Dark matter search at SNOLAB with DEAP-3600

Marcin Kuźniak for DEAP-3600

Queen's University

Neutrinos & Dark Matter 2009
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DEAP & CLEAN collaborators

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Carleton University: **K. Graham**, K. Boudjelmine
Harvard: **J. Doyle**
Los Alamos National Laboratory: C. Alexander, S.R. Elliott, V. Gehman, V. Guiseppe, W. Louis, **A. Hime**, **K. Rielage**, S. Siebert, J.M. Wouters
MIT: **J. Monroe, J. Formaggio**
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NIST Boulder: **K. Coakley**
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SNOLAB: I. Lawson, K. McFarlane, P. Liimatainen
University of South Dakota: D.-M. Mei
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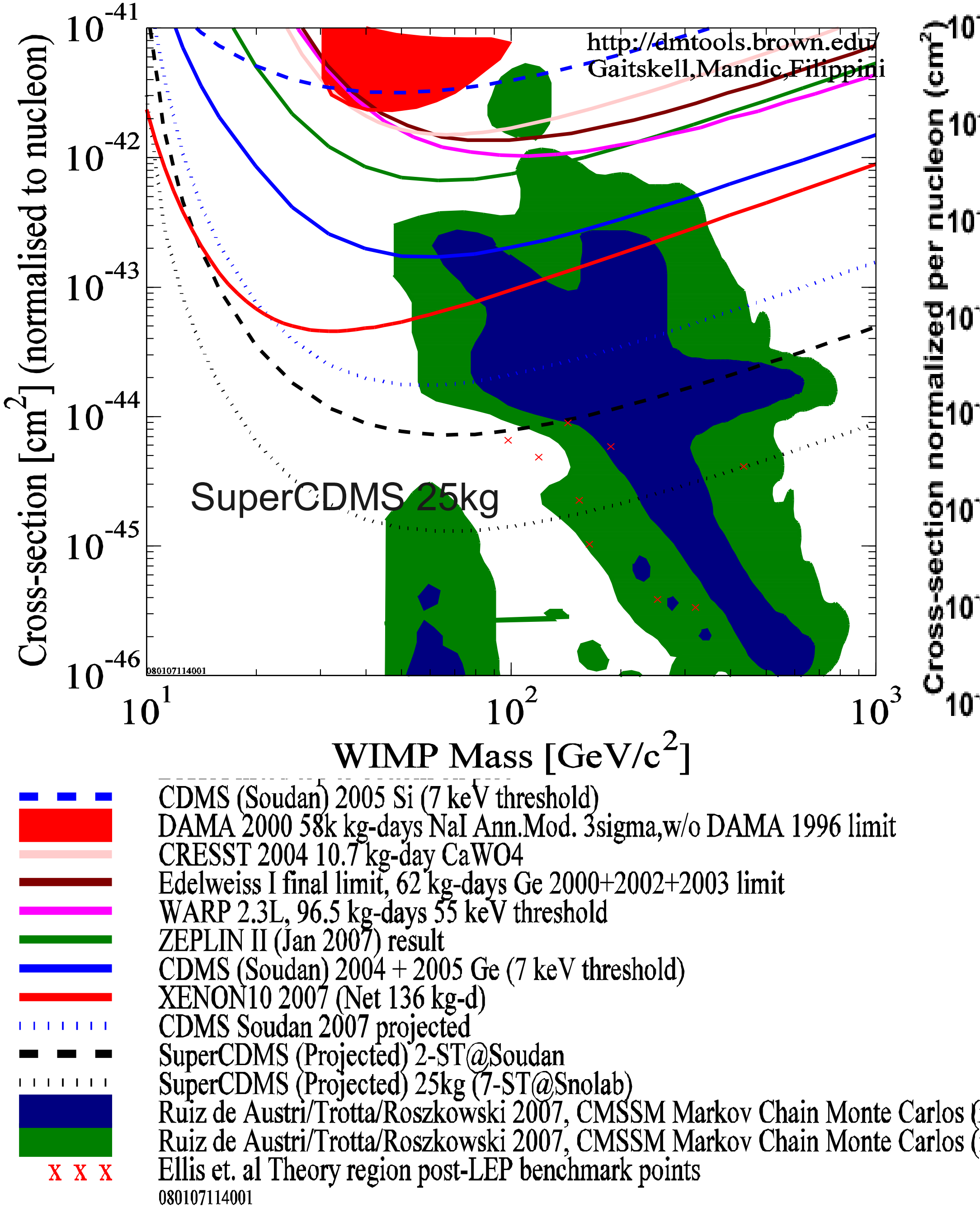
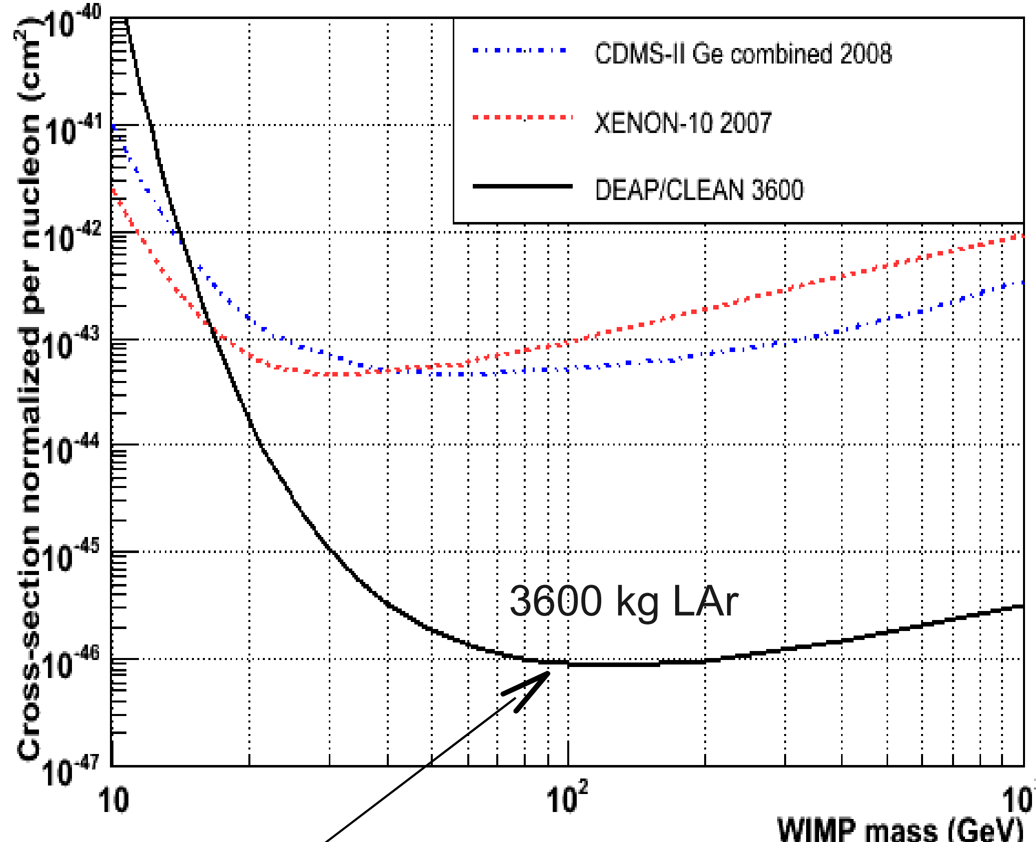
TRIUMF: **F. Retiere**
Yale University: W. Lippincott, **D.N. McKinsey**, J. Nikkel

Outline

- Motivation
- Design principle
- Backgrounds
- Lessons learned from DEAP-1
- Ongoing R&D
- Summary

Motivation

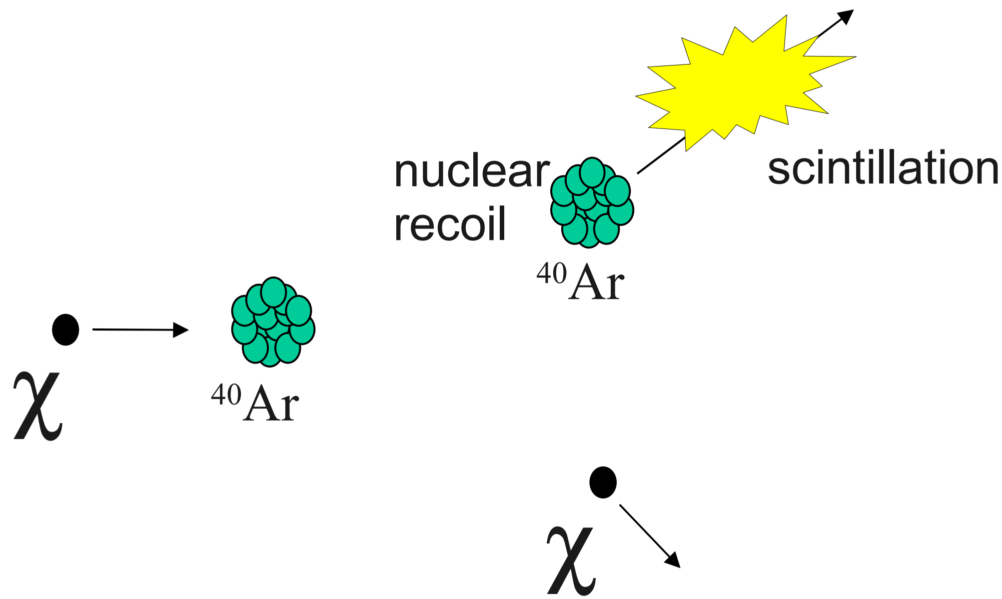




Current schedule, 2014 for this sensitivity, 2011 for 10^{-45} cm^2

CDMS-II:	~50 kg-days	(Ge)
XENON-10:	~300 kg-days	(Xe)
DEAP 3600:	1,000,000 kg-days	(Ar)

WIMP detection in liquid Ar



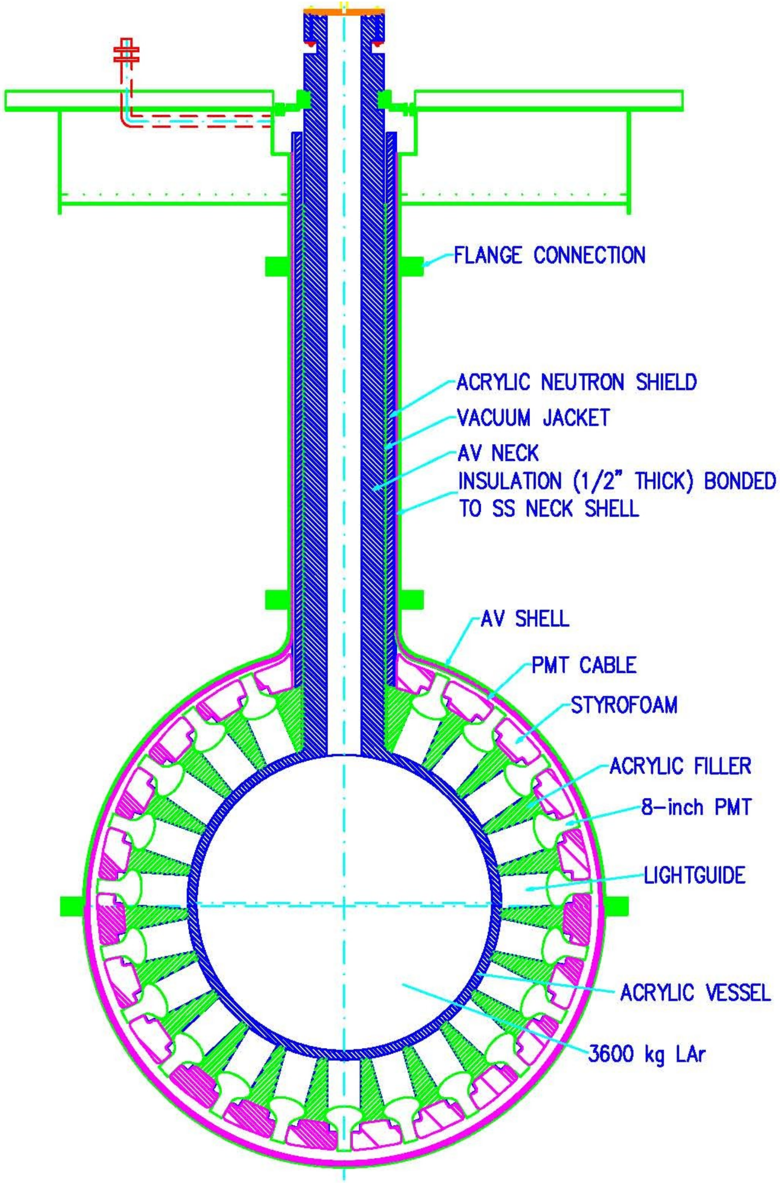
Liquid Argon:

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

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 (SI) with ~20 keV_{ee} threshold

DEAP-3600 design



85 cm radius acrylic sphere contains 3600 kg Lar (55 cm, 1000 kg fiducial)

256 8" PMTs (warm)

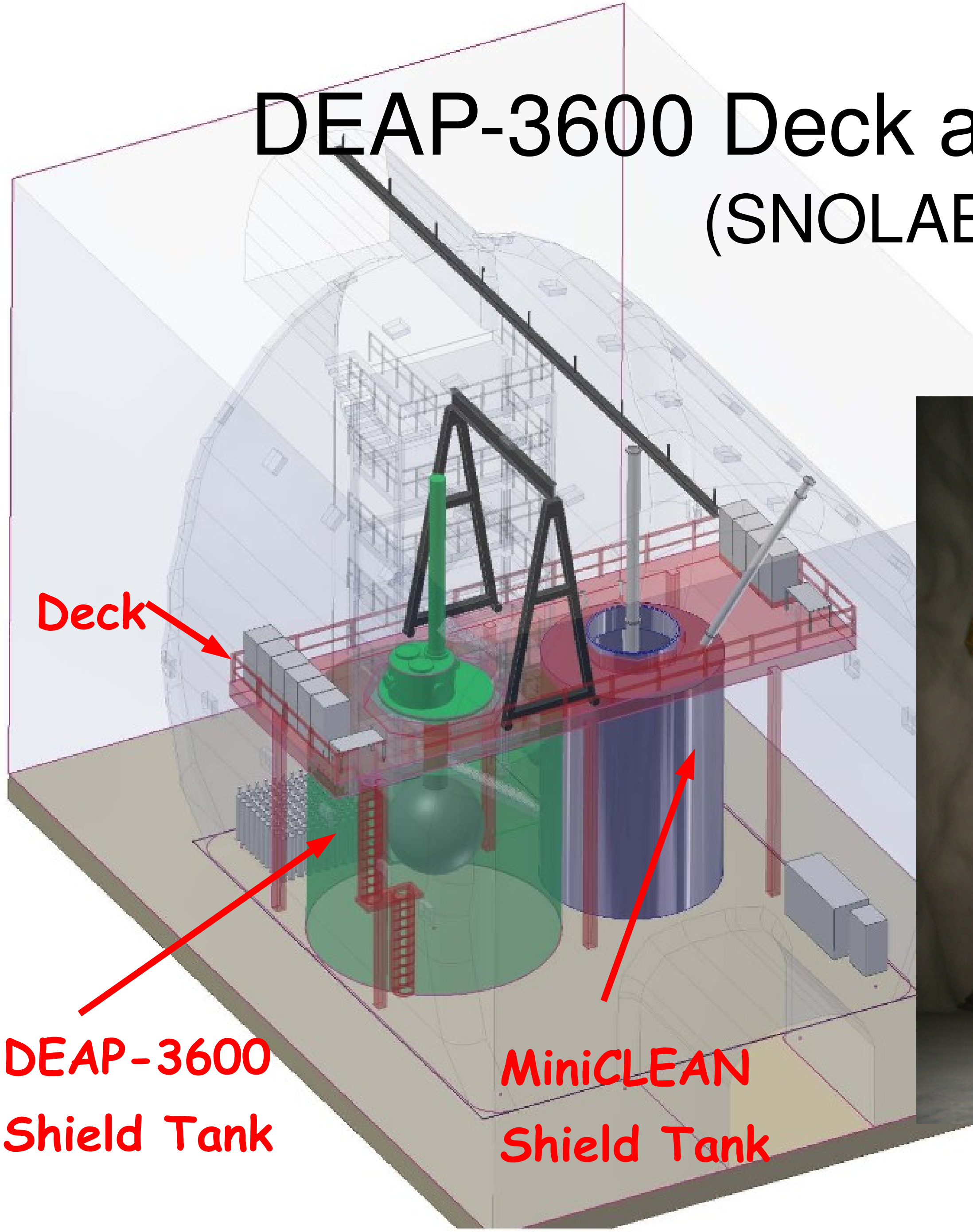
50 cm acrylic light guides and fillers for neutron shielding (from PMTs)

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

Only LAr, acrylic, and wavelength shifter inside of neutron shield

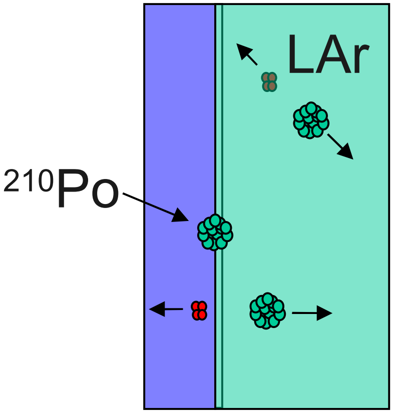
8.5 m diameter water shielding tank

DEAP-3600 Deck and Shield Tank
(SNOLAB/LU)

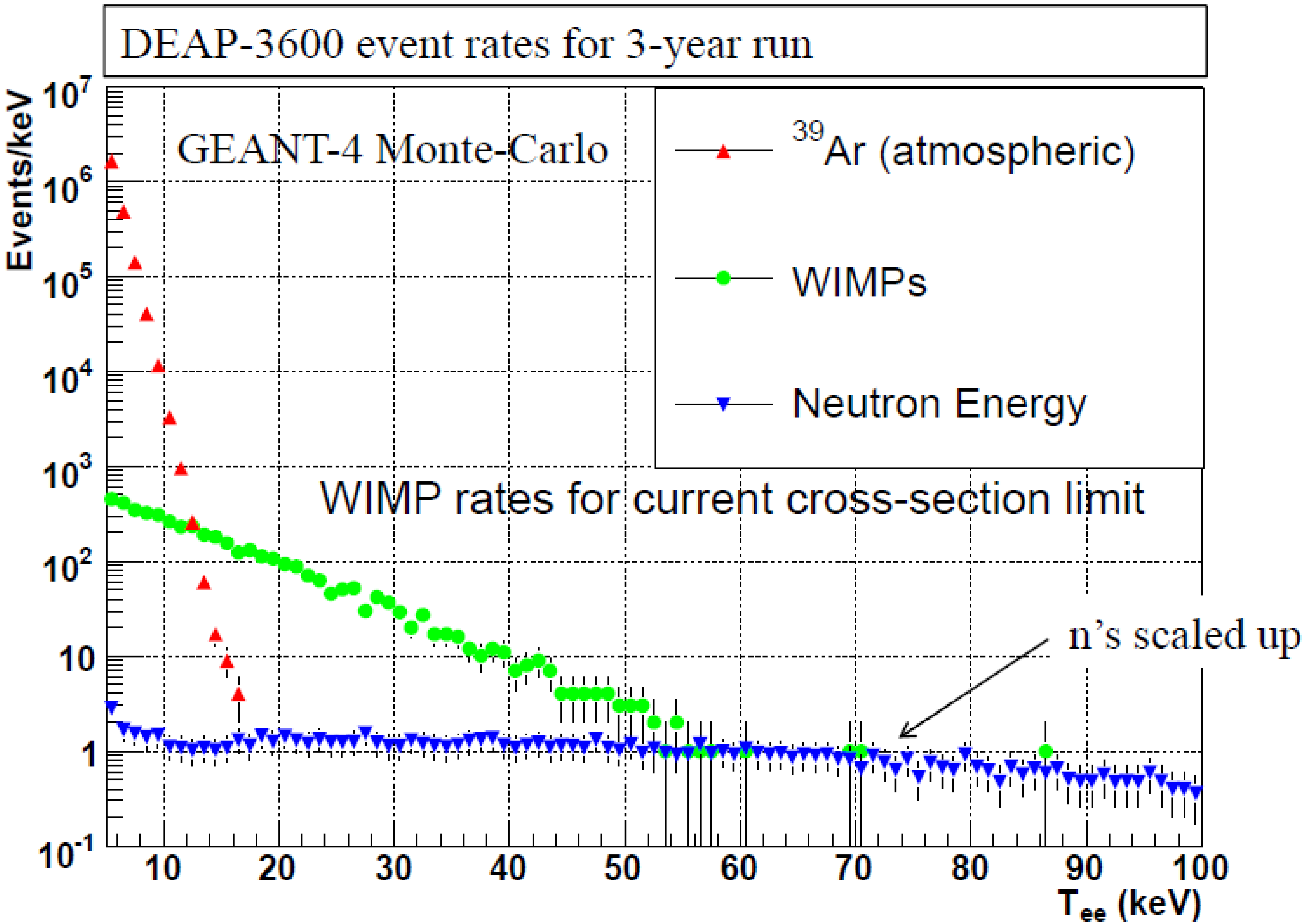


Backgrounds

- Electrons and gammas
  - Pulse Shape Discrimination (projected reduction factor: 10^{-10})
  - Potential for further reduction with depleted Ar (20x)
- Radon daughters (α-emitters)
  - Surface treatment, high purity materials
  - Fiducialization



- Neutrons
  - 2 km underground at **SNOLAB** (less muon induced neutrons)
  - Water shielding around the detector
  - Liquid Ar surrounded by ~50 cm of acrylic (vessel, lightguides, filler blocks)



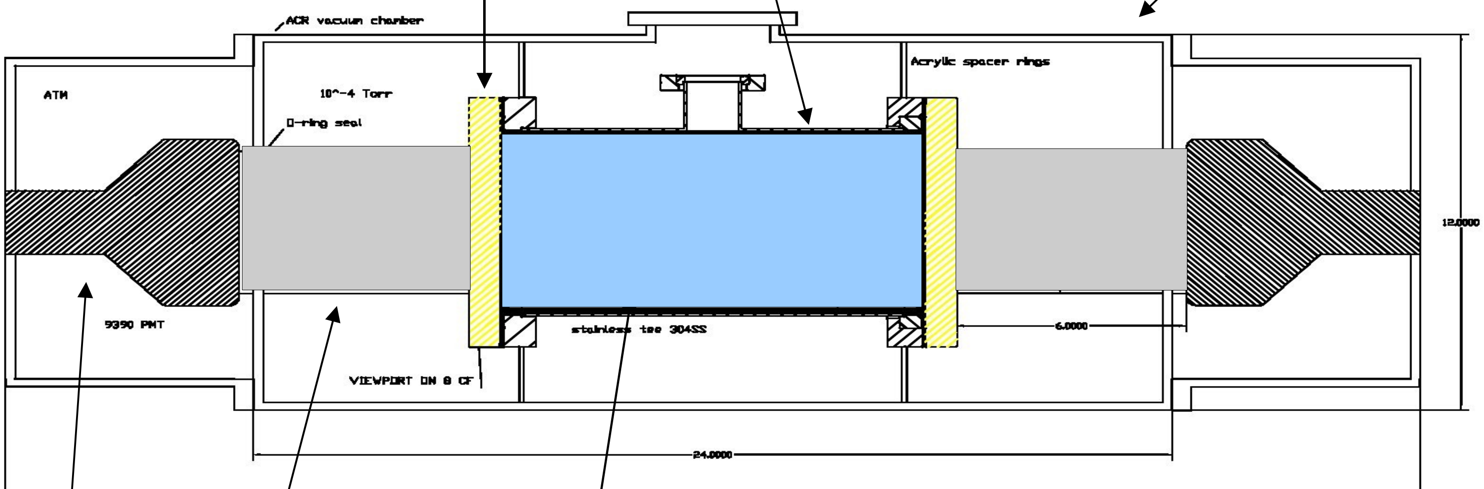
DEAP-3600 event rates for 3-year run
GEANT-4 Monte-Carlo
39Ar (atmospheric)
WIMPs
Neutron Energy
WIMP rates for current cross-section limit
n's scaled up
Events/keV
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10
20
30
40
50
60
70
80
90
100
T_ee (keV)

DEAP-1

Quartz windows

11” x 6” tee

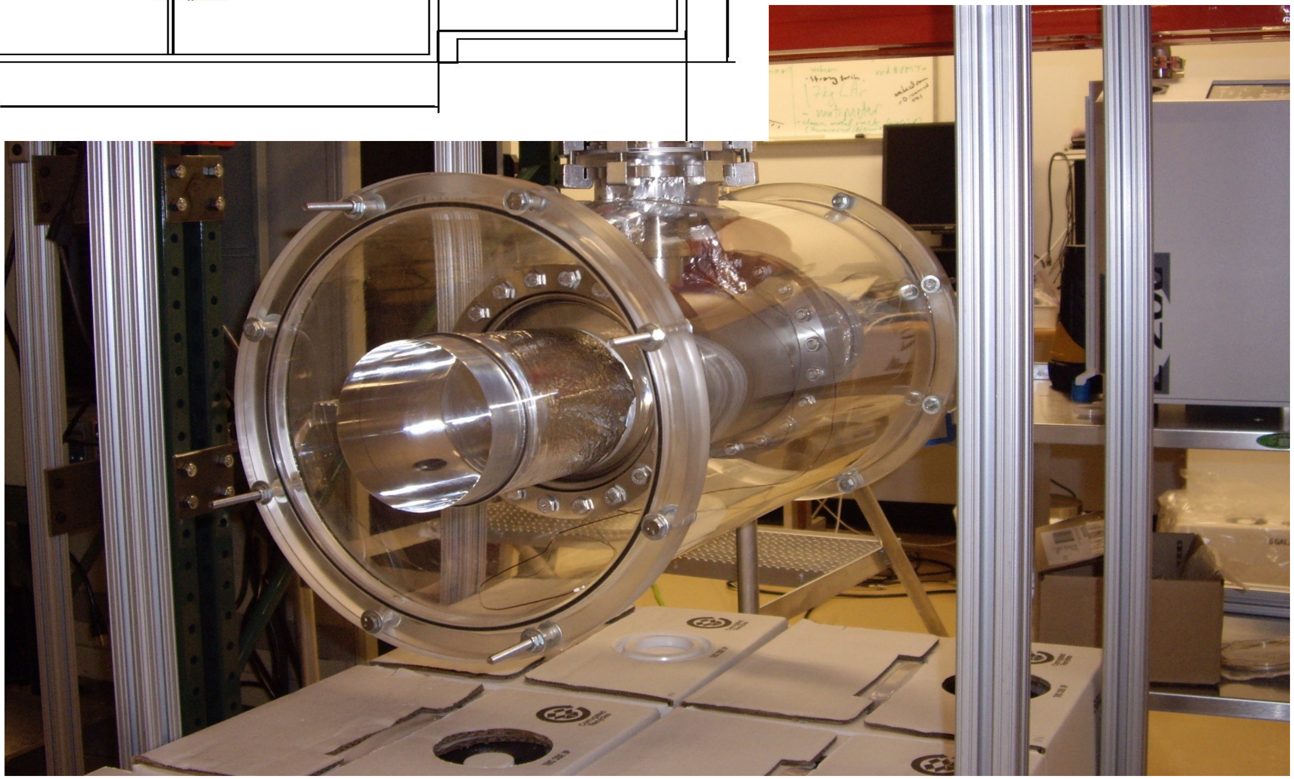
Acrylic vacuum chamber



PMT acrylic light guide

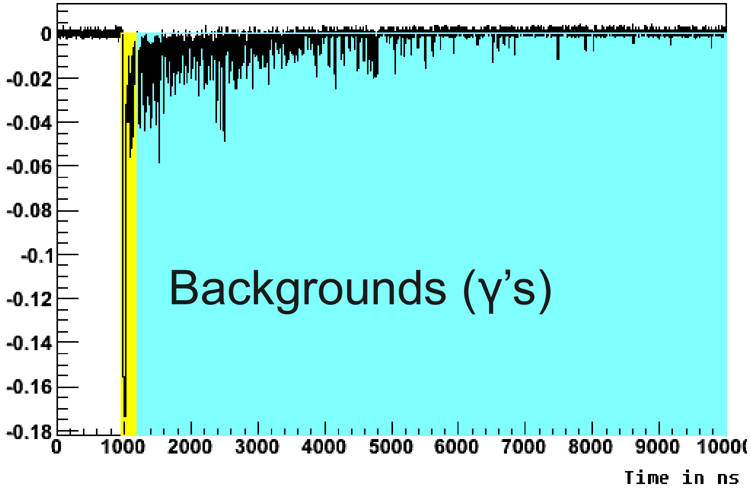
Acrylic liquid Ar vessel,
covered with wavelength shifter

Currently taking data at SNOLAB

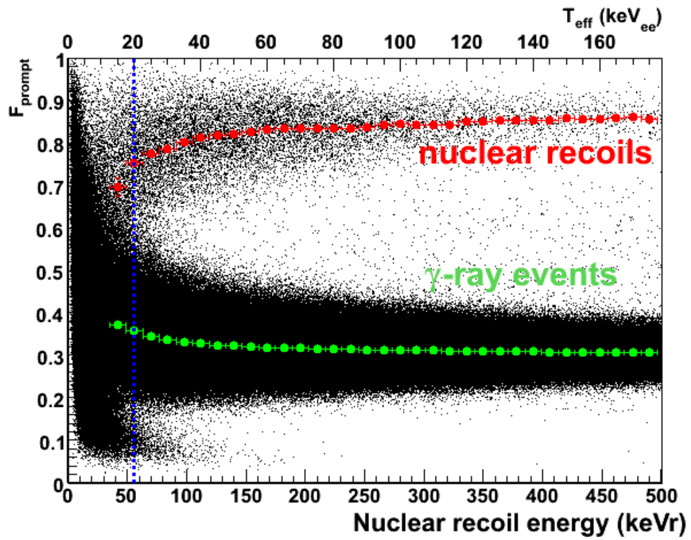


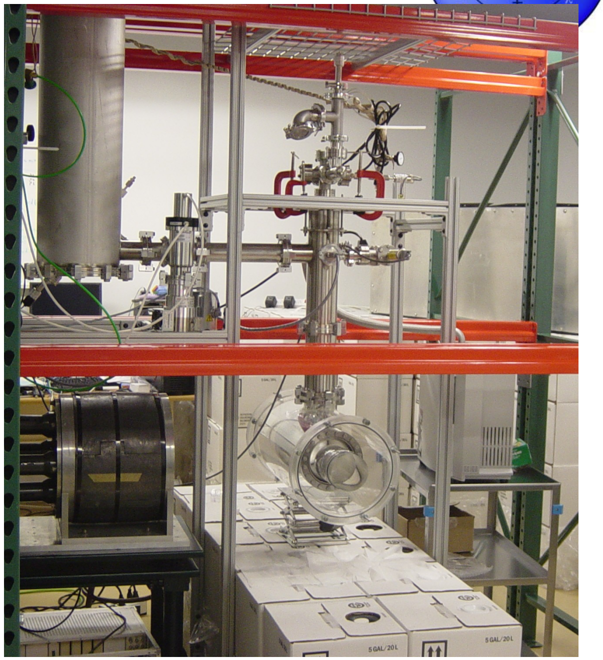
09/01/09

PSD in LAr

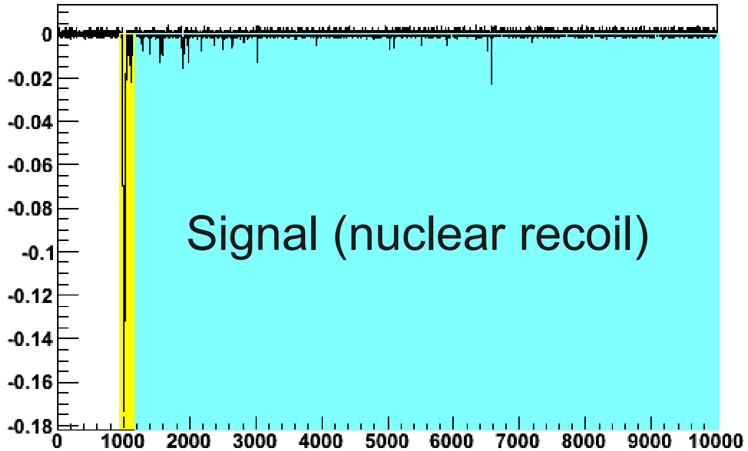


Yellow: Prompt light region
Blue: Late light region

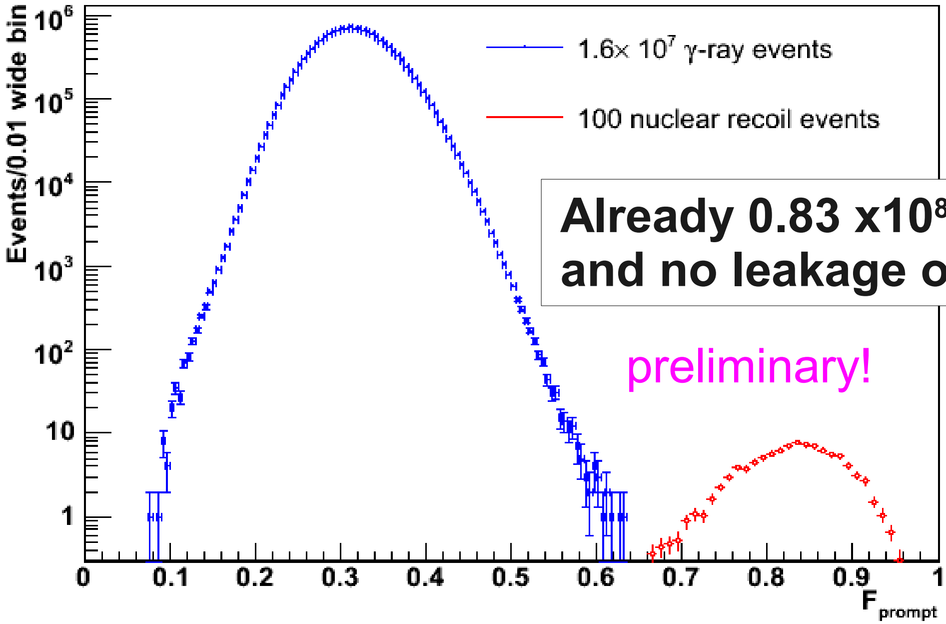




DEAP-1 at SNOLAB

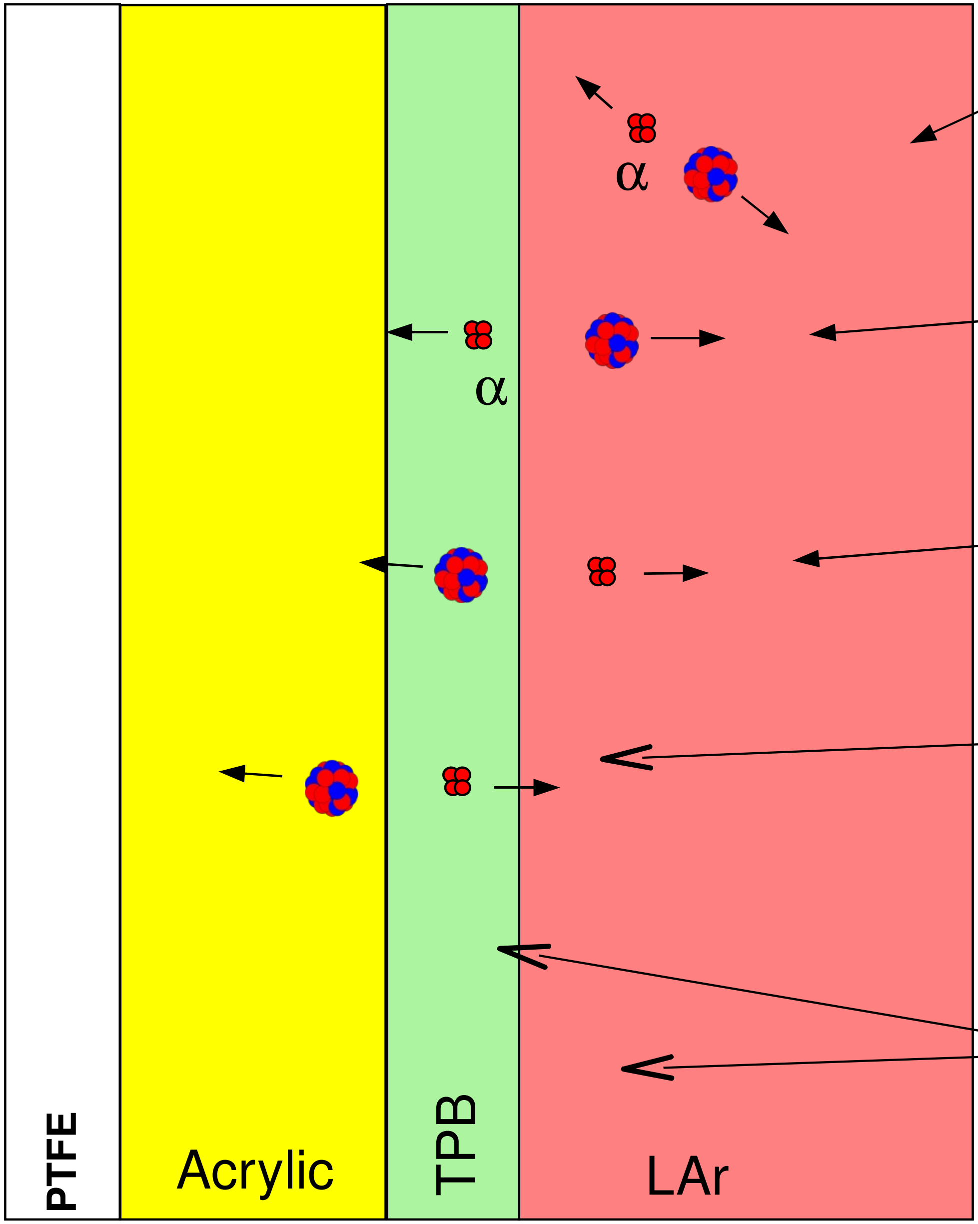


Courtesy M. Boulay



Already 0.83 x10^8 events and no leakage observed!

α Backgrounds in LAr



DEAP-1 and DEAP-3600 surface profile

Decay in **bulk argon** tagged by α-particle energy

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

Decay from **TPB surface** releases α in argon and recoil nucleus in TPB (see mostly α-particle, high energy)

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)

both TPB and LAr scintillate

α Backgrounds in DEAP-1

Some residual (small) source of 222Rn (~few atoms/day)

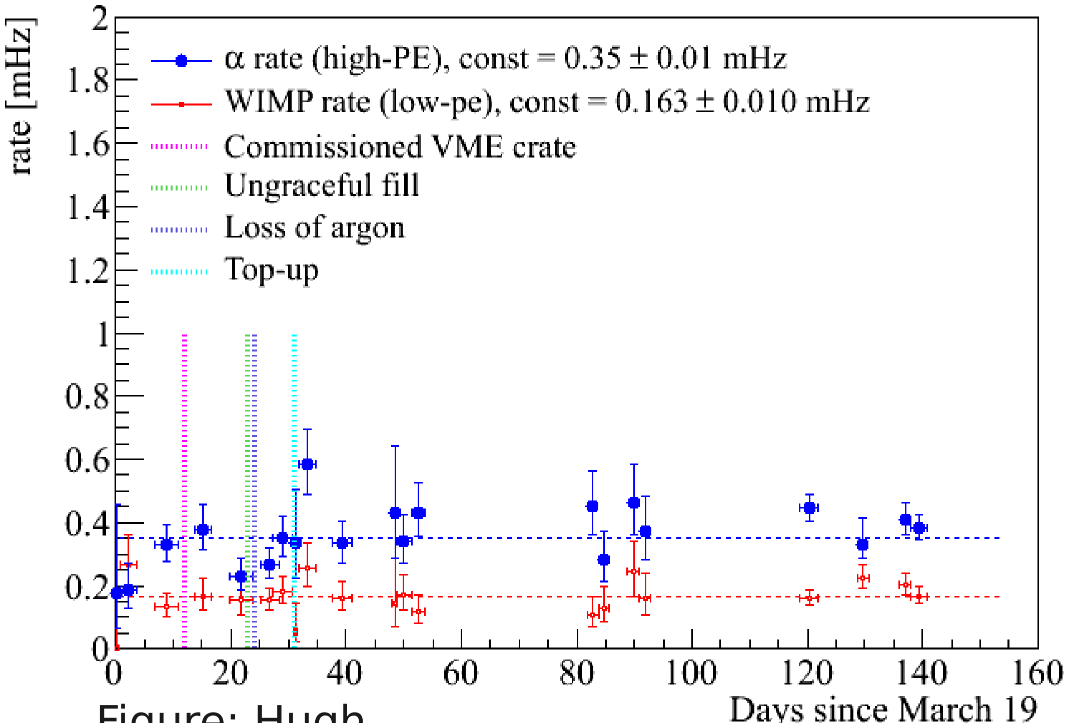
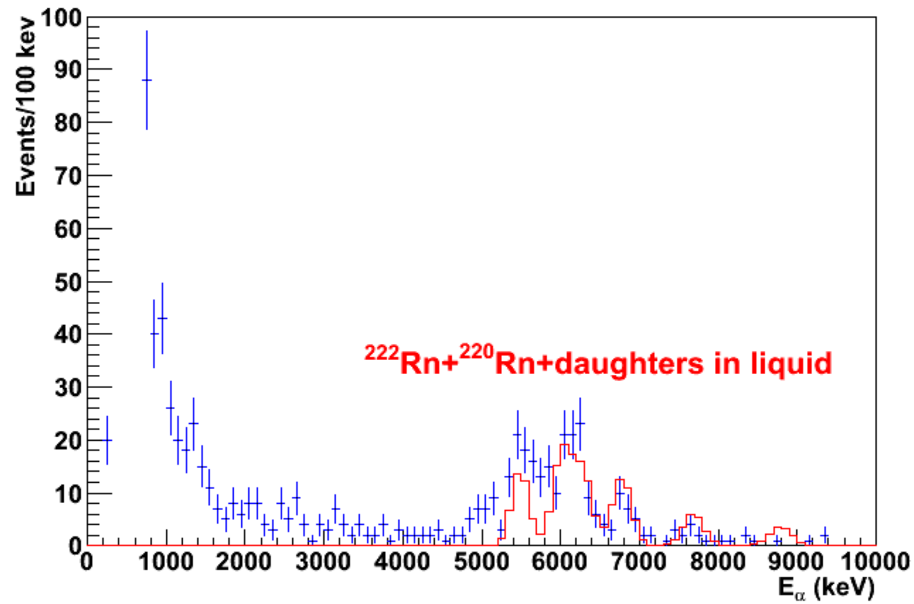
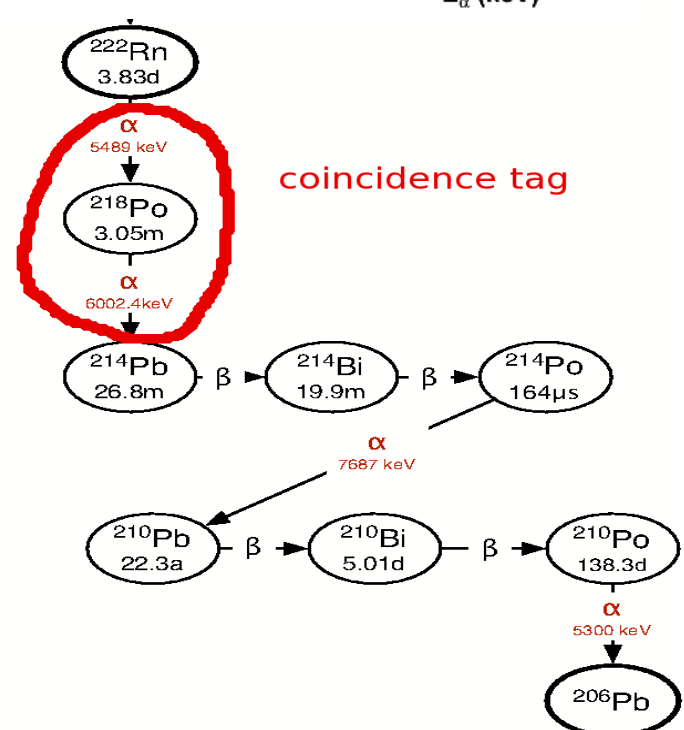
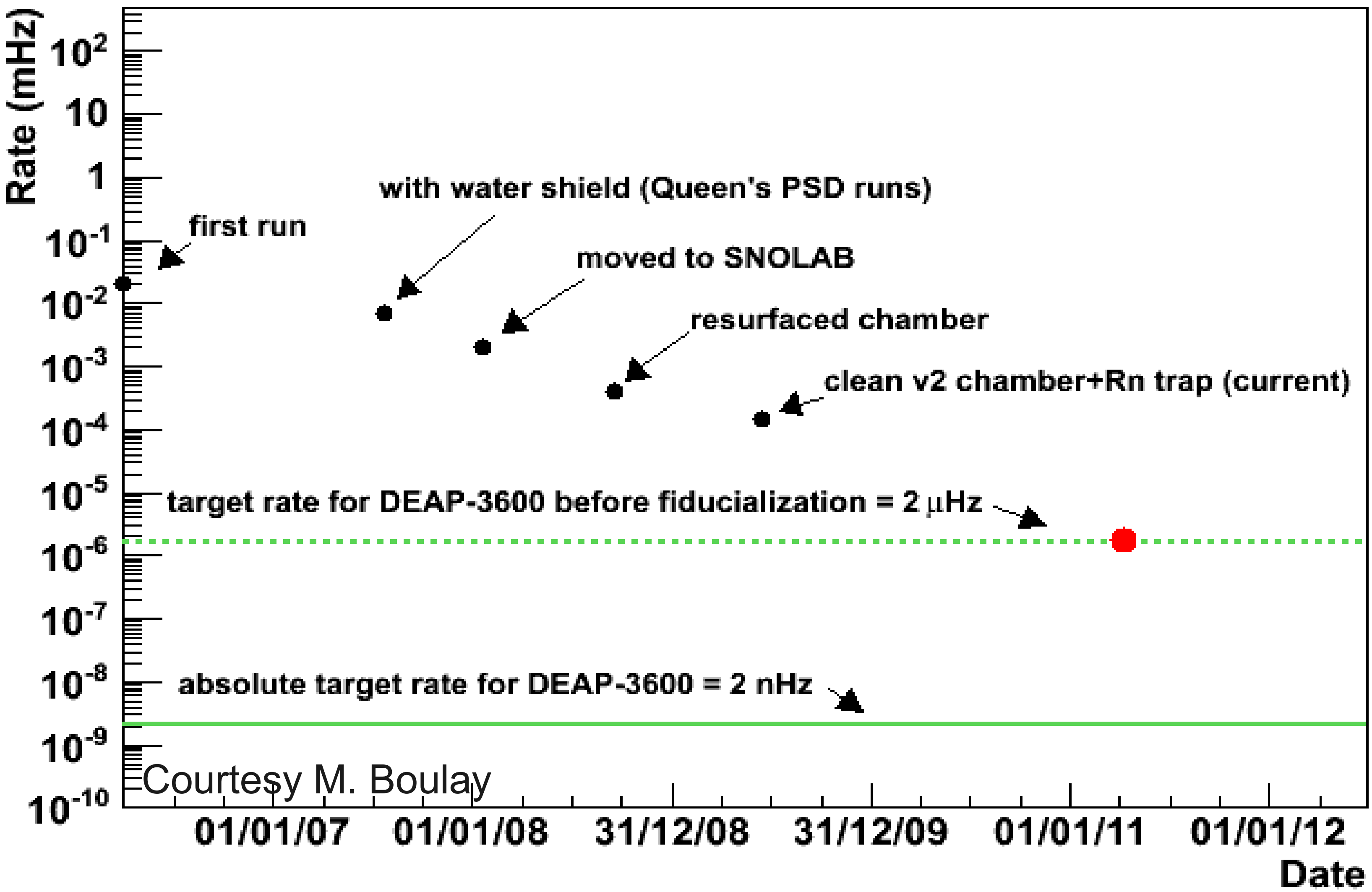


Figure: Hugh Lippincott, Yale

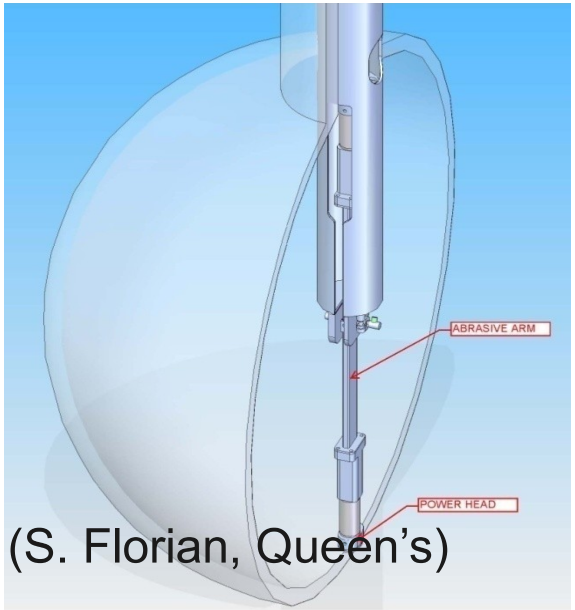


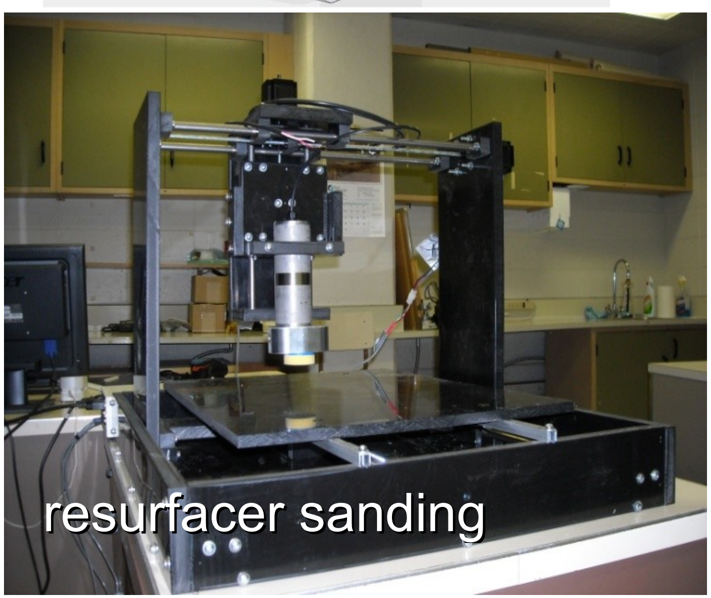


α Backgrounds in DEAP-1



α Backgrounds reduction





1) 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)
- Rn diffusion length in acrylic is 100 microns

2) Rn trap (for the Ar liquifier) successfuly tested

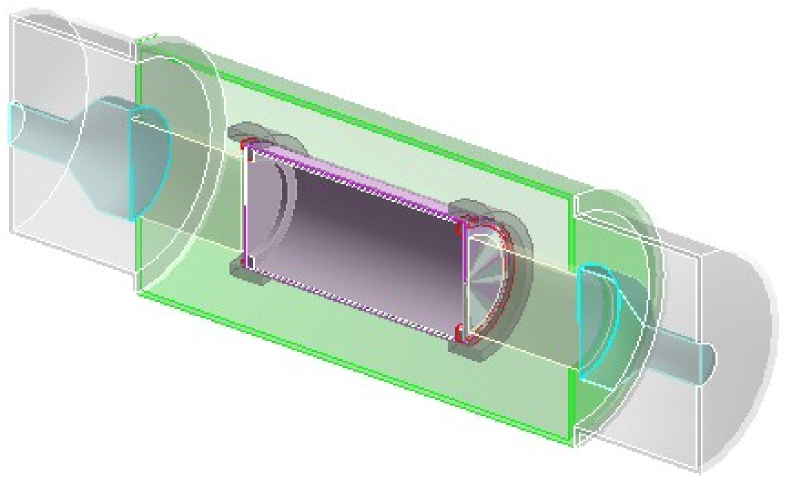
3) Careful selection of low-emanation materials for the systen

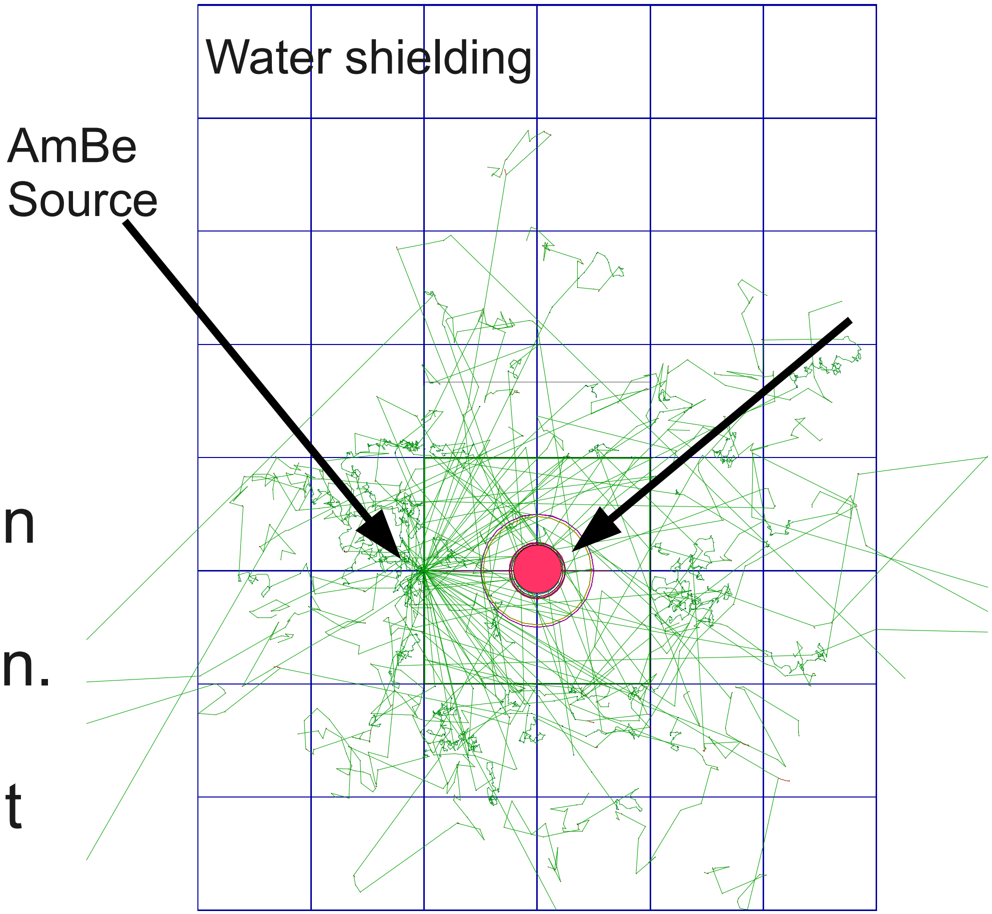
4) Separate R&D studies on:

- wavelength shifter (TPB) purification
- acrylic assay/purification

Neutron calibration

- Neutron detection efficiency in DEAP-1 was measured and simulated using *Geant4*

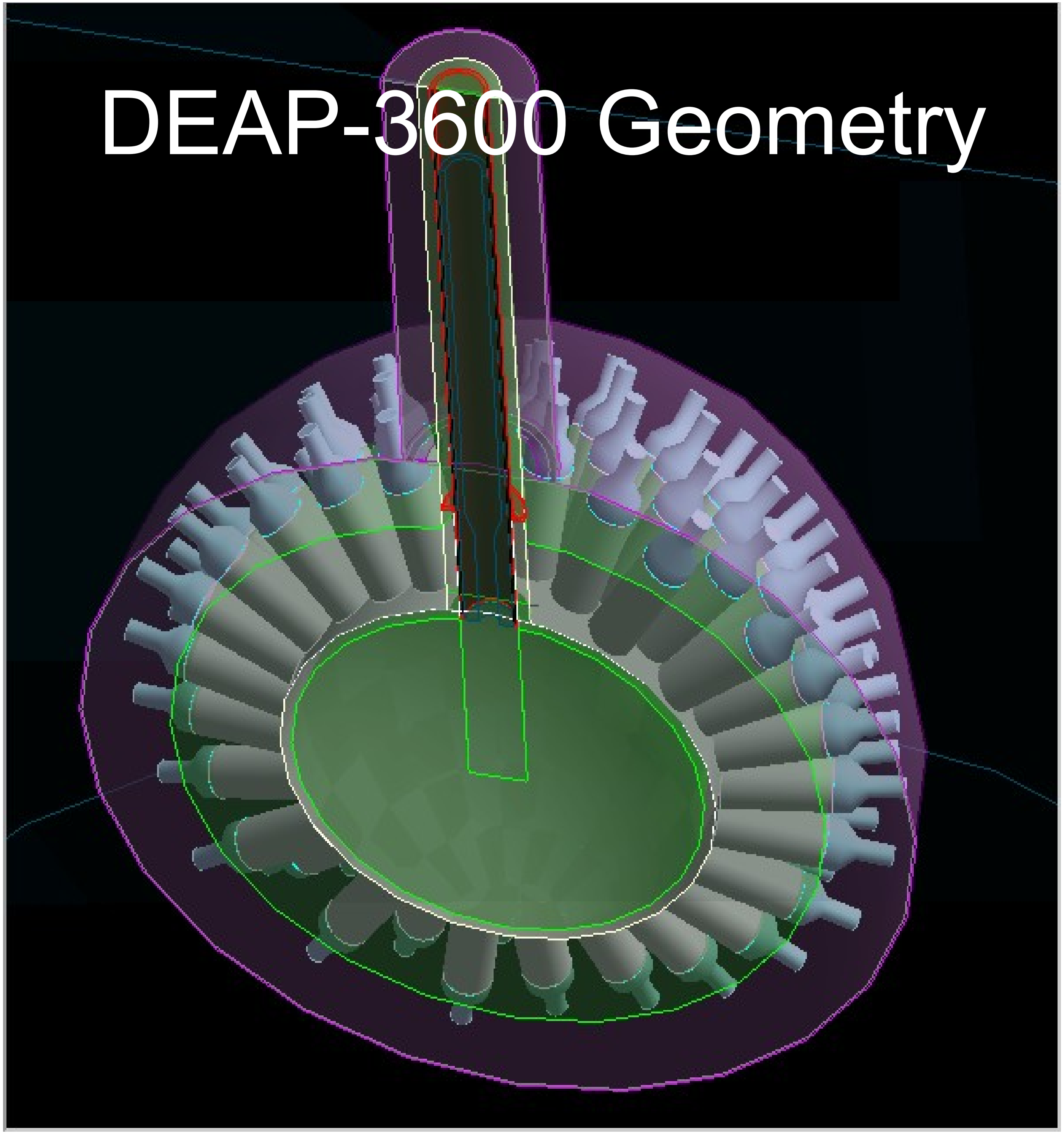




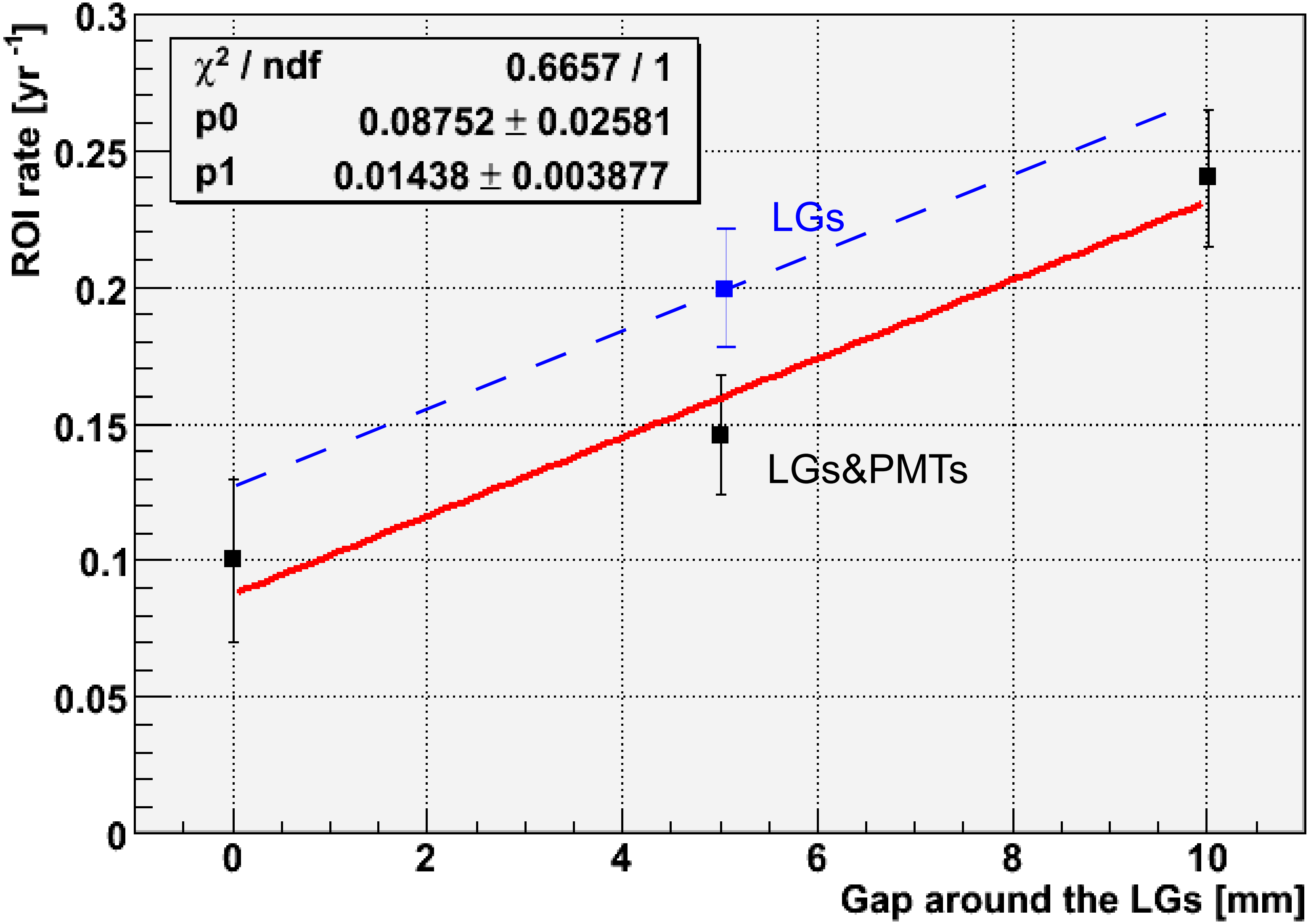
Measured n detection efficiency (in the energy region of interest) reproduced with the MC simulation.

In real life, PMTs are the dominant source of n background.

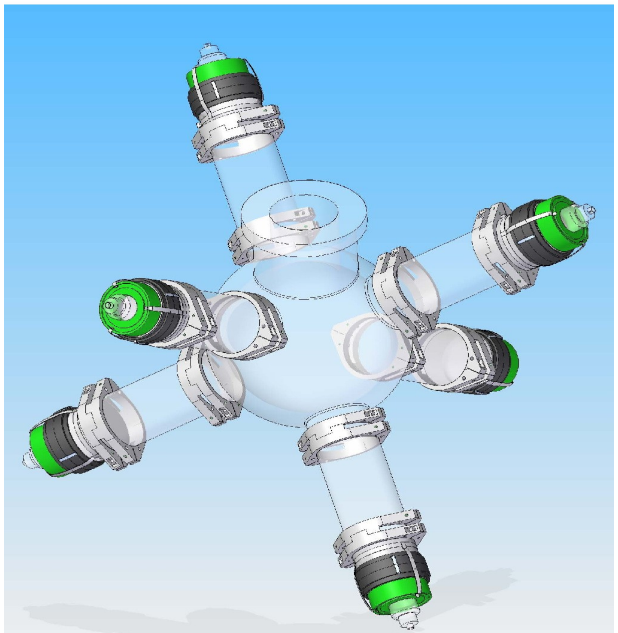
DEAP-3600 Geometry



N rate (and filler geometry)



Photon collection/readout



20-inch test cell:

- to develop TPB deposition
- test optics
- test process systems

acrylic guide+8” PMT

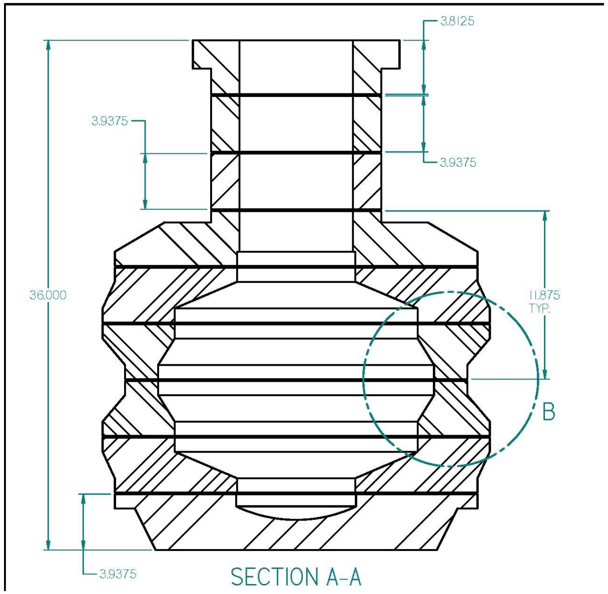
(low-background tubes: Hamamatsu 5912, high quantum efficiency option discussed)

CAEN v1720 waveform digitizer

(Prototype+MIDAS installed on DEAP-1 - F. Retiere, TRIUMF)

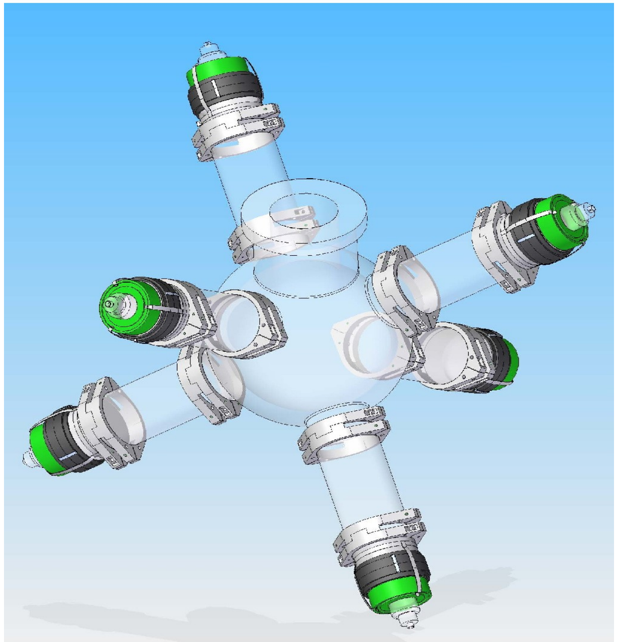
20-inch test vessel

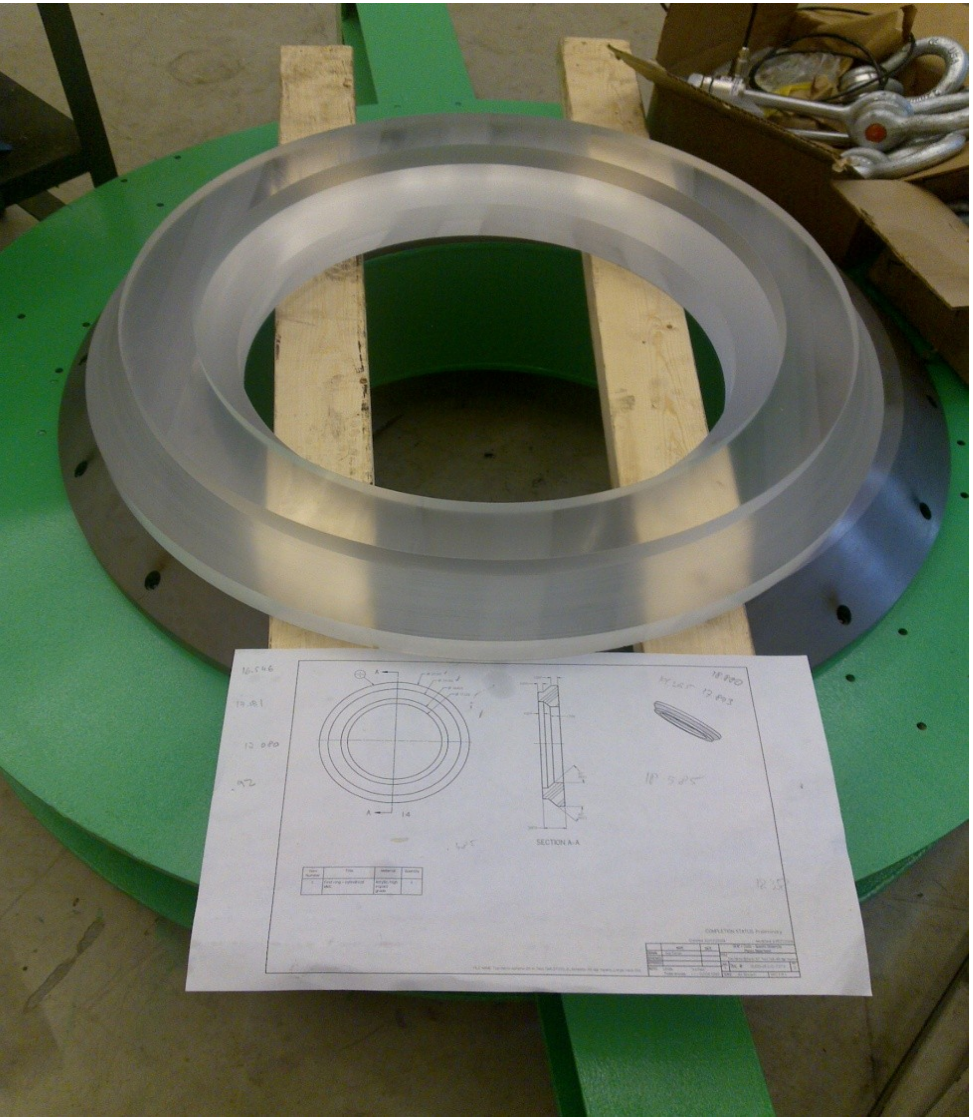
- Qualify light guide + PMT optics
- Develop 4-pi TPB deposition
- 6-PMT setup for DAQ/trigger
- surface alpha backgrounds
- Develop purification and cooling systems for DEAP-3600
- Cryogenic bond tests (long-term, cycling tests)
- Experience machining acrylic for DEAP-3600

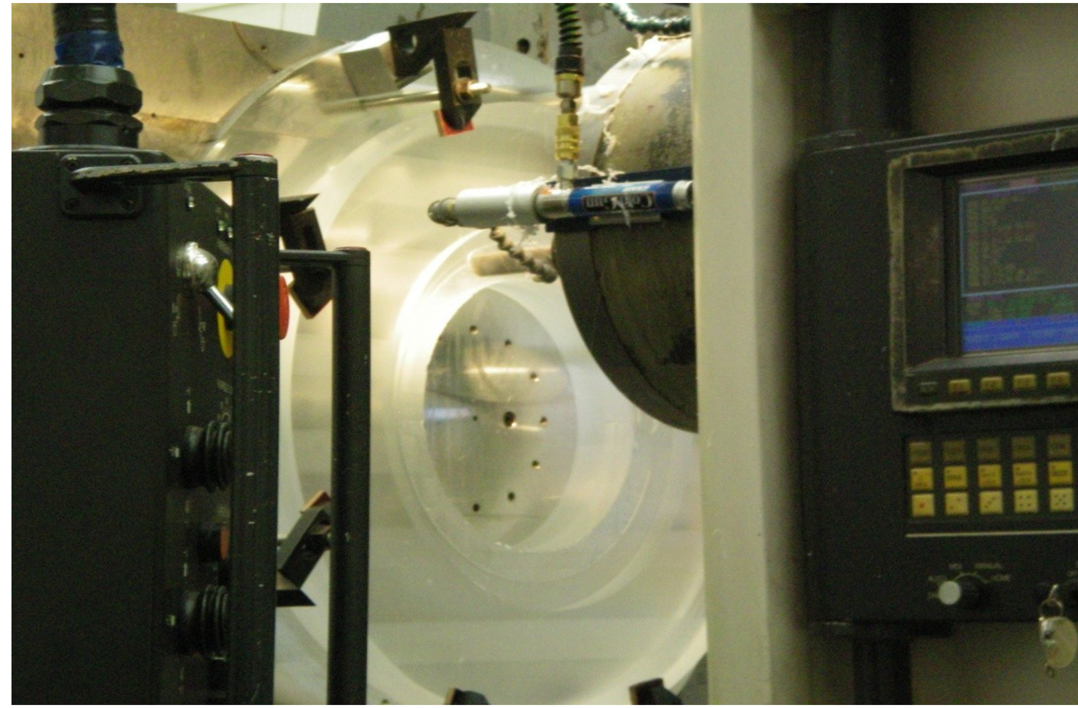


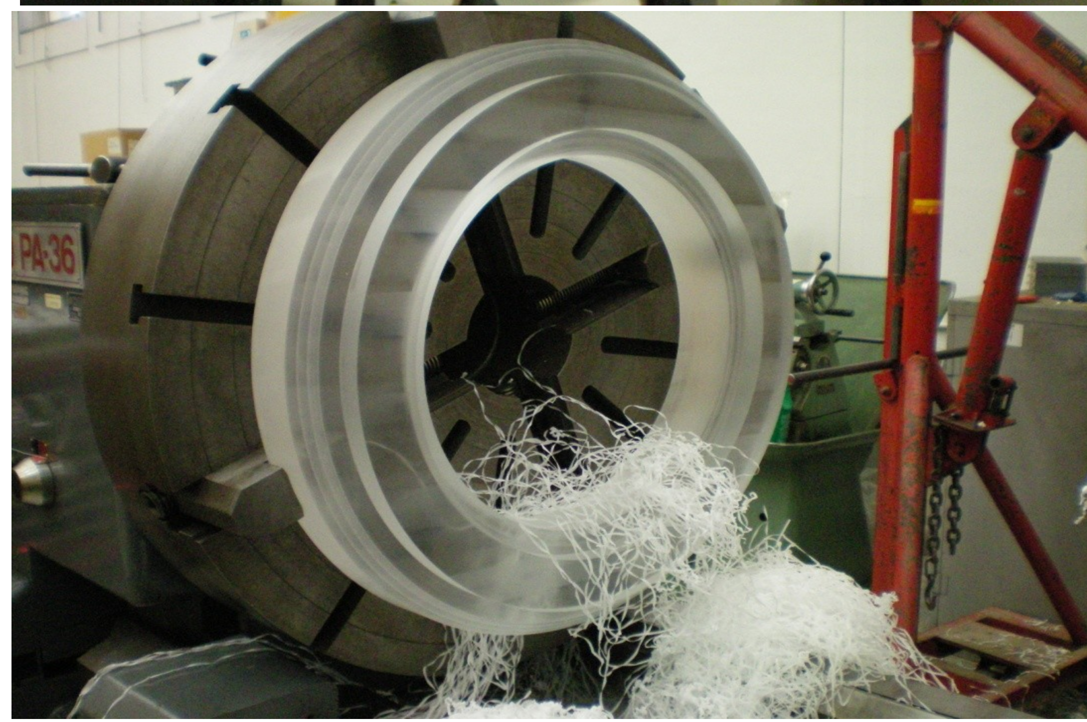
vessel will be constructed from bonded 4” rings

(ready Jan 2010)







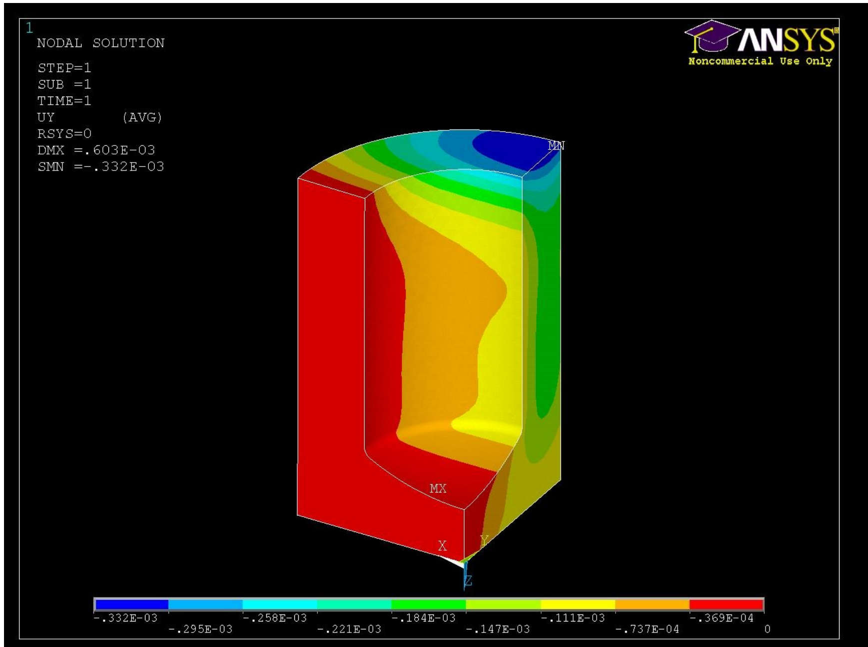


July, Aug 2009 (Alberta)

Other R&D activities

- Cooling system (prototype achieved required 400 W) [Carleton]
- Magnetic compensation coils [Queen's, UNM]
- Light attenuation measurements in acrylic for the lightguides [Queen's, LANL]
- Studies of TPB properties [UPenn, LANL, Queen's]
- 2 independent Monte Carlo models of DEAP-3600 (Geant4, RAT) [Queen's, UNM, UNC]
- FEA calculations for the AV and the test vessel [Alberta]
- DAQ & electronics [TRIUMF, Boston]
- ...

Testing safety factor in acrylic at cryogenic temperatures



FEA of mini-bucket (Chris Ng)

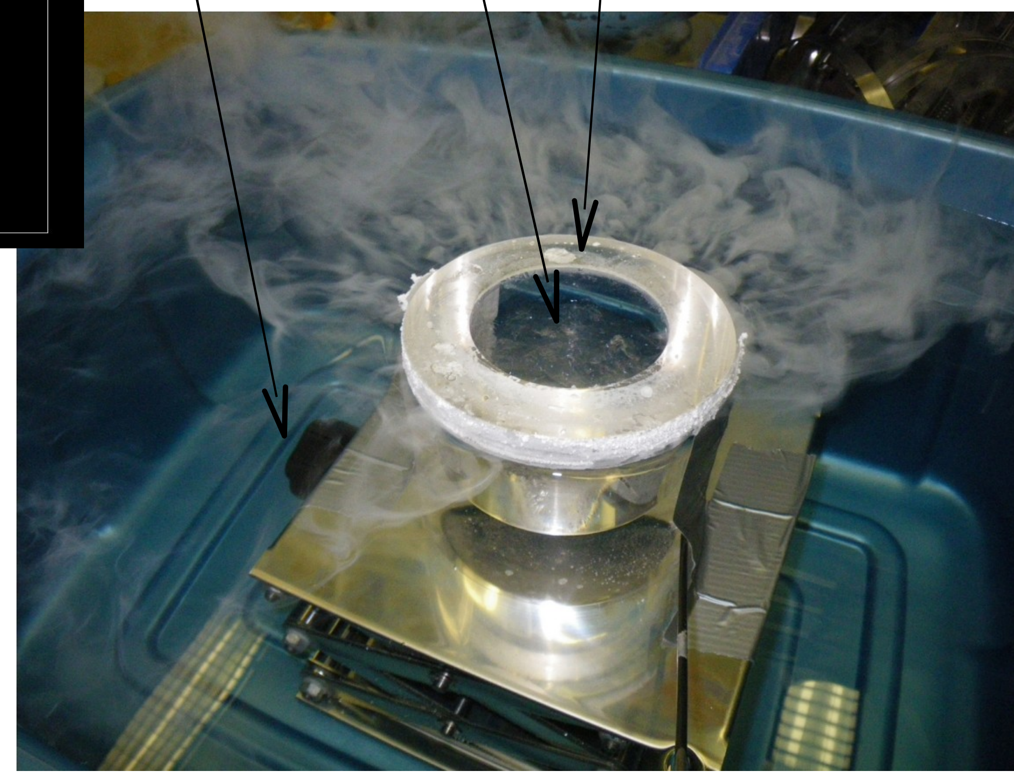
Stress in bucket is >10X
max stress in DEAP-3600 AV

"mini-bucket"

LN

water bath

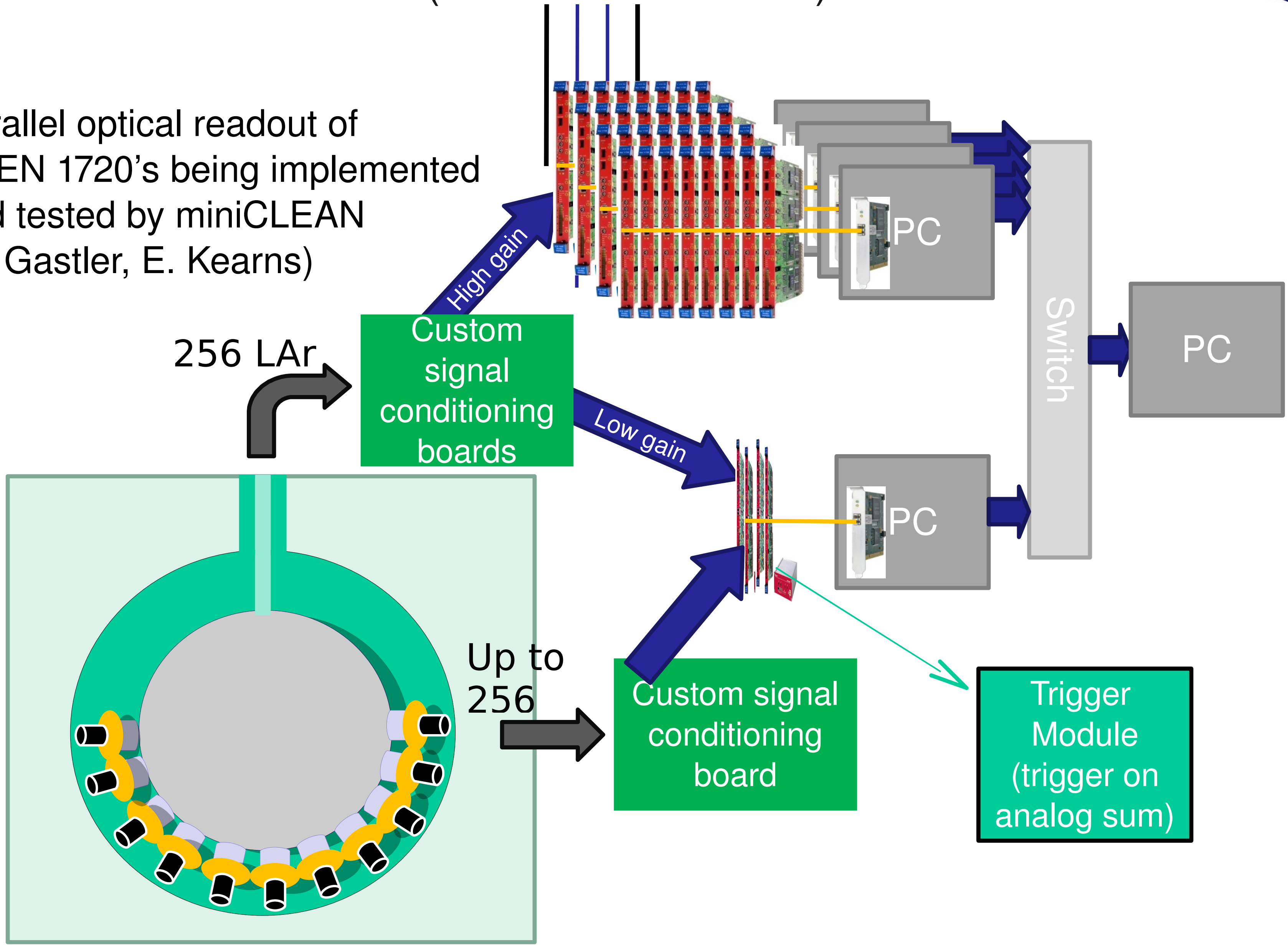
V. Golovko



DEAP-3600 Electronics

(F. Retiere TRIUMF)

Parallel optical readout of CAEN 1720's being implemented and tested by miniCLEAN (D. Gastler, E. Kearns)



Summary

1) CFI/NIF SNO+ and DEAP grant funded (26.4 M$) in 2009

2) Submitted PSD results from DEAP-1 (6x10-8), continued background reduction and PSD demonstration at SNOLAB

3) Good progress in prototyping electronics, process systems, cooling system, lightguides, resurfacer, vessel machining

4) Deck and shield tank planned for installation by end of 2009

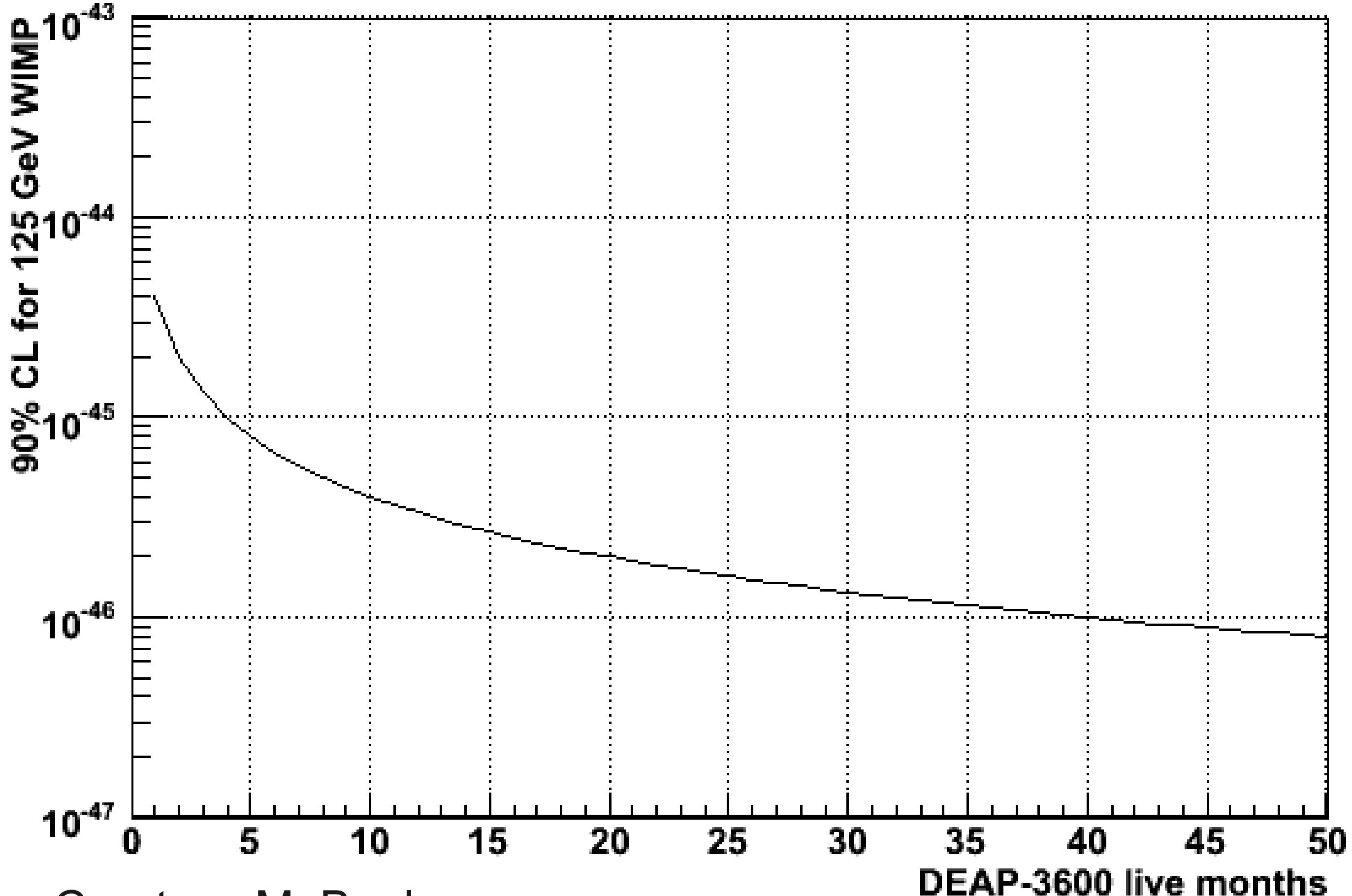
5) Beginning construction of resurfacer, purification systems now

6) Late fall 2009: begin procurement of acrylic

7) 2010: Detector installation and assembly at SNOLAB

8) 2011: Commissioning, first data!

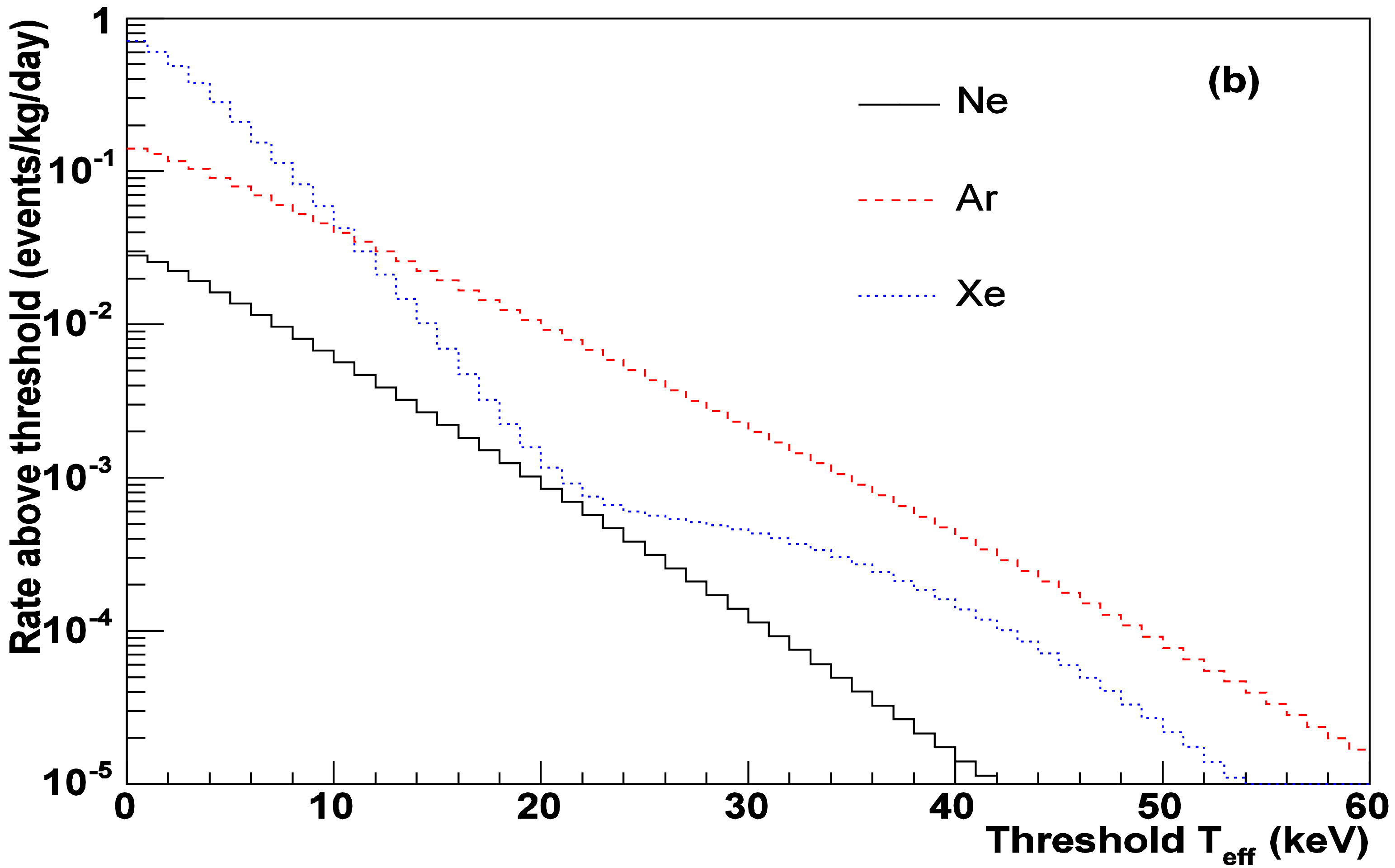
DEAP-3600 sensitivity for background-free exposure



Courtesy M. Boulay

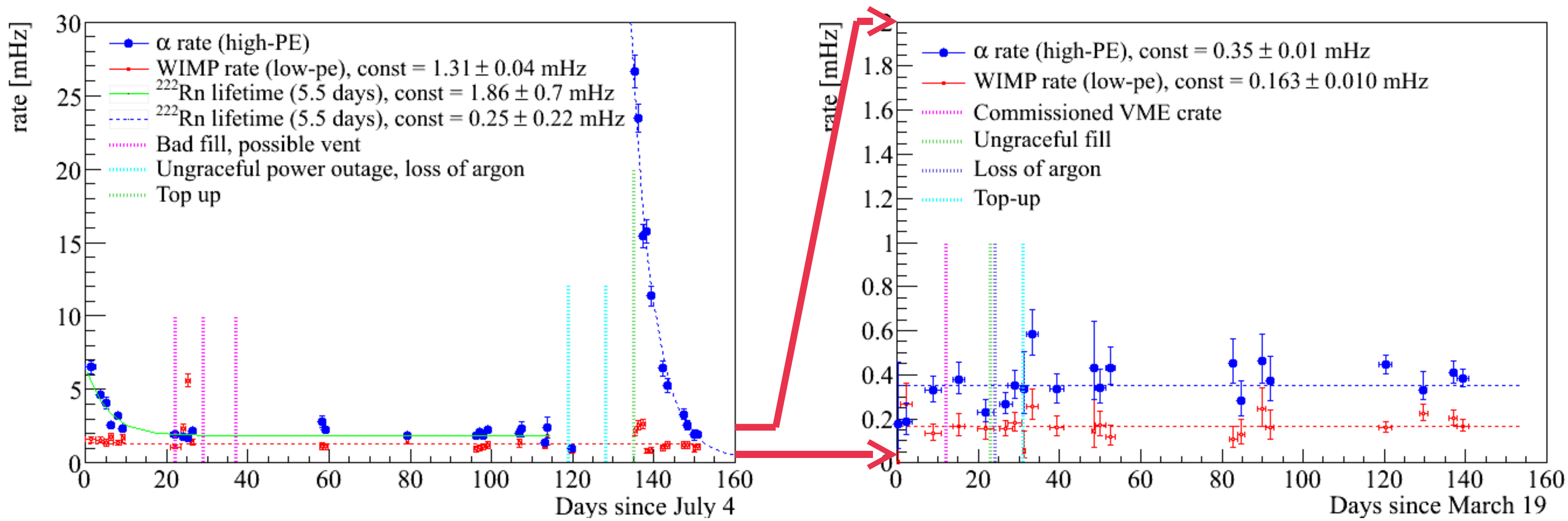
Backup

The WIMP rate



with “standard” assumptions about the WIMP halo and distribution and for a 100 GeV WIMP

Background Rates



July 4, 2008 Run

2-4 mHz steady state

Top-up added large ^{222}Rn spike

Used to develop U-chain tags

March 19, 2009 Run

0.2 to 0.4 mHz

No initial spike

Courtesy C. Jillings

Results and projections for spin-independent searches (from IDM 2008 Conference August 2008)

Project	Target	Location	Mass	Start (UG run)	Sensitivity (cm^2)
CDMS	Ge, Si	Soudan	5 kg (14 kg by 2010)	2003	4.6×10^{-44}
XENON-10	Xe (2- phase)	Gran Sasso	15 kg	2006	4.5×10^{-44}
DEAP-1	Ar (1-phase)	SNOLAB	7 kg	2007	10^{-44}
XENON-100	Xe (2-phase)	Gran Sasso	70 kg	2008	2×10^{-45}
ZEPLIN-III	Xe (2-phase)	Boulby	12 kg	2008	7×10^{-45}
WaRP	Ar (2-phase)	Gran Sasso	140 kg	2009	10^{-45}
LUX	Xe (2-phase)	Homestake	350 kg	2009	7×10^{-46}
XMASS	Xe (1-phase)	Kamioka	800 kg	2010	10^{-45}
DEAP-3600	Ar (1-phase)	SNOLAB	3600 kg	2011	10^{-46}
Super-CDMS	Ge	SNOLAB	25 kg	>2010	10^{-45}
EURECA	Several	Modane	~1000 kg	~2014	10^{-46}