

Ton-scale Detector for Dark Matter with Liquid Argon: Current status of DEAP-3600

Pierre Gorel for the DEAP collaboration



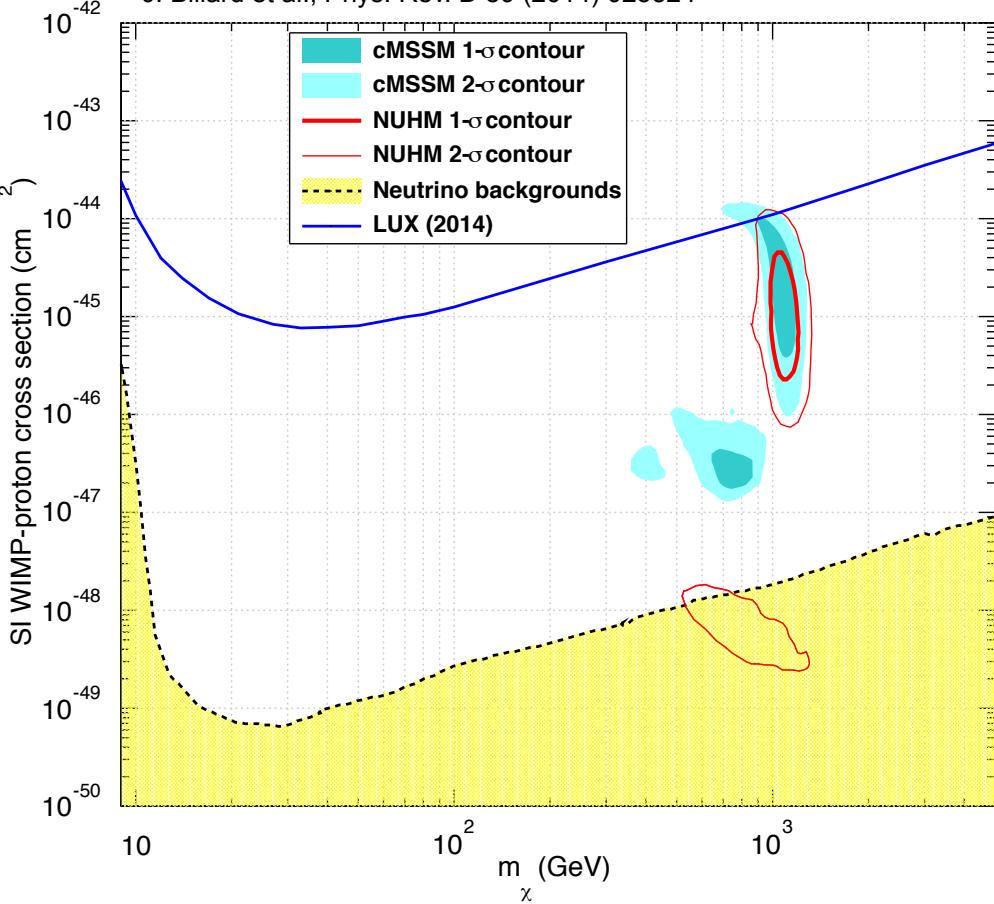
UNIVERSITY OF
ALBERTA

WIMP: Some room for search

<http://cedar.berkeley.edu/plotter>

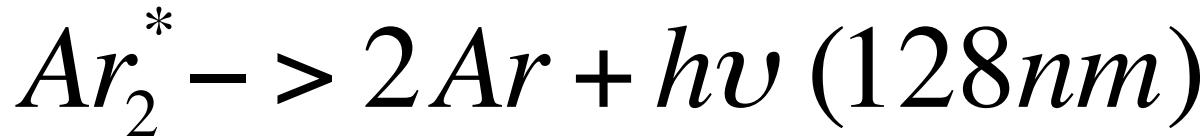
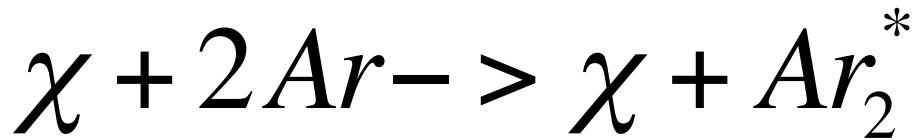
Roszkowski et al, JHEP 1408 (2014) 067

J. Billard et al., Phys. Rev. D 89 (2014) 023524



- 1 GeV-10 GeV
 - Requires complicated models
- 100 GeV-1 TeV
 - Favoured by simple extensions of the Standard Model (cMSSM, NUHM,...)

Liquid Argon: good scintillator for WIMP detection



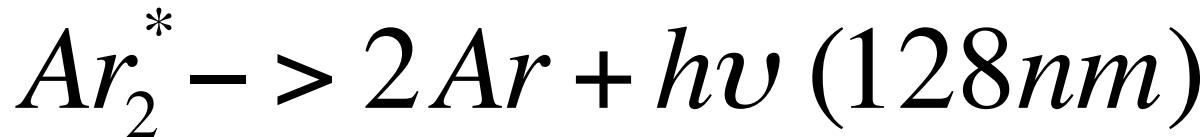
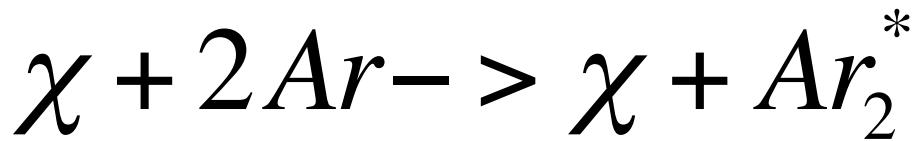
Pros:

- Easy to purify
- Transparent to scintillation light
- 40 photons/keV
- Relatively high Z

Cons:

- Need Wavelength Shifter

Intrinsic background



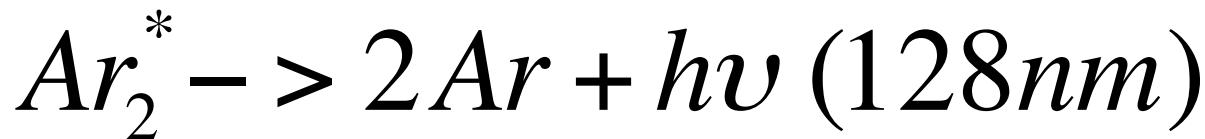
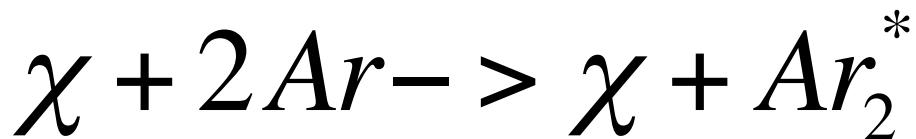
Pros:

- Easy to purify
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Cons:

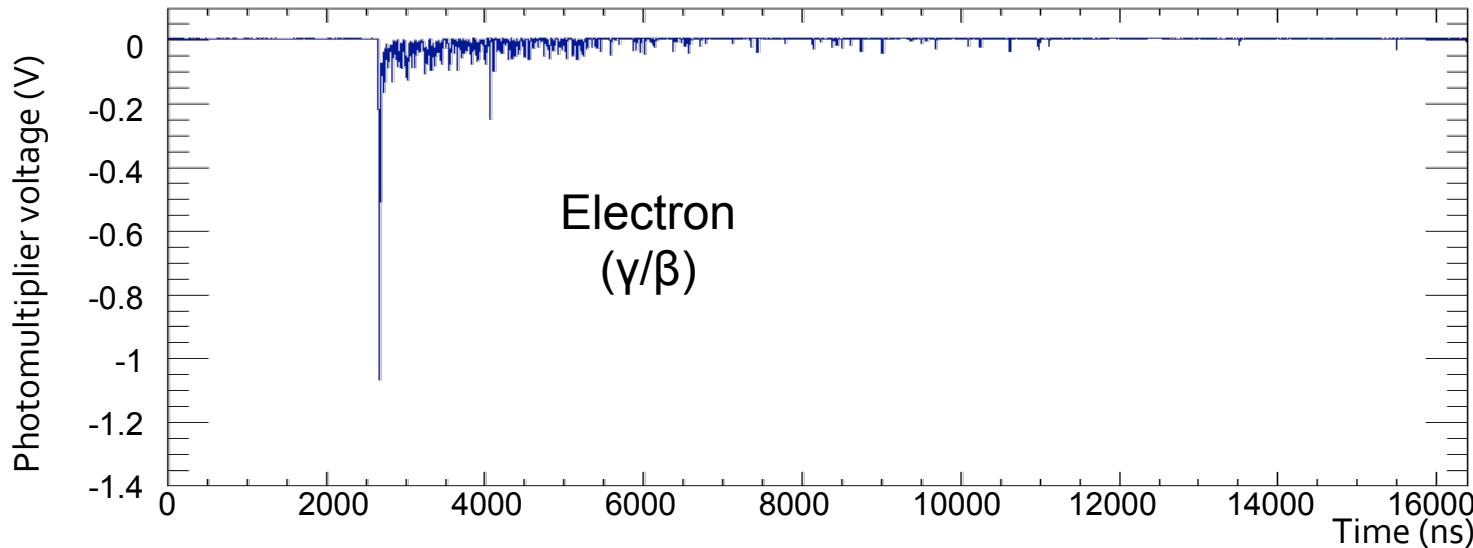
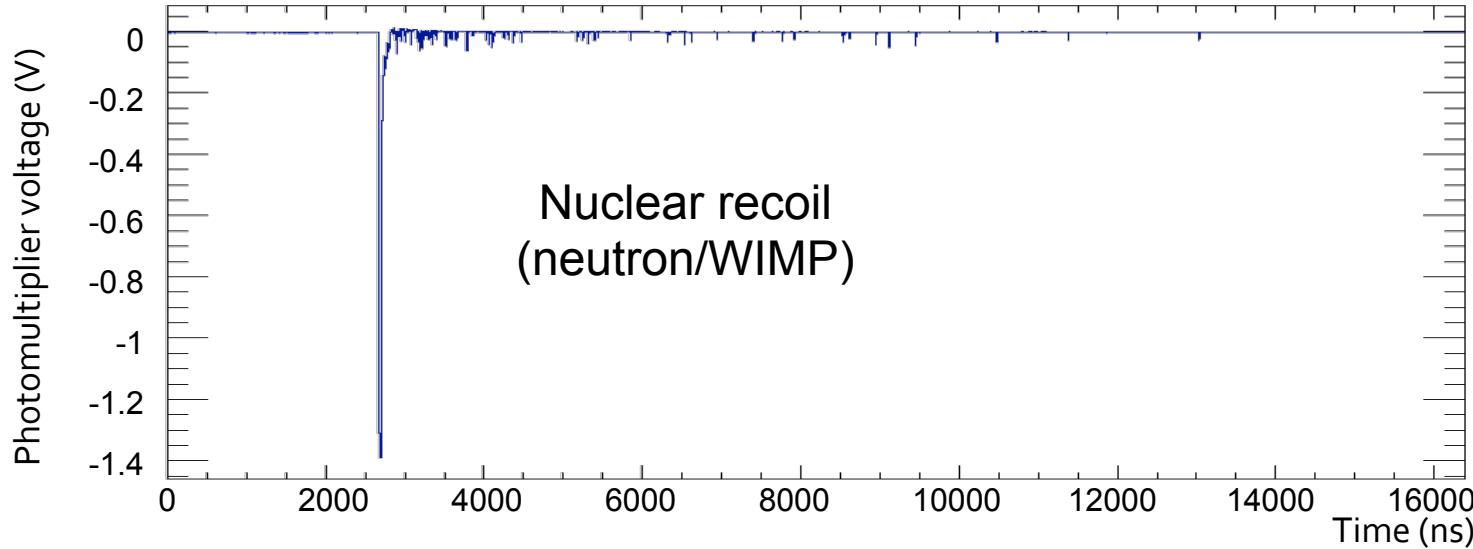
- Need Wavelength Shifter
- Natural Argon:
1Bq/kg ^{39}Ar (β^- , 565keV)

Signal depending on incident particle nature

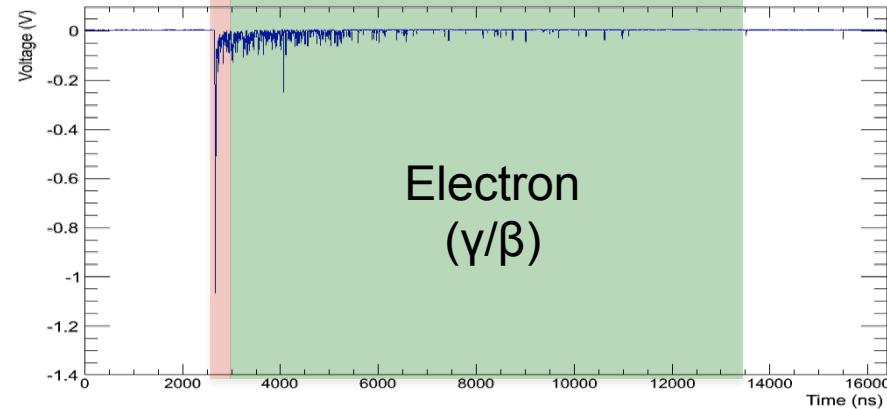
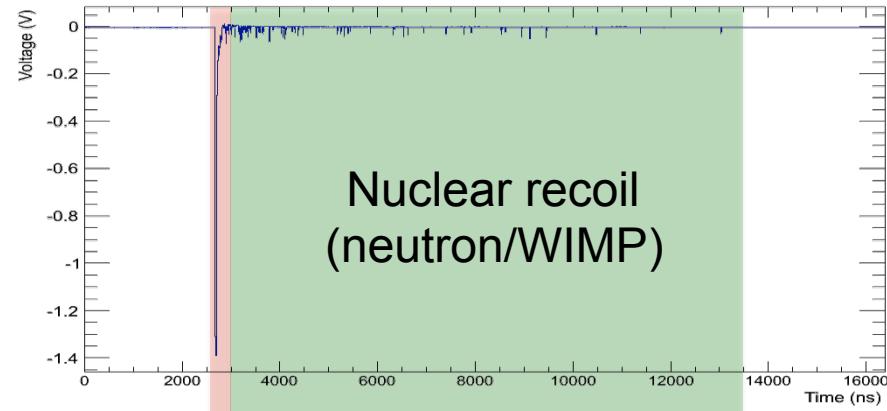


State (time constant)	Singlet (~7ns)	Triplet (~1.6μs)
Electron	23%	67%
Nuclear recoil	75%	25%

Pulse shape discrimination



Argon PSD: Fprompt

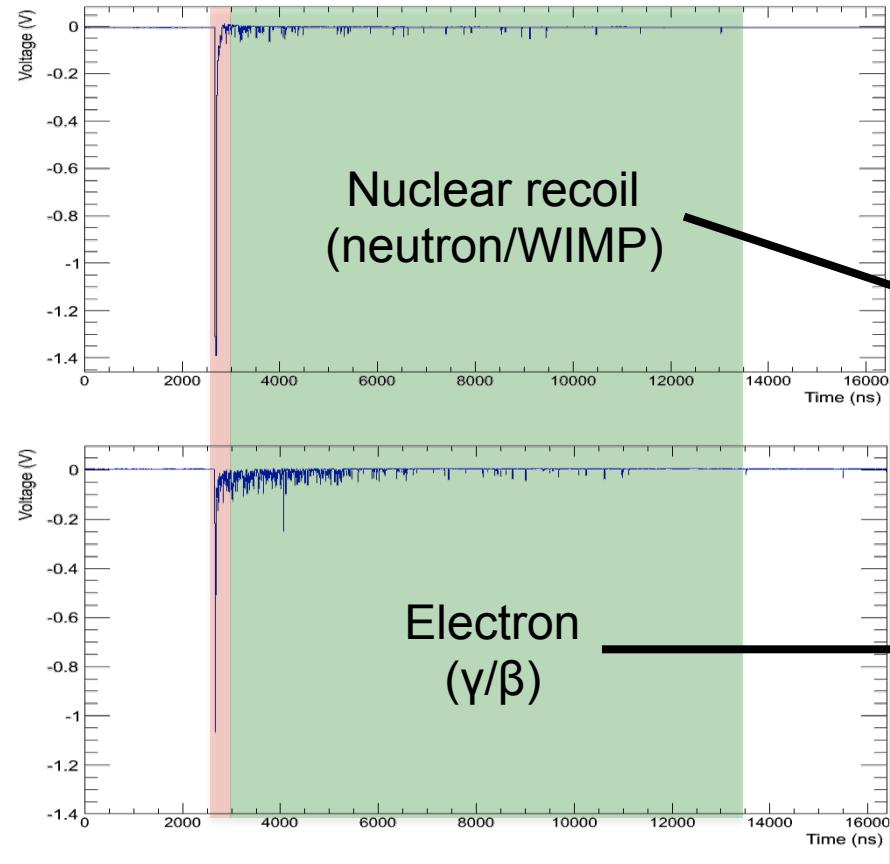


$$FPrompt = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$

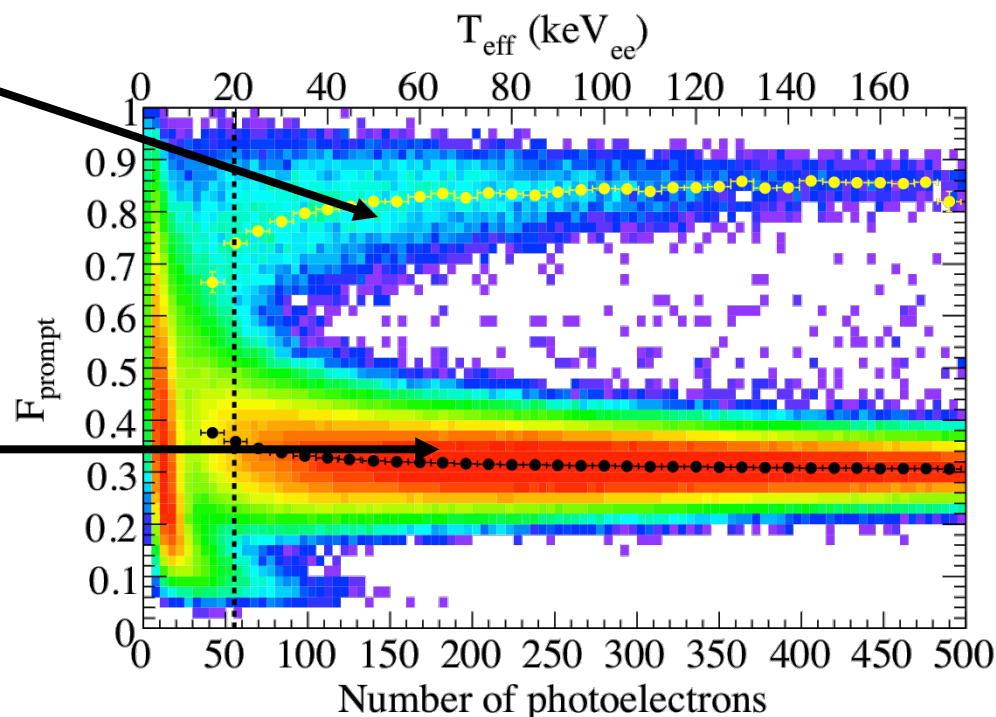
Prompt : -50ns → 150ns

Late: 150ns → 10μs

Argon PSD example



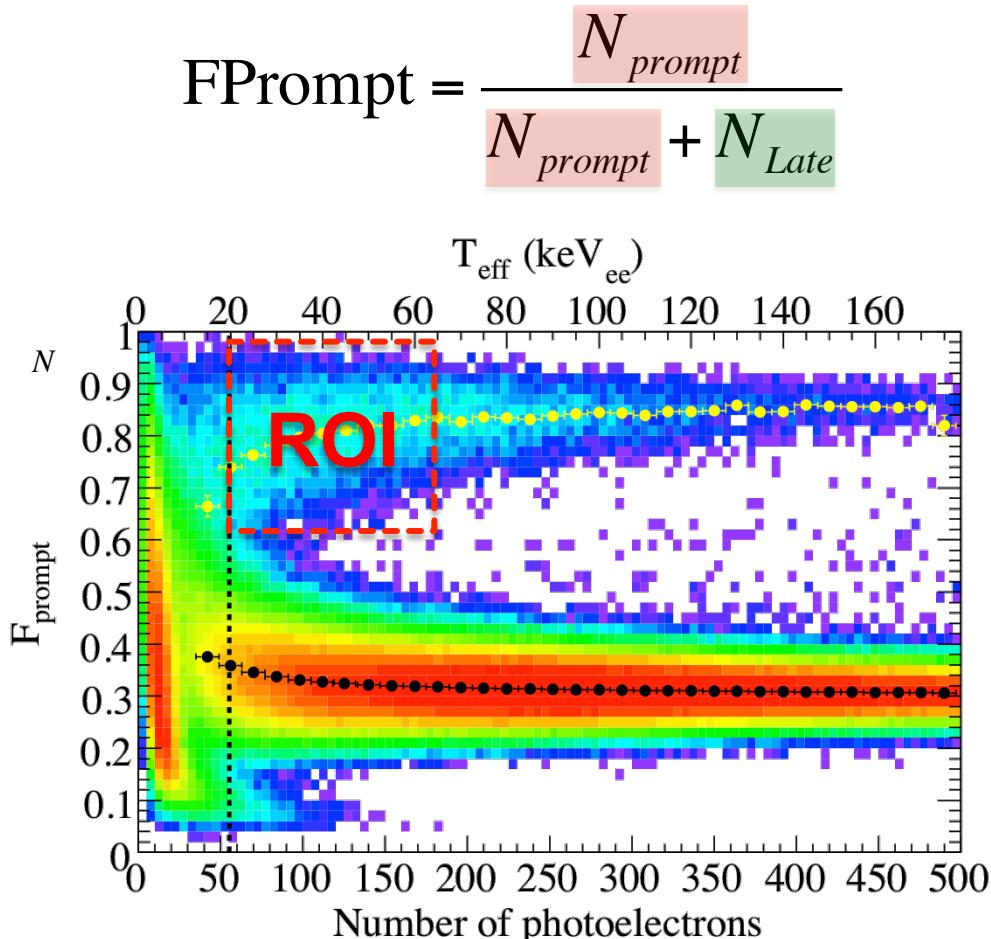
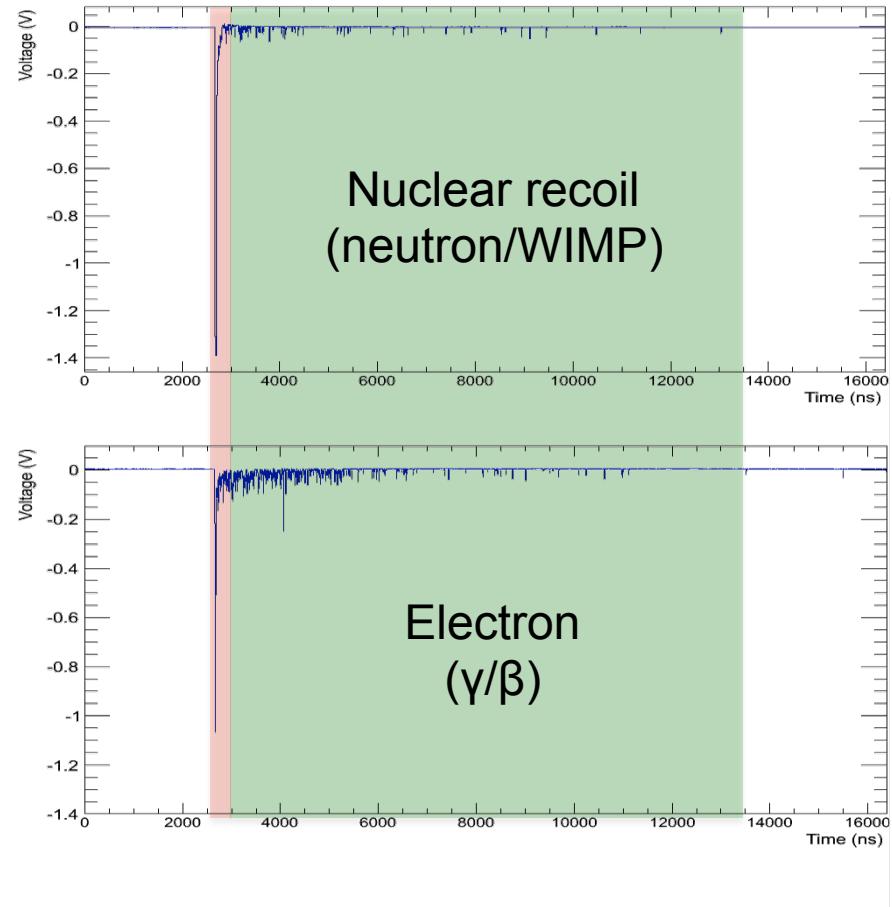
$$FPrompt = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$



arXiv:0904.2930

$N_{PE} = \text{Energy} \times \text{Light Yield} \times \eta_{\text{Collection}} \times \eta_{\text{Detection}}$

Leakage into ROI → Energy threshold



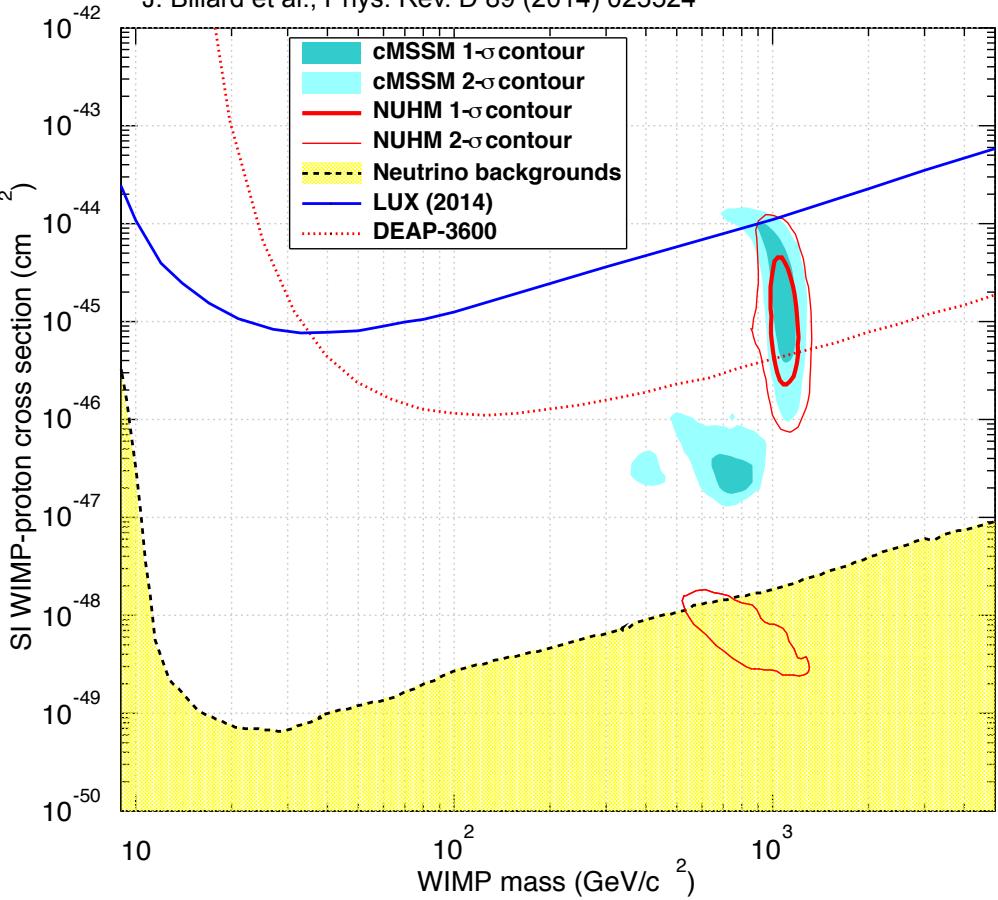
$$N_{PE} = \text{Energy} \times \text{Light Yield} \times \eta_{\text{Collection}} \times \eta_{\text{Detection}}$$

DEAP-3600: 10^{-46}cm^2 @100GeV

<http://cedar.berkeley.edu/plotter>

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3000 kg/year
background-free data
(in the ROI)
 $E_{\text{recoil}} > 60 \text{ keVr}$

1000 kg Fiducial mass → 3 years background-free data

External background

→ Suppression

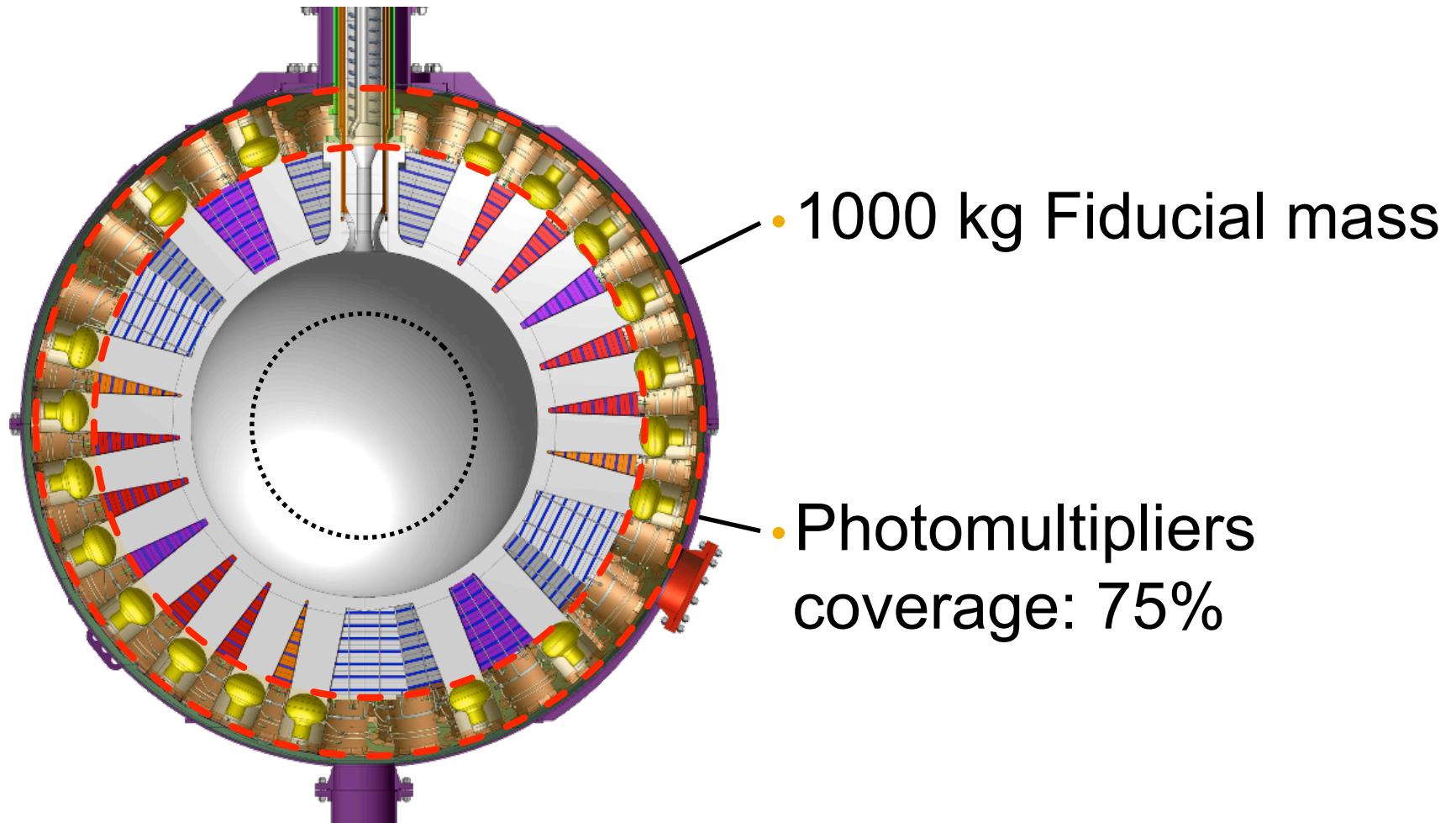
- Neutron < 2 pBq/kg
 - Material selection
 - Shielding
- α (surface) < 0.2 mBq/m²
 - Source removal
 - Fiducialization

Internal background

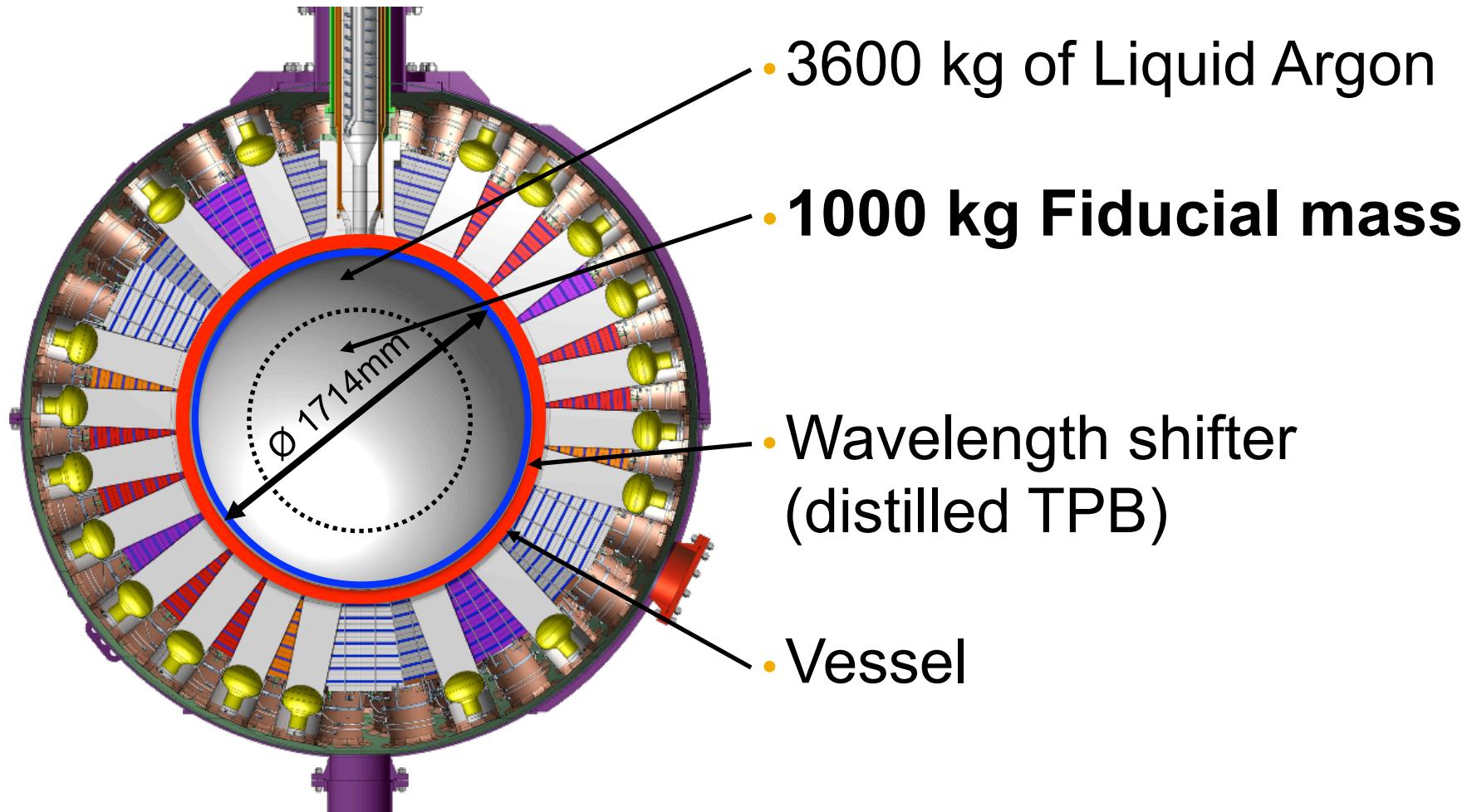
→ Discrimination

- β/γ (1 Bq/kg 39Ar)
 - Rejection 10¹⁰
 - Optimization PSD
 - Maximum light collection/detection (8PE/keV)

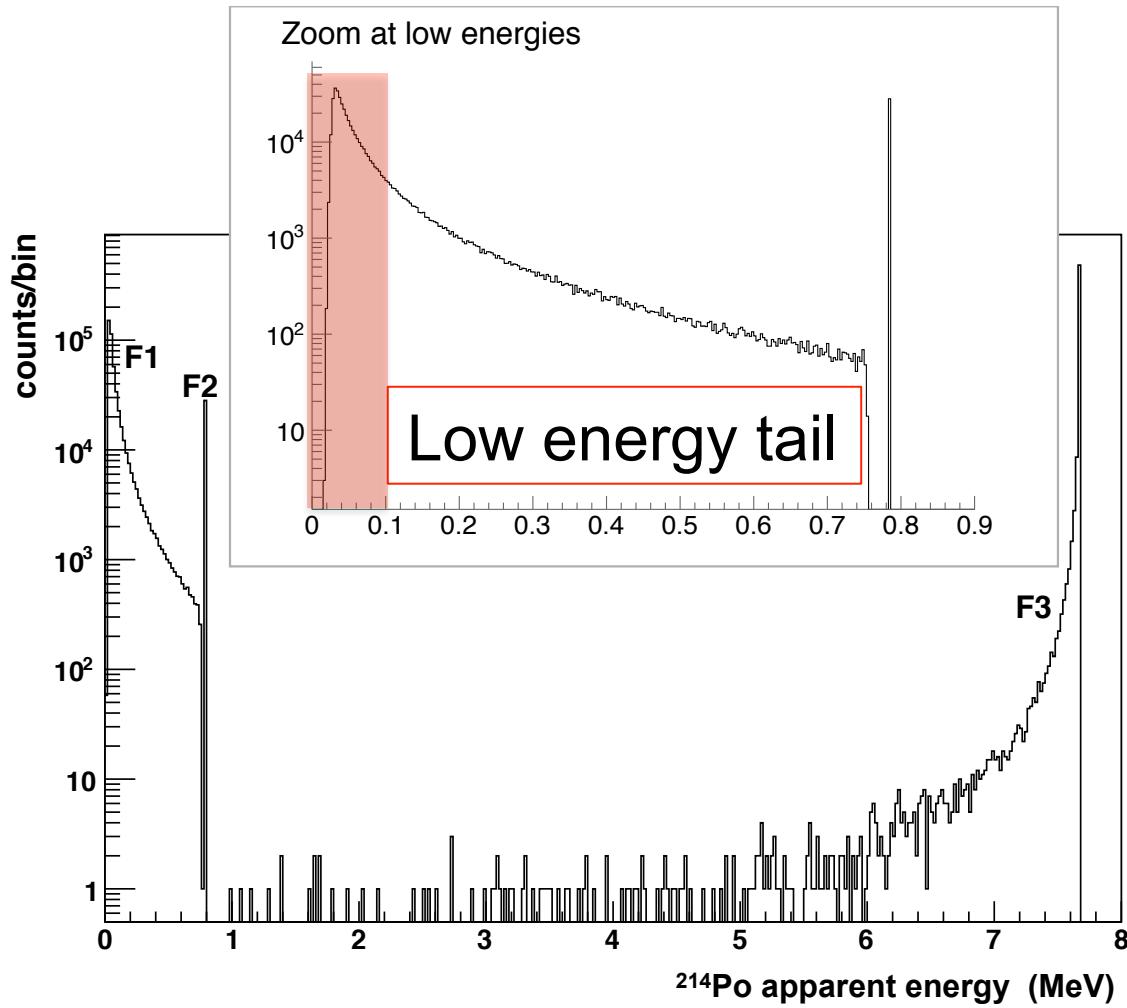
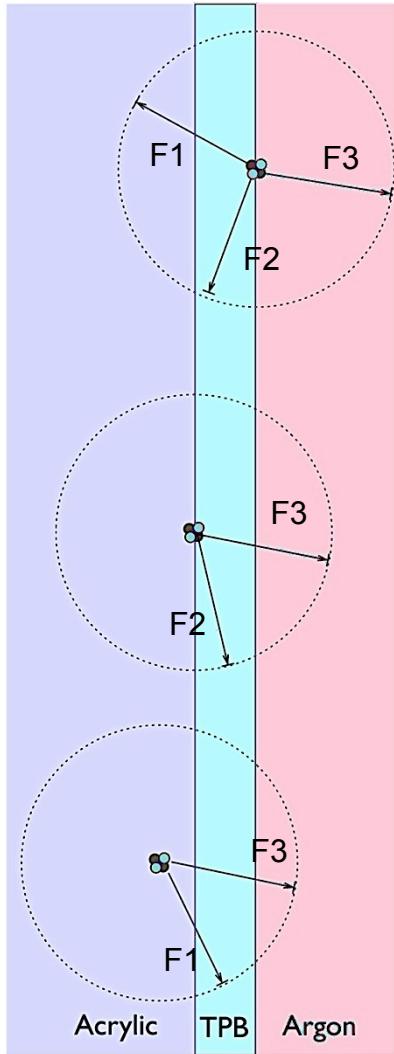
Single phase, spherical detector



Fiducialization



Surface α leaking at low energy



Vessel made of clean acrylic (AV)



Background suppression

- Cast from distilled monomer
- Radon history

Maximum light collection

- 75% coverage with light detector (photomultipliers)

Bonded acrylic light guides



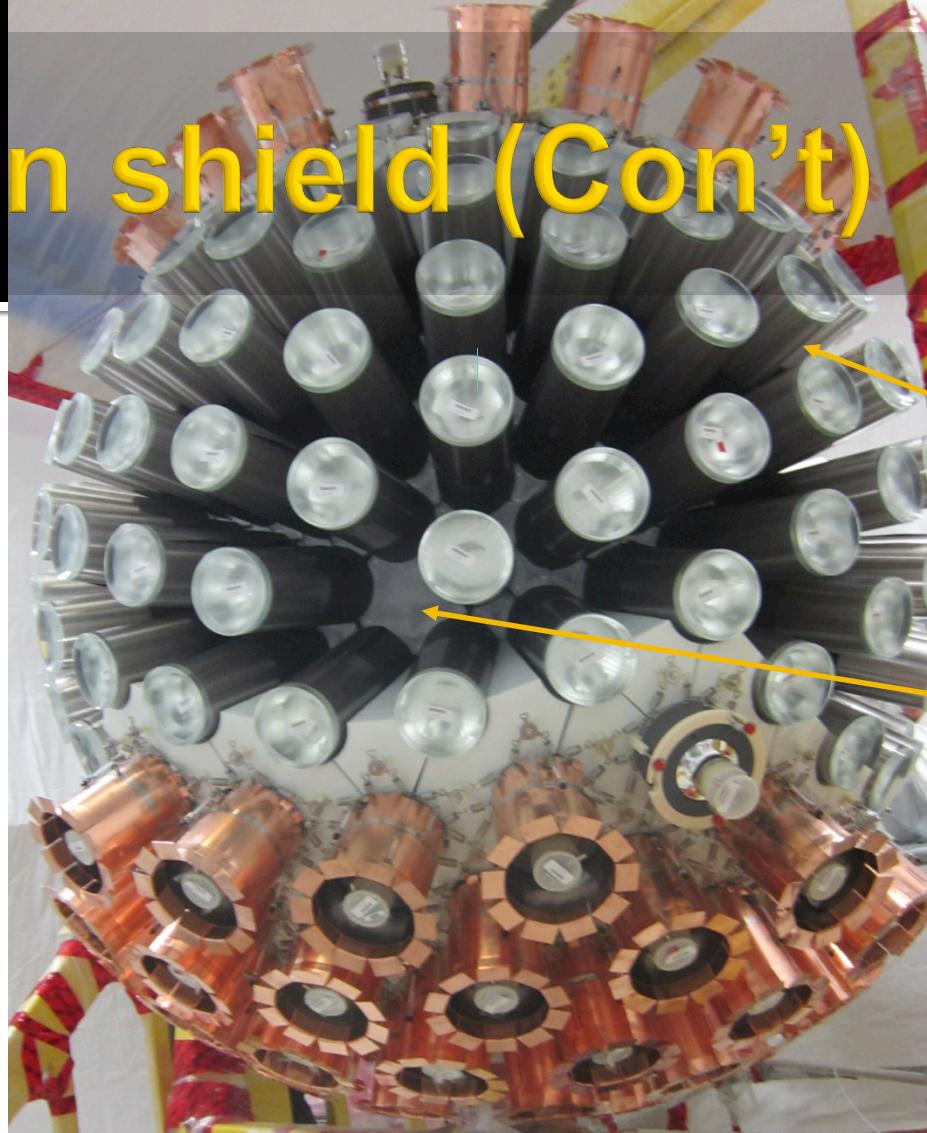
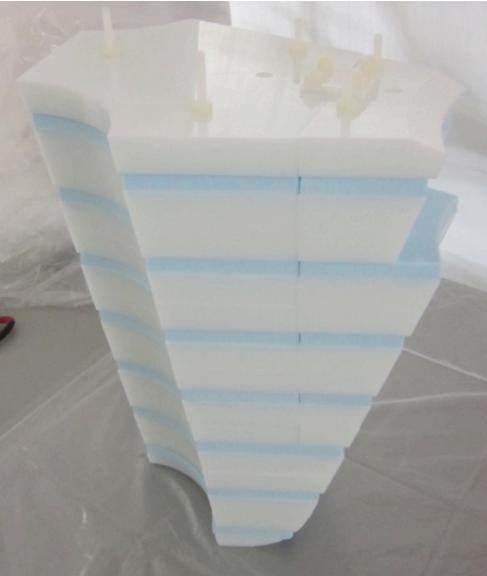
Background suppression

- Neutron shielding (PMTs)
- No additional support

Maximum light collection

- Improves light collection
- Attenuation > 1m

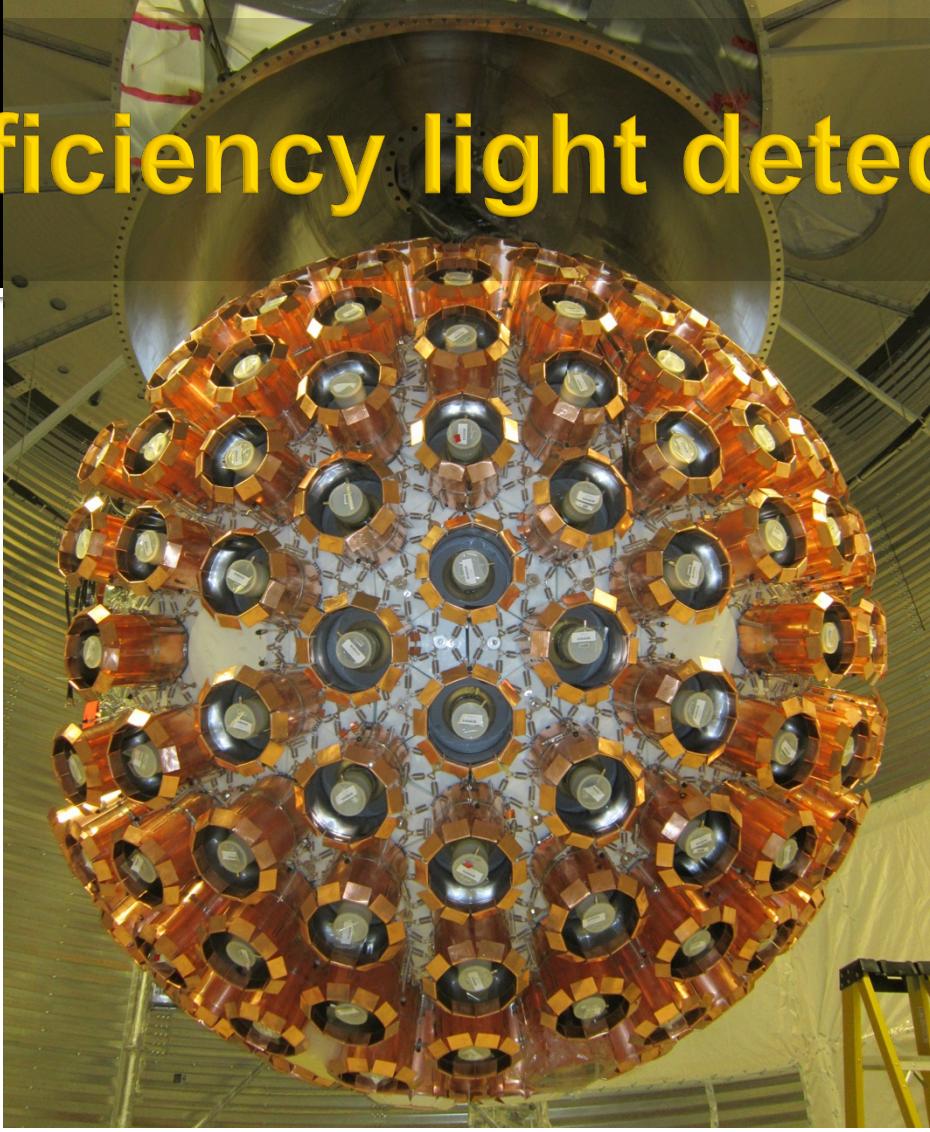
Neutron shield (Con't)



Background suppression

- Assayed Polyethylene (white) & Styrofoam (blue)
- Neutron shielding (PMTs)

High efficiency light detectors



Background suppression

- 50 cm of plastic shield
- $2.6 \times 10^5 n \rightarrow 0.14n$ (in ROI)

Maximum light detection

- Hamamatsu R5912 HQE (32% QE)

Muon veto / Gamma shield



Background suppression

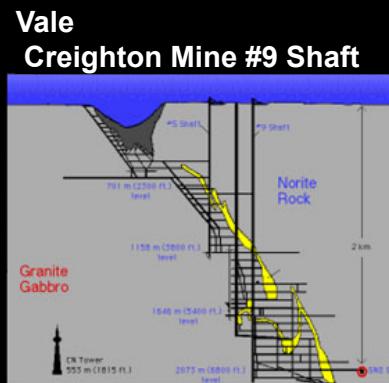
- $\varnothing 7.9\text{m} \times 7.6\text{m}$ ultra-pure water tank
- 48 PMTs

DEAP-3600
MiniCLEAN

PICO
DEAP-1
DAMIC
HALO
PICASSO
COUPP
SuperCDMS (proj)

SNO+

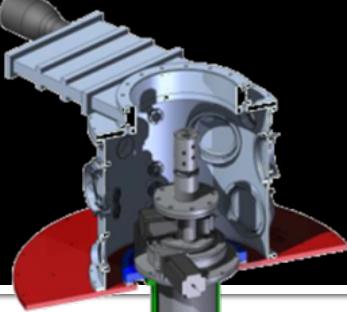
- Mine
- Airlock
- Clean room (Class 2000)



Machine Shop
Chemistry lab
Car wash
Change rooms/Shower
Lunch room
Chiller/air filters

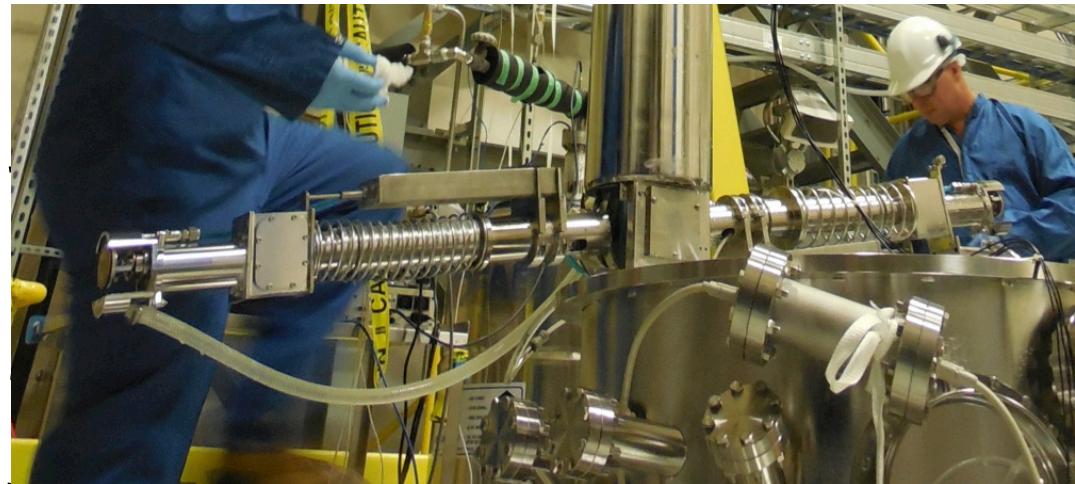
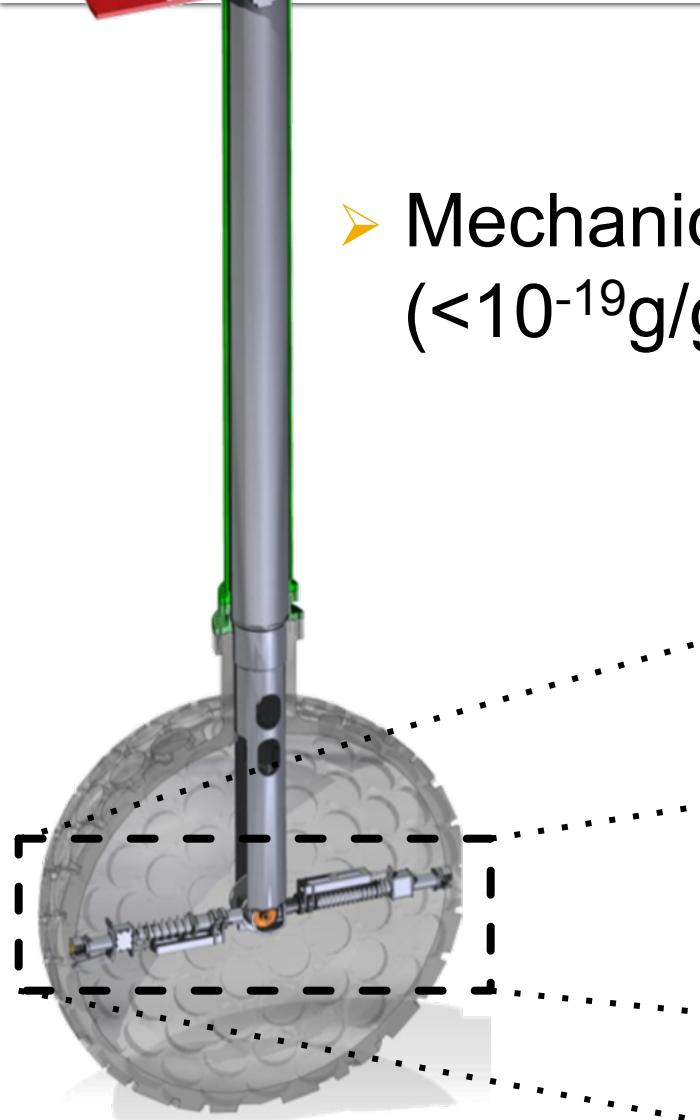


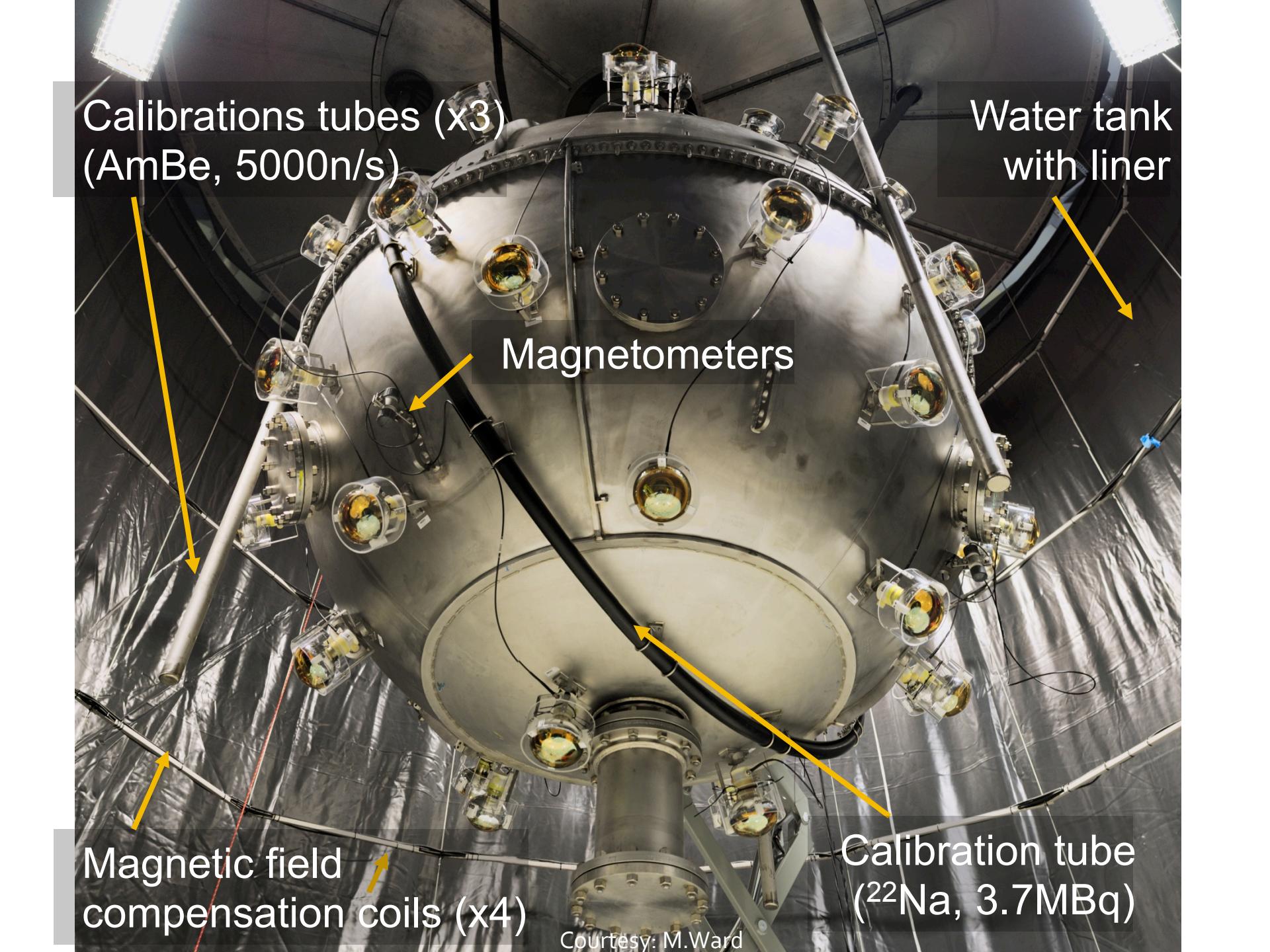
2073 m Underground (6010 mwe) => 0.27 muon/m²/day



Resurfacer

- Mechanical sanding of the AV inside surface ($<10^{-19}\text{g/g}$ of ^{210}Pb)





Calibrations tubes (x3)
(AmBe, 5000n/s)

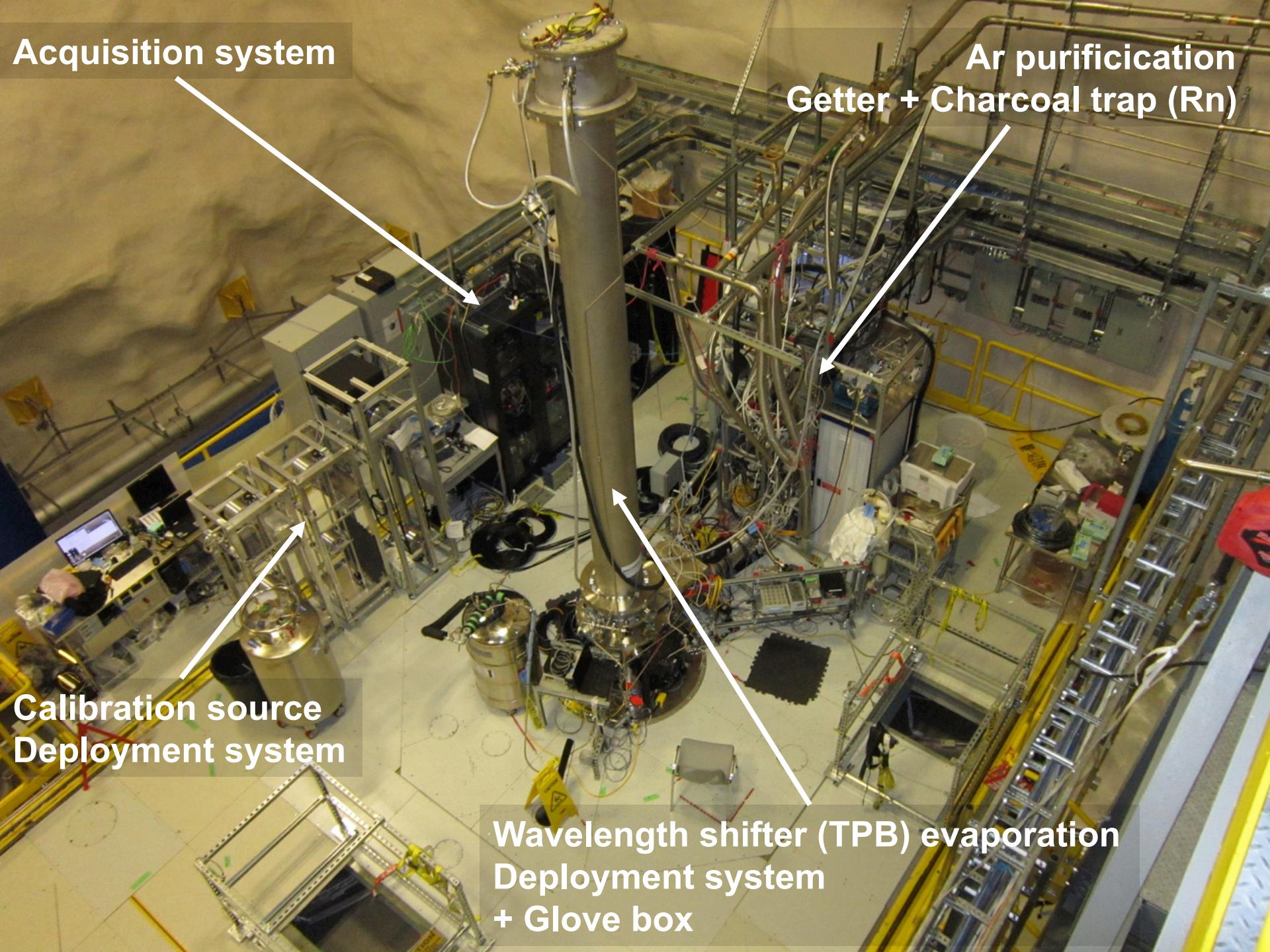
Water tank
with liner

Magnetometers

Magnetic field
compensation coils (x4)

Calibration tube
(^{22}Na , 3.7MBq)

Courtesy: M.Ward



Process system



Data Acquisition system...

- Single photo-electron counting & timing
 - Conditioning of the PMTs signal
 - Fast digitizers (CAEN V1720 @250MHz)
- Dead time suppression (3.6kHz ^{39}Ar)
 - Trigger: rough selection on analog PMT signals
 - Event Builder: fine selection on digital waveforms

... rising to the challenge

- Single photo-electron counting & timing
 - Conditioning of the PMTs signal
 - Fast digitizers (CAEN V1720 @250MHz)

COMMISSIONING:

- MAX TRIGGER RATE > 50 kHz
- MAX DATA RATE > 1500 kHz

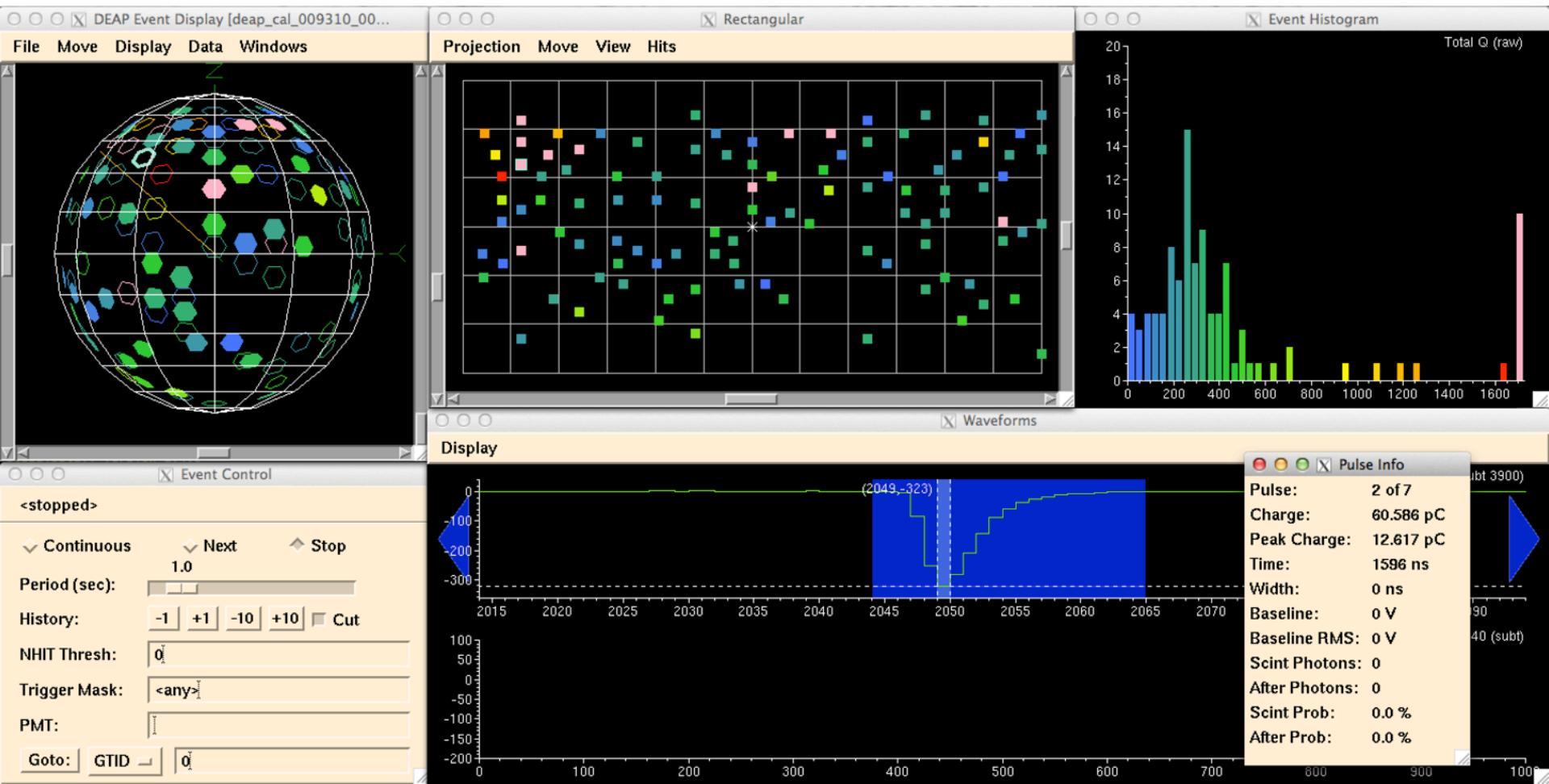
Last steps

- Wavelength shifter evaporation (few days)
- Insertion of the cooling coil next
- Cooling: within the next couple of months

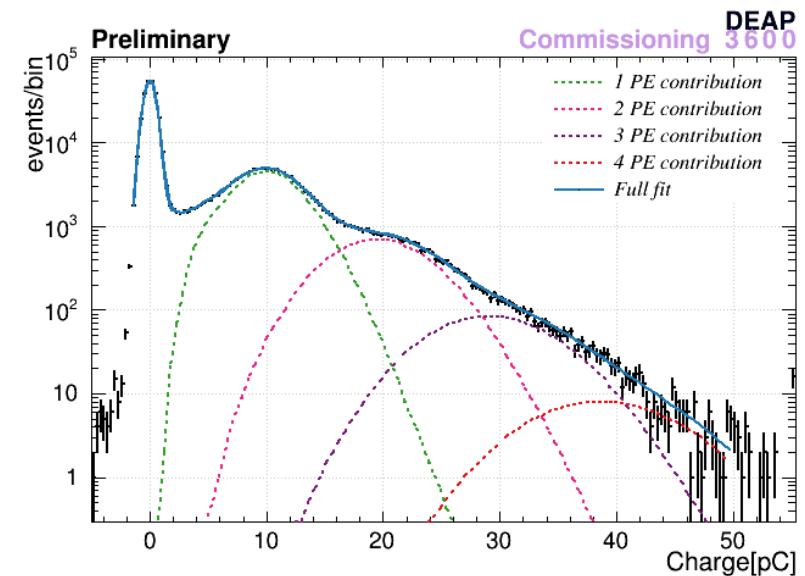
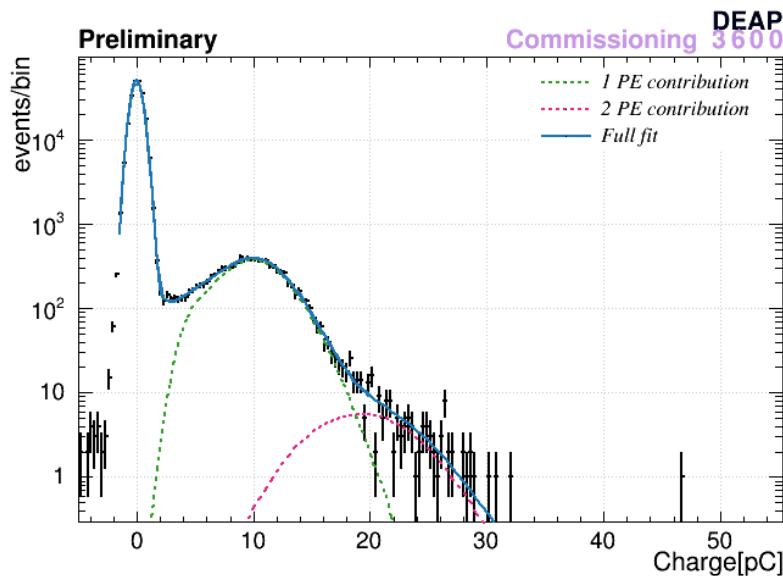
DATA: END OF THE SUMMER

LEADING SENSITIVITY: END OF THE YEAR

Light injection through fibers

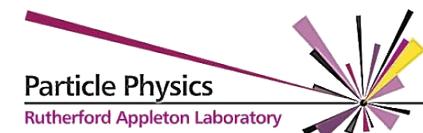


Single Photo-electron spectra

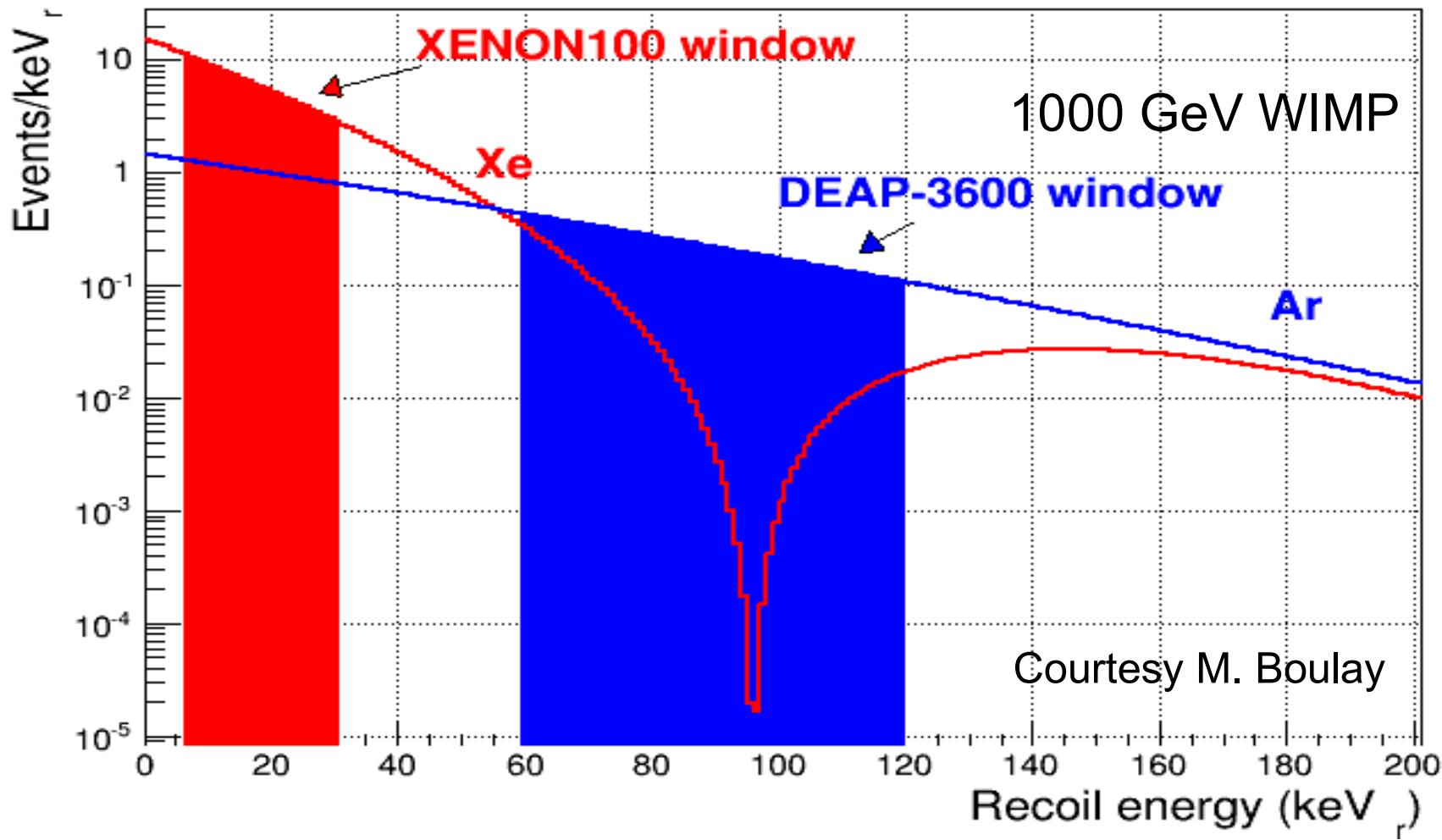


Low light intensity:
Single photo-electrons

High light intensity
Multiples photon-electrons

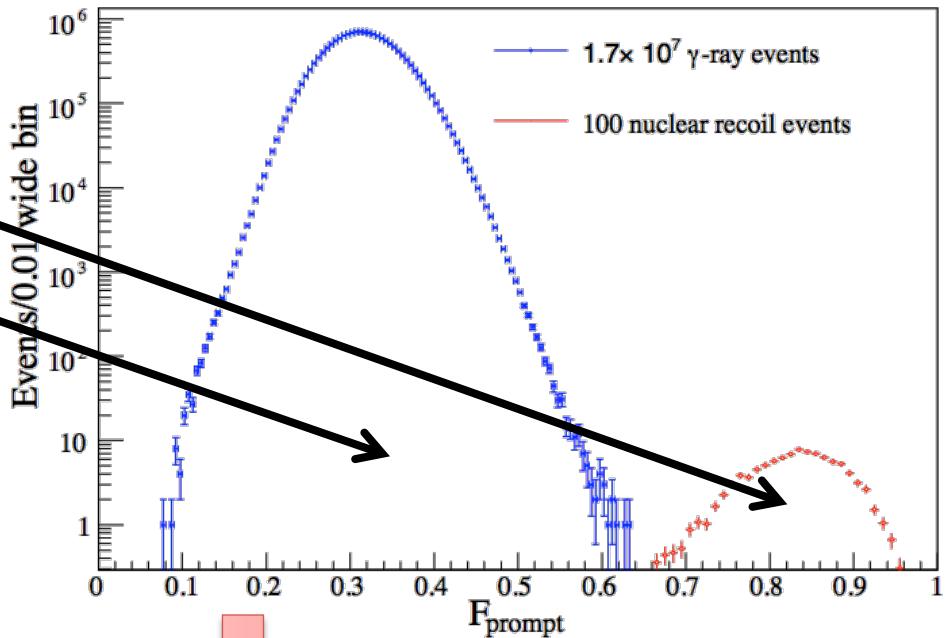
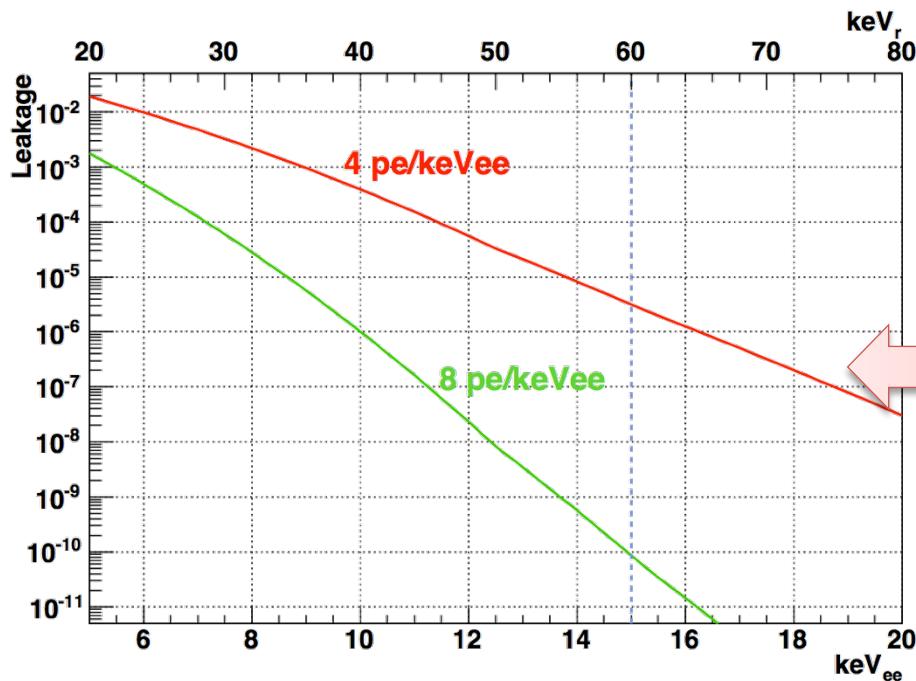


Ar competitive with Xe (high mass)



PSD evaluation

- High FPrompt :
AmBe source
- Low FPrompt :
 ^{22}Na tagged source



Simple statistical model

Model predicts 10^{-10} at 60keV_r
with 8 PE/keV

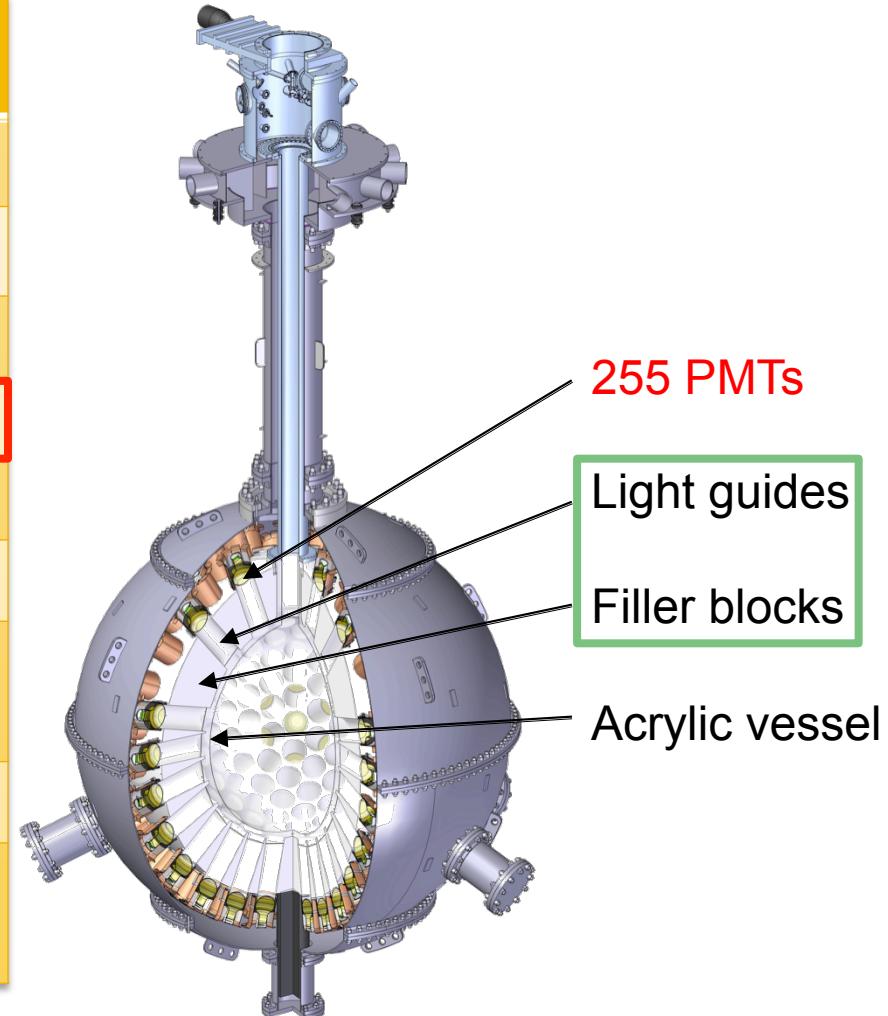
Background targets

3 Ton-year in fiducial volume and Region of Interest (ROI)

Background	Target
Radon in argon	< 1.4 nBq/kg
Surface α 's (tolerance using conservative position resolution)	< 0.2 mBq/m ²
Surface α 's (tolerance using best position resolution)	< 100 mBq/m ²
Neutrons	< 2 pBq/kg
β/γ , dominated by ^{39}Ar	< 2 pBq/kg
Total Backgrounds	< 0.6 events

Review: Neutron backgrounds

(In 3 years)	# of neutrons (produced)	Events in ROI
Acrylic vessel	<44 (Ge γ -assay)	<0.096
Light guides	<127 (Ge γ -assay)	<0.015
Filler blocks	<173 (Ge γ -assay)	<0.034
PMTs	2.6×10^5	0.140
PMT mounts	7565	0.010
Rn emanation	<44	<0.081
Rn deposition (3 months UG)	38	0.010
Other sources		0.04
Total	<2.7x10⁵	<0.35



Courtesy: Koby Dering

Extensive calibration program

Calibration Tools	Optical Response	Energy Reconstruction	Radius Reconstruction	Detector response and stability vs time
Light injection (LED/ Laser), in-situ single PE tails	✓	✓		✓
Gamma sources (^{22}Na 37MBq)		✓	✓	✓
Neutron sources (AmBe, 5000 n/s)		✓	✓	✓
In-situ radioactivity (^{39}Ar , U, Th gammas)	✓	✓	✓	✓