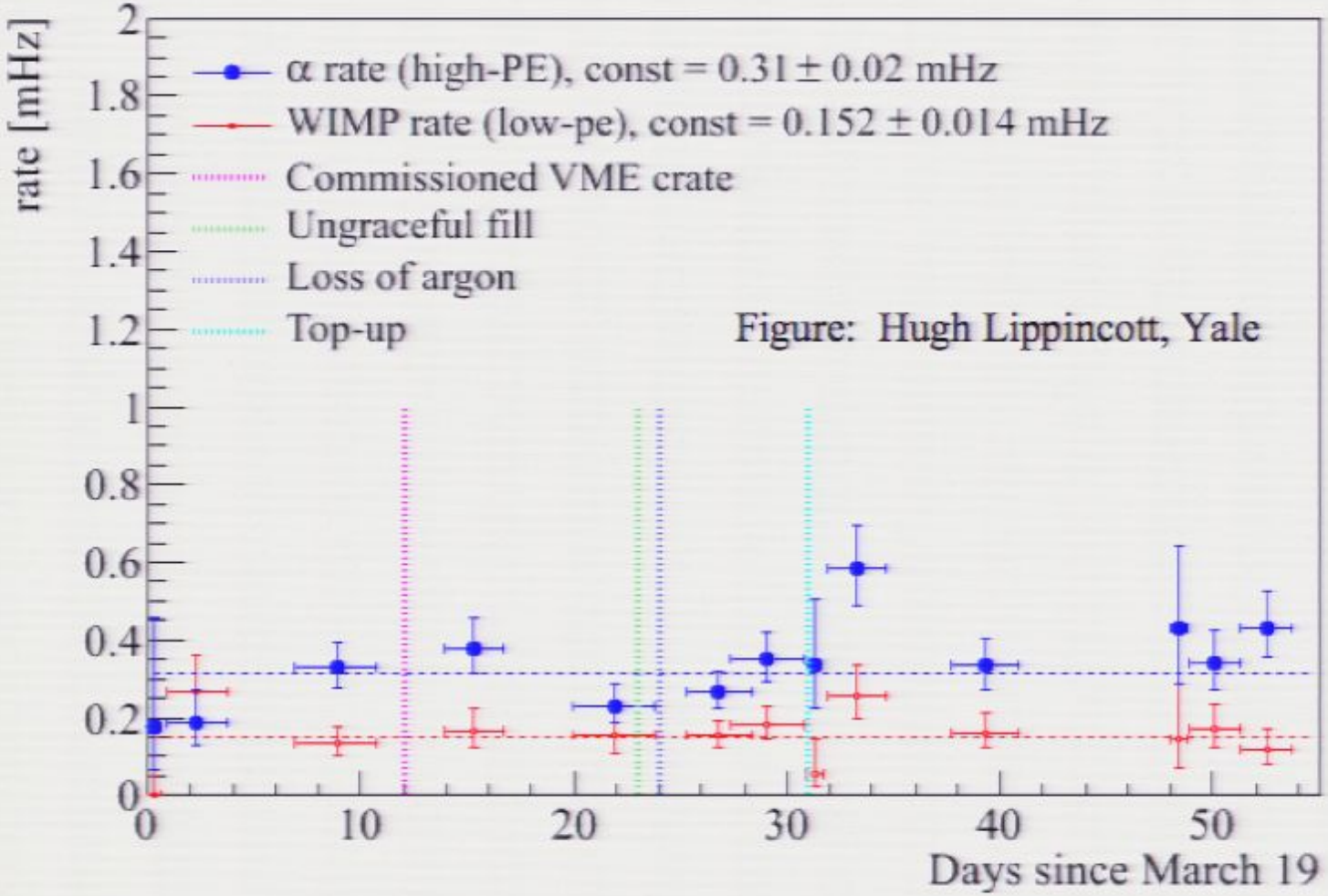
"Radon-Spike in DEAP-1"



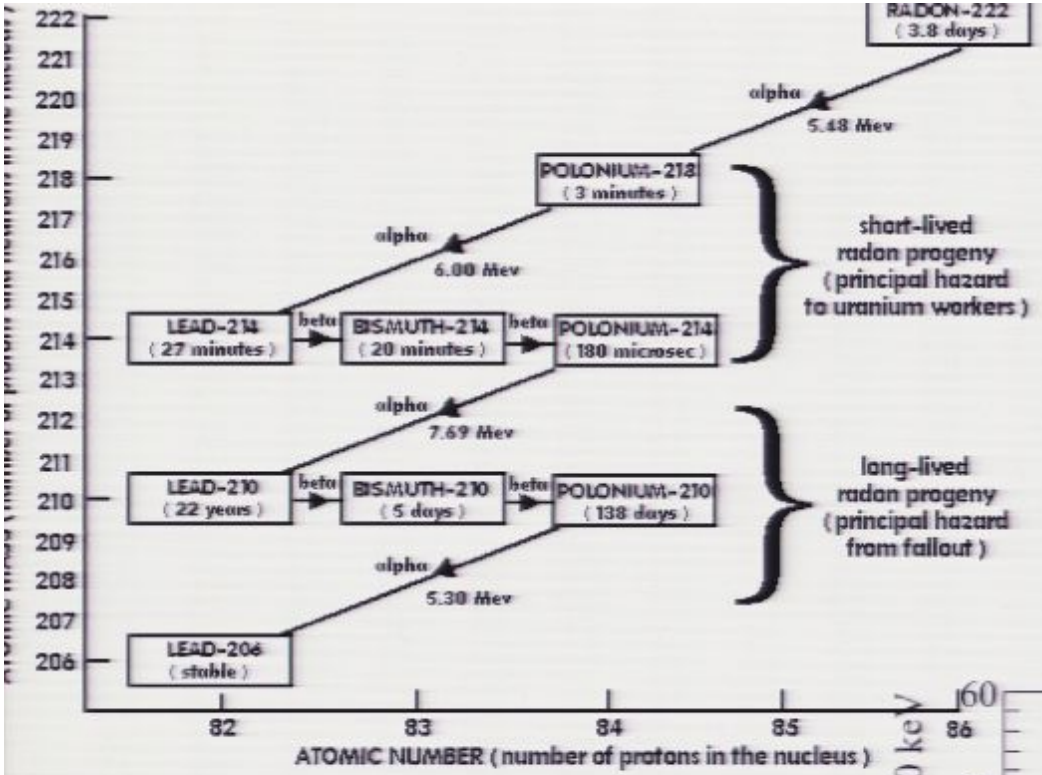
Only see about ½ of ^{214}Po:

consistent with ^{214}Po sticking to walls.

Backgrounds in DEAP-1 at SNOLAB (with Rn trap)



Some residual (small) source of 222Rn (~few atoms/day)
Backgrounds low enough for continued PSD (10^{-9})
New DAQ for high throughput being commissioned (~ kHz)



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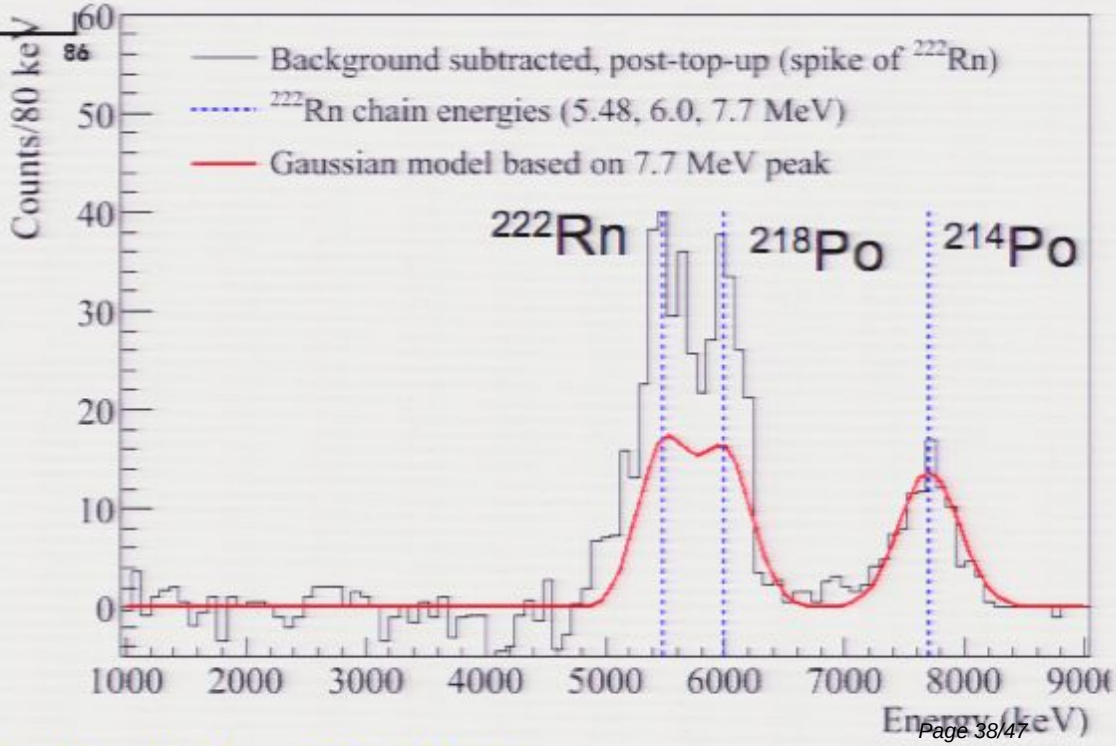

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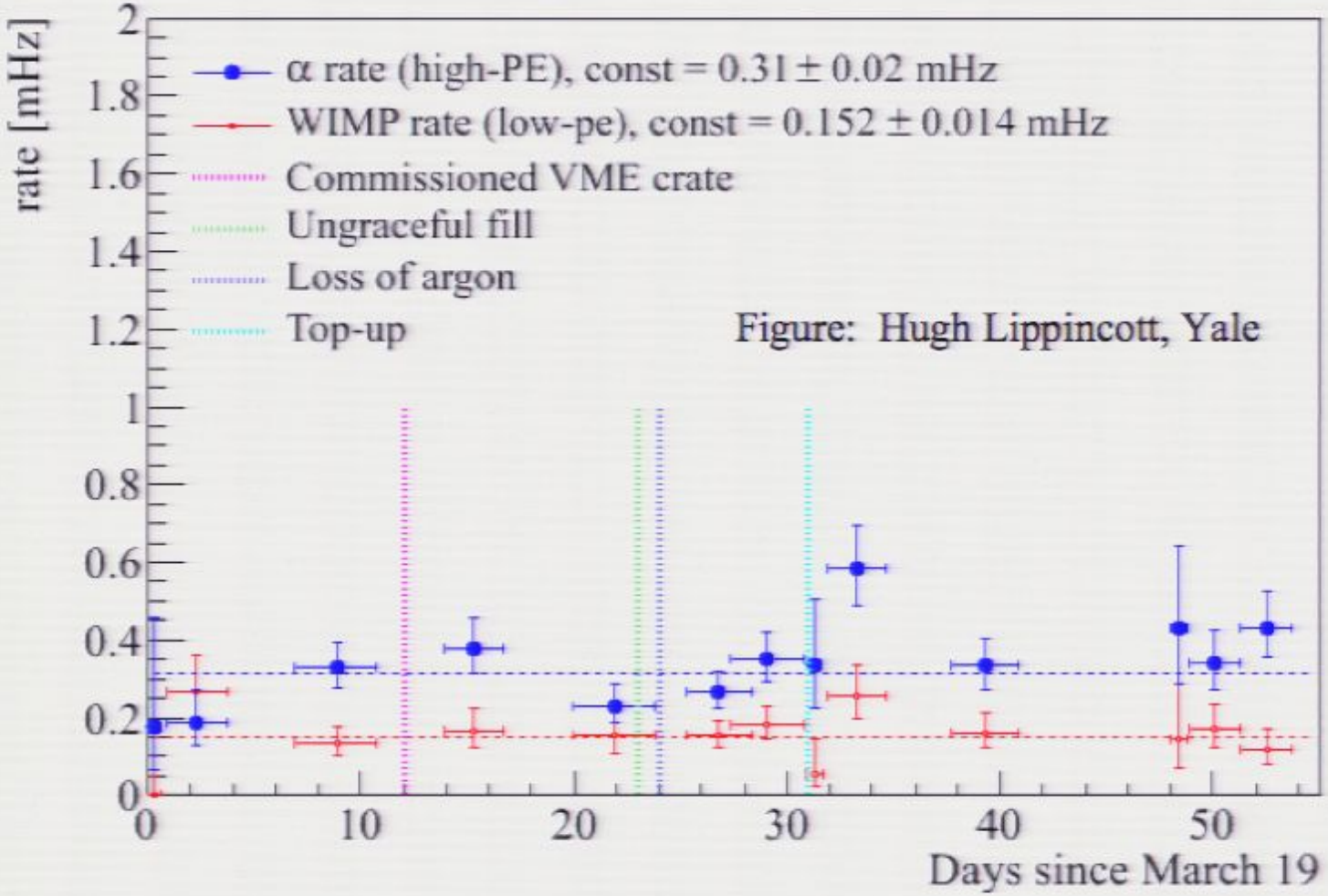


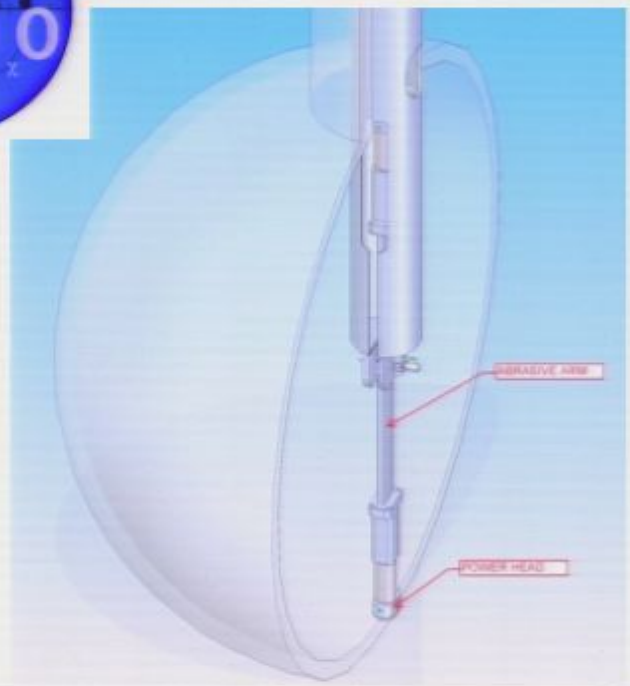
Some residual (small) source of 222Rn (~few atoms/day)
Backgrounds low enough for continued PSD (10^{-9})
New DAQ for high throughput being commissioned (~ kHz)

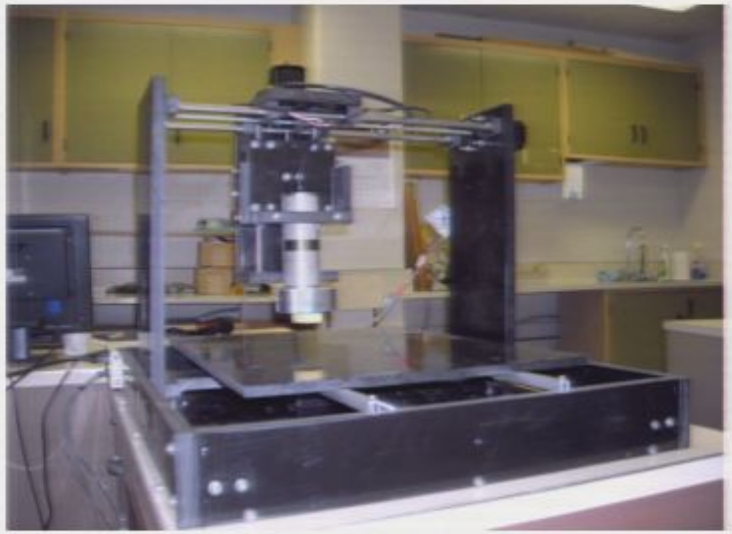
Acrylic Surfaces

- Will be exposed to mine air during construction
- Will have radon daughters plate onto surface
- **Even worse: will have Rn diffuse (~0.11mm) into acrylic**

- Need to remove Radon-daughter contamination *after construction in controlled atmosphere.*

DEAP-3600 Acrylic Resurfacer





resurfacer sanding head

Mechanical resurfacer removes surface contamination in inert environment.

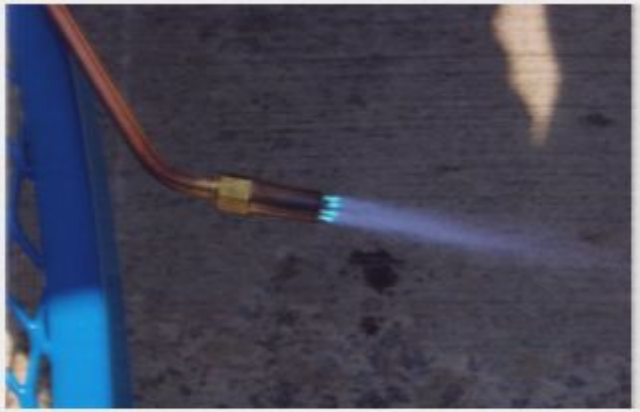
Debris is flushed and removed with ultrapure water.

Resurfacer components are low-emanation materials (for Radon-load)

Finalizing drawing package in place for resurfacer component construction

Bulk Acrylic

- After surface contamination is removed, is the acrylic bulk sufficiently clean?
- Likely yes, we intend to prove it. Levels are so low we need to reduce acrylic.



Test setup at SNOLAB.

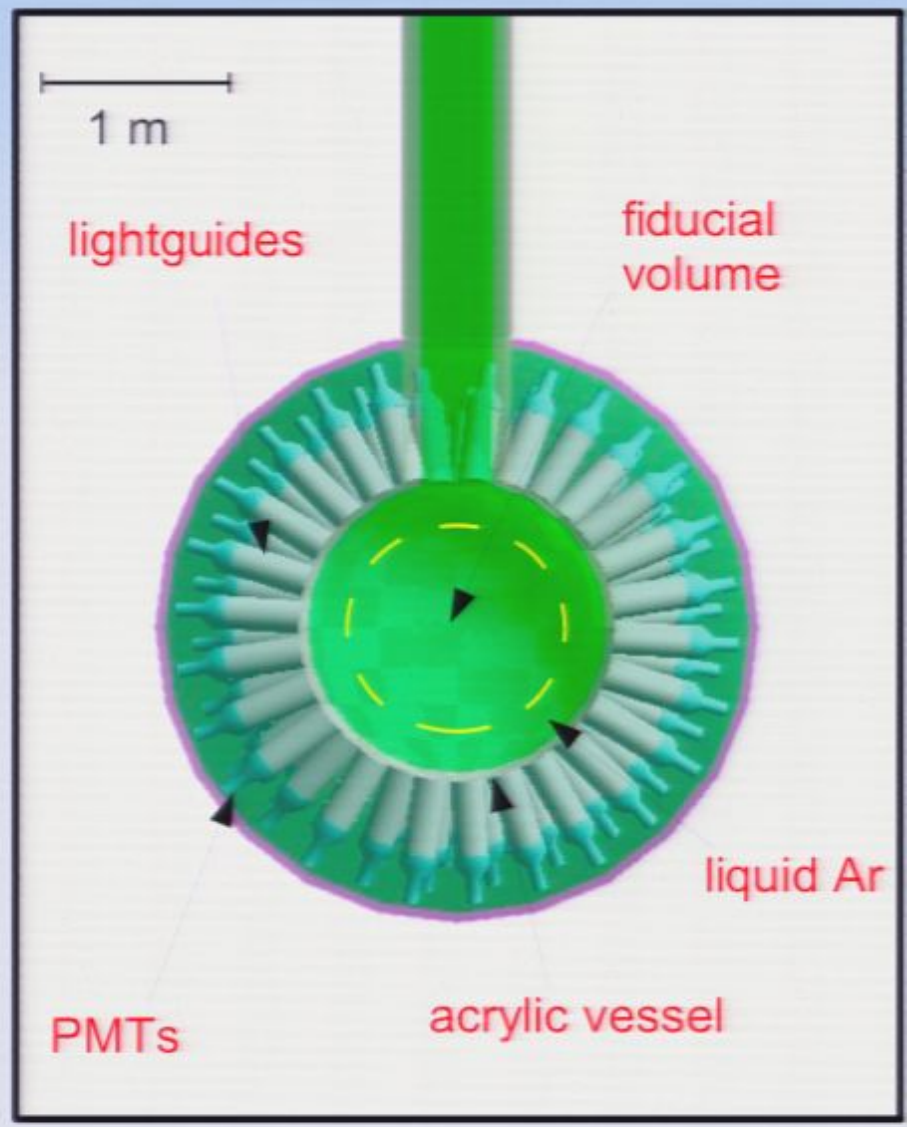
Counting residue

- Th chain and above ^{222}Rn in U chain is pains-taking but straight-forward gamma counting in a Ge well detector.

- Below Rn is hard because Po is volatile and Pb comes only with a 4% γ branch.
- Can not do NMR because Pb has spinless nucleus.
- ICPMS?

DEAP-3600

- Large scale detector under construction
  - Neutron shielding design based on simplified MC model
- We expect the PMTs to be the main source of neutron background
  - Now full MC model of the geometry available
  - Background simulations help to optimize the setup



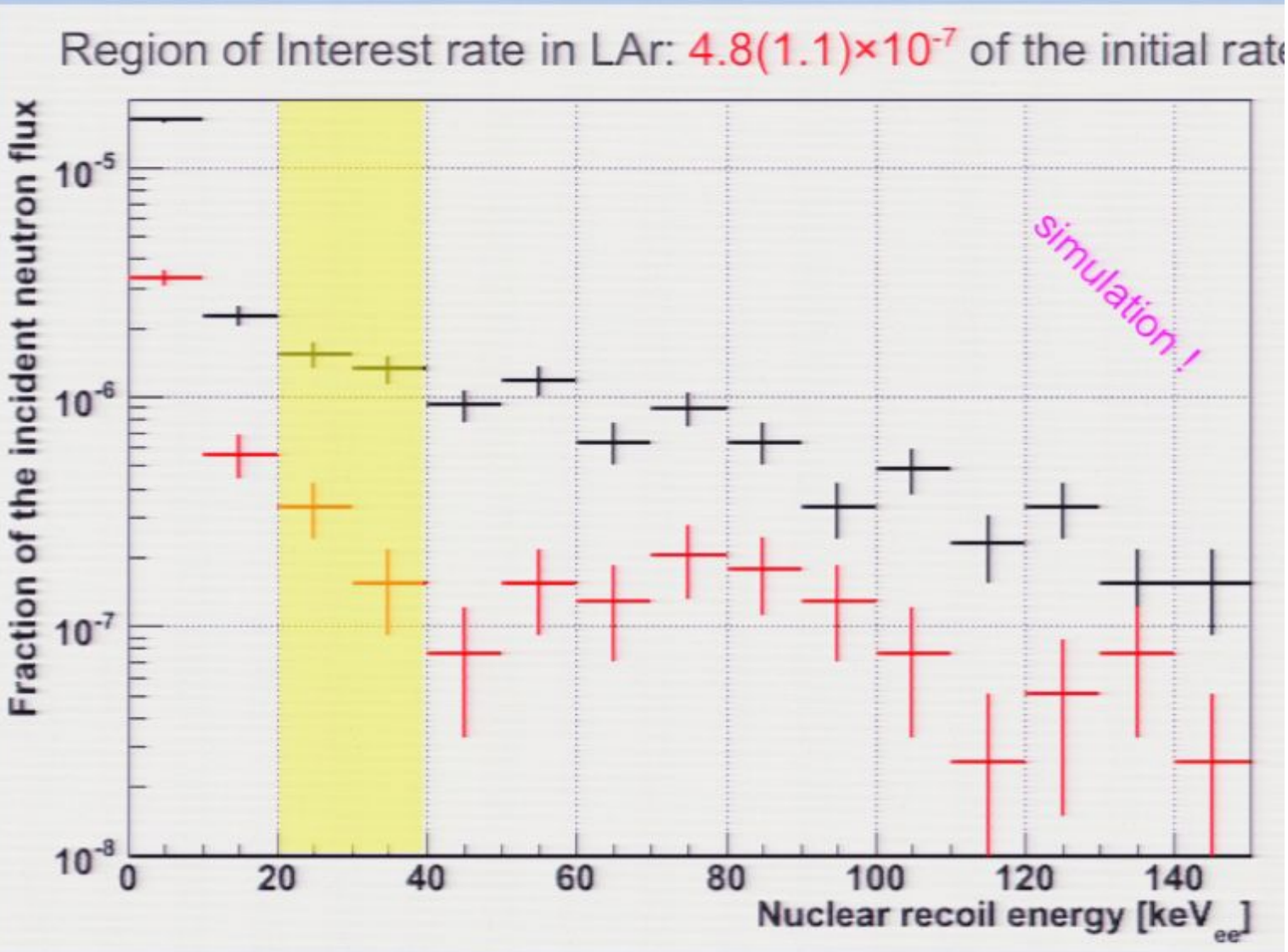
PMT background

Neutrons are generated from PMTs

The energy spectrum includes fission (U, Th) and (α, n) neutrons

Assuming total PMT activity of $2 \cdot 10^5$ yr $^{-1}$, the neutron rate in the fiducial volume becomes:

1 yr $^{-1}$ (preliminary)



Summary

- DEAP-3600 must control backgrounds to
  ~0.1 events / tonne / year
- Detector designed based on only acrylic and wavelength shifter touching Argon in central volume.
- Need exquisite control of surfaces
  - Resurfacing under vacuum
  - TPB application under vacuum in situ
- Need excellent control of acrylic quality
- Need lots of plastic to absorb PMT (α,n)

Thank you

- To the Perimeter Institute for this great meeting.