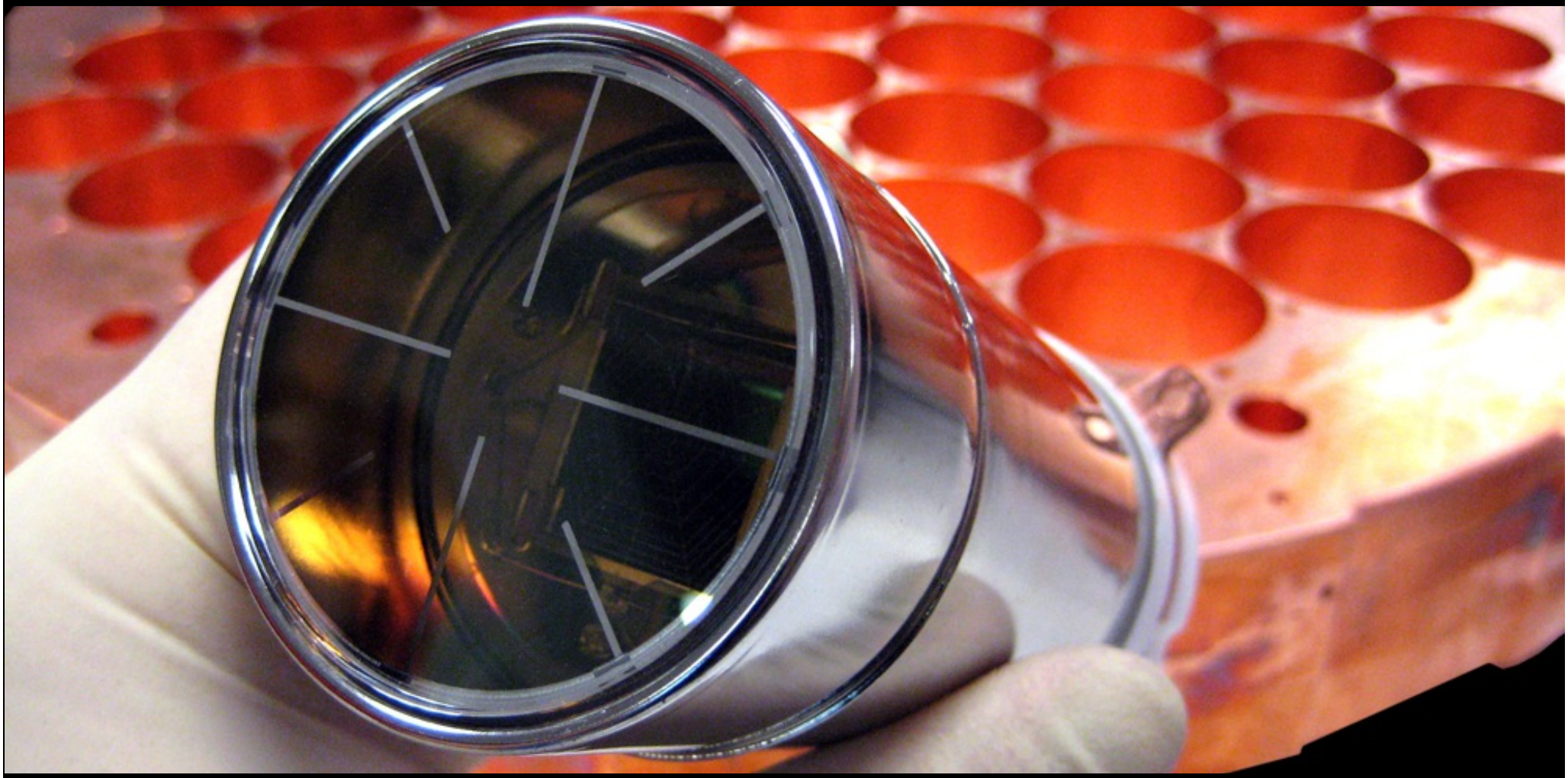
Performance and Radioactivity Measurements of the PMTs for the LUX and LZ Dark Matter Experiments



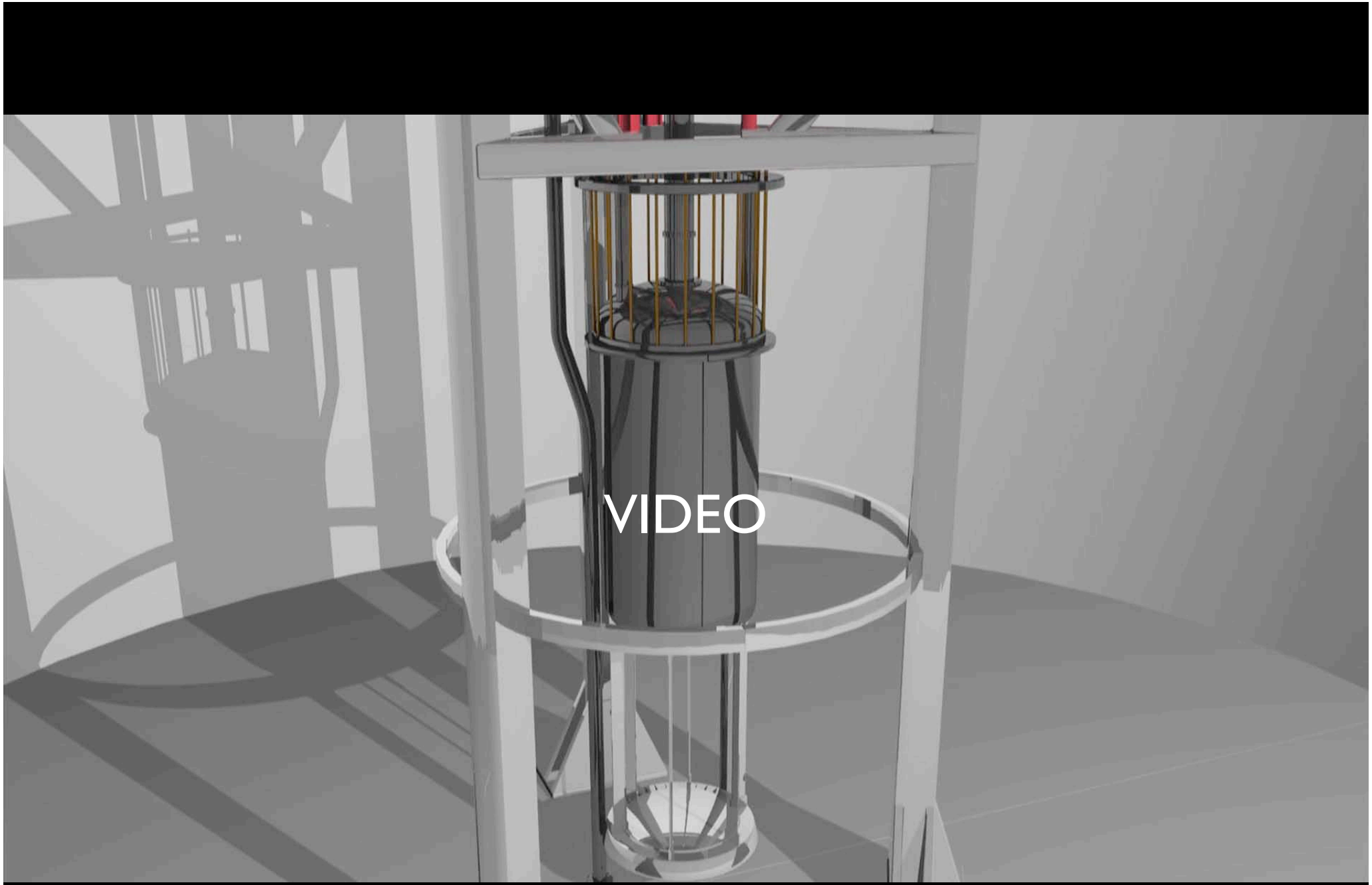
Carlos Faham
Brown University
Particle Astrophysics Group

TIPP 2011, June 11

The LUX Detector

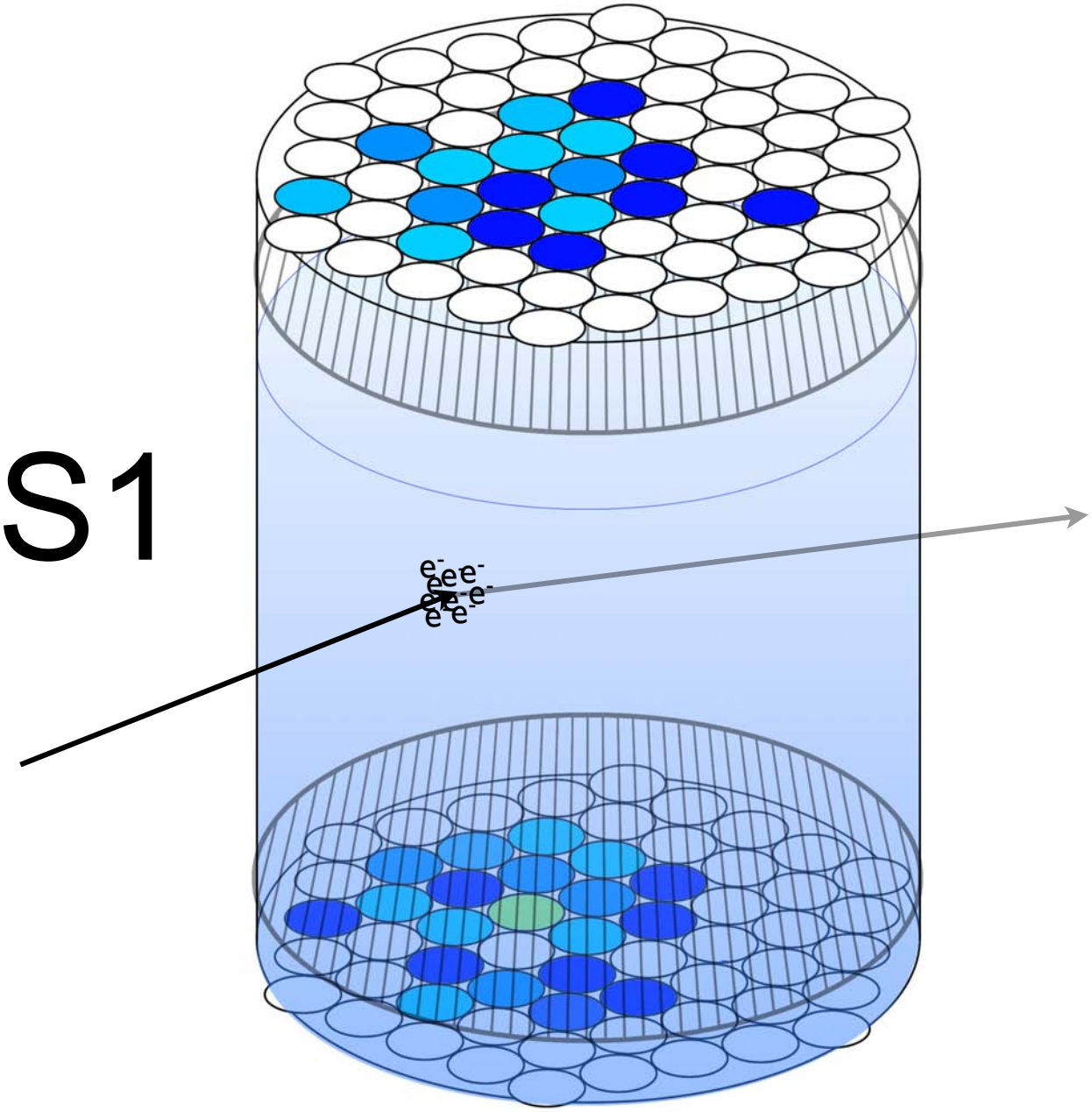
The Large Underground Xenon Experiment

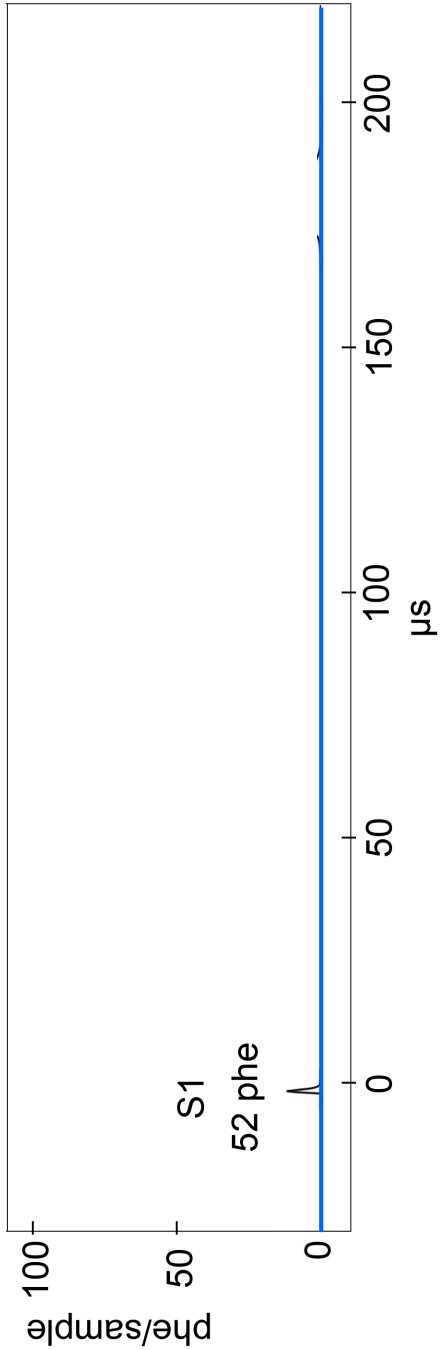
Video by Harvard-Smithsonian Center for Astrophysics and Learner



Video by Harvard-Smithsonian Center for Astrophysics and Learner

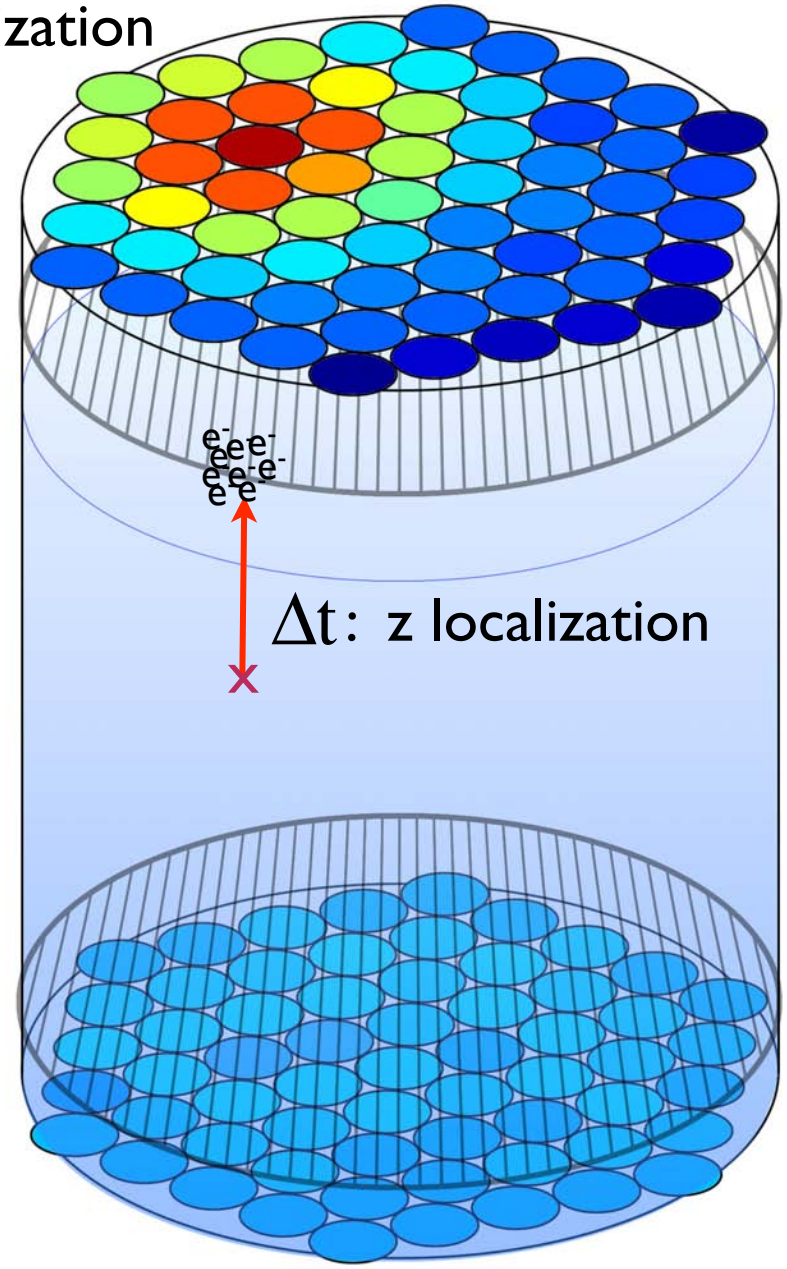
S1





top hit pattern:
x-y localization

S2



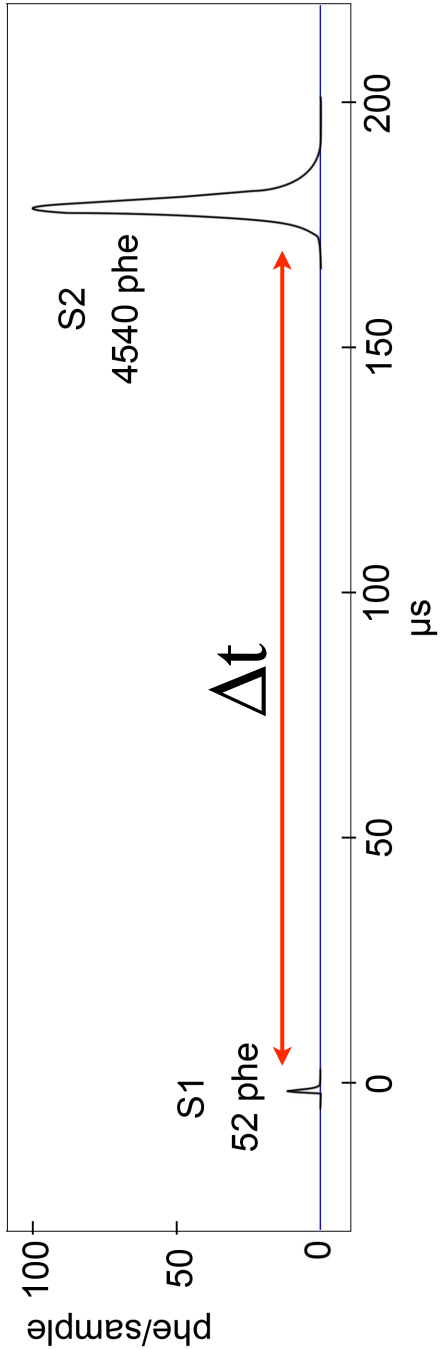
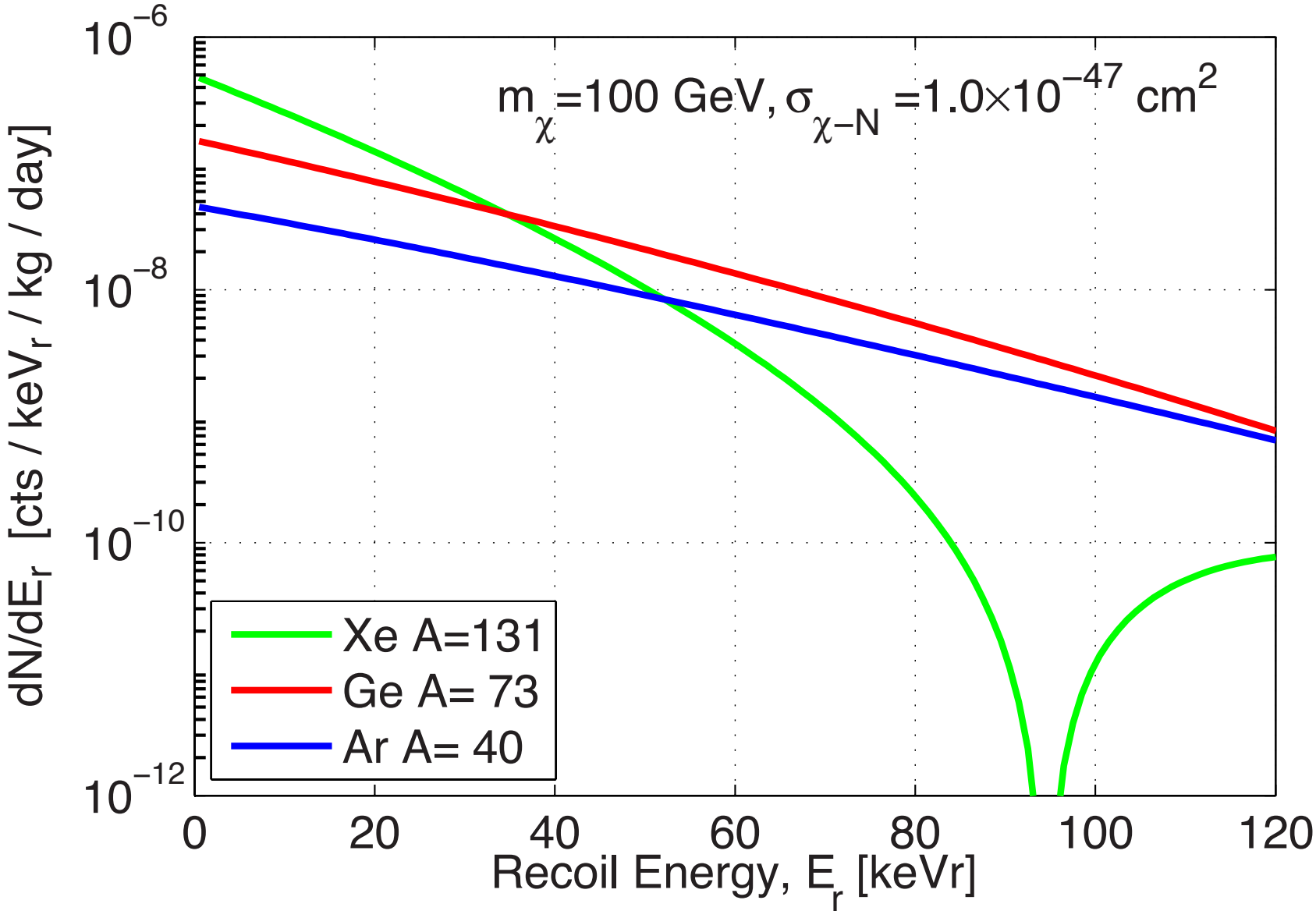


Photo by C. Faham

Dark Matter

Dark Matter: Direct Detection



The LUX Hamamatsu R8778 PMTs

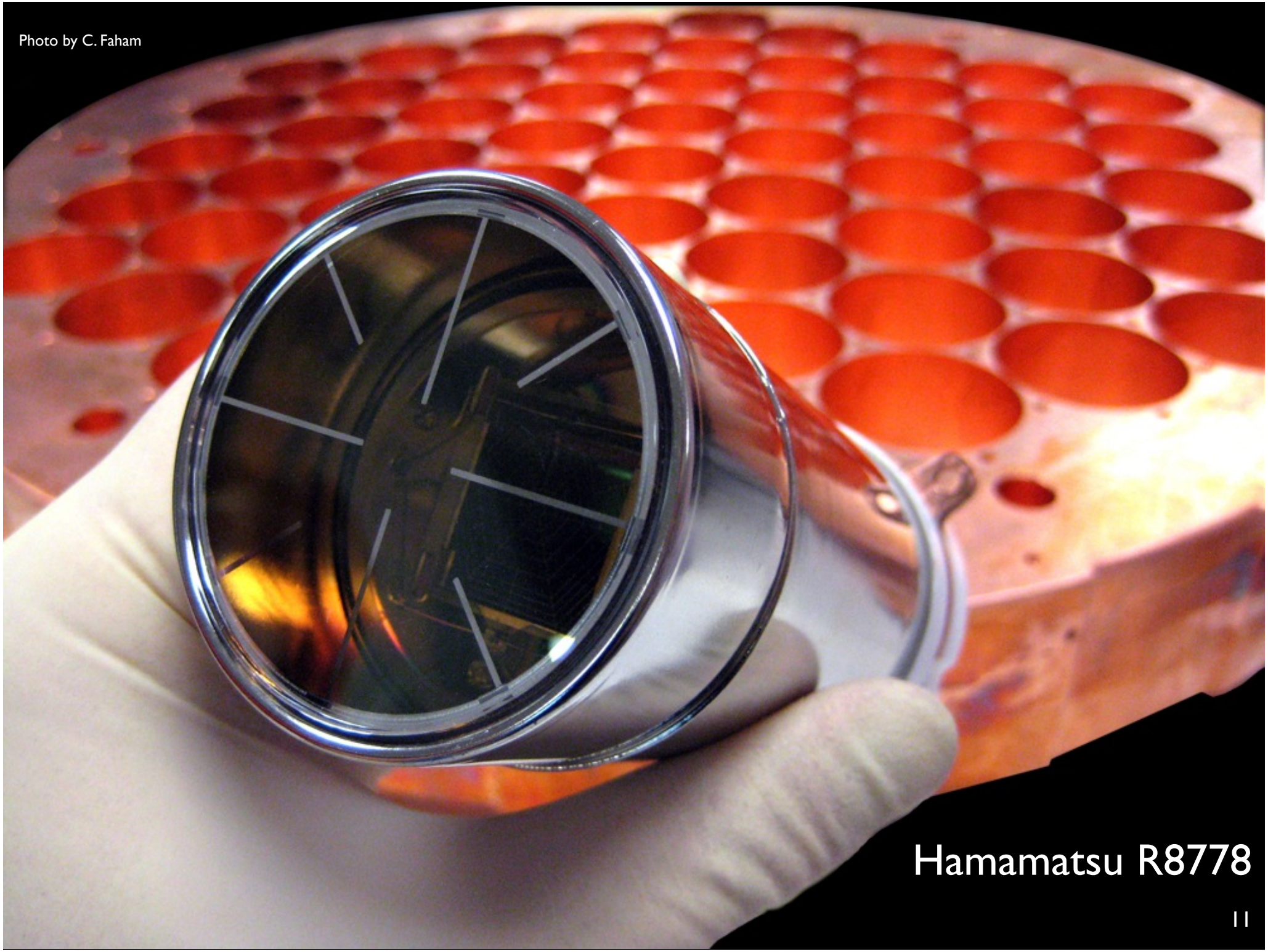


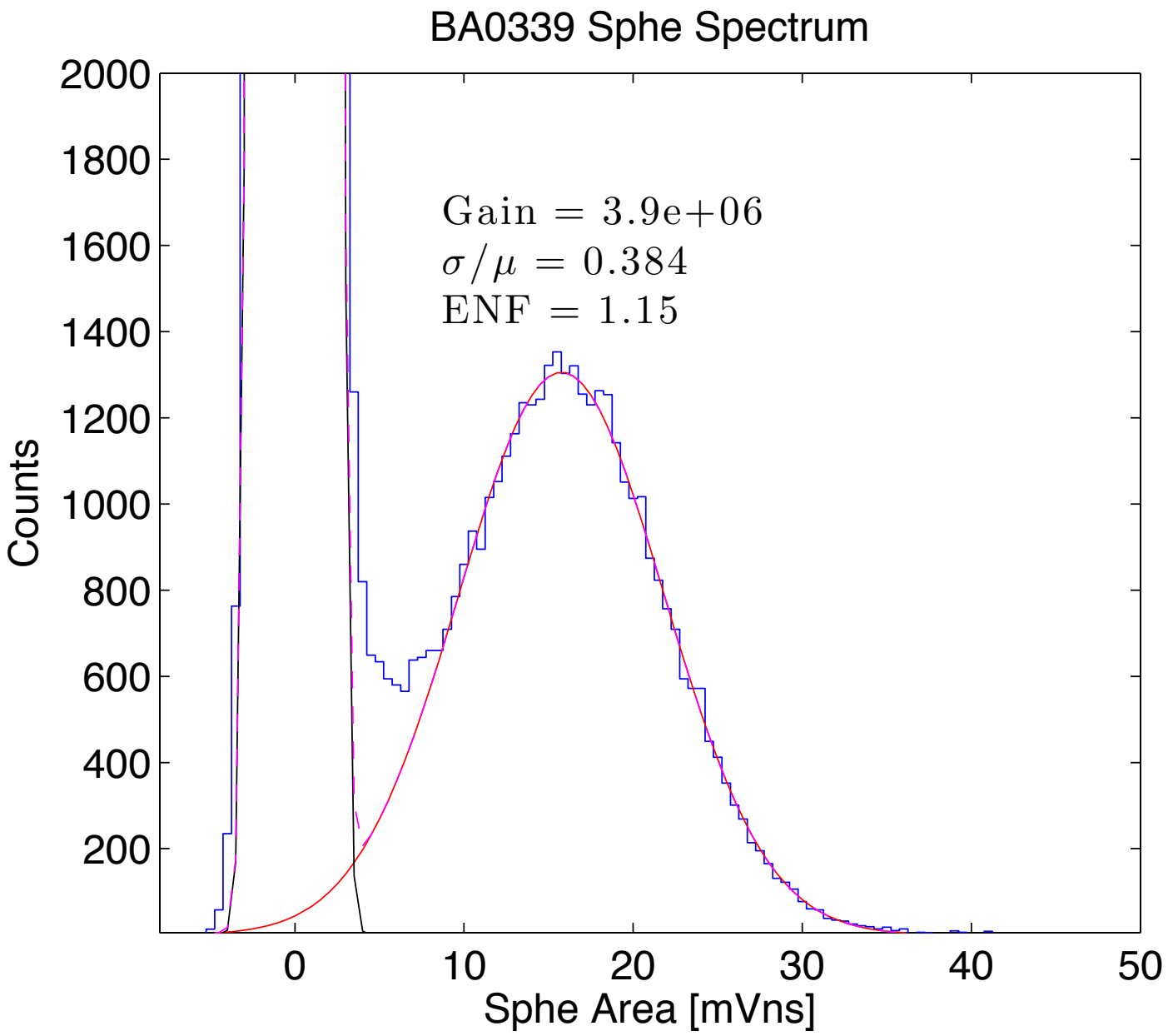
Photo by C. Faham
Hamamatsu R8778

Hamamatsu R8778: High Expectations

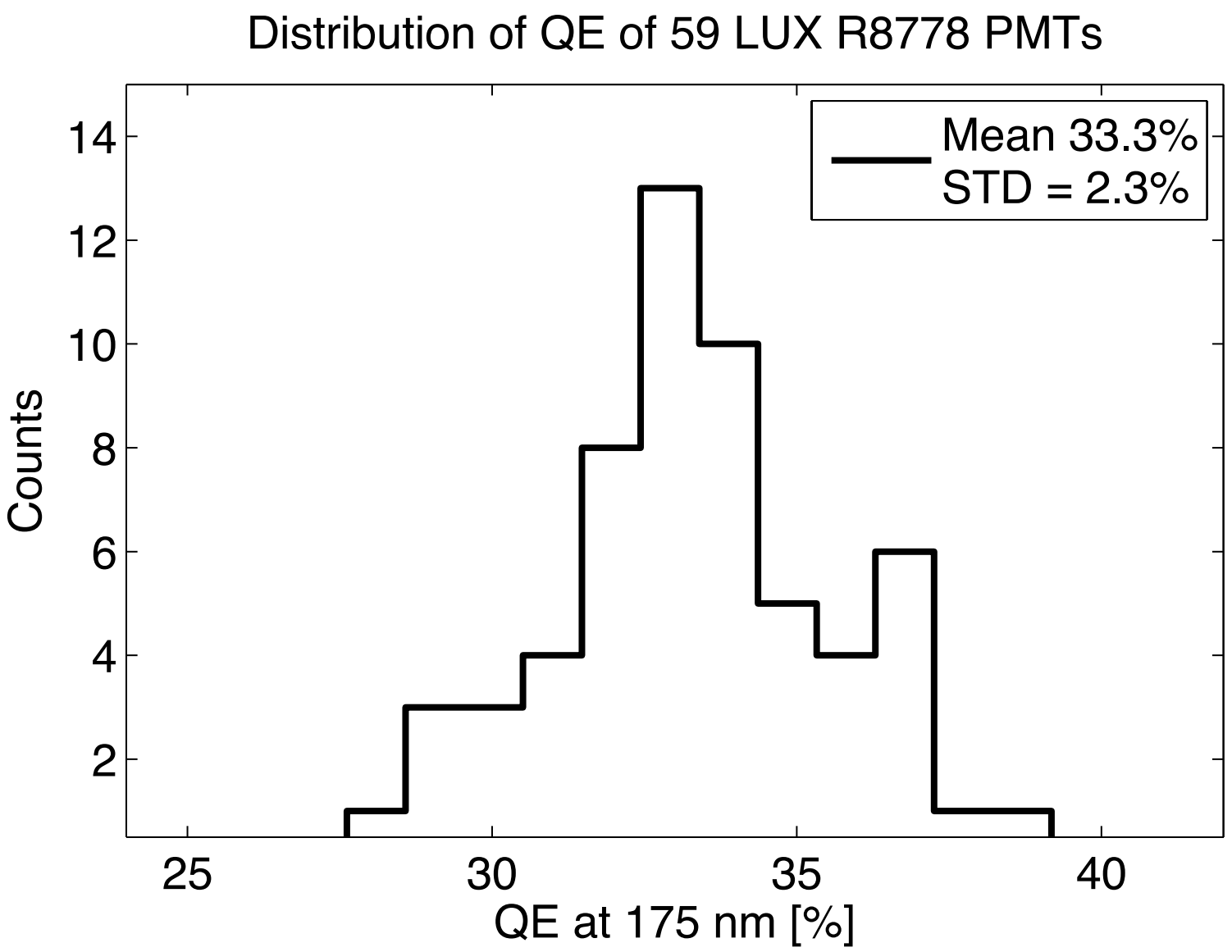
Developed by Hamamatsu Photonics, in collaboration with XMASS, specifically for liquid xenon operation

Desired Characteristic	**Value**
Operational at LXe temperatures	-110 C min. temperature
High QE at 175 nm (UV)	~33%
High CE	90%
Single-photon sensitive, good single phe resolution	~35% sphe sigma/mu (ENF ~1.15)
High peak anode current linearity	2% at 14 mA (~100 keV_{ee} S2)
Low afterpulsing	< 5% (charge) for new PMTs

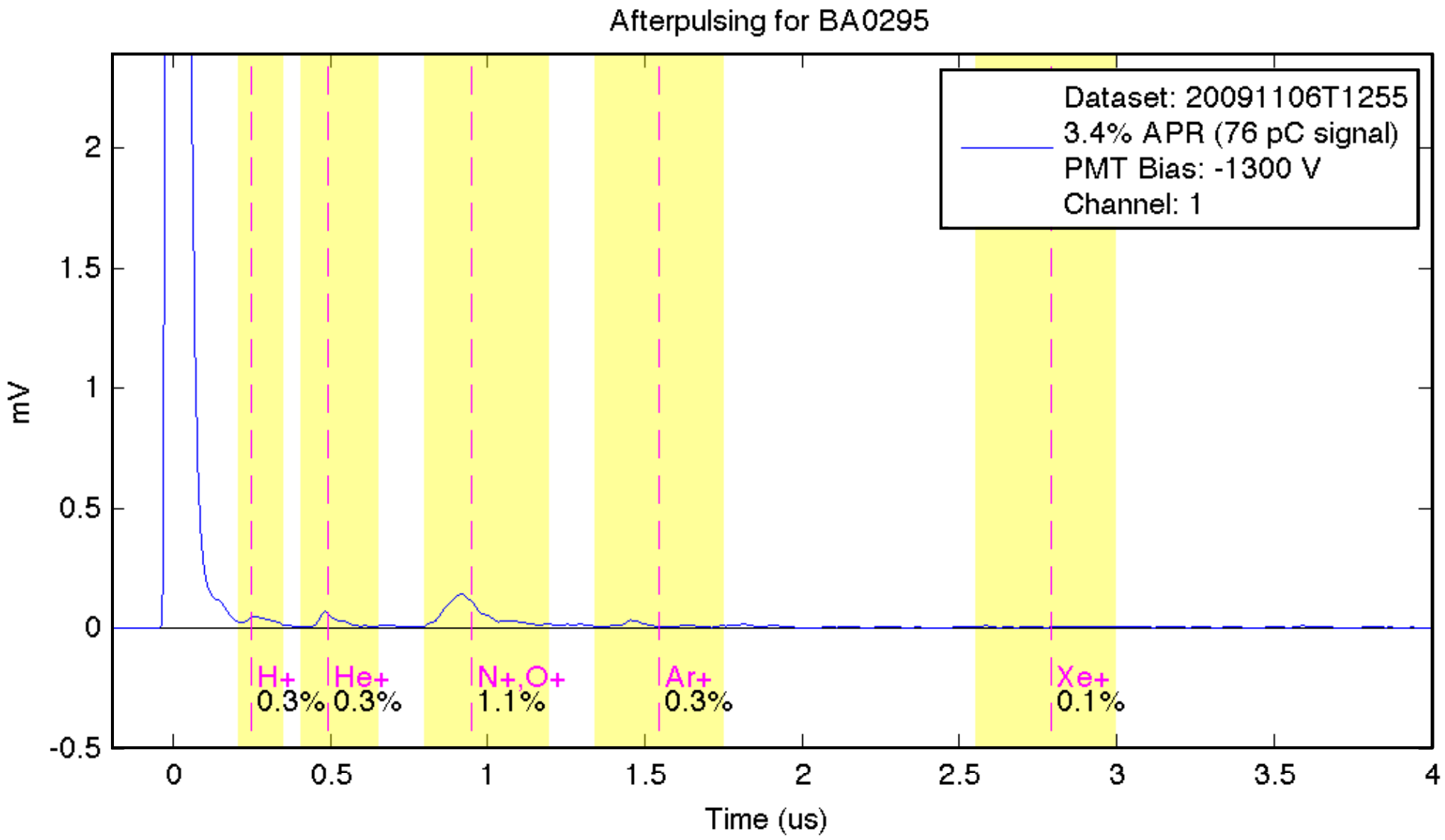
Hamamatsu R8778 Single-phe (Sphe) Spectrum



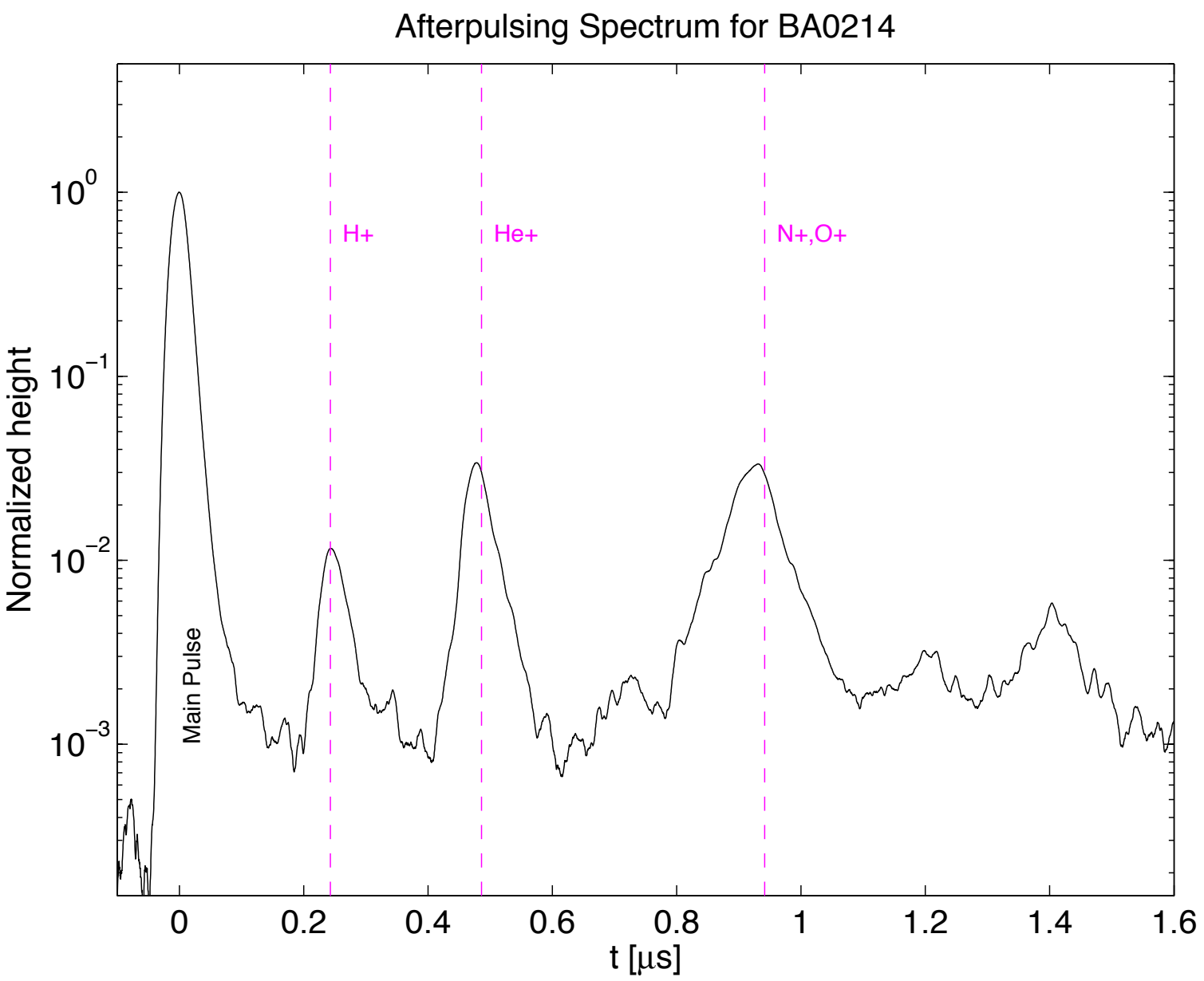
Hamamatsu R8778 QE in LUX

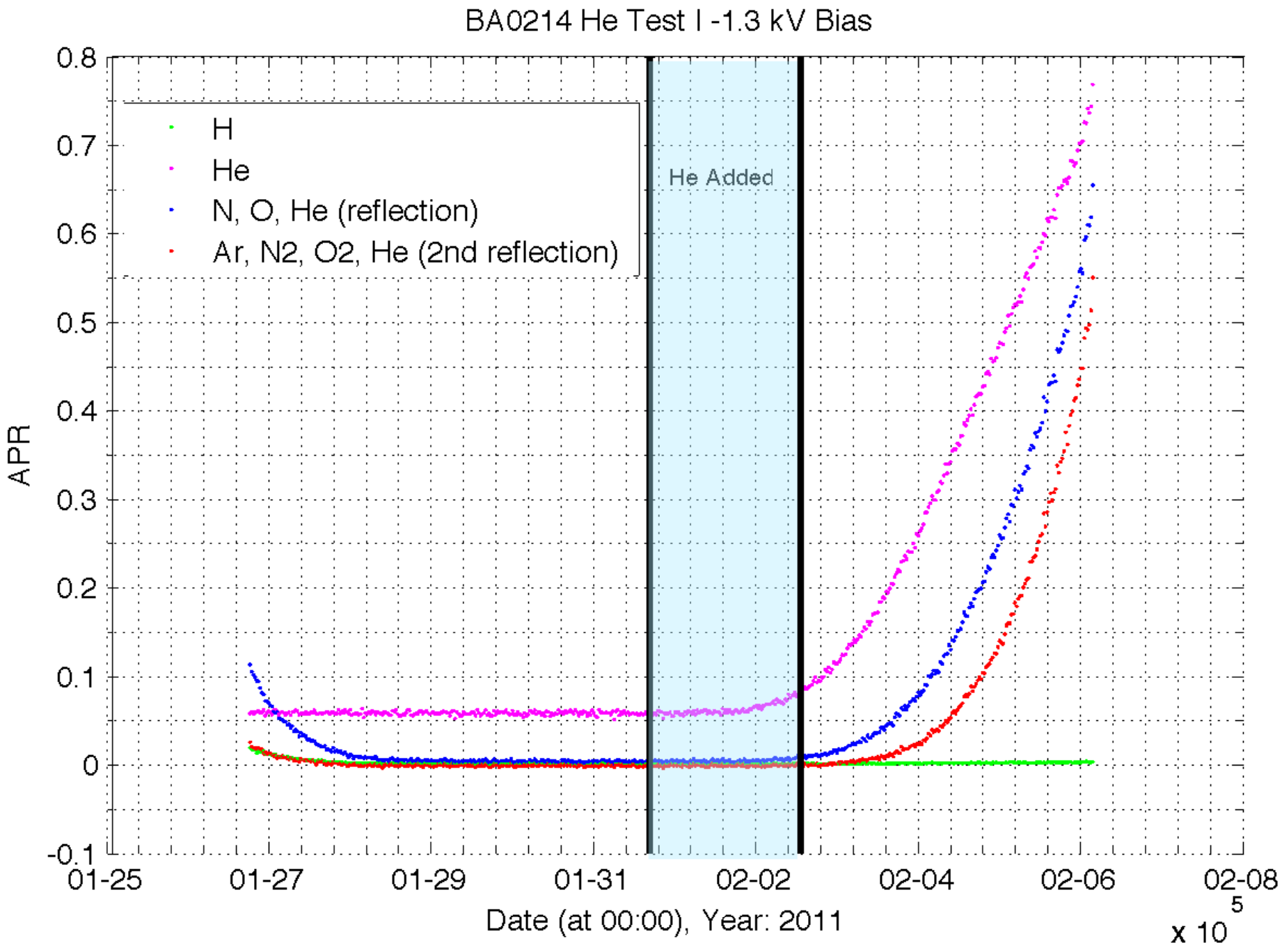


Healthy R8778 PMT Afterpulsing Spectrum

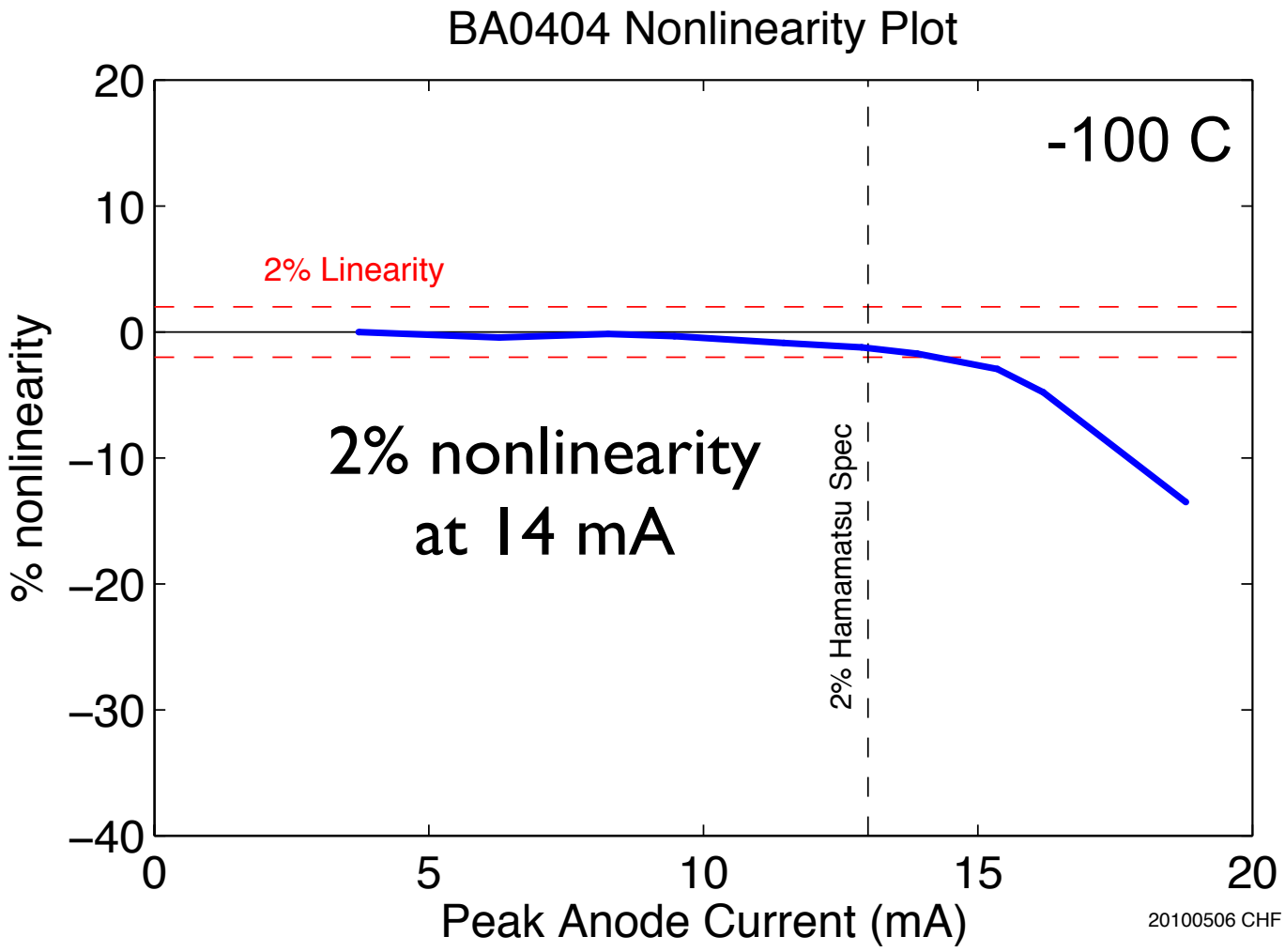


R8778 exposed to He, and having a small air leak



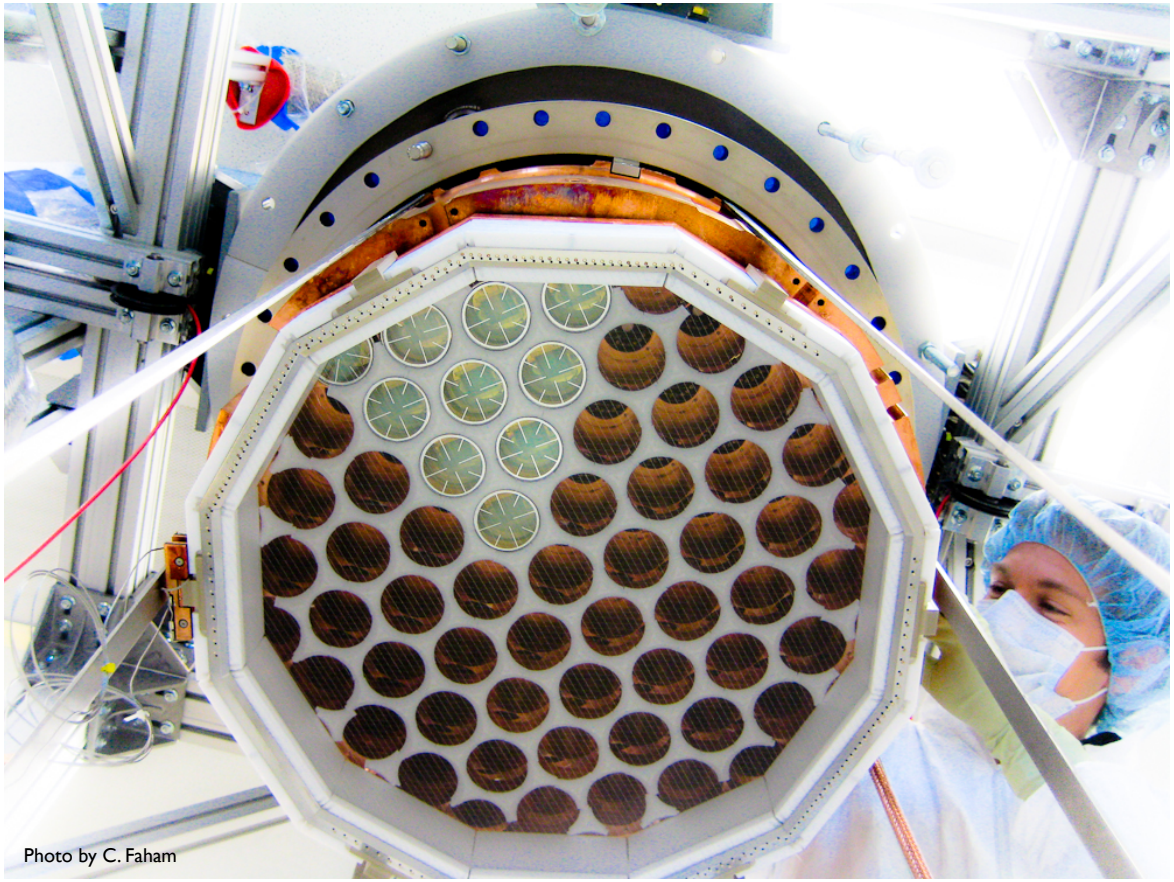

BA0214 He Test I -1.3 kV Bias
H
He
N, O, He (reflection)
Ar, N2, O2, He (2nd reflection)
He Added
APR
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
01-25
01-27
01-29
01-31
02-02
02-04
02-06
02-08
Date (at 00:00), Year: 2011
x 10^5

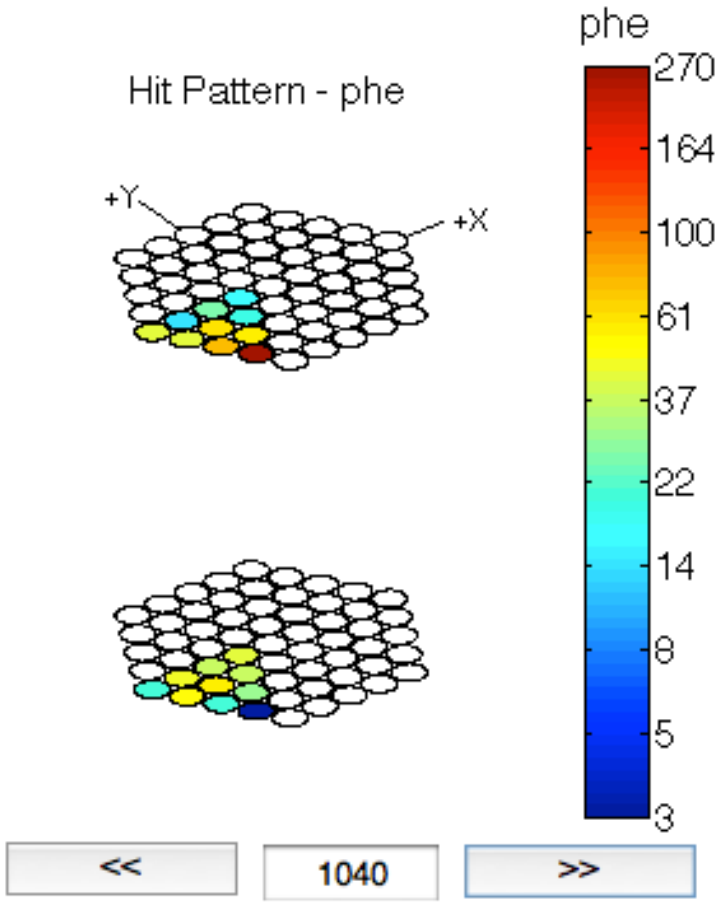
Hamamatsu R8778 Output Linearity



QUPID 2% nonlinearity ~1 mA

LUX 20 PMT Commissioning



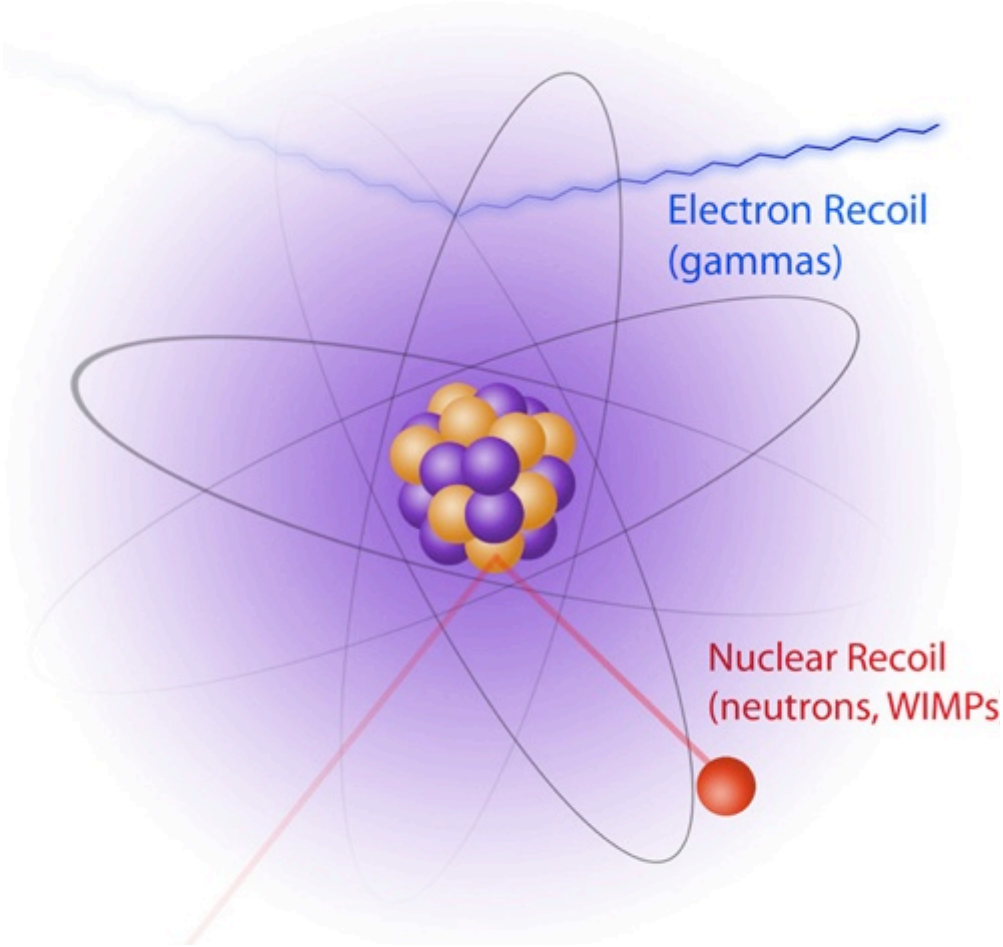


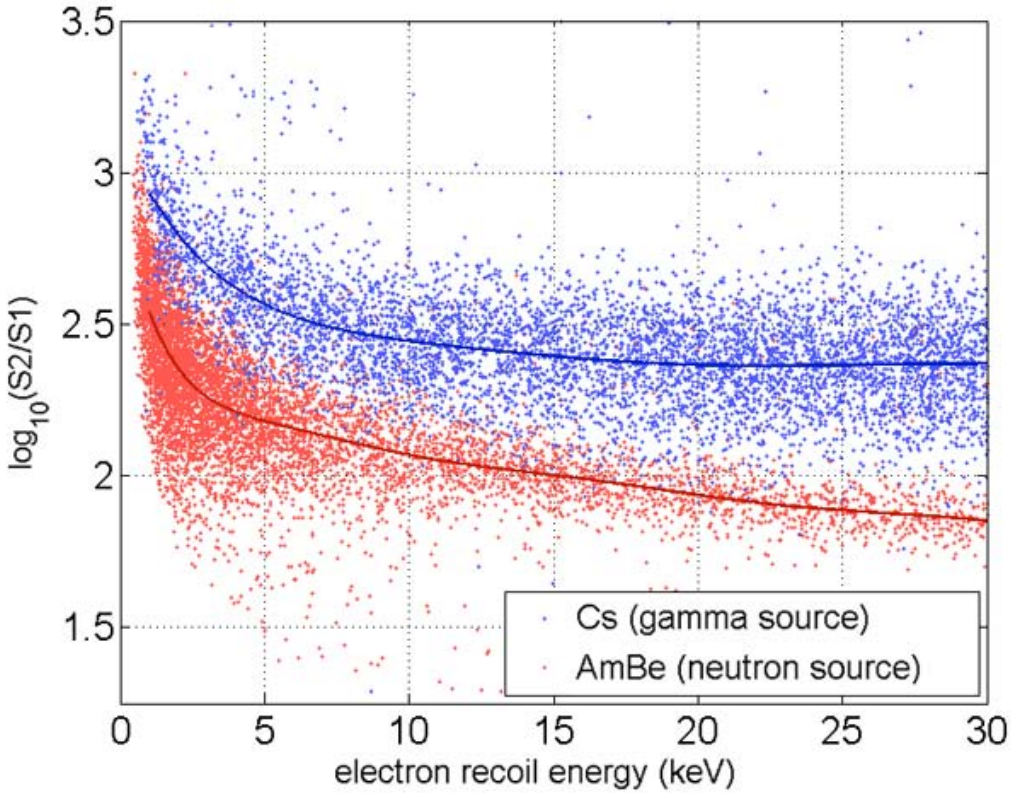
Partial PMT deployment due to pressure testing of vessel

All 122 PMTs scheduled to be deployed in July, 2011

Radioactivity

Faking a WIMP





1) Electron Recoil Leakage
2) Single-scatter neutrons
3) Other non-gaussian rare events

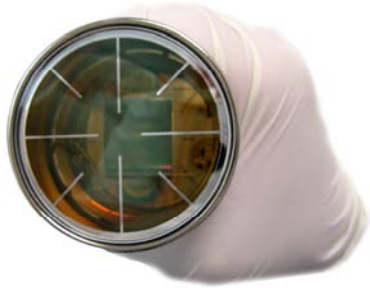
Radioactivity Comparison

10 kBq

^{40}K, ^{14}C

10 Bq

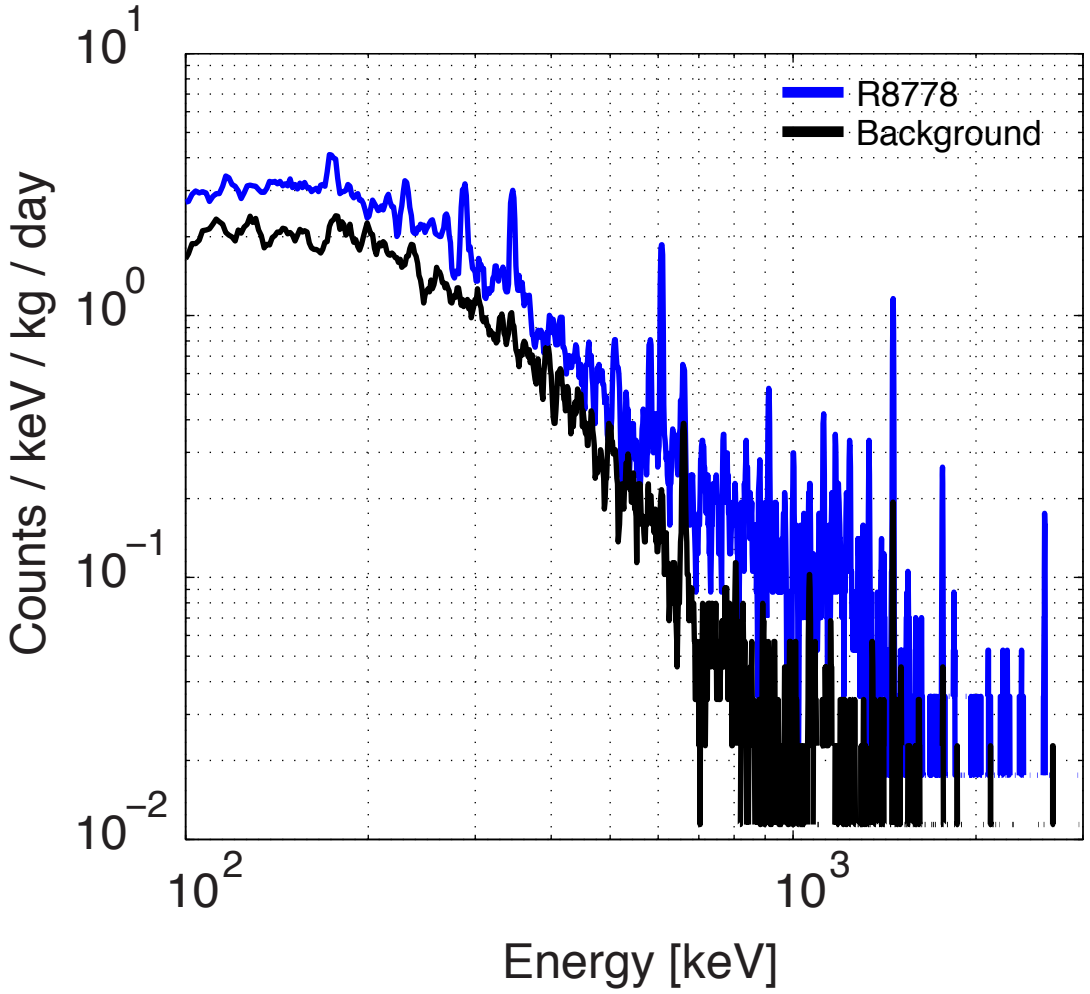
^{40}K

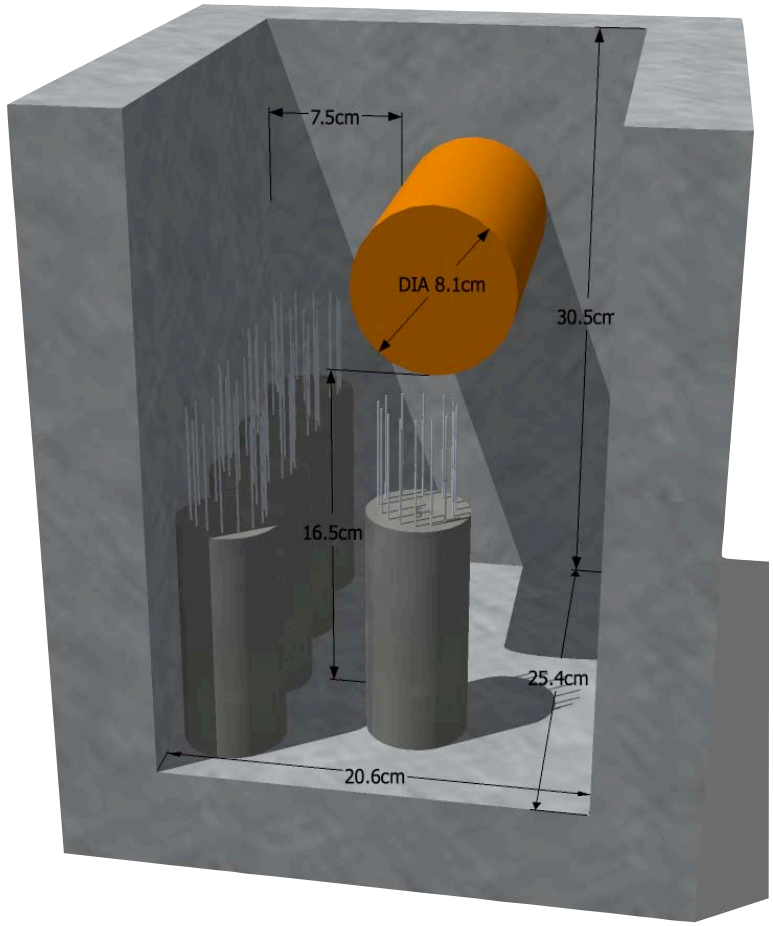


10 mBq

^{238}U, ^{232}Th, ^{40}K, ^{60}Co

LUX's R8778 Measured Radioactivity





SOLO counting facility

LUX Component Radioactivity Comparison

	Unit	Screening Result				
		U238	Th232	Co60	K40	Sc46
PMTs	mBq/PMT	9.5±0.6	2.7±0.3	2.6±0.1	66±2	
Ti	mBq/kg	<0.18	<0.25			4.4±0.3*
Cu	mBq/kg			2.1±0.19*		
PTFE	mBq/kg	<3	<1			
HDPE	mBq/kg	<0.5	<0.35			
Stainless steel**	mBq/kg			19±1		

D. Malling

**Type 304 stainless steel used in electric field grids

*Cosmogenic equilibrium at 1 mile above SL; decays below ground

These PMTs are not ultra-low background. Levels have improved much since then (see R11410 MOD radioactivity levels coming up...)

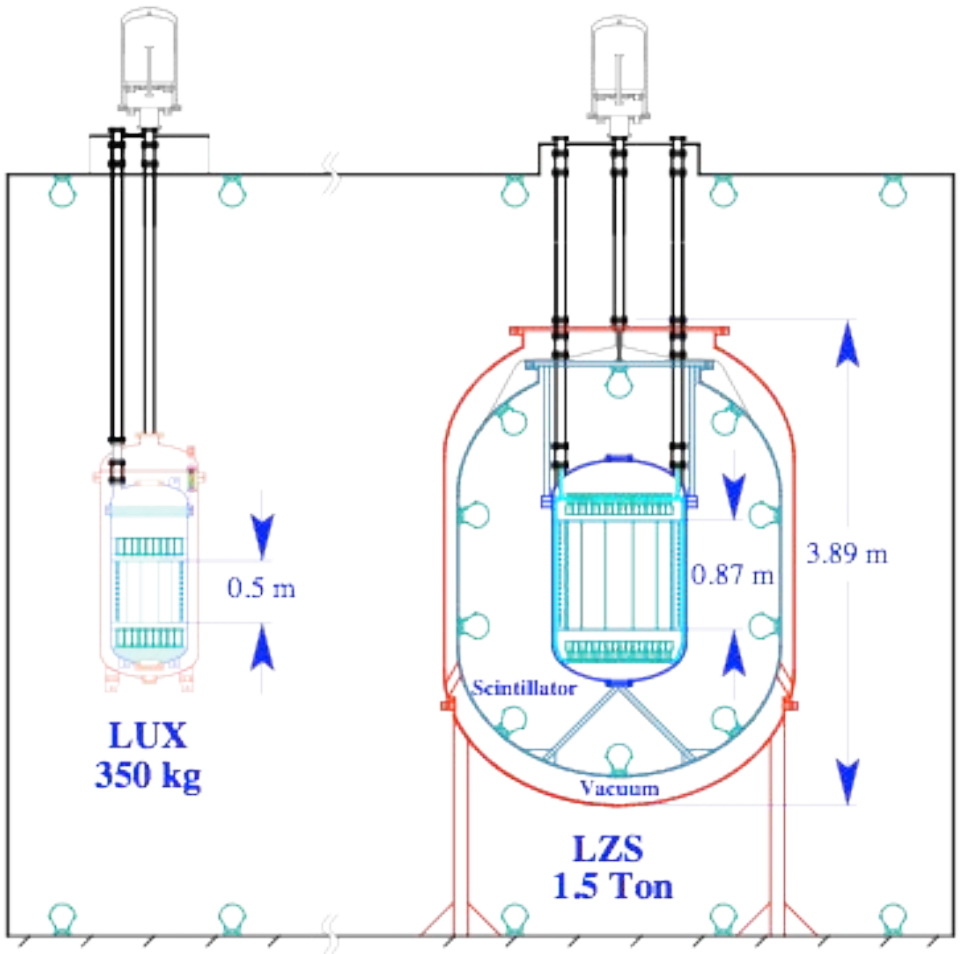
Implications for LUX

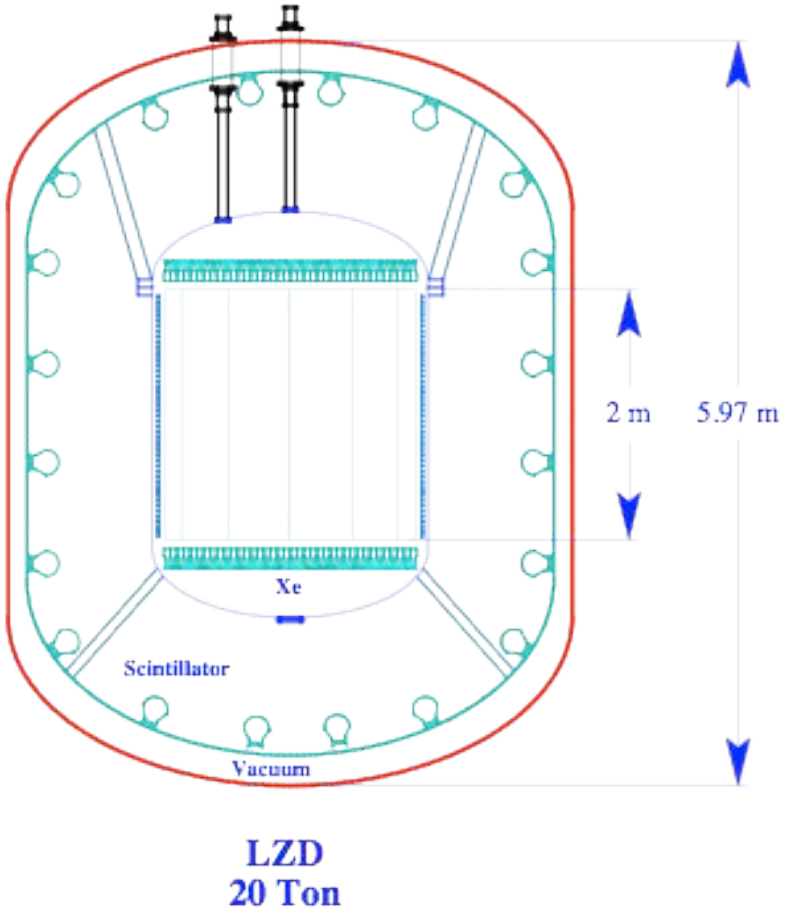
- Screening of all major components ensures <1 WIMP-like event in 300 livedays
- Sums includes applied analysis cuts
  - Energy window
  - Single-scatter
  - Fiducial
  - ER/NR rejection

	WIMP-Like Events (300 Livedays)	
	ER	**NR**
PMTs	0.4	0.03
Cryostats	<0.02	<0.002
Grid wires	<0.01	<0.001
PTFE panels	<0.05	<0.009
HDPE	<0.01	<0.002
Cu	<0.03	$<10^{-4}$
^{85}Kr	<0.07	--
Total	<0.59	<0.044

The LZS and LZD Experiments

LUX-ZEPLIN (LZ)



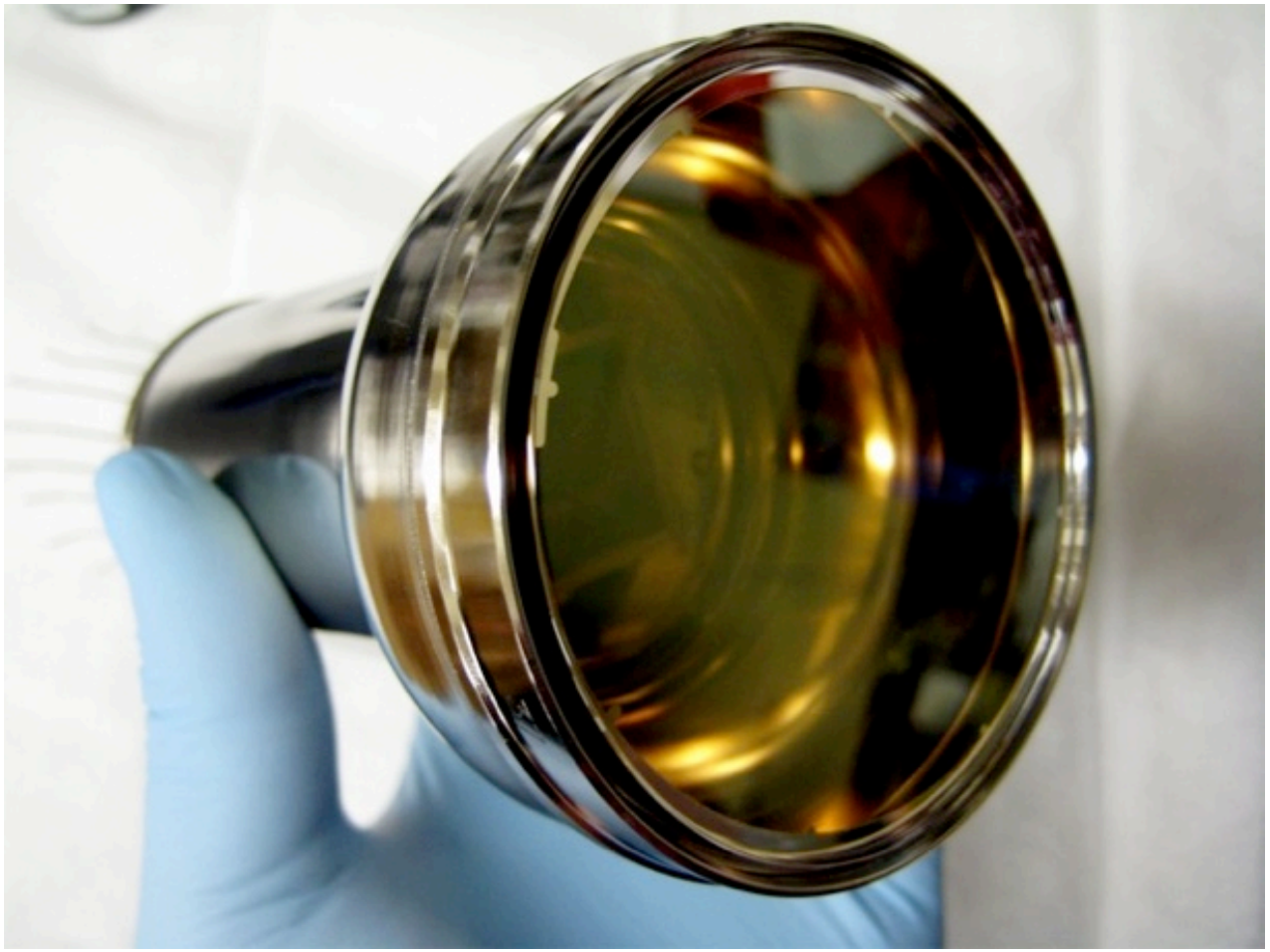


1000 3” PMTs

The Hamamatsu R11410 MOD

An ultra-low background PMT

R11410 MOD



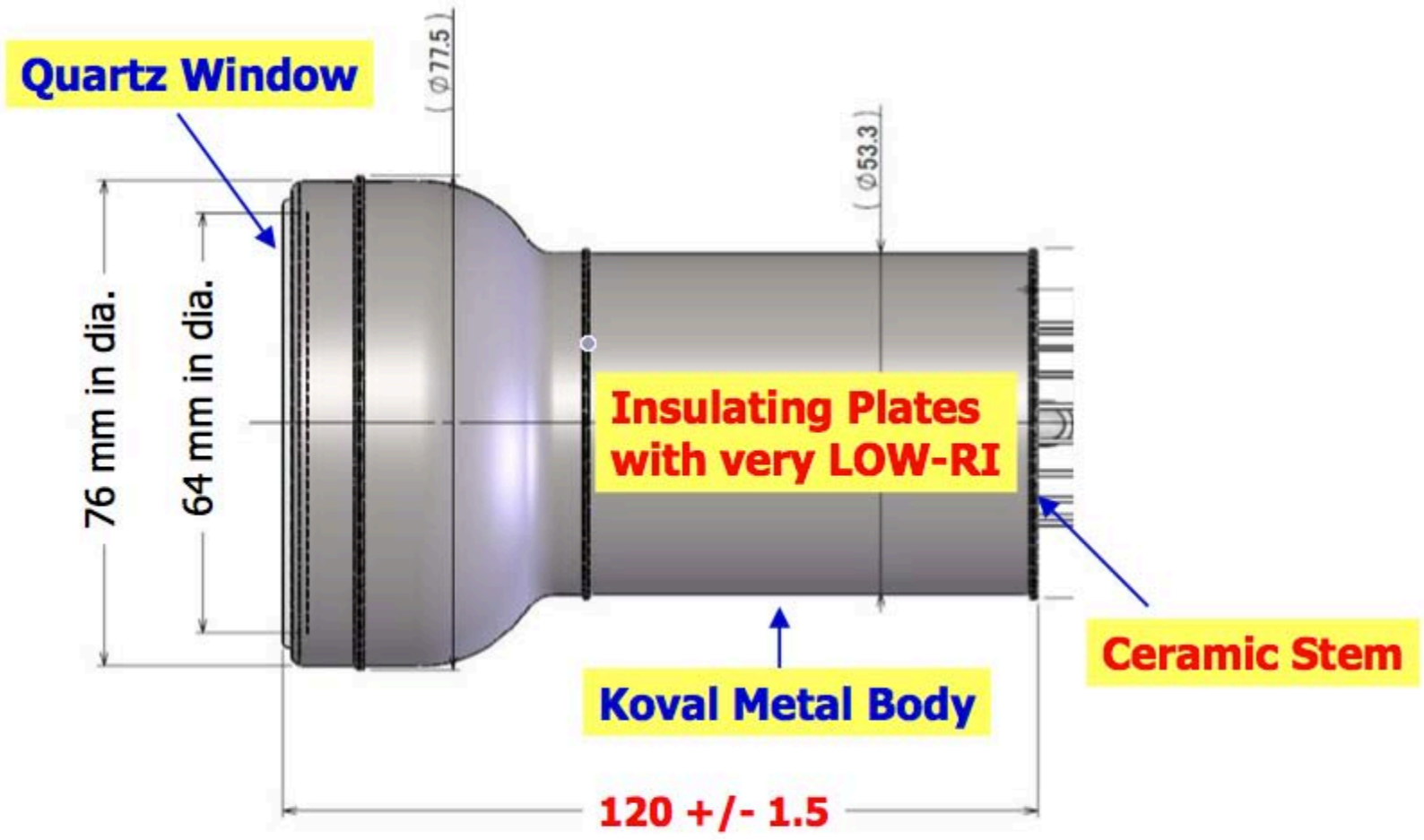
Twice the photocathode area of the R8778

QE, gain, etc. equivalent to R8778

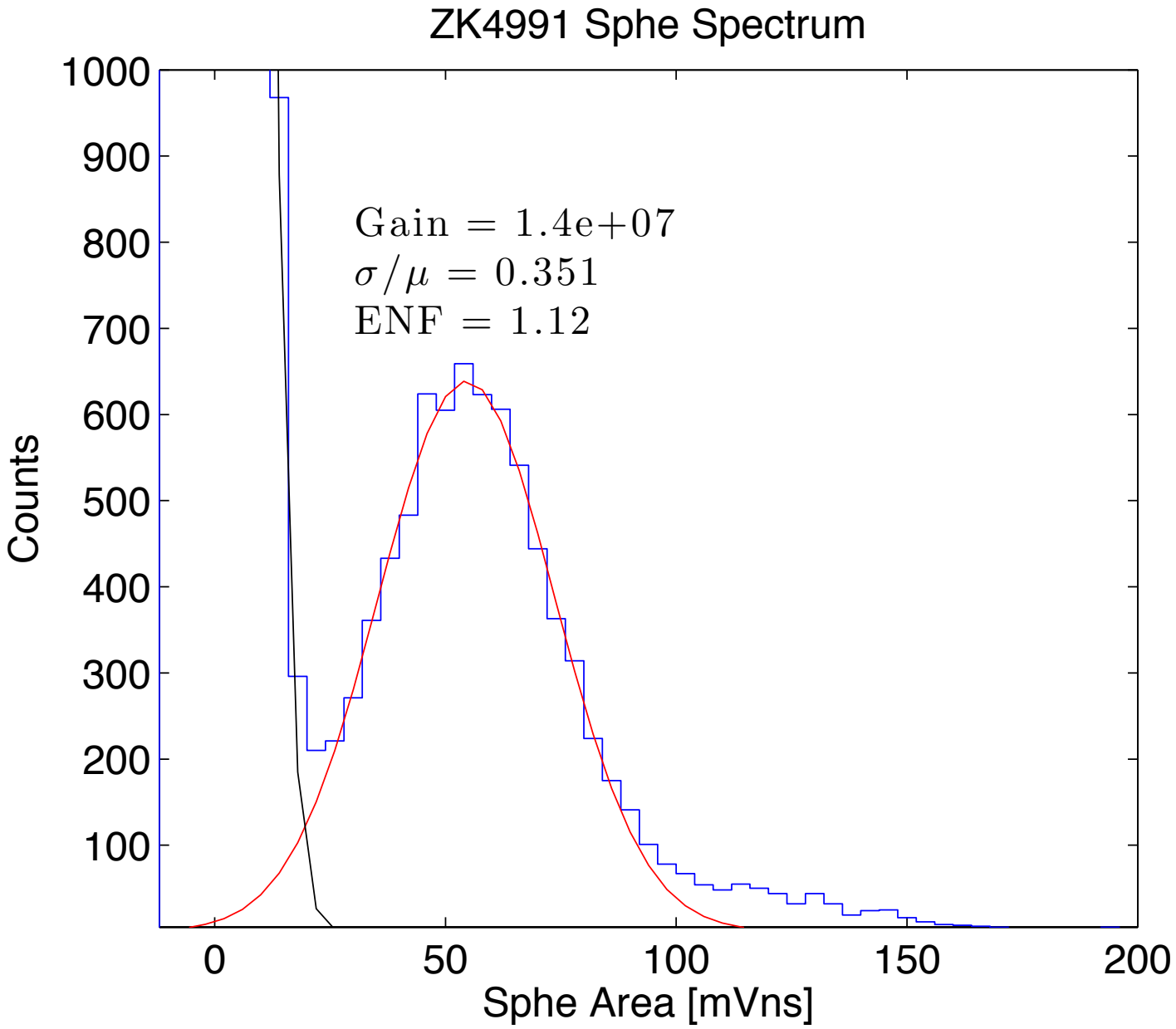
~x2 better anode linearity

See Yoshizawa's presentation

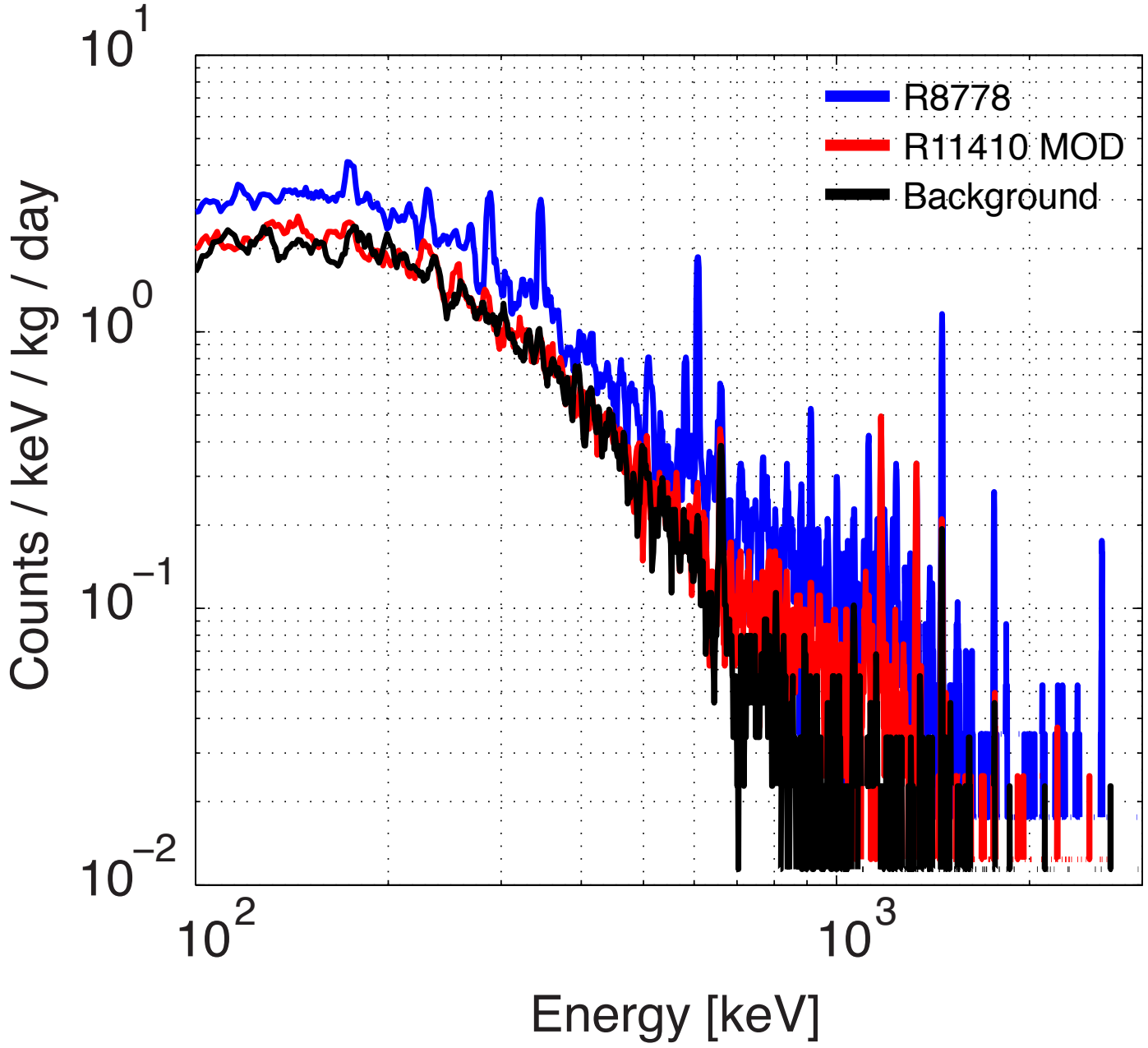
Hamamatsu R11410 MOD



Hamamatsu R11410 MOD Sphe Spectrum



Hamamatsu R11410 MOD Measured Radioactivity



Hamamatsu R11410 MOD Radioactivity Results

mBq/PMT	Decay chain
<0.4	^{238}U
<0.3	^{232}Th
<8.3	^{40}K
2 ± 0.2	^{60}Co

90% CL for upper limits, 1-sigma error bars

- ^{60}Co will be further reduced in new Hamamatsu production units by replacing Kovar metal enclosure

- Further, ^{60}Co always decays with correlated gammas, making the single-scatter probability lower

- ^{40}K only has a 10% BR to EC + gamma decay mode

Conclusions

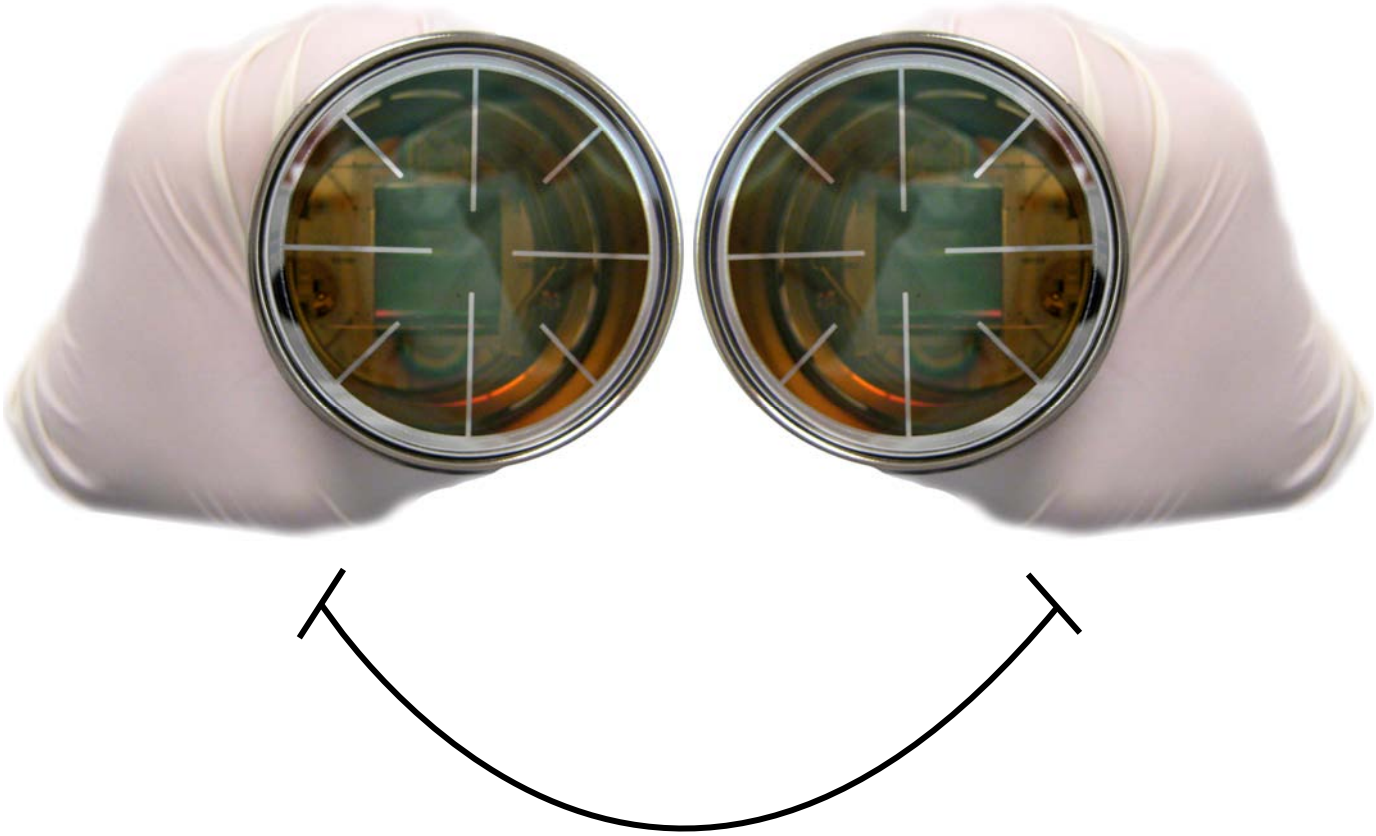
- LUX employs 122 Hamamatsu R8778 for signal detection. These PMTs fulfill all performance benchmarks for physics requirements.
  - They are the dominant source of radioactivity in LUX.
  - However, measured radioactivity levels yield <1 WIMP-like event in 300 days.

- New ultra-low background Hamamatsu R11410 MOD PMTs have been measured to have < 1 mBq/PMT combined U/Th.
  - Co remains at 2.0 ± 0.2 mBq, but will be removed by Hamamatsu in future productions by changing Kovar enclosure
  - K, at 10% gamma decay BR, has negligible effects in backgrounds

- Performance of R11410 MOD is identical to the thoroughly tested R8778 PMTs. The LZS and LZD experiments will greatly benefit from using these PMTs.

- This new technology is the best available in PMTs, and has equivalent radioactivity levels to those of QUPIDs.

- Background reduction in photodetectors beyond current limits will not result in further gains for dark matter experiments, as coherent atmospheric neutrino scattering will remain the limiting background signal.



Thank you

Extra Slides

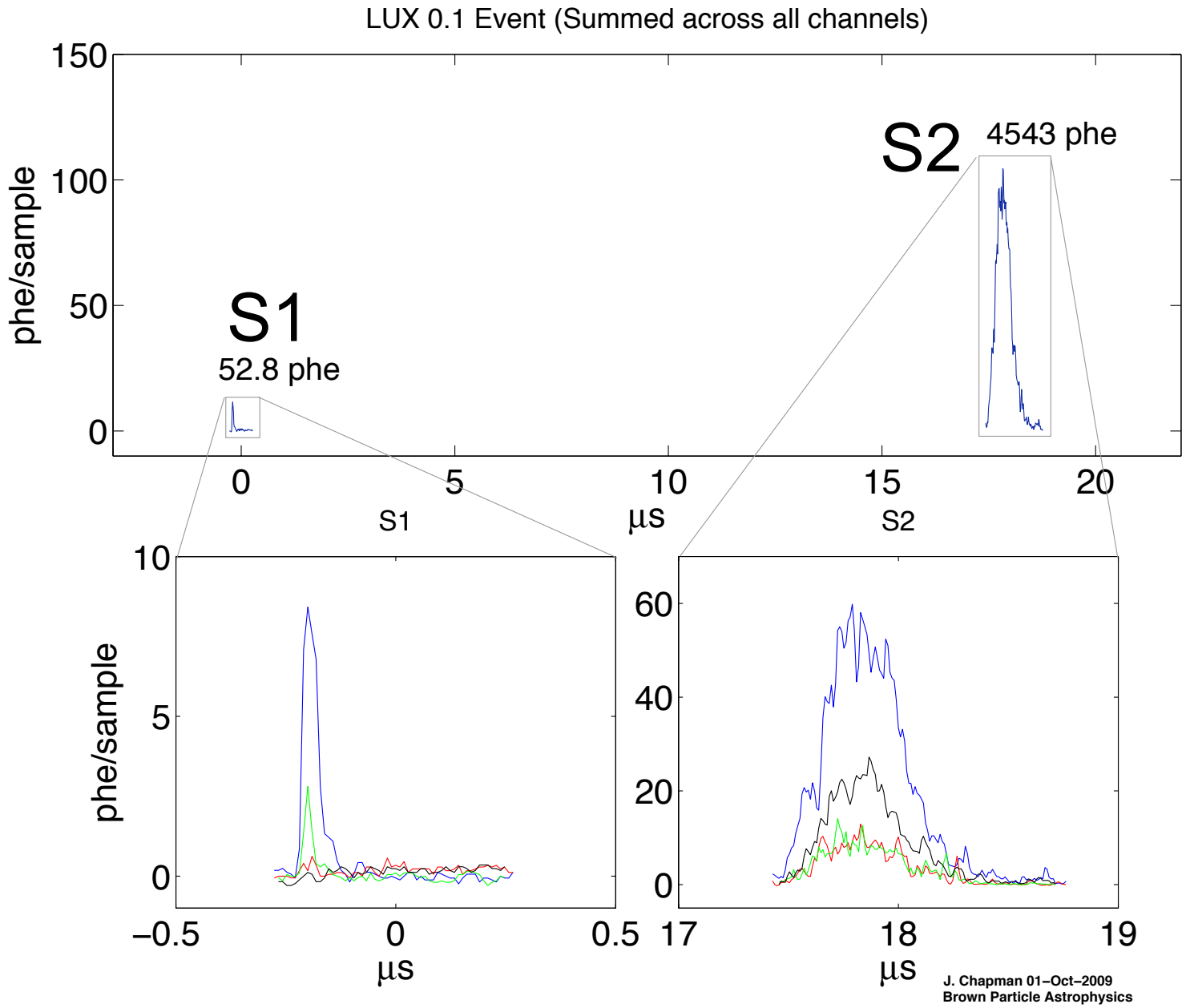

LUX 0.1 Event (Summed across all channels)
150
100
50
0
phe/sample
S1
52.8 phe
S2
4543 phe
0
5
10
15
20
µs
S1
S2
10
5
0
phe/sample
–0.5
0
0.5
µs
60
40
20
0
17
18
19
µs
J. Chapman 01–Oct–2009
Brown Particle Astrophysics

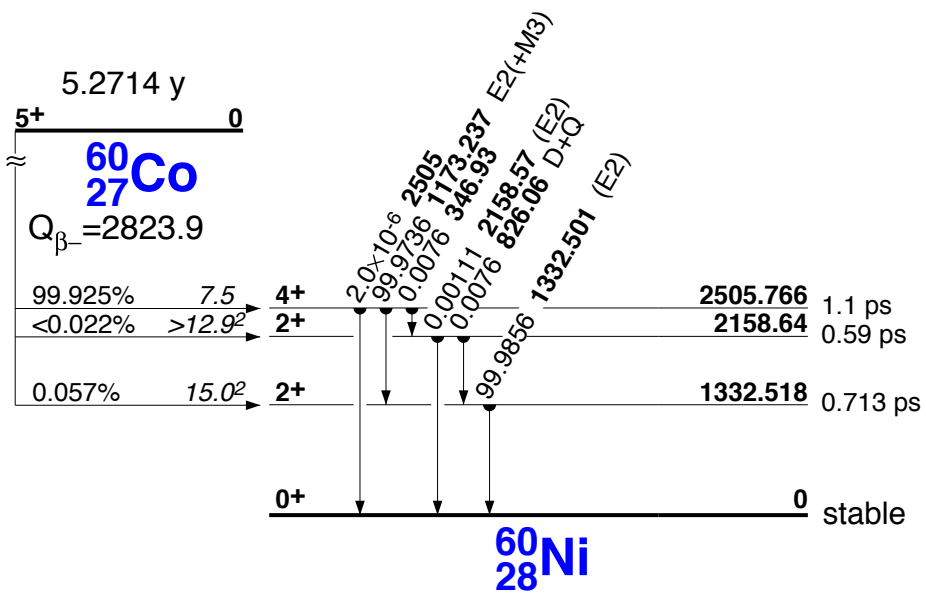
Photo by J. Chapman

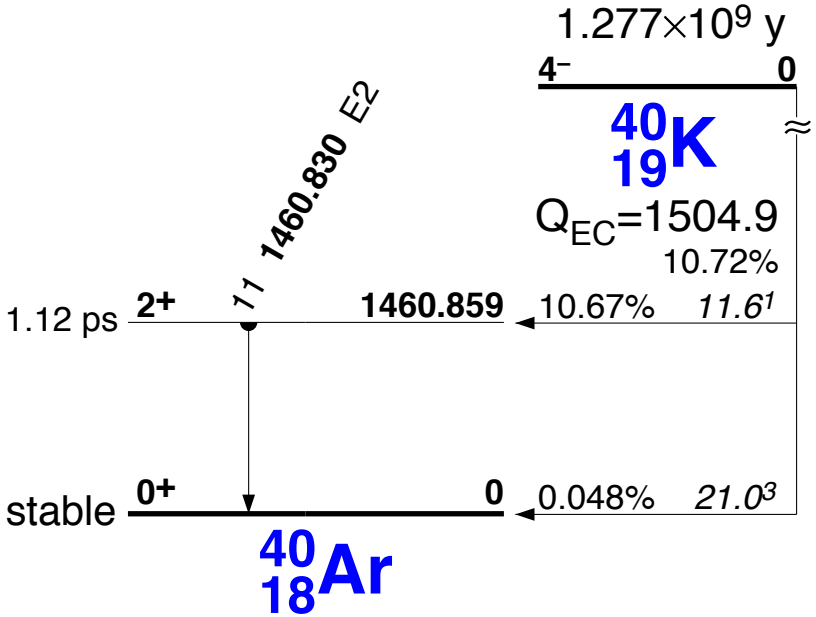
SOLO

Soudan Low-Background Counting Facility

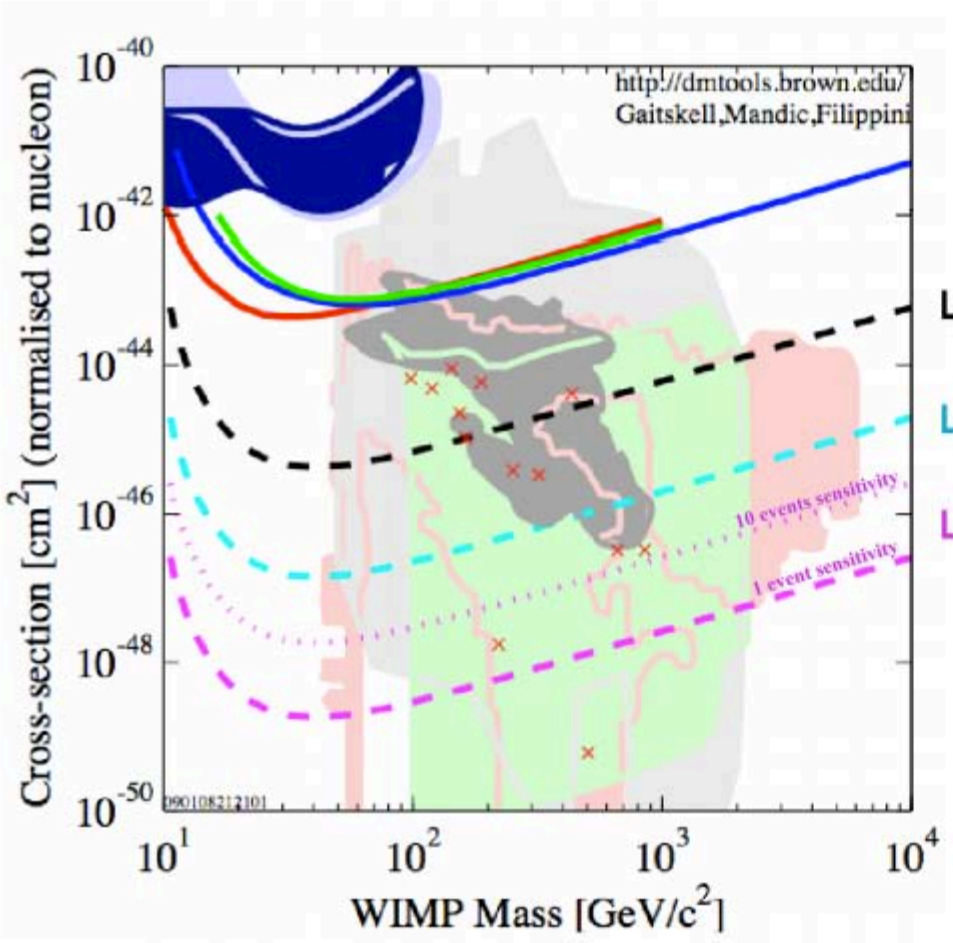
- 0.6 kg HPGe detector, 0.15 cm copper shield
- Located at the Soudan Underground Laboratory (2000 mwe)
- >30 cm lead shielding
- The inner 5 cm lining of the chamber is comprised of ancient lead, with ^{210}Pb activity measured below 50 mBq/kg
- A mylar shell and 2.5 slpm nitrogen gas purge are used to eliminate gaseous radon from the chamber

Co-60 and K-40 Decay Chains





LUX, LZS and LZD Sensitivities



- Projections based on
  - Known background levels
  - Previously obtained e$^-$ attenuation lengths and discrimination factors

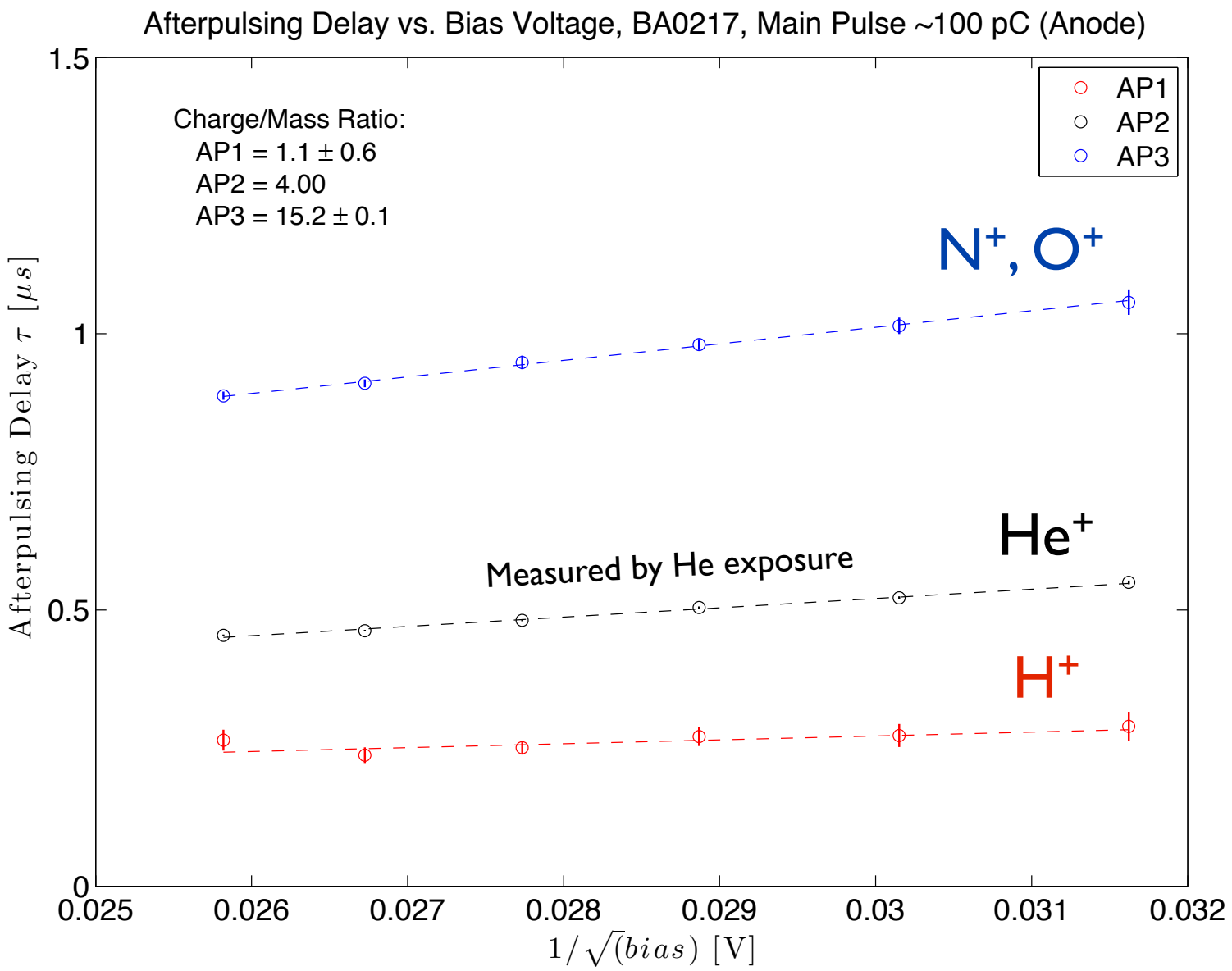
LUX (constr: 2009-2011, ops: 2011-2012)
100 kg x 300 days

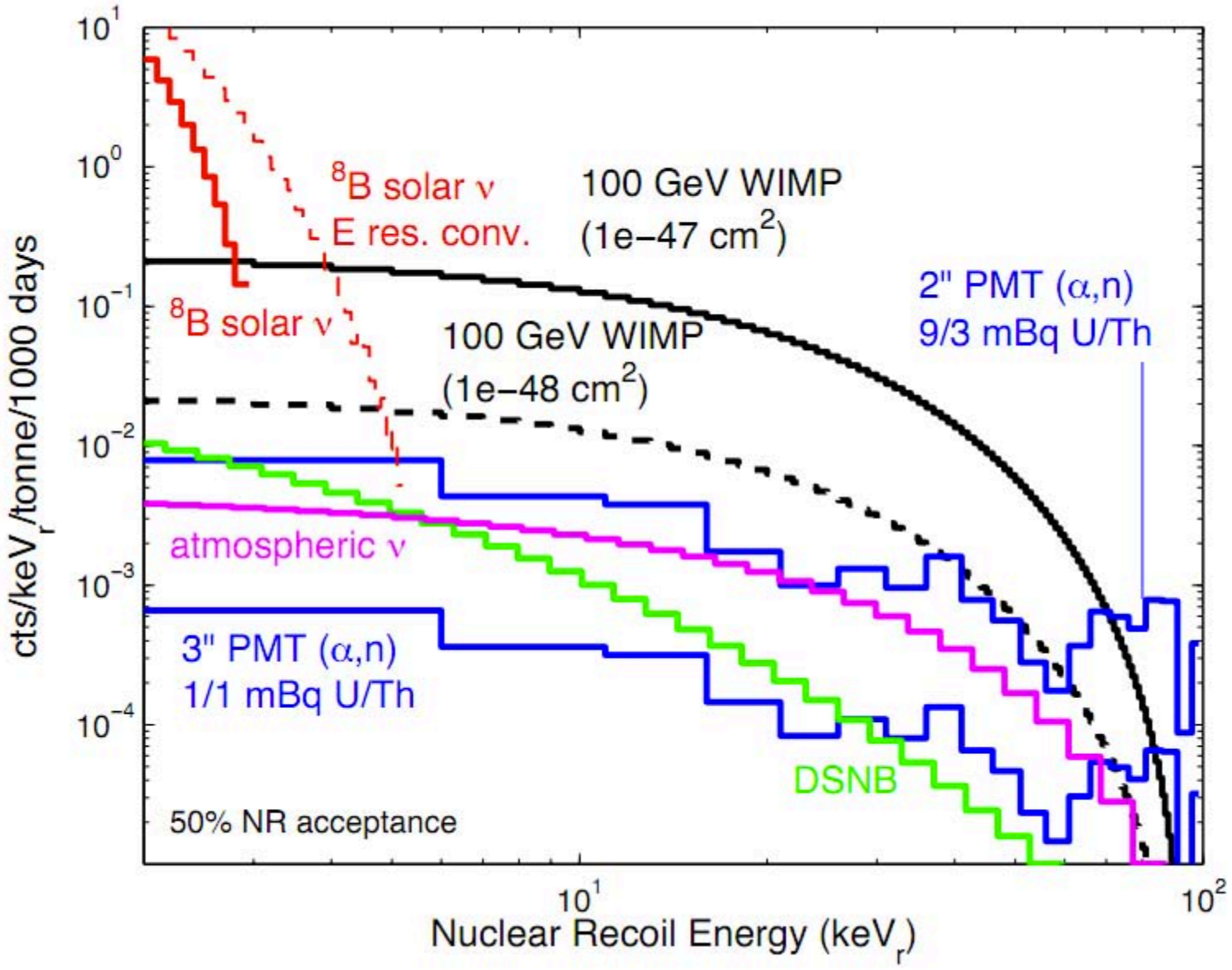
LZ-S (constr: 2012-2013, ops: 2013-2014)
1,200 kg x 500 days

LZ-D (constr: 2014-2017, ops: 2017-2022)
17,000 kg x 1,000 days

- Fiducial volumes selected to match < 1 NR event in full exposure

Afterpulsing Delay - Ion Identification




cts/keV$_r$/tonne/1000 days
Nuclear Recoil Energy (keV$_r$)
^{8}B solar ν
E res. conv.
^{8}B solar ν
100 GeV WIMP
(1e−47 cm^2)
100 GeV WIMP
(1e−48 cm^2)
2" PMT (α,n)
9/3 mBq U/Th
atmospheric ν
3" PMT (α,n)
1/1 mBq U/Th
DSNB
50% NR acceptance