A DEAP Search For Dark Matter

NExT Physics Meeting
Dr Joseph Walding
Royal Holloway, University of London

1st November 2017

Outline

- What is DEAP-3600?
- Backgrounds
- Calibrating DEAP
- First Physics from DEAP
- Summary and Outlook

DEAP Collaboration: 75 researchers in Canada, UK, Germany and Mexico

University of Alberta · Carleton University · Laurentian University / Université Laurentienne · Queen's University · Royal Holloway University of London · Particle Physics Rutherford Appleton Laboratory · SNOLAB (Mining for Knowledge / Creuser pour trouver... l'excellence) · University of Sussex · TRIUMF · Instituto de Física (UNAM)

What is DEAP-3600?

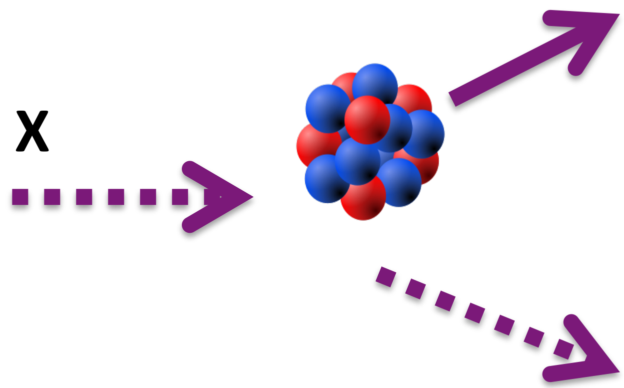
- **D**ark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination
- DEAP-3600: Liquid Argon (LAr) detector
  - Designed for 3600 kg LAr, 1000 kg Fiducial mass
  - SNOLAB – Sudbury, Ontario
  - 6800 feet underground = 6000 m.w.e
  - Single phase detector
- Single phase – No gaseous amplification region
  - No electron drift requirements
  - 4π PMT coverage
    ➔ Detector scalability to O(kTonne)

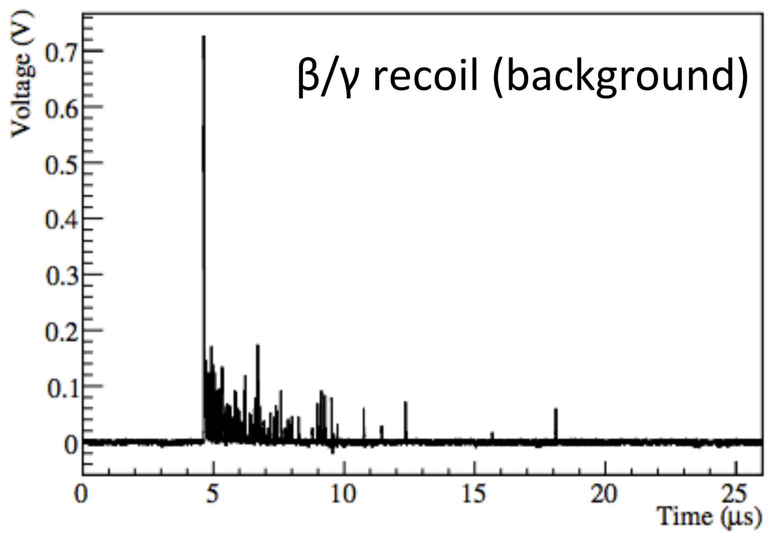
What is DEAP-3600?

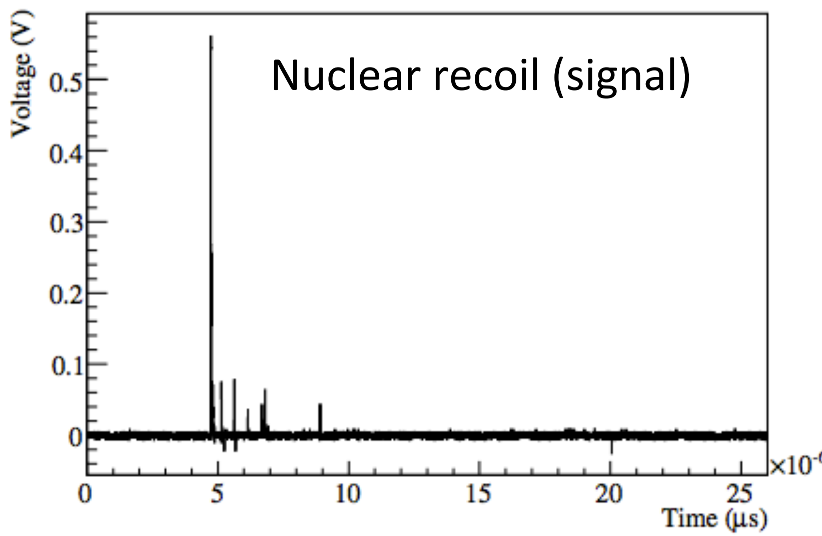
- Why Argon?
  - Ar transparent to 128nm scintillation photons
    - Large fiducial masses
  - Well separated singlet (6ns) and triplet state lifetimes (1.3us)
    - Signal and background events produce different ratio of singlet and triplet states
  - Easy to purify and inexpensive

Experimental Signature

- Pulse Shape Discrimination (PSD) used to distinguish nuclear and β/γ recoils







Experimental Signature

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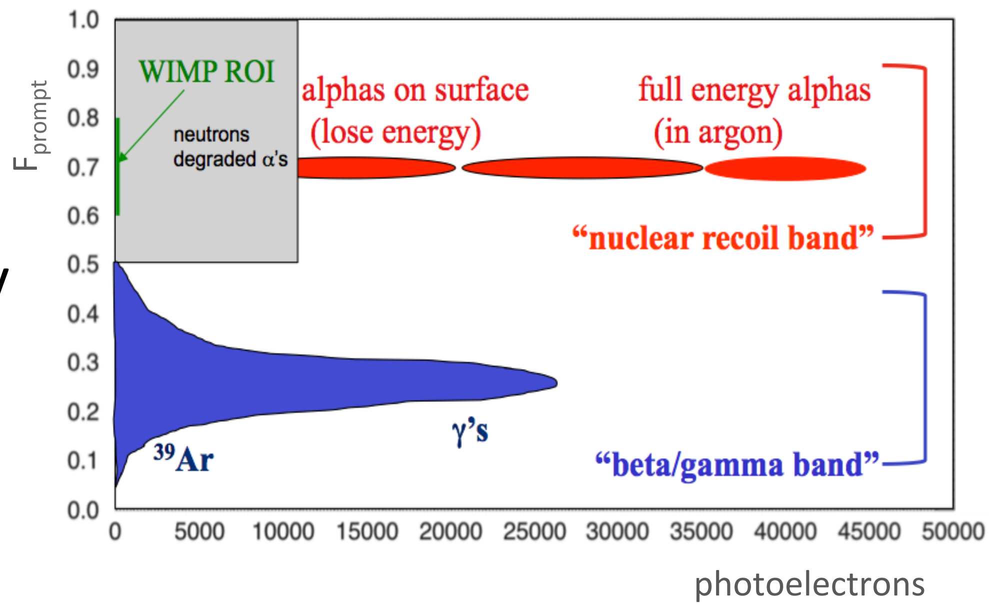
$$F_{\text{prompt}} \equiv \frac{\sum_{\{i|t_i\in(-28\text{ ns},150\text{ ns})\}} Q_i}{\sum_{\{i|t_i\in(-28\text{ ns},10\ \mu\text{s})\}} Q_i},$$

- Width of Fprompt distribution key to minimising leakage
  – Understanding PMTs key



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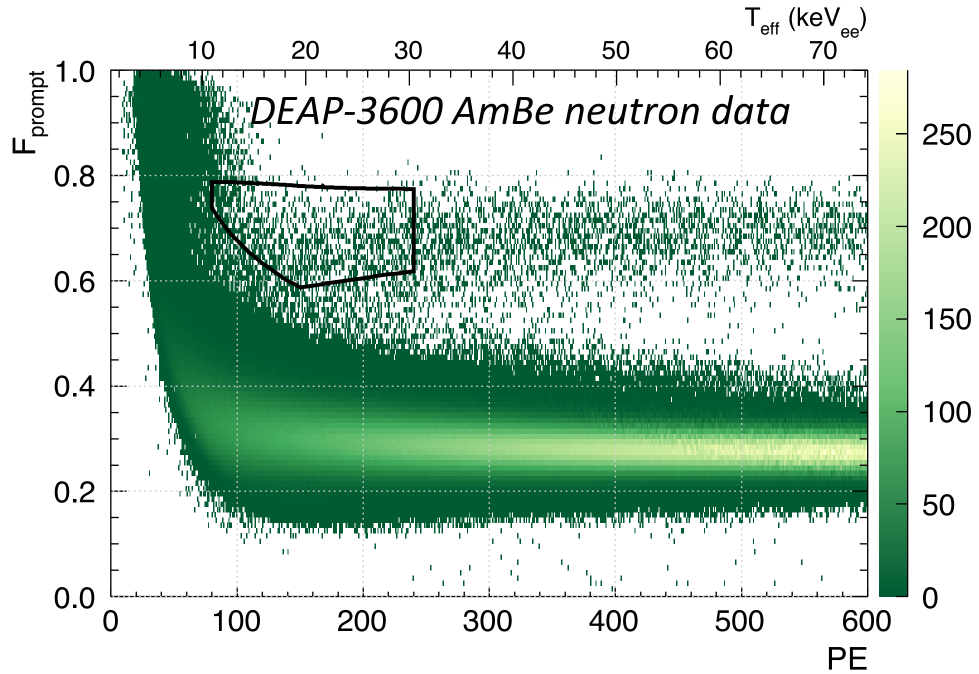
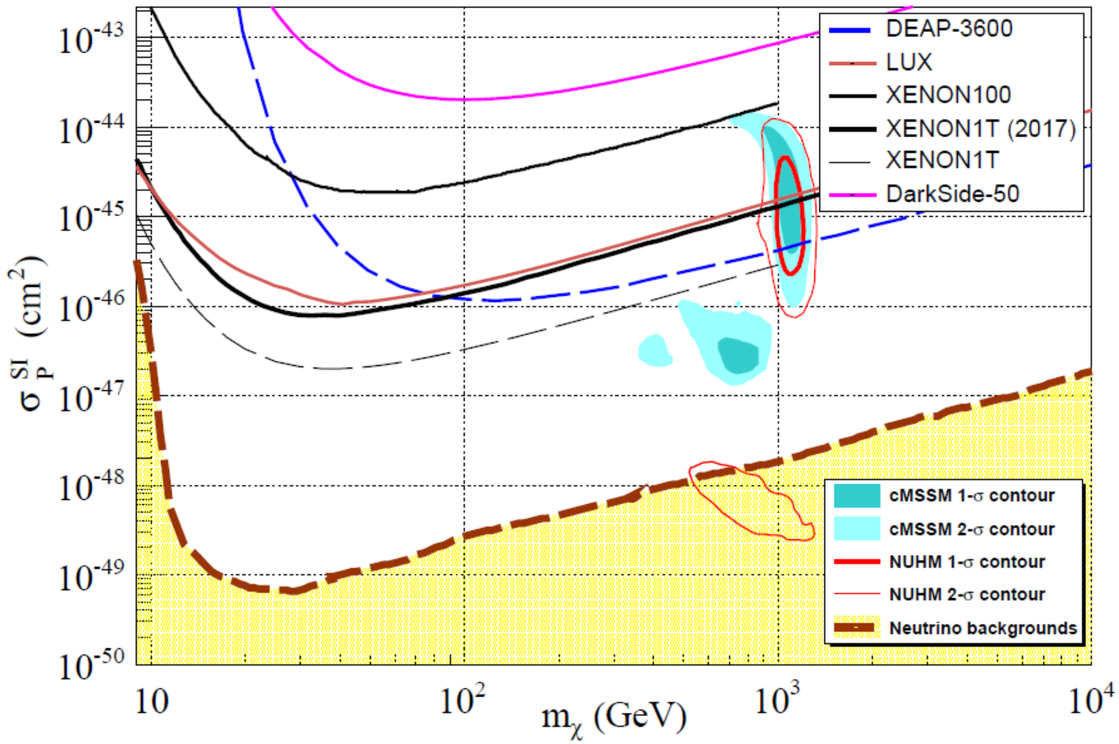
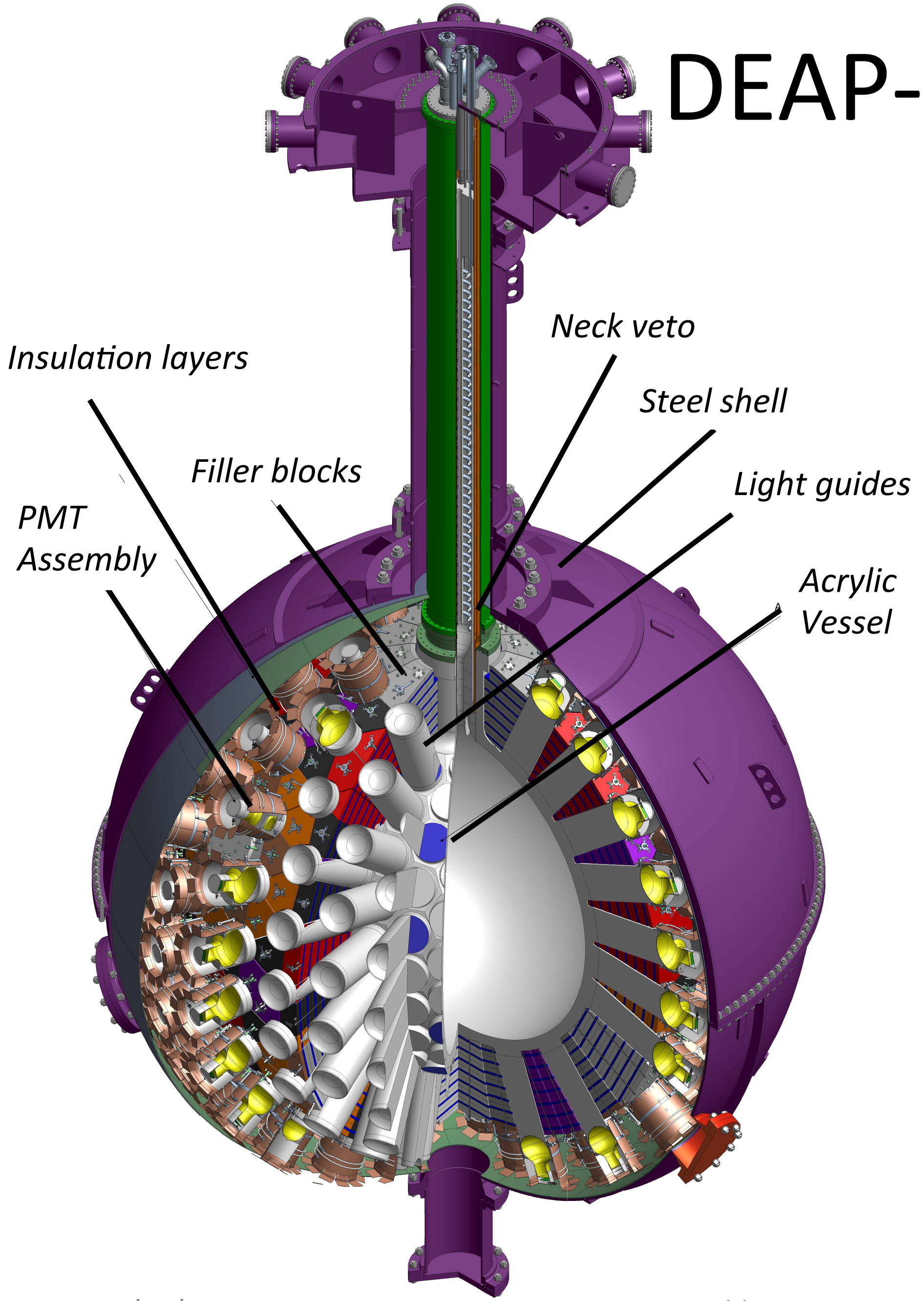


DEAP Sensitivity



GOAL: 3000 kg-year allows ~10^{-46} cm^2 sensitivity (SI) with ~15 keVee (60 keVr) threshold (bkgd limit)

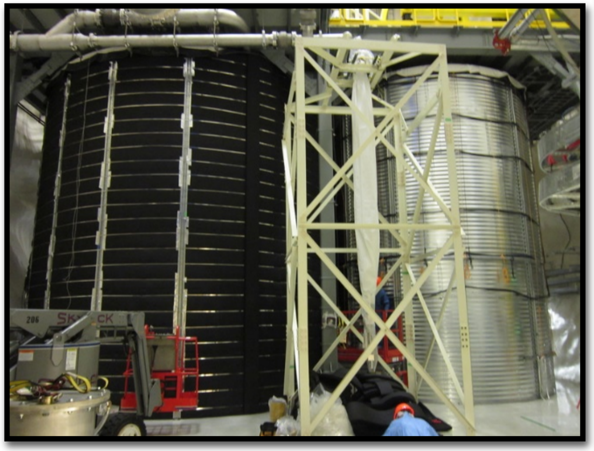
DEAP-3600 Detector

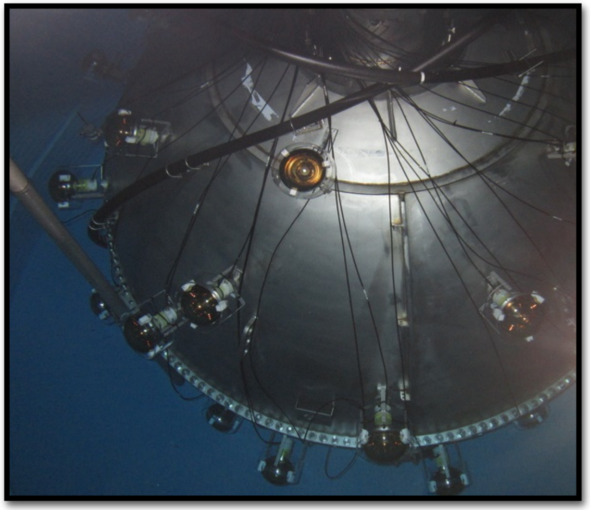


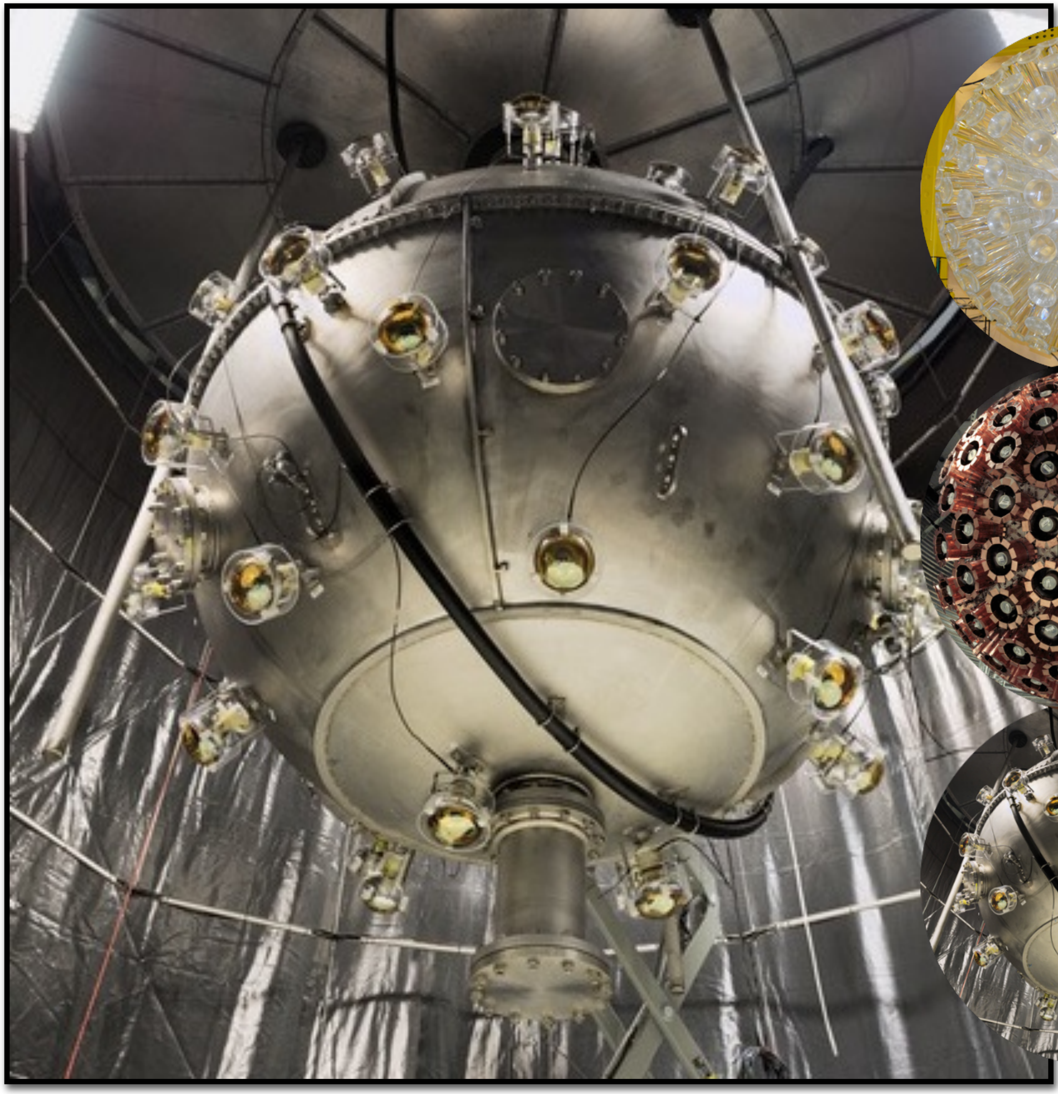
- LAr housed in sealed ultraclean acrylic vessel
- Strict material control and assaying procedures
- 255 8-inch Hamamatsu R5912 HQE PMTs
  - 32% QE, 75% coverage
- 85cm radius acrylic vessel & 50cm light-guides provide PMT neutron shielding
- Tetraphenyl-butadiene (TPB) used as wavelength shifter (128nm to 430nm)
- Cosmic veto
  - SNOLAB (2km underground)
  - Detector submerged in 8m diameter water tank

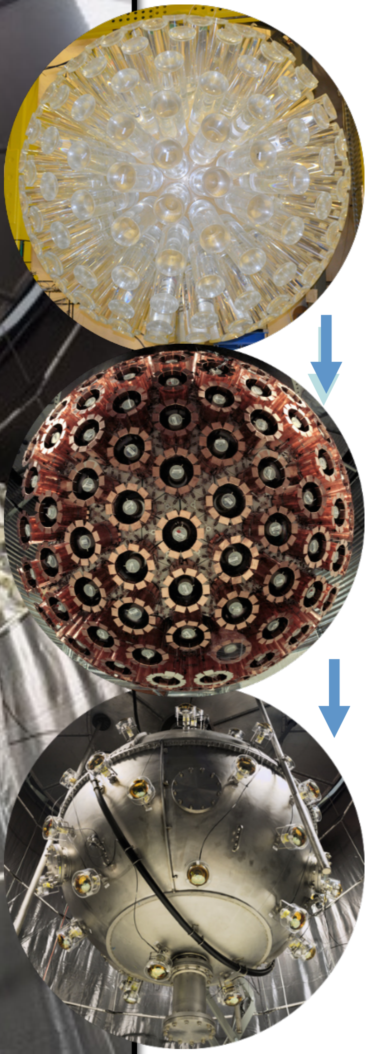
DEAP Construction

Completed early 2016





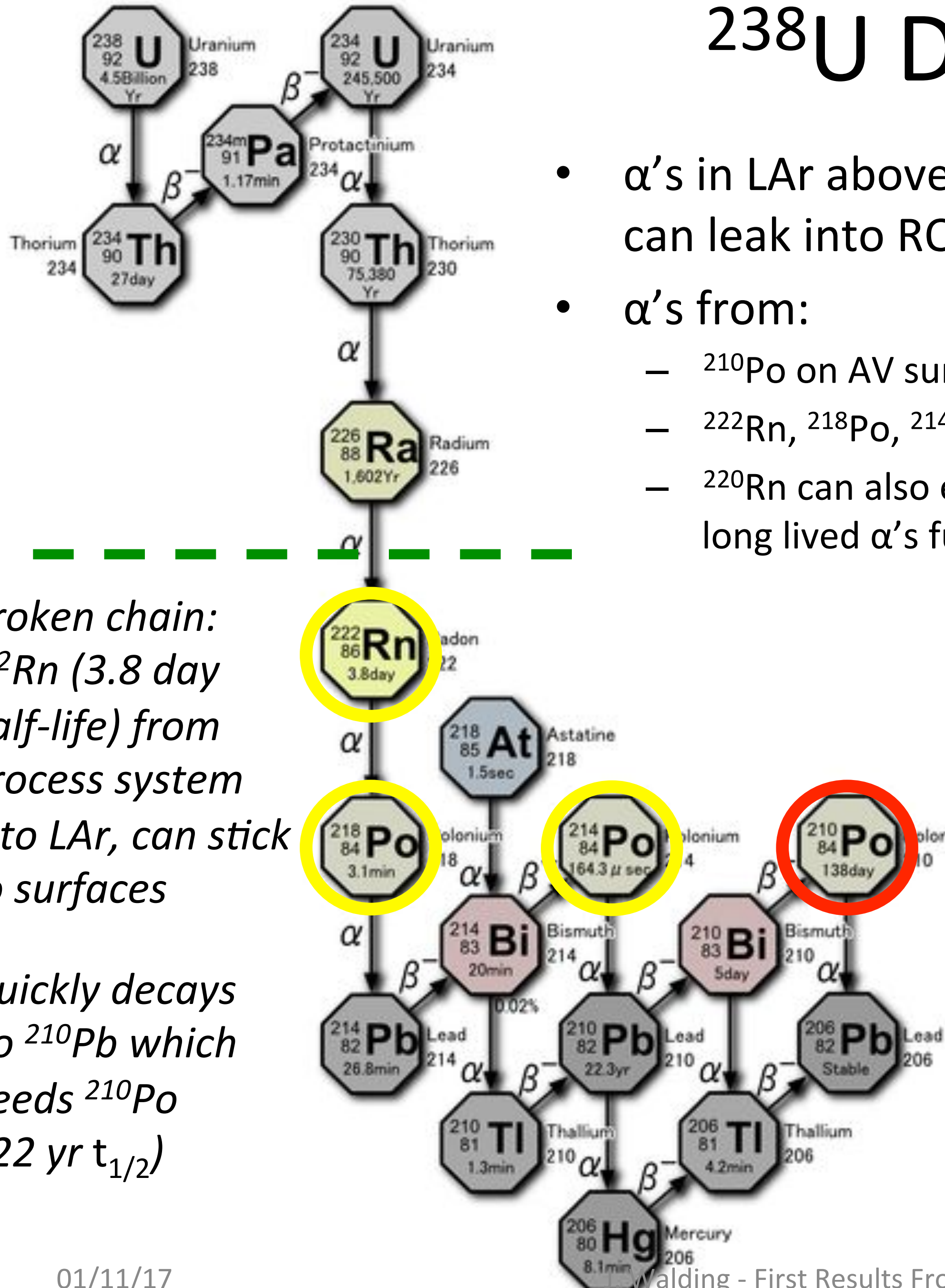




Backgrounds

^{238}U Decay Chain

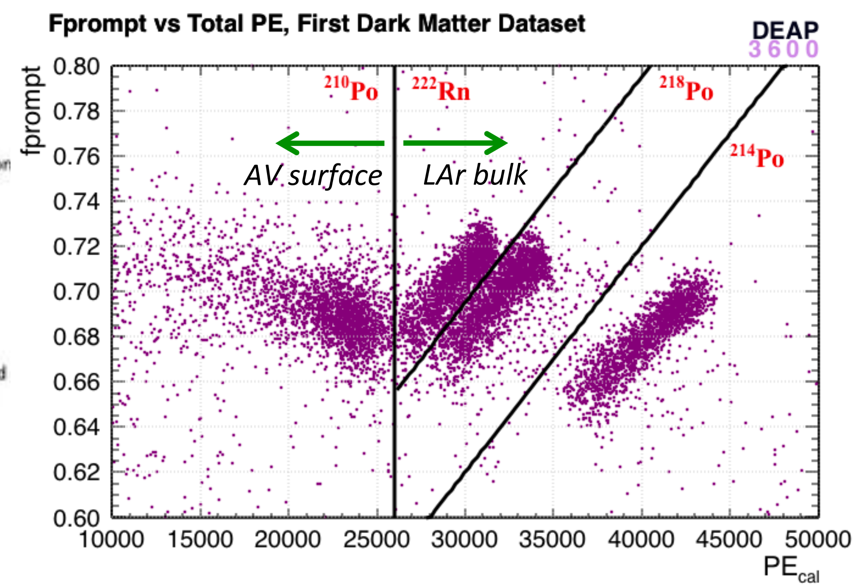
ROYAL HOLLOWAY UNIVERSITY OF LONDON



Broken chain: ^{222}Rn (3.8 day half-life) from process system into LAr, can stick to surfaces

Quickly decays to ^{210}Pb which feeds ^{210}Po (22 yr $t_{1/2}$)

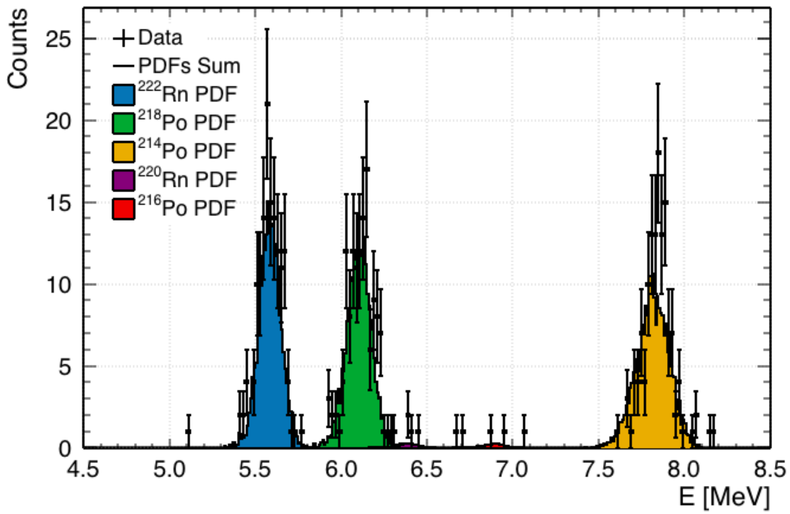
- α's in LAr above ROI window, however surface alpha can leak into ROI…
- α's from:
  - ^{210}Po on AV surface (from ^{210}Pb: 22 yr $t_{1/2}$)
  - ^{222}Rn, ^{218}Po, ^{214}Po in LAr bulk (short $t_{1/2}$'s)
  - ^{220}Rn can also enter LAr bulk through process system but no long lived α's further down the chain

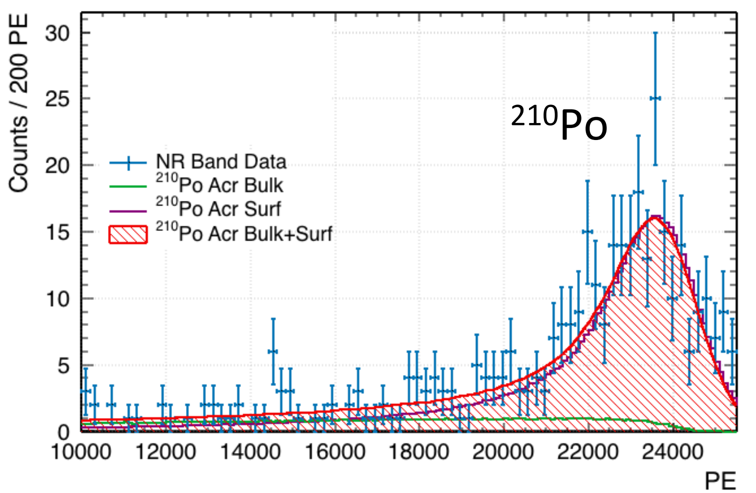


Surface and bulk alphas

- ^{222}Rn, ^{218}Po, ^{214}Po tagged from time delayed coincidences (α-α, β-α)
- ^{214}Po activity in LAr consistent with activity earlier in the chain
- ^{210}Po (out-of-equilibrium) tagged with degraded energy signal (^{210}Po below TPB surface)
  - Simulation of surface contamination to 80um and bulk contamination agree with data

Component	Activity
^{222}Rn LAr	$(1.8\pm0.2)\times10^{-1}$ µBq/kg
^{214}Po LAr	$(2.0\pm0.2)\times10^{-1}$ µBq/kg
^{220}Rn LAr	$(2.6\pm1.5)\times10^{-3}$ µBq/kg
^{210}Po AV surface	0.22 ± 0.04 mBq/m^2
^{210}Po AV bulk	<2.2 mBq



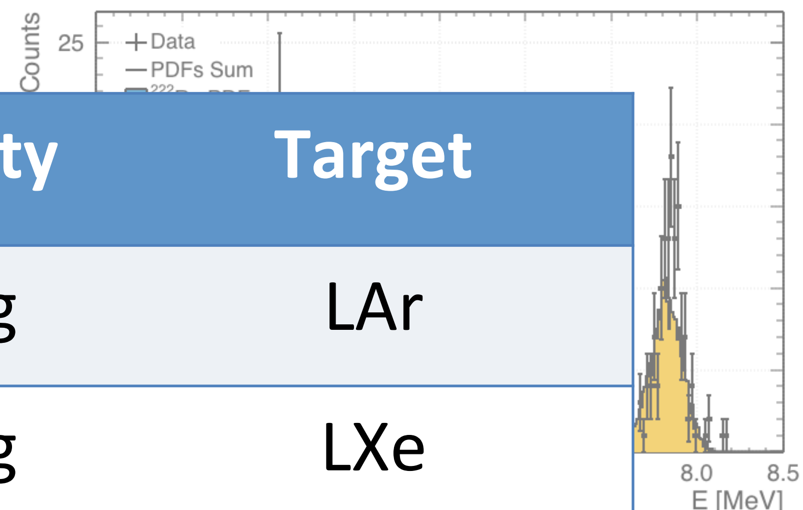


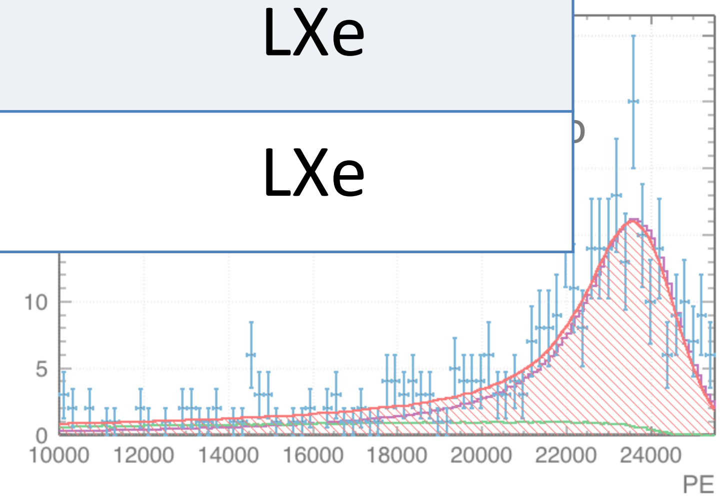
Surface and bulk alphas

- ^{222}Rn, ^{218}Po, ^{214}Po tagged from time delayed coincidences (α-α, β-α)
- 2
  e
- 2
  c
  s

Experiment	^{222}Rn Activity	Target
DEAP-3600	0.2 uBq/kg	LAr
PandaX-II	6.6 uBq/kg	LXe
LUX	66 uHz/kg	LXe
XENON-1T	10 uBq/kg	LXe

^{214}Po LAr	$(2.0\pm0.2)\times10^{-1}$	µBq/kg
^{220}Rn LAr	$(2.6\pm1.5)\times10^{-3}$	µBq/kg
^{210}Po AV surface	0.22 ± 0.04	mBq/m^2
^{210}Po AV bulk	<2.2	mBq



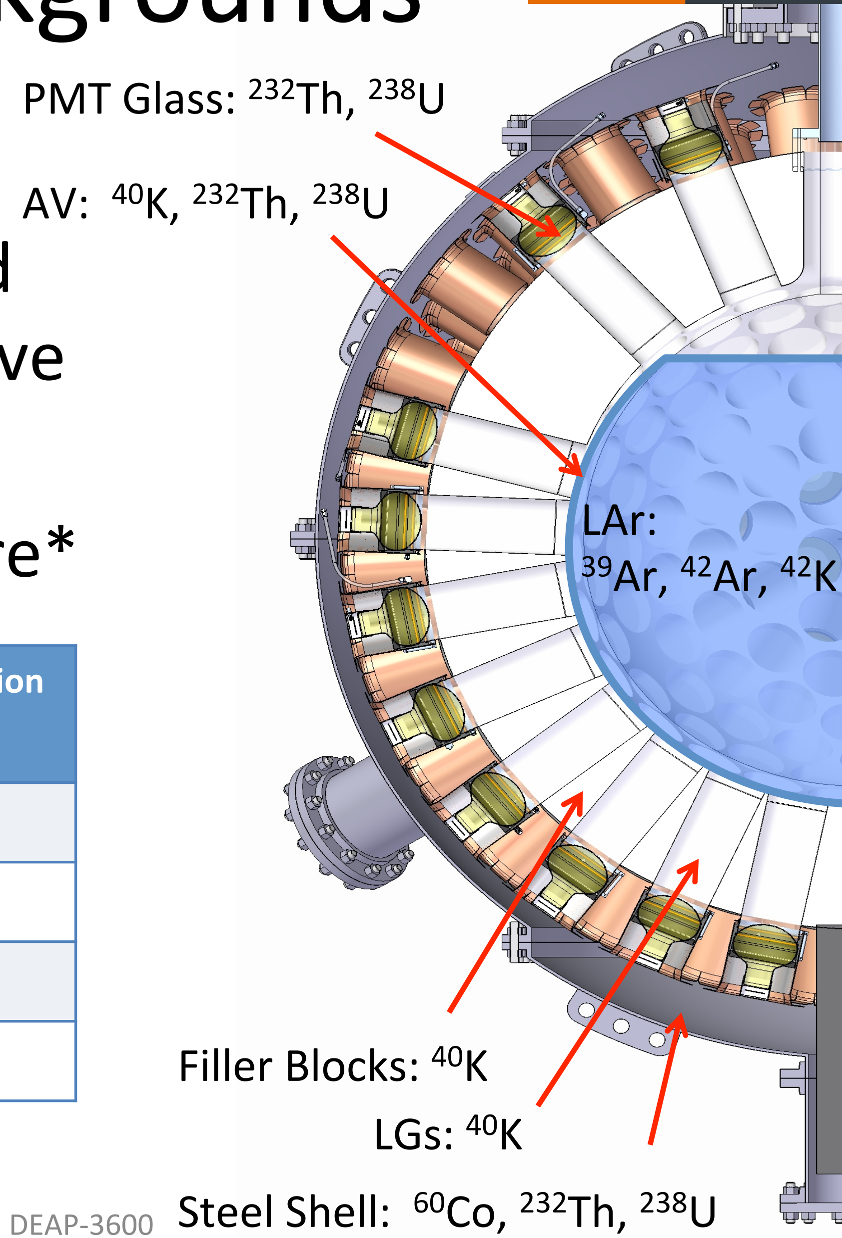


Gamma/Beta Backgrounds

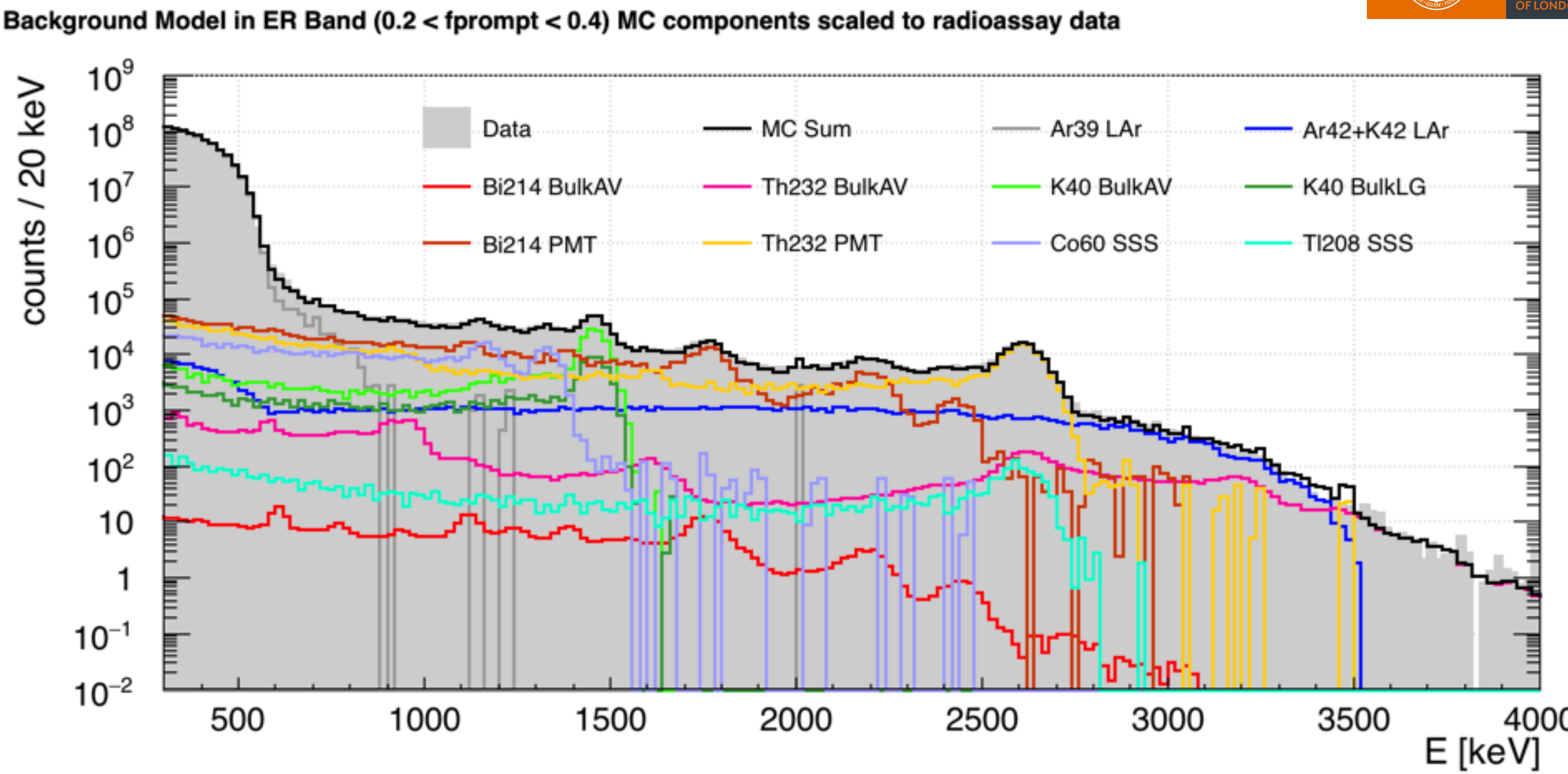
- Activities of materials predicted from results from comprehensive screening program
- LAr activity taken from literature*

Isotope	Location	Activity	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

**P. Benetti et al., NIM A 574, 83 (2007)*



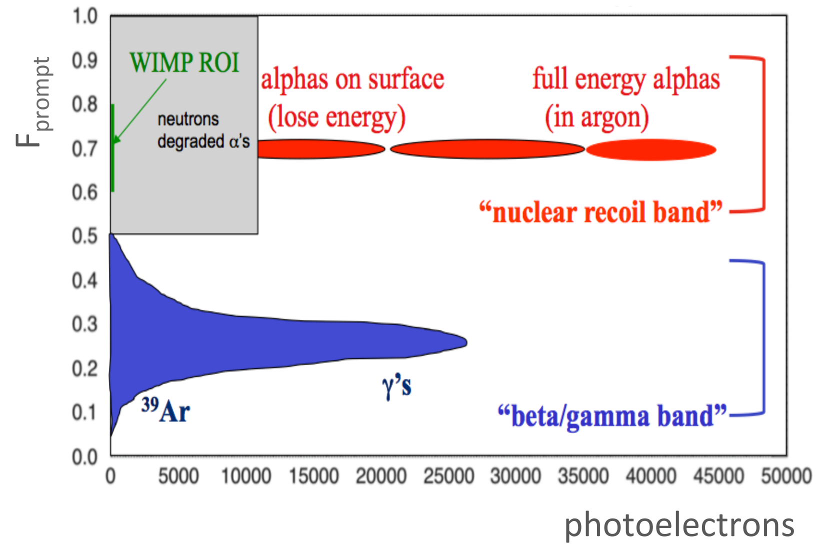
Electron Recoil Band Model

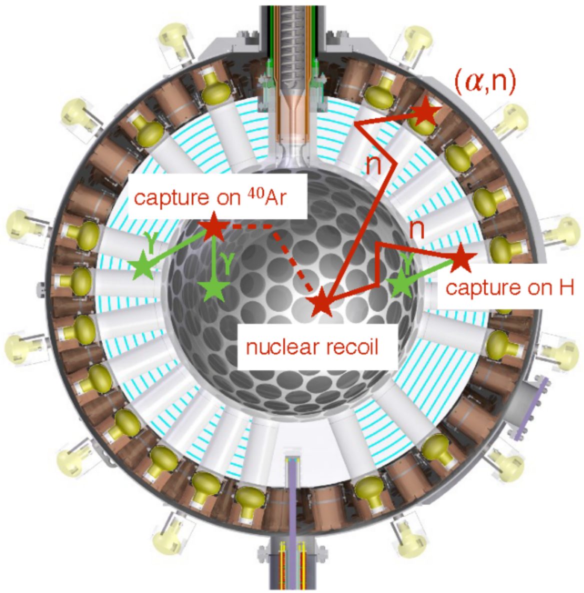


- MC scaled screening values or literature values (^{39}Ar)
- Low energy region (<500 keV) dominated by ^{39}Ar
- Mid energy region (500-2600 keV) dominated by external componentry gammas (PMT glass)
- High energy region (>2600 keV) dominated by ^{42}K & bulk AV ^{232}Th

Neutron Backgrounds

- Neutrons from:
  - (α-N) interactions in detector and external materials
  - Fission neutrons
  - Cosmogenic muon induced neutrons
- Extensive MC campaign using radio-purity assays and (α-N) yields from SOURCES-4C*
  - PMT glass dominant source (~70%)
  - Well constrained using gamma from ^{238}U and ^{232}Th – consistent with target values





Data driven limit on neutron interactions:

- **Idea:** Eventually all neutrons capture and leave gamma signature
  - 2.2 MeV γ form ^1H 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

**E.F.Shores, LA-UR-02-1839 (April 2002)*

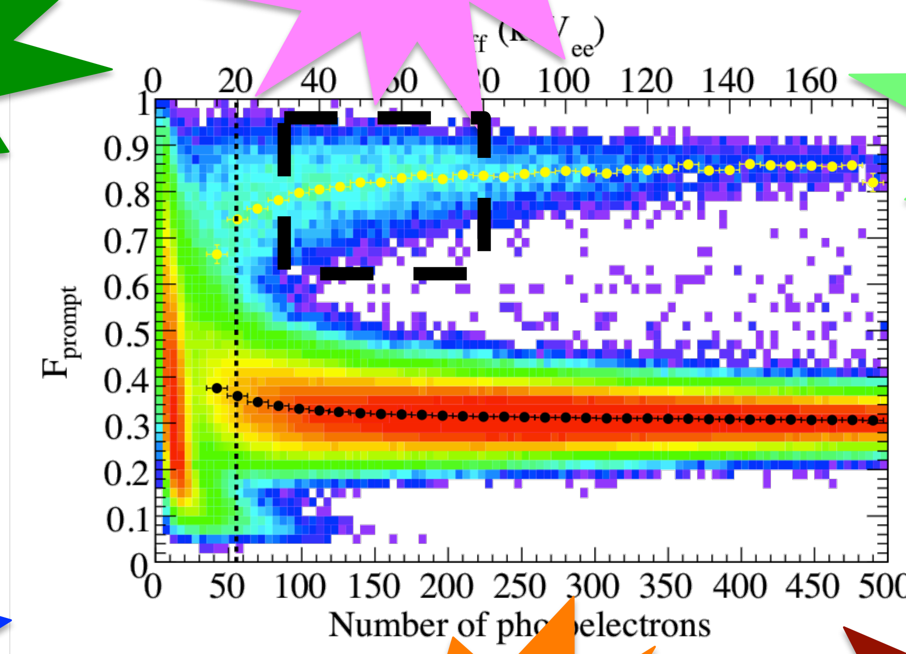
Calibrating DEAP

Calibrating DEAP

Relative PMT Efficiencies

Event position reconstruction

Cut acceptance



PMT timing offsets

Energy Response

Neutron response

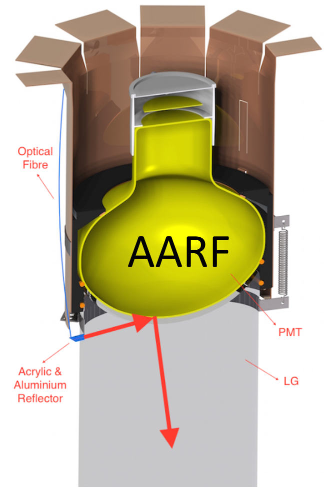
Calibrating DEAP

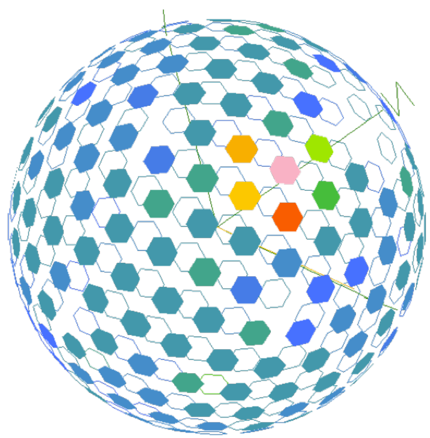
Extensive calibration program

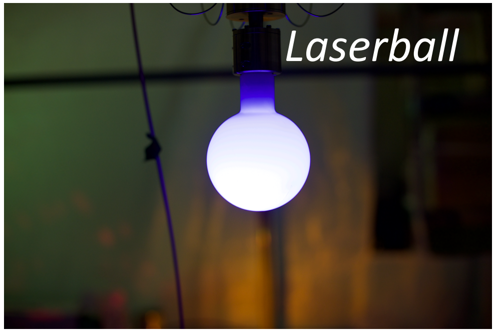
- Begun in 2015 (once PMTs ramped up)

Five calibration handles

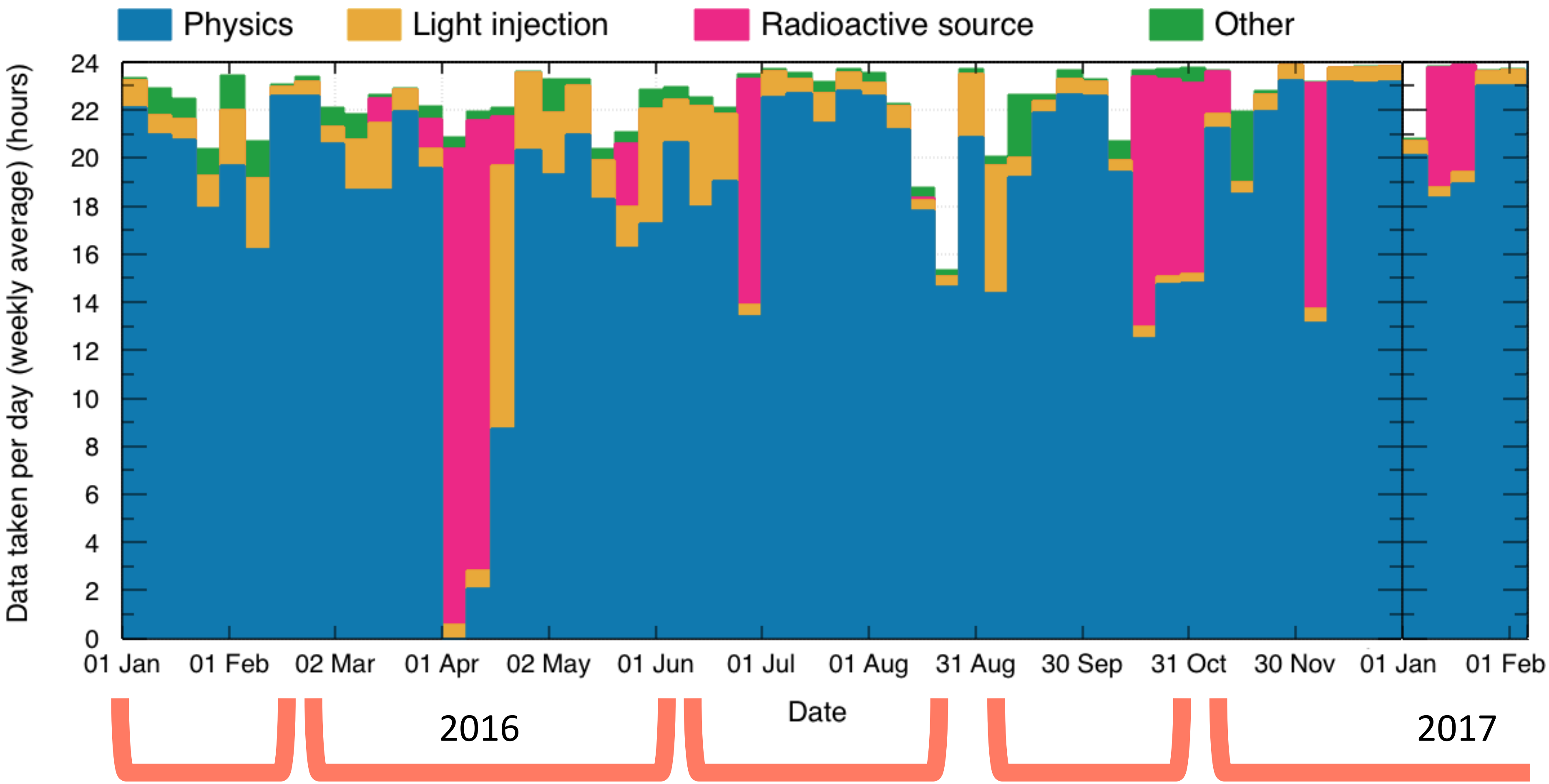
- Developed by UK groups
- Two optical systems:
  - Acrylic-Aluminium Reflector Fibre System (AARFs)
  - Laserball
- Three external sources:
  - Tagged ^{22}Na source
  - ^{232}Th source
  - Tagged AmBe source
- And Ar-39!







Calibrating DEAP

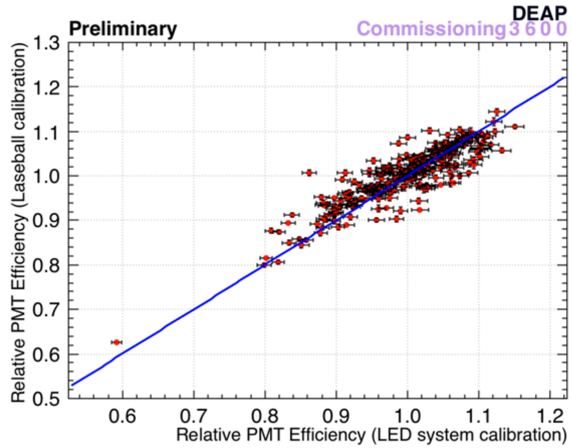


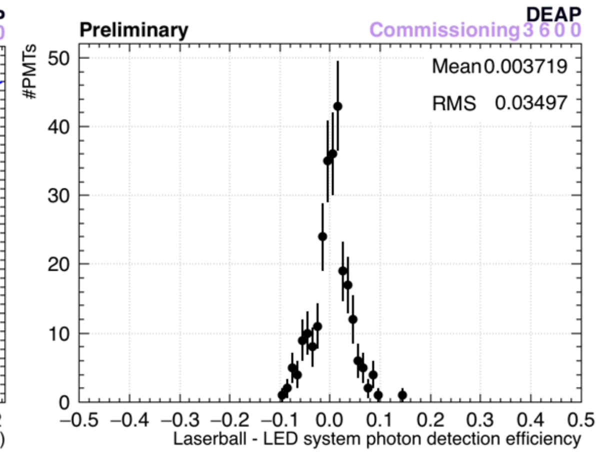
N_2 | Gaseous Ar | 1st Fill | 2nd Fill | Physics…

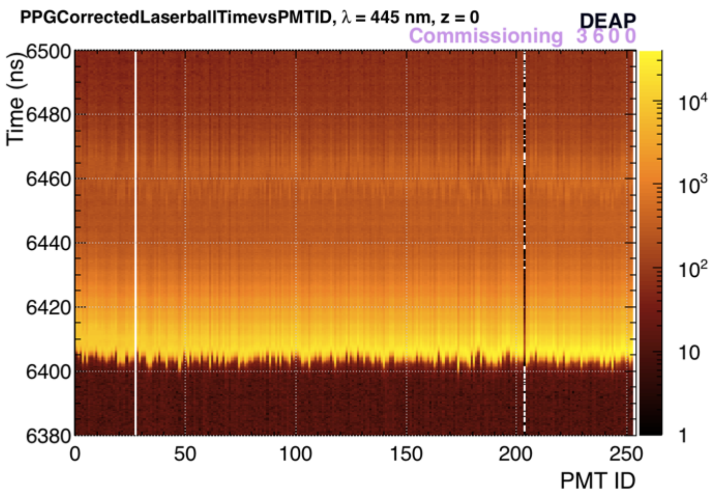
Calibrating DEAP

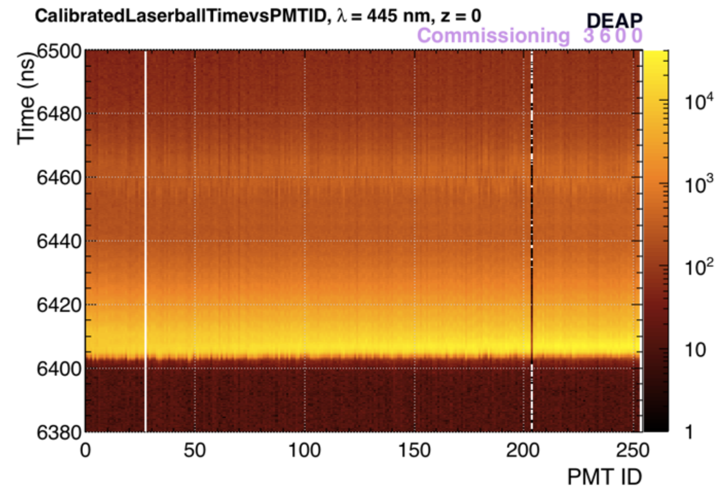
Vacuum/N_2:

- Relative PMT efficiency (AARFs, Laserball) – 3%
- PMT timing (Laserball) – 1 ns
- Detector Optics (Laserball, AARFs





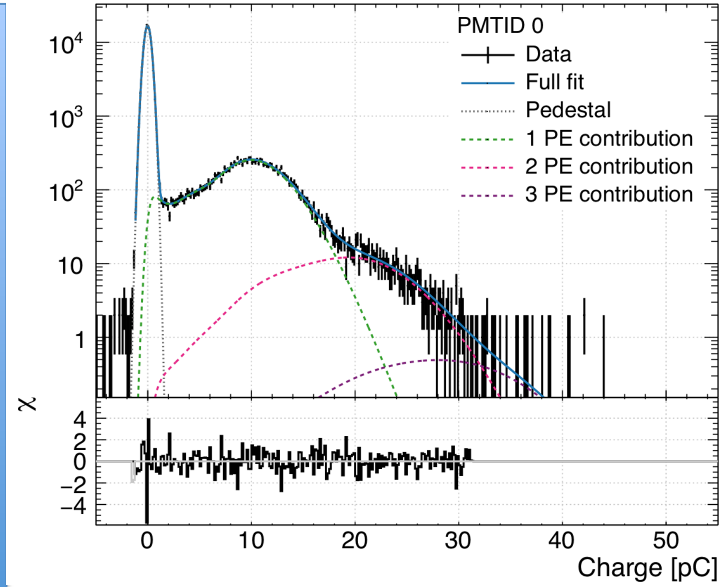




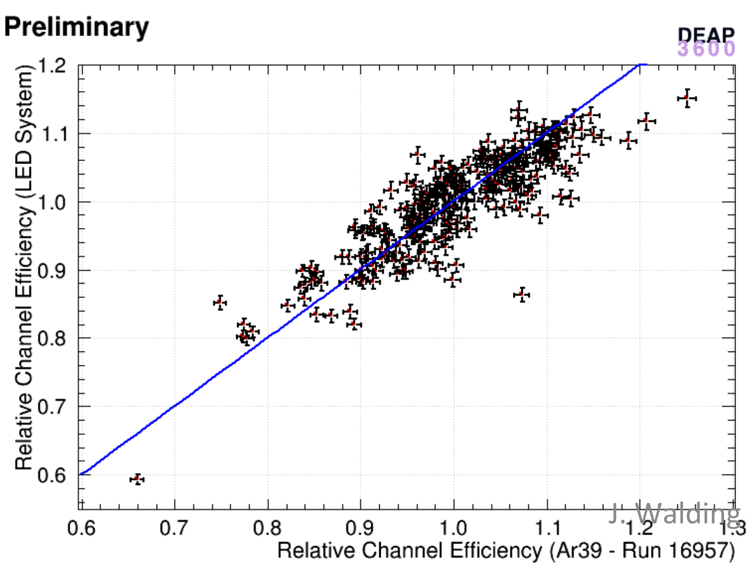
Calibrating DEAP

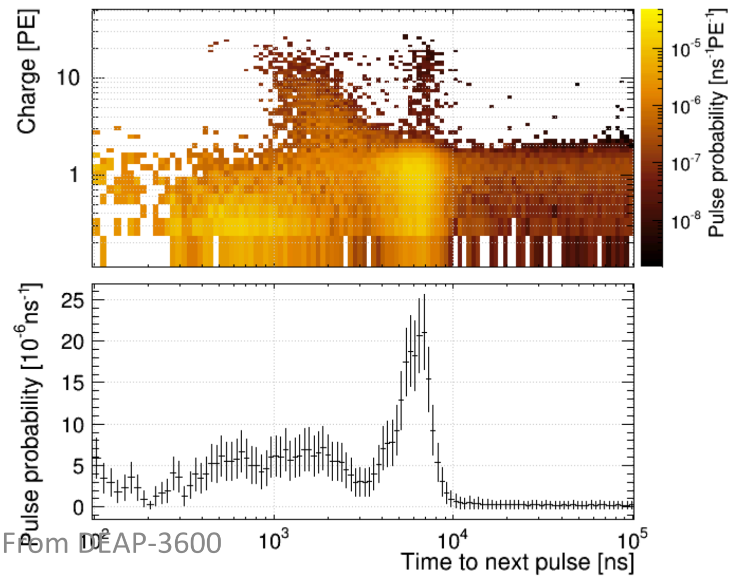
LAr:

- PMTs:
    - Relative PMT efficiency (AARFs, ^{39}Ar)
    - PMT SPE response (3% uncertainty)
    - PMT Afterpulsing
- Energy response (^{39}Ar, ^{22}Na, ^{232}Th)
- Position reconstruction (^{22}Na)
- Neutron response (AmBe)

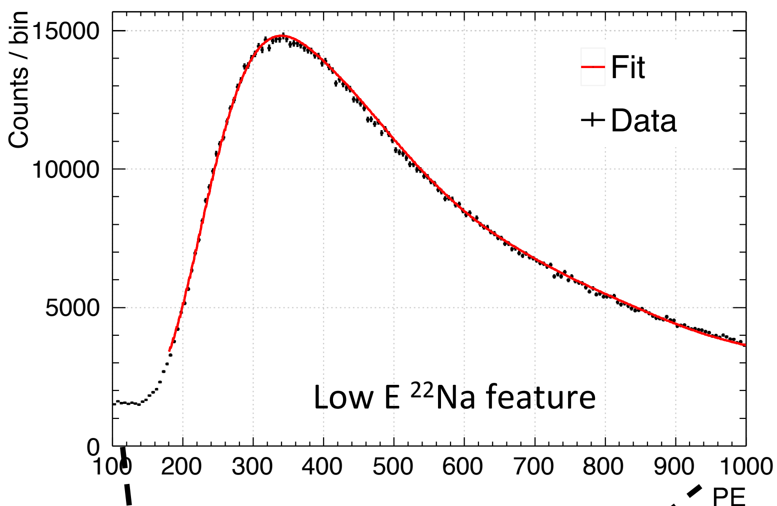


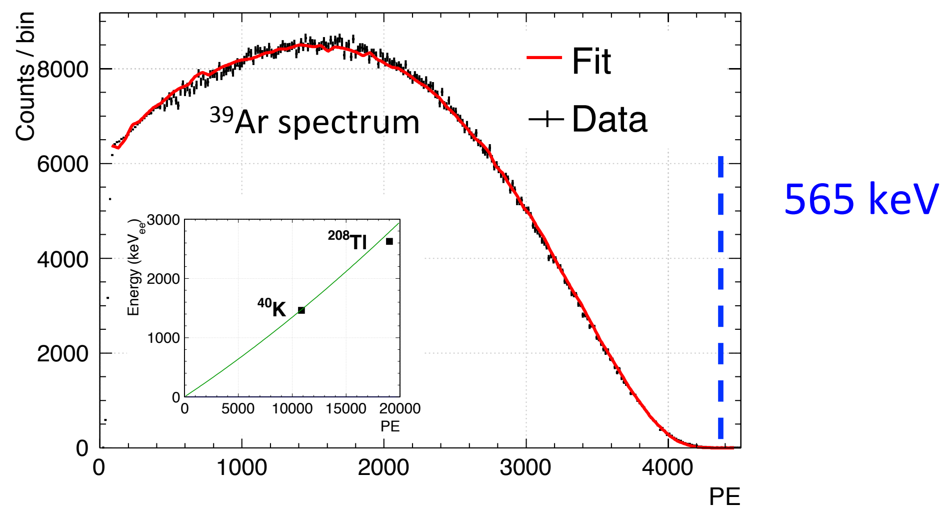
DEAP-3600 PMT Paper: arXiv:1705.10183v1

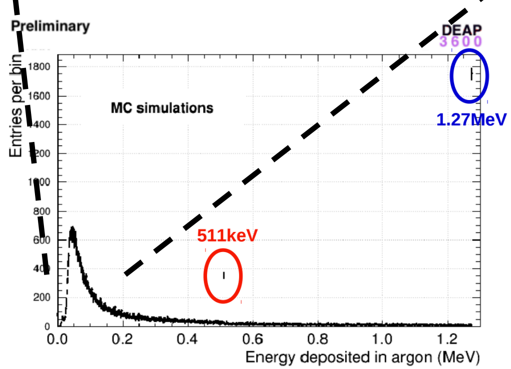




Energy Calibration





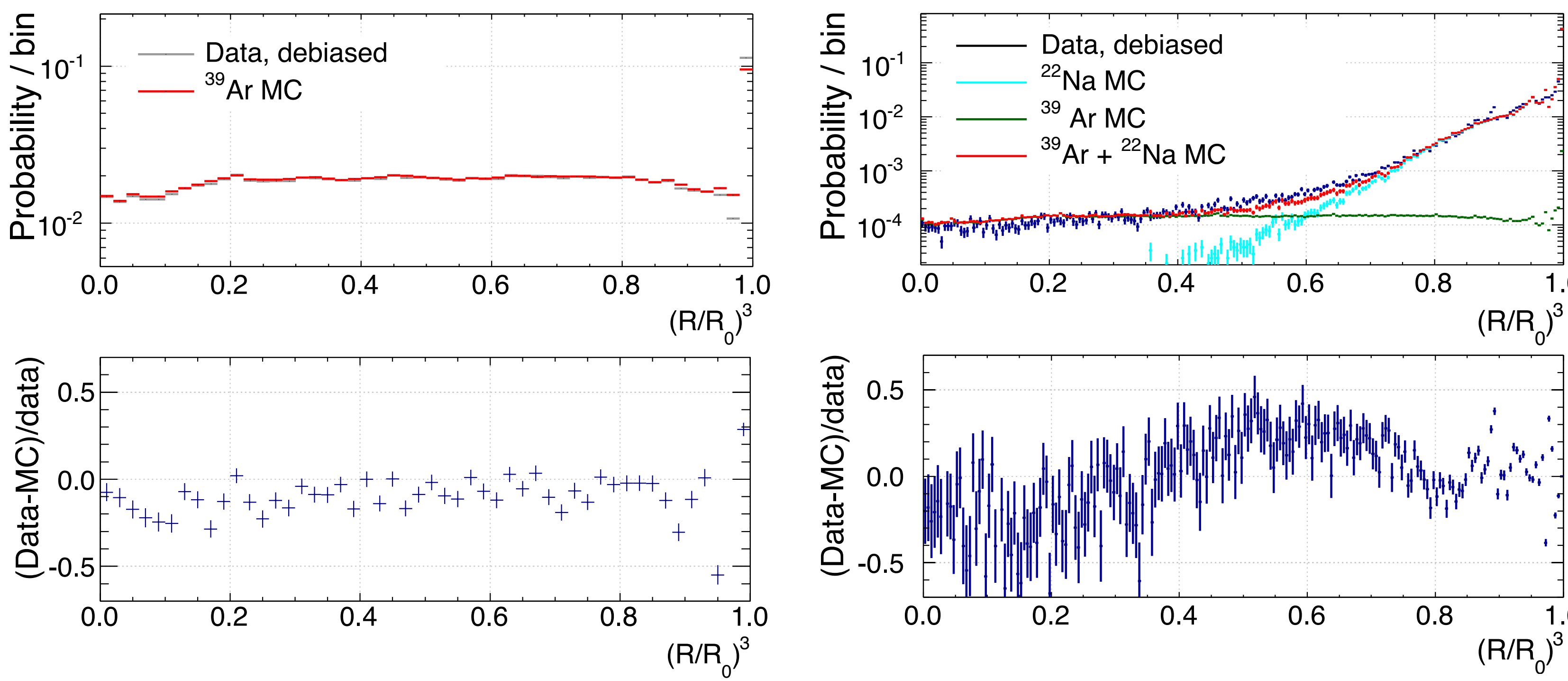


- Quadratic fit to full ^{39}Ar spectrum: $c_0+c_1PE+c_2PE^2$
- Extrapolating light yield fit from ^{22}Na feature and ^{39}Ar spectrum agrees with high energy line (^{40}K), discrepancy with ^{208}Tl from saturation effects not yet accounted for

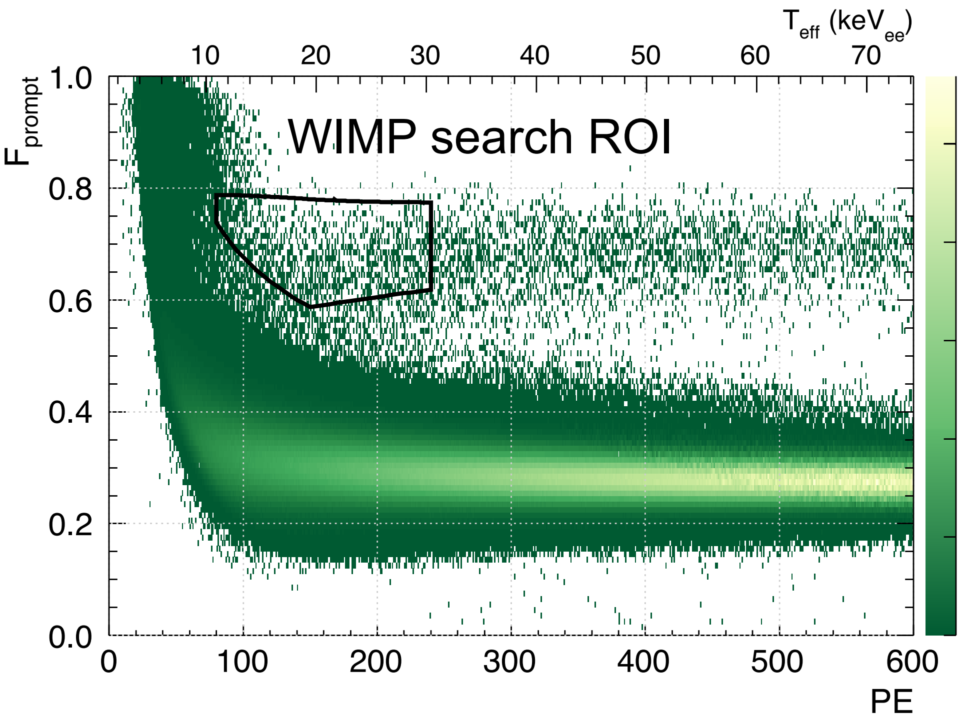
$$LY = 7.36^{+0.61}_{-0.52}\text{(fit syst.)} \pm 0.22\text{(SPE syst.)PE/keV}_{ee}\ @80\ \text{PE}$$

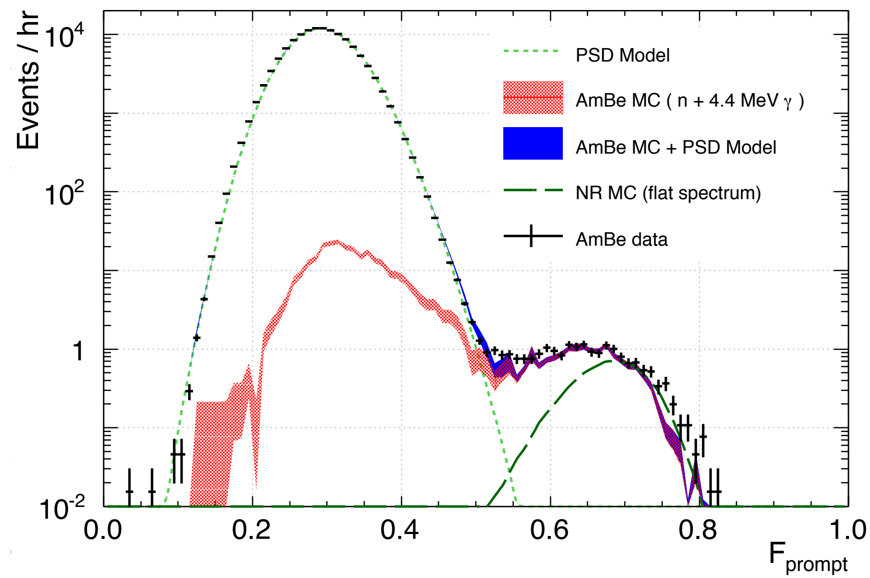
Position Reconstruction

- Likelihood based position reconstruction algorithm developed
  - Good agreement between debiased data and MC
- Not used for this analysis
  - Lower level variables used instead
- Fiducial mass (using lower level variables: 2,223 kg) – Calculated using ^{39}Ar rate
  - Design goal: 1000 kg!

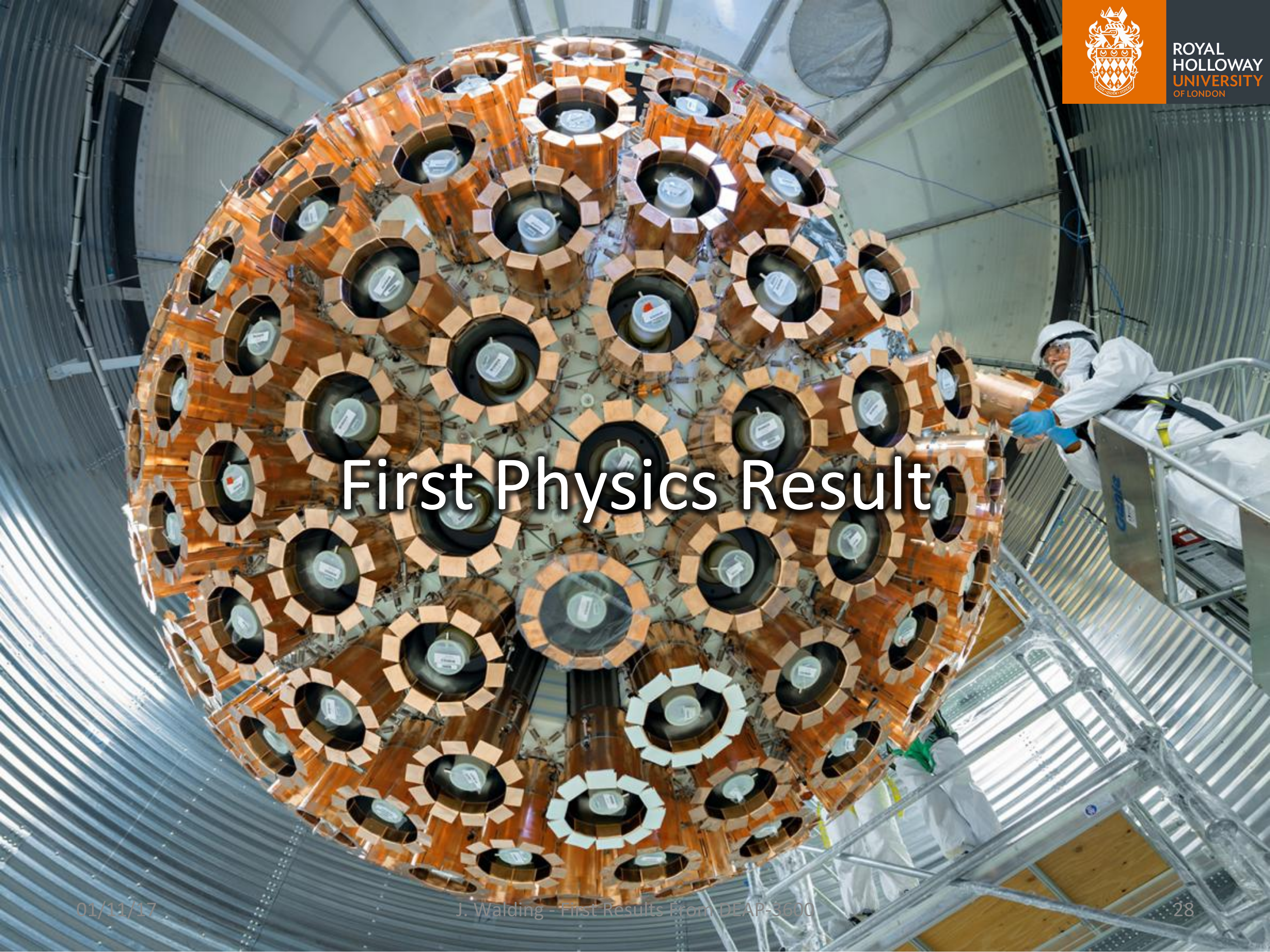


Neutron Response in DEAP





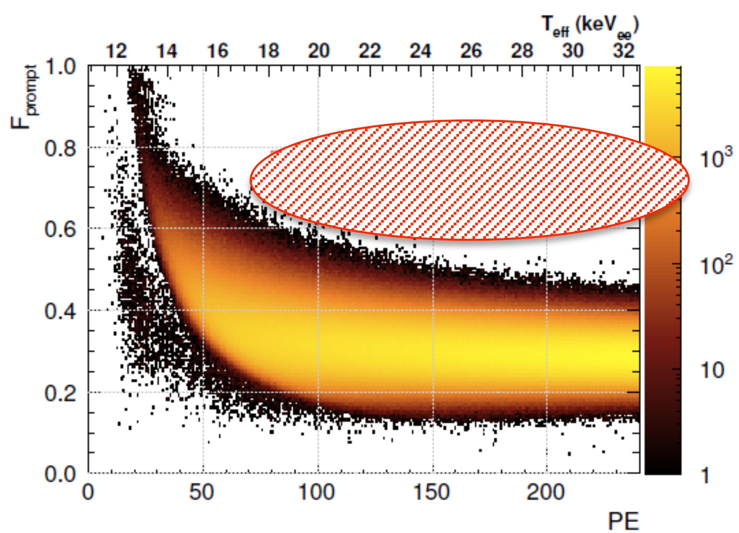
- AmBe neutron source deployed outside of Steel Shell
- Detect neutrons and gammas from source (+ capture gammas)
- Use data for cross-check of simulation
- Simulation used to evaluate single-recoil response



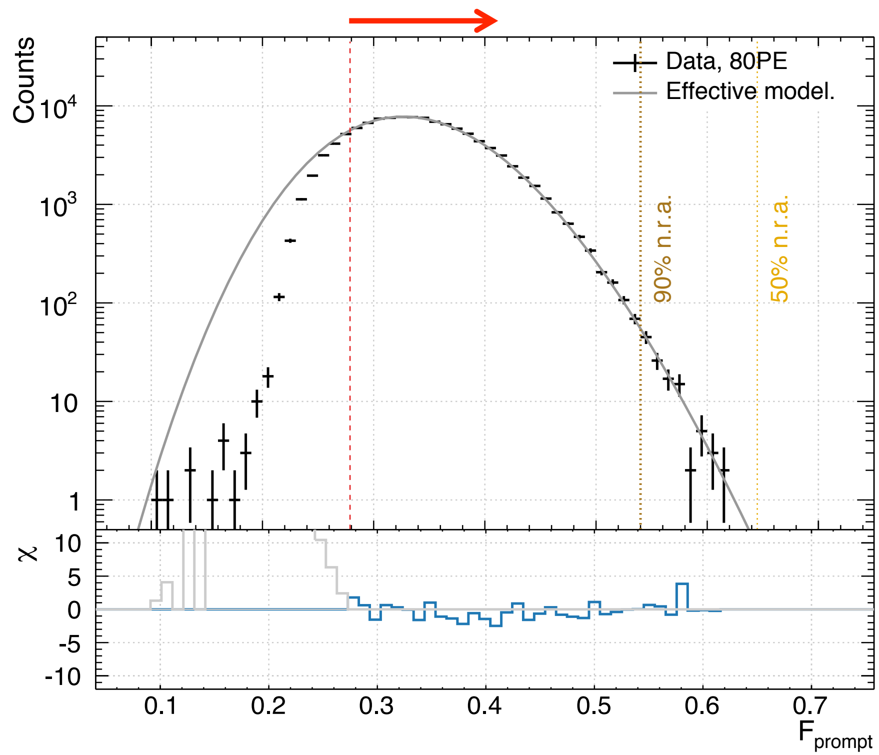
First Physics Result

Pulse-Shape Discrimination

- Observe good PSD of β event down to 11 keVee
  - Best ever demonstrated at low PE



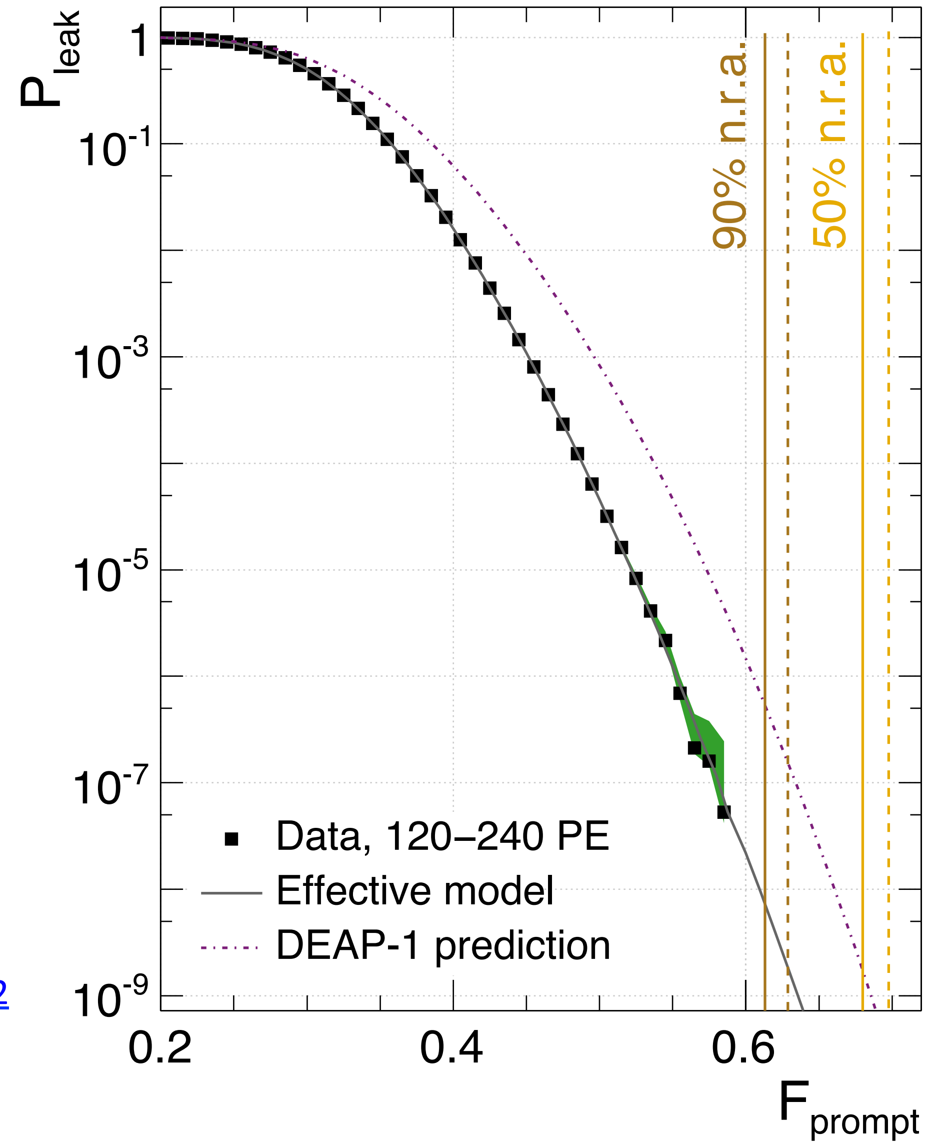
100% Trigger efficiency



DEAP-1 PSD paper: https://arxiv.org/abs/0904.2930

Pulse-Shape Discrimination

- Better leakage than DEAP-1 prediction
  - Detector calibration key
  - Allowed us to drop our ROI window from 120 to 80 PE!
    - Equivalent to a 39keV$_{NR}$ threshold (design goal: 60 keV$_{NR}$)



DEAP-1 PSD paper: *https://arxiv.org/abs/0904.2930*
Our new measurement: https://arxiv.org/abs/1707.08042

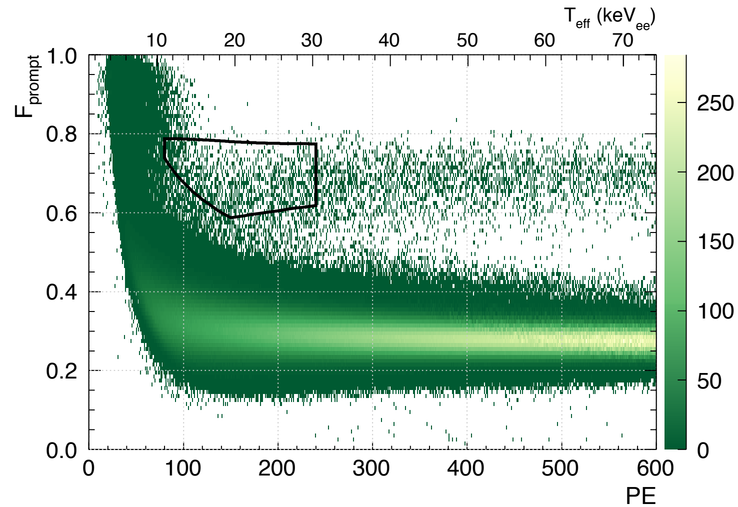
DEAP’s First Search!

- 4.44 live days of data
- Acceptance for NR calculated using ^{39}Ar
  - No cut variables depend on pulse time
- Selected ROI for <0.2 leakage from β’s

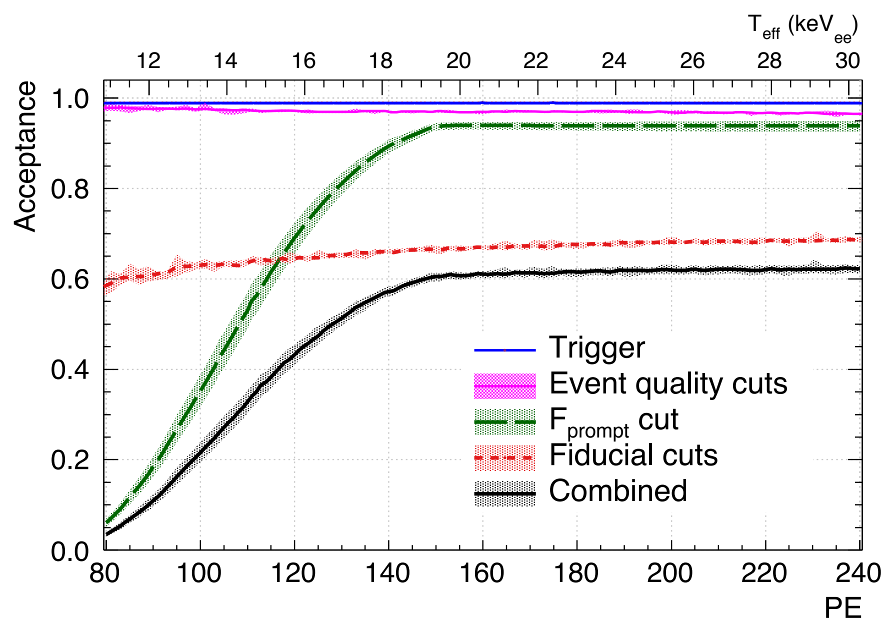
- ROI: 80-240 PE
- 95% acceptance of NR above 150PE
- 9,870 kg-day exposure

So what do we see…?!

ROI illustration (AmBe data)



	Cut	Livetime	Acceptance %		$\#^{\mathrm{ROI}}_{\mathrm{evt.}}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58 ± 0.01		654
	Event time		99.85 ± 0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	
	Total	4.44 d	96.94 ± 0.03	$66.91^{+0.20}_{-0.15}$	!

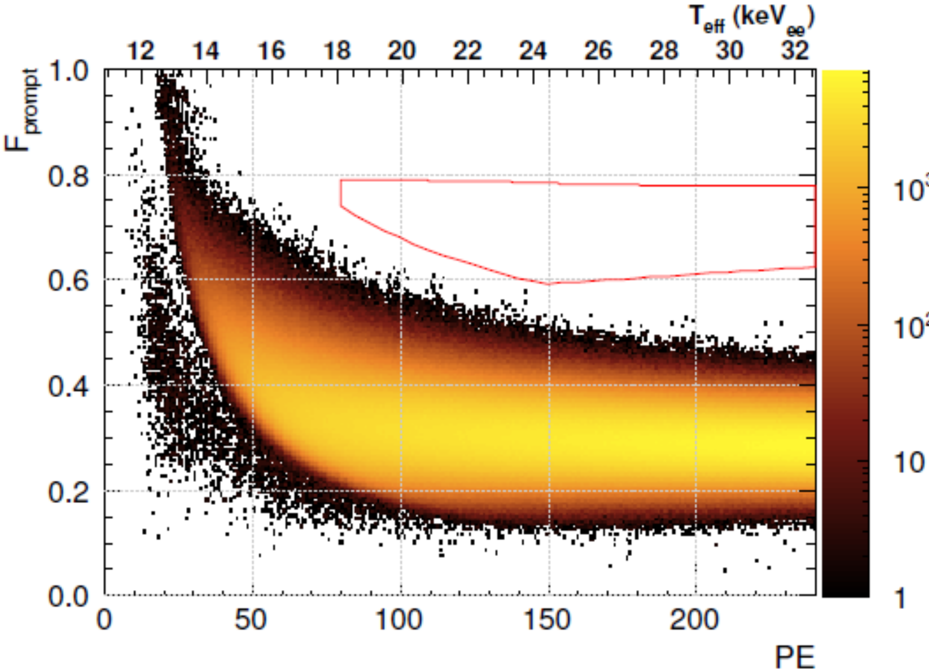


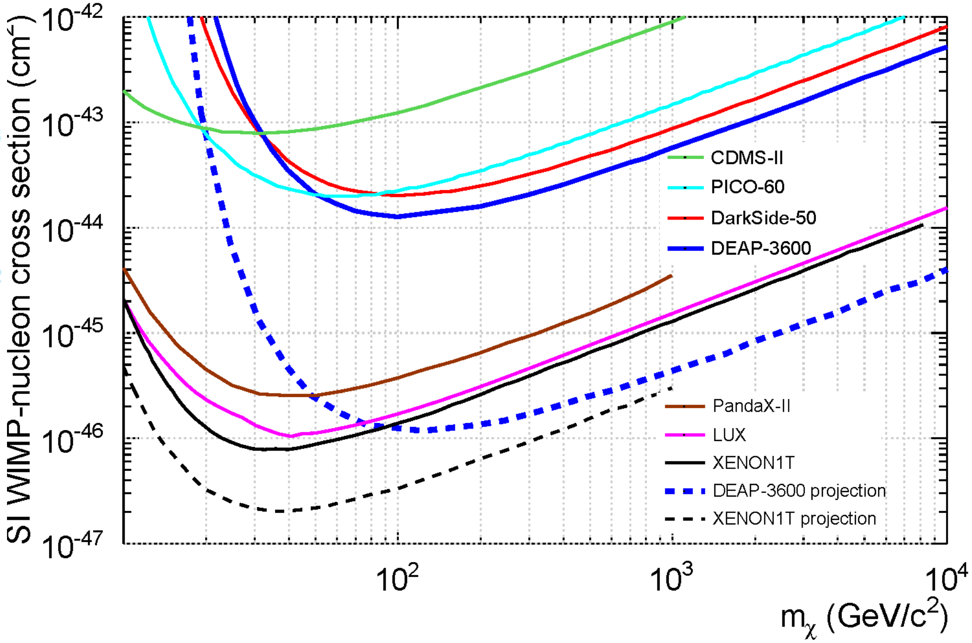
Zero events

WIMP Exclusion

Worlds best limit on Ar above 100 GeV/c^2

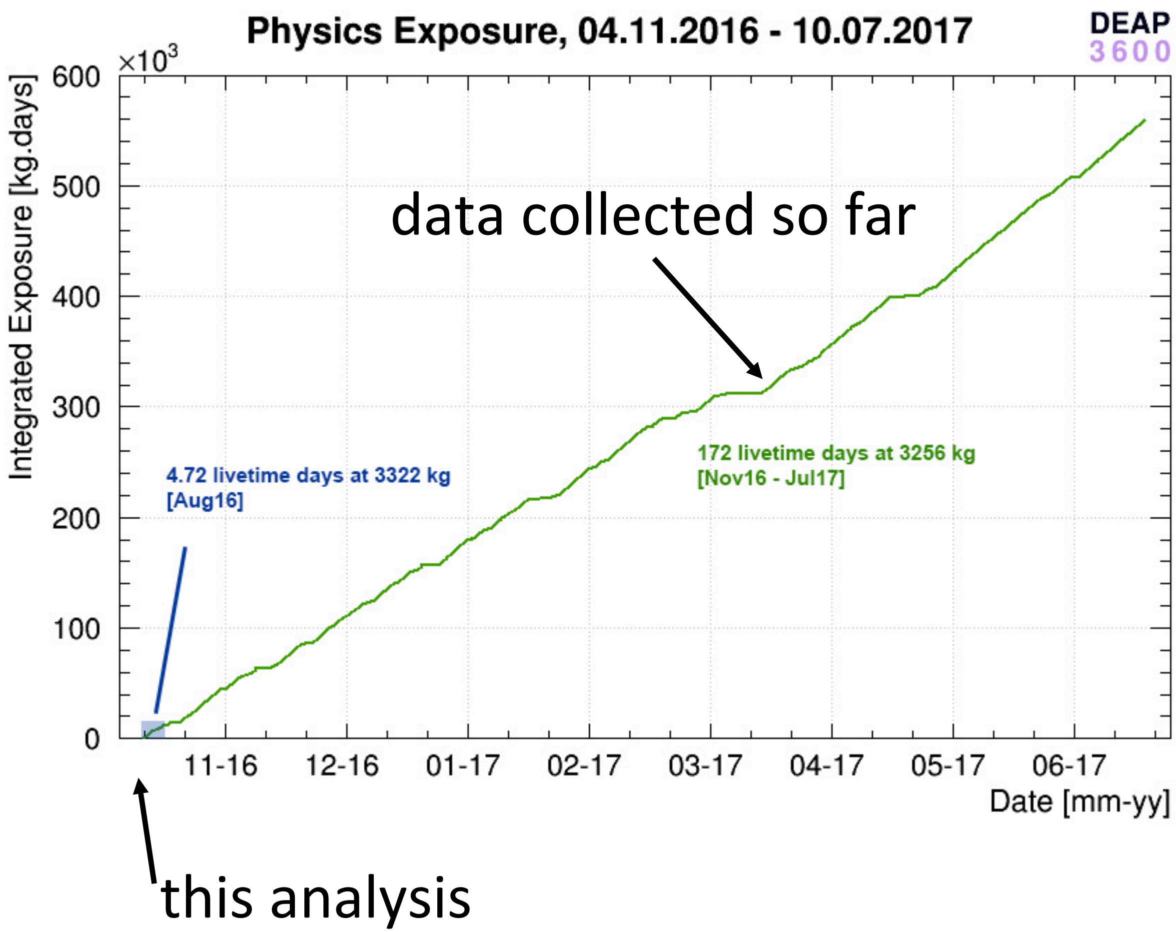
$\sigma < 1.2 \times 10^{-44}$ cm^2 (90% C.L.)





DEAP projection assumes 120 PE threshold and 1 tonne fiducial mass

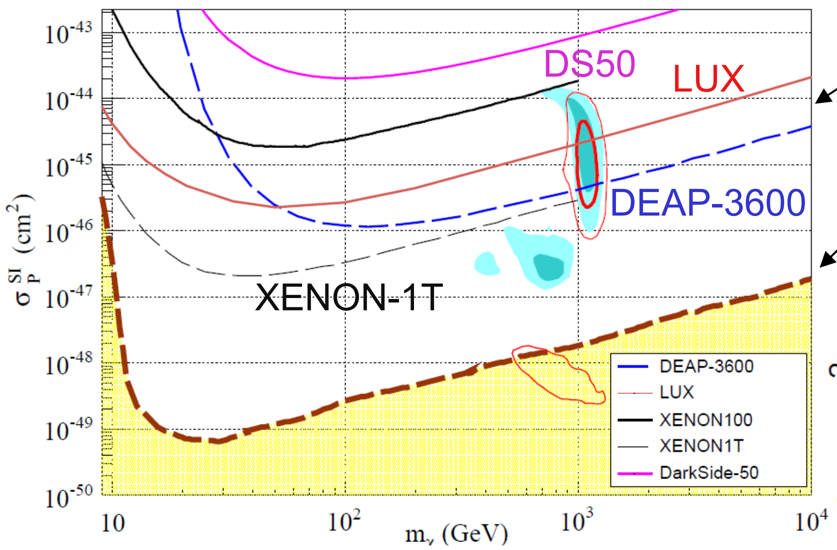
What next…

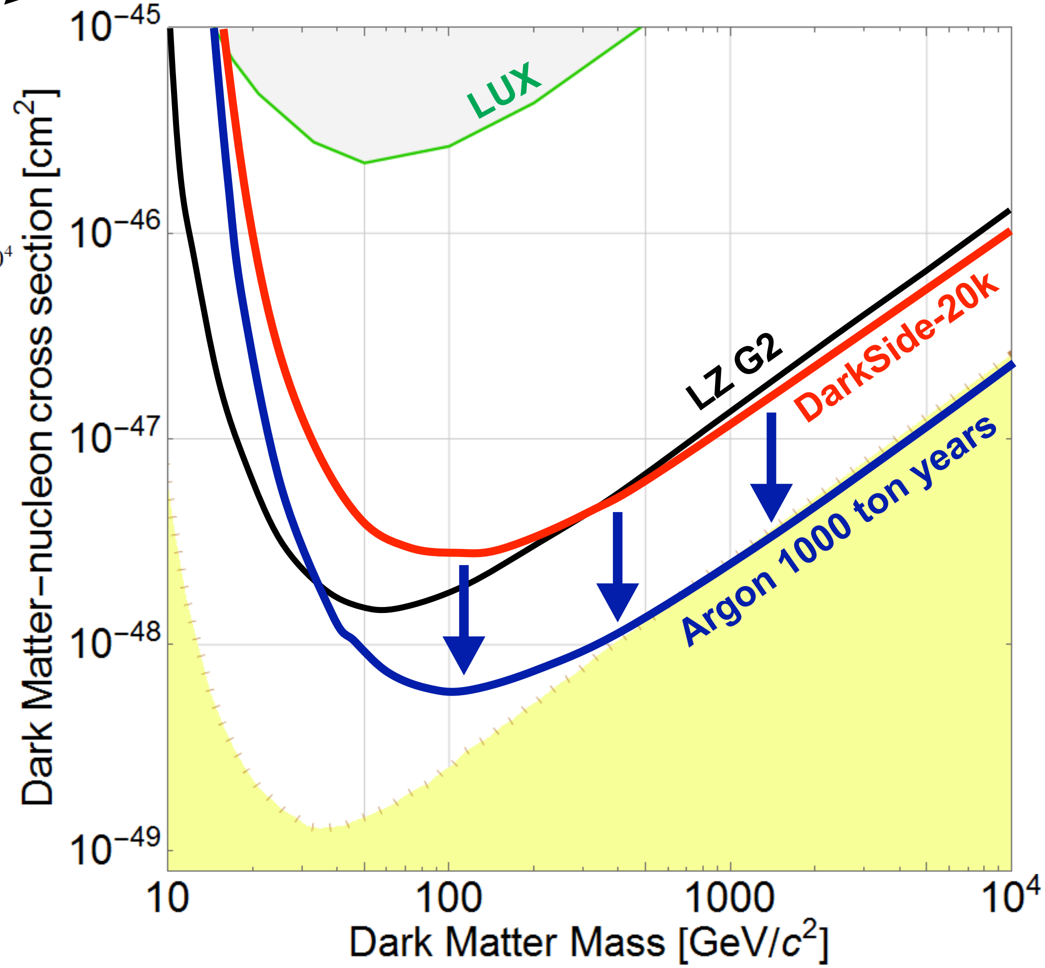


Next result: Early 2018 – on one year of data

DEAP Goal: Cover ~1 TeV allowed region for SUSY

Beyond DEAP-3600: Sensitivity with Argon





Argon has good sensitivity in high-mass region

Have shown PSD potential in low-mass region

DarkSide-20k (20 tonnes argon) competitive with LZ

1000-tonne years (future detector) reaches down to neutrino floor

Complimentary to xenon – only other target allowing such large exposure

Conclusions and Outlook

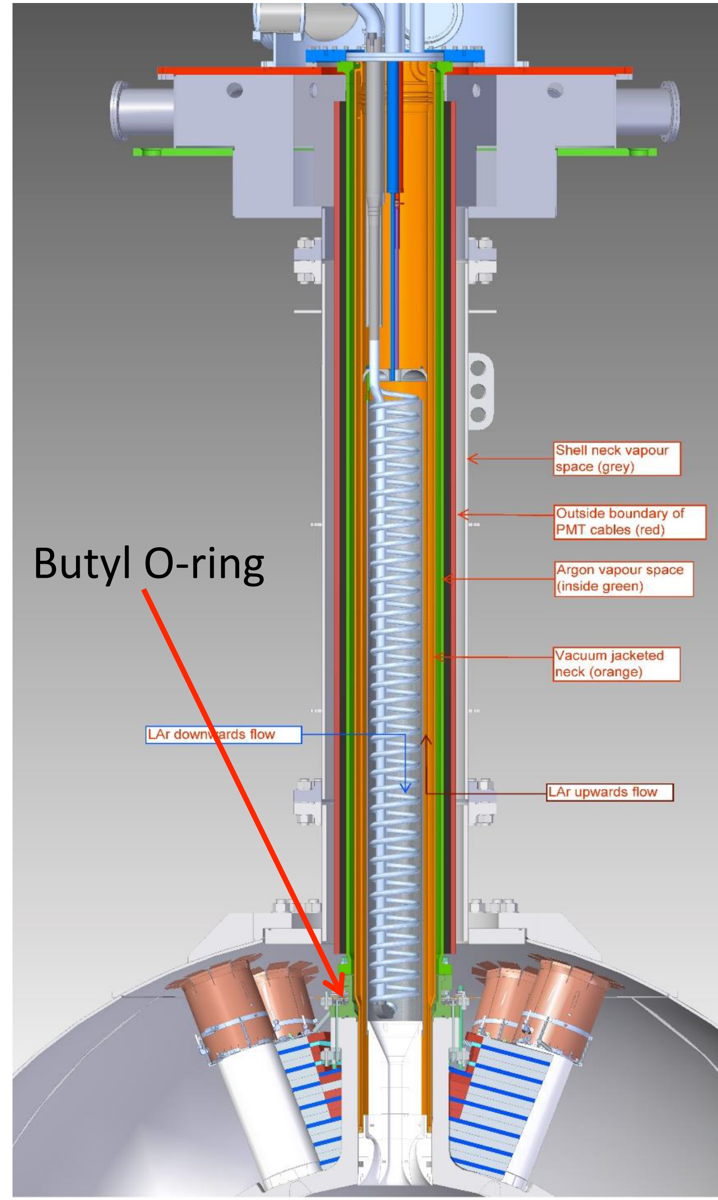
- DEAP-3600 collecting data since 2016
  - UK delivered all the calibration systems
- First analysis presented here used approximately 5 days of data collected in August 2016:
  - Stable performance
  - Good light yield
  - Good PSD – best ever demonstrated at low threshold in argon
  - Preliminary analyses of internal background components promising
  - Larger fiducial volume and lower energy threshold than design goal!
- No events observed in WIMP ROI allows best-ever limit on WIMP-nucleon cross-section at high mass in argon
- Data collection with DEAP-3600 ongoing:
  - Approx. 600,000 kg-days total exposure in the can (this analysis: 12,000 kg-days)
- Beyond DEAP: DS20k @LNGS – first physics in 2021!

https://arxiv.org/abs/1707.08042

Thank you!

Why the second fill…

- Aug. 17th 2016: Butyl O-ring leak at the acrylic/steel interface in the neck of the detector
- Due to seals getting too cold
- ~100 ppb Rn scrubbed N_2 entered LAr – too much for purification system
- Decision to vent Ar and to refill detector



Why the second fill…

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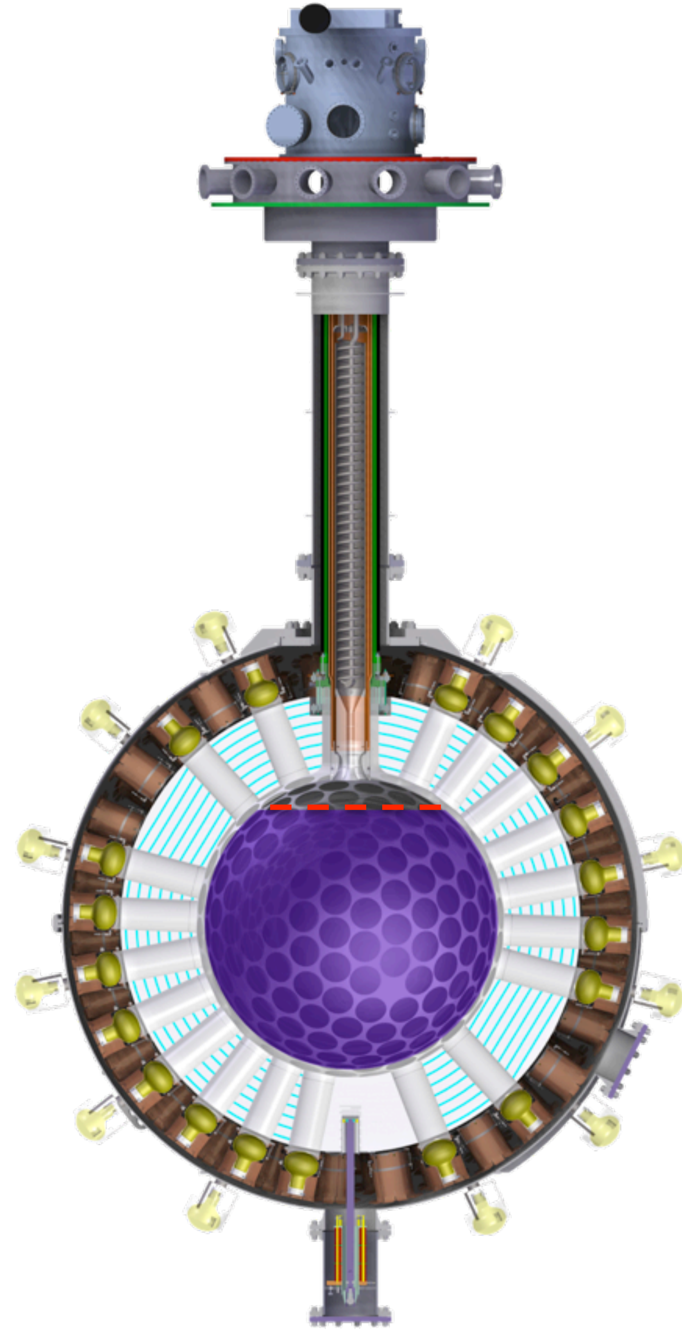
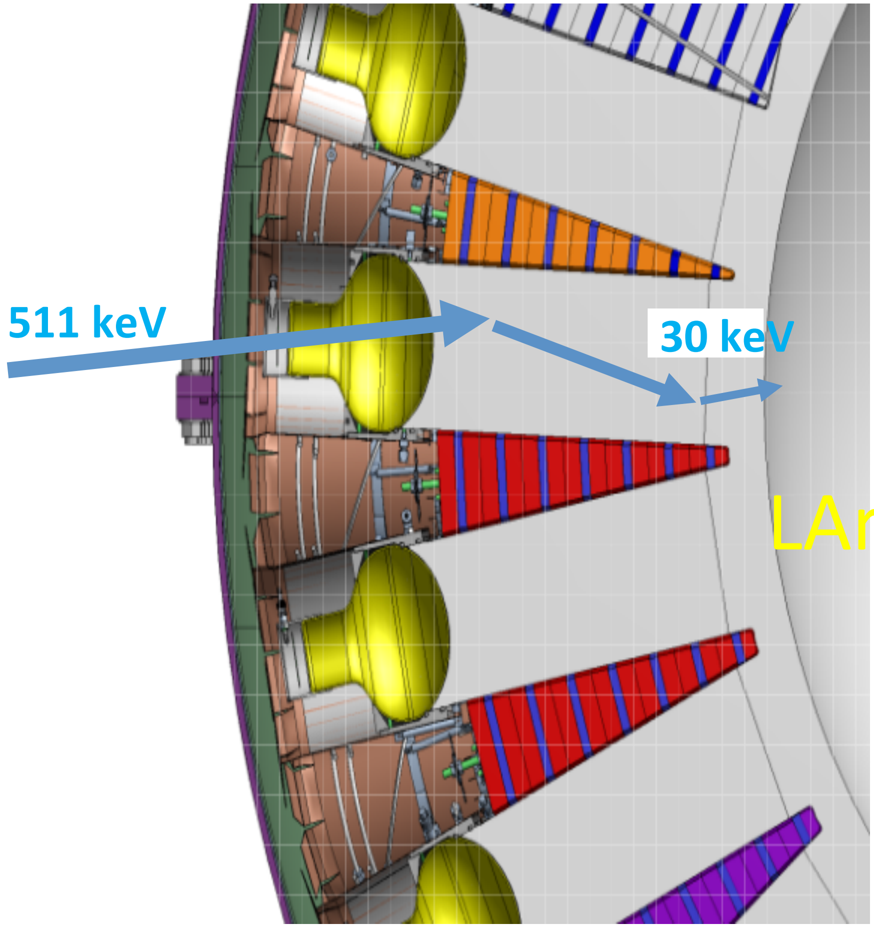
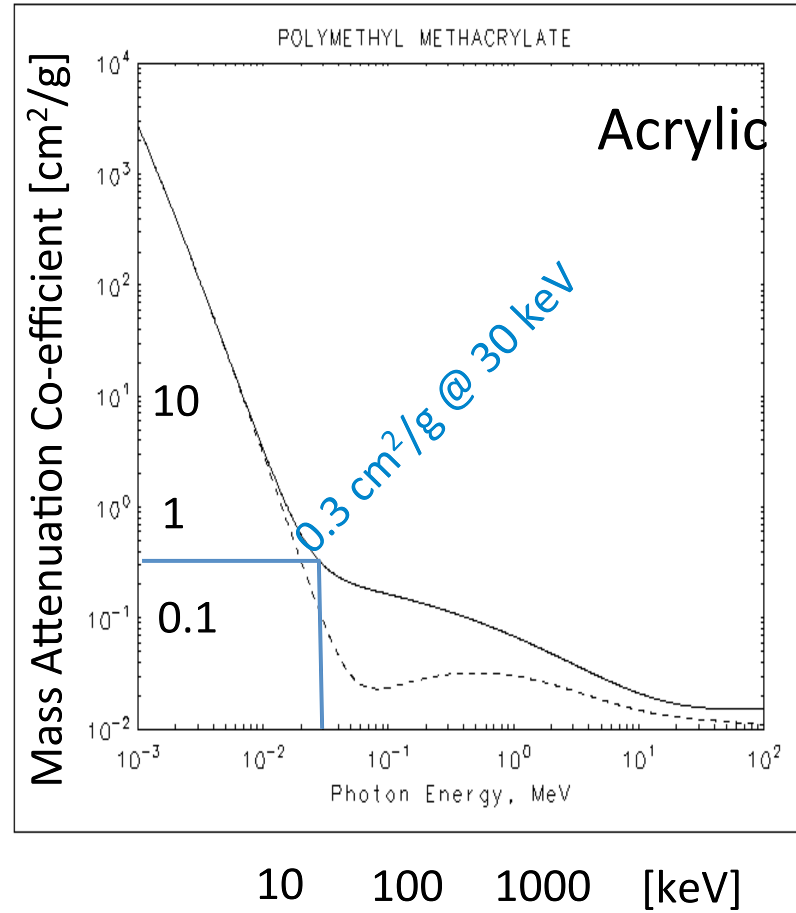
- Due to seals getting too cold
- ~100 ppb Rn scrubbed N_2 entered LAr – too much for purification system
- Decision to vent Ar and to refill detector
- New fill level below neck to prevent issue occurring again
  - 3,600kg LAr → 3,322 kg LAr
- Continued data collection from Nov. 1st 2016

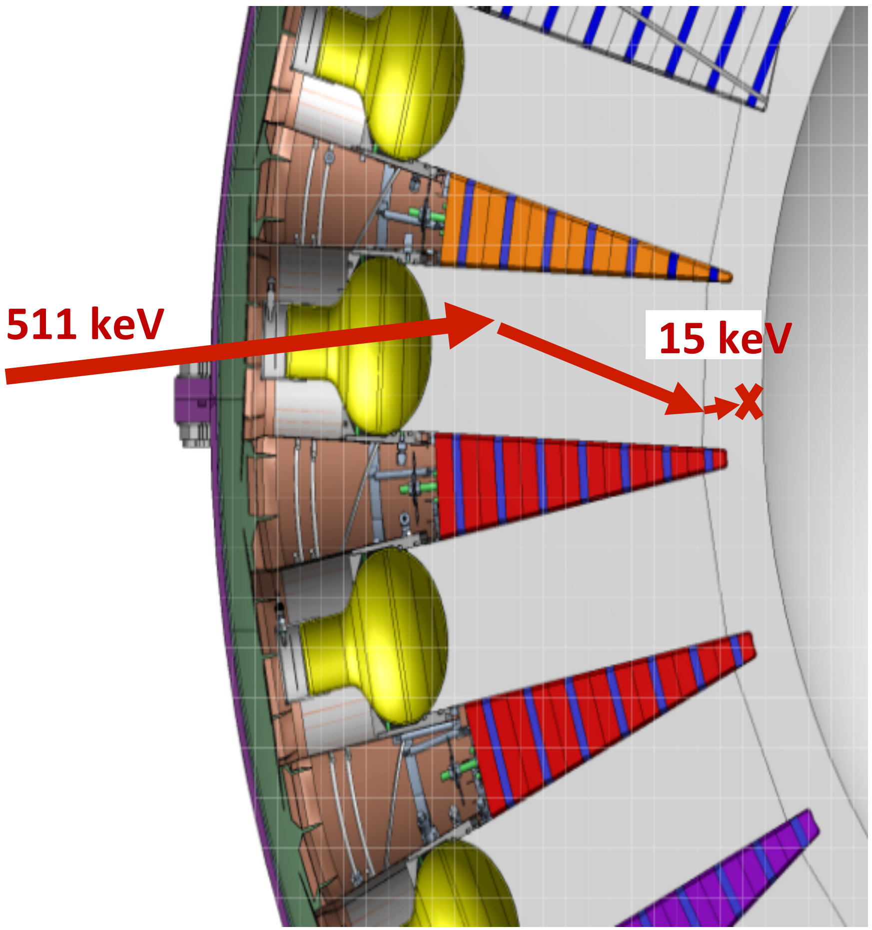


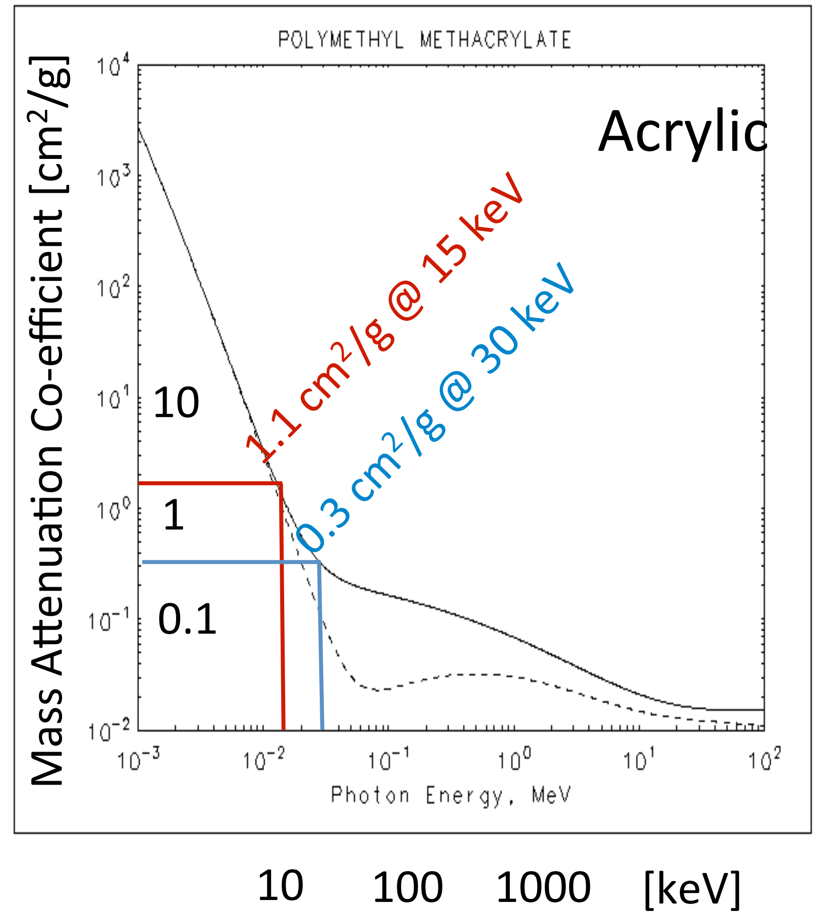
^{22}Na 300 PE feature





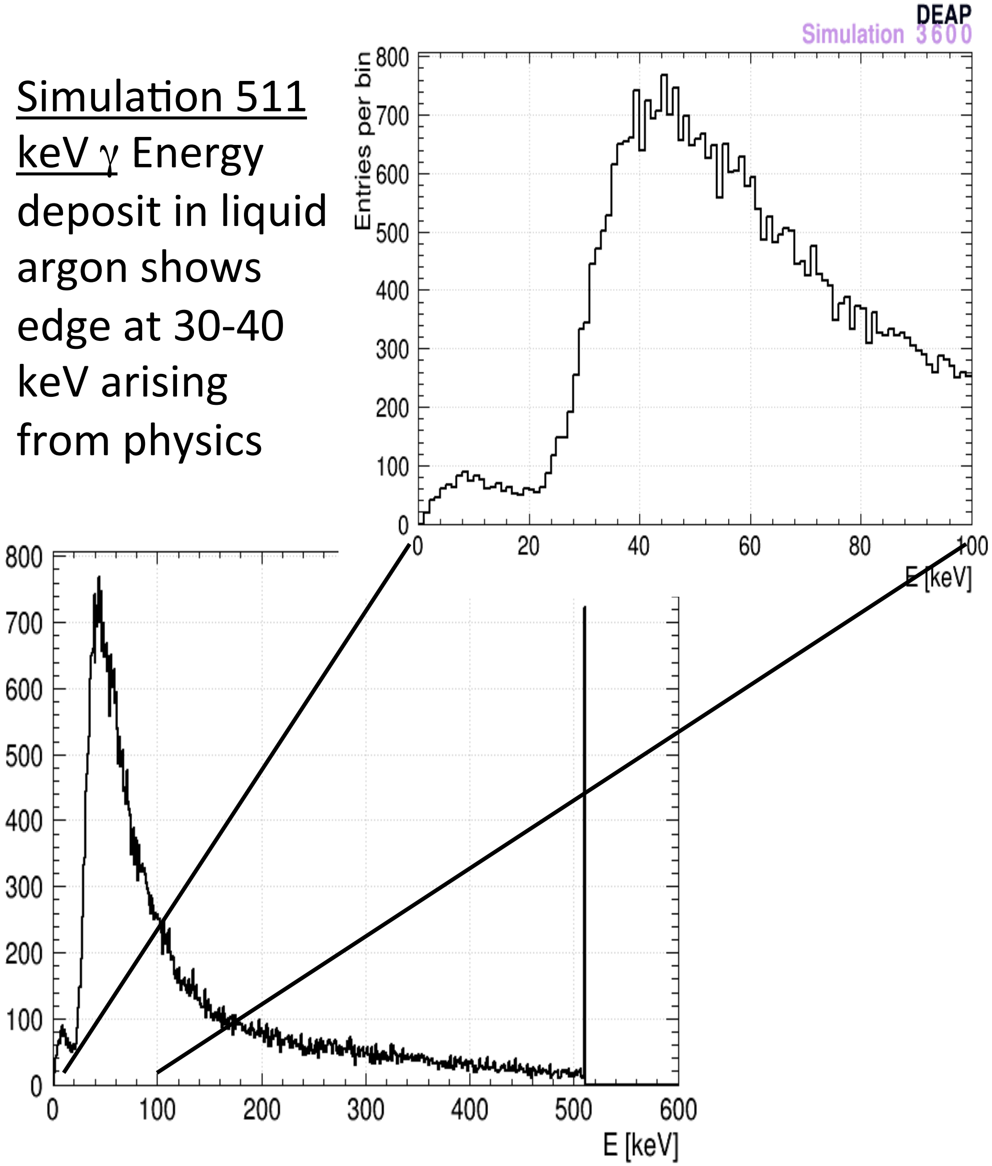
Plot and data from NIST.gov
X-ray mass attenuation coefficients

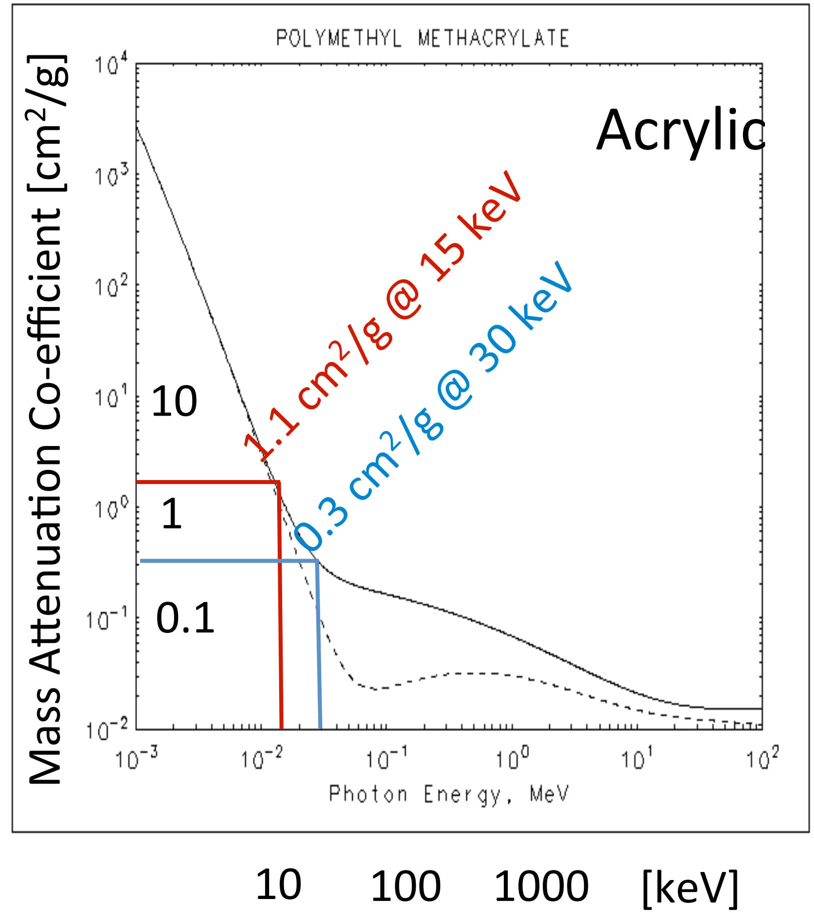




Plot and data from NIST.gov
X-ray mass attenuation coefficients

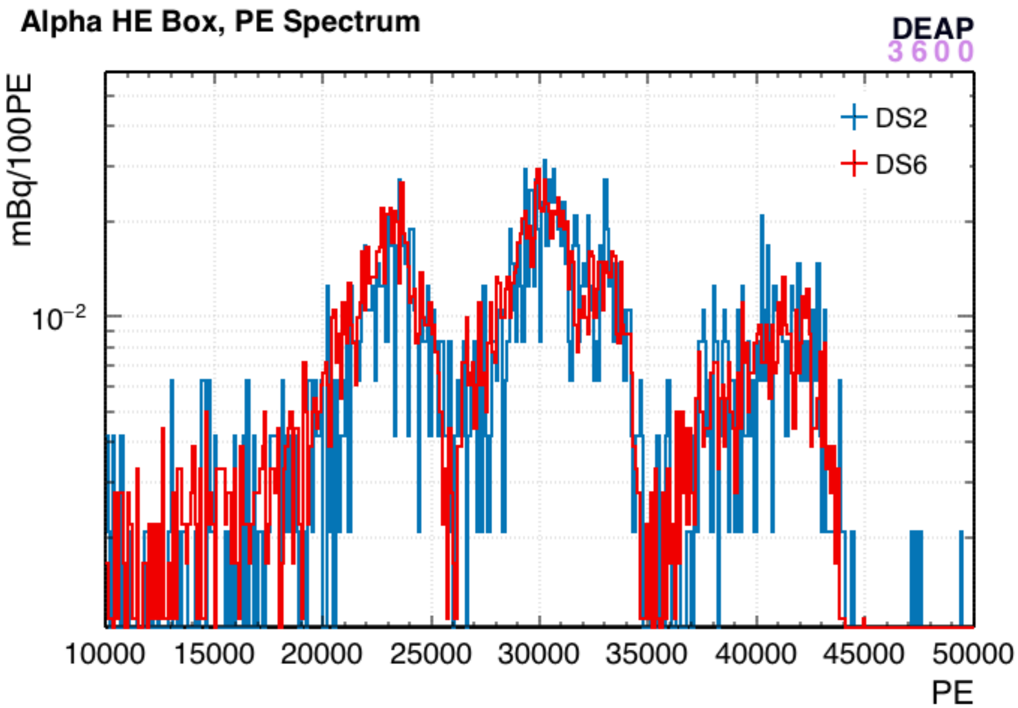
Simulation 511 keV γ Energy deposit in liquid argon shows edge at 30-40 keV arising from physics





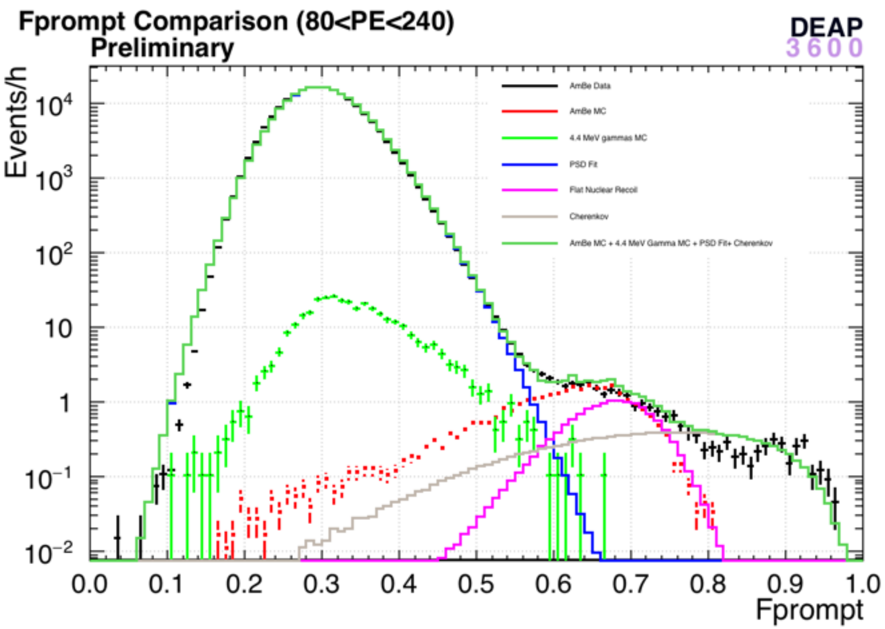
Plot and data from NIST.gov X-ray mass attenuation coefficients

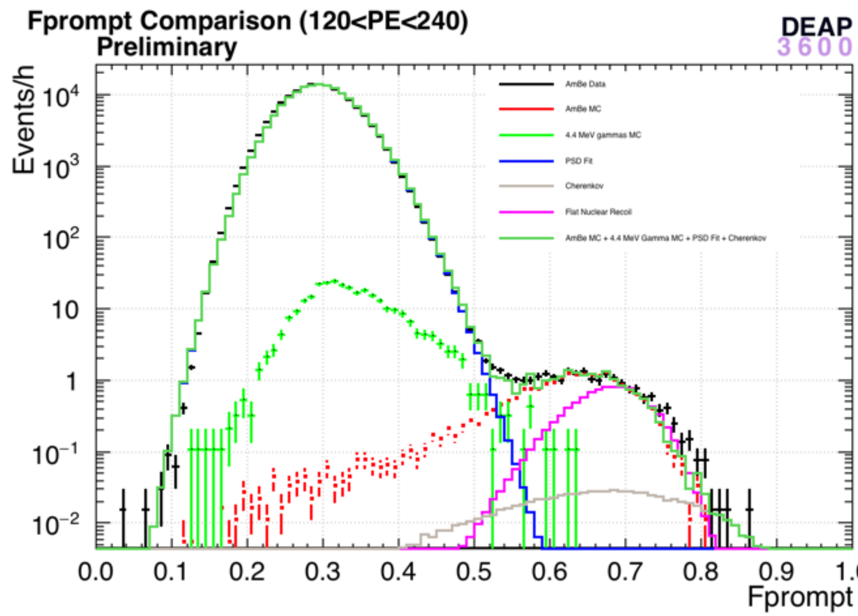
Radon rate before and after…



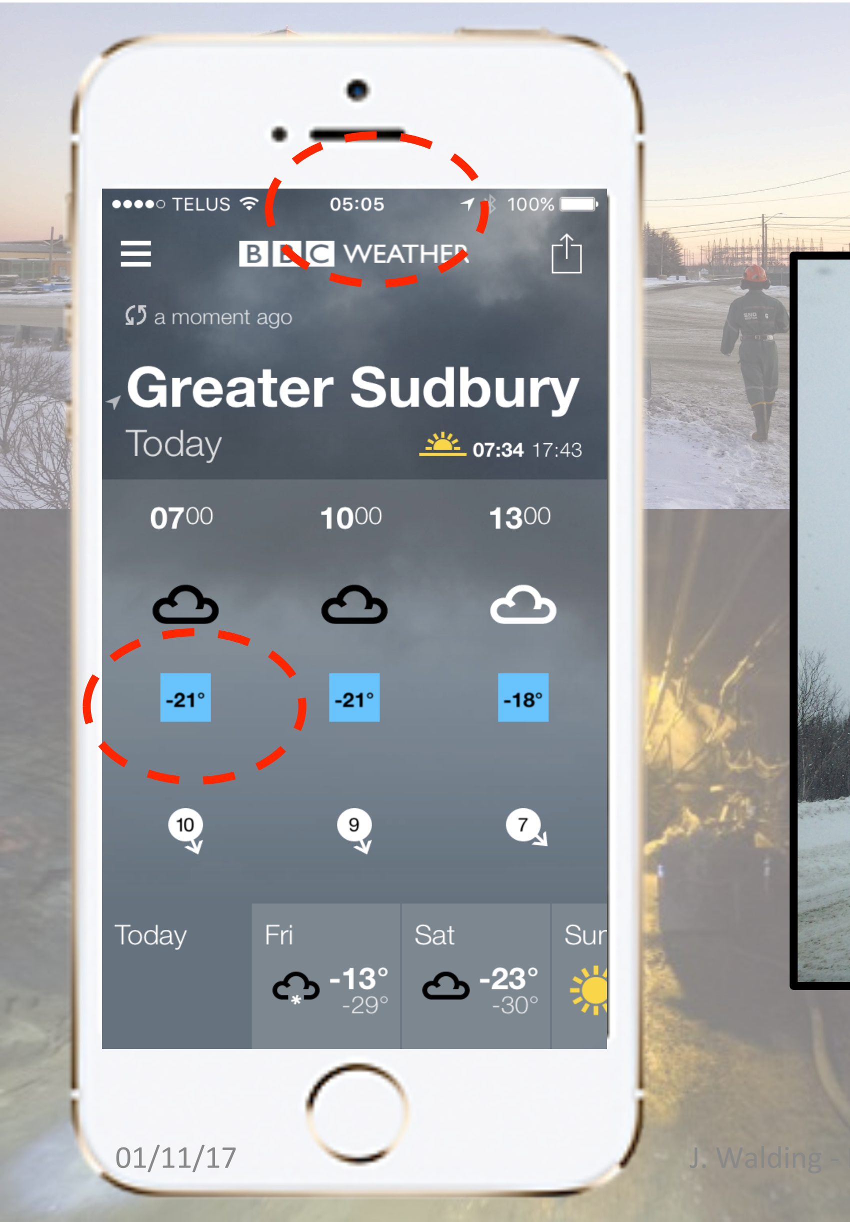
Alpha	DS2	DS6
222Rn	0.55±0.05 [mBq]	0.53±0.06 [mBq]
210Po	0.93±0.1 [mBq]	0.91±0.1 [mBq]

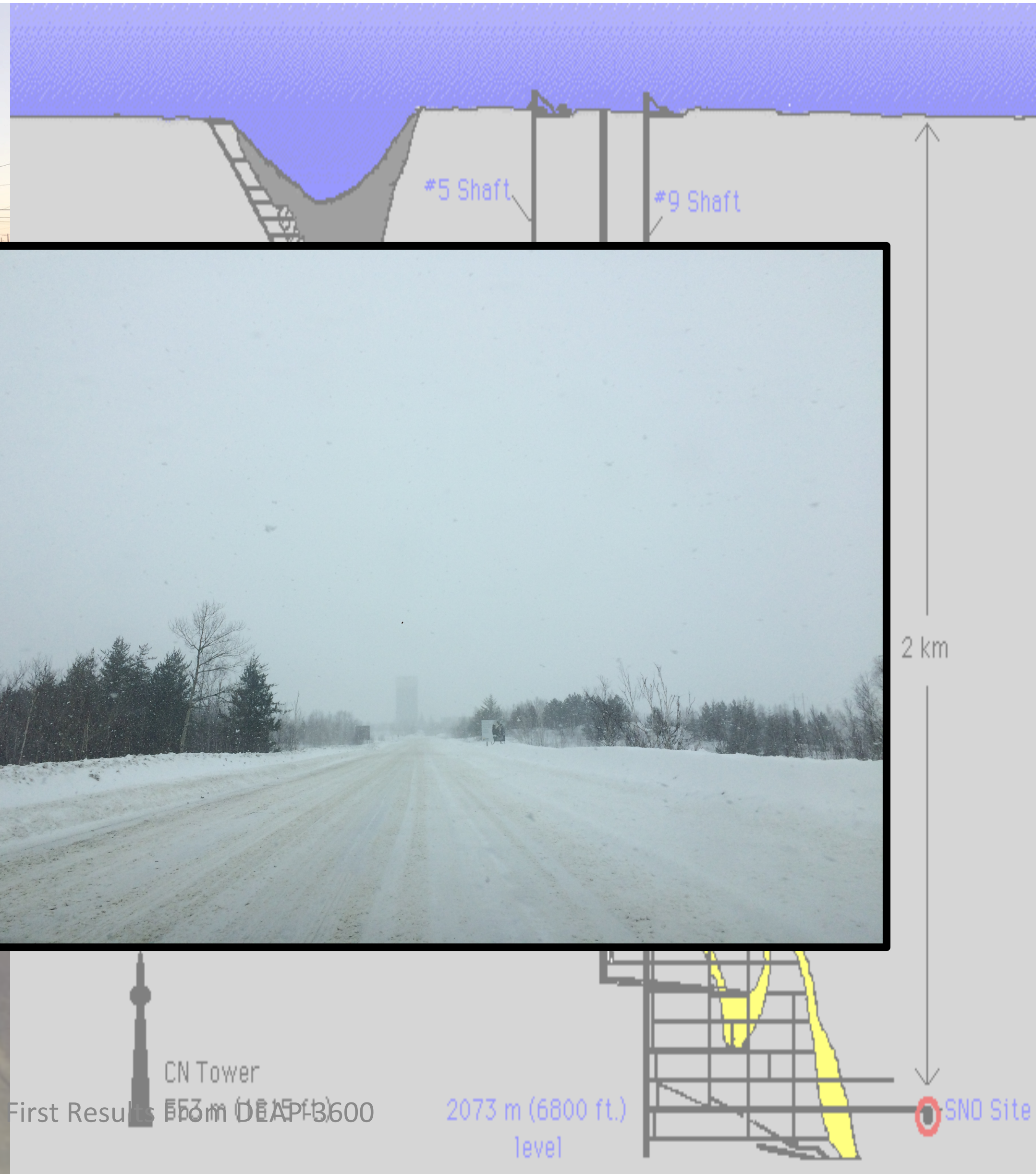
Neutron calibration





Going DEAP underground!

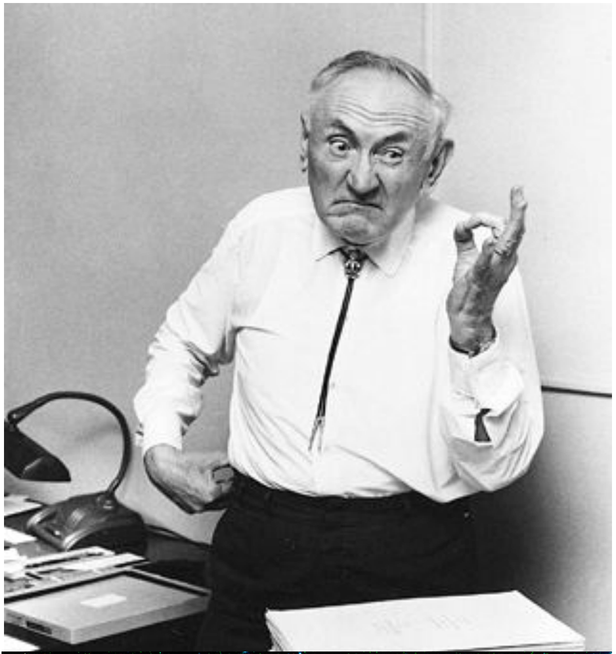


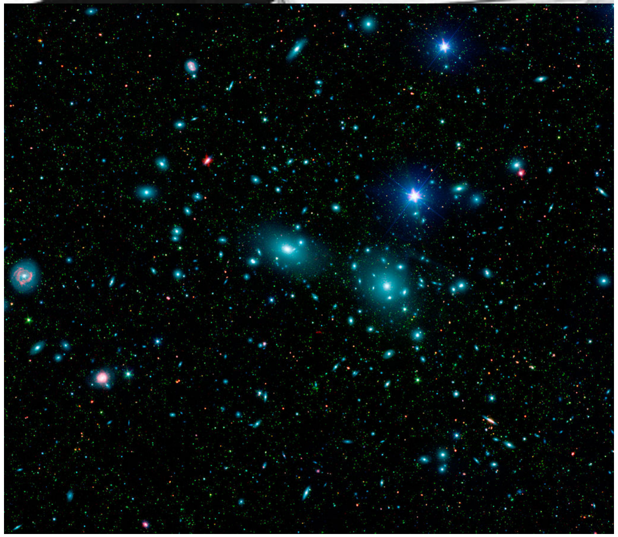


Why do we think there’s dark matter?

A brief history of dark matter

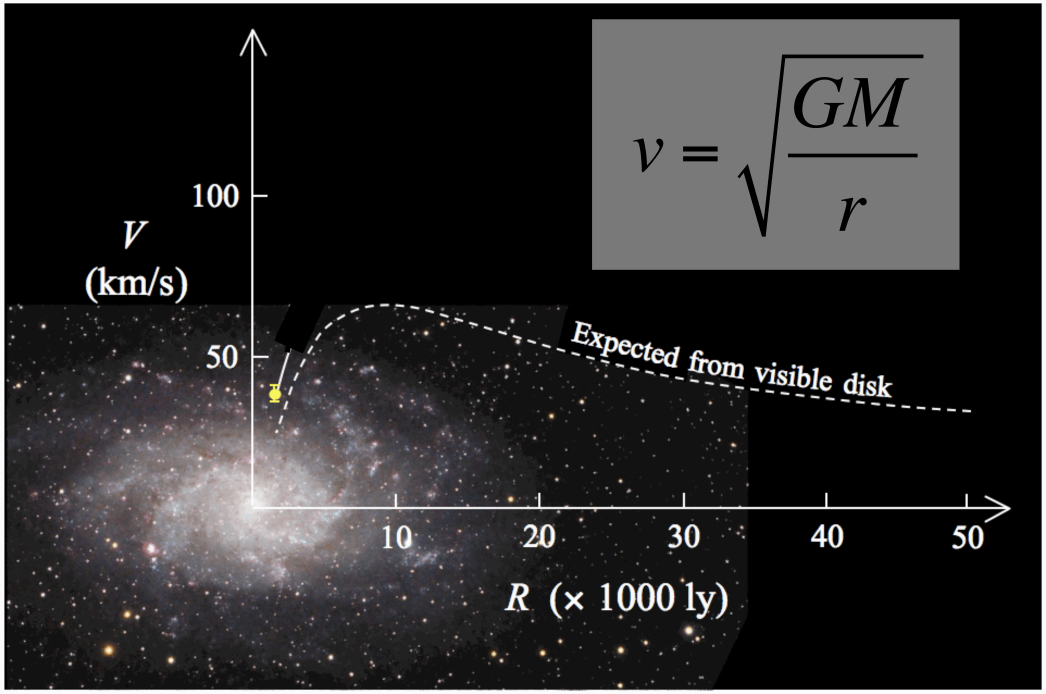
- Fritz Zwicky observed motions of Coma cluster of galaxies (1933)
- Calculated the mass of the cluster from the velocities of the outer galaxies
- Also estimated the mass of the cluster based on the Luminosity
- The calculations differed by a factor of 400!
- The cluster needed much more mass to explain their velocities than was present from stars and hot gas alone…





A brief history of dark matter

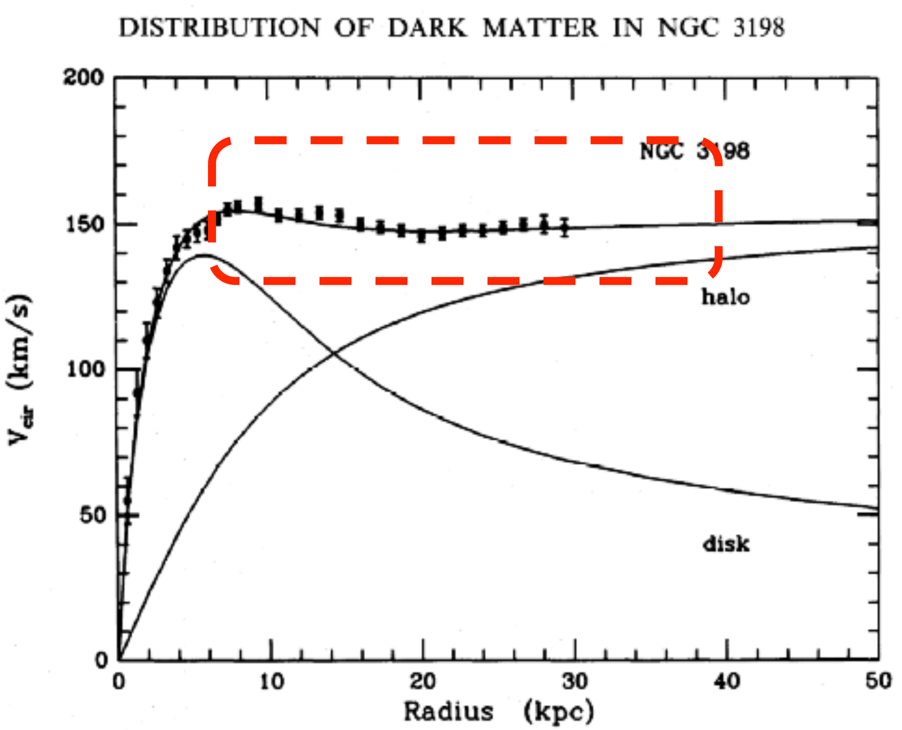
- In the 1970's Vera Rubin saw the same anomaly when observing rotations of individual galaxies
- If no dark matter:

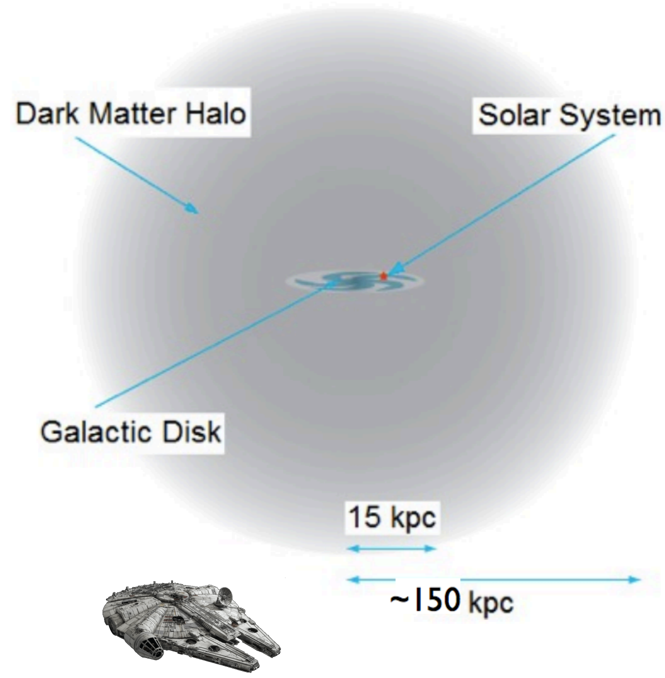


However...

A brief history of dark matter

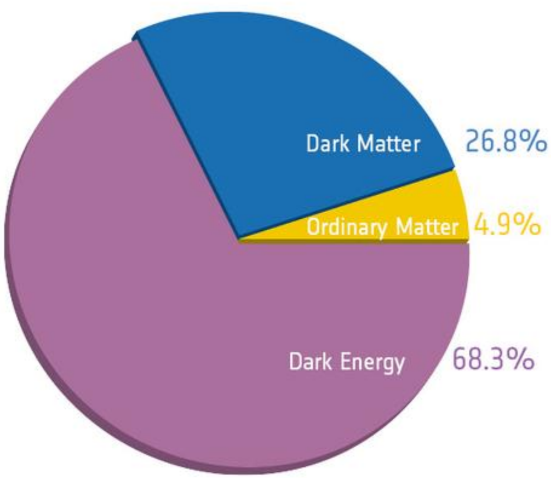
- Velocities constant at large radii!

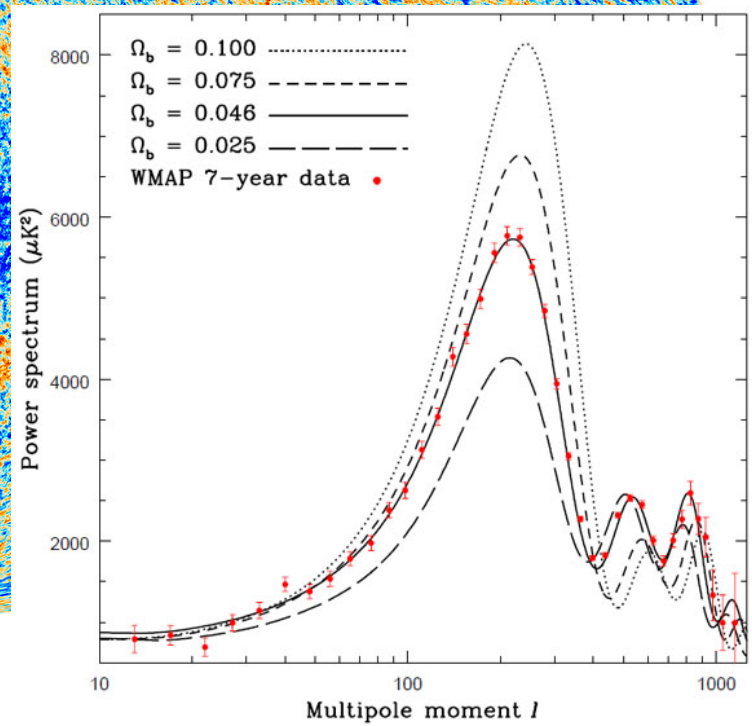




A brief history of dark matter

- Best measurement from Cosmic Microwave Background
- Cobe, WMAP and PLANCK surveys
- 26.8% Dark Matter, < 5% baryonic matter!

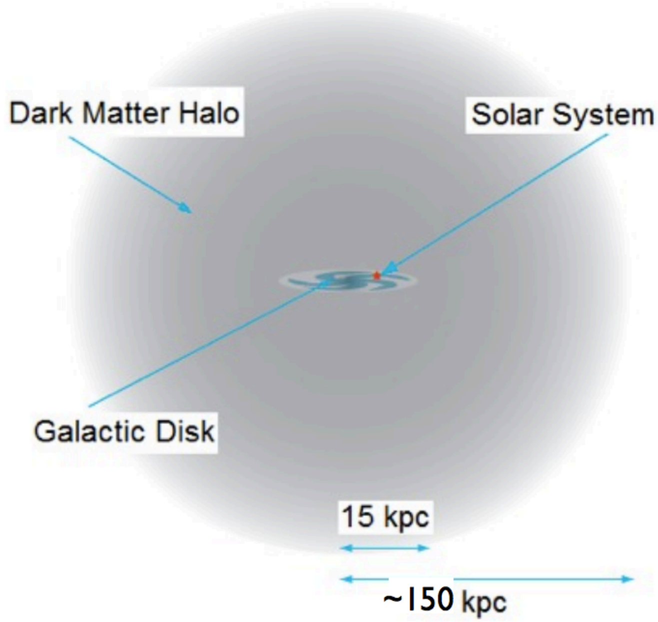




Ordinary matter: 4% is hot H and He gas, 0.5% stars, 0.3% neutrinos, 0.03% heavy elements

How much Dark Matter is there?

- The dark matter density in this room is ~0.3 GeV/cm^3
- Essentially 1 dark matter particle per teacup
- In comparison, the baryonic matter density is ~5 g/cm^3
  which is ~3 x 10^{24} GeV/cm^3!

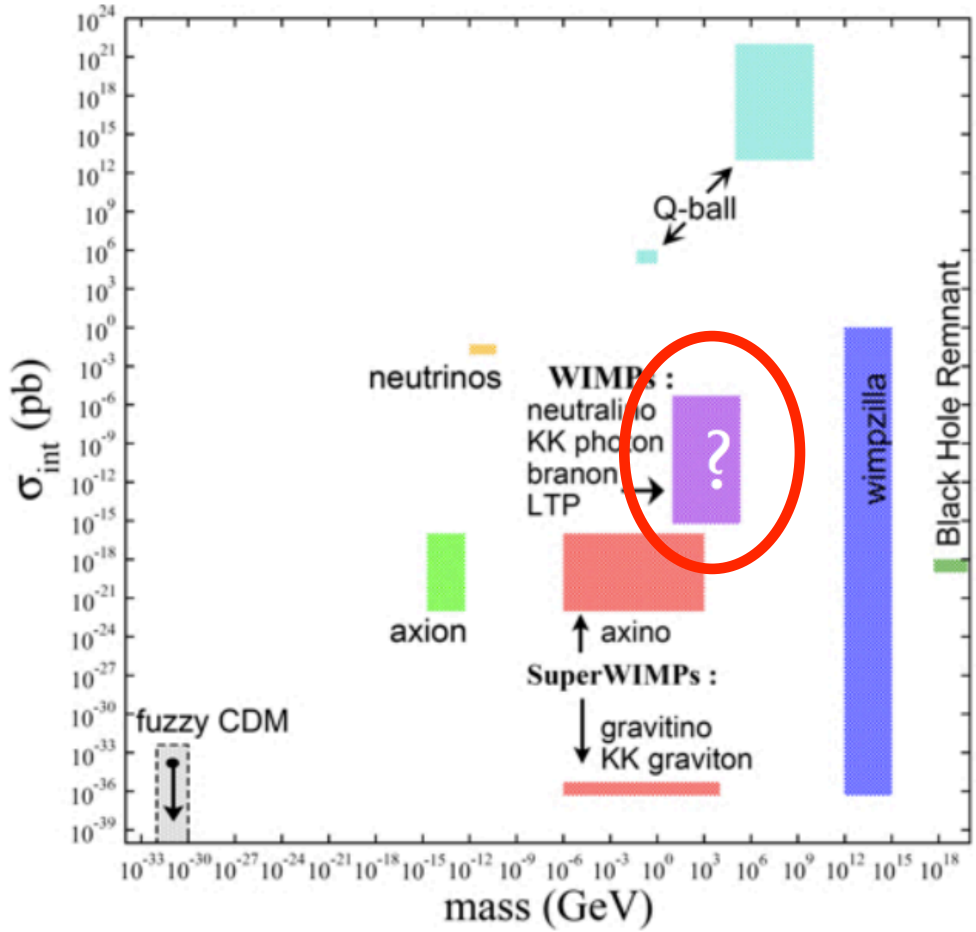


I take mine dark and weak!

What is dark matter?

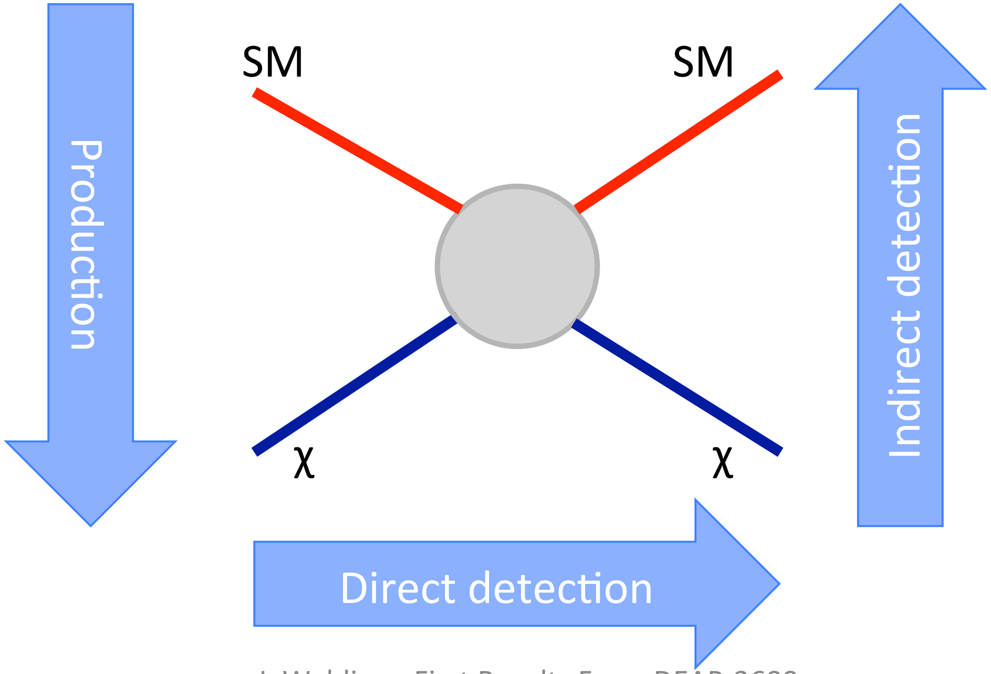
- Many models spanning orders of magnitude in mass and cross-section

- Concentrate on Weakly Interacting Massive Particles (WIMPs)
  - Motivated by SUSY



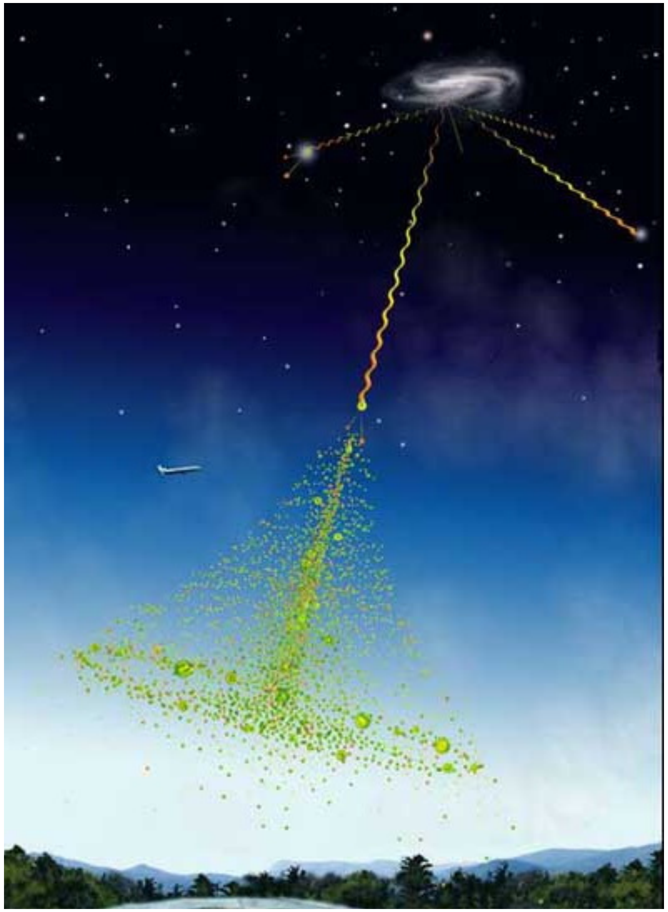
If it's so dark, how do we see it?

- Three methods of observation – "Break it, make it, shake it!"
  - Indirect detection: Annihilation (AMS…)
  - Production: LHC
  - Direct detection (DEAP)
- Two methods needed for discovery. Or directionality…



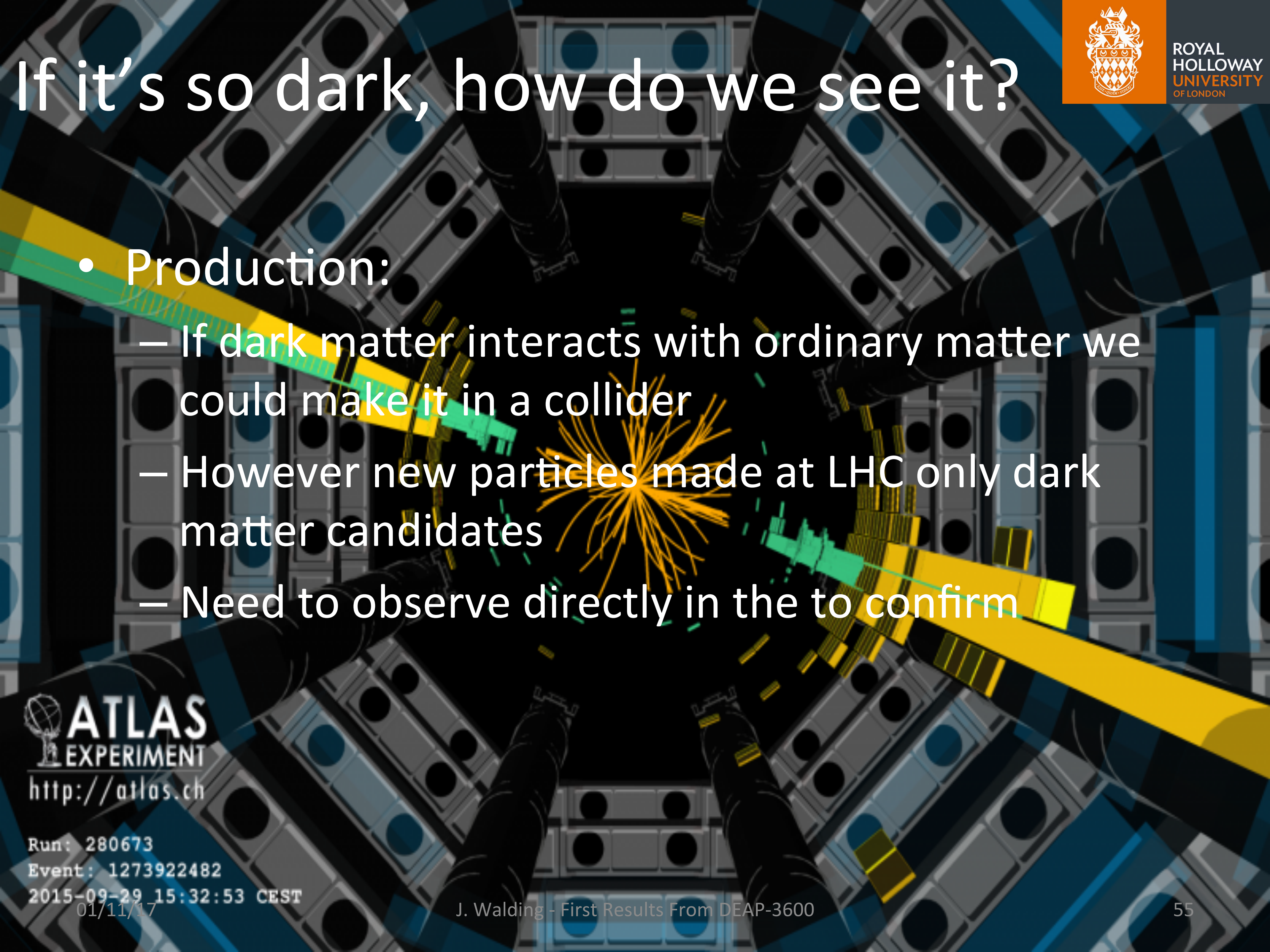
If it's so dark, how do we see it?

- Indirect detection (e.g. AMS):
  - Look for signals of dark matter annihilation in the cosmos
    - Resonant peak
  - Dark matter weakly interacting so rare in the galaxy, but could happen at high enough rate to be visible if high enough dark matter density
  - e.g. Centre of stars and galaxies (large gravitational well's)



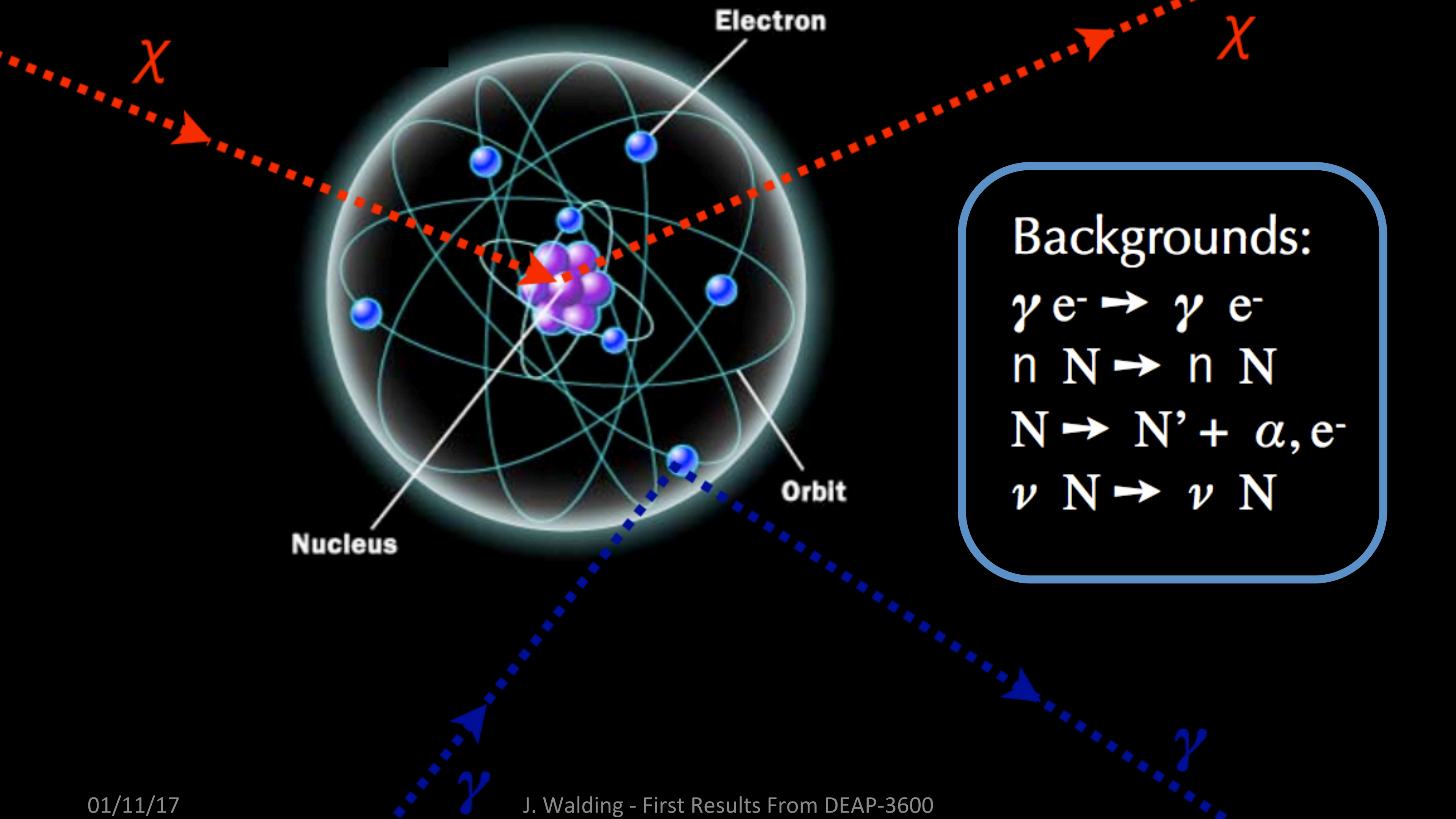
If it’s so dark, how do we see it?

- Production:
  - If dark matter interacts with ordinary matter we could make it in a collider
  - However new particles made at LHC only dark matter candidates
  - Need to observe directly in the to confirm



Direct Detection

Signal: $\chi N \rightarrow \chi N$



Backgrounds:

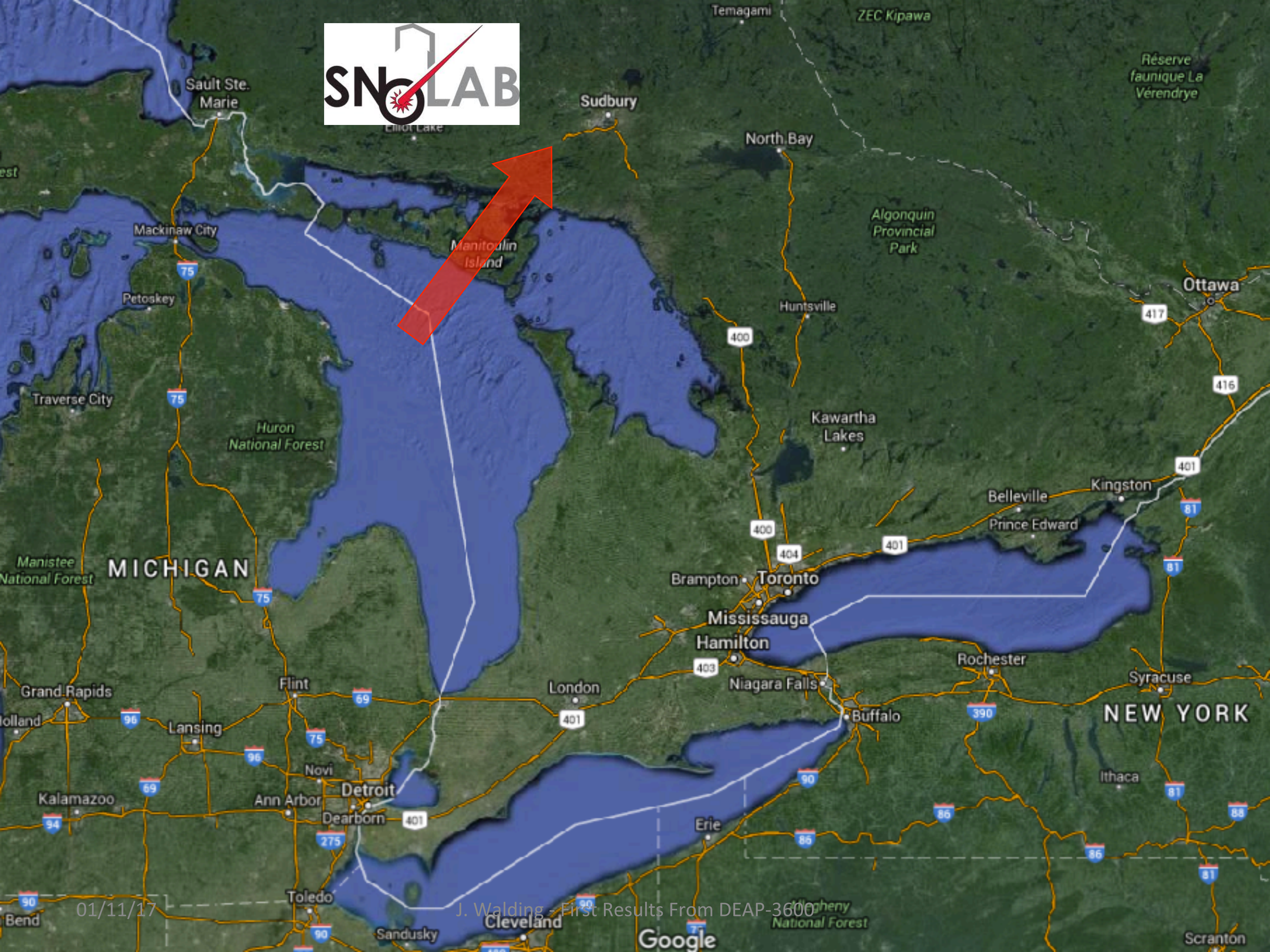
$\gamma\, e^- \rightarrow \gamma\, e^-$

$n\, N \rightarrow n\, N$

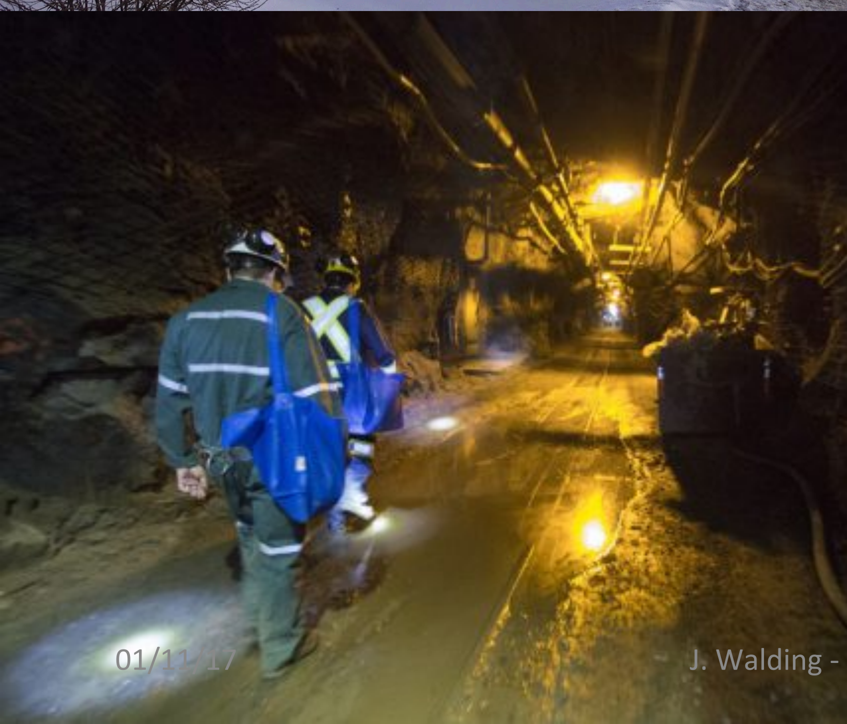
$N \rightarrow N' + \alpha, e^-$

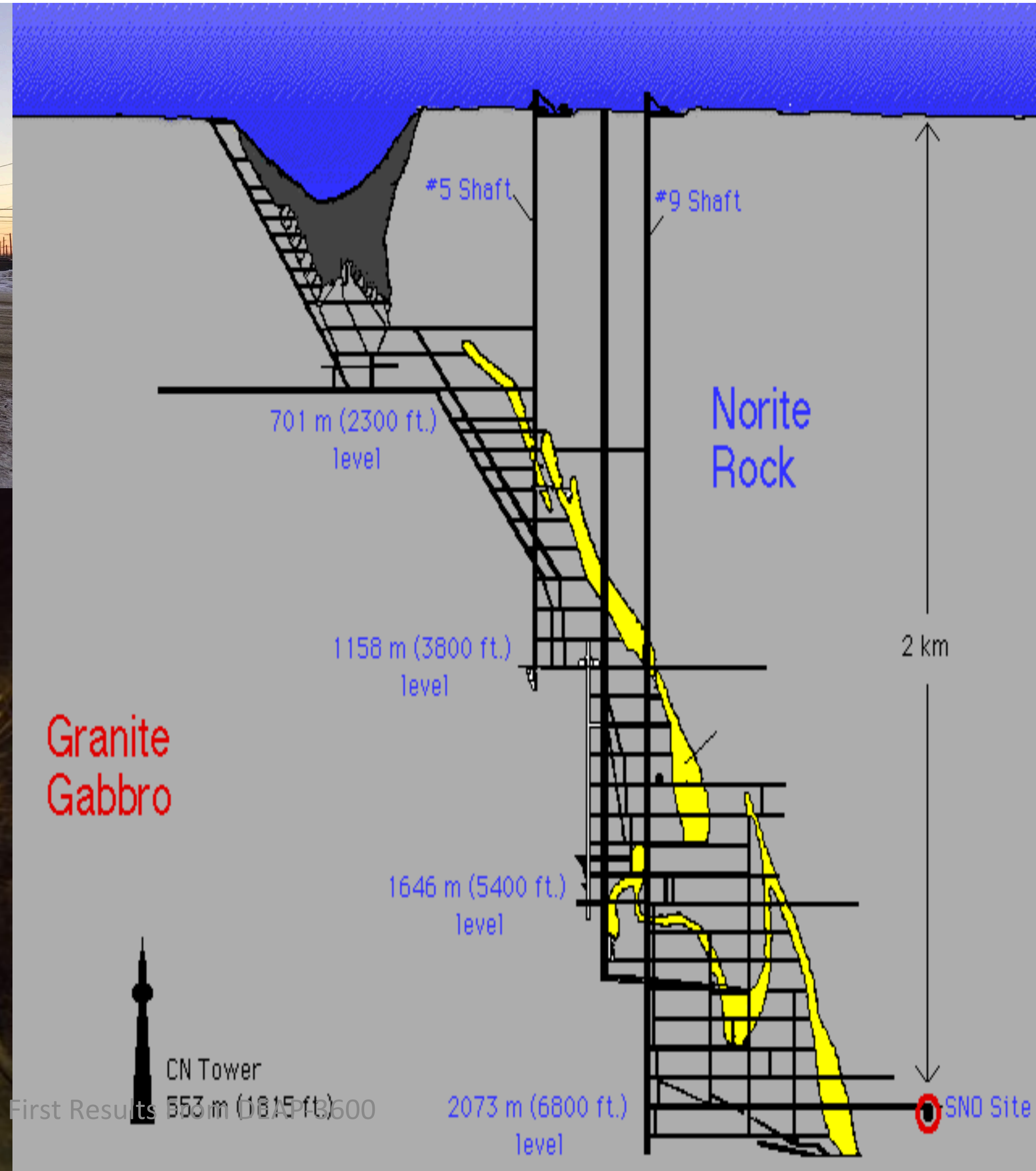
$\nu\, N \rightarrow \nu\, N$

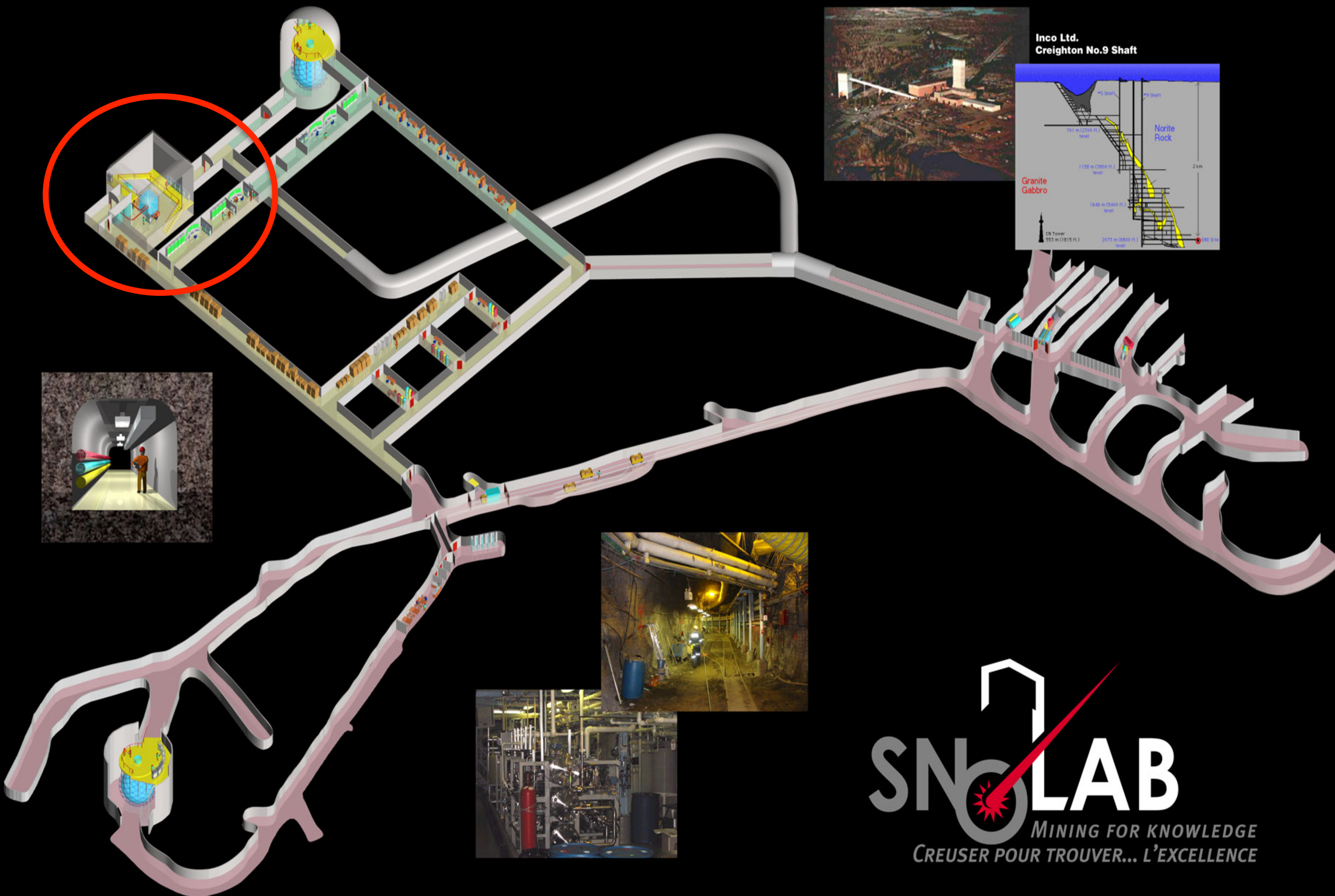
What is DEAP-3600


SNOLAB
Sault Ste. Marie
Sudbury
Temagami
ZEC Kipawa
Réserve faunique La Vérendrye
North Bay
Mackinaw City
Manitoulin Island
Algonquin Provincial Park
Petoskey
Huntsville
Ottawa
Traverse City
Huron National Forest
Kawartha Lakes
Manistee National Forest
MICHIGAN
Belleville
Kingston
Prince Edward
Brampton
Toronto
Mississauga
Hamilton
Rochester
Syracuse
Grand Rapids
Flint
London
Niagara Falls
Buffalo
NEW YORK
Lansing
Novi
Detroit
Ann Arbor
Dearborn
Kalamazoo
Ithaca
Erie
Toledo
Cleveland
Sandusky
Allegheny National Forest
Scranton
Google

Going DEAP underground!







SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE


2011-07-11 11:22:35

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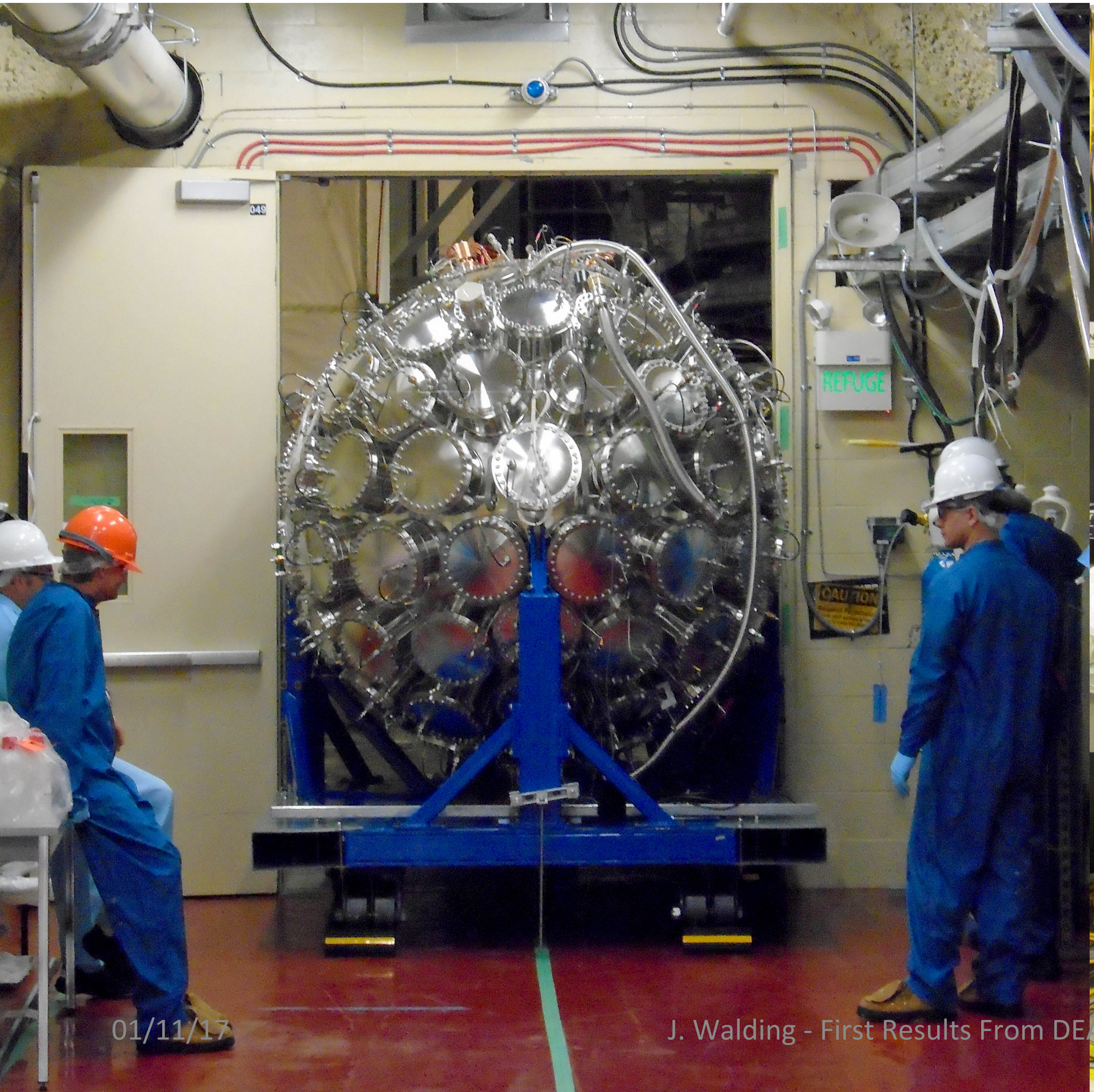
Are we the unwitting henchmen of a Bond villain…?



Are we the unwitting henchmen of a Bond villain…?

Things to remember…

- When searching for dark matter we want to…

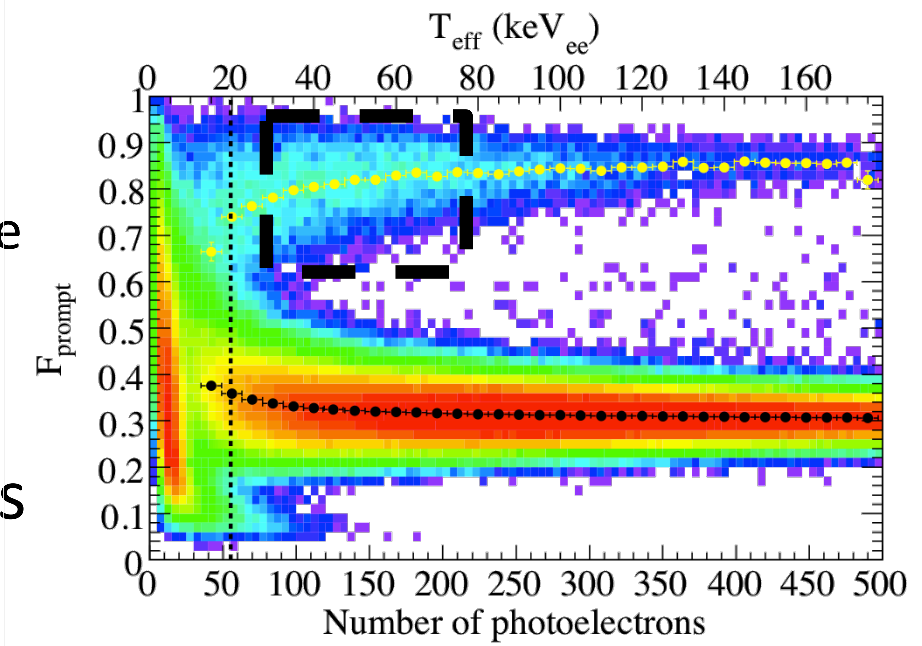
  1. Use as large a Region of Interest (ROI) as possible

  2. Use as large a fiducial mass as possible

Things to remember…

1. Use as large a Region of Interest (ROI) as possible:
   - Large PSD: More PE/keV
   - Well understood timing: Reduce Fprompt variance
   - Well understood energy scale

2. Use as large a fiducial mass as possible:
   - Mitigate surface and bulk backgrounds: Reduces leakage
   - Position reconstruction: Reduces leakage



Things to remember…

1. Use as large a Region of Interest (ROI) as possible:
   – Large PSD: More PE/keV
   – Understood timing: Reduce Fprompt variance
   – Energy Resolution:
2. Use as large a fiducial mass as possible:
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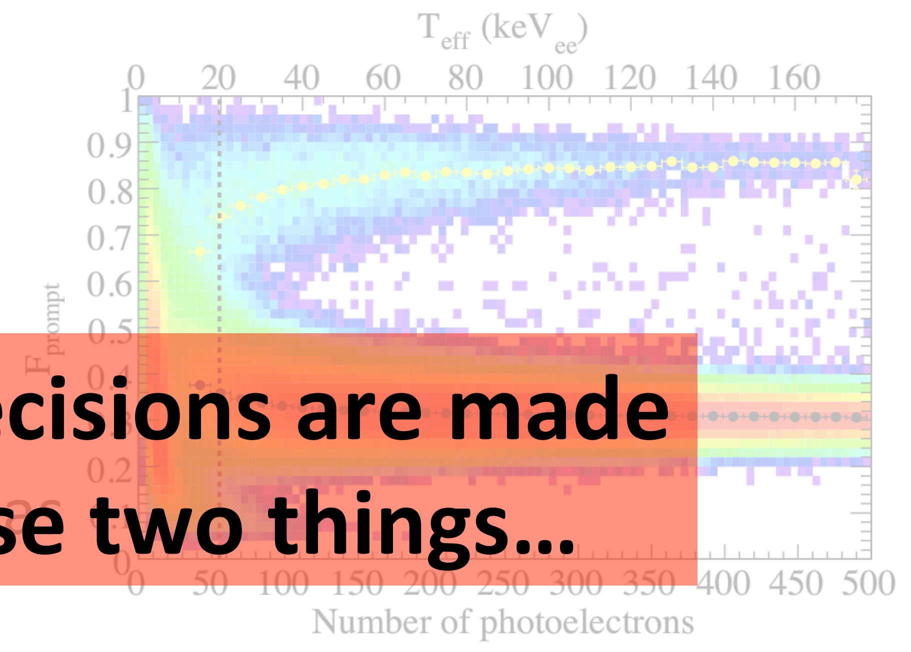

All experimental decisions are made to maximise these two things…

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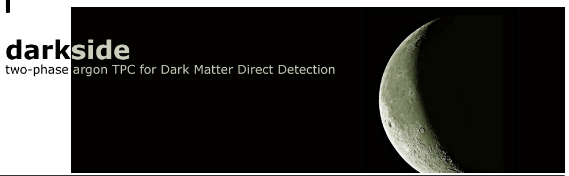
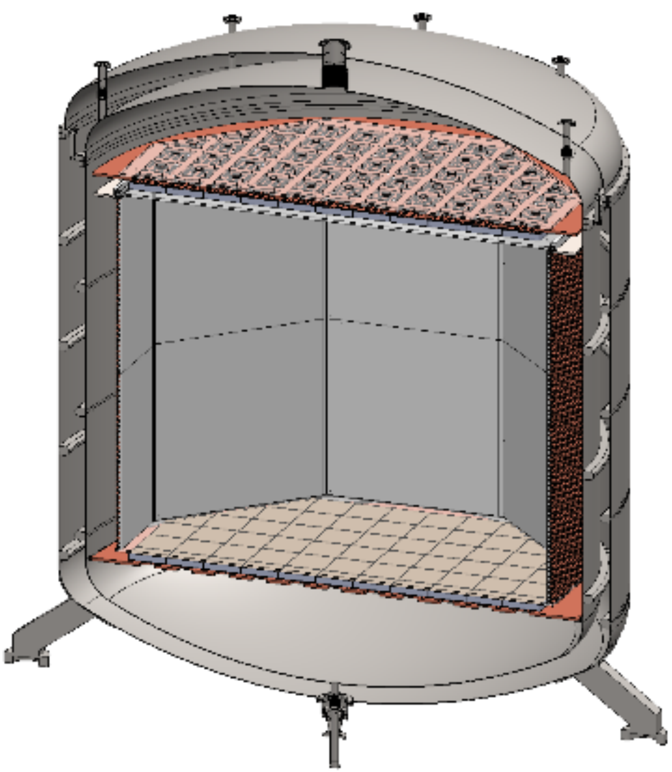
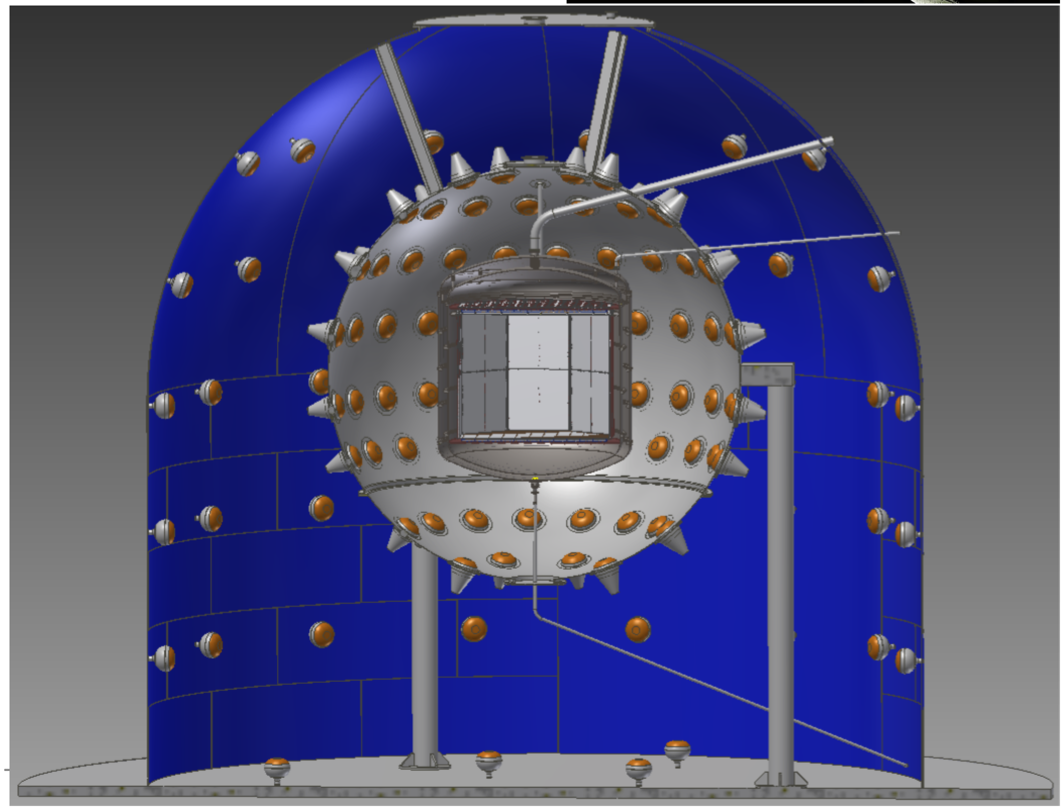
DarkSide-20k

- TPC: Scaled up version of DS-50
- 20 tonnes of depleted argon, starts operation at LNGS in 2021
- Collaboration of DarkSide, DEAP, MiniCLEAN and ArDM
- First large-scale use of SiPMs for light readout



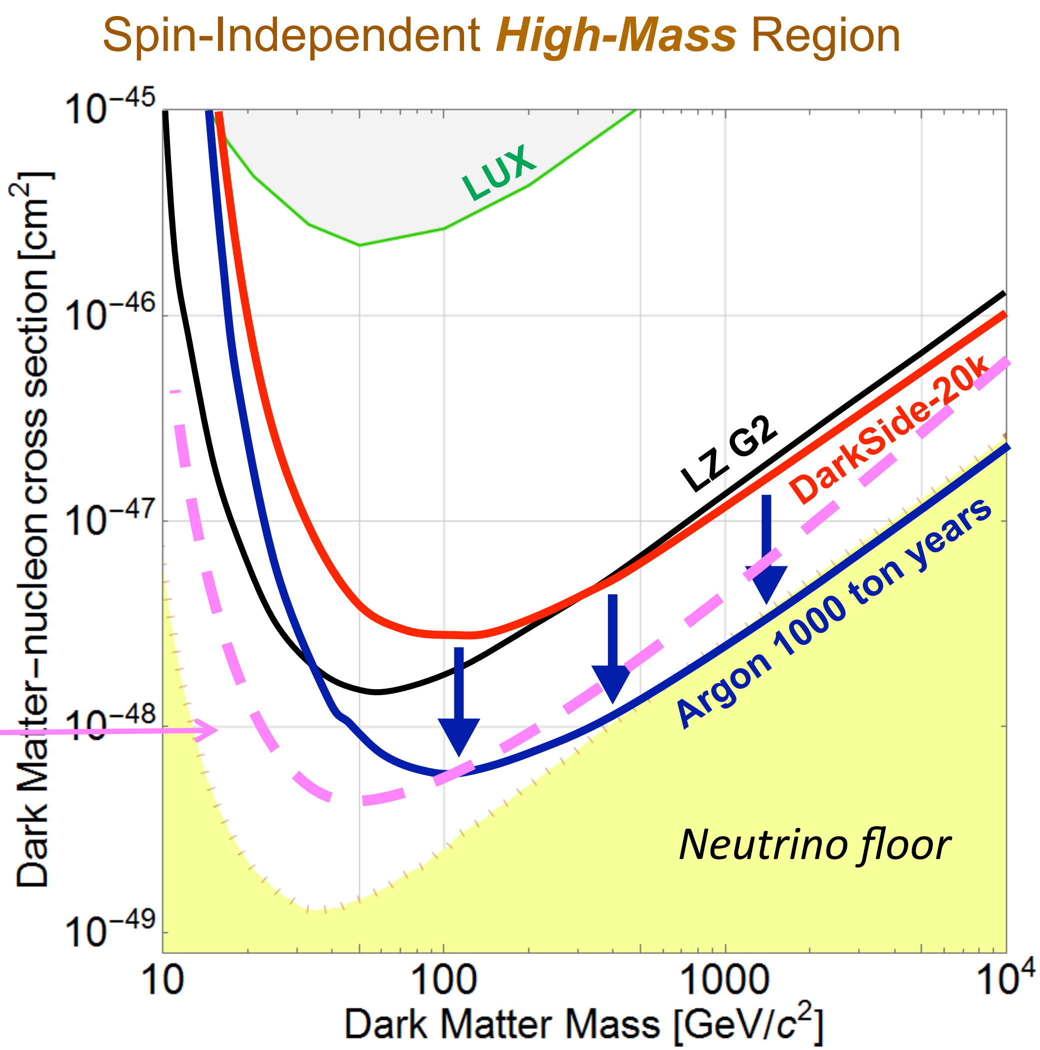




Beyond DarkSide

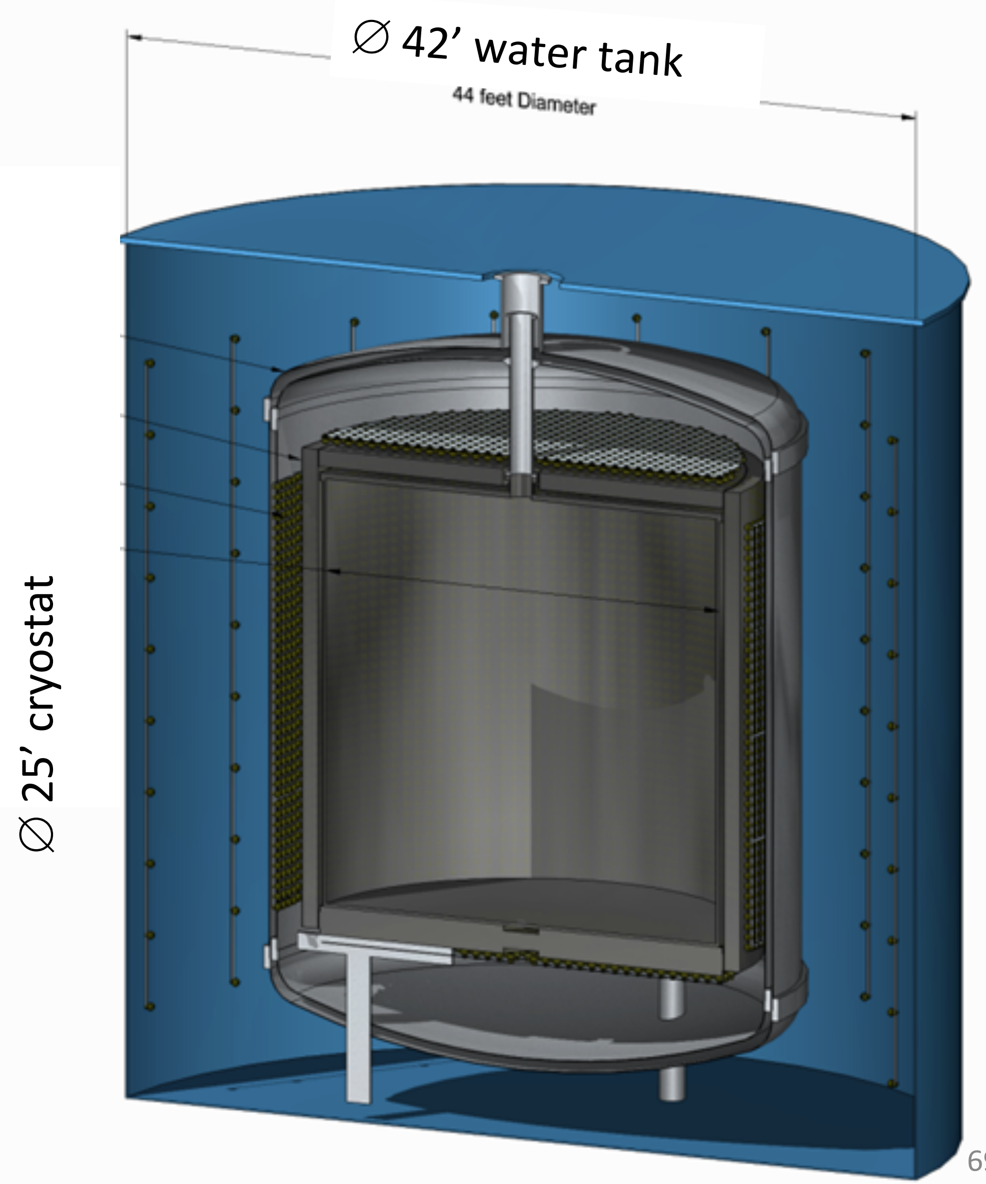
- PSD in argon can distinguish β/γ
- Therefore Ar neutrino floor lower than for Xe

Neutrino-electron elastic scattering cross-section

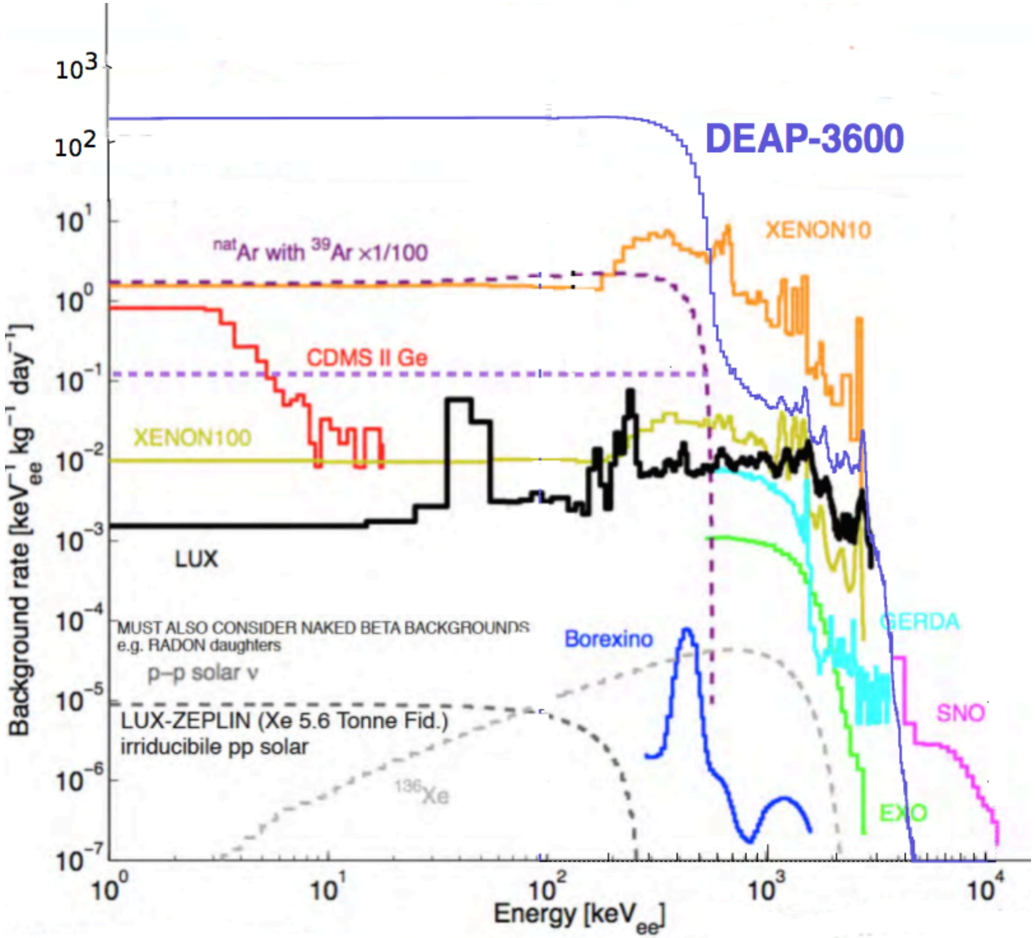


Beyond DarkSide

- PSD in argon can distinguish β/γ
- Therefore Ar neutrino floor lower than for Xe
- ~100's tonnes depleted argon detector
- Design TBD



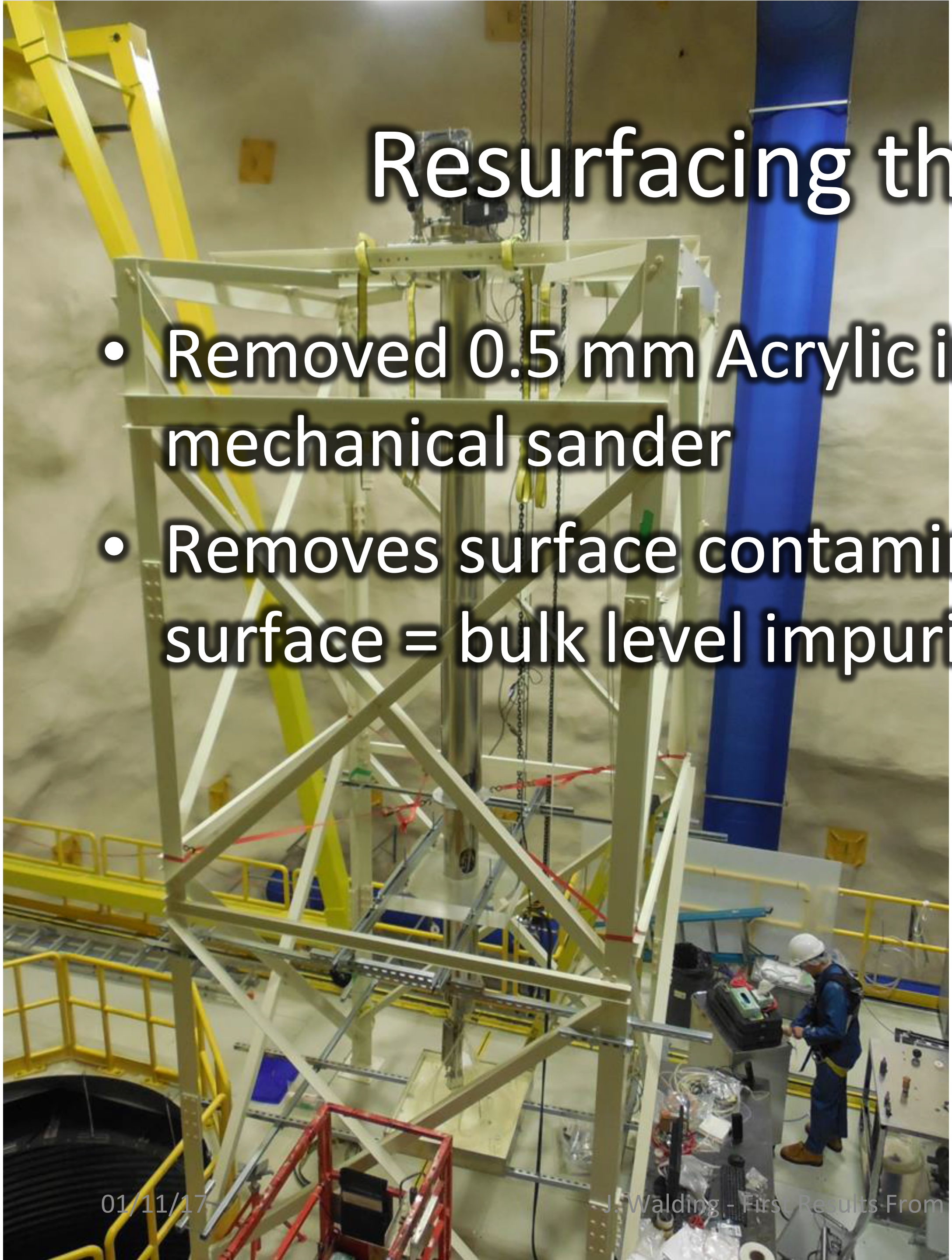
Electron Recoil Band Model

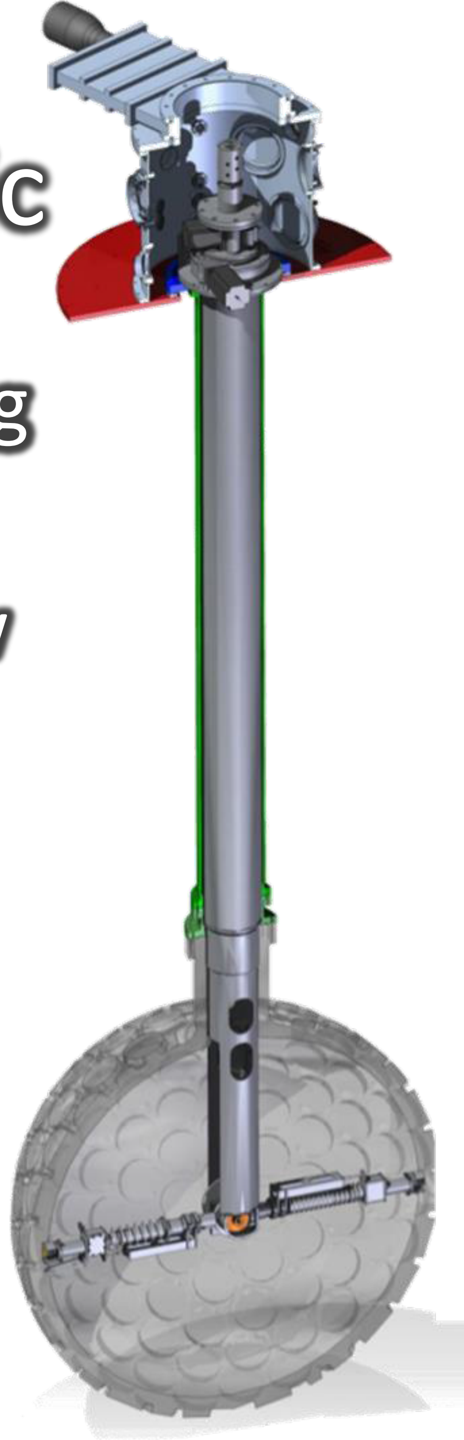


- MC scaled screening values or literature values (^{39}Ar)
- Low energy region (<500 keV) dominated by ^{39}Ar
- Mid energy region (500-2600 keV) dominated by external componentry gammas (PMT glass)
- High energy region (>2600 keV) dominated by ^{42}K & bulk AV ^{232}Th

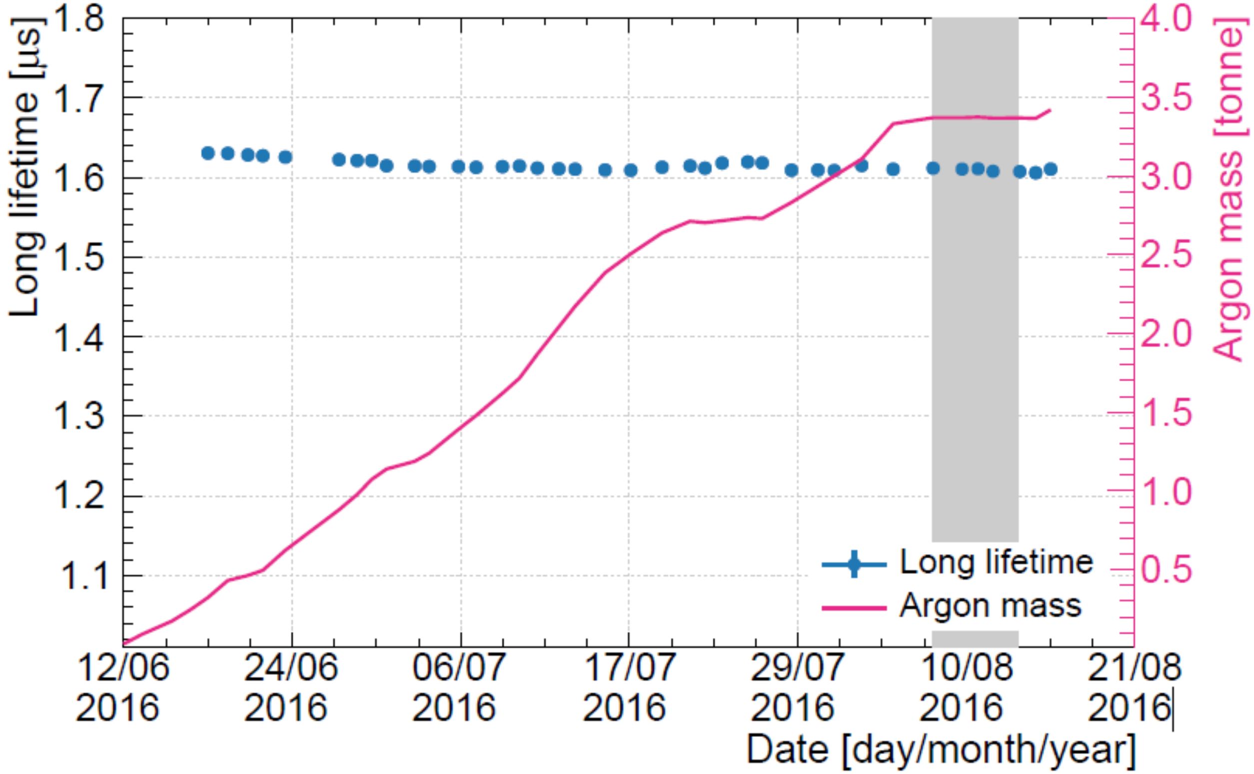
Resurfacing the Acrylic

- Removed 0.5 mm Acrylic in-situ using mechanical sander
- Removes surface contaminants (new surface = bulk level impurities)





DEAP-3600 detector filling



- Argon triplet lifetime measured during fill
  - Higher than 1.3us: afterpulsing and TPB scintillation
- First analysis uses 4.4 days of data taken during first fill in August 2016
  - Originally a data challenge

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Construction

The DEAP Acrylic

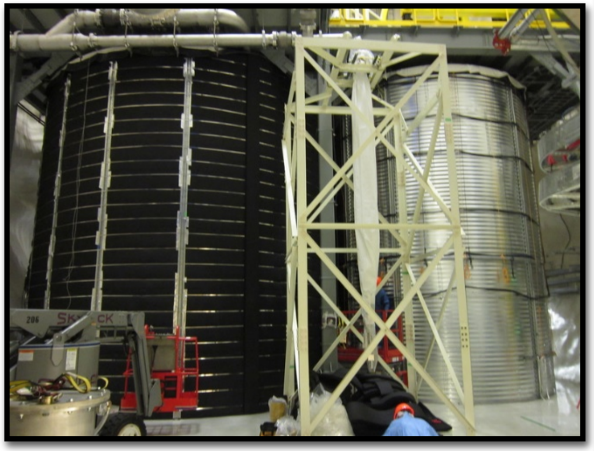
- Fabrication from pure MMA monomer at RPTAsia (Thailand),
- Strict control of radon exposure
  - < 10^{-20} g/g ^{210}Pb
- RPT fabricated the SNO Acrylic Vessel
- Assay of production acrylic < 2.2×10^{-19} g/g ^{210}Po
  - Equivalent to < 0.2 bkg events/3 years (C. Nantais Thesis, 2014)

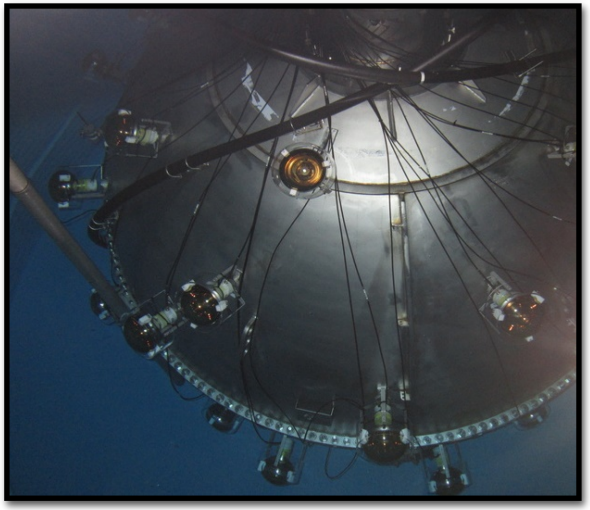
Monomer cast at RPT Asia, 2010

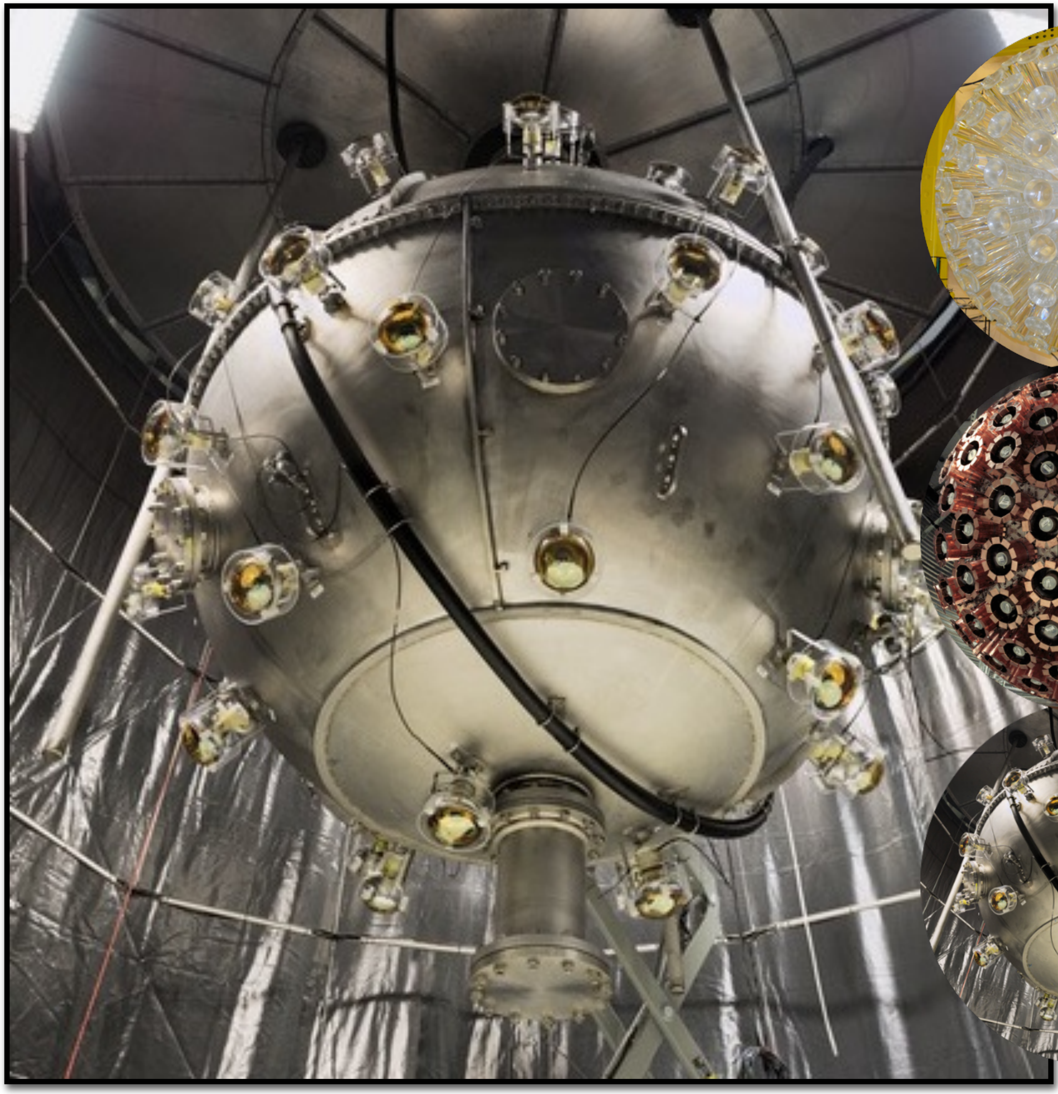
Thermoformed Panel at RPT Colorado

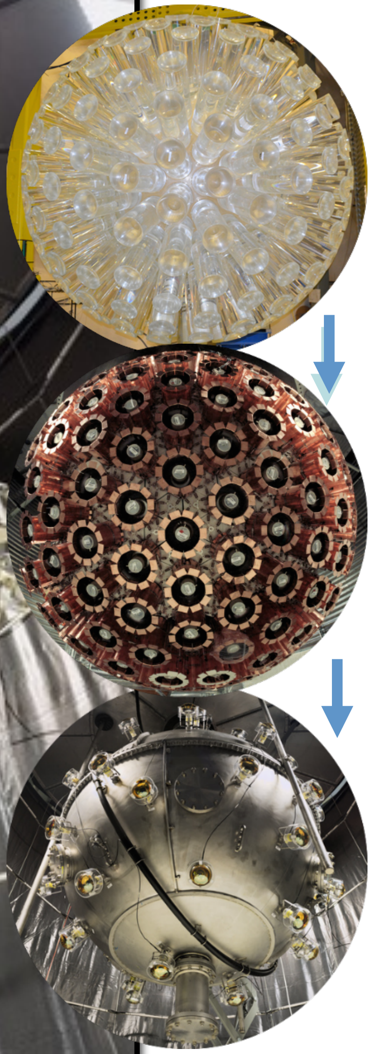
DEAP Construction

Completed early 2016



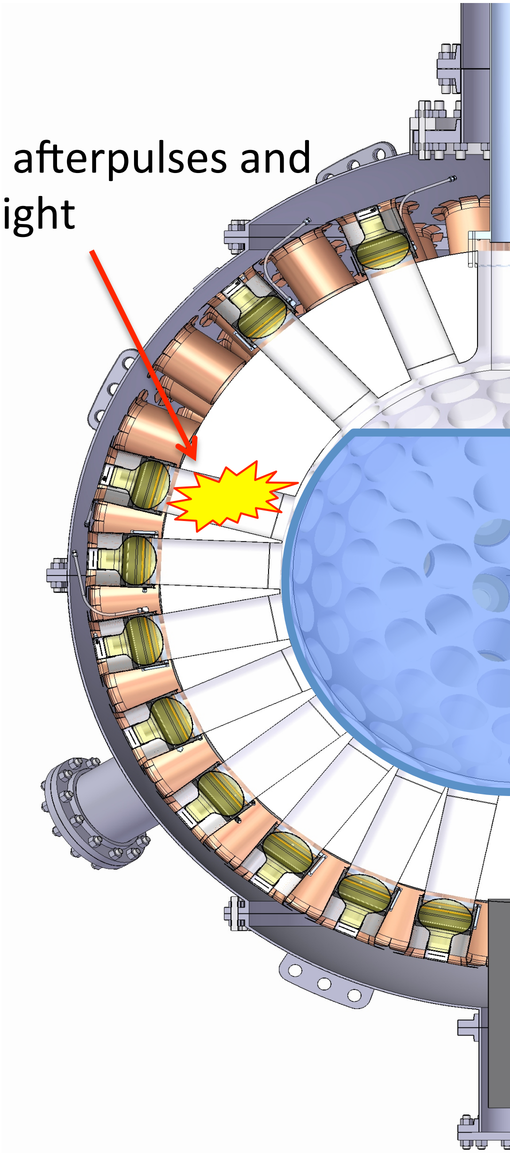






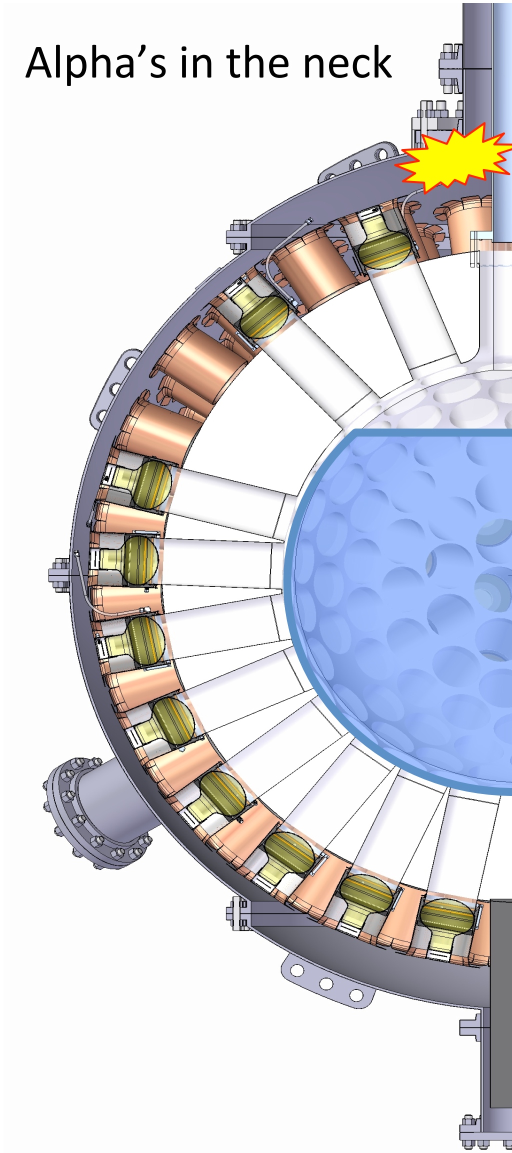
DEAP's First Search!

	Cut	Livetime	Acceptance %		$\#^{\mathrm{ROI}}_{\mathrm{evt.}}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58±0.01		654
	Event time		99.85±0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	
	Total	4.44 d	96.94±0.03	$66.91^{+0.20}_{-0.15}$	!



DEAP's First Search!

	Cut	Livetime	Acceptance %		$\#^{\text{ROI}}_{\text{evt.}}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58±0.01		654
	Event time		99.85±0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	!
	Total	4.44 d	96.94±0.03	$66.91^{+0.20}_{-0.15}$	



DEAP's First Search!

	Cut	Livetime	Acceptance %		$\#^{ROI}_{evt.}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
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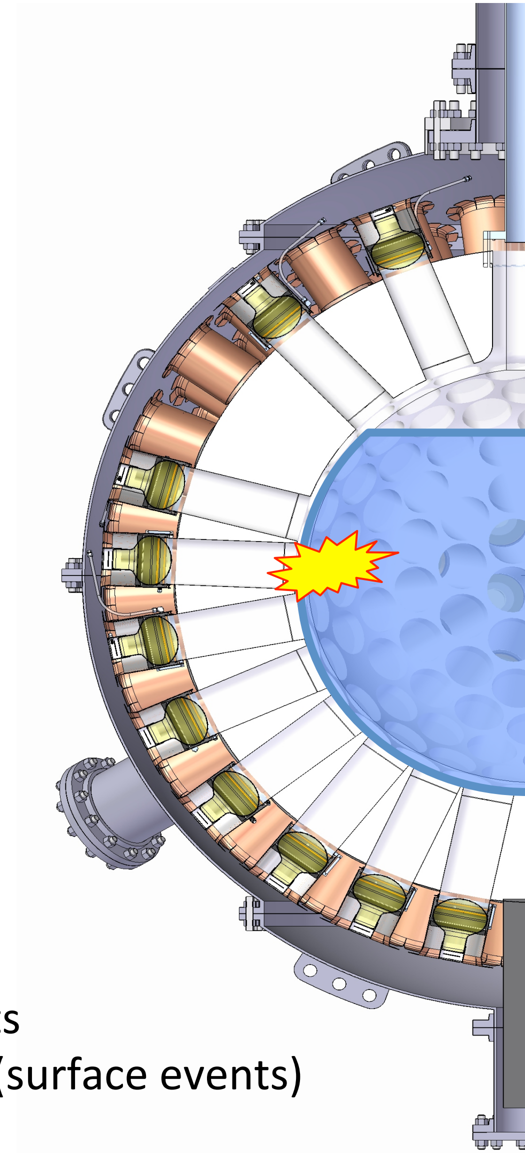

Removes events
at large radius (surface events)

DEAP's First Search!

	Cut	Livetime	Acceptance %		$\#^{ROI}_{evt.}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
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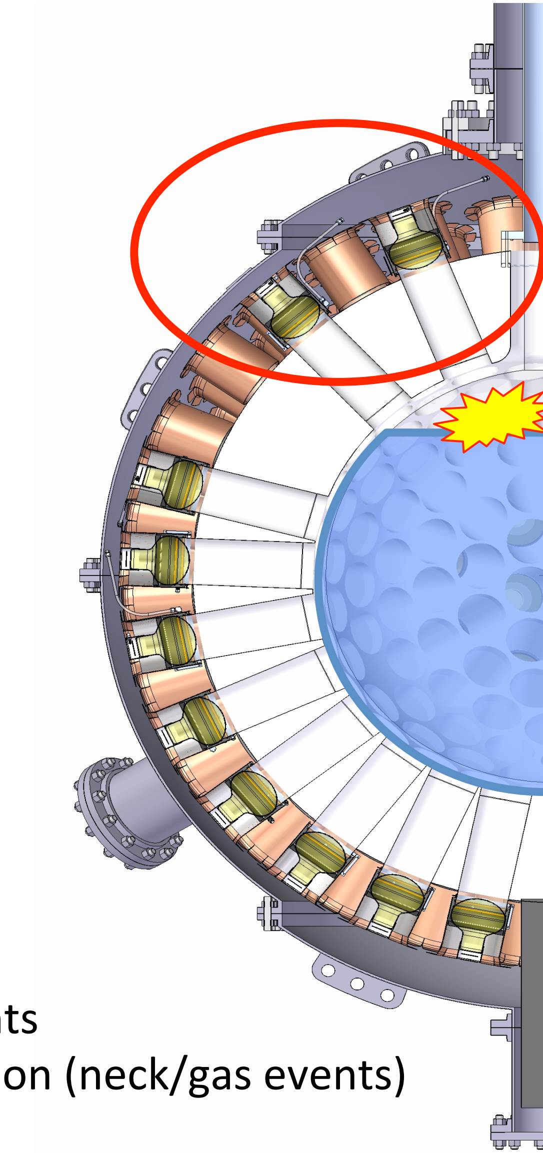
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	!
	Total	4.44 d	96.94 ± 0.03	$66.91^{+0.20}_{-0.15}$	

Developed cuts to remove instrumental and external-source events
2,223 kg fiducial mass



Removes events at high z position (neck/gas events)