Recent Progress from the DEAP-3600 Dark Matter Direct Detection Experiment

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Outline

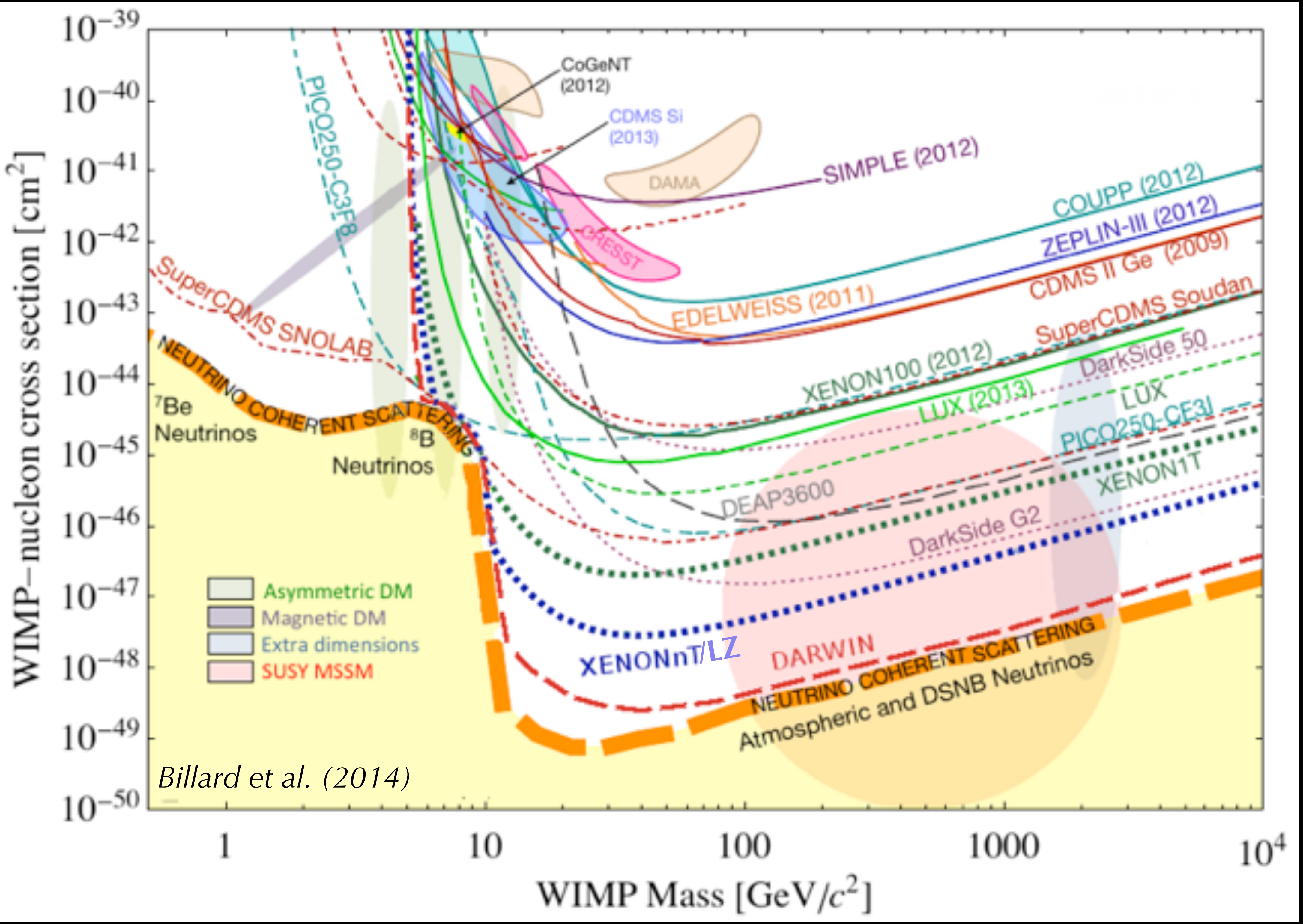
Experiment Strategy

The DEAP-3600 Detector

Recent Progress, Commissioning and Calibration

DEAP Collaboration: 65 researchers in Canada, UK, and Mexico

The Low-Background Frontier: Status and Prospects



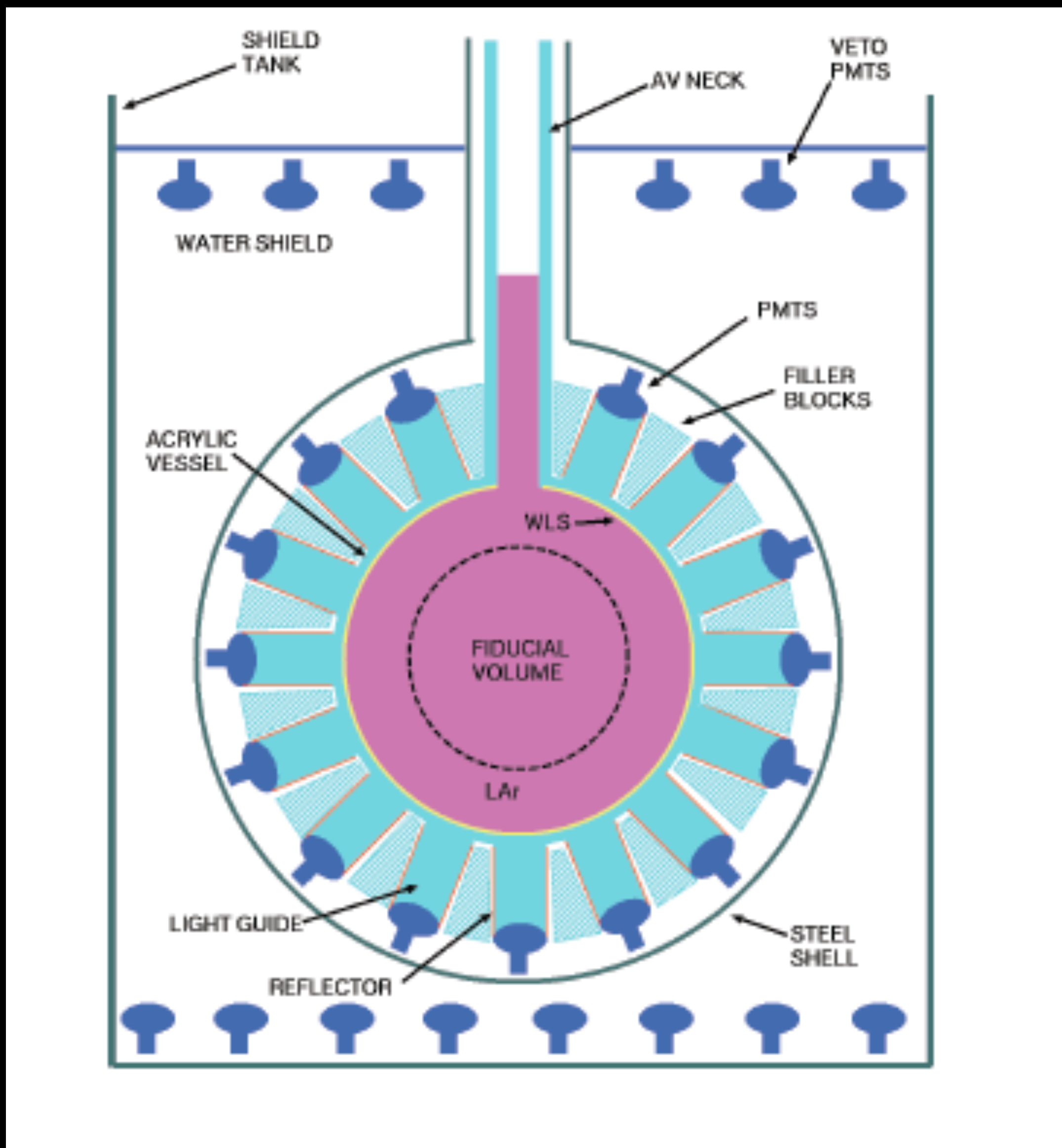
under construction

proposed

so far: <1 event at ~1E-45 cm^2, therefore need ***at least*** 1E-47 cm^2 sensitivity for 100 events to measure M_X,σ

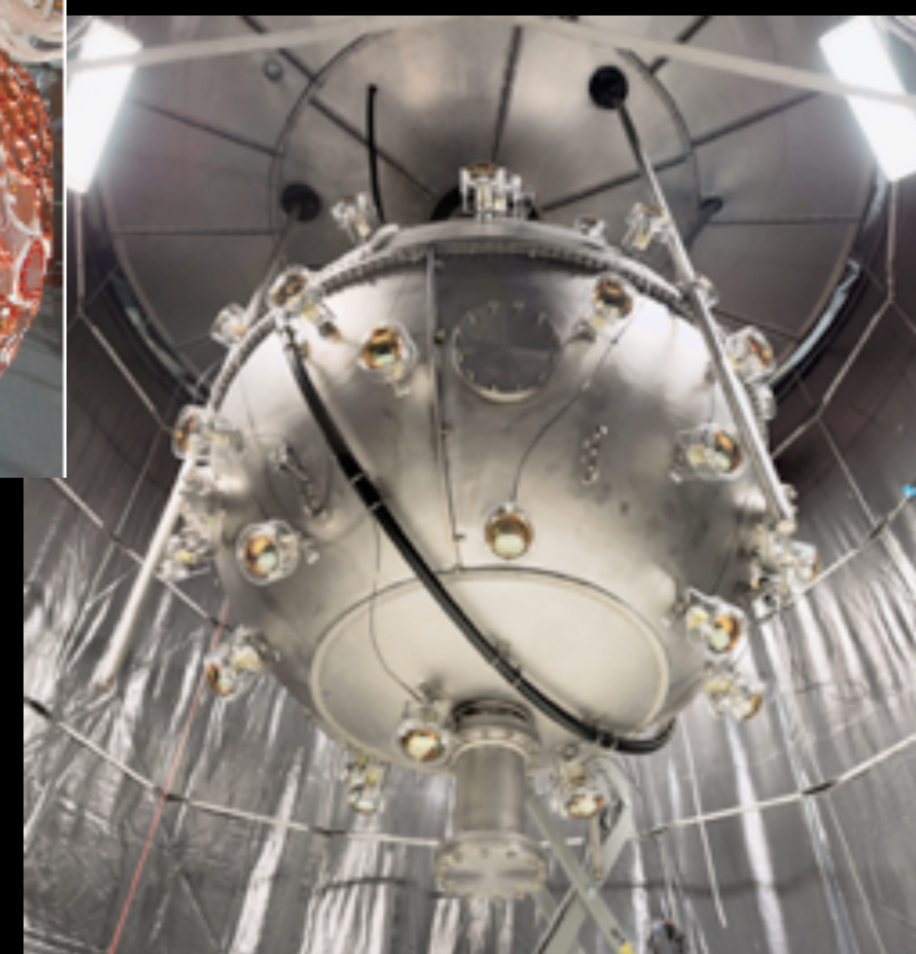
Single Phase Liquid Nobles, a la Neutrinos

high light yield from 4π PMT coverage, self-shielding of liquid target, only detect scintillation



XMASS: 832 kg LXe detector at Kamioka, running from 2013, upgrading PMTs to reduce backgrounds, future 5T detector.

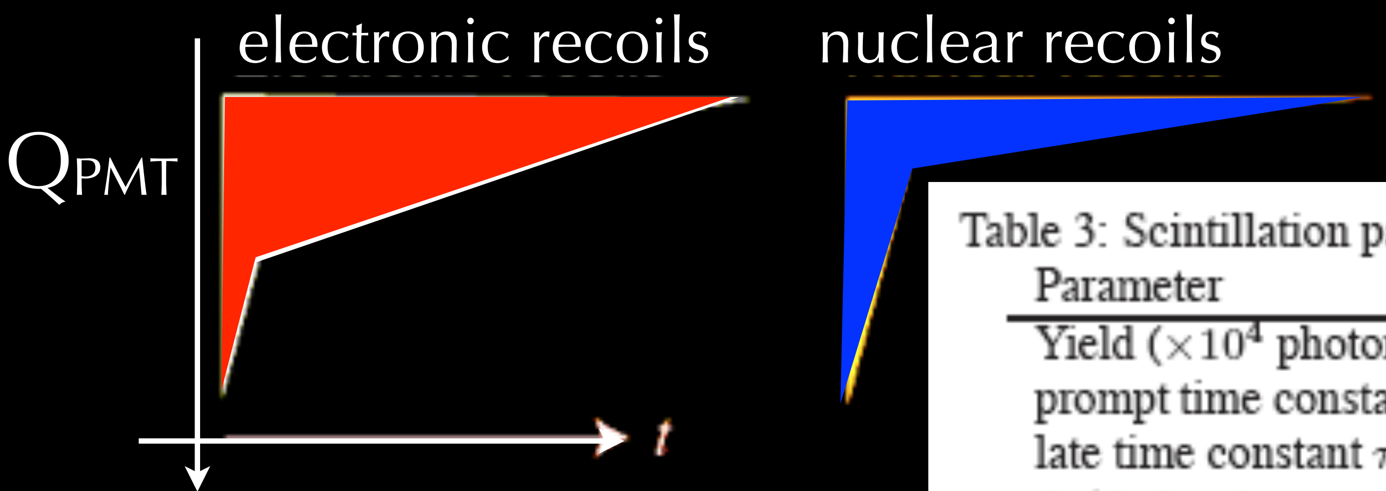
DEAP/CLEAN: LAr at SNOLAB. DEAP 3.6T, MiniCLEAN 0.5T commissioning now, DEAP physics start Summer 2015, project <0.6 background/3000 kg-days, 1E-46 cm^2 sensitivity



no electric fields = scale to large mass (O(100 T))
1) no pile-up from ms-scale electron drift in TPC
2) no recombination in E field
but background discrimination from scintillation only!

Why Argon

price, ease of purification, and LAr scintillates ~40 photons/keV with fast and slow components



Lippincott et al., Phys.Rev.C 78: 035801

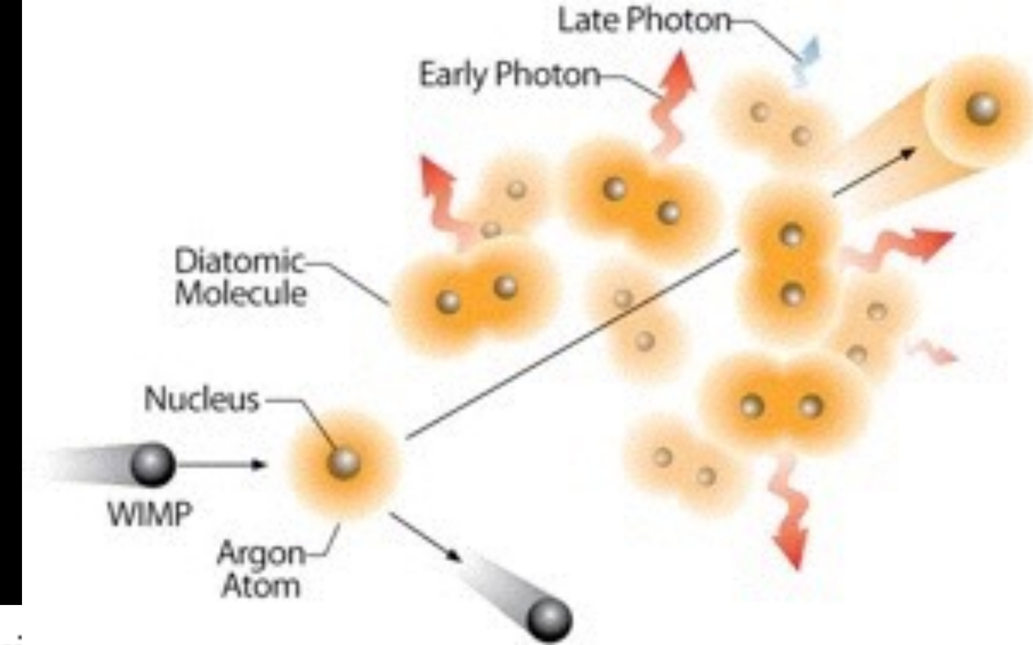
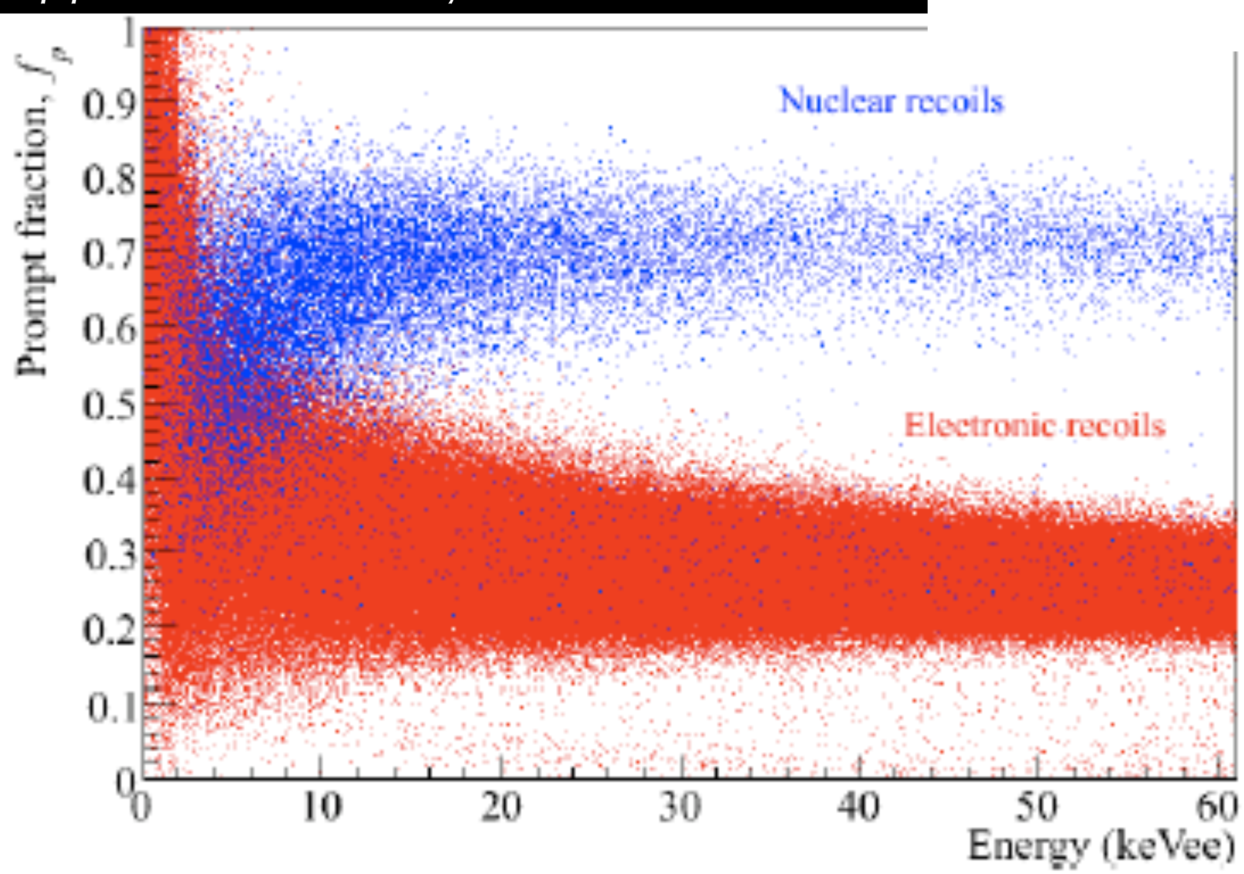


Table 3: Scintillation parameters for liquid neon, argon, and xenon.

Parameter	Ne	Ar	Xe
Yield ($\times 10^4$ photons/MeV)	1.5	4.0	4.2
prompt time constant τ_1 (ns)	2.2	6	2.2
late time constant τ_3	15 μs	1.59 μs	21 ns
I_1/I_3 for electrons	0.12	0.3	0.3
I_1/I_3 for nuclear recoils	0.56	3	1.6
λ(peak) (nm)	77	128	174
Rayleigh scattering length (cm)	60	90	30



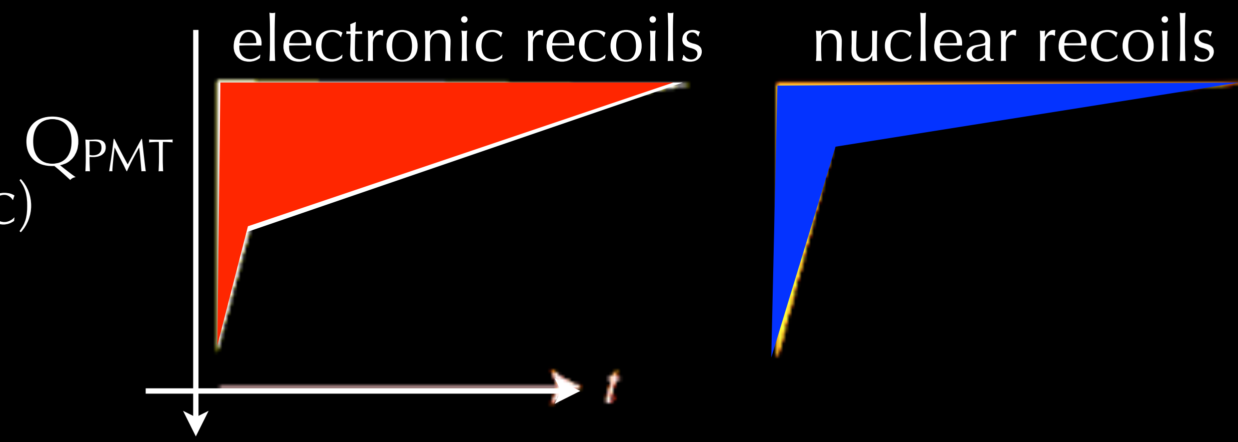
identify, reject electronic backgrounds via pulse shape vs. time difference

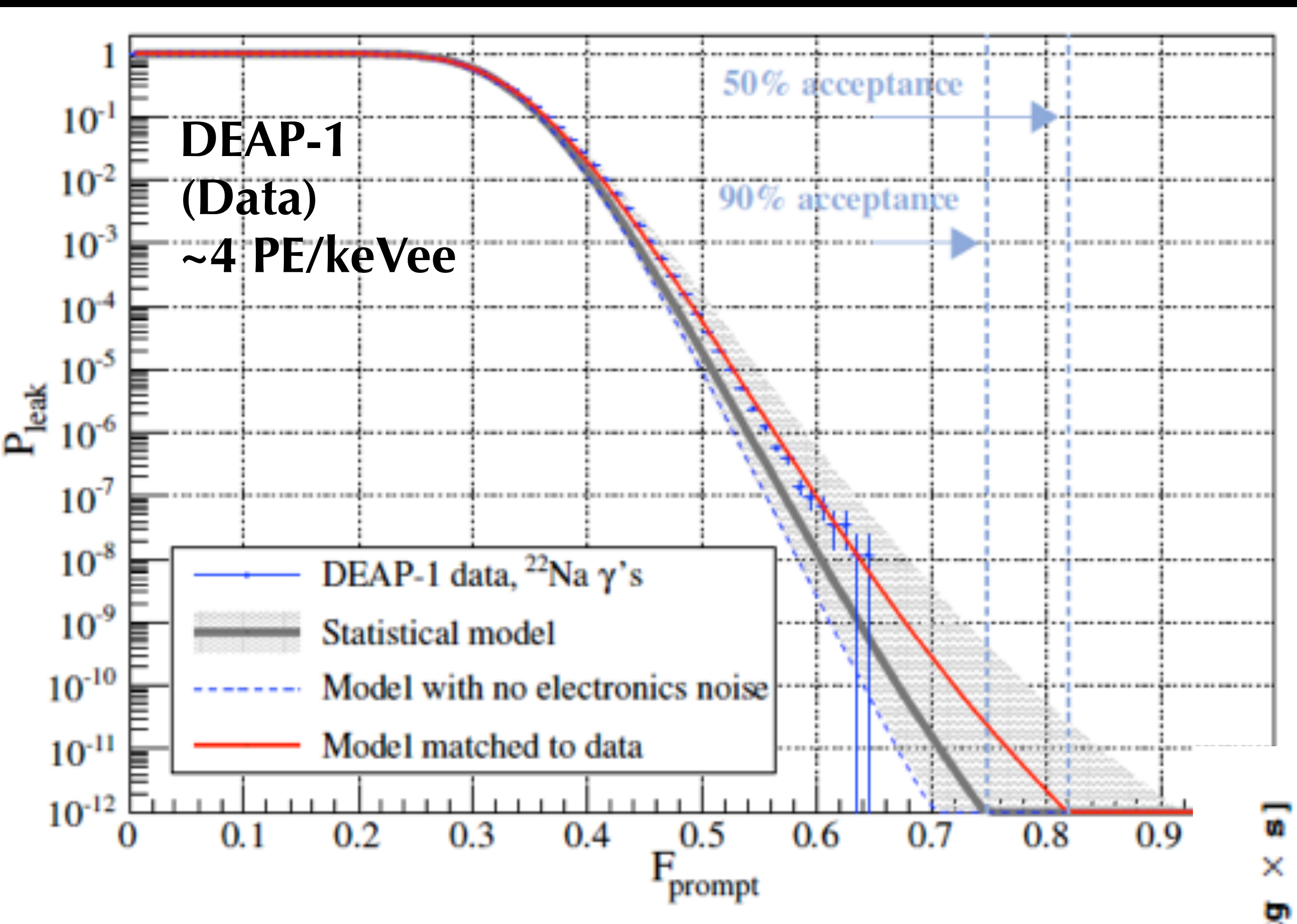
McKinsey & Coakley, Astropart. Phys. 22, 355 (2005).
Boulay and Hime, Astropart. Phys. 25, 179 (2006)

- ★ Very large detectors possible, without solar neutrino-electron scattering backgrounds
- ★ Critically important for LAr: Ar-39 background beta decay at 1 Bq/kg, with 550 keV endpoint.

Argon Detectors

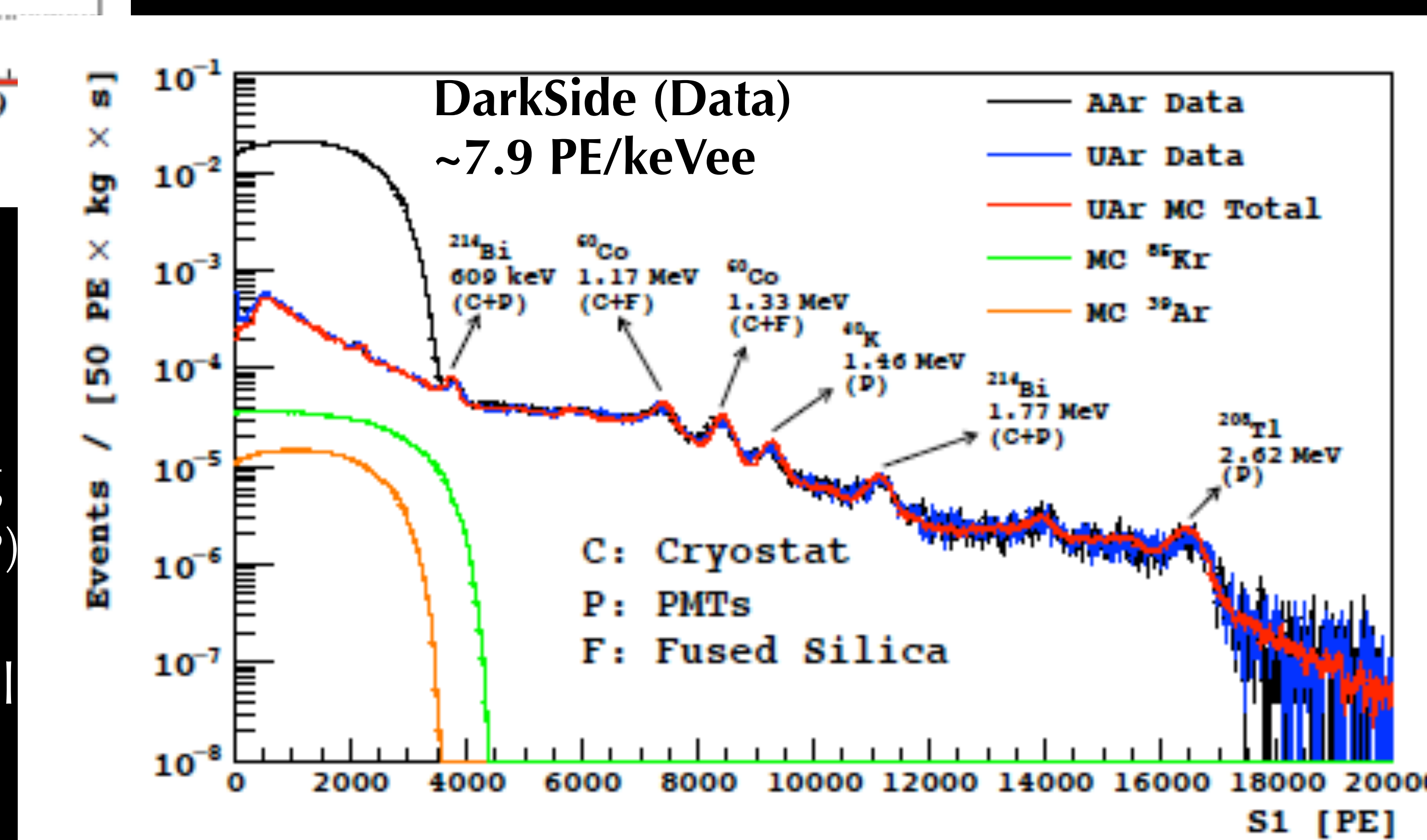
DEAP (SNOLAB), DarkSide (LNGS), ArDM (Canfranc)





'ppb-ppt' pulse shape discrimination (PSD): leakage probability of electrons into nuclear recoil F_{prompt} region** leverages x250 difference in scintillation time constants in Ar.

**Fancier statistics gain ~10x in PSD leakage
,Astropart. Phys. 65 (2014) 40



DEAP-3600: measures PSD to 3E-8 in DEAP-1, predict >1E-10 in DEAP-3600 *(arXiv:0904.2930)*

DarkSide-50: measure depletion x1600, in 50kg detector, zero background limit *(arXiv:1510.00702)*

ARGO: Coordination of LAr detectors, ArDM wil test depleted UAr samples with 100x sensitivity.

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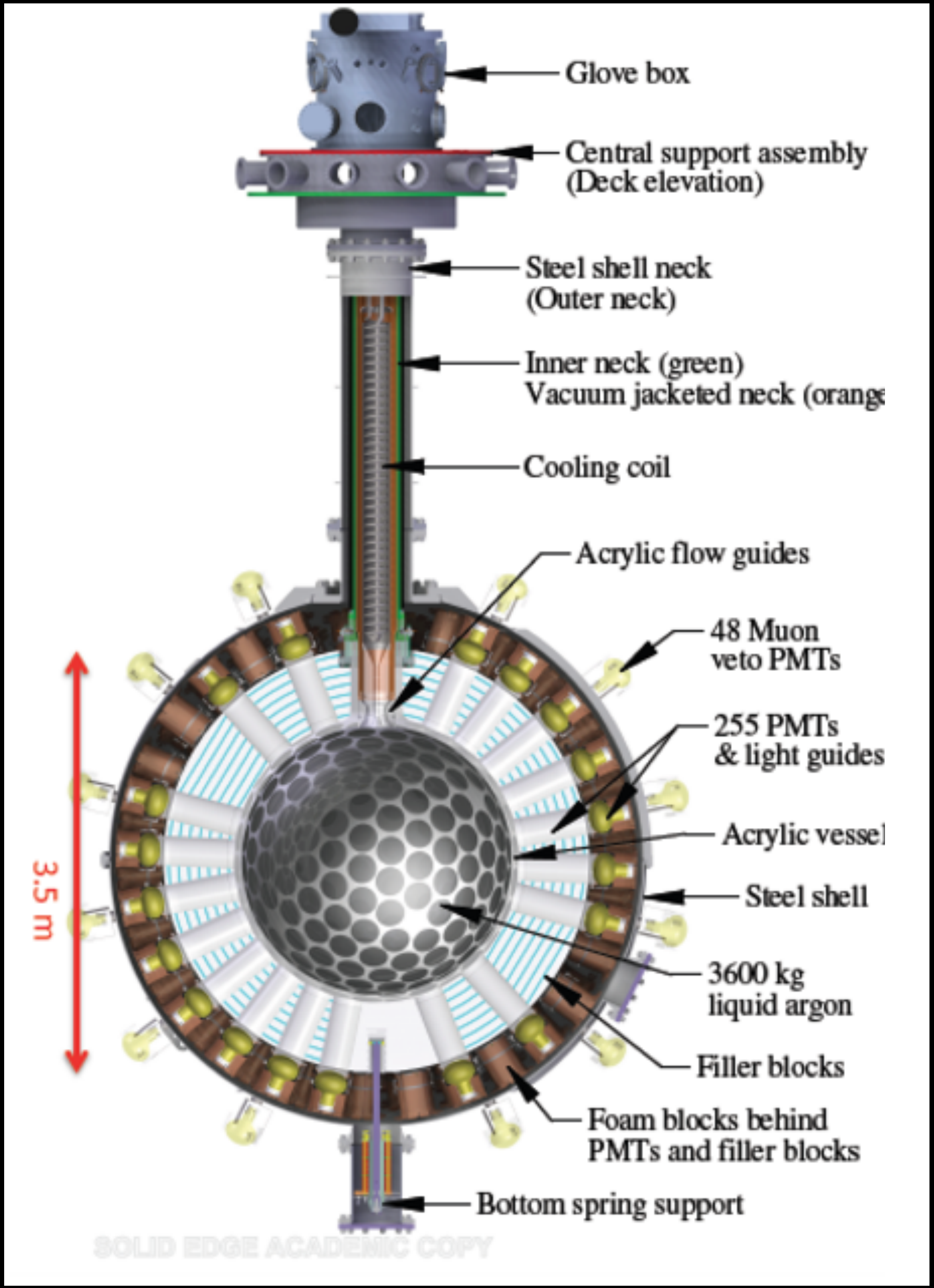
DEAP-3600 Detector



85 cm radius acrylic sphere contains 3600 kg of liquid argon (LAr)

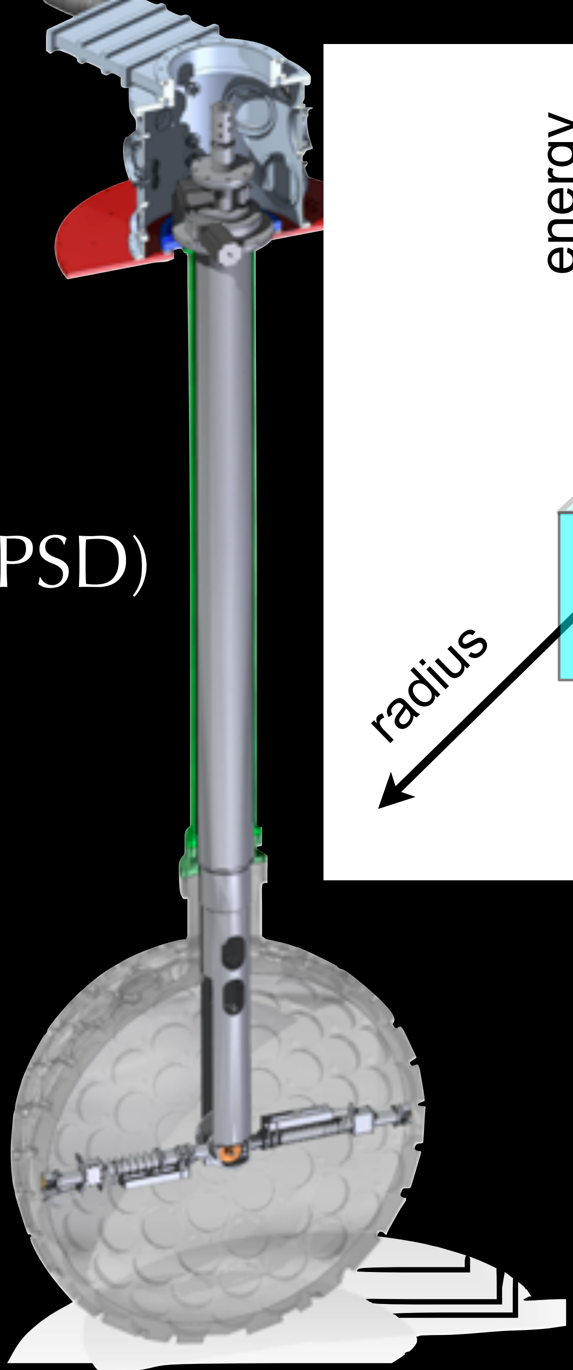
- TPB coats inside surface of sphere, to wavelength shift from 128 nm to 420 nm
- viewed by 255 8″ Hamamatsu R5912 HQE PMTs (32% QE, 75% coverage)
- 50 cm of acrylic light guide between LAr and PMTs to mitigate PMT neutrons
- PTFE filler blocks between light guides to moderate neutrons

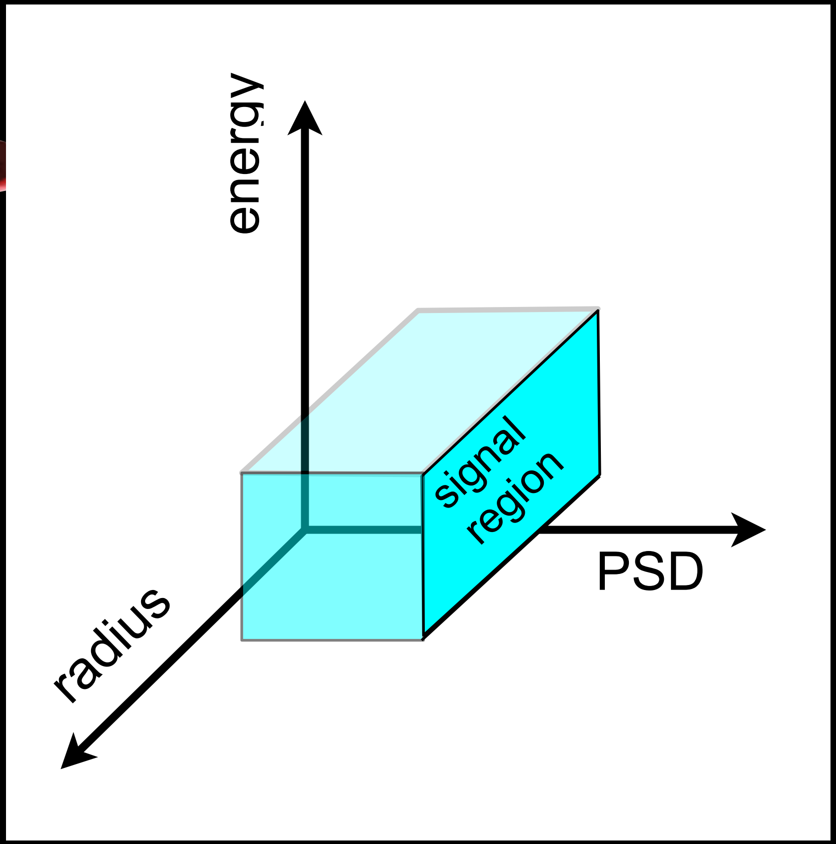
Outer steel shell prevents LAr / water mixing (important for safety!)

Inside 8.5m diameter water tank, with 48 8″ R1408 PMTs for muon veto, and to moderate cavern neutrons and gammas.

6200′ underground in SNOLAB Cube Hall

Background Strategy





Electrons and Gammas:

- Ar-39 decay rate ~1 Bq/kg, Q=550 keV. Dominates data rate.
- mitigated with pulse shape discrimination (PSD)
- threshold for PSD determines energy threshold for dark matter search

Alphas and Radon Progeny:

- stringent radiopurity control, ex-situ assays
- resurfacing of vessel before TPB + argon fill
- fiducialization, determines fiducial volume for dark matter search

Neutrons and Gammas:

- passive moderation
- cross-check with active tagging: measure neutron inelastic scattering gammas
- stringent radiopurity control for (alpha,n)

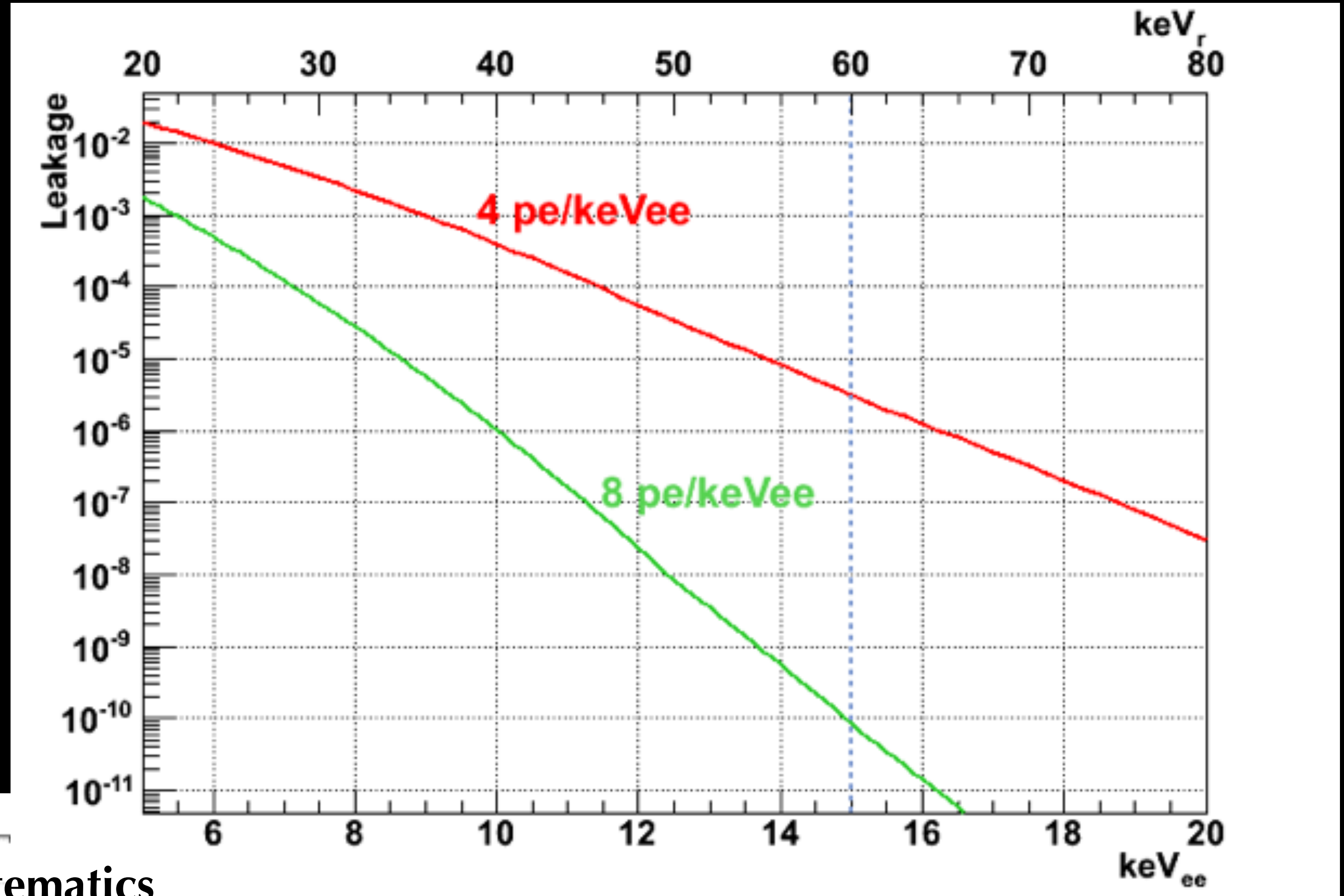
Background (in Fid Vol)	DEAP-3600 Goal
Radon in Ar	< 1.4 nBq/kg
Surface α's	< 100 μBq/m^2
Neutrons (all sources)	< 2 pBq/kg
Ar-39	< 2 pBq/kg
Total (3 tonne-yr)	**< 0.6 events**

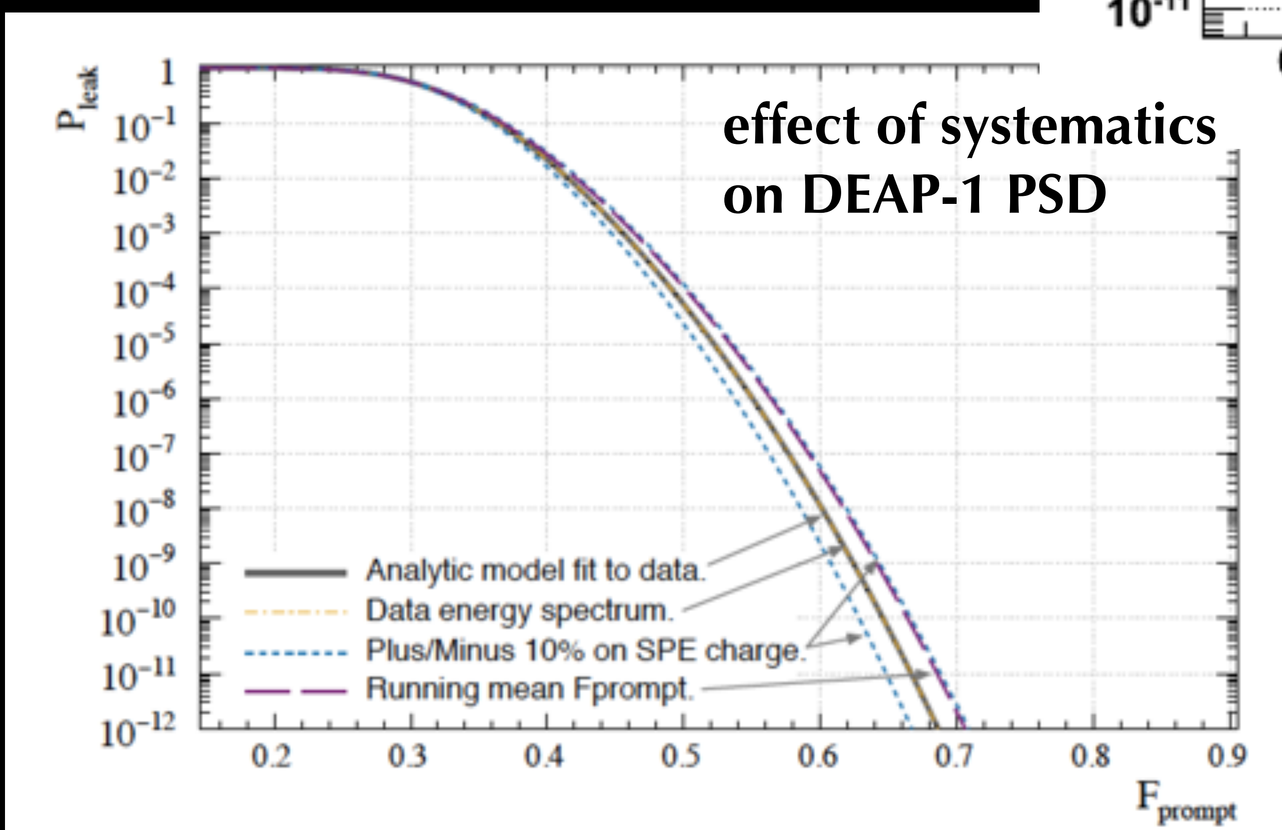
Electron/Gamma Mitigation in DEAP-3600

Background target corresponds to <0.2 events in 3 Tonne-years.

This requires 1E-10 leakage of electrons into WIMP region.

Projected leakage in DEAP-3600 is <1E-10, based on fitting DEAP-1 data over 60-260 PE + noise model from measurements of DEAP-3600 electronics.





Main increase in PSD from light yield: (conservative) projection is 8 PE/keVee.

Effect of systematics in PE counting is important!

Developed Bayesian PE counter to reduce variance for DEAP-3600, and full PMT after pulsing model and correction.

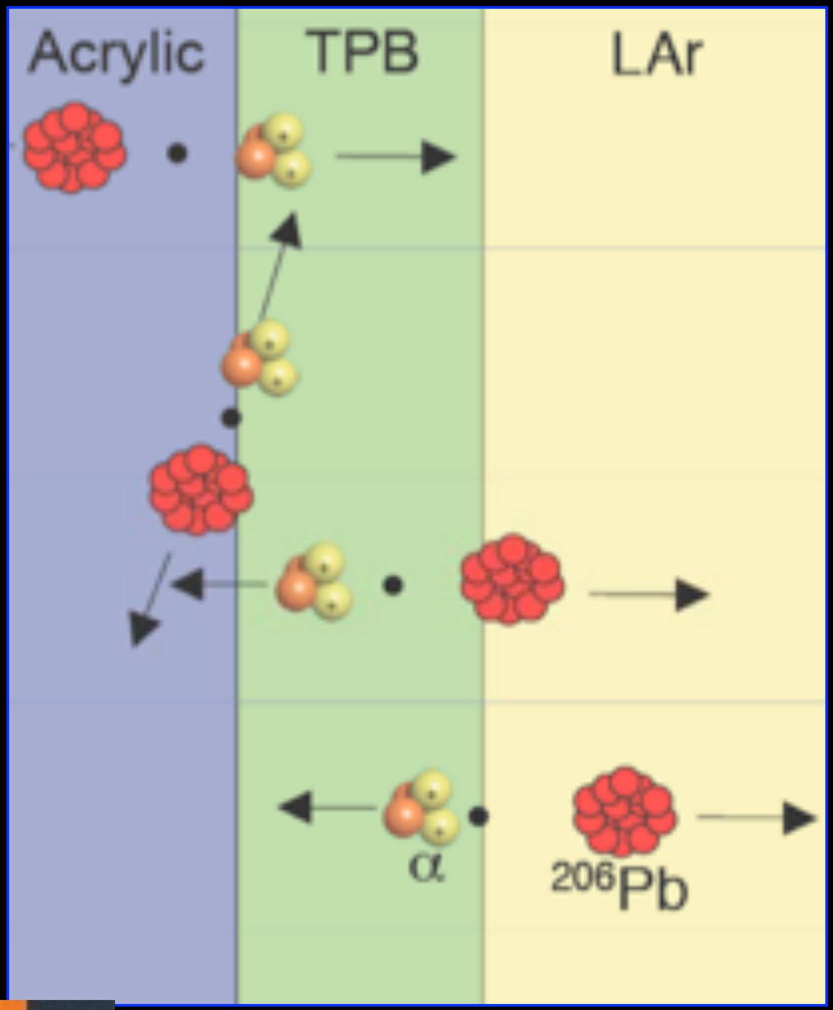
Caldwell, et al.,Astropart. Phys. 65 (2014) 40

Radon Mitigation in DEAP-3600

Dangerous Radon (Rn) backgrounds come from decay of Rn progeny on surfaces, and between Acrylic Vessel (AV) and wavelength shifter (TPB).

Dominant source of Rn comes from plate-out on AV and acrylic during manufacture and construction.

So, sand off a thin layer of of acrylic from inside of the detector before TPB deposition, x25 reduction.



With a
gigantic
robot!

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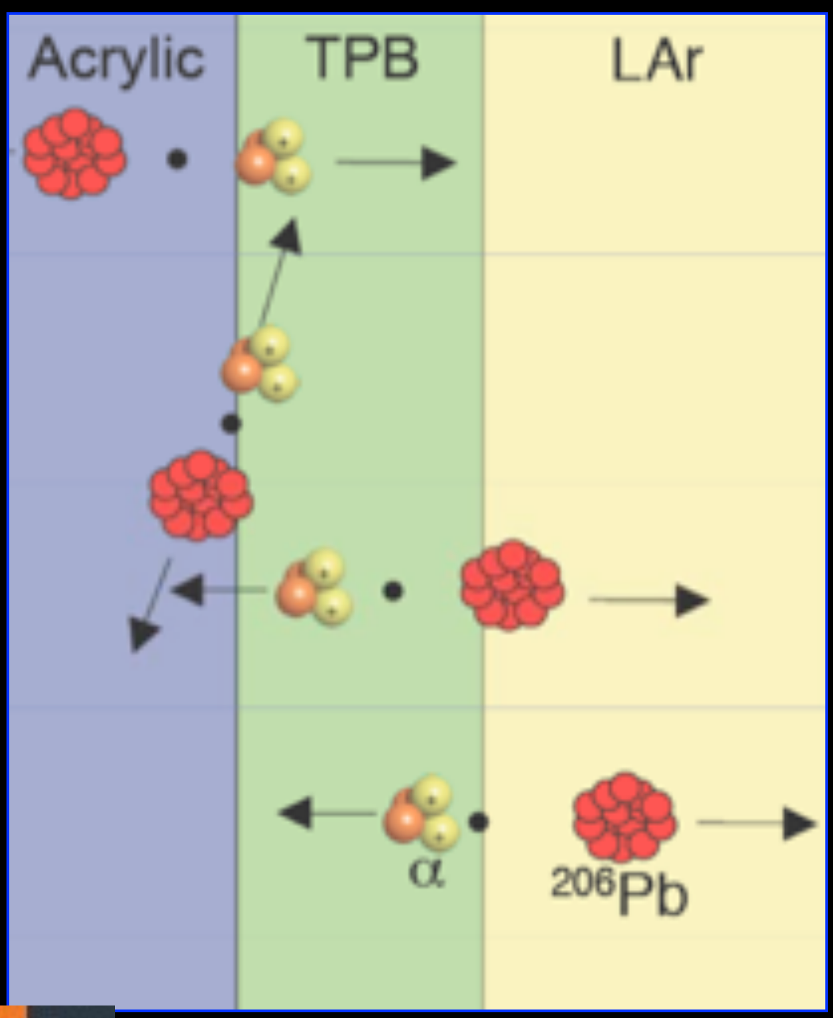
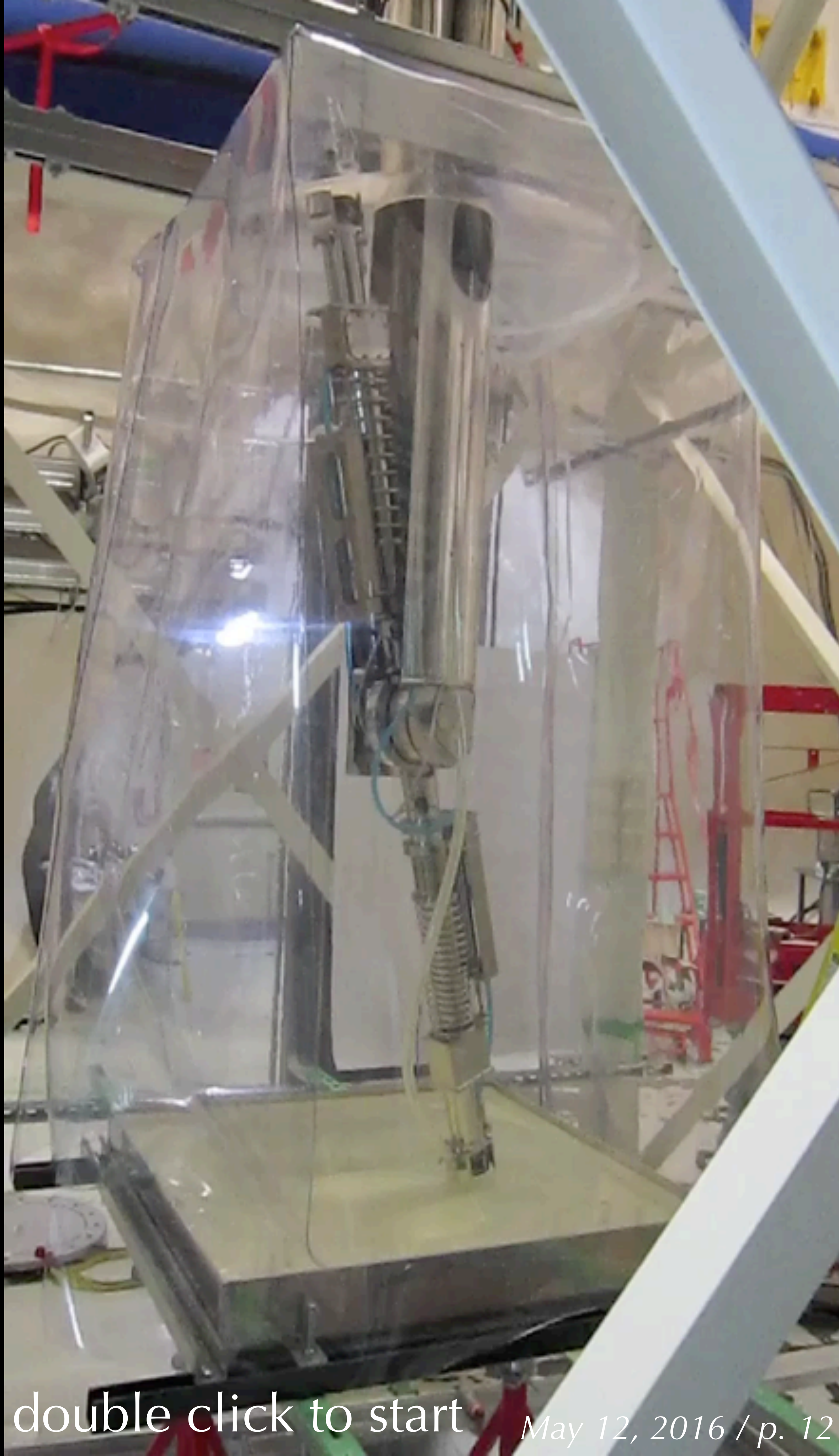


With a ***gigantic*** *robot!*

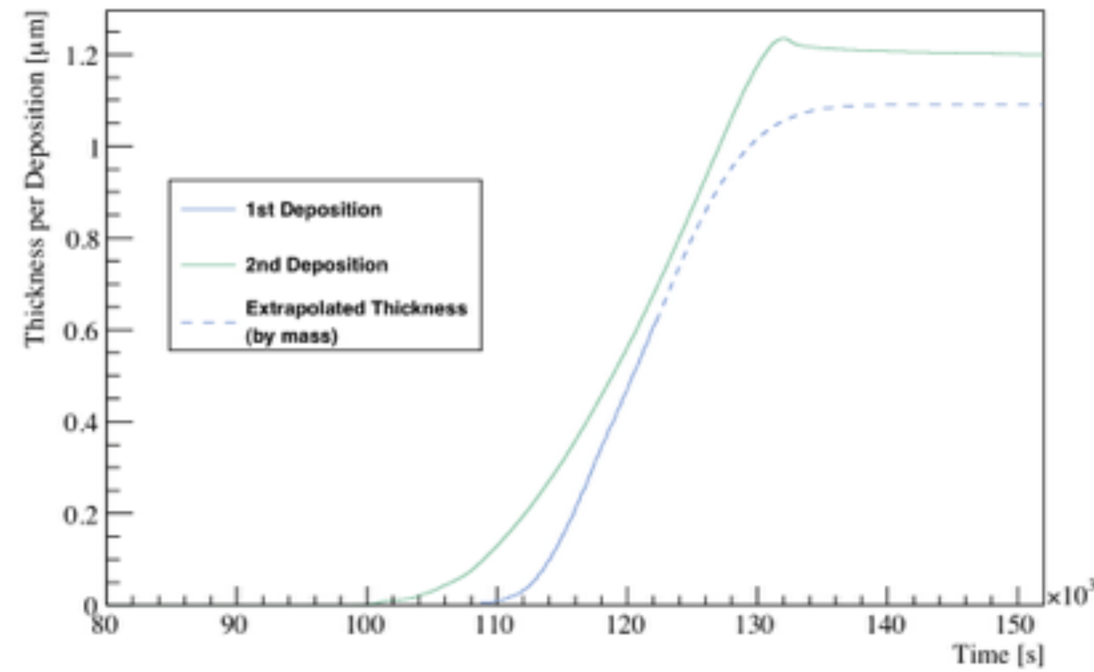


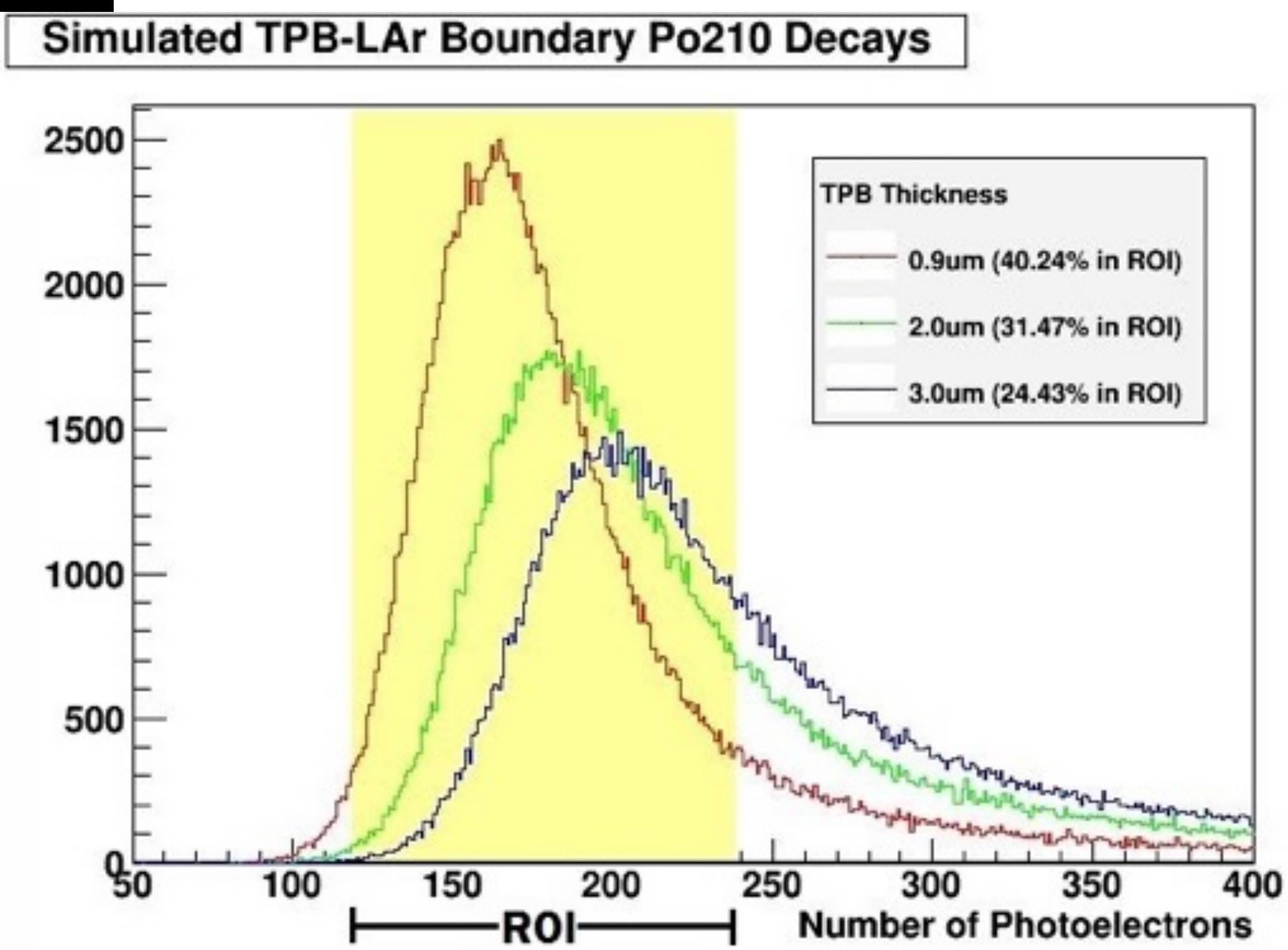
Radon Mitigation: Resurfacer

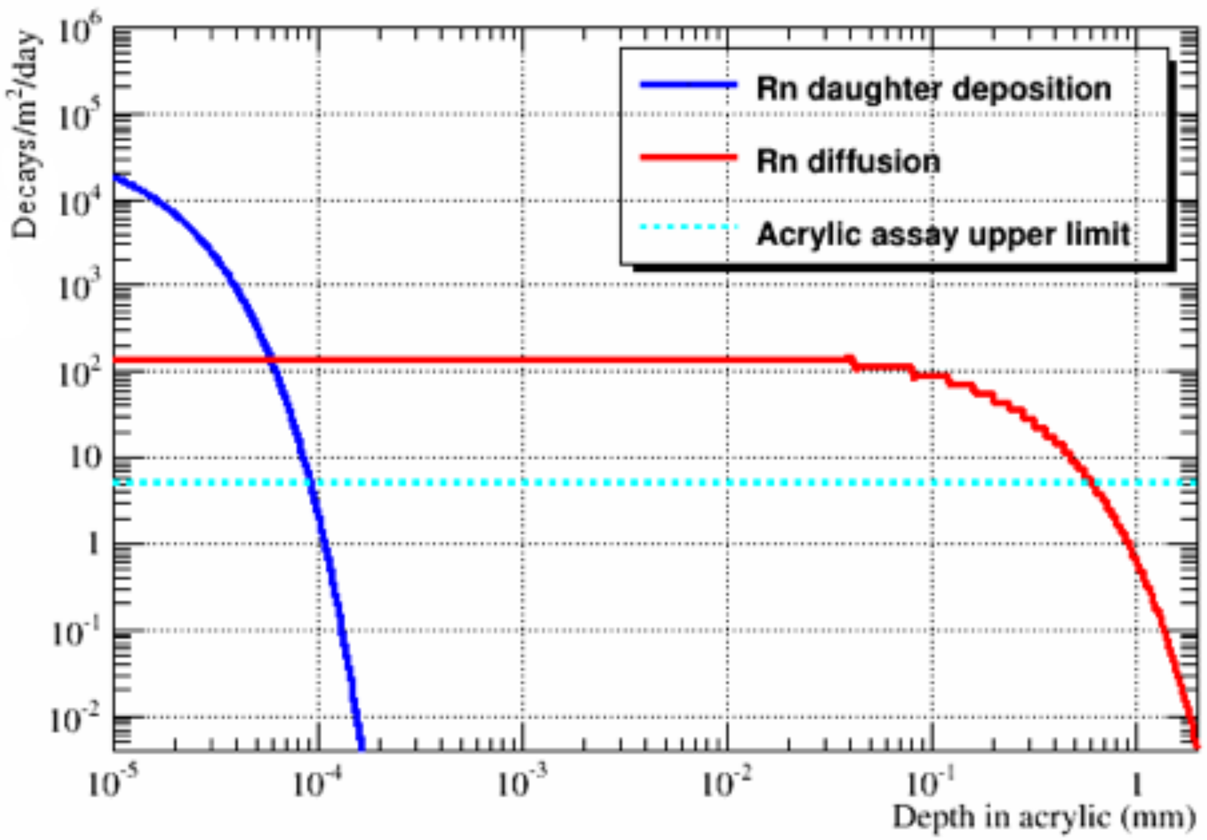
Deposited 3 um of TPB in two runs (total 200 hours).

TPB thickness chosen to optimize light level vs. background from Po-210 decays.

Based on material assay and exposure history of the acrylic vessel, the projected residue activity after resurfacing is ~10 alphas/m²/day.







Measured residue activity in 1 month vacuum run (1/16) prior to cool down for LAr fill.

Neutron Mitigation in DEAP-3600

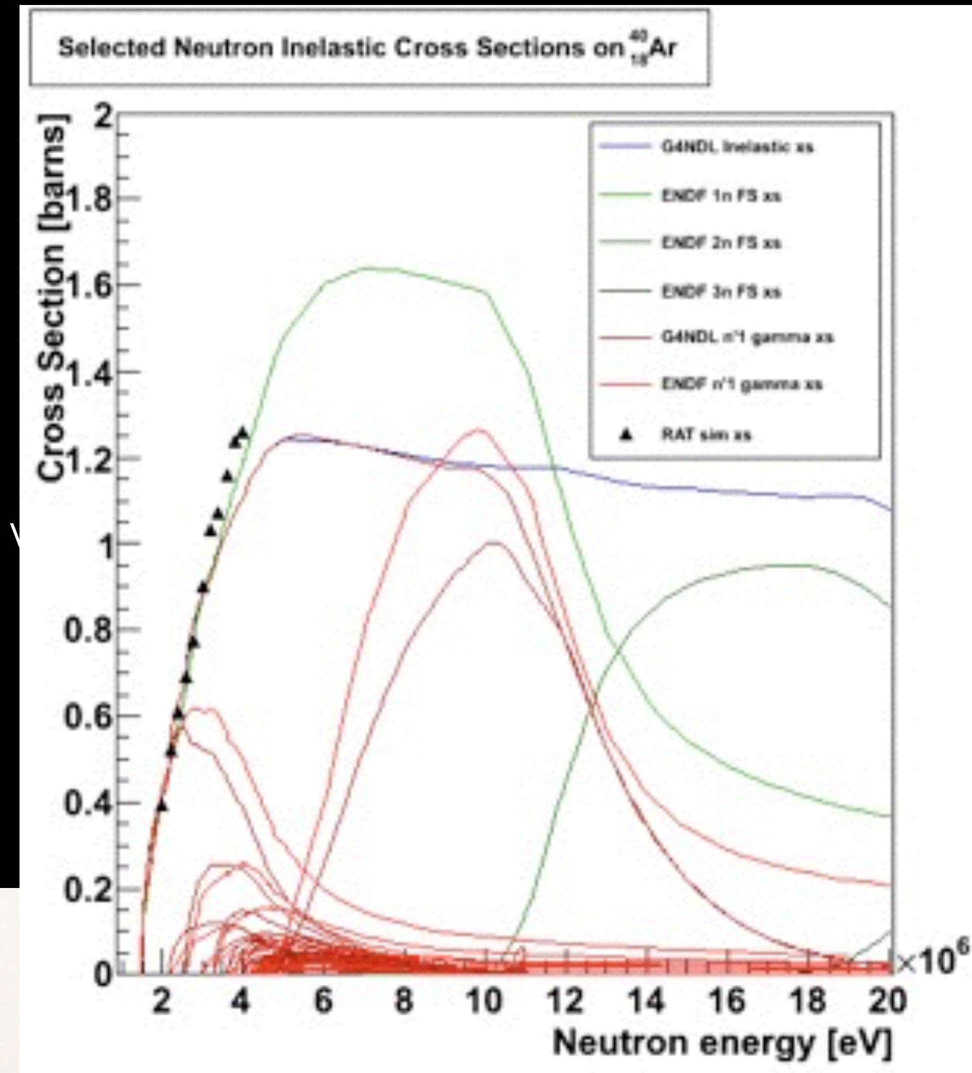
Dominant source of neutron backgrounds comes from (alpha,n) in PMT glass.

Passive: shield LAr target from PMTs by 50 cm of acrylic to moderate this neutron flux.

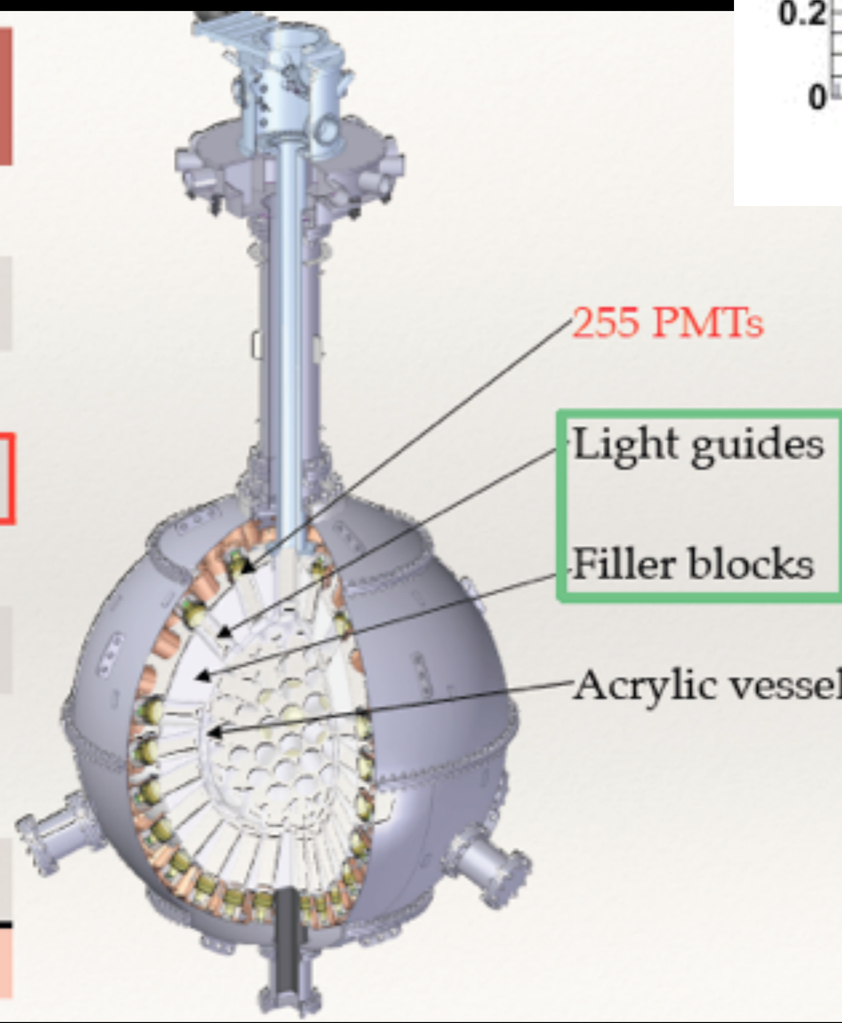
Active: tag inelastic neutron scatters by characteristic gammas.

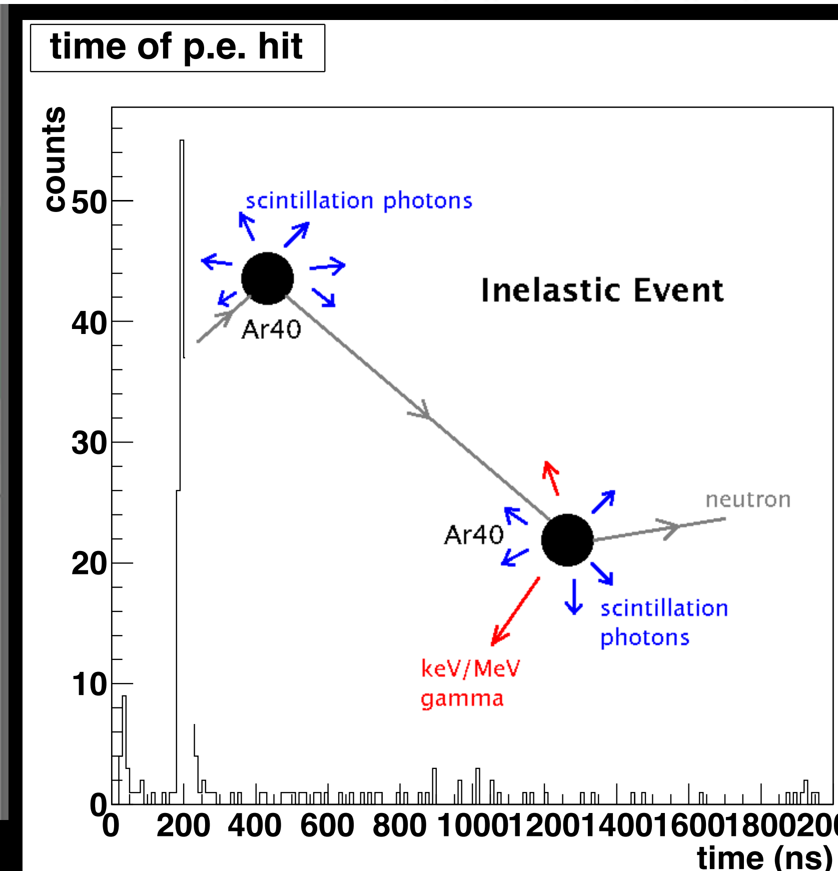
(A. Butcher, PhD thesis 2015)

Validate both active and passive mitigation efficiency using external tagged AmBe source.



(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	2.6x10	0.140
PMT mounts	7565	0. 010
Rn emanation	<44	<0.081
Rn deposition (3 months	38	0.010
Other sources		0.04
Total	**<2.7x10**	**<0.35**





Outline

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Recent Progress, Commissioning and Calibration

DEAP-3600 Construction

Acrylic vessel

light guide bonding

A. Hall, RHUL student

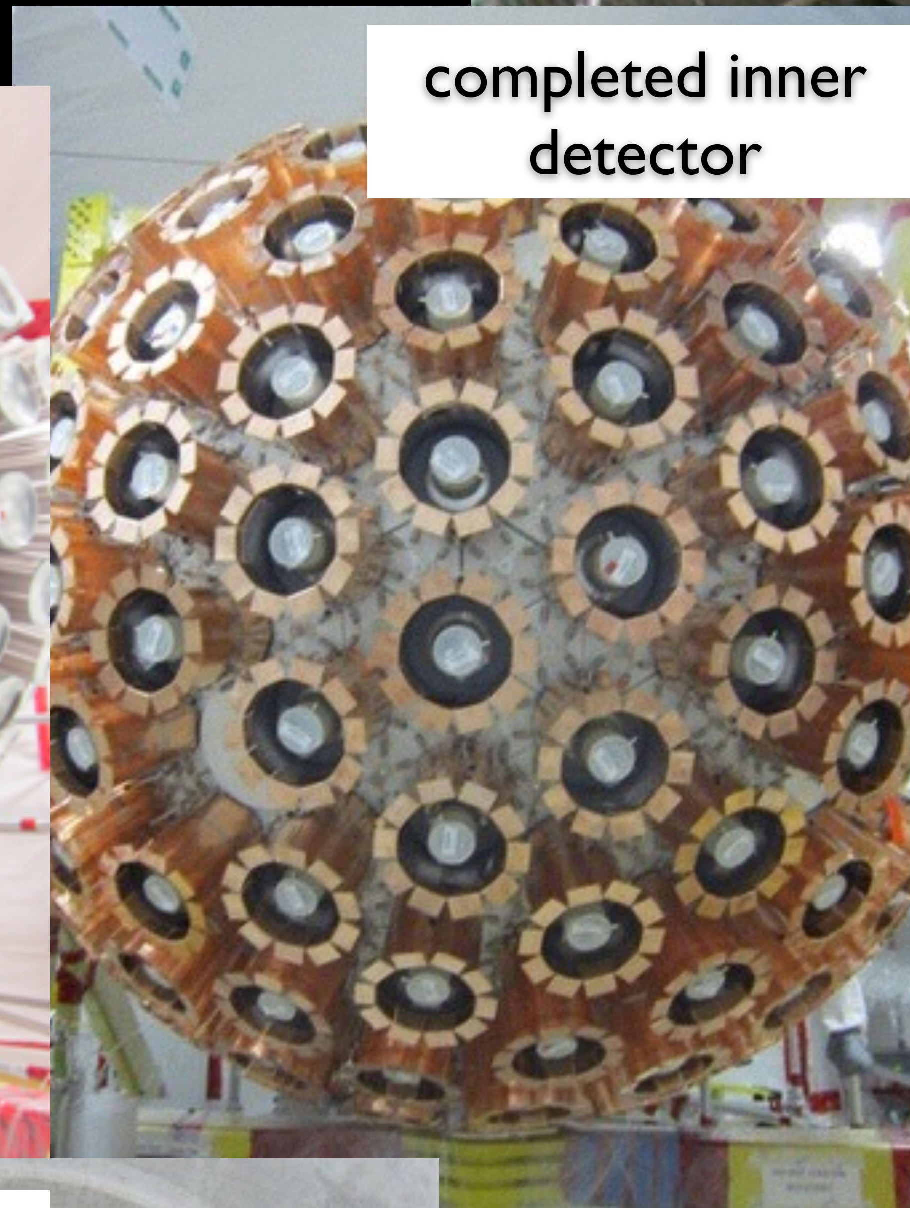
Annealing in place

Bonding complete

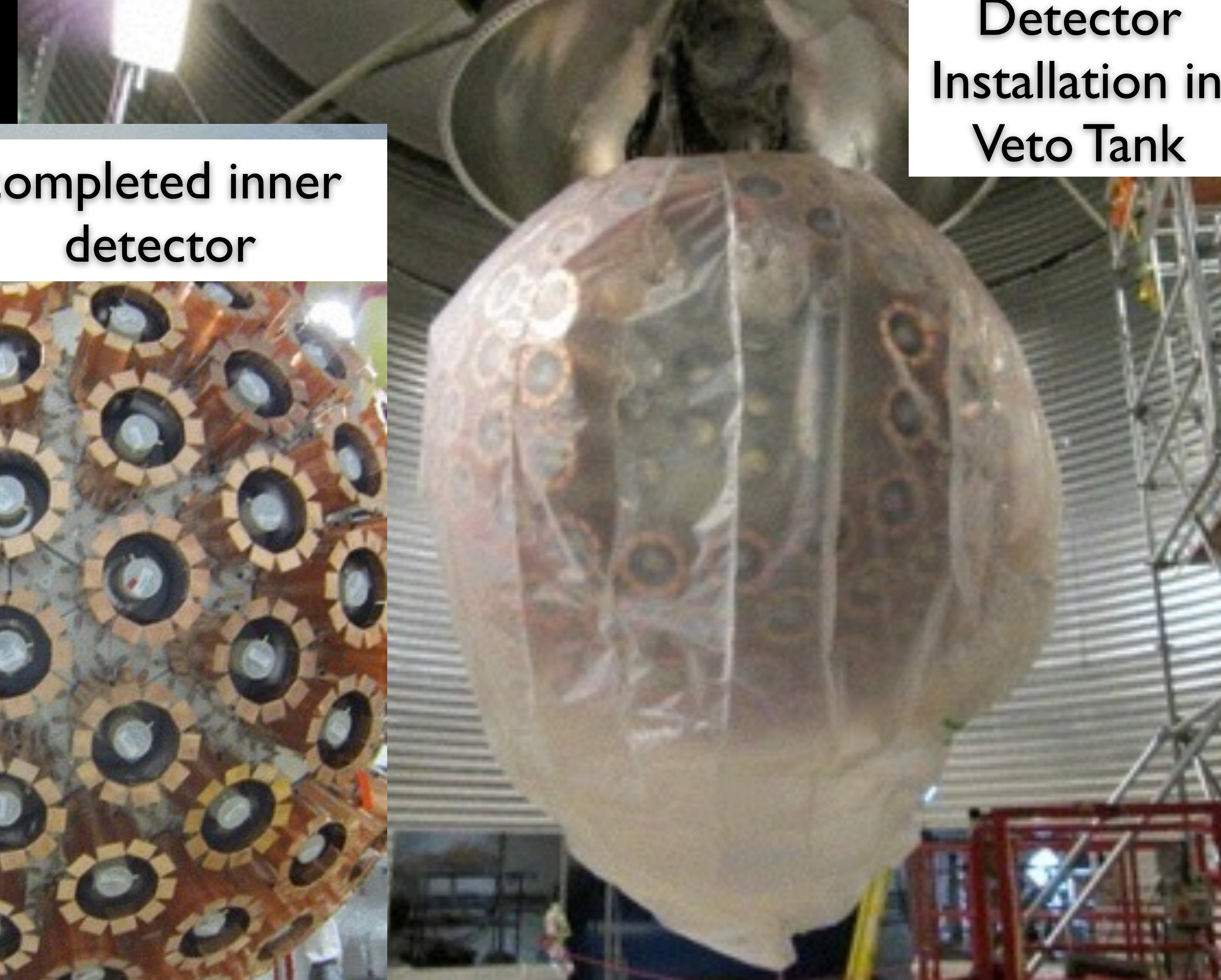
DEAP-3600 Construction

PMT Installation

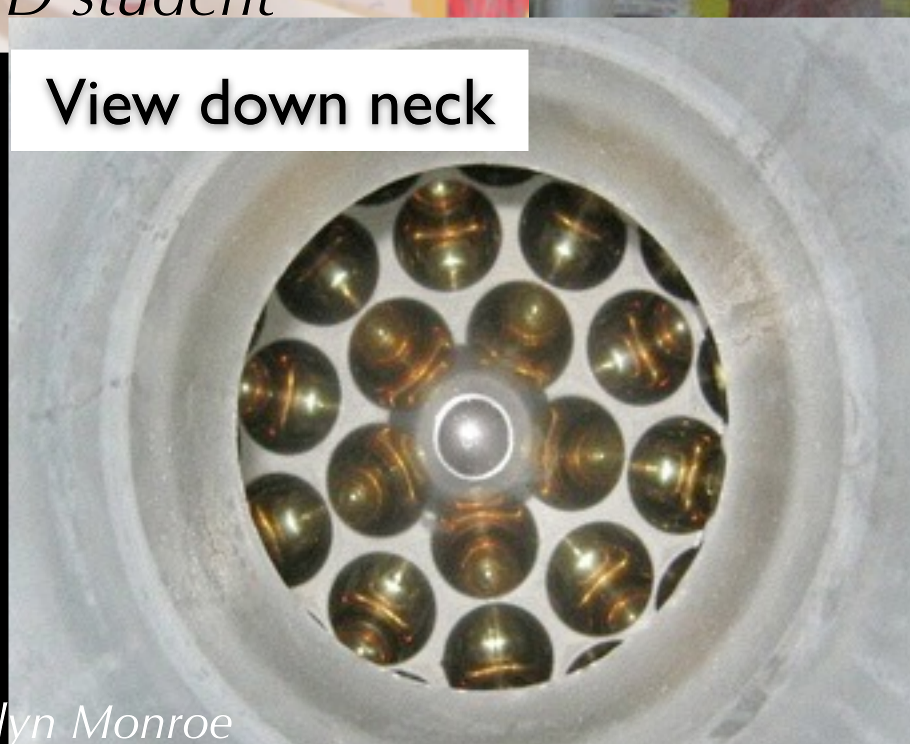
N. Seeburn, RHUL PhD student



completed inner detector



Detector Installation in Veto Tank

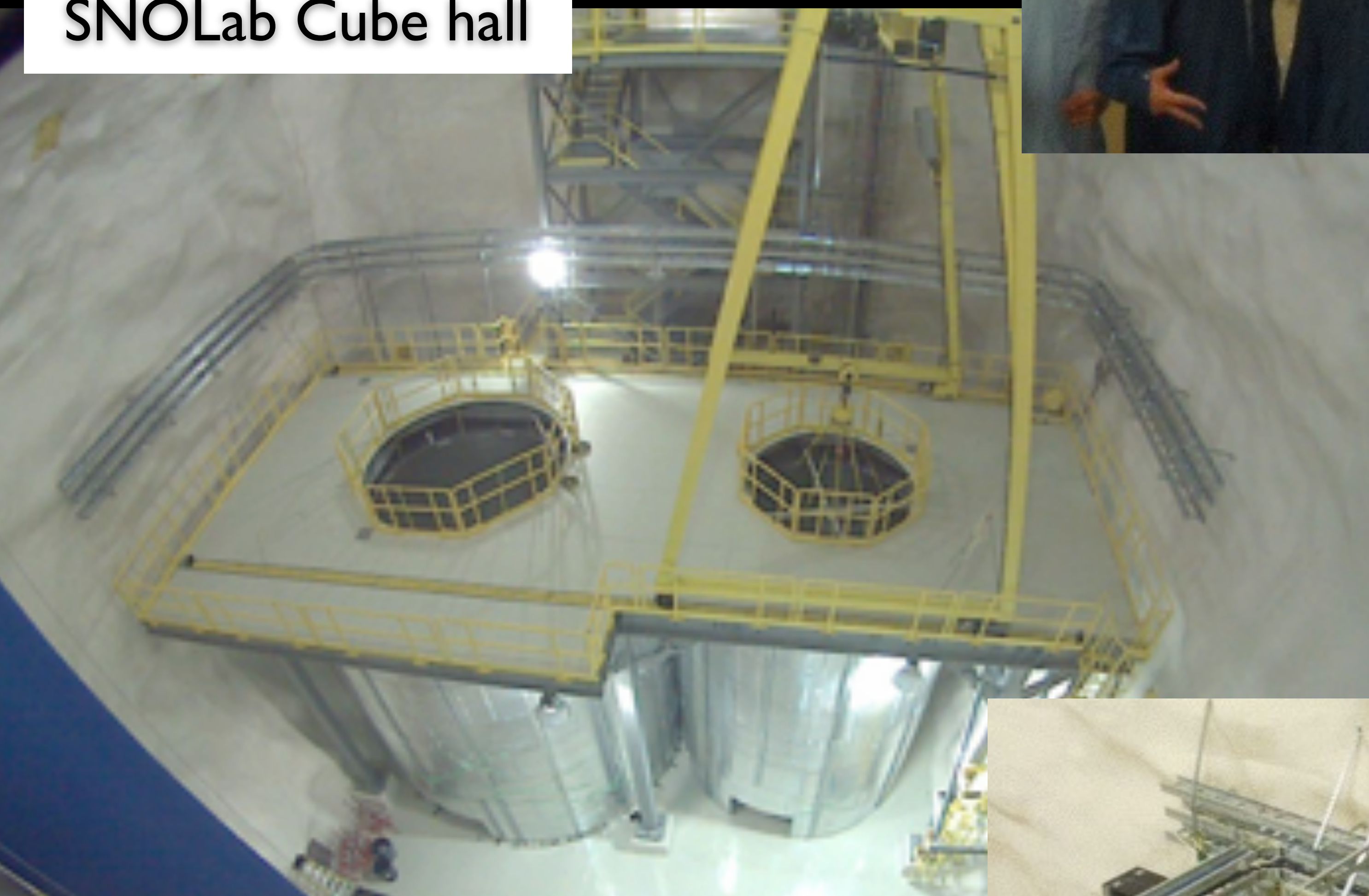


View down neck

Steel Shell in the veto tank

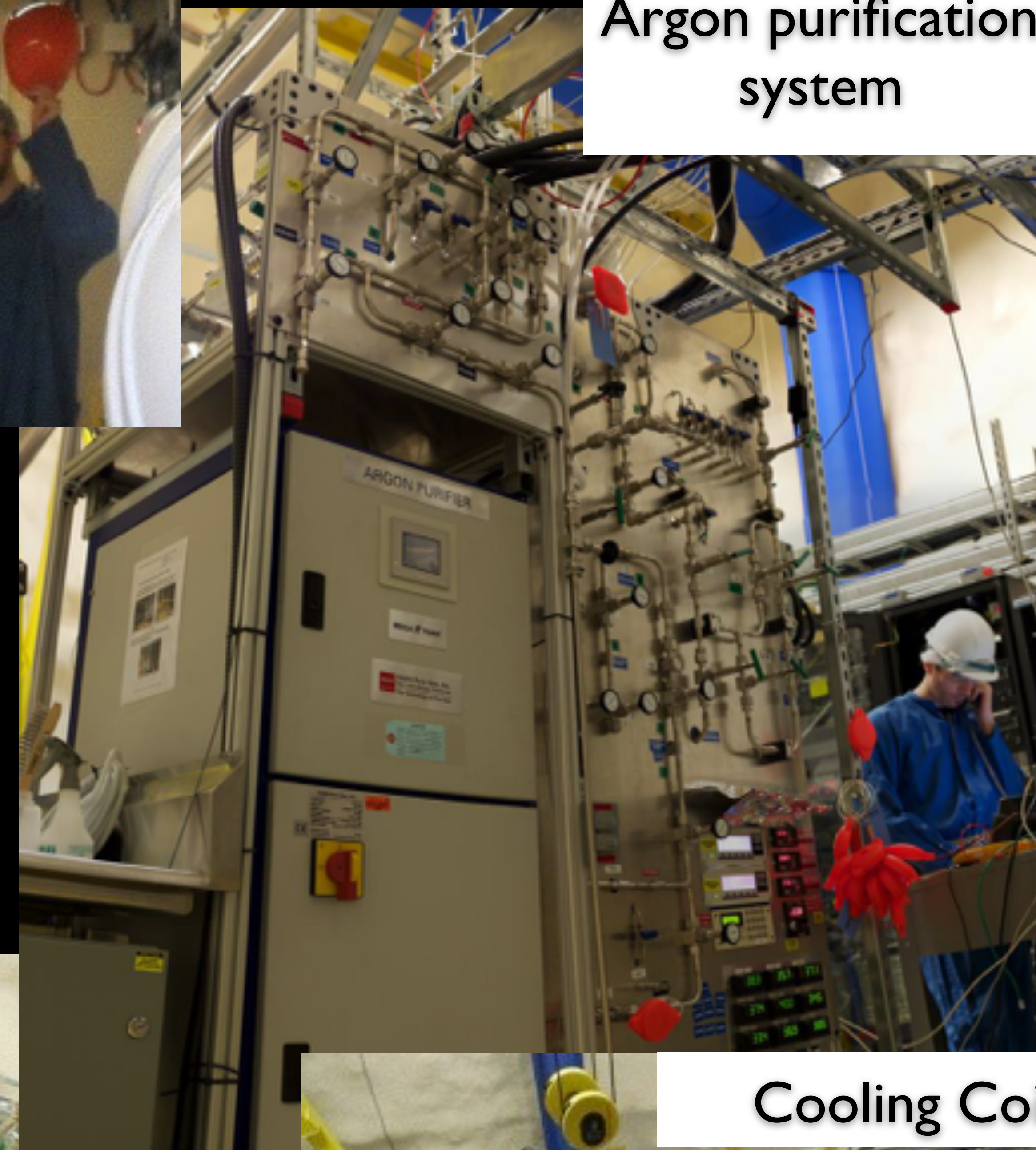
DEAP-3600 Construction

LAr cool down started Feb. '16!

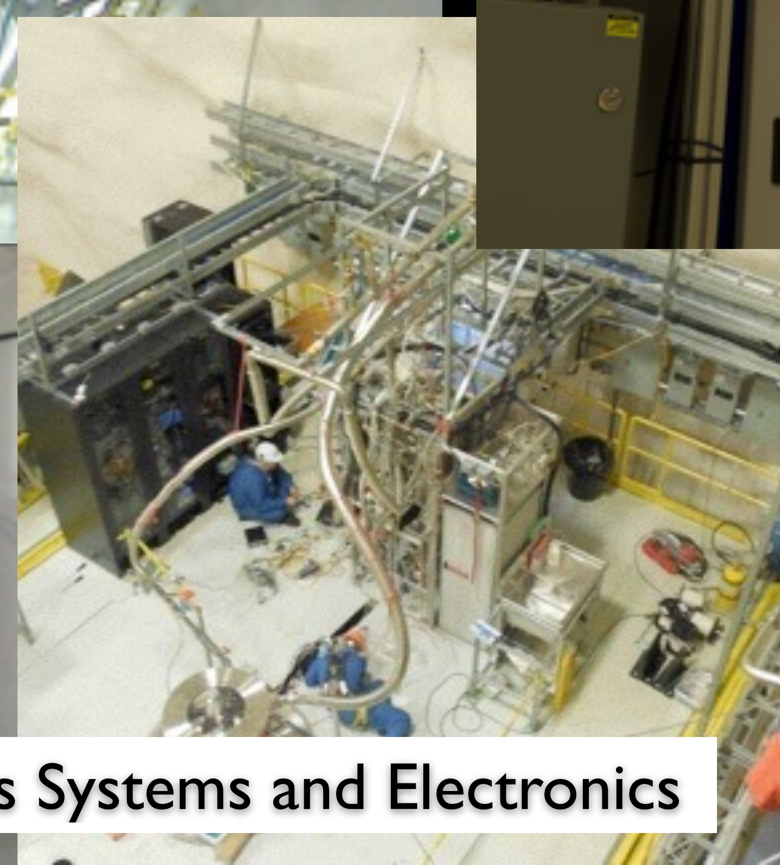


SNOLab Cube hall

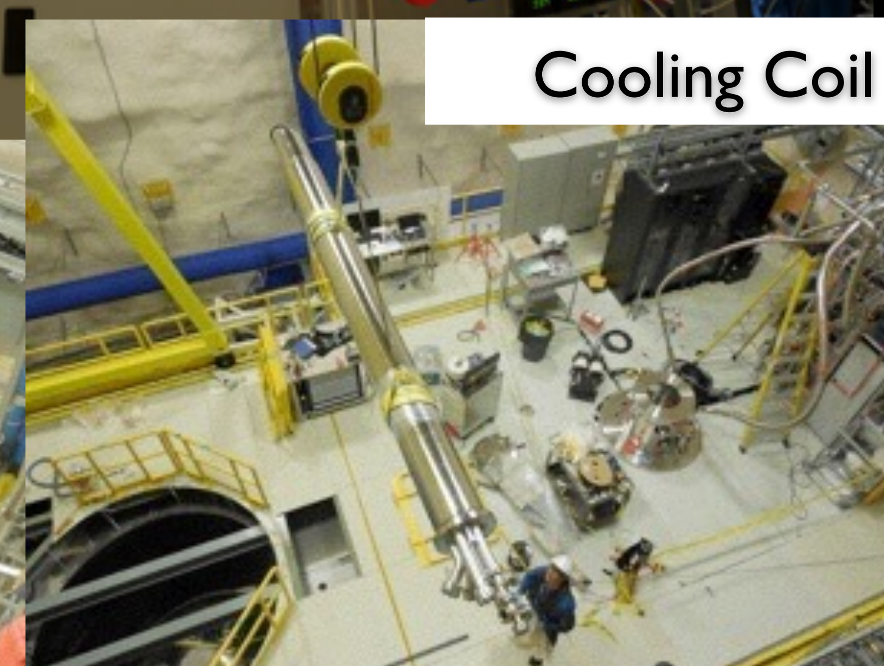
Deck Installation



Argon purification system

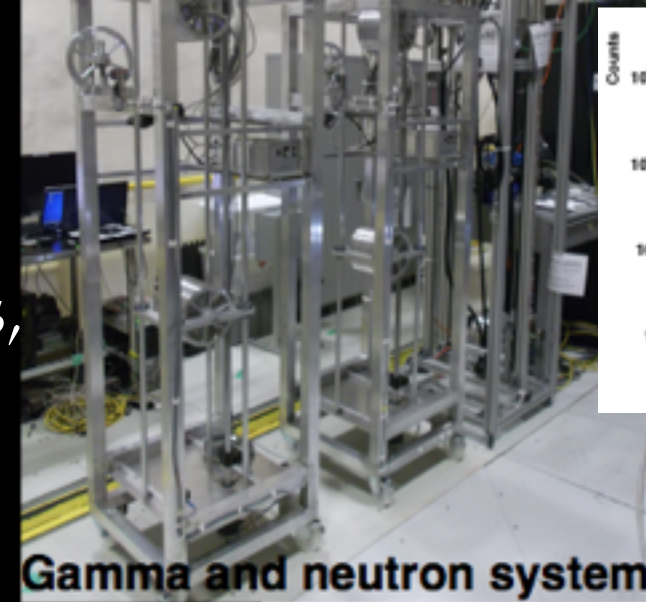


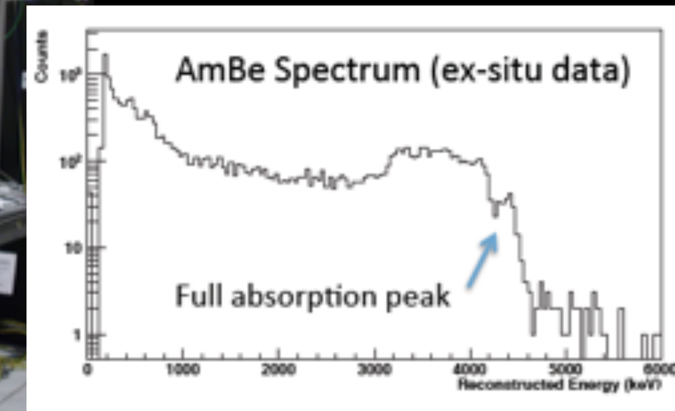
Process Systems and Electronics



Cooling Coil

DEAP-3600 Calibration Systems

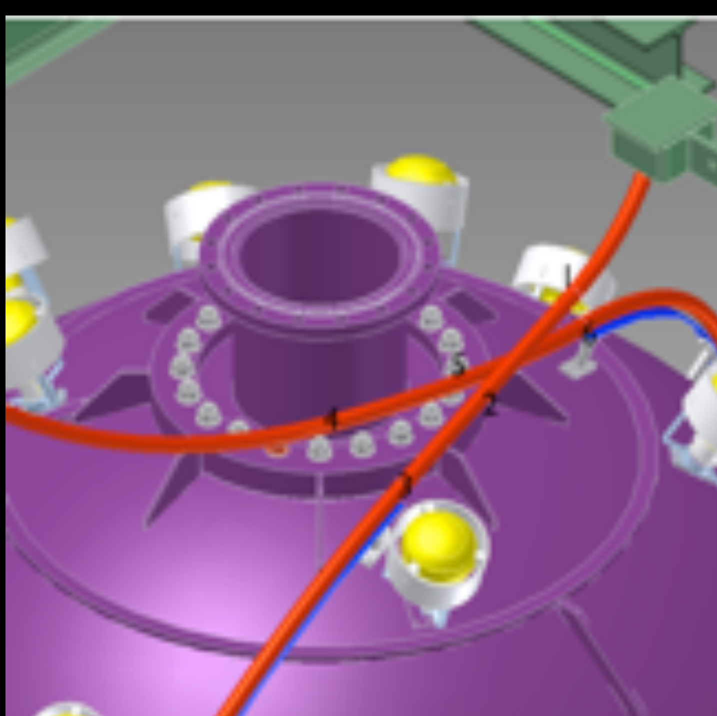


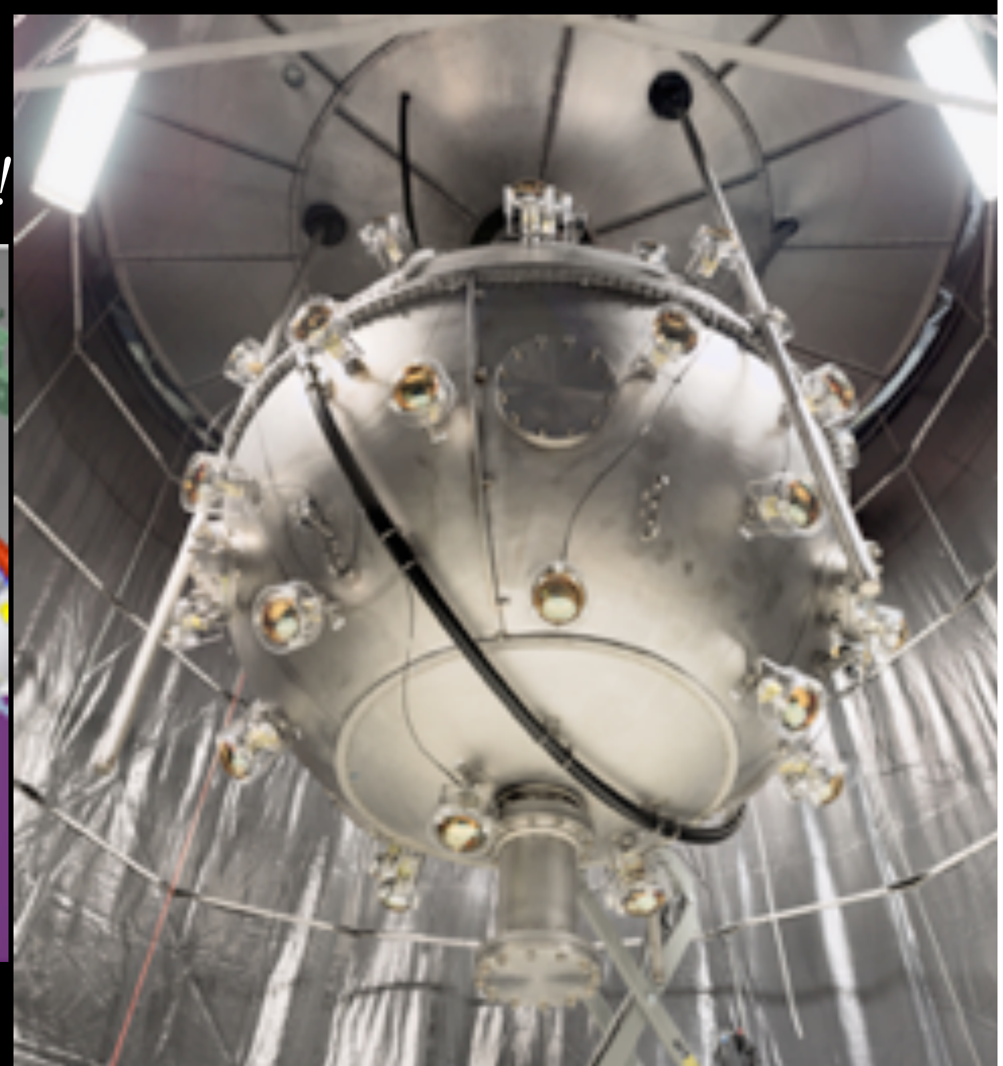


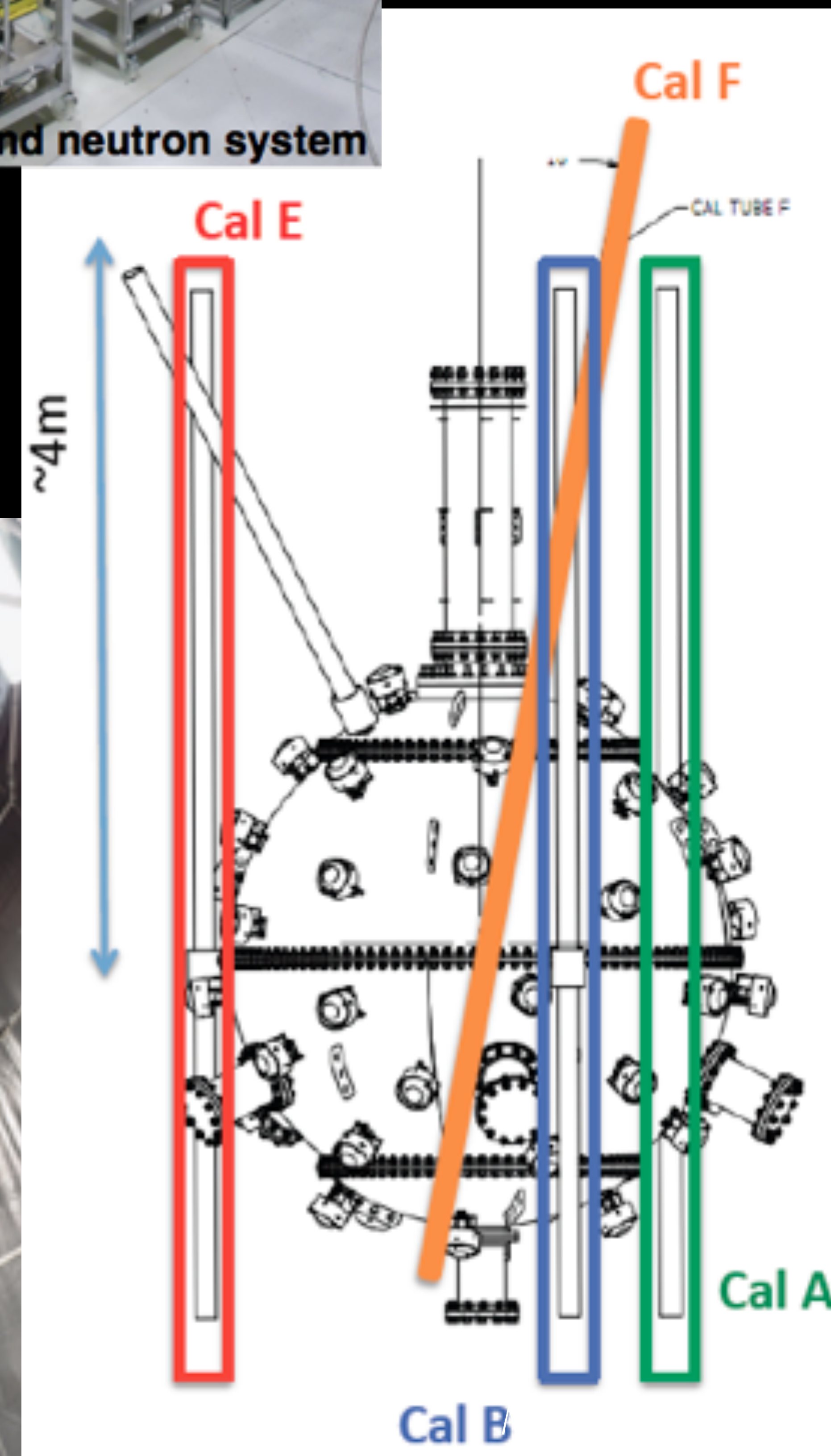
0. Optical Calibration Systems:
- in-situ array of reflectors, fed by LEDs via fibers, fixed in position in 20 light guides + 2 at neck
- movable, multi-wavelength laser-diffuser flask

1. Radioactive Source Calibrations:
- tagged Na-22 source Cal A,B,E pipes, Cal F racetrack
- tagged AmBe source in vertical pipes
- hot Th-232 source at neck, in vertical pipes
- Ar-39 in-situ

All have been deployed!



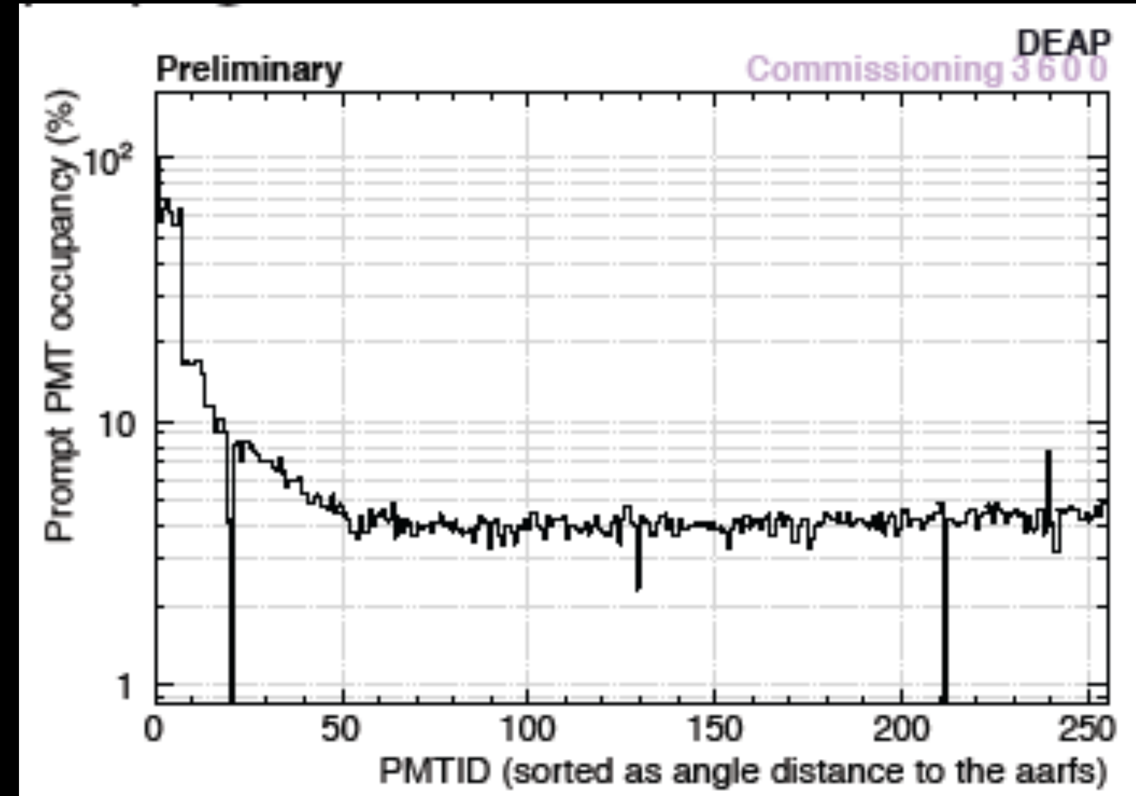


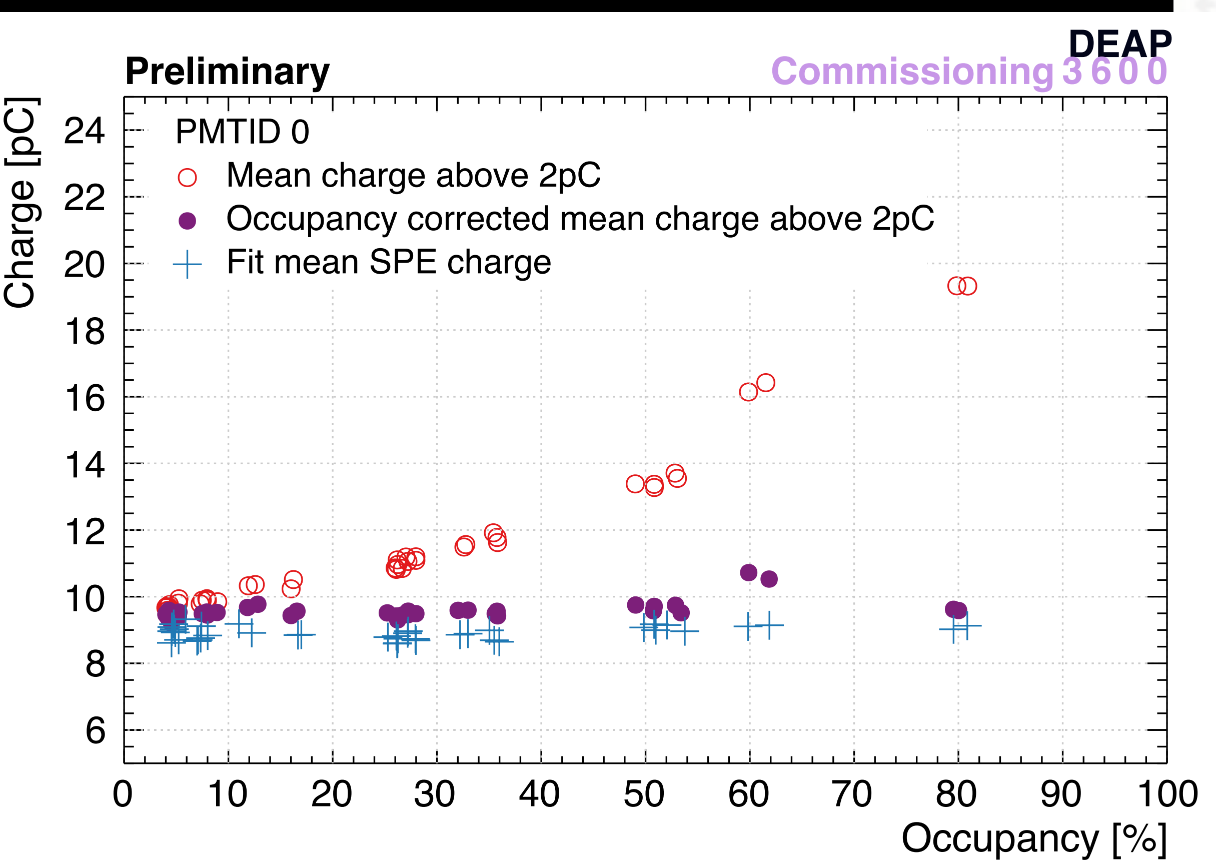


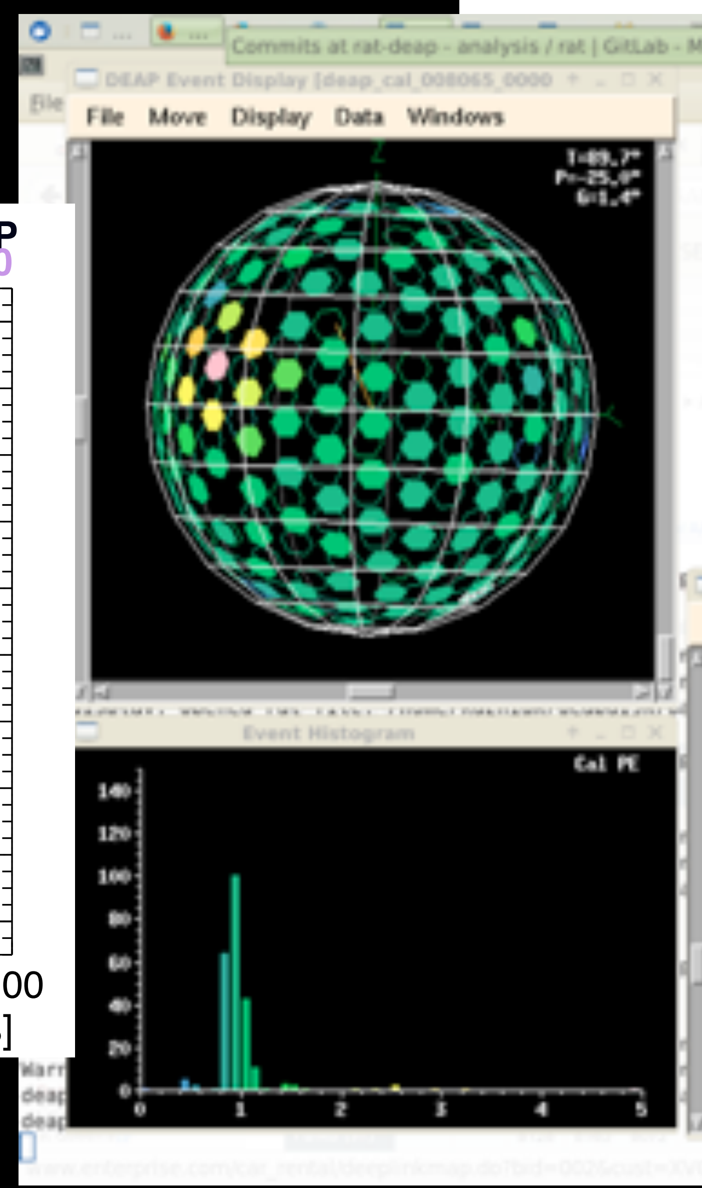
In-Situ PMT Commissioning

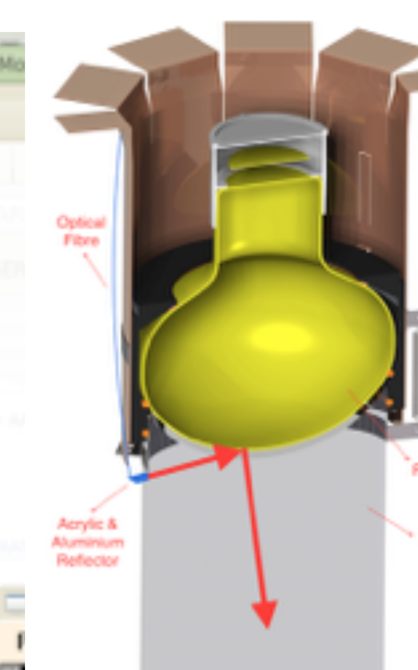
Acrylic Array of Reflectors fed by LEDs + Fibers:

- initial voltage scans to verify gain matching
- low- and high-occupancy calibrations
- detector stability monitoring
- trigger performance validation
- detector simulation optical model tuning
- trigger performance validation
- PMT afterpulsing measurement

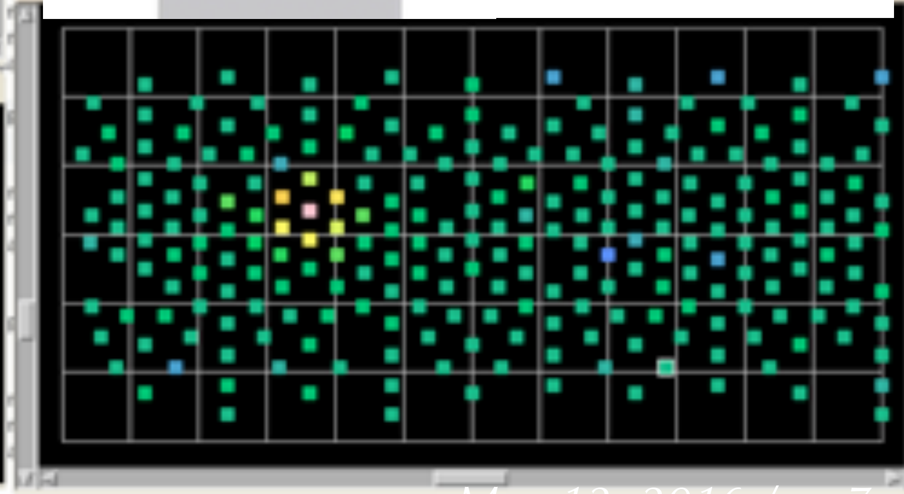






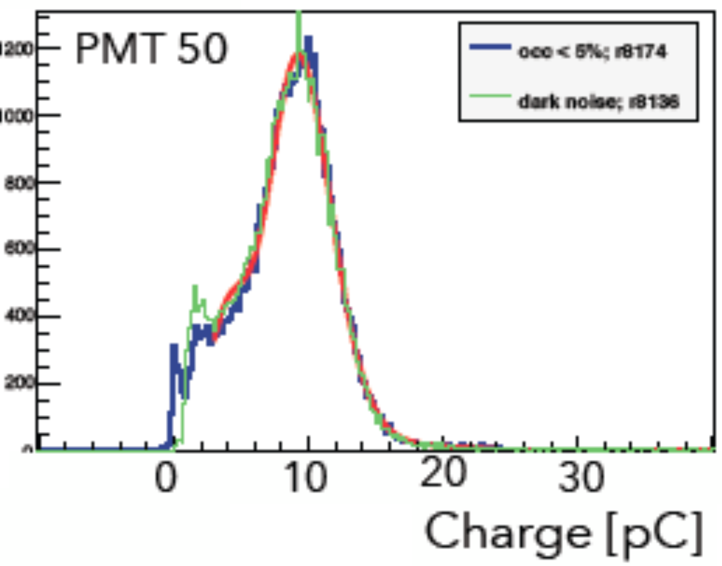


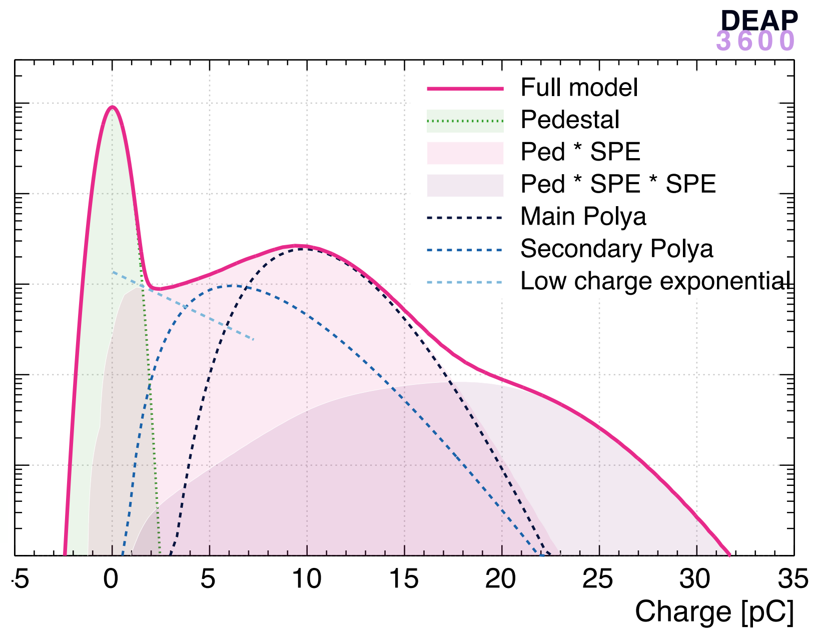
installed
AARF reflector
+ fiber sources

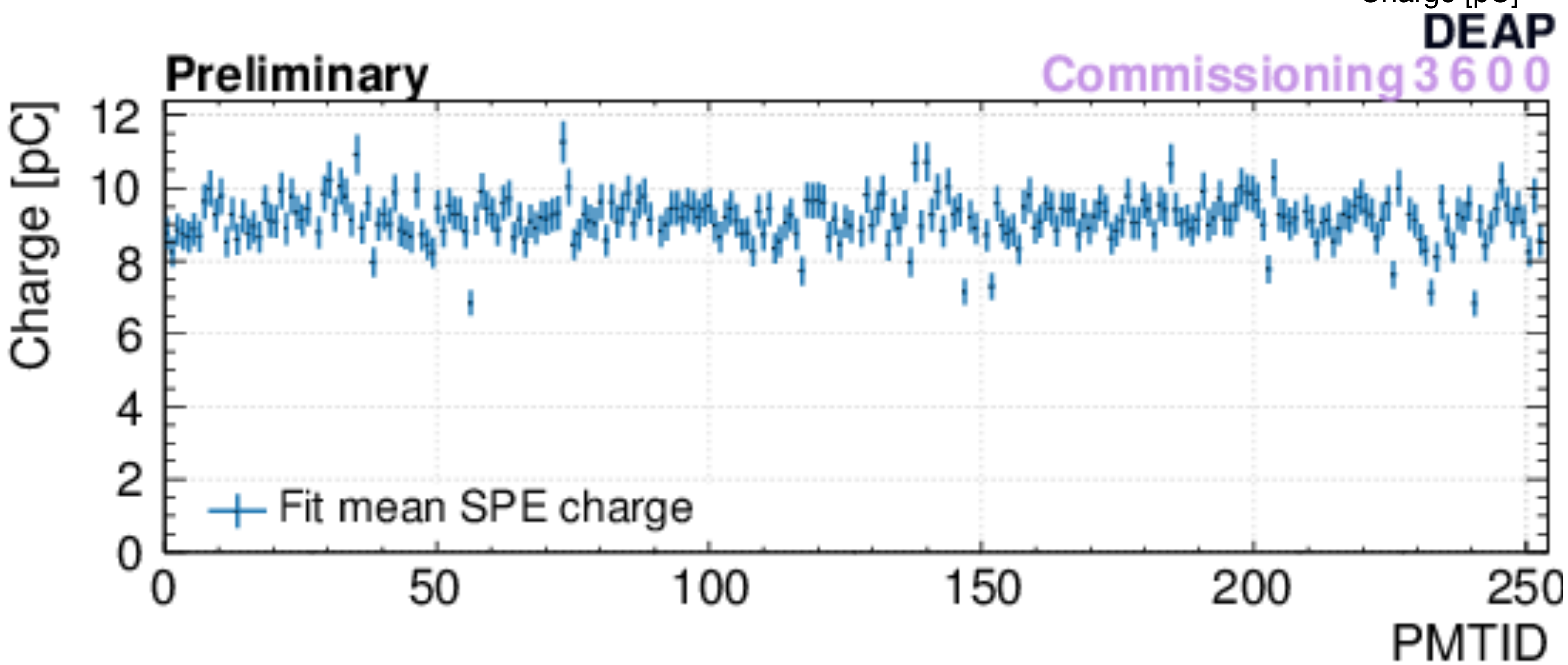


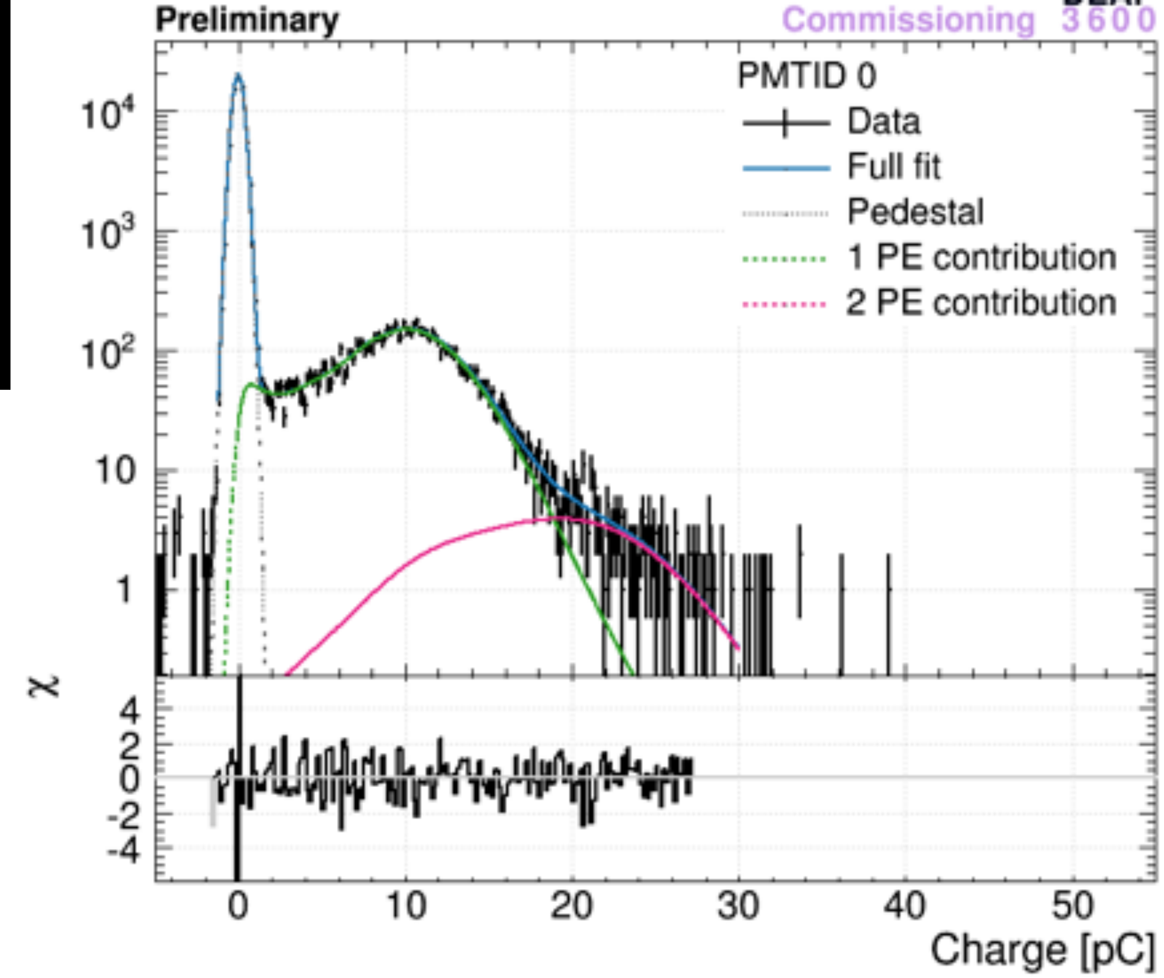
PMT Charge Calibration

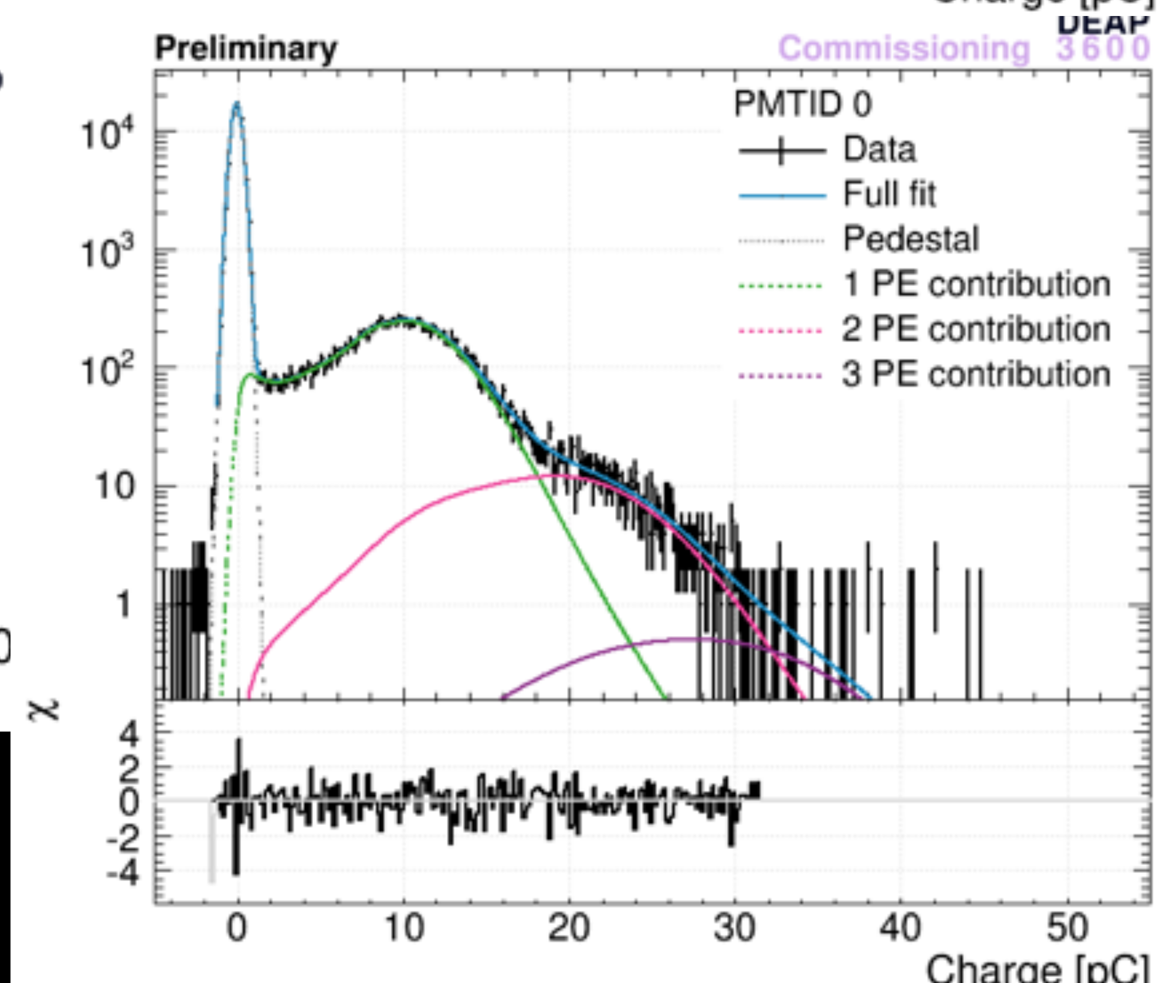
PMT charge calibration model fits calibration data and dark rate data well for low+high occupancy.









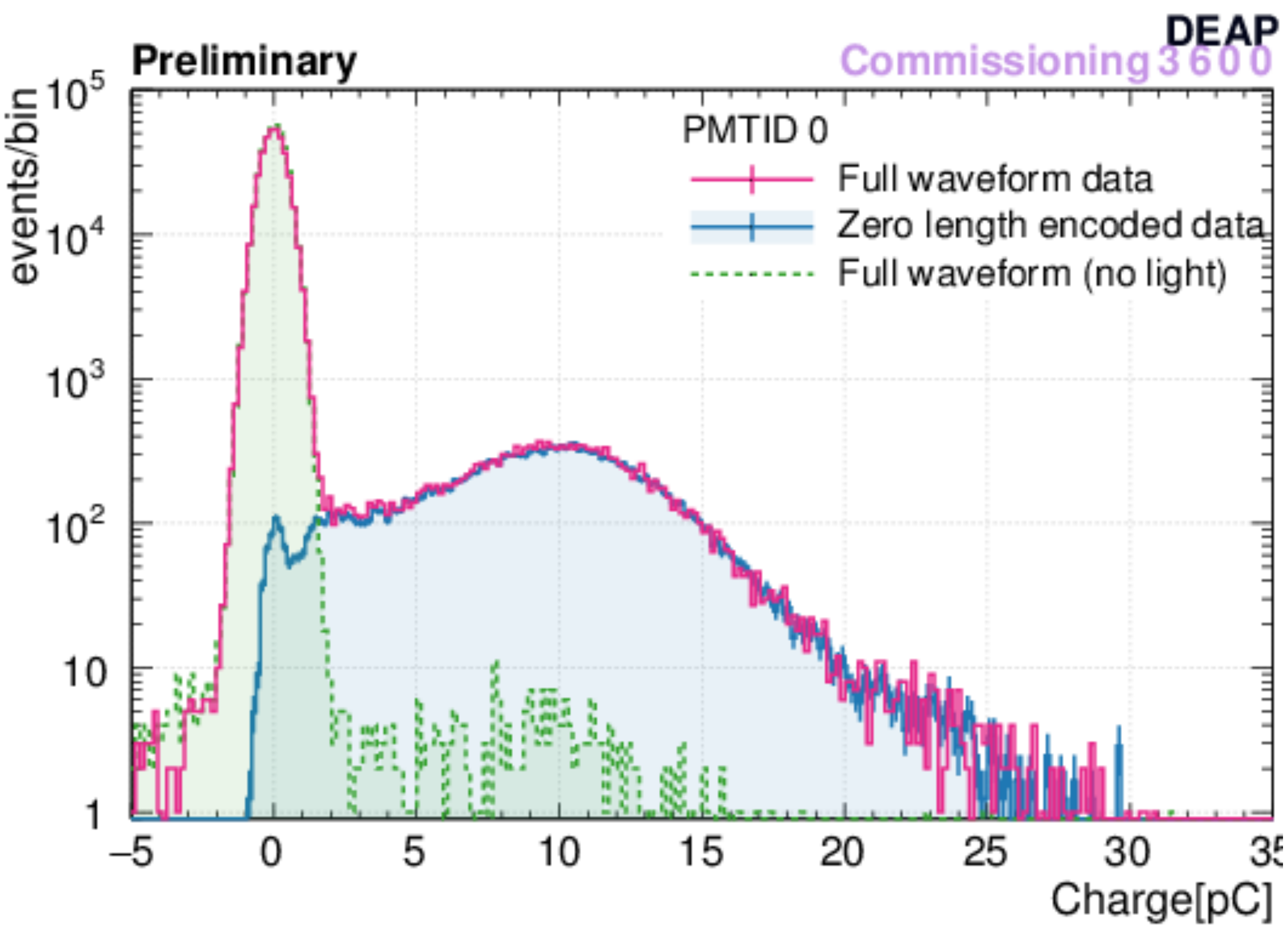


Gain uniformity better than 10% before PMT voltage adjustment for fine gain matching.

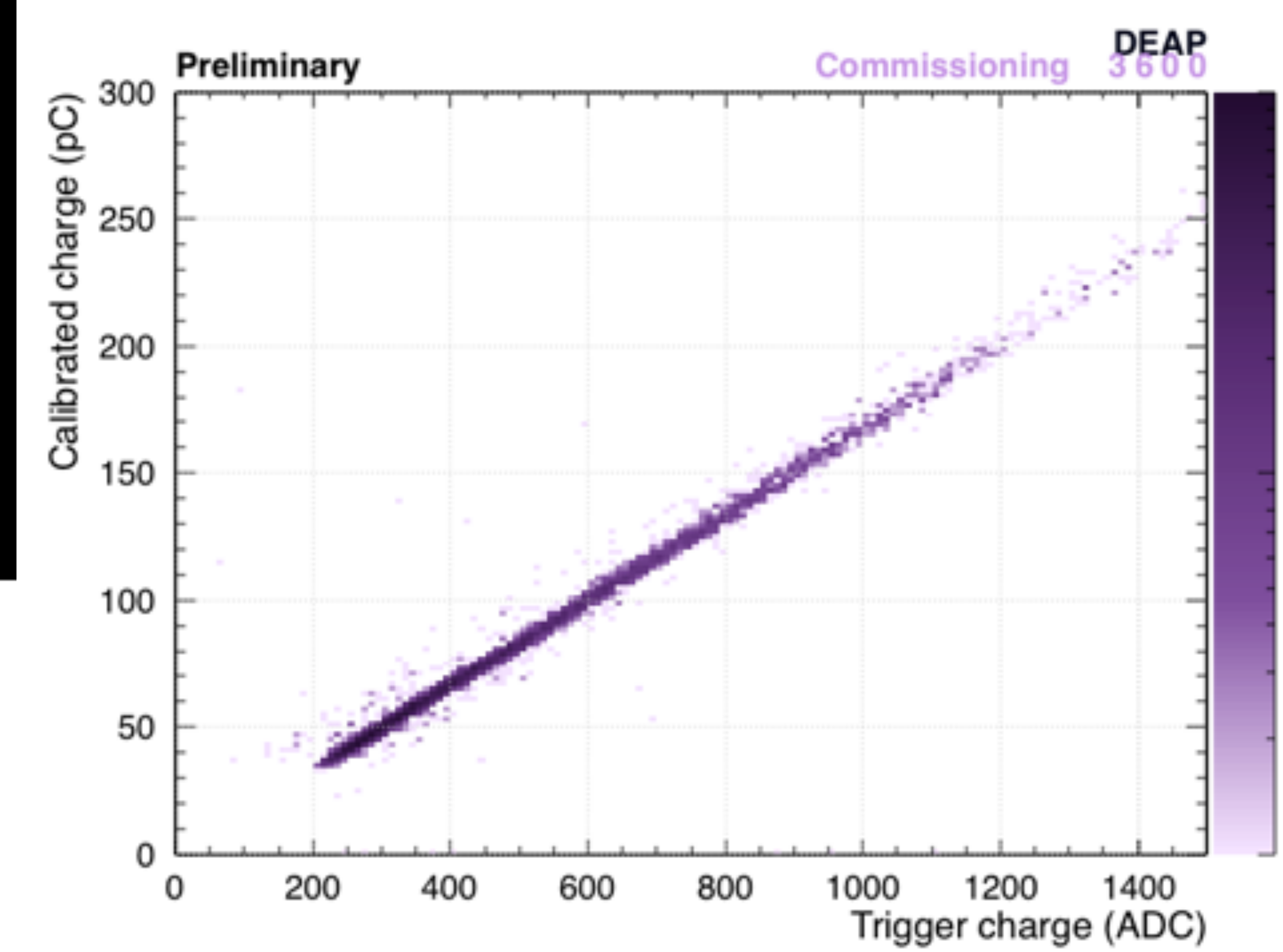
Trigger Commissioning

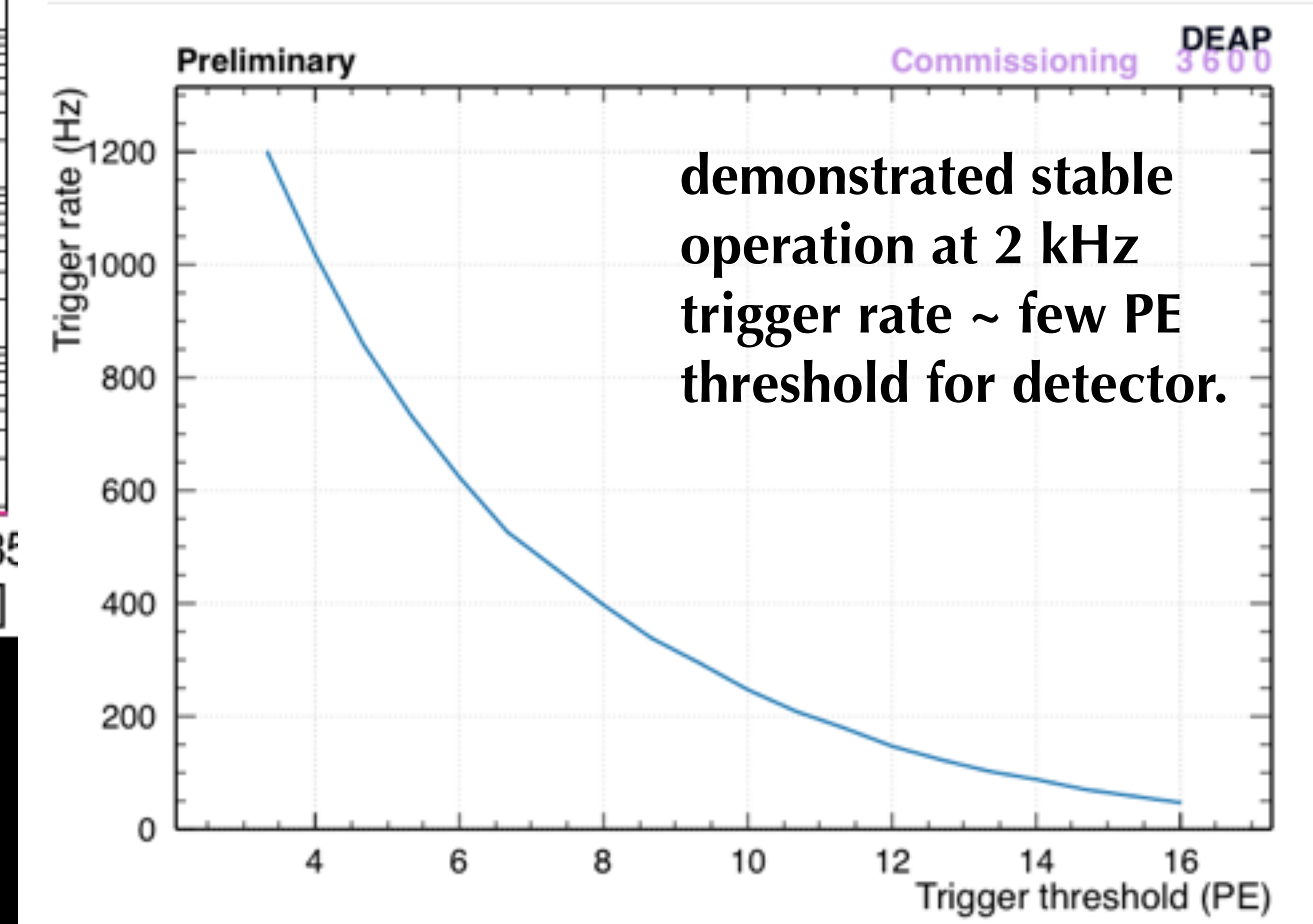
Physics trigger on analog sum of charges on groups of PMTs (ASUM) to make decision.

Data compression (ZLE) happens on-board the waveform digitizers.



AARF data used to verify SPE calibration with full vs. ZLE waveforms, and estimate trigger threshold in PE.

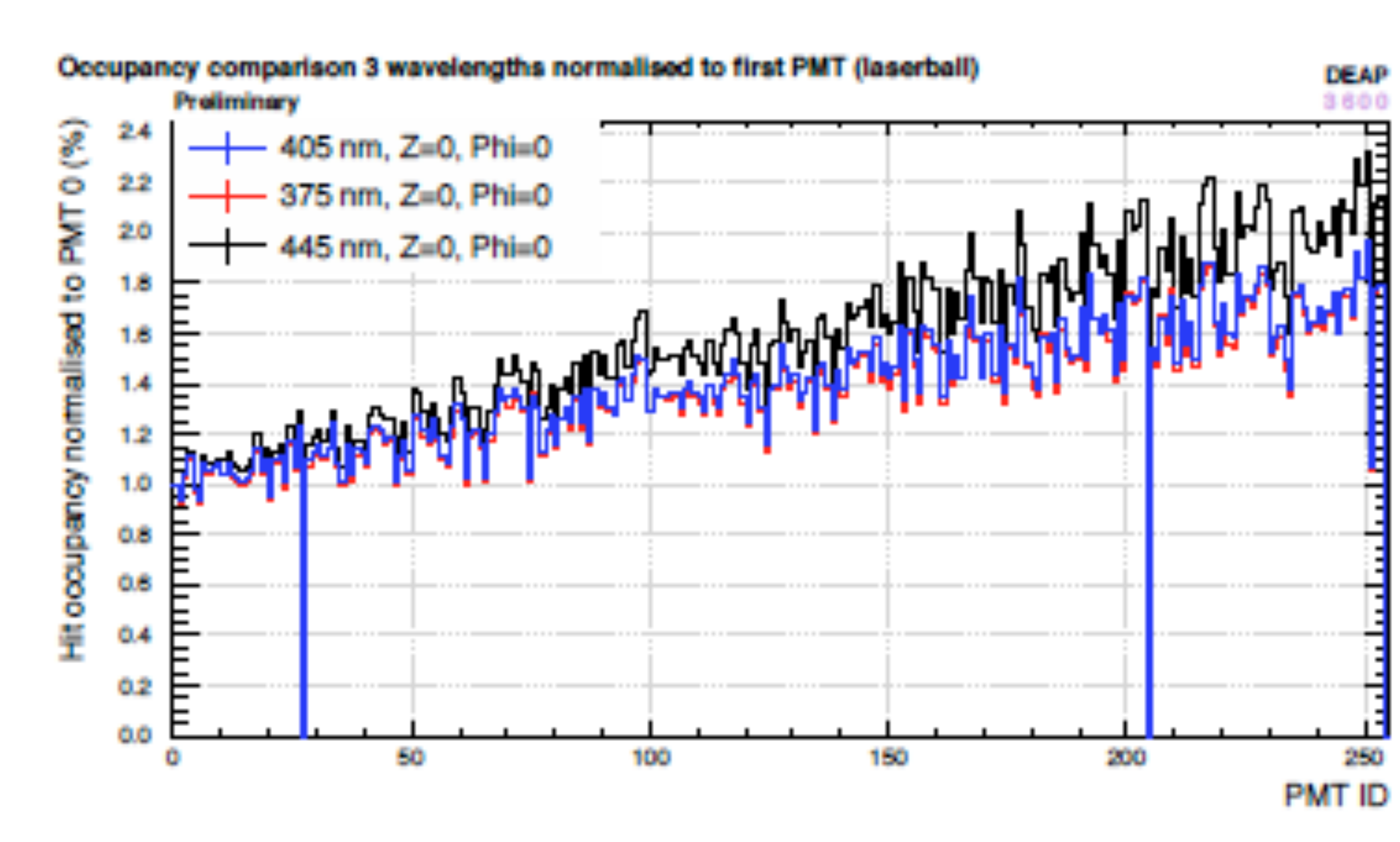


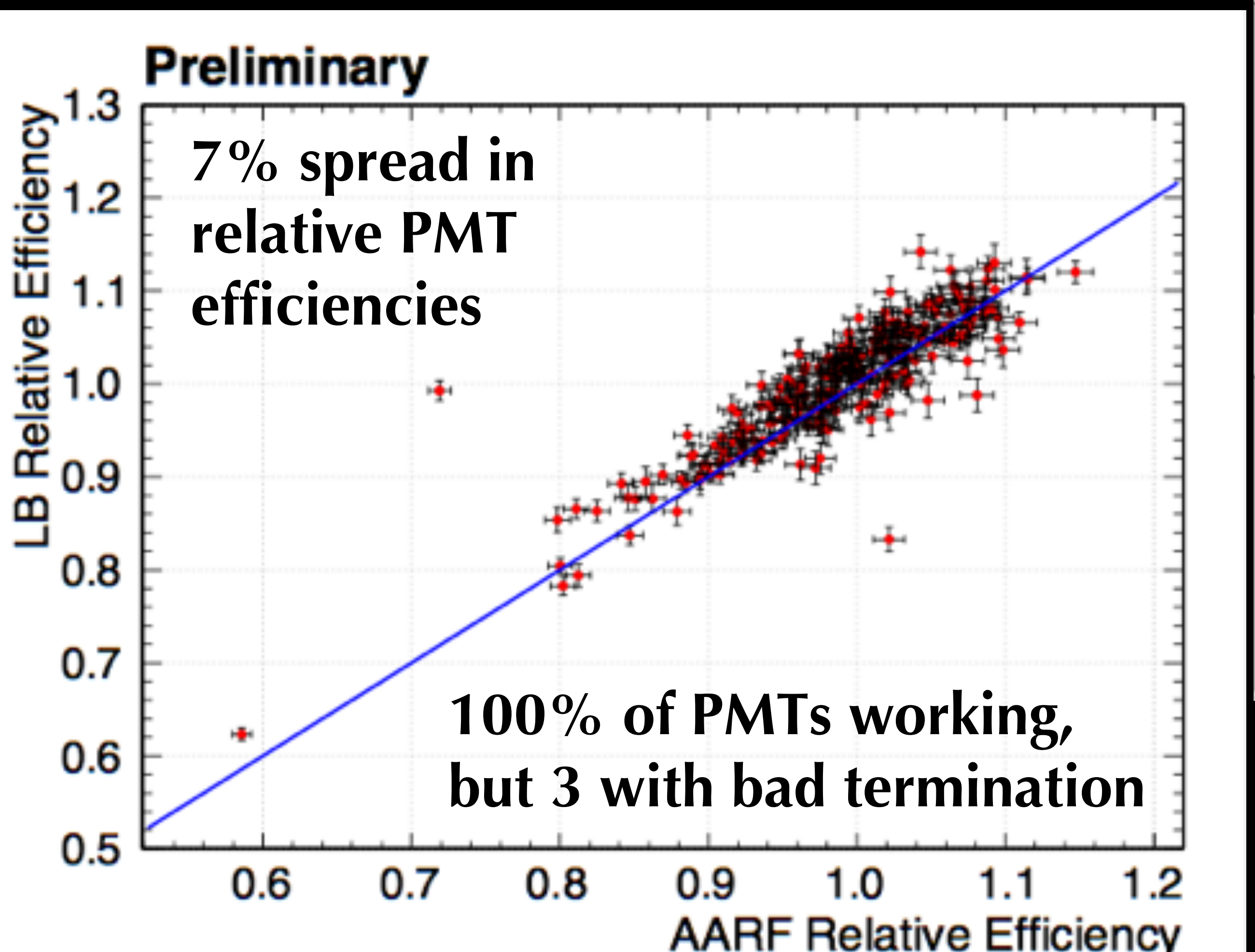


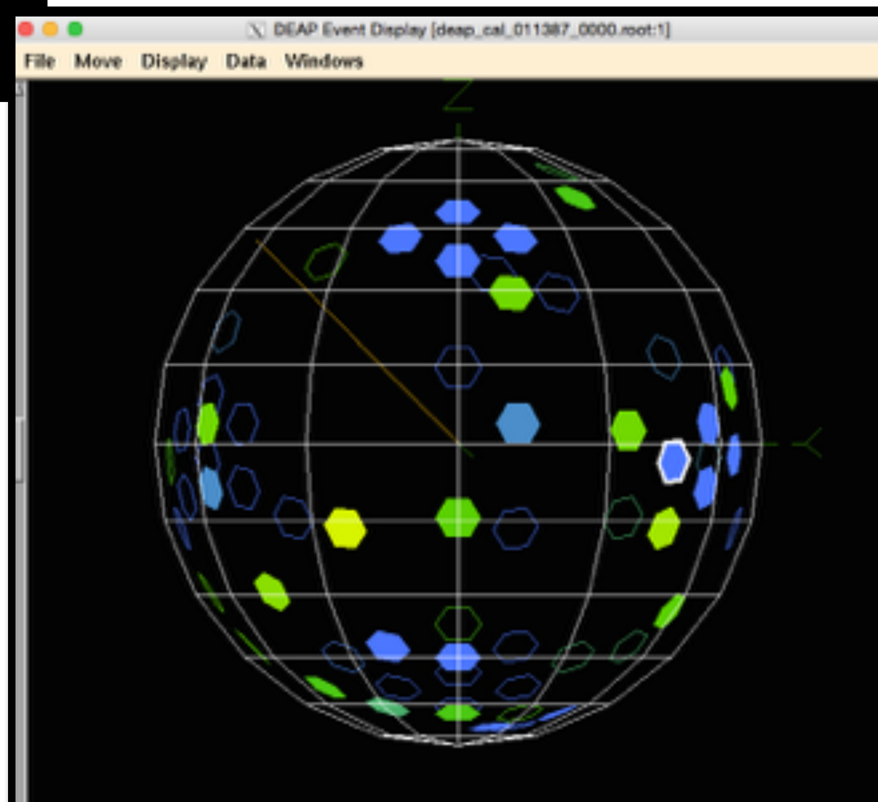
In-Situ Optics Commissioning

Multi-wavelength laser-fed diffuser flask deployed through glovebox into detector

- z = +55,0,-55 cm
- phi = 0,90,180,270
- wavelength = 375, 405, 455 nm
- measure PMT + light guide relative efficiencies, consistent with AARFs
- extract TPB uniformity for optical model







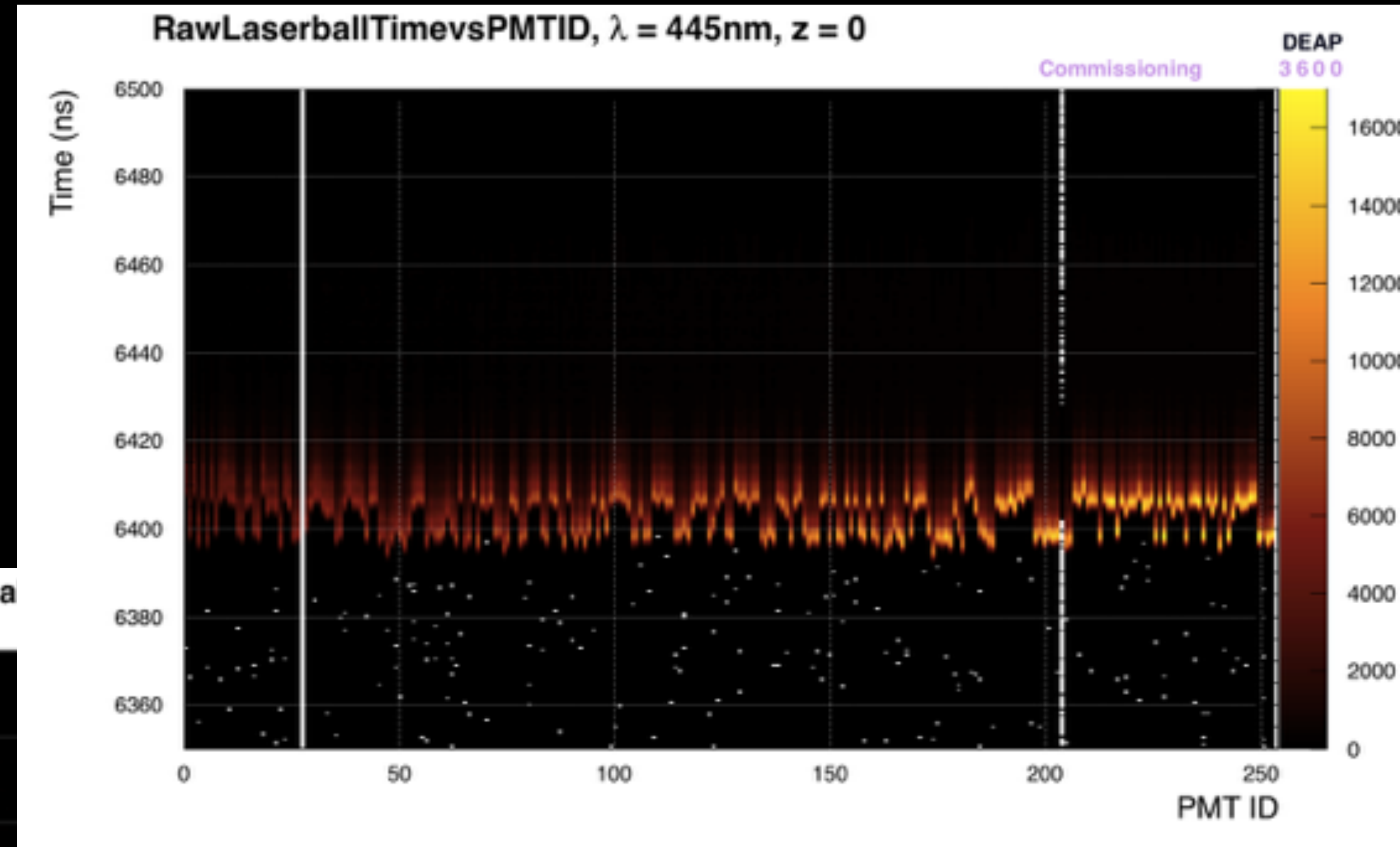
multi-wavelength laser source

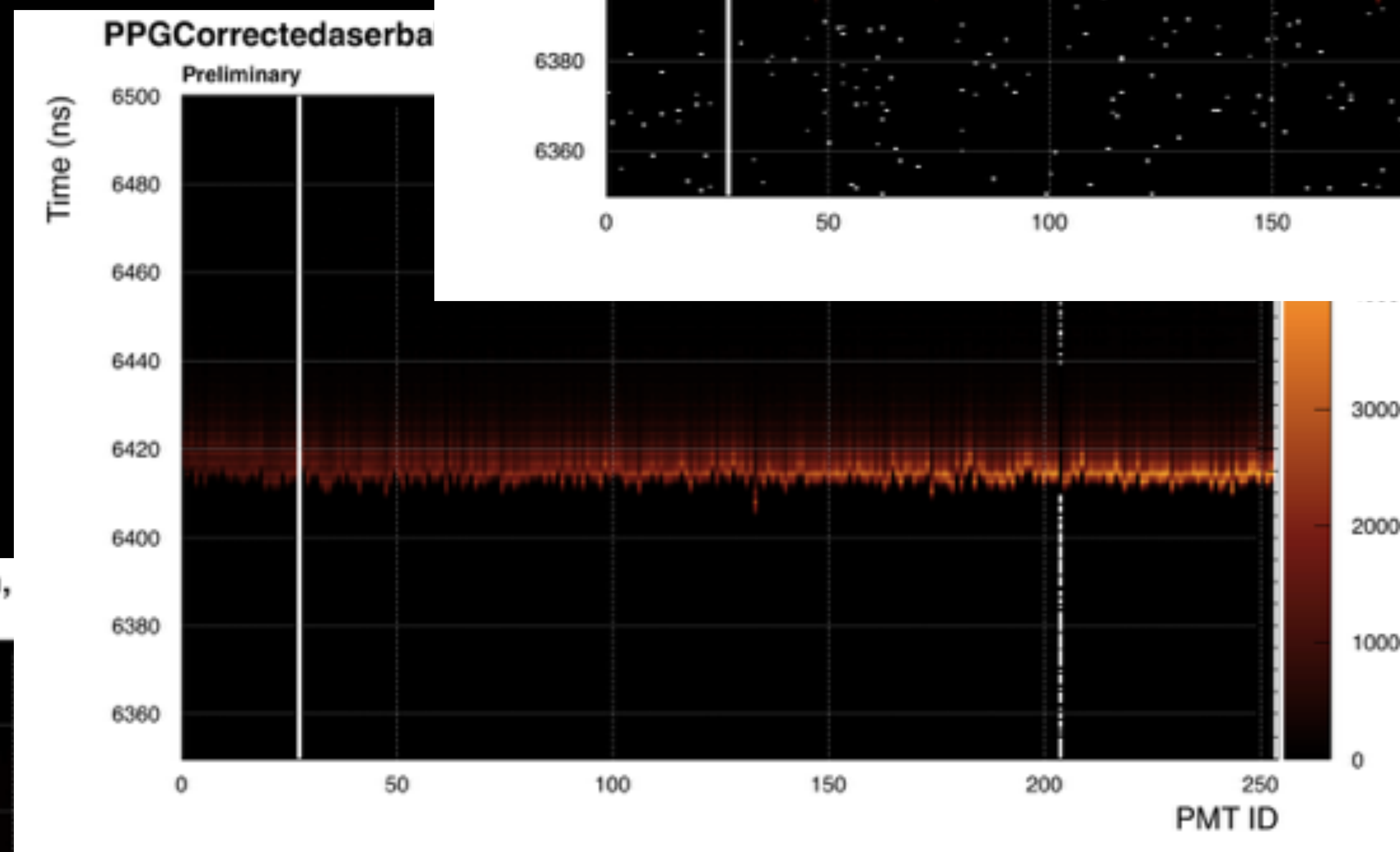
in-situ laser calibration campaigns in gas-filled detector in July, Aug. 2015

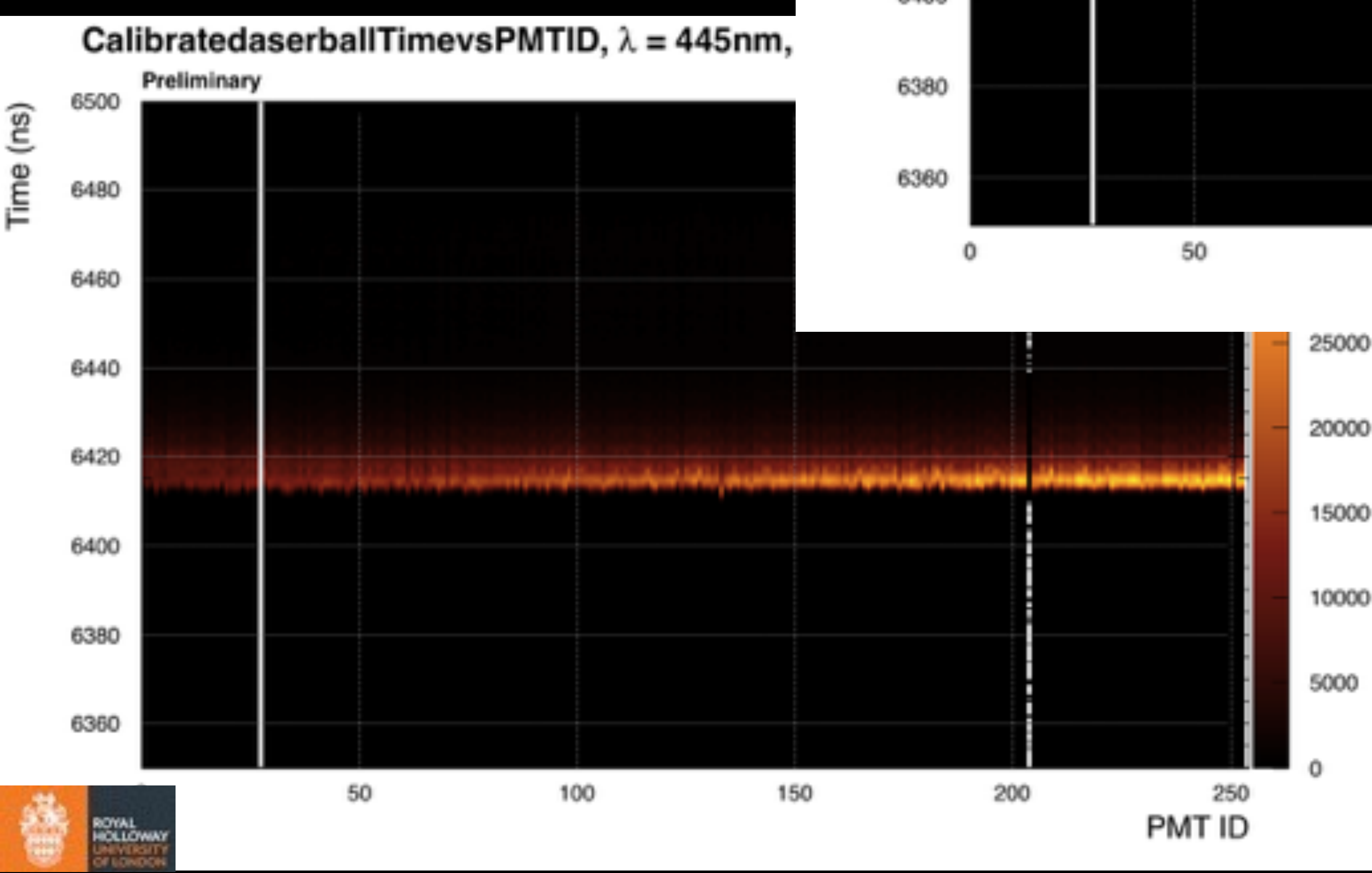
PMT Time Calibration

PMT signal digitization at 250 MHz. Raw signal has up to 32 ns offset from trigger, cable lengths, board-to-board timing, etc.

Electronics pulse pattern generator (PPG) signal injection for channel-to-channel timing correction:







laserball timing calibration used to measure timing offsets for each channel and correct.

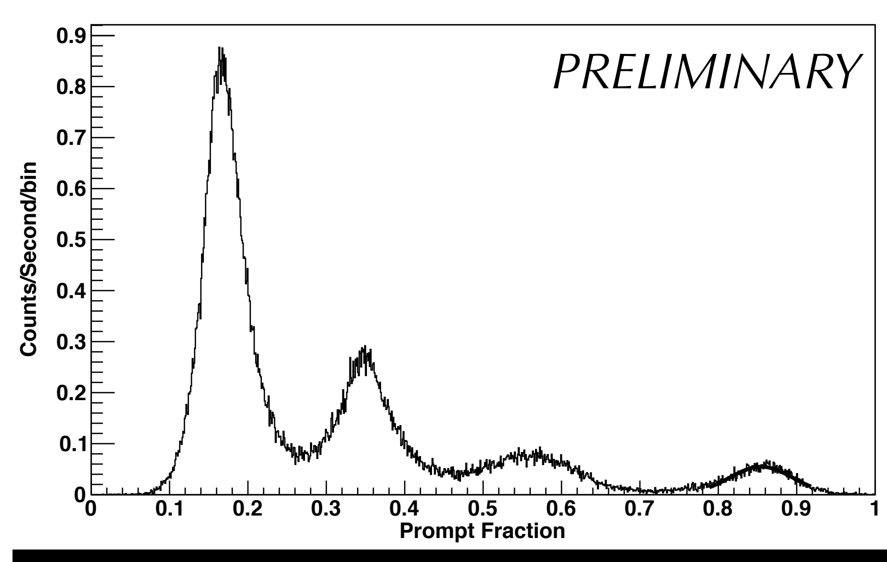
Resulting PMT peak time spread: ~1 ns RMS

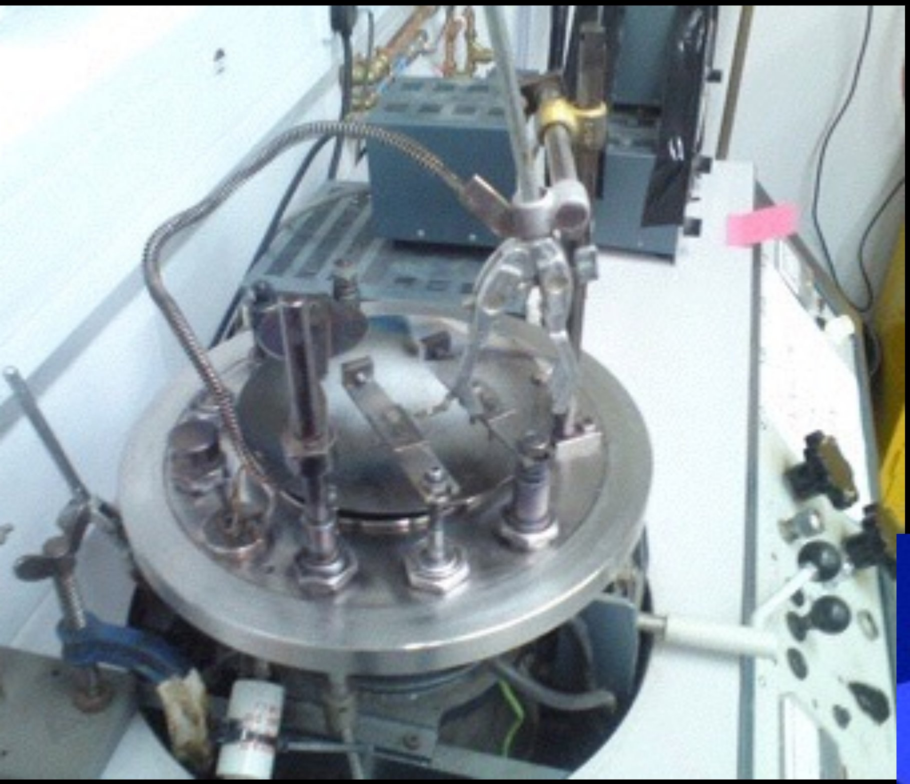
Calibration R&D Ex-Situ

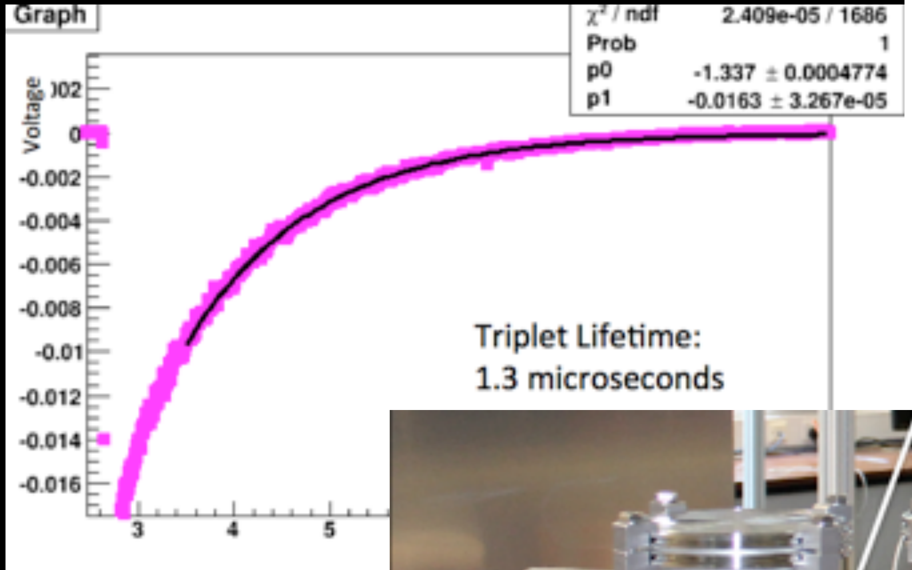
What if we see 5 events? How would we know if its a signal?

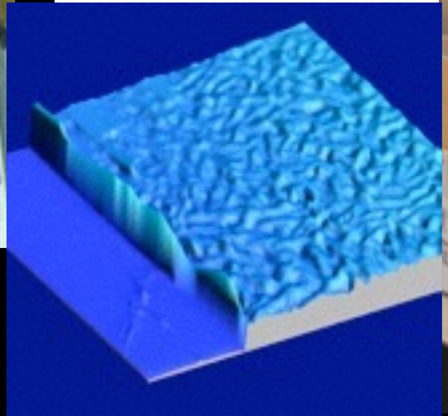
•ex-situ measurement input to calibration analysis,
  (i) reduce systematics on energy, radius reconstruction,
  (ii) break correlations between parameters for MC tuning

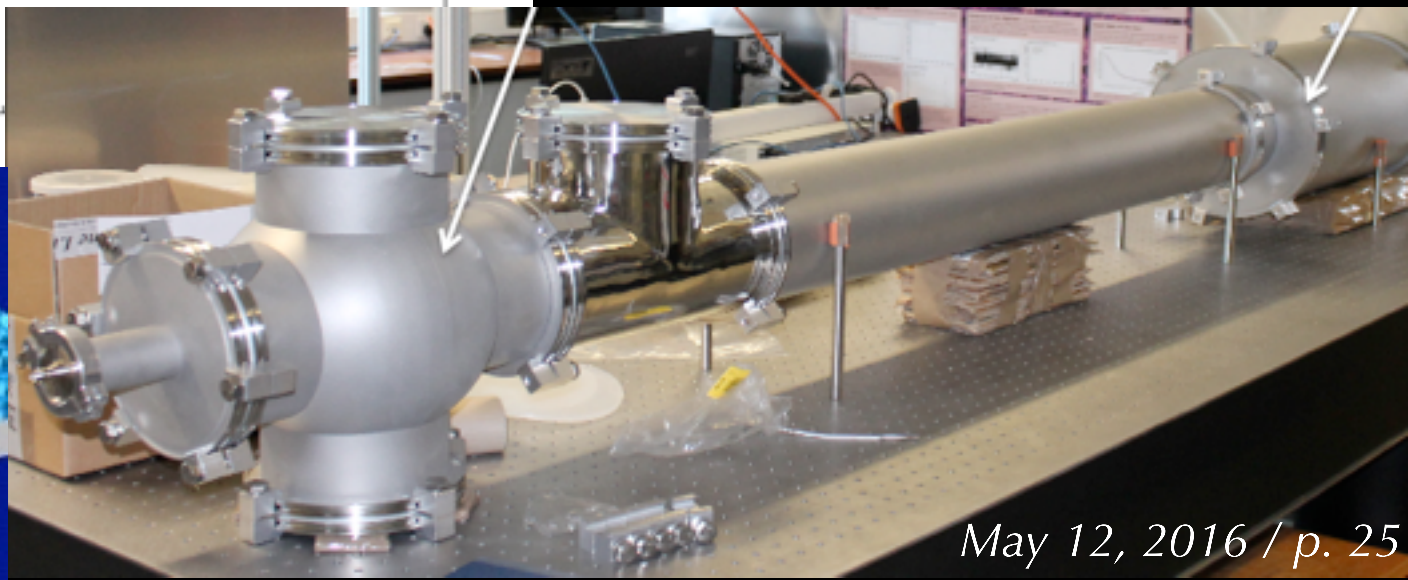
-measure angular distribution of TPB emission
-measure TPB scattering length
-measure the Rayleigh scattering length in LAr
  (new calculation: *Grace et al, arXiv:1502.04213*)
-measure the scintillation time constant temperature dependence









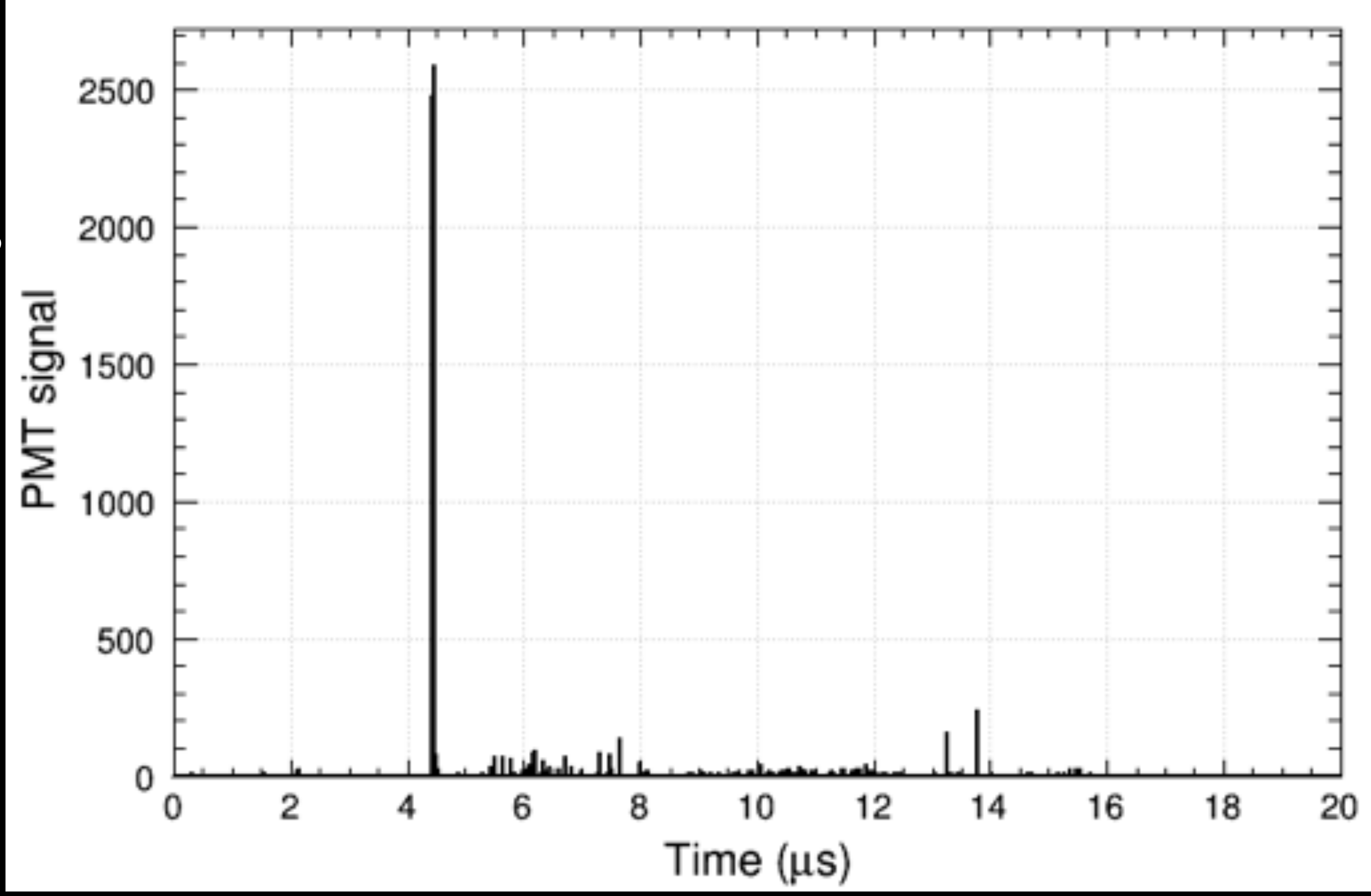


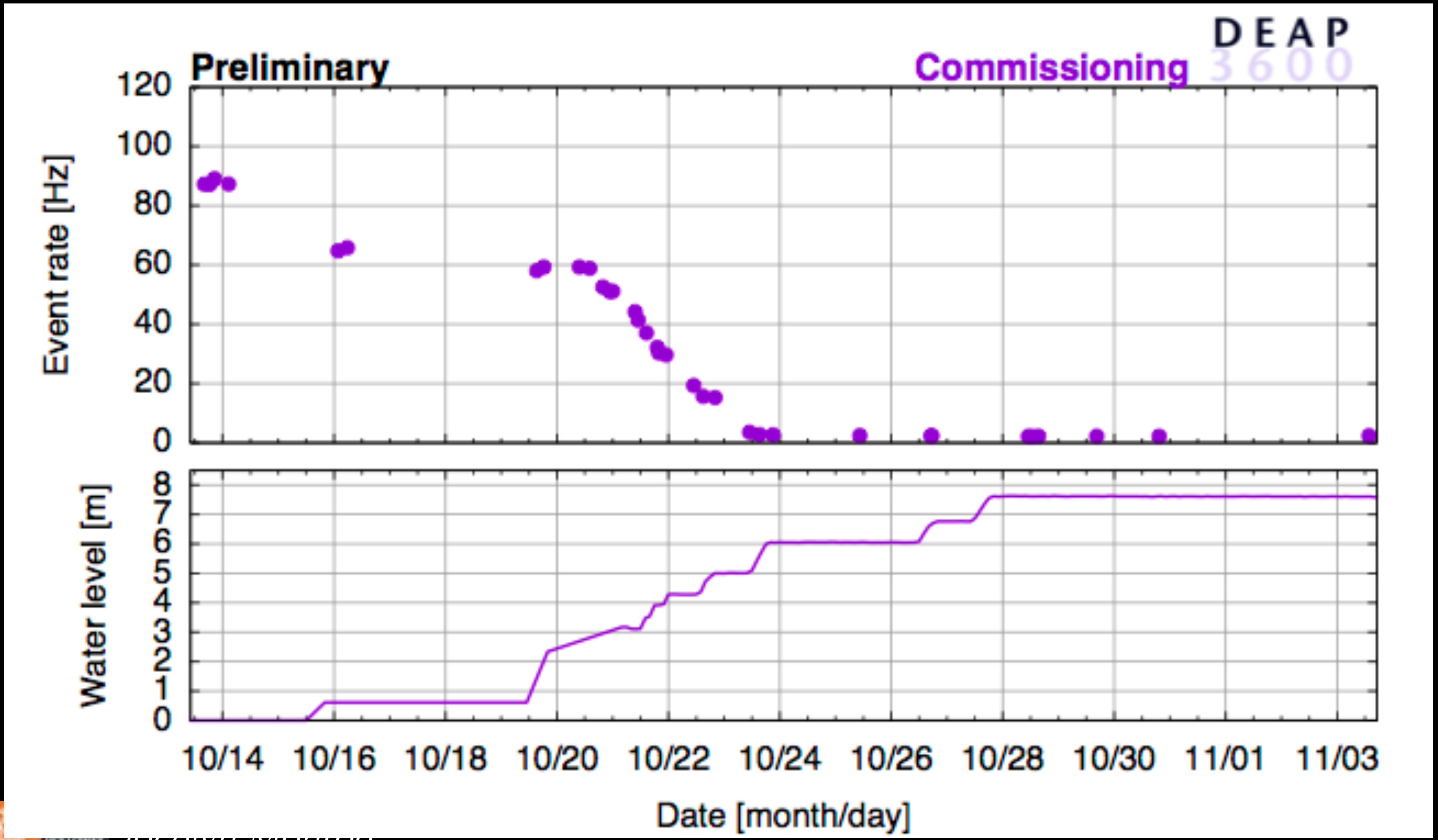
Water Veto

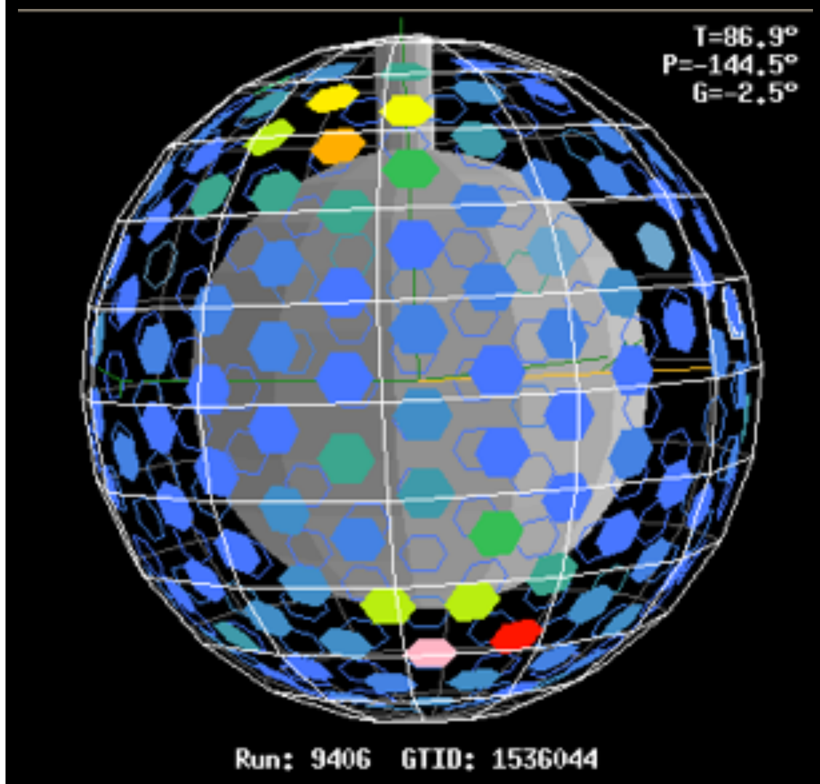
Before water fill, event rate in detector PMTs dominated by Cherenkov from gammas
• after water fill, rate drops as expected

Expected muon rate ~1.6/day
• measure high energy event rate of ~1/day

example high energy event:



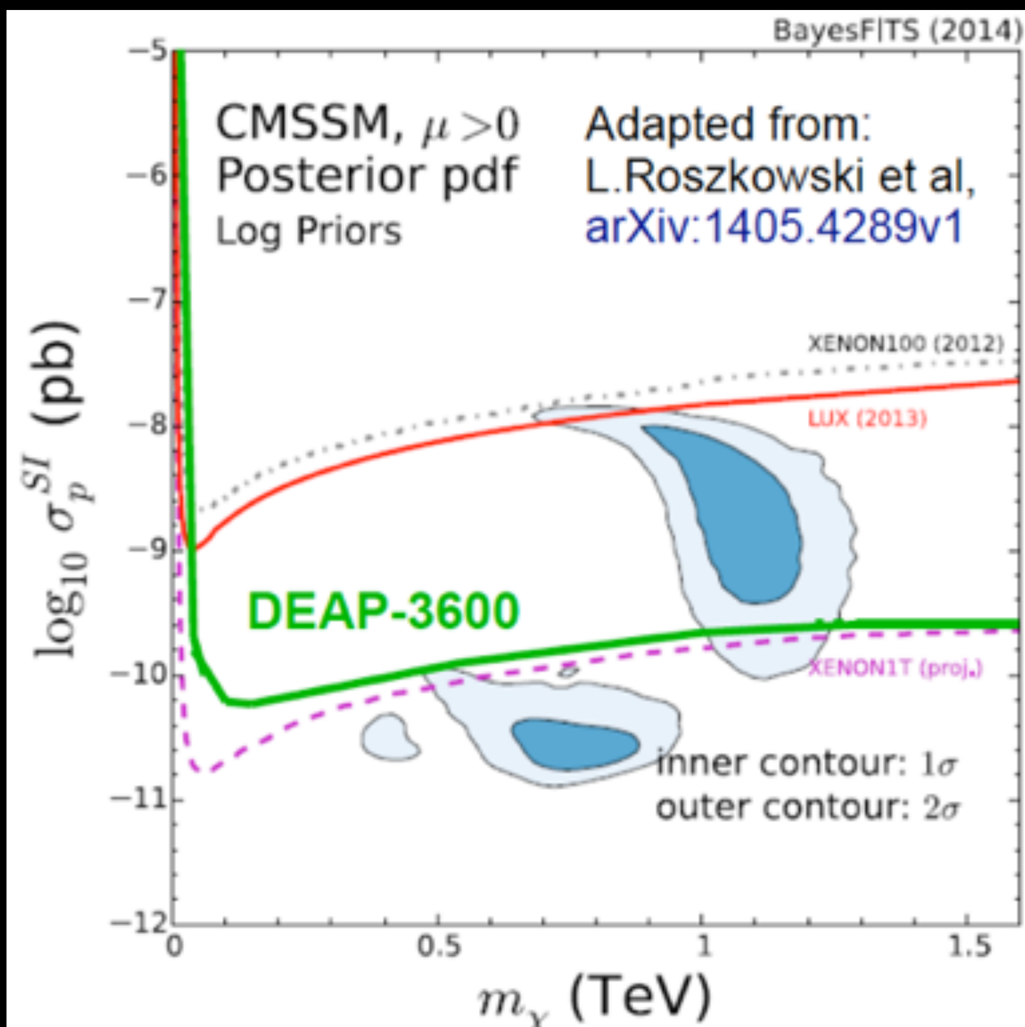




Summary & Outlook

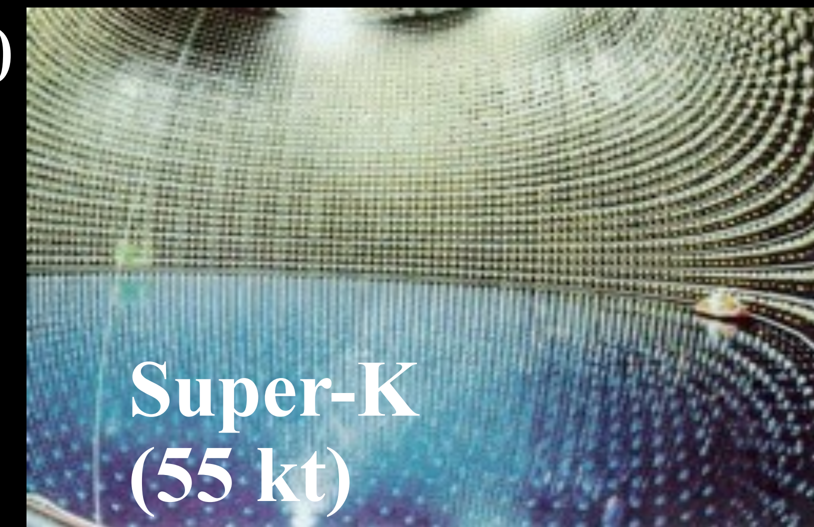
DEAP3600 will be the 1st demonstration of single-phase liquid Argon technology.

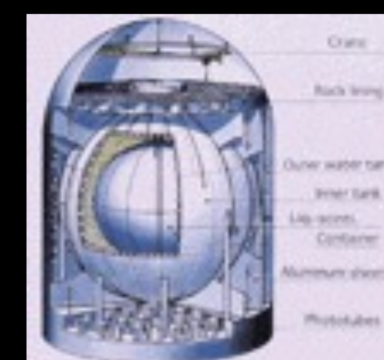
- discovery reach of 10^{-46} cm^2 in 3 T-yrs exposure,
- LAr filling now…. *Stay tuned!*



- prototype for kT-scale, O(10s) keV threshold detector for 'low-energy frontier' physics

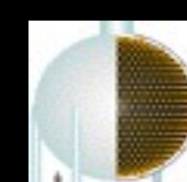
σ(cm^2)	detector mass (ktonnes)
10^{-46}	100
10^{-45}	30
10^{-44}	10
10^{-43}	3
	1
10^{-42}	
10^{-39}	0.1





Kamland (3 kt)

SNO (1 kt)

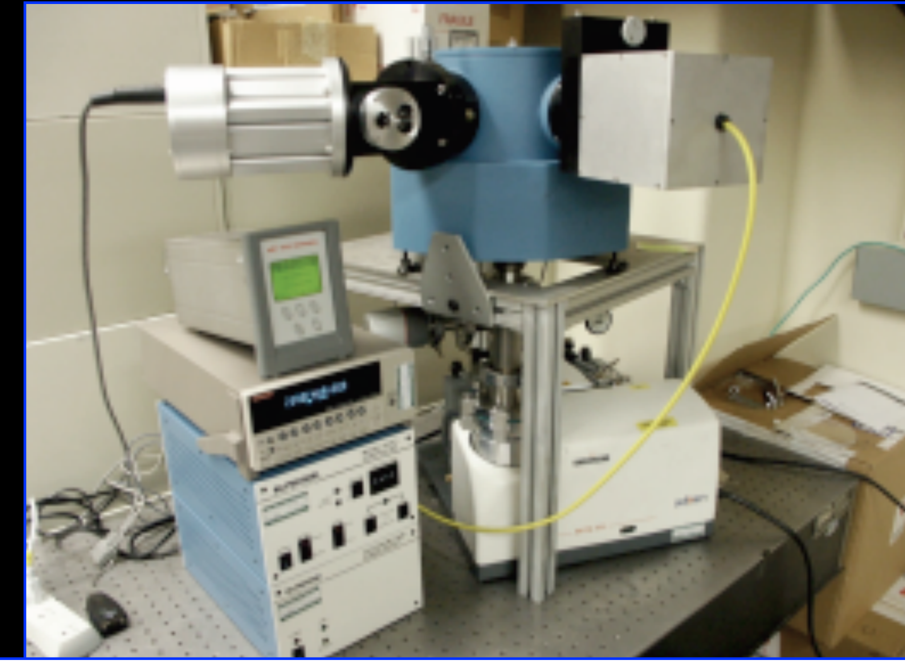


MiniBooNE (0.8 kt)

Neutrino lesson: key to large, low-rate sensitive detectors is simple, open-volume design.

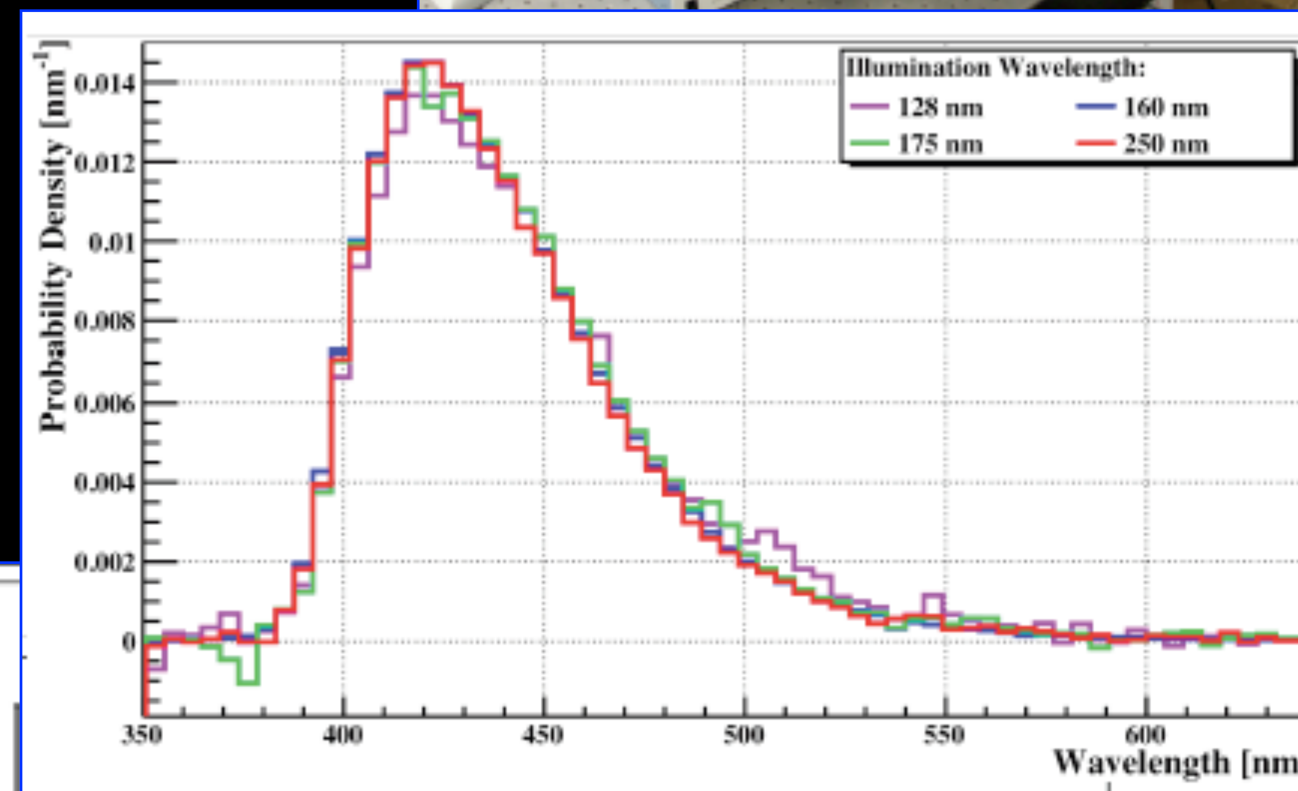
Other Slides

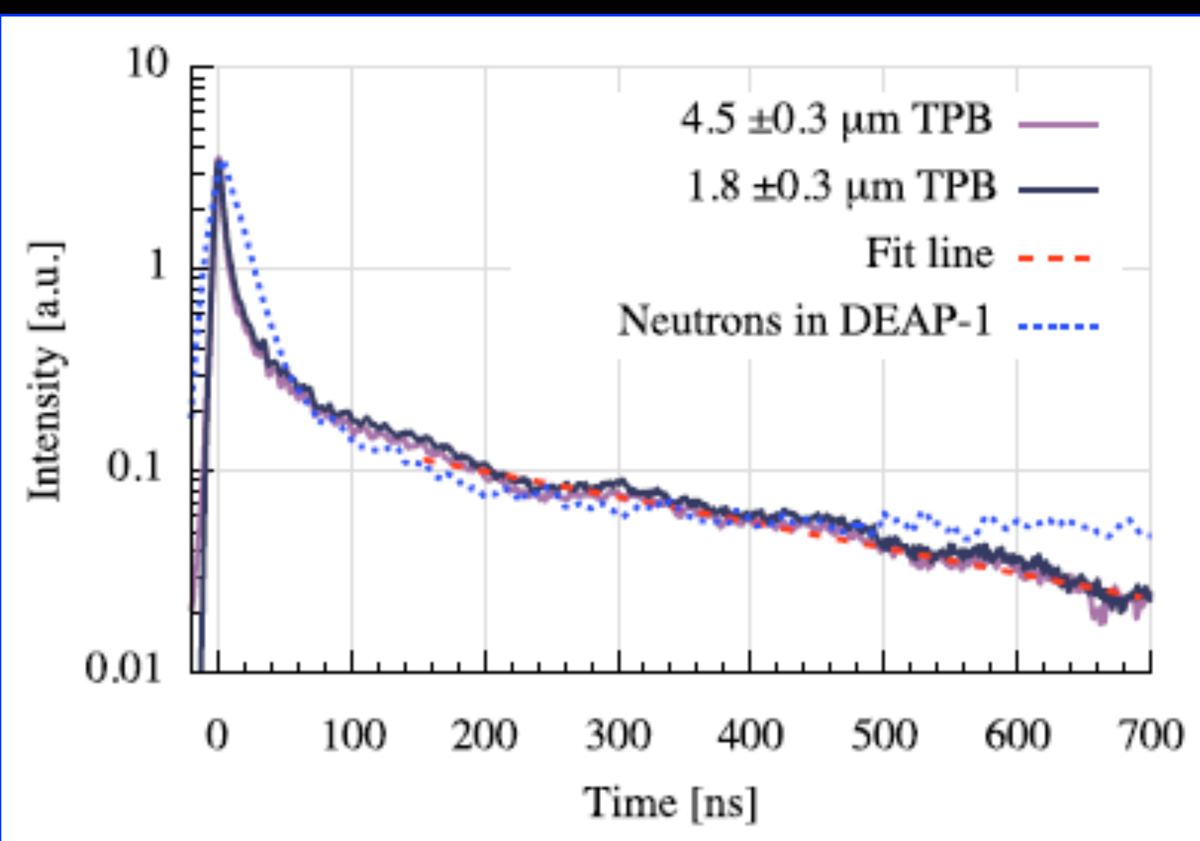
Alpha Scintillation in TPB

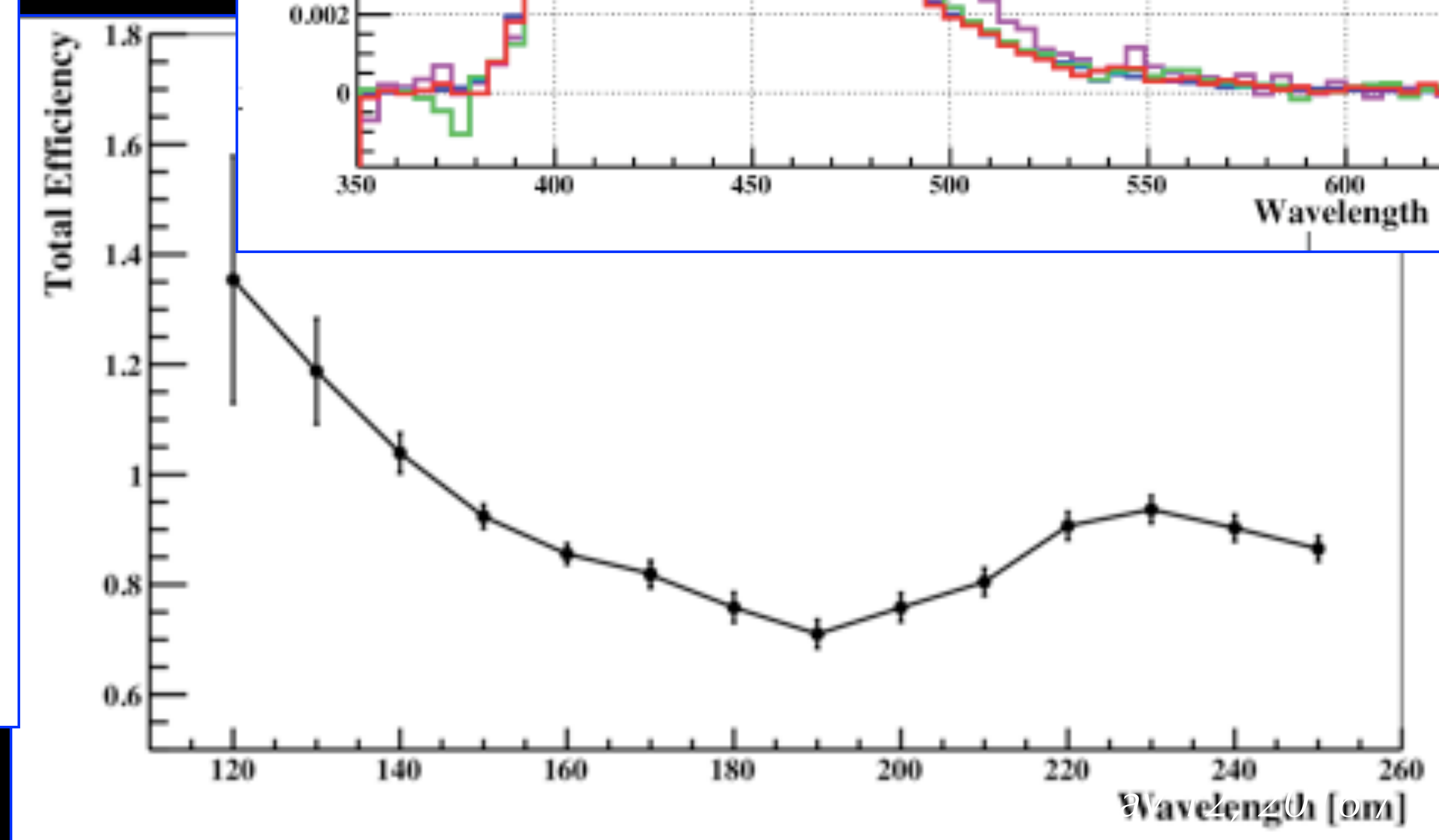


TPB wavelength-shifts from 128 nm to visible (fluorescence)
ex-situ test benches for spectrum, efficiency, angular dist.
V. M. Gehman et al., NIM A 654 1 (2011) 116-121

Alpha scintillation in TPB has rejection power, ex-situ test stand finds 11±5 and 275±10 ns fast and slow time constants, and fast:total intensity ratio of 0.67±0.03
(cf. 7 ns and 1600 ns, and 0.75)
T. Pollmann et al., NIM A 635 1 (2011) 127-130

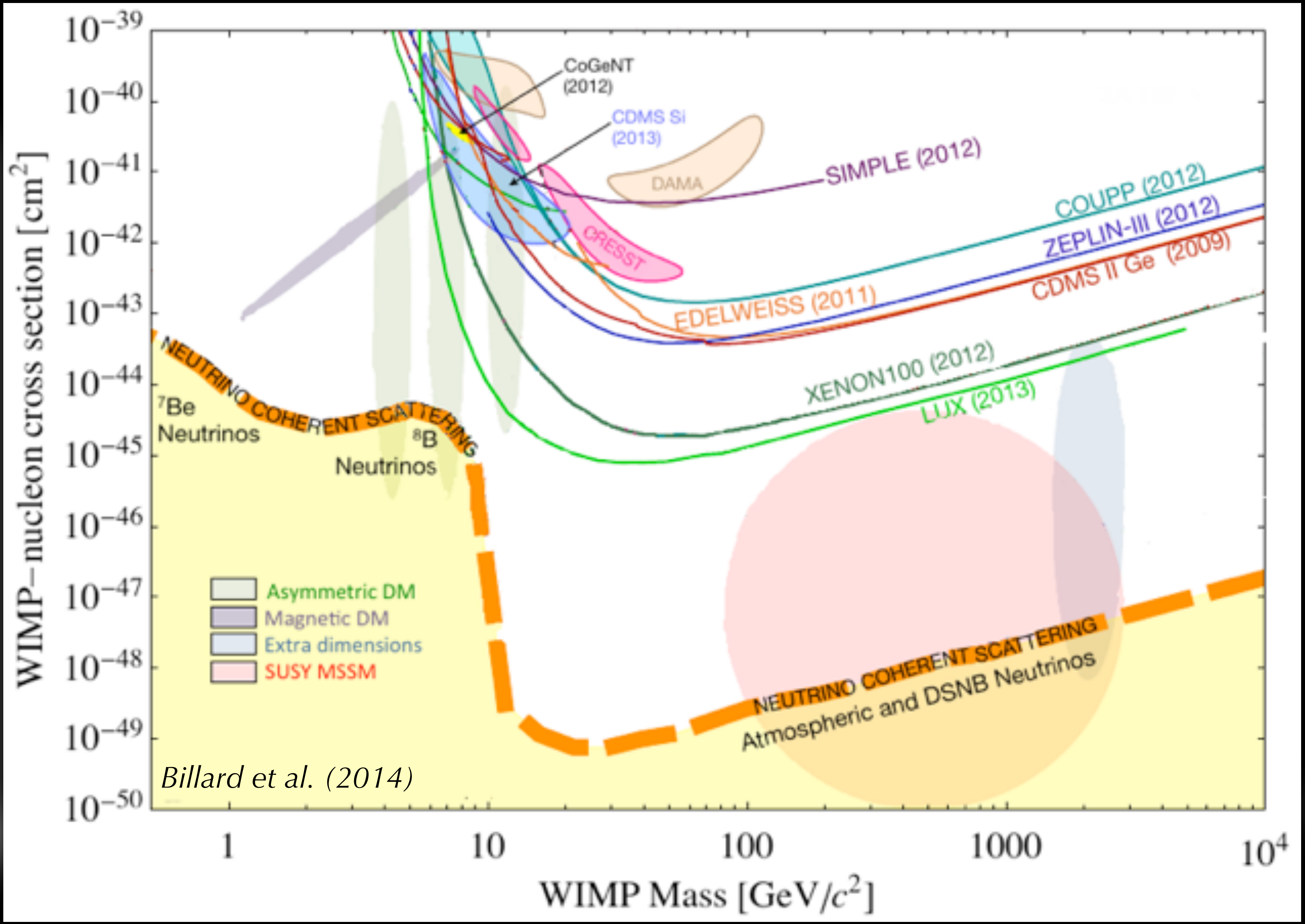






The Low-Background Frontier: Status and Prospects

Scalability of Detector Technology



New Techniques for Backgrounds

1 event/ kg/day

1 event/ 100kg/day

1 event/ 100 kg/ 100 days

Complementary with High-Energy Frontier