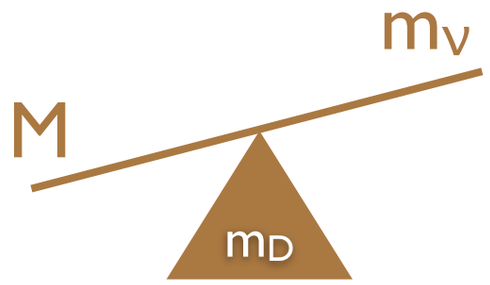
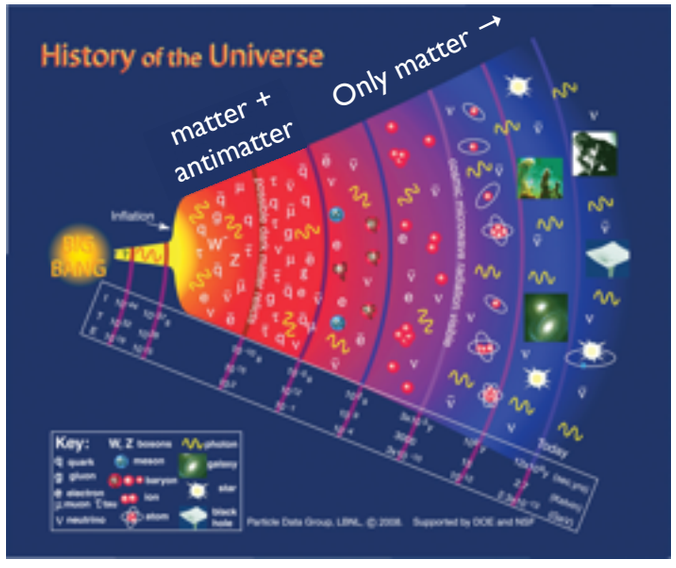
Double-Beta Decay:
Experiments and Site Needs

Jason Detwiler
University of Washington
CJPL Town Meeting, Asilomar, CA
September 8, 2013

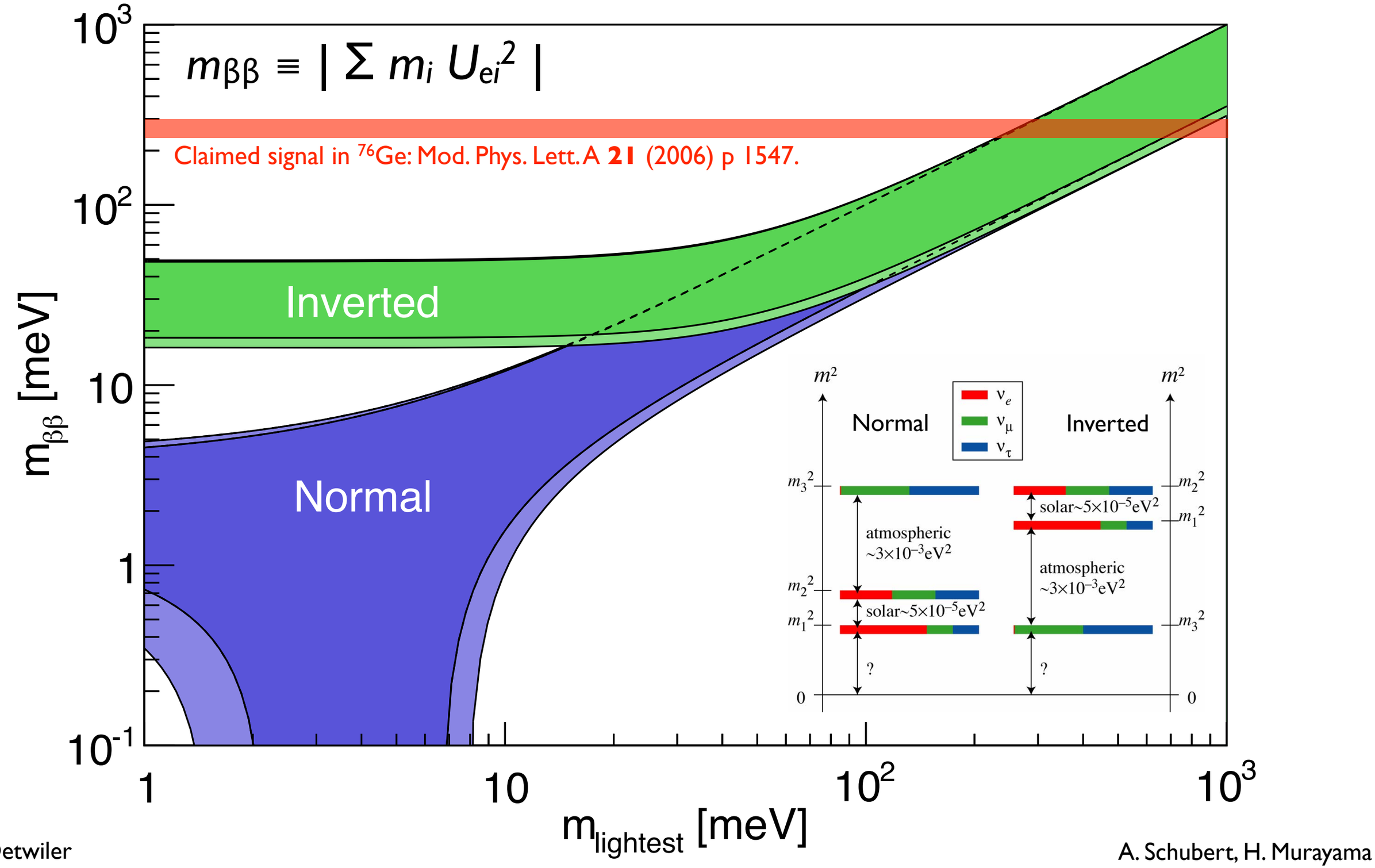
Majorana Neutrinos

- "Natural" models for small m_ν
- Connection to GUT-scale physics
- Implies L violation
- Allows for viable models of matter dominance
- Neutrinoless double-beta decay is currently the only viable probe





Neutrinoless Double-Beta Decay



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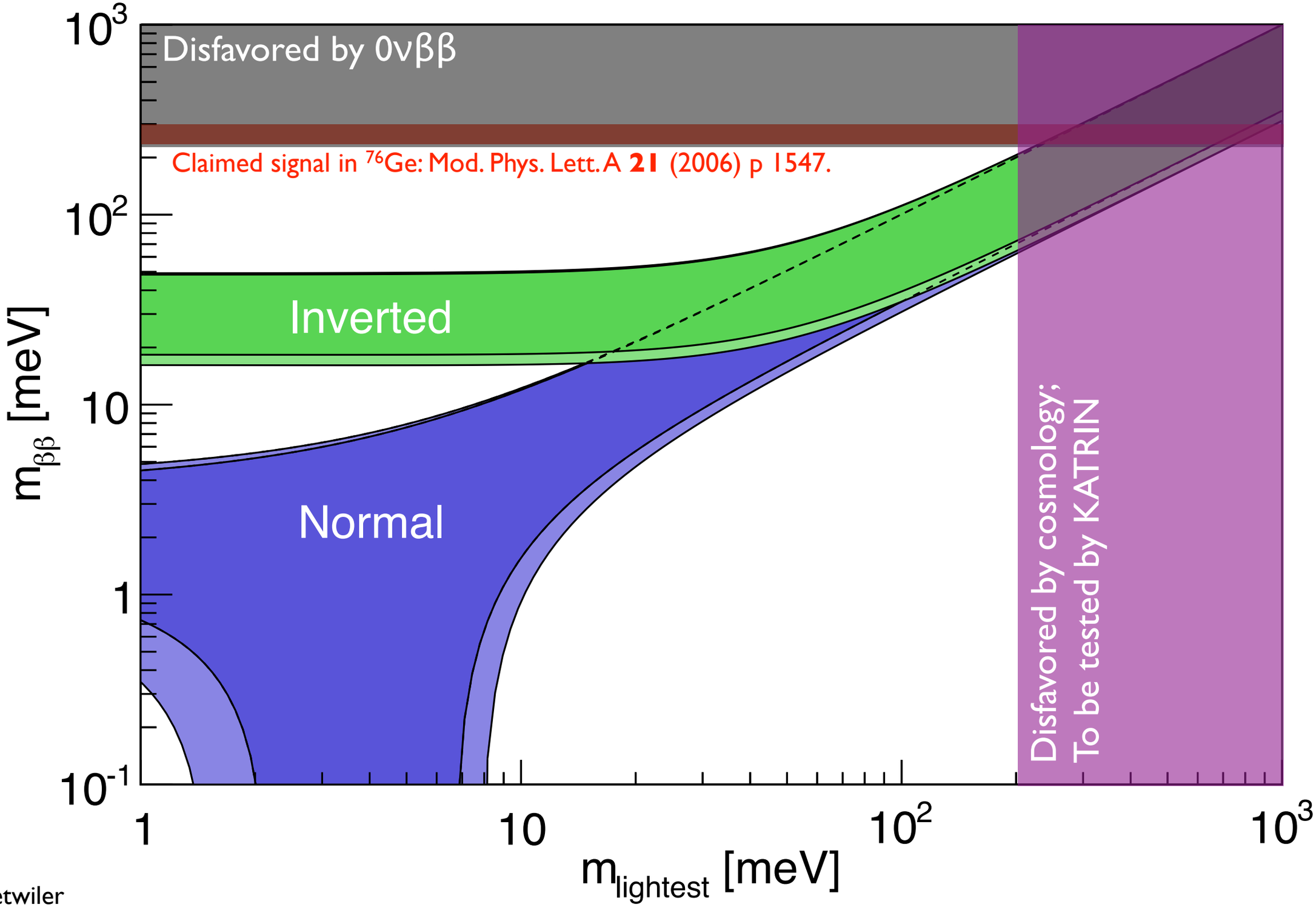
A. Schubert, H. Murayama

Neutrinoless Double-Beta Decay



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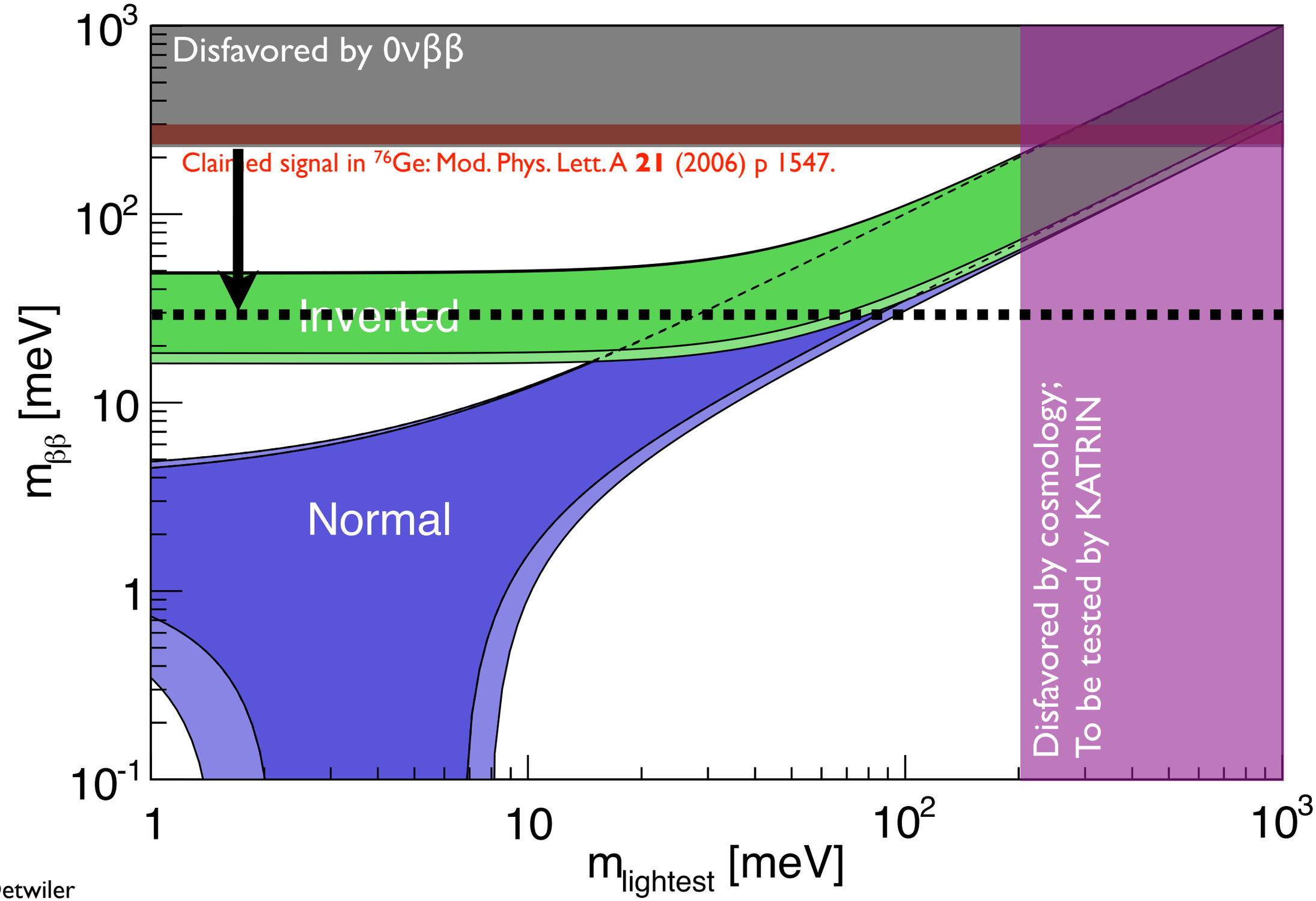
Neutrinoless Double-Beta Decay



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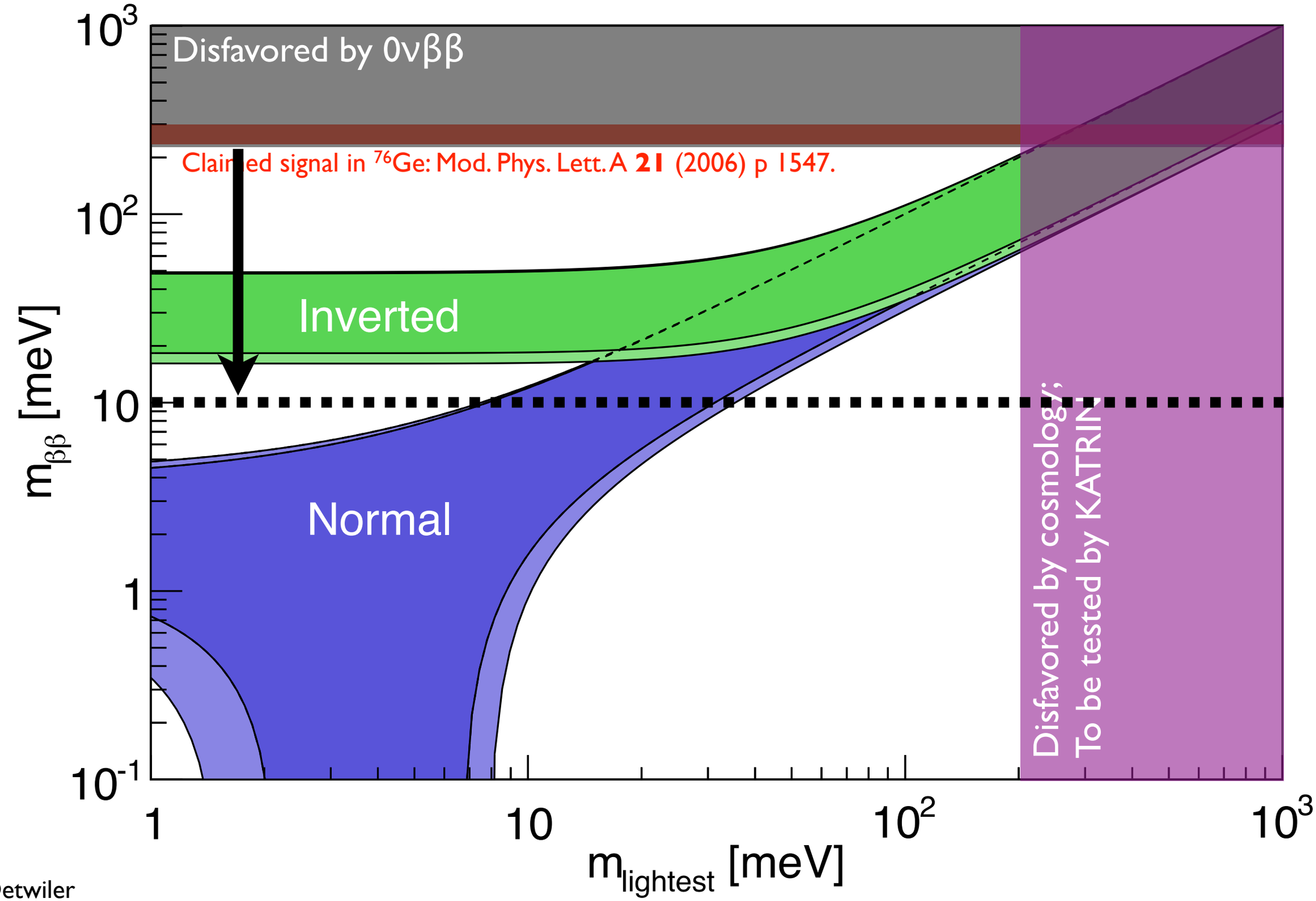
Neutrinoless Double-Beta Decay



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Combination with ν Oscillation

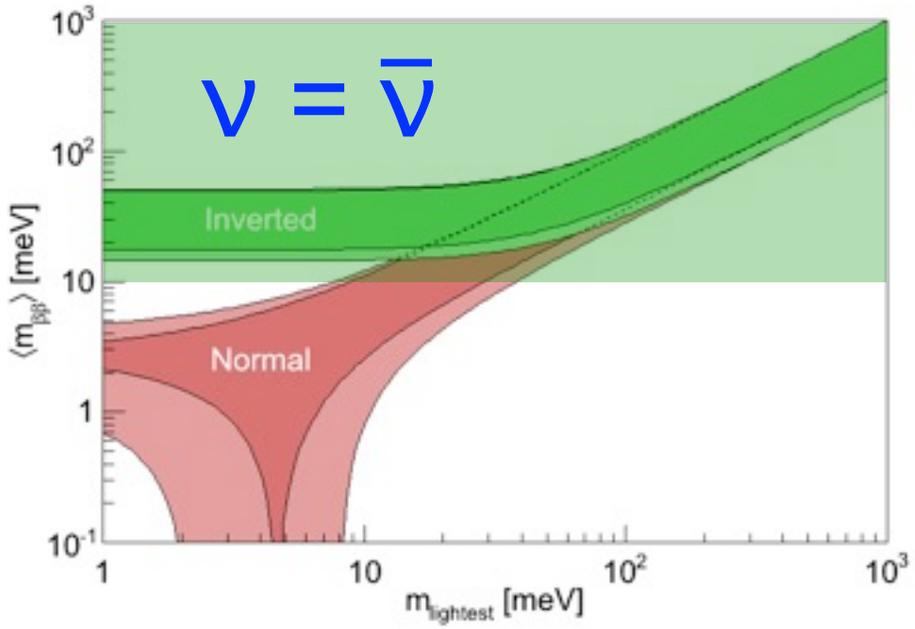
Next-Generation 0νββ Decay

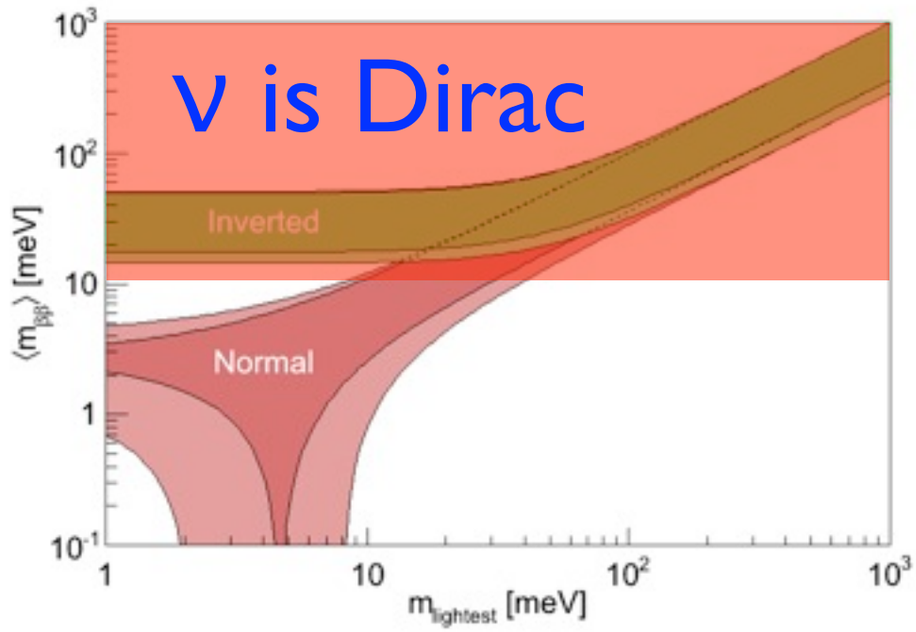
Observed

Not observed

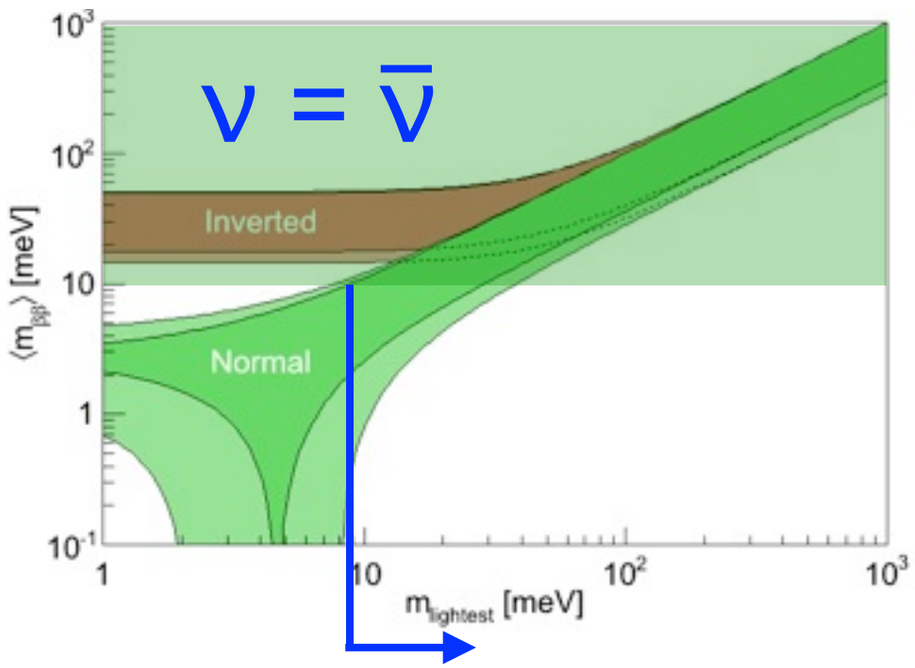
ν Oscillation: Hierarchy

Inverted

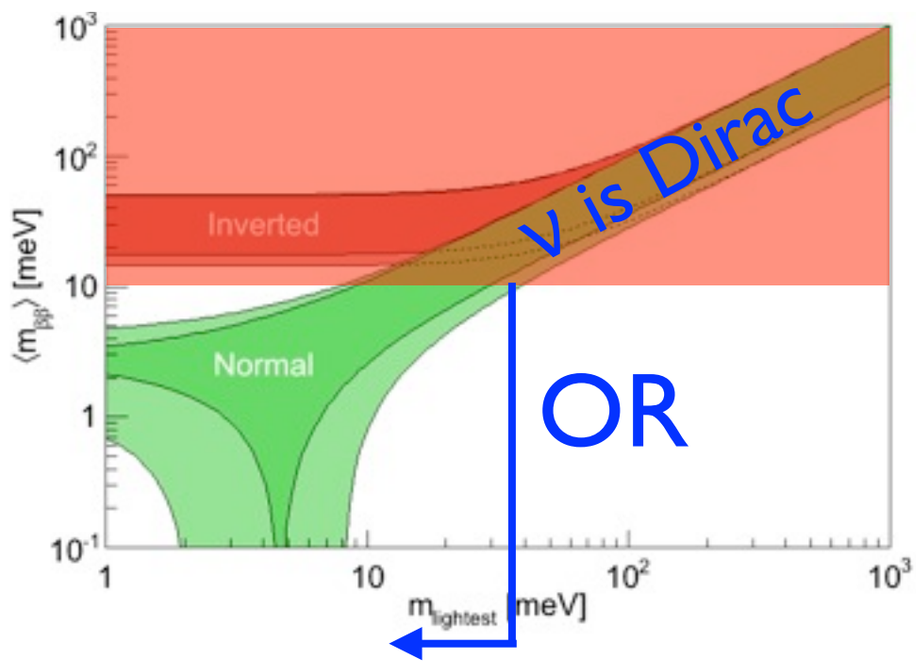




Normal

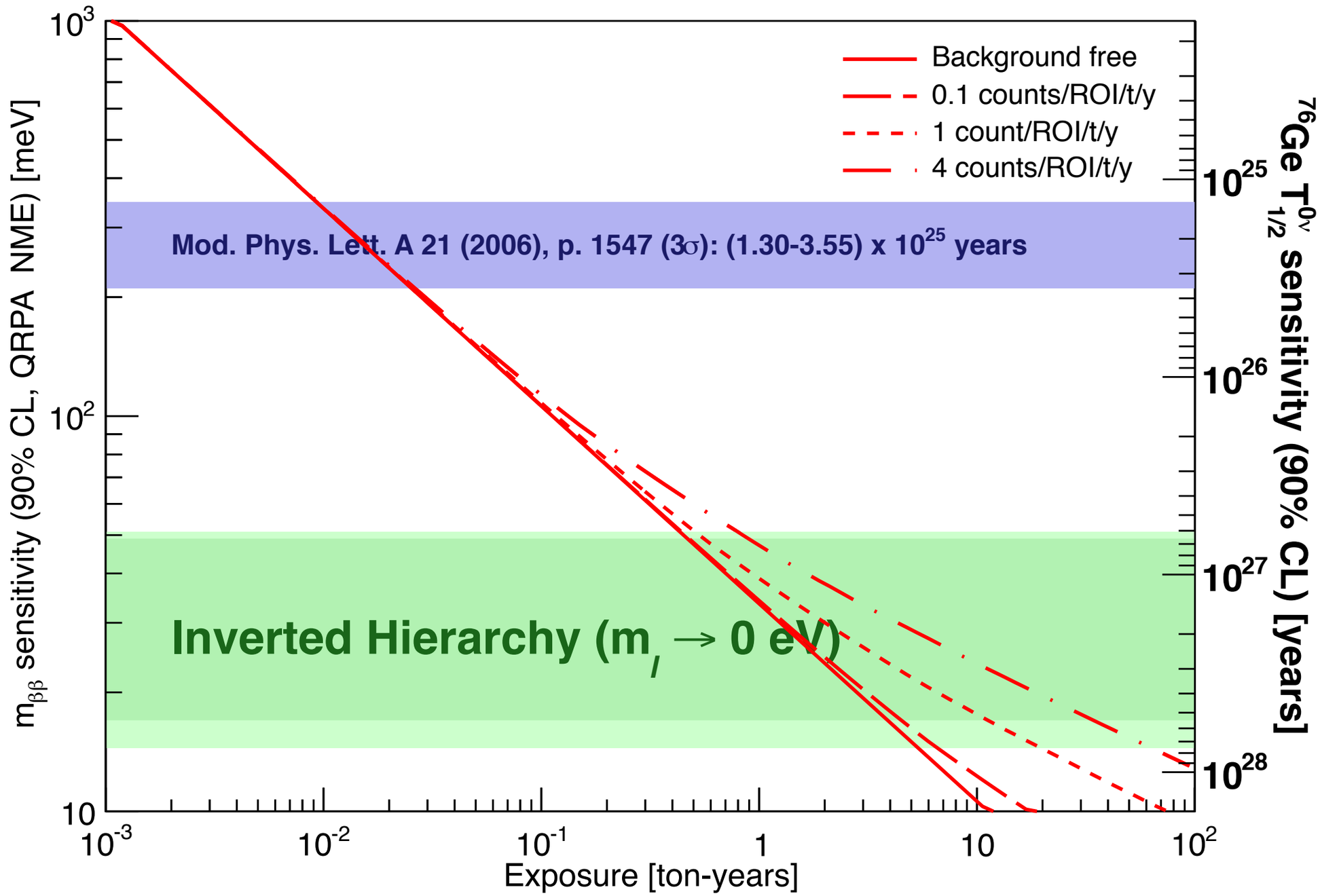


m_l > 10 meV



m_l < 30 meV

Inverted Hierarchy Sensitivity



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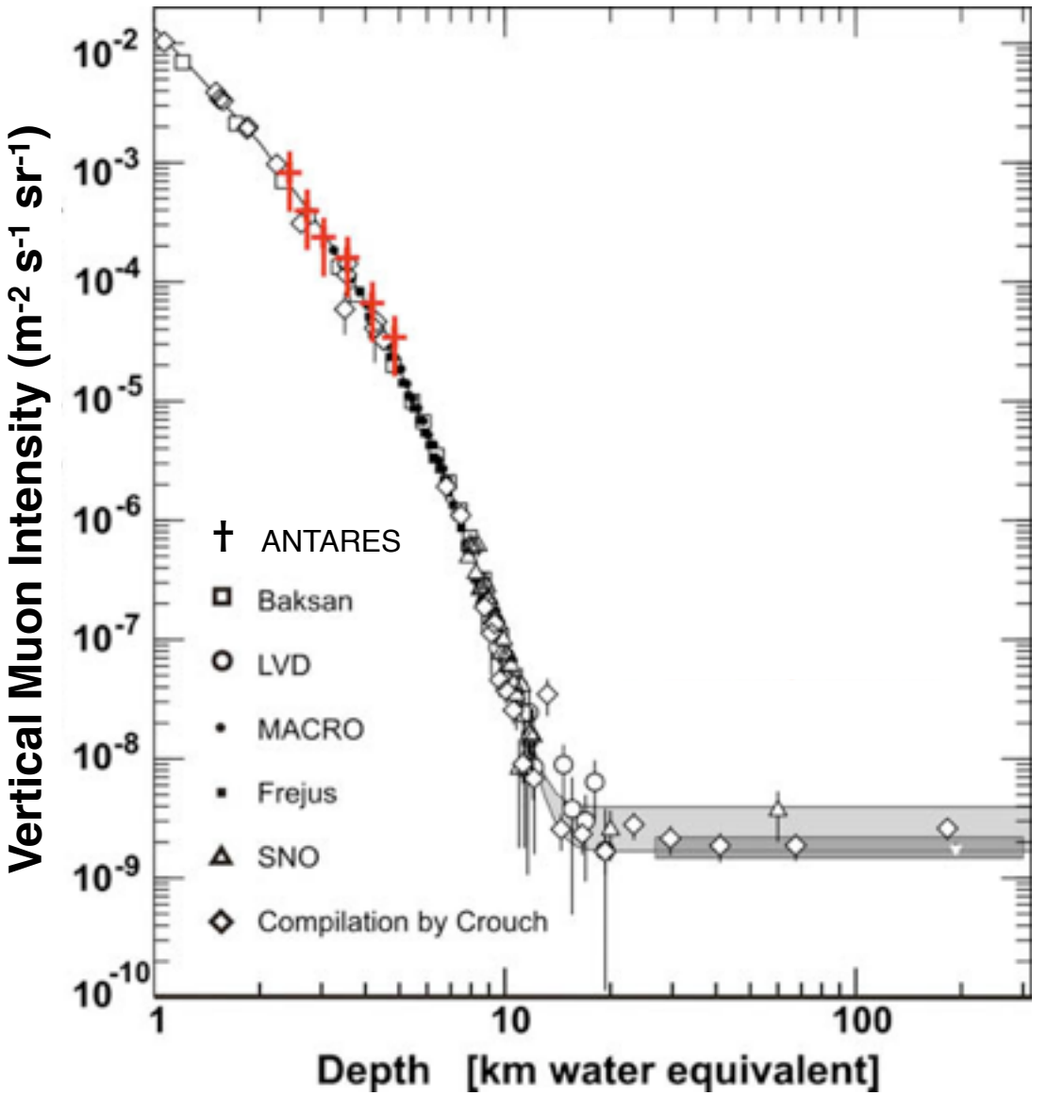
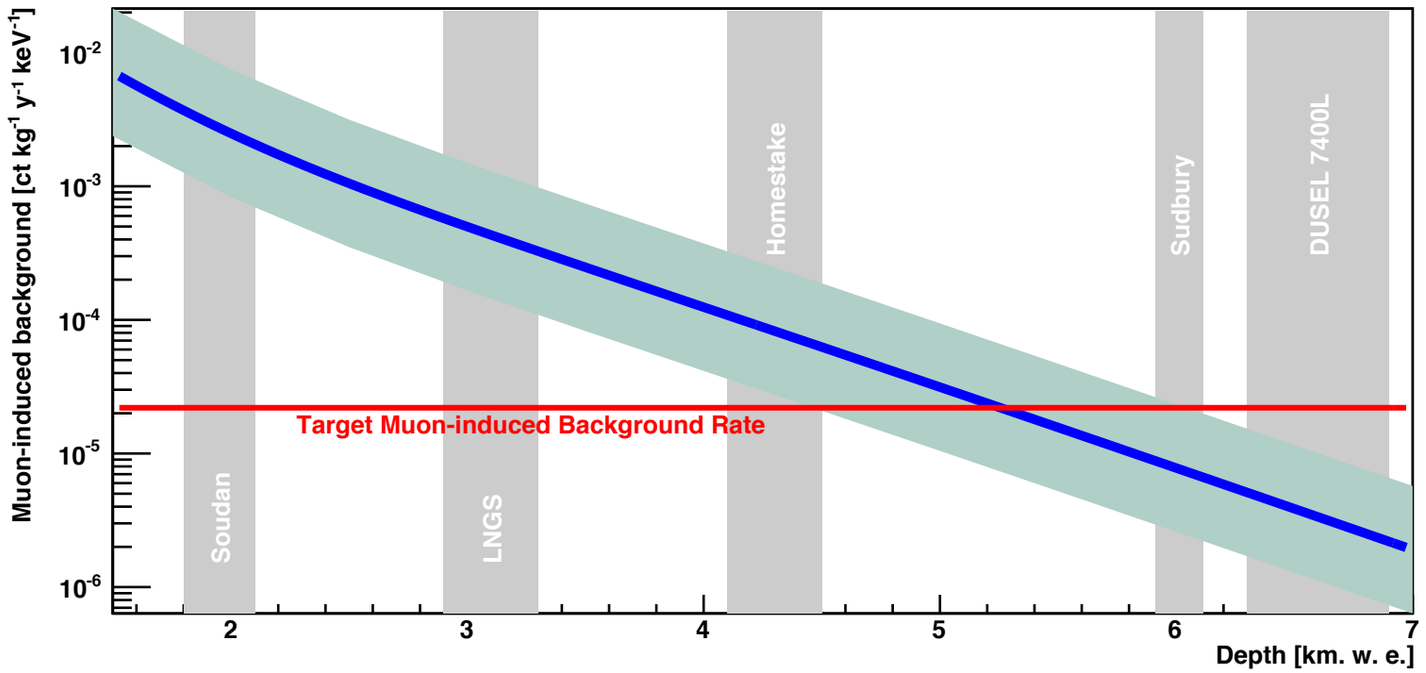
Need To Go Deep

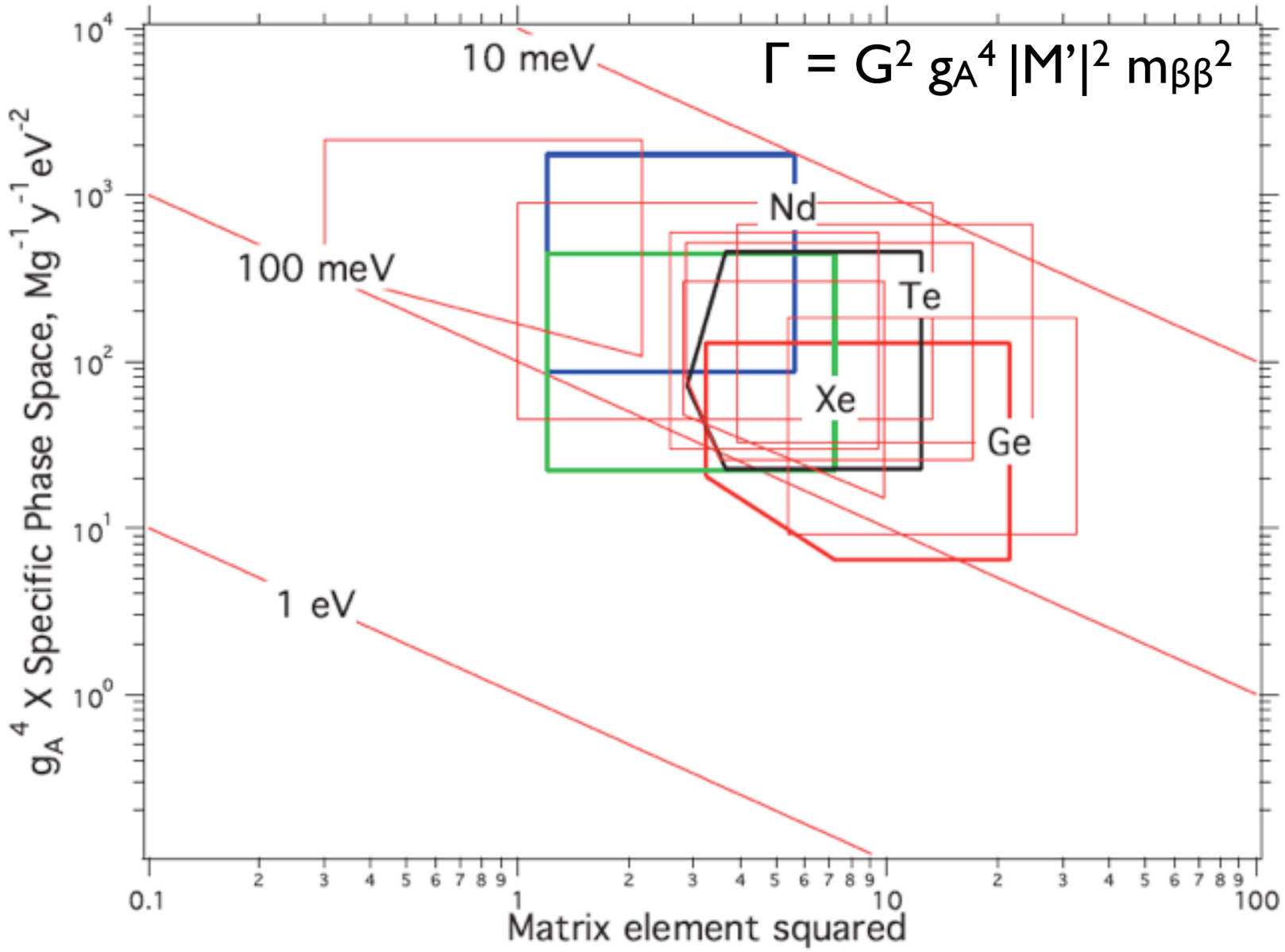


Astropart. Phys. **31** (2009) 277–283.



Scaled from PRD **73**, 053004 (2006).
Uncertainty larger than shown.

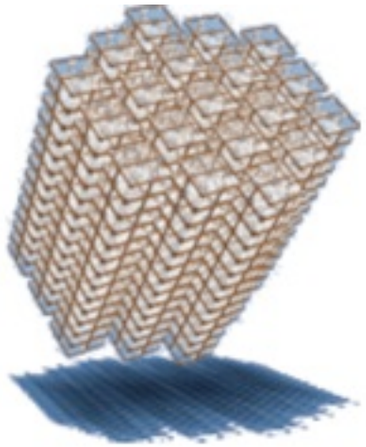
All isotopes are created equal...



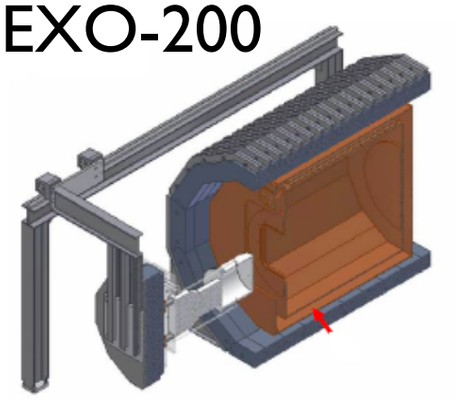
 R.G.H. Robertson, Mod. Phys. Lett. A **28**, 1350021 (2013).

0νββ Decay Experiments

CUORE



EXO-200

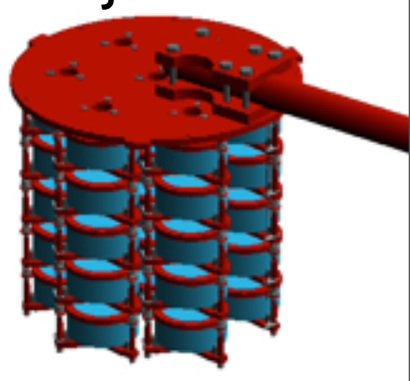


NEMO3

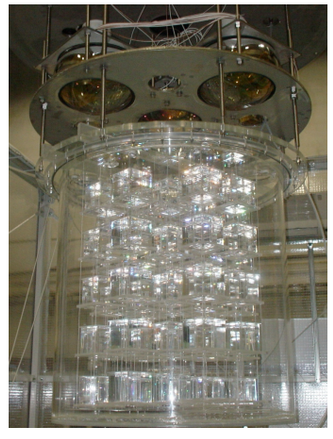
Collaboration	Isotope	Technique	mass (0νββ isotope)	Status
CANDLES	Ca-48	305 kg CaF_2 crystals - liq. scint	0.3 kg	Construction
CARVEL	Ca-48	$^{48}CaWO_4$ crystal scint.	16 kg	R&D
GERDA I	Ge-76	Ge diodes in LAr	15 kg	Operating
GERDA II	Ge-76	Point contact Ge in LAr or LN	30-35 kg	Construction
MAJORANA DEMONSTRATOR	Ge-76	Point contact Ge	26 kg	Construction
1TGe (GERDA & MAJORANA)	Ge-76	Best technology from GERDA and MAJORANA	~ tonne	R&D
NEMO3	Mo-100 Se-82	Foils with tracking	6.9 kg 0.9 kg	Complete
SuperNEMO Demonstrator	Se-82	Foils with tracking	7 kg	R&D
MOON	Mo-100	Mo sheets	200 kg	R&D
CAMEO	Cd-116	$CdWO_4$ crystals	21 kg	R&D
COBRA	Cd-116, Te-130	CdZnTe detectors	10 kg	R&D
CUORICINO	Te-130	TeO_2 Bolometer	11 kg	Complete
CUORE-0	Te-130	TeO_2 Bolometer	11 kg	Operating
CUORE	Te-130	TeO_2 Bolometer	206 kg	Construction
SNO+	Te-130	0.3% ^{nat}Te in liquid scint.	800 kg	Construction
KamLAND-ZEN	Xe-136	2.7% in liquid scint.	370 kg	Operating
NEXT-100	Xe-136	High pressure Xe TPC	80 kg	R&D
EXO-200	Xe-136	Xe liquid TPC	160 kg	Operating
nEXO	Xe-136	Xe liquid TPC	5 tonnes	R&D
DCBA	Nd-150	Nd foils & tracking chambers	32 kg	R&D

GERDA

MAJORANA



CANDLES



From J. F. Wilkerson

Complete | Construction | Operating

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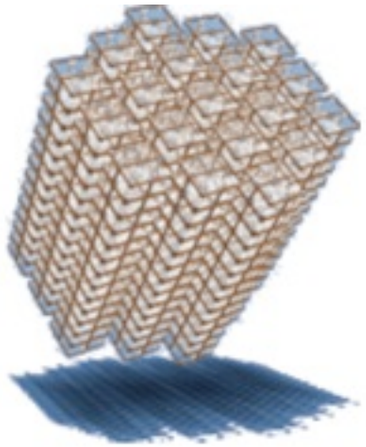
0νββ Decay Experiments

CUORE



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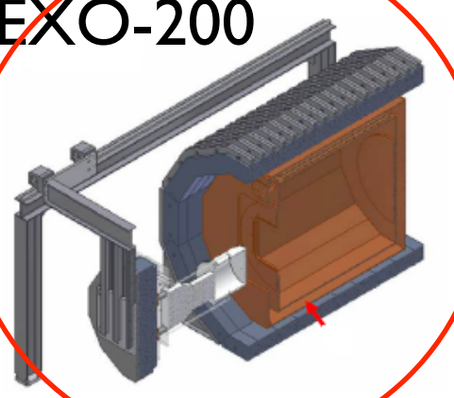

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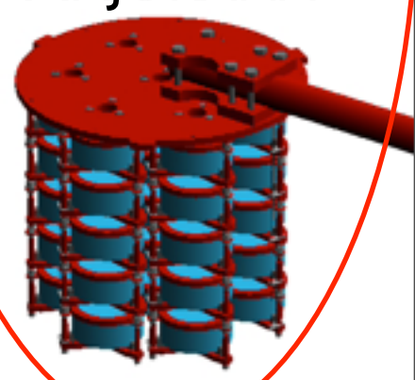
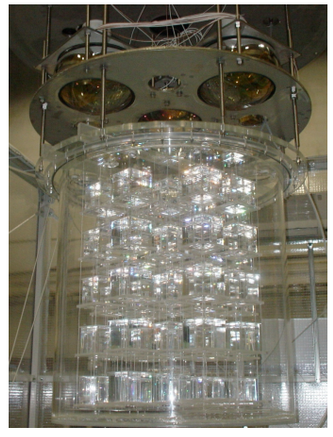
GERDA

MAJORANA



CANDLES



Complete | Construction | Operating

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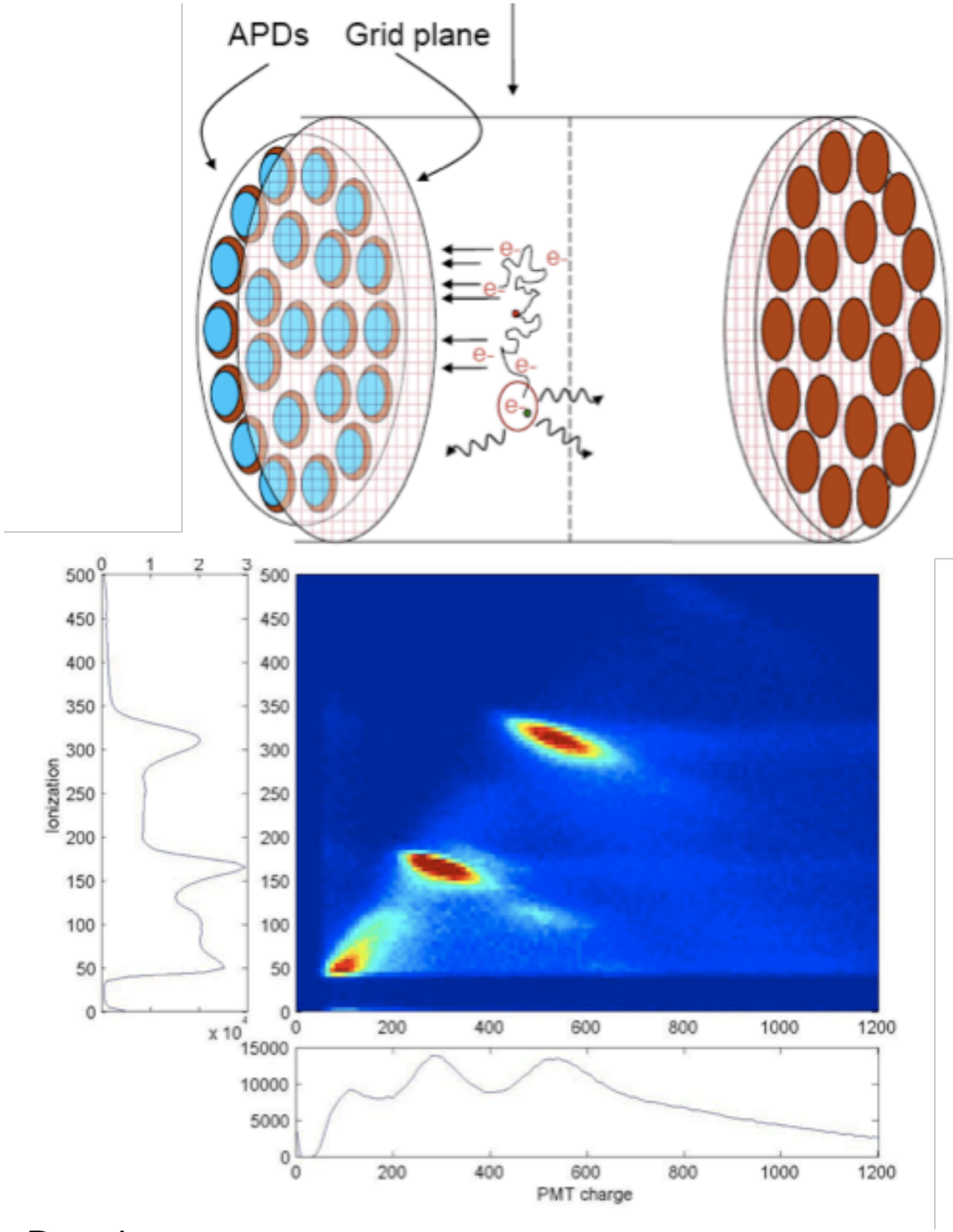
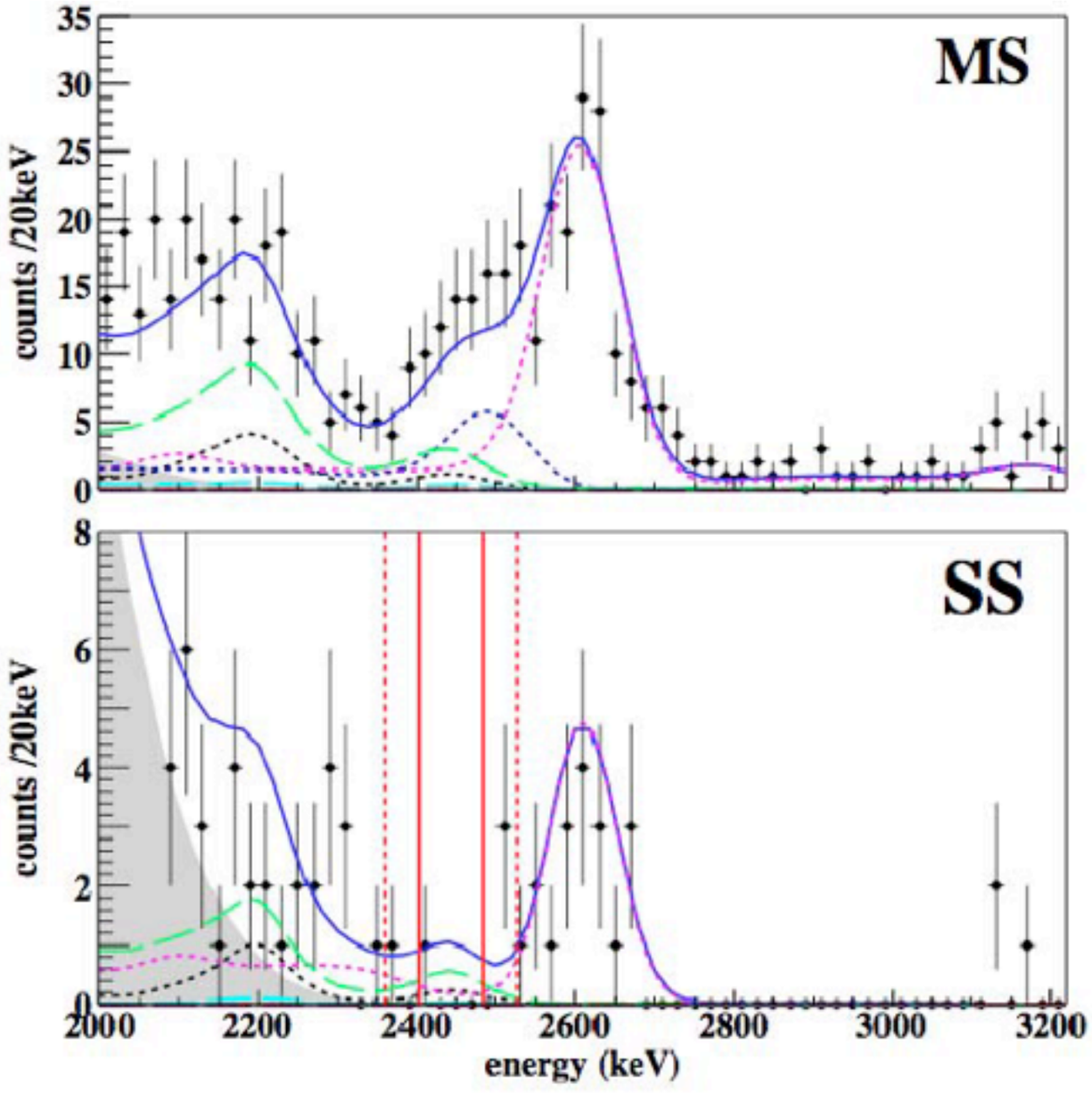
From J. F. Wilkerson

EXO-200: LXe TPC

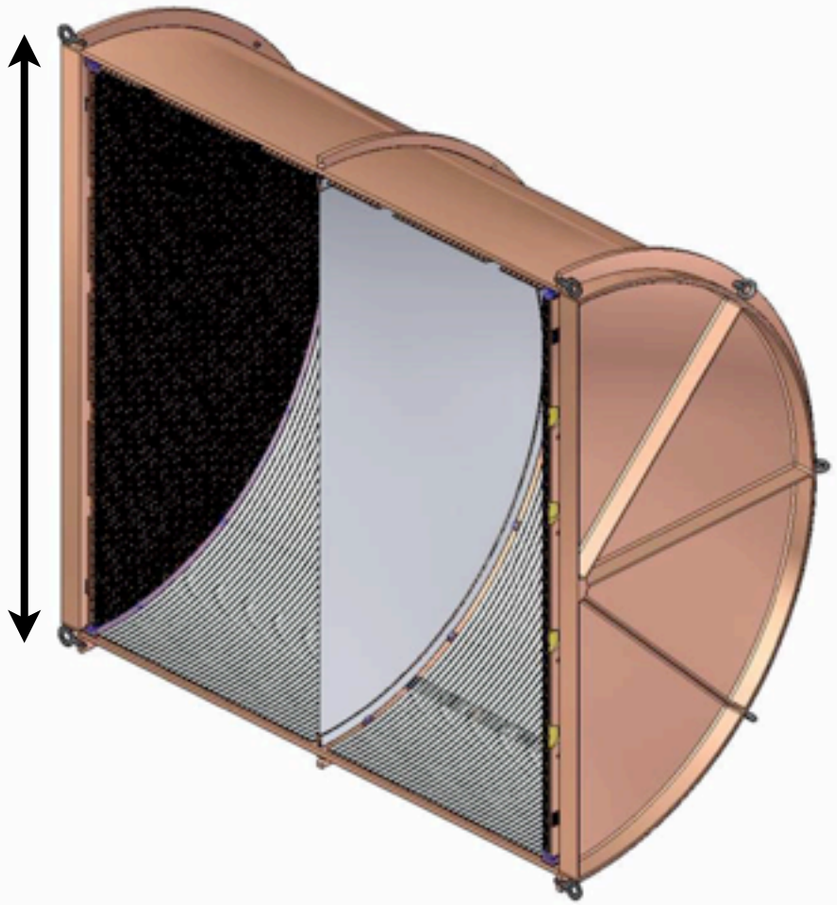




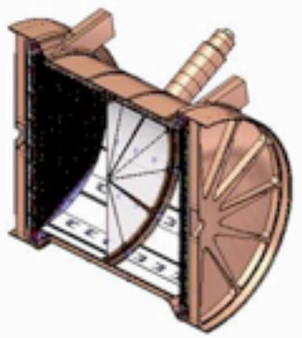
PRL **109**, 032505 (2012).

nEXO

nEXO:
~150 cm
(5 tonnes)



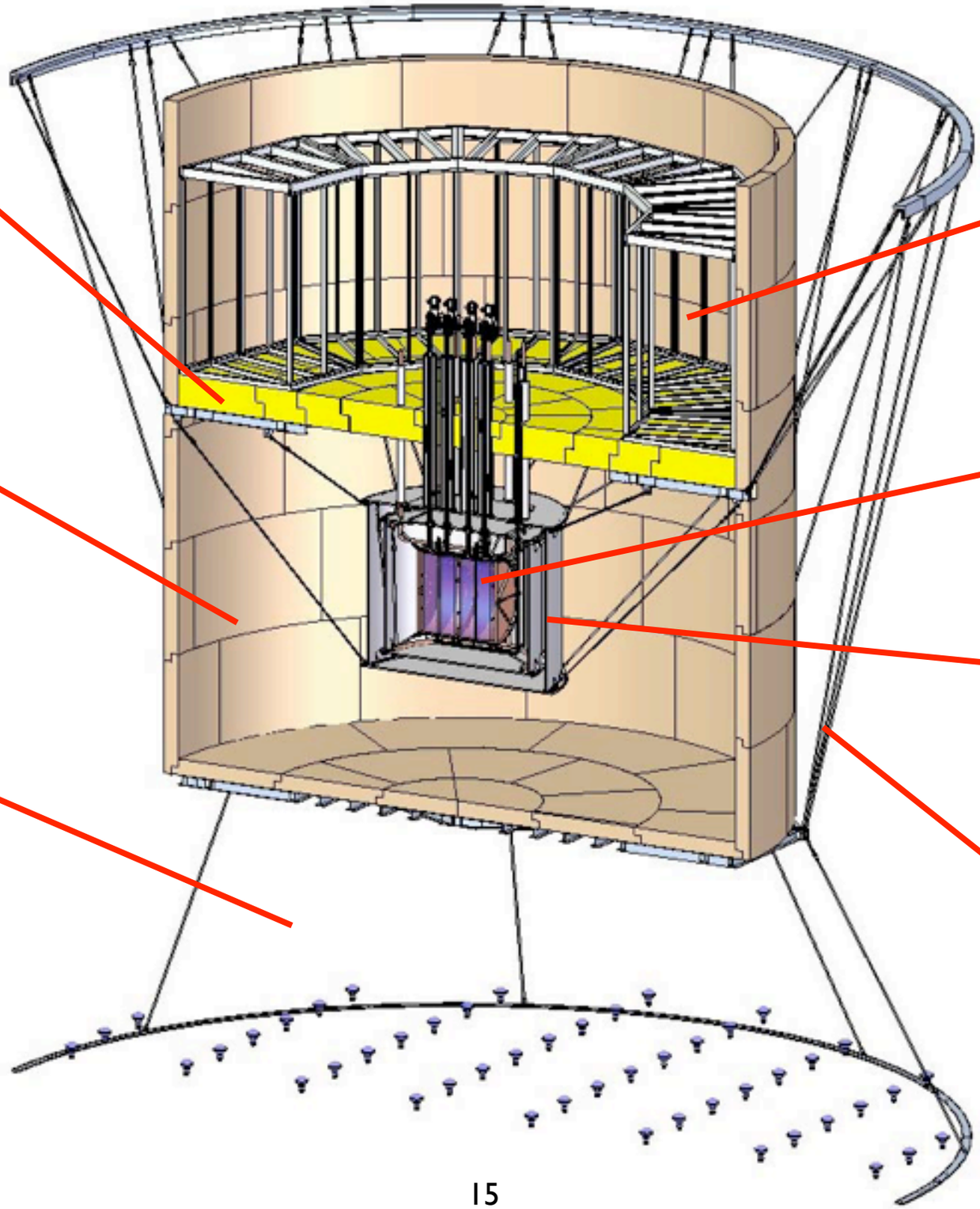
"As similar to
EXO-200 as possible"



EXO-200:
40 cm
(200 kg)

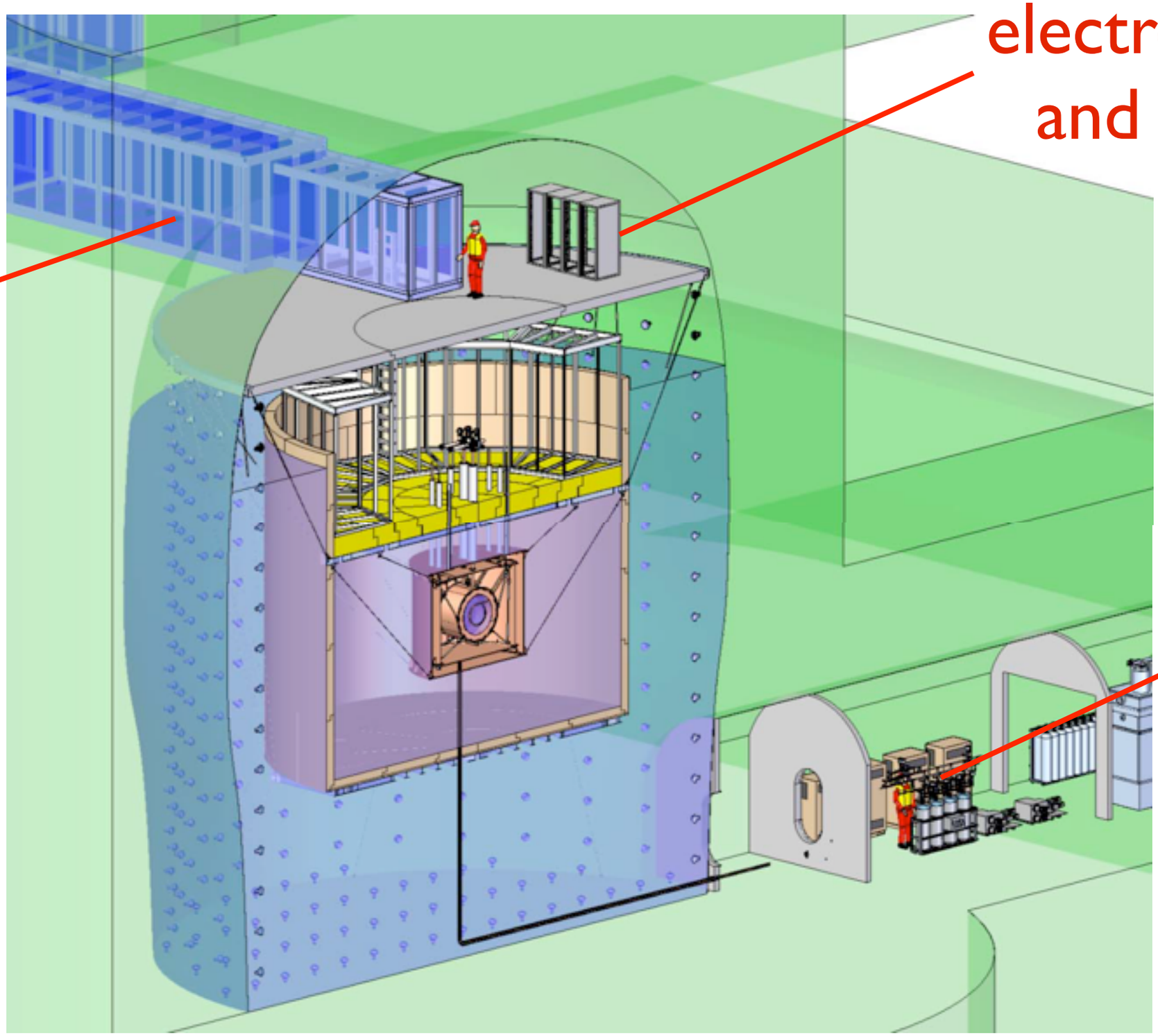
- Upgrade path for Ba tagging
- Proposed for SNOLab cryo pit

nEXO Conceptual Design

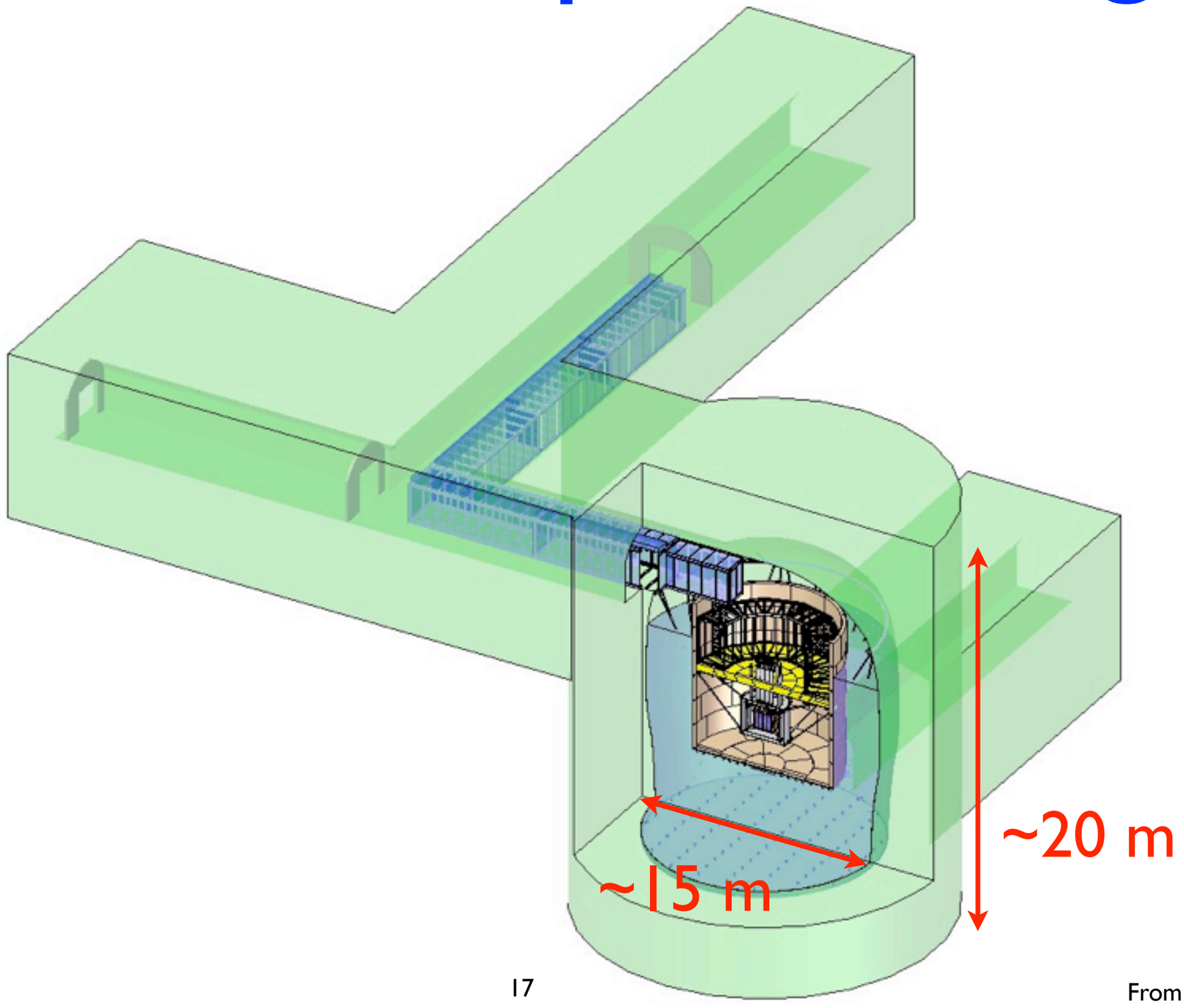


From G. Gratta

nEXO Conceptual Design



nEXO Conceptual Design



From G. Gratta

nEXO Facility Requirements

- Uninterruptible power for cryogenics, controls, and communication
- Cooling: LN2 + chilled water
- Networking
- UG machine shop, including e-beam welding
- Chemical processing (etching)
- Shielding water

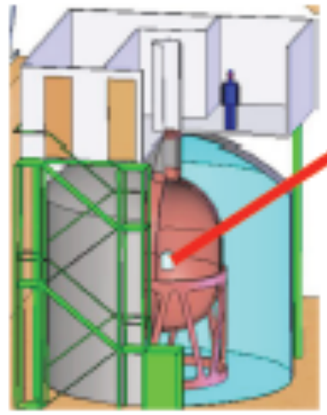
(quantitative figures available)

nEXO Schedule

Description	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
EXO-200 Low background run											
EXO-200 Ultra-low background run											
EXO-200 Detector R&D											
nEXO R&D											
Conceptual Design											
DOE CD-1											
Preliminary Design											
DOE CD-2											
Final Design											
DOE CD-3											
Long Lead Procurement											
Procurement, Fabrication and Assembly											
Installation											
Commissioning											
Ready for Operations											
DOE CD-4											
Xenon Procurement (5T enrichment)											

MAJORANA / GERDA

- ^{76}Ge modules in electroformed Cu cryostat, Cu / Pb passive shield
- 4π plastic scintillator μ veto
- DEMONSTRATOR: 30 kg ^{76}Ge and 10 kg ^{nat}Ge PPC xtals



- ^{76}Ge array submersed in LAr
- Water Cherenkov μ veto
- Phase I: ~18 kg (H-M/IGEX xtals)
- Phase II: +20 kg segmented xtals

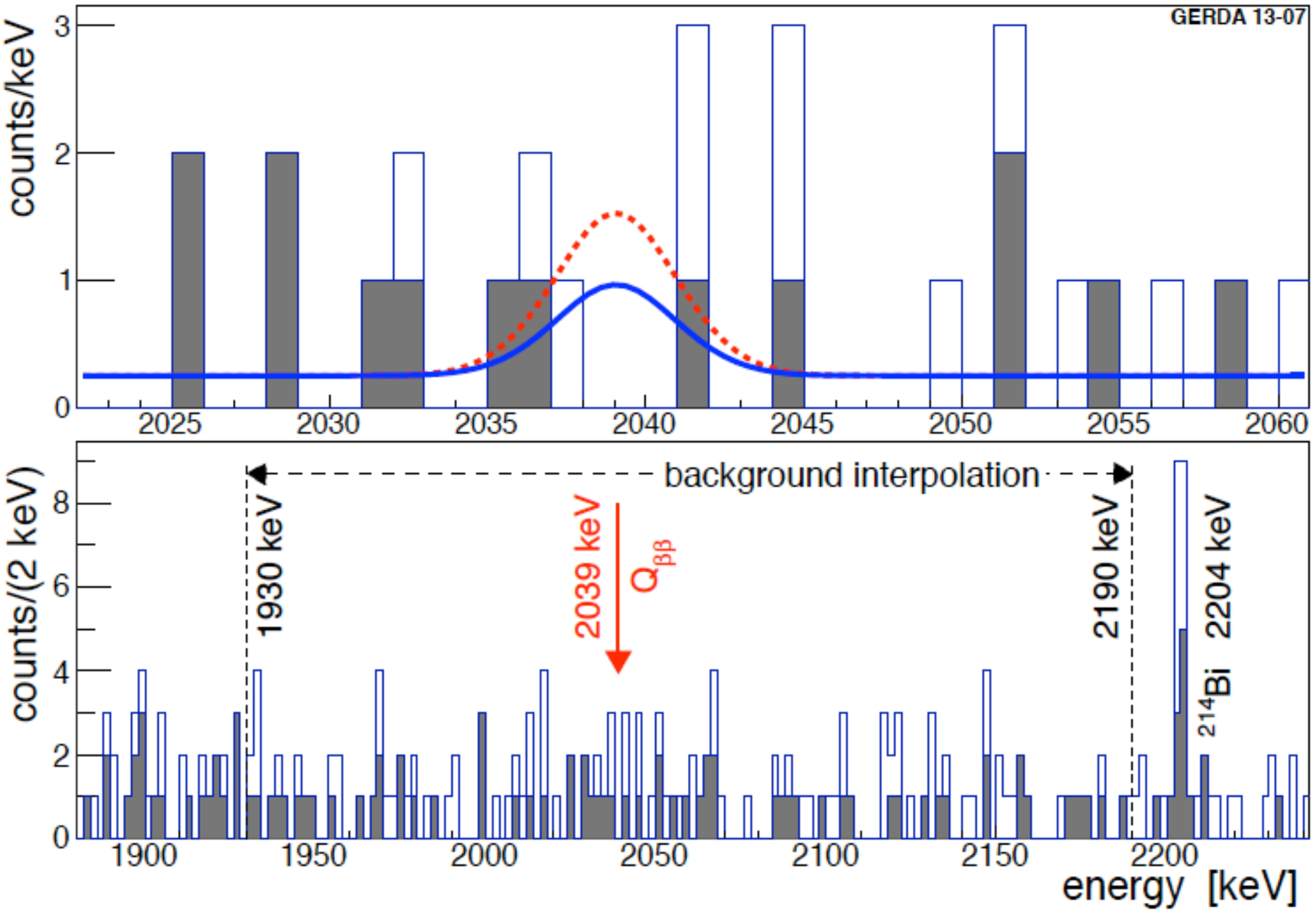
Joint Cooperative Agreement:

Open exchange of knowledge & technologies (e.g. MaGe, R&D)

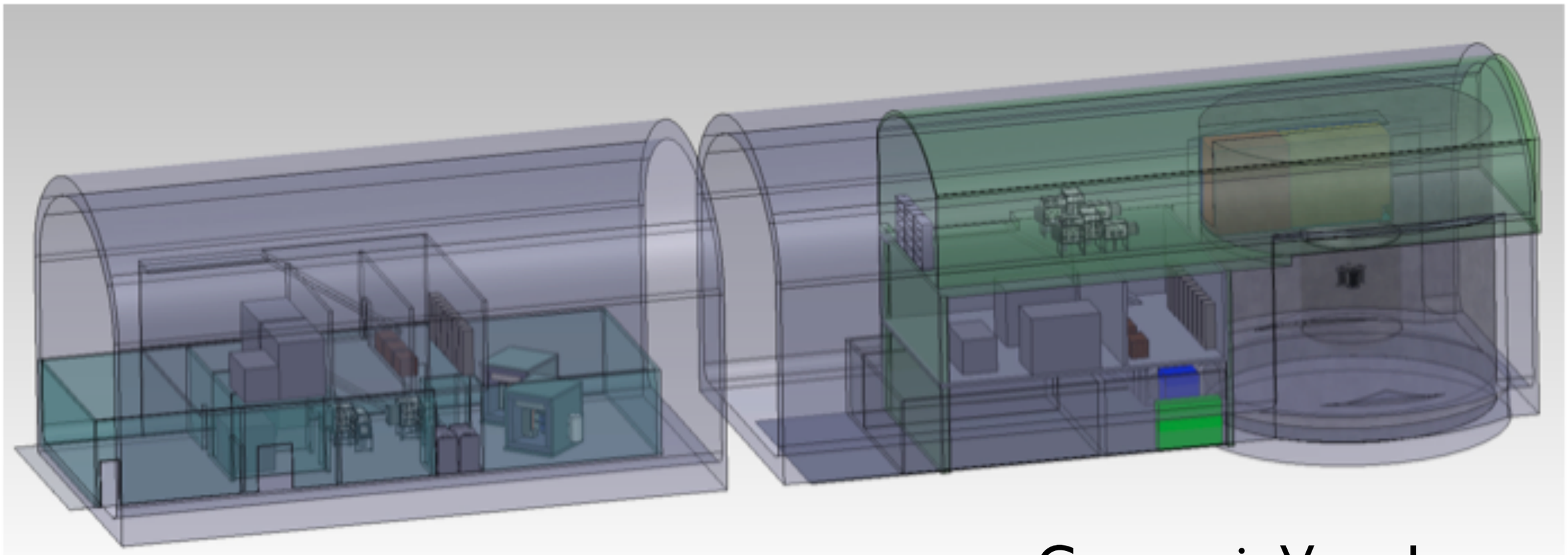
Intention to merge for larger scale 1-tonne exp.

Select best techniques developed and tested in GERDA and MAJORANA

GERDA Results



Tonne-Scale Ge Options



Compact

Two shields, each with 8 EFCu vacuum cryostats

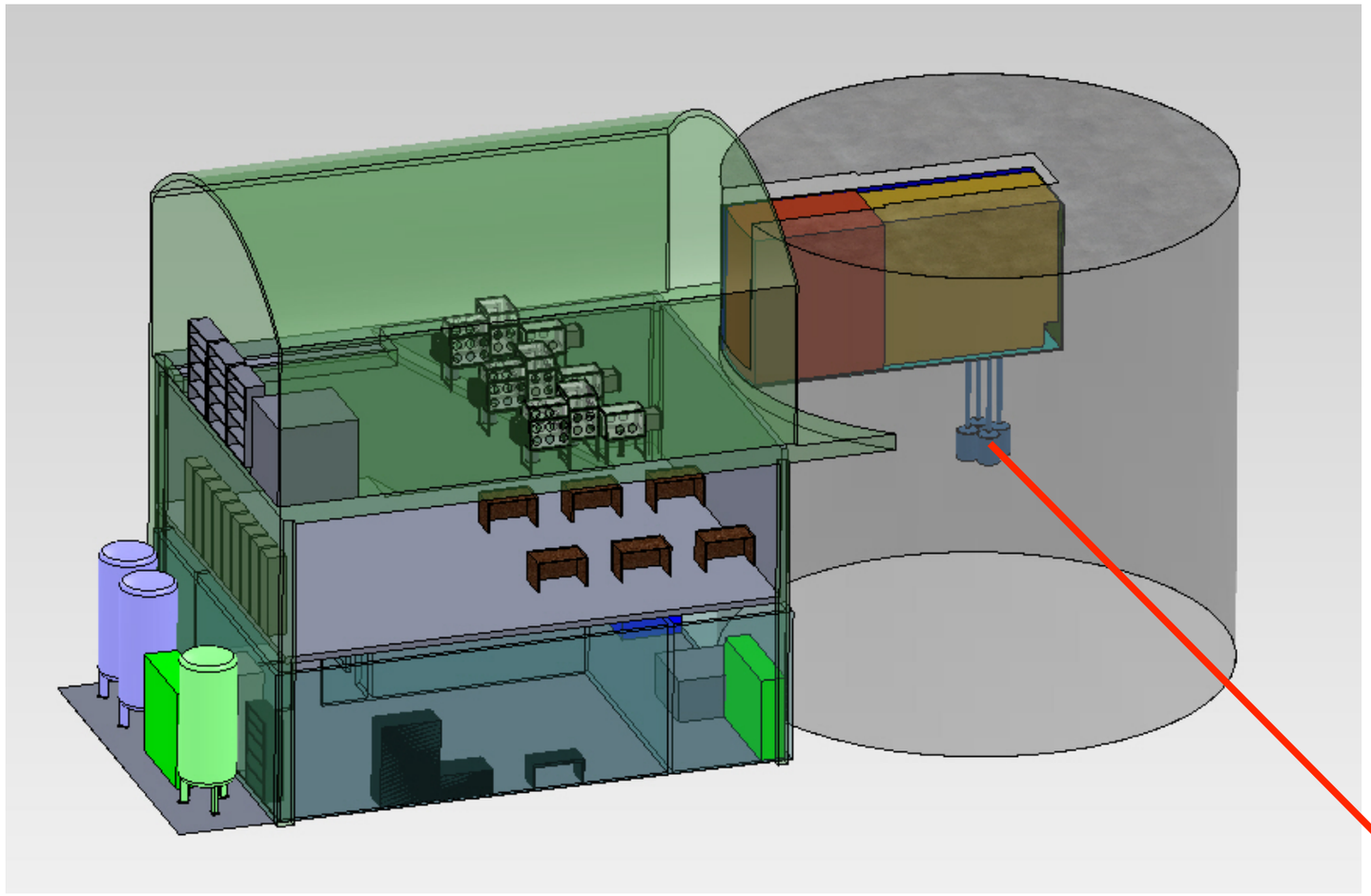
Cryogenic Vessel

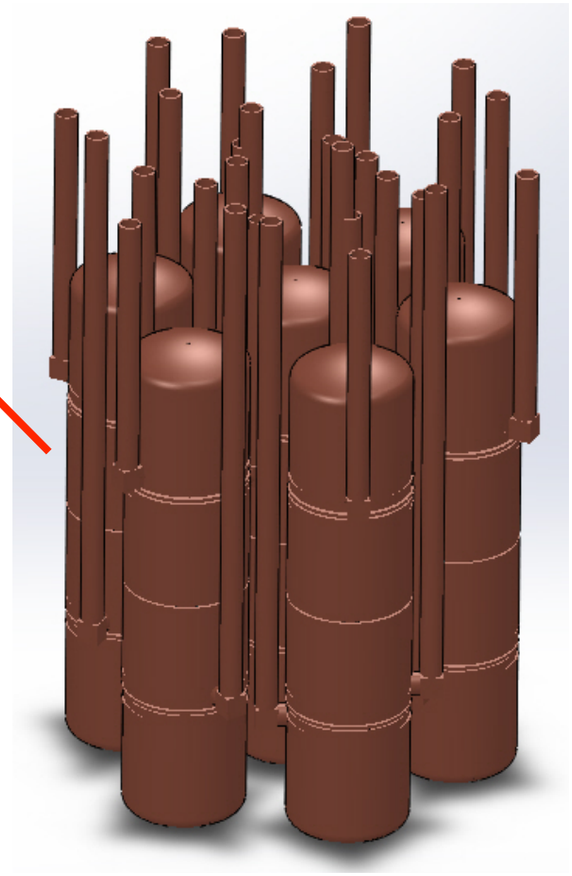
Diameter of water tank:

~11 m for LAr,

~15 m for LN (shown)

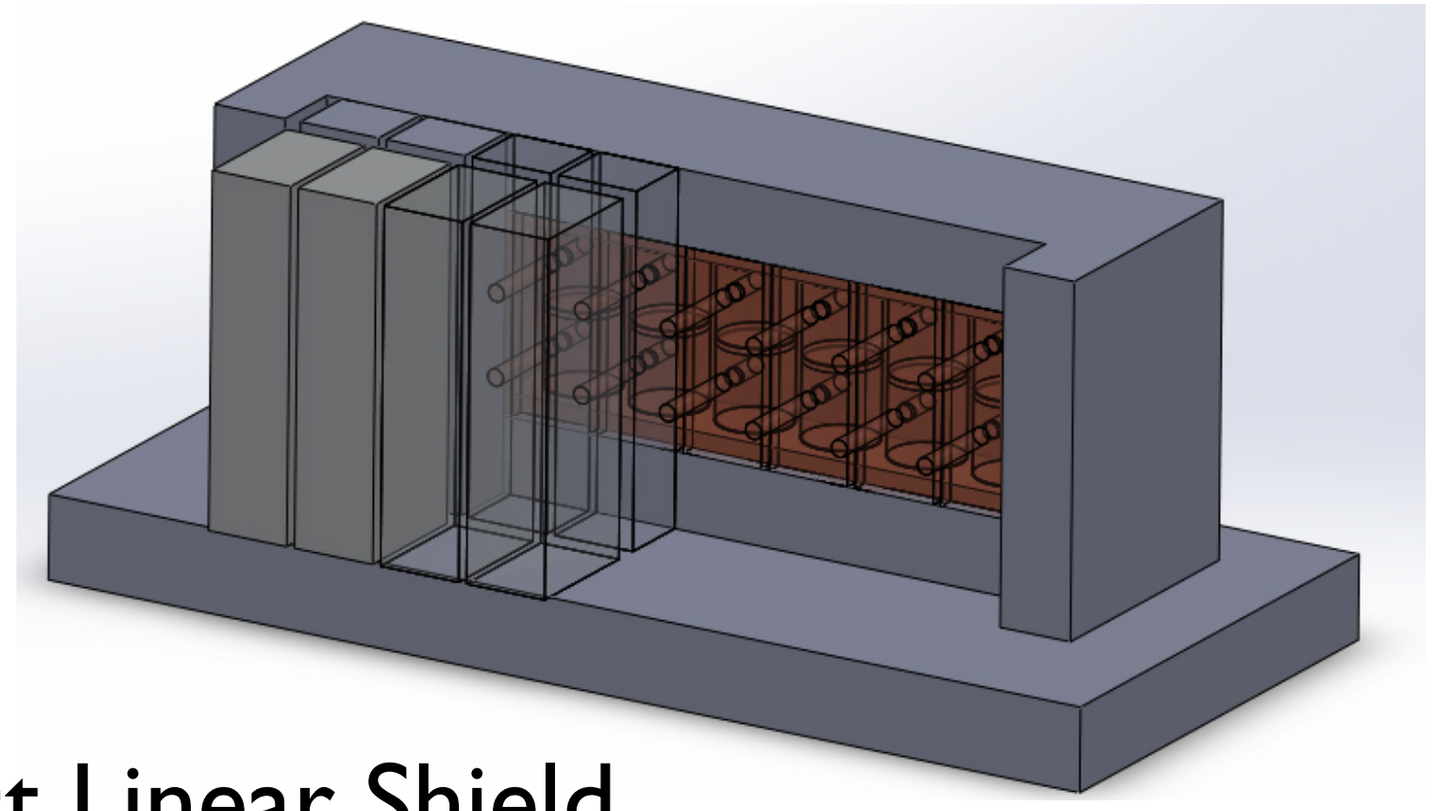
Conceptual Designs





Hybrid: EFCu cryostats suspended in LS or water

Conceptual Designs



Compact Linear Shield

Ge Facility Requirements

Space	Power	Water	Ventilation	Temp	Rn air	Clean room	IT needs	Other
Assembly room	Ave: 28 kW	High purity DI water			3 Bq/m^3	class 1000 or better	100 Mbs LAN	Compressed air, LN transport
Control Room	Ave: 42kW UPS: 4.2 kW			19-23 deg C	3 Bq/m^3		full IT + storage	
Cu/Pb Detector	included in assembly room	High purity water	LN exhaust	19-23 deg C	3 Bq/m^3	class 2000	100 Mbs LAN	need strong floor , compresed air
LAr Detector	included in assembly room	High purity water purification system	LN exhaust	19-23 deg C	3 Bq/m^3	class 2000	100 Mbs LAN	

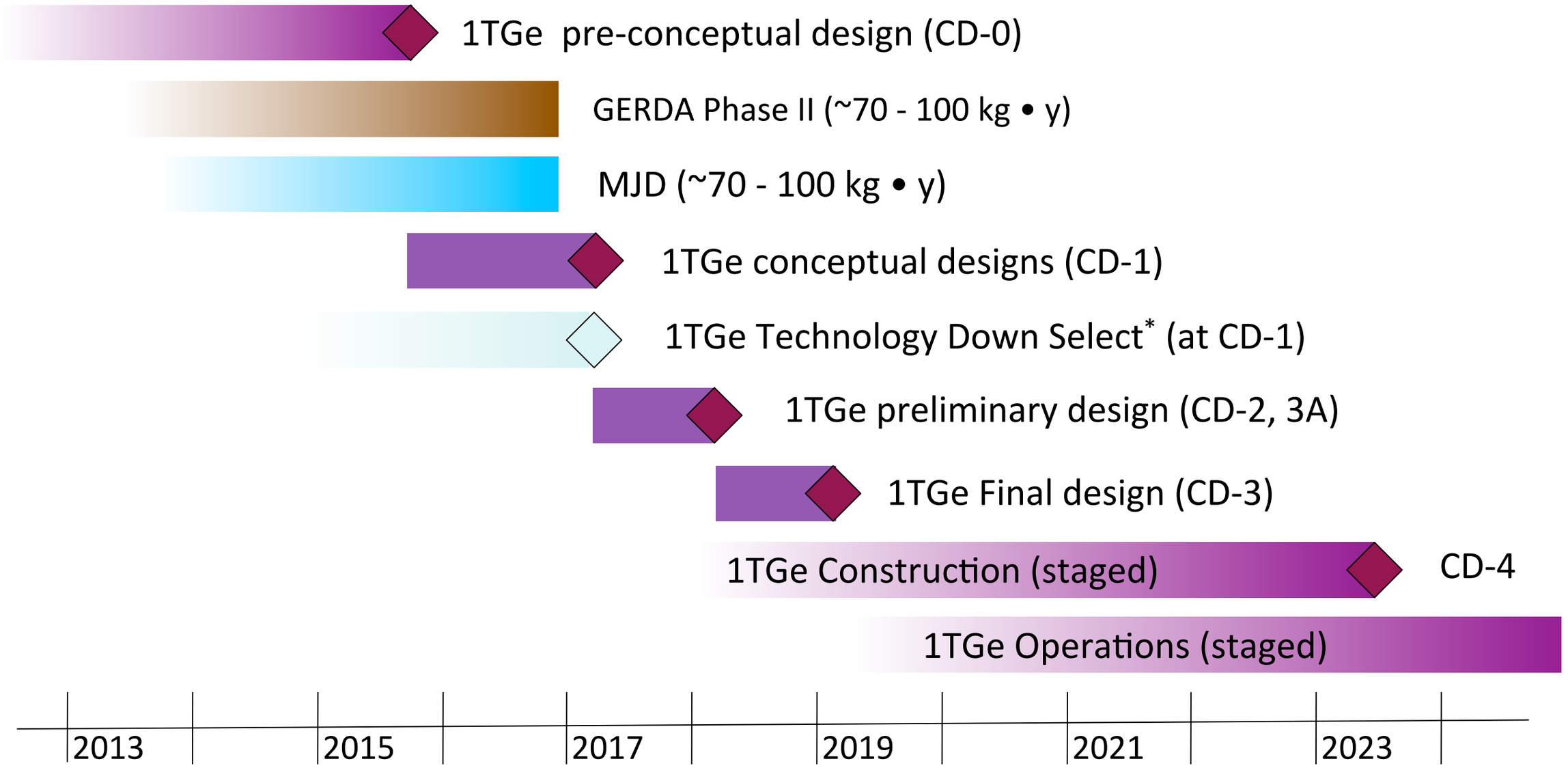
Ge Facility Requirements

Space	Power	Water	Ventilation	Temp	Rn air	Clean room	IT needs	Other
Electroform Lab	136 kW UPS 5kW	Industrial tap water + HP DI water	exhaust Hydrogen from EF baths	19-23 (15%-60% humid)	3 Bq/m^3	class 2000, airlock entry	remote control and internet	spill containment lining - compressed air - Hazmat transport
Cu Cleaning lab	28 kW	HP water		19-23 (15%-60% humid)	1 Bq/m^3	class 100	remote control and internet	Hazmat transport
Machine Shop	107 kW peak 45 kW ave	HP water	30,000 cfm	Under investigation	3 Bq/m^3	class <10000	remote control and internet	compressed air
Storage Area				max 50% humid				

Hazards / Safety

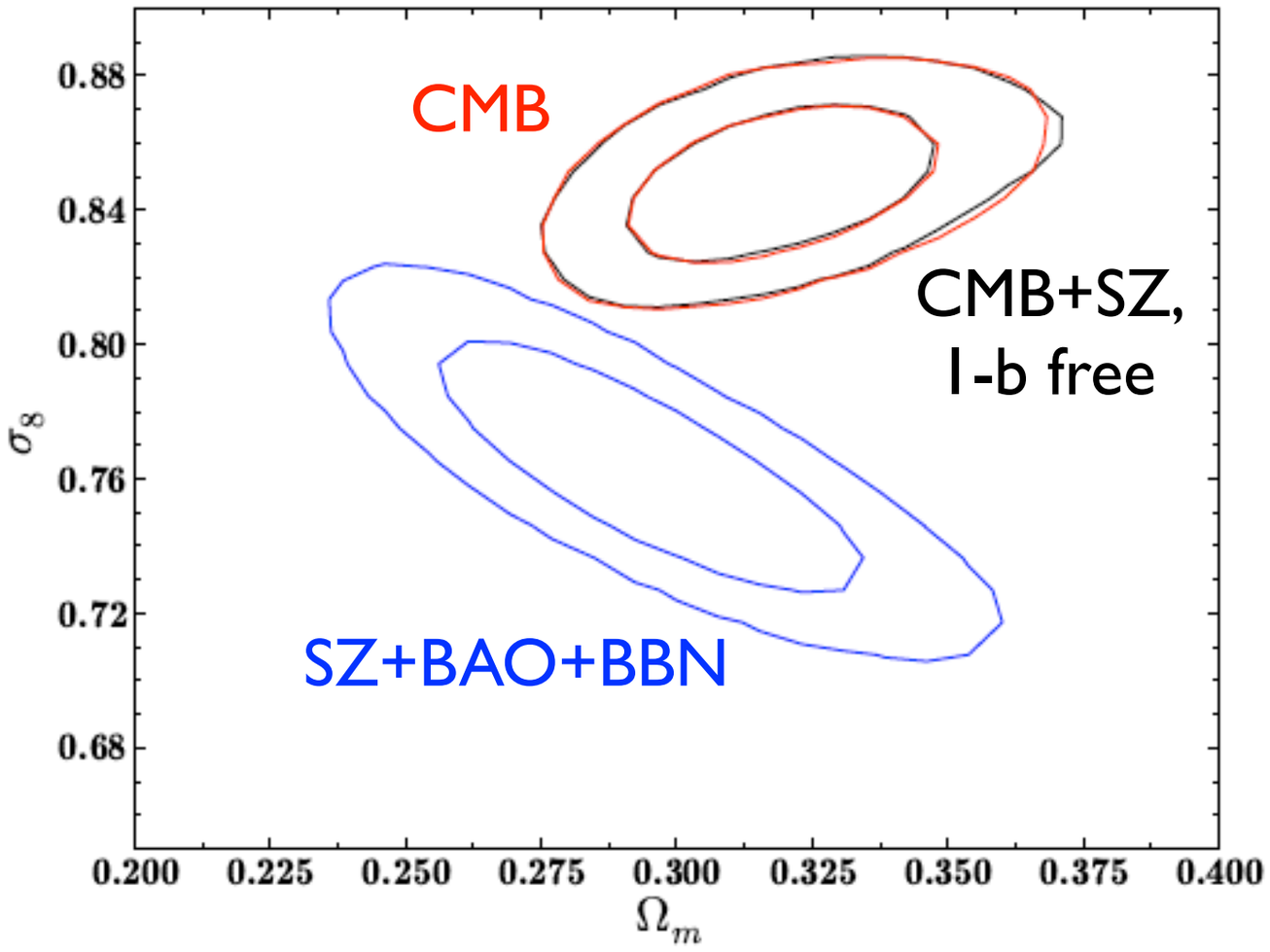
- Cryogens: venting, O_2 deficiency, vacuum systems
- Chemical: hydrofluoric, sulfuric, and nitric acids for EFCu, etching
- HV systems

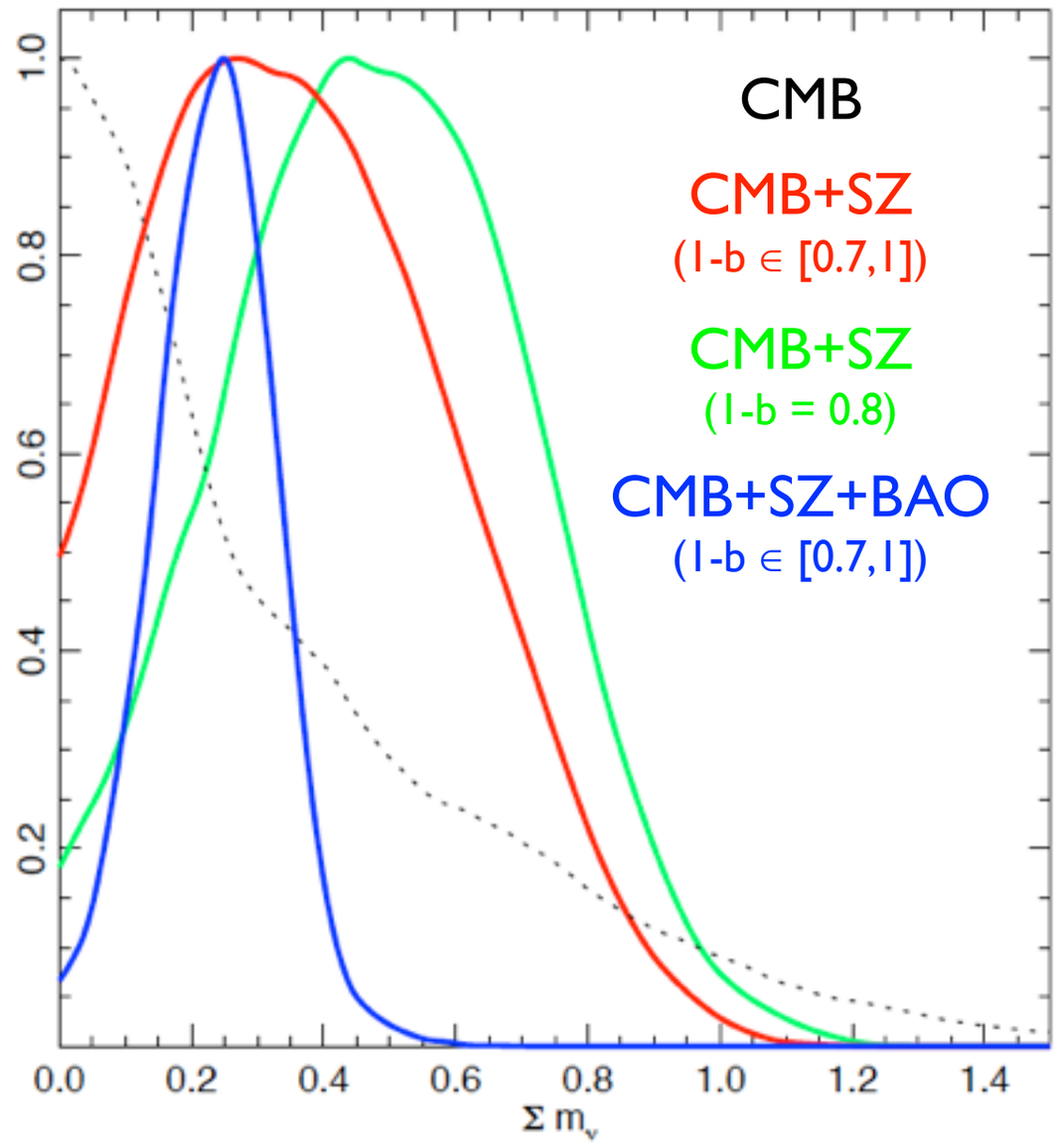
Tonne-Scale Ge Schedule



Backup Slides

Hints from Planck?

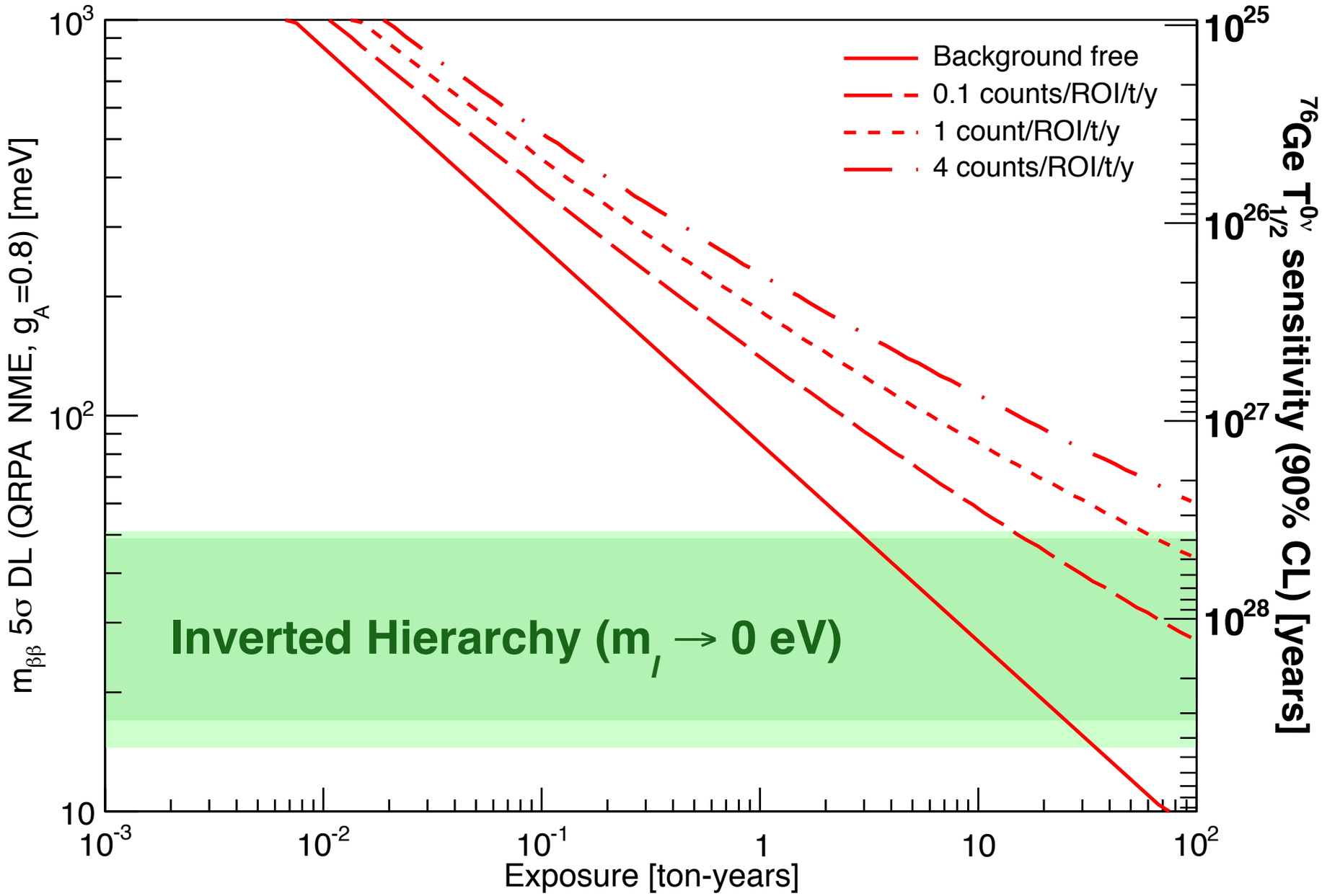




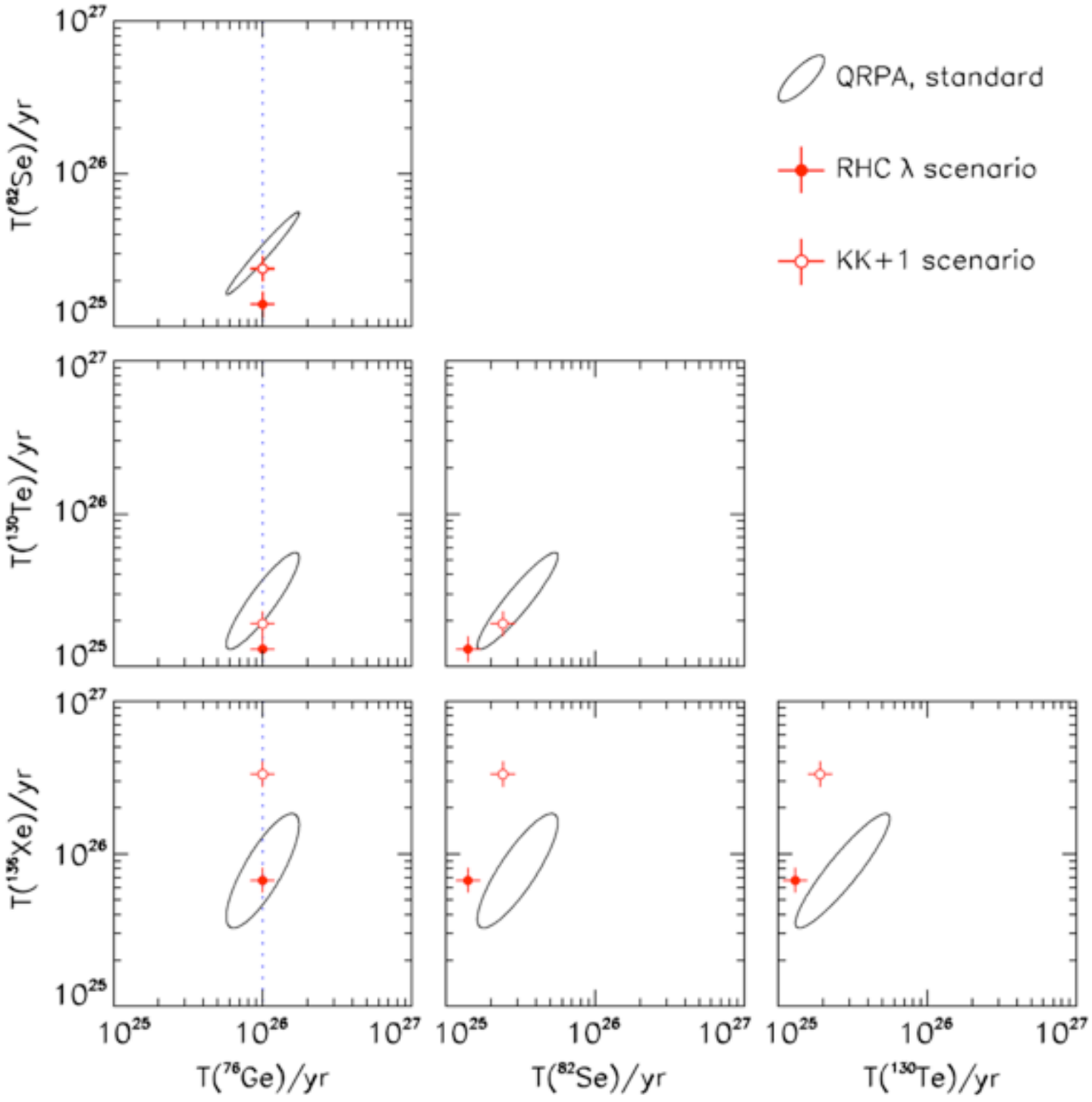
Tension relieved by
$\Sigma m_\nu \sim$ 200-500 meV at 2-3σ
Stay tuned in 2014...

Planck XX, arXiv:1303.5080

Discovery

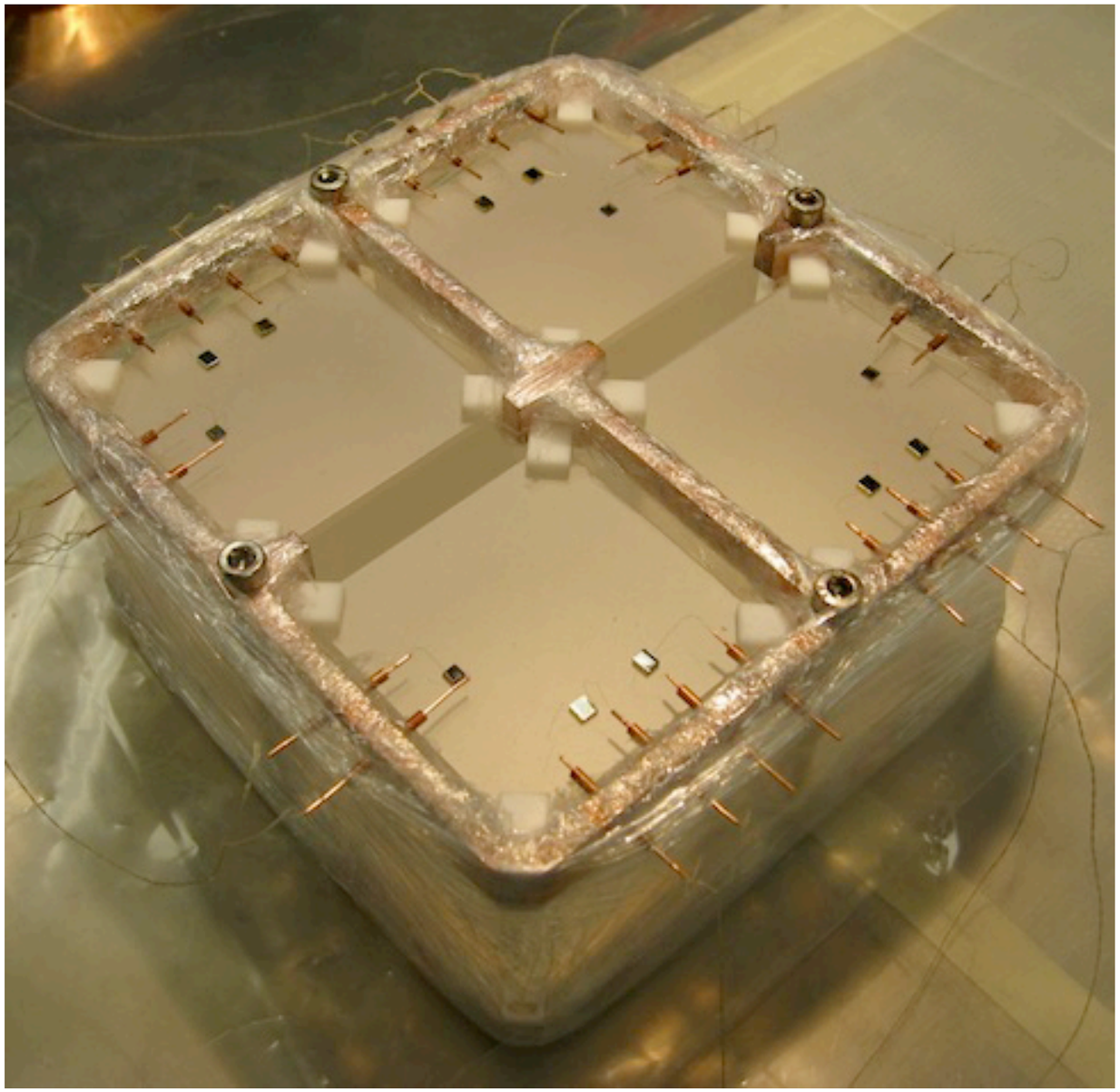

Background free
0.1 counts/ROI/t/y
1 count/ROI/t/y
4 counts/ROI/t/y
Inverted Hierarchy ($m_i \rightarrow 0$ eV)
$m_{\beta\beta}$ 5σ DL (QRPA NME, g_A=0.8) [meV]
^{76}Ge $T^{0\nu}_{1/2}$ sensitivity (90% CL) [years]
Exposure [ton-years]
10^3
10^2
10
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
10^{25}
10^{26}
10^{27}
10^{28}

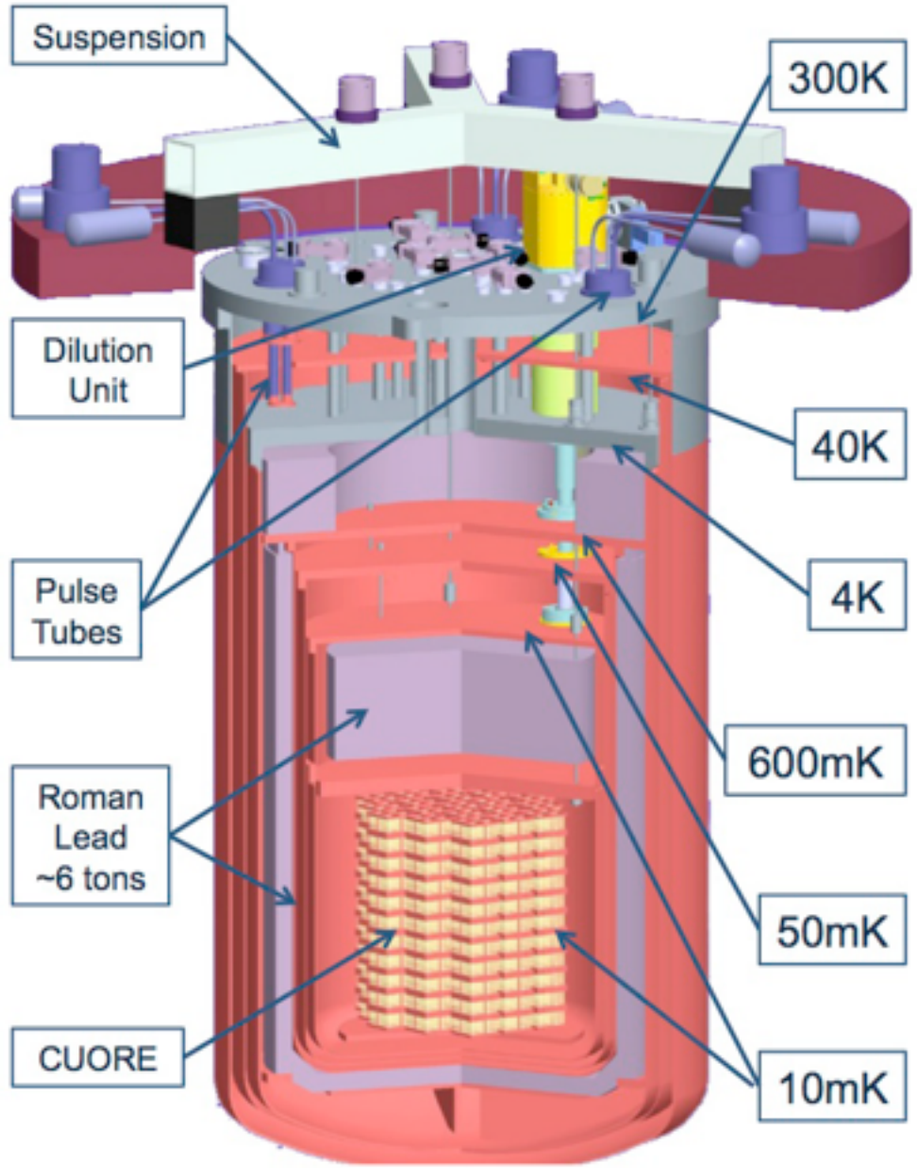
Mechanism Determination



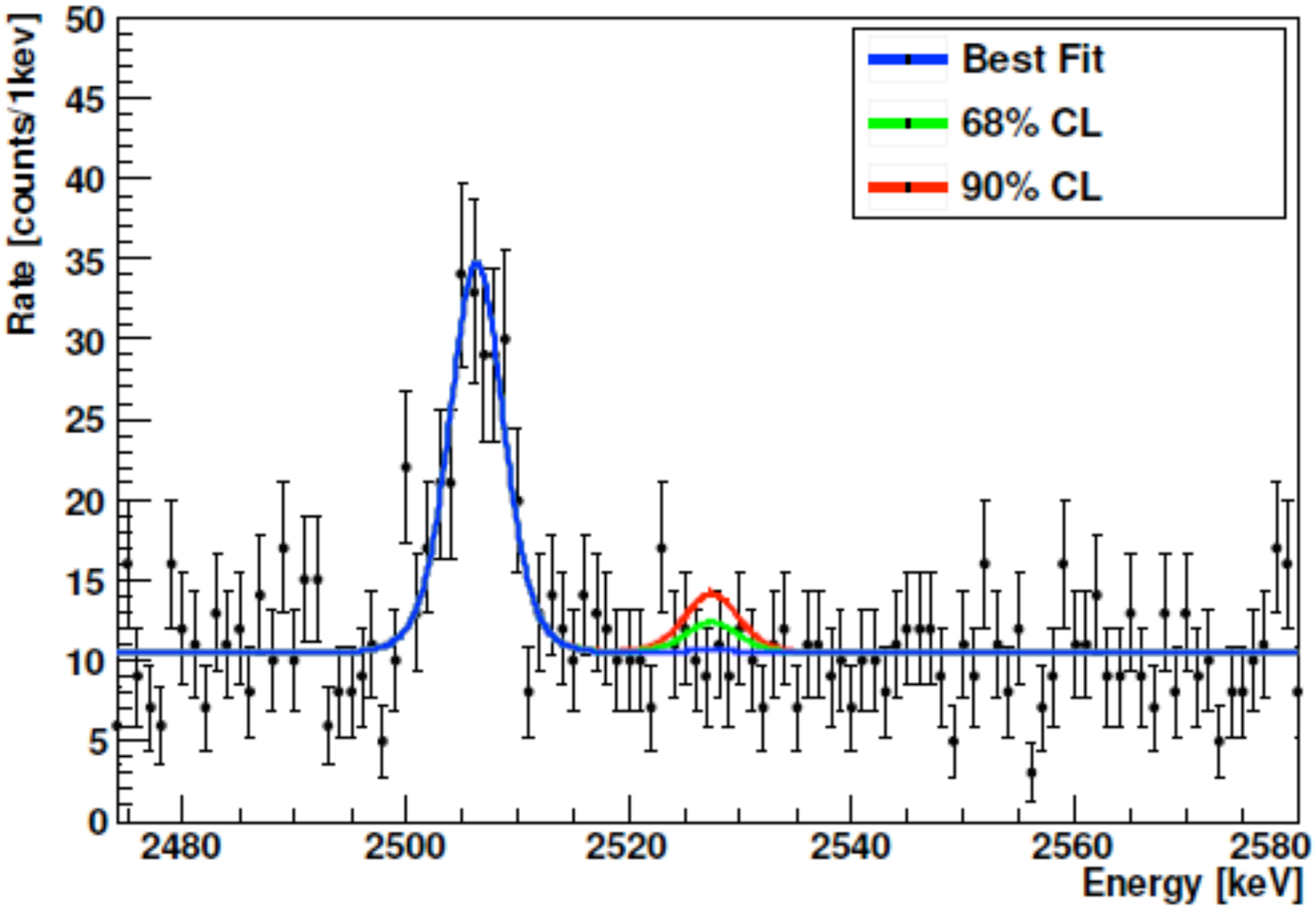
Fogli, Lisi and Rotunno, Phys. Rev. D **80**, 015024 (2009).

CUORE

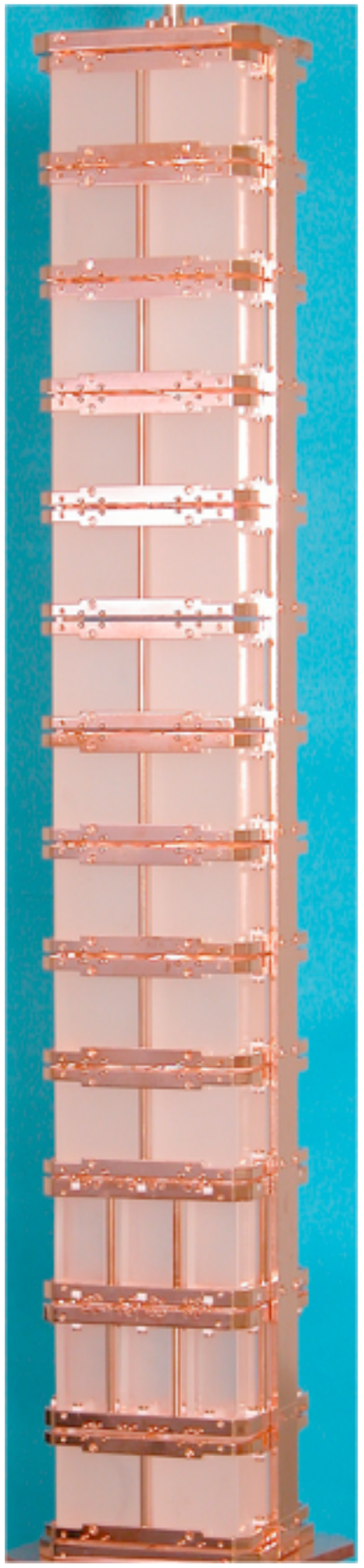



Suspension
300K
Dilution Unit
40K
Pulse Tubes
4K
600mK
Roman Lead ~6 tons
50mK
CUORE
10mK

CUORICINO



E. Andreotti et al., Astr. Phys. **34**, 822 (2011)



Appendix I : Tonne Scale Ge Facility Needs Overview		
Description	**Requirements**	**Interface point / notes**
general requirements (applies to all spaces unless otherwise noted)		
cleanliness	CLASS 2000 or better	structure, ductwork and lighting provided by facility with experimental input
temp/ humidity	21°C±2°, 15-60%RH	all HVAC and associated maintenance provided by facility, except for internal local CLASS 200 and N2 purged areas built and maintained by experiment
exhaust	TBD	by facility with experiment input. ODH will dictate larger throughput for L-cryogen option.
Rn mitigated air	<3 Bq/m3	Rn mitigation system will be designed and installed by experiment if required
phone/network	yes	wall jacks provided by facility
detector and shielding hall	15-20m x 15-20m x 15-24m	liquid shield options only for this depth
electrical power construction	50-75kW	electrical supply up to wall receptacles provided by facility, with input from experiment, options are Rn scrubbers, Welding receptacles for L-cryogen tank.
electrical power operations	5-10kW	utility costs covered by facility
standby power capacity	5kW	battery backup by experiment (short term), diesel generator by facility to maintain vacuum and cryogens.
water	tap occ use, DI water 0-60 l/min	tap water supplied by facility, DI water system (to fill shield) by experiment.
compressed air	occasional use	see mech room
Shielding setup/laydown space	20m x 10m x 20m high	Need only during tank construction, could be less with creative installation
Gowning / bathrooms / showers	10m x 15 m x 3m high	construction and utilities by facility, consumables by experiment
Mechanical	7m x 15m x 3m high	HVAC, air compressor and water heater by facility, cryogen transfer and handling by experiment
Cleanliness	No requirements	access must be controlled between this and clean ar
Electrical Power Construction	30-50kW	HVAC blowers, small air compressor, water heater
Electrical Power Operations	30-50kW	Mainly HVAC blowers
Clean Room Control	8m x 15m x 3m high	(2nd story) control racks, monitoring and DAQ computers, desk space
Electrical Power Construction	5-10kW	
Electrical Power Operations	5-10kW	
Standby power Capacity	5-10kW	battery backup only (by experiment)
Clean fab / assembly	10-15m x 15m x 4m high	must be at cryostat loading level (ground level)
Cleanliness	CLASS 200 or better	internal softside cleanroom (by experiment)
LN	200l/day	boiloff or purge. Experiment provides ~2 large dewars /wk or UG generation facility
Electrical Power Construction	5-10kW	Facility: room lighting and receptacles, experiment: custom lighting
Electrical Power Operations	5-10kW	
TOTAL space requirements for main experimental module	30-40m x 15-20m x 15-20m high	range reflects uncertainty of shielding thickness requirements

Ge Facility Needs (cont.)

Other spaces		
e-forming lab	6m x 9m	included in MJD lab
Exhaust	2000 CFM	facility provide exhaust, snorkel fitting on tanks by experiment
Electrical Power construction	50kW	range for possible expansion of tanks for higher mass shield options
Electrical Power operations	5-50kW	e-forming ramps down as operations ramp up
Standby power capacity	5kW	battery UPS supplied by experiment
Water	tap occ. use, DI water 0-5 l/min	tap water supplied by facility, DI water system by experiment
Compressed air	Occasional use	
LN	201/day	boiloff only for cover gas, LN provided in dewars by experiment
Clean Machine Shop	~12m x 8m	included in MJD lab, welder to be added near clean assembly
Exhaust	2000 CFM	cutting fluid mist (non flammable, non toxic)/ particulate exhaust
Electrical Power Construction	40-70kW	high estimate includes additional tools for 1T (large Mill, welder)
Electrical Power Operations	4-25kW	moderate to very low duty cycle, depending on operations phase
Water	tap occ. use, DI water 0-5 l/min	tap water supplied by facility, DI water system by experiment
Compressed Air	Occasional use	
Surface lab	Details TBD	a few offices, and possible Cryogen transfer area (depending on shielding choice, UG LN generation)
Lift Services	1.5m x 3.5m x 2m high	200-300 trips for hardware (including L-Ar for tank option), ~daily trips for personnel, ~weekly trip for cryogen