EXO-200

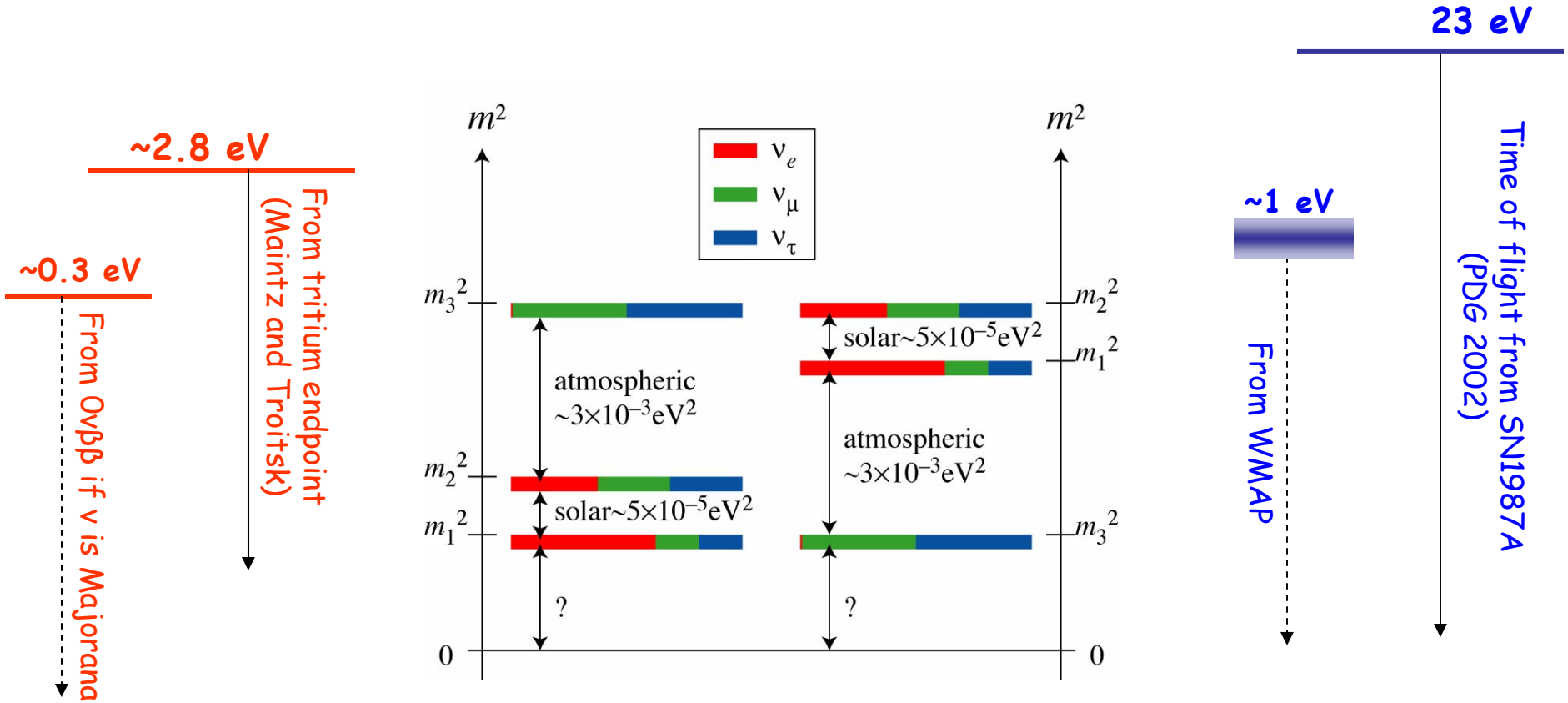
status report

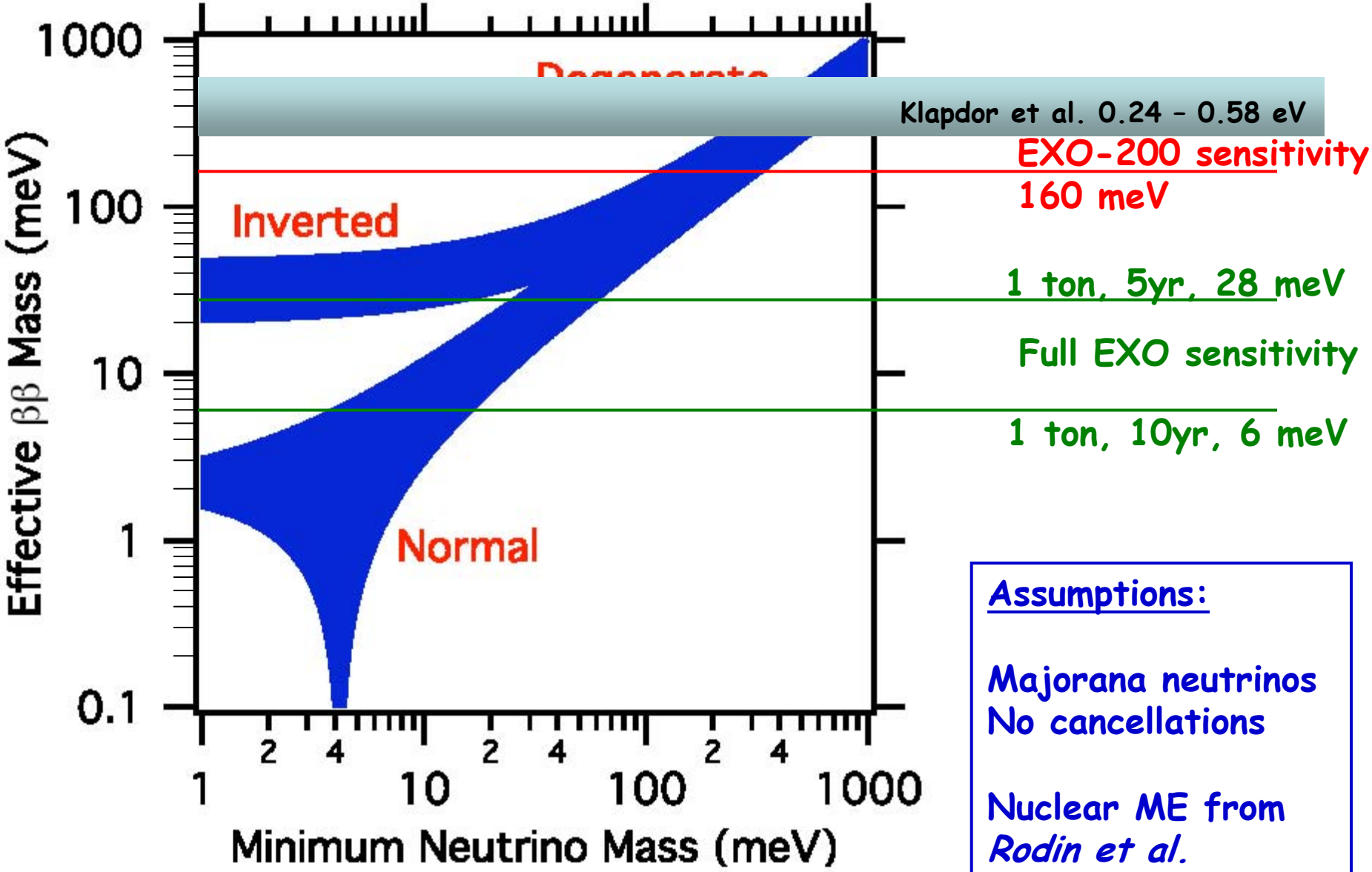
P5, FNAL Sept 25, 2007

D.Leonard, A.Piepke *Physics Dept, University of Alabama, Tuscaloosa AL*
P.Vogel *Physics Dept Caltech, Pasadena CA*
A.Bellerive, M.Bowcock, M.Dixit, I.Ekchtout, C.Hargrove, D.Sinclair, V.Strickland
Carleton University, Ottawa, Canada
W.Fairbank Jr., S.Jeng, K.Hall *Colorado State University, Fort Collins CO*
M.Moe *Physics Dept UC Irvine, Irvine CA*
K.Kumar *University of Massachusetts at Amherst, MA*
D.Akimov, A.Burenkov, M.Danilov, A.Dolgolenko, A.Kovalenko, D.Kovalenko, G.Smirnov, V.Stekhanov
ITEP Moscow, Russia
J.Farine, D.Hallman, C.Virtue, U.Wichoski *Laurentian University, Canada*
H.Breuer, C.Hall, L.Kaufman *University of Maryland, College Park MD*
M.Hauger, F.Juget, L.Ounalli, D.Schenker, J-L.Vuilleumier, J-M.Vuilleumier
Physics Dept University of Neuchatel, Switzerland
M.Breidenbach, R.Conley, W.Craddock, J.Hodgson, D.McKay, K.Kumar, A.Odian, C.Prescott, P.Rowson, K.Skarpaas, J.Wodin, L.Yang, S.Zalog
SLAC, Menlo Park CA
R.DeVoe, P.Fierlinger, B.Flatt, G.Gratta, M.Green, F.LePort, M.Montero-Diez, R.Neilson, K.O'Sullivan, A.Pocar
Physics Dept Stanford University, Stanford CA

The next crucial measurement in neutrino physics:

Discovery of the neutrino mass scale





Plot from Avignone, Elliott, Engel arXiv:0708.1033 (2007)

Assumptions:

Majorana neutrinos
No cancellations

Nuclear ME from *Rodin et al. nucl-th\0706.4304*

To reach $\langle m_\nu \rangle$ ~ 10 meV very large fiducial mass (tons)

(except for Te) need massive isotopic enrichment

Need to reduce and control backgrounds in qualitatively new ways

these are the lowest background experiment ever built

For no bkgnd	$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/\sqrt{Nt}$
Scaling with bkgd goes like $(Nt)^{1/4}$	$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/(Nt)^{1/4}$

In addition want a multi-parameter experiment, so that possible discovery can be backed-up by cross checks with more than one single variable

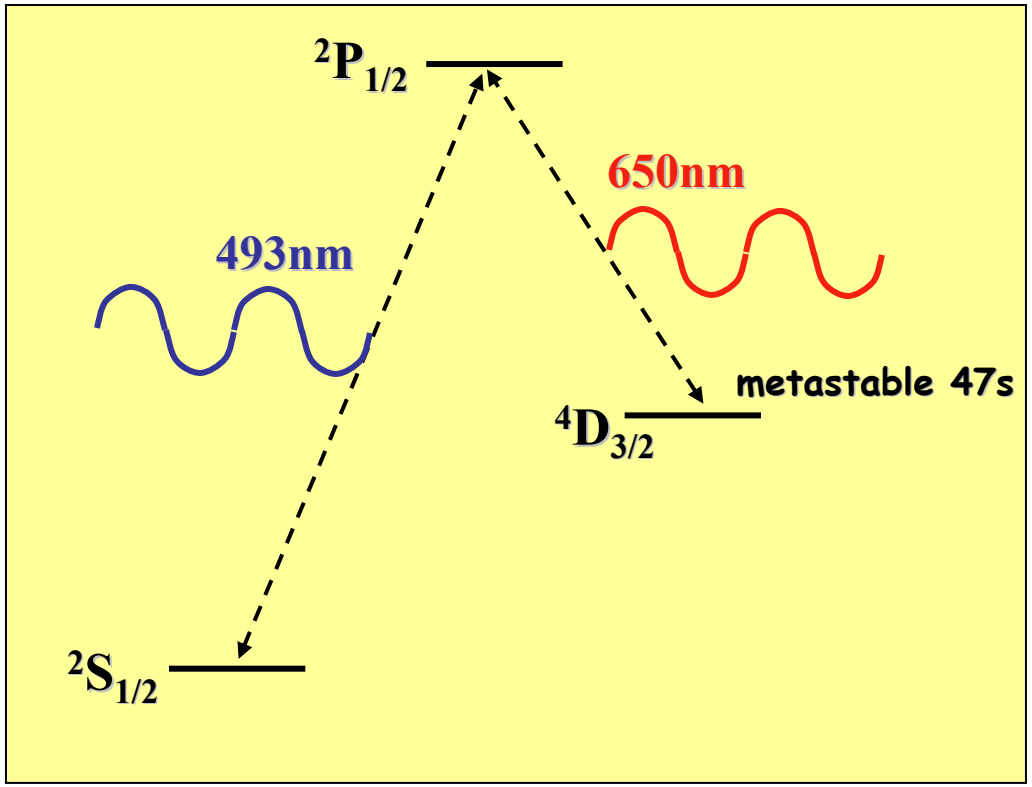
Xe is ideal for a large experiment

- No need to grow crystals
- Can be re-purified during the experiment
- No long lived Xe isotopes to activate
- Can be easily transferred from one detector to another if new technologies become available
- Noble gas: easy(er) to purify
- ^{136}Xe enrichment easier and safer:
  - noble gas (no chemistry involved)
  - centrifuge feed rate in gram/s, all mass useful
  - centrifuge efficiency ~ Δm. For Xe 4.7 amu
- ^{129}Xe is a hyperpolarizable nucleus, under study for NMR tomography… a joint enrichment program ?

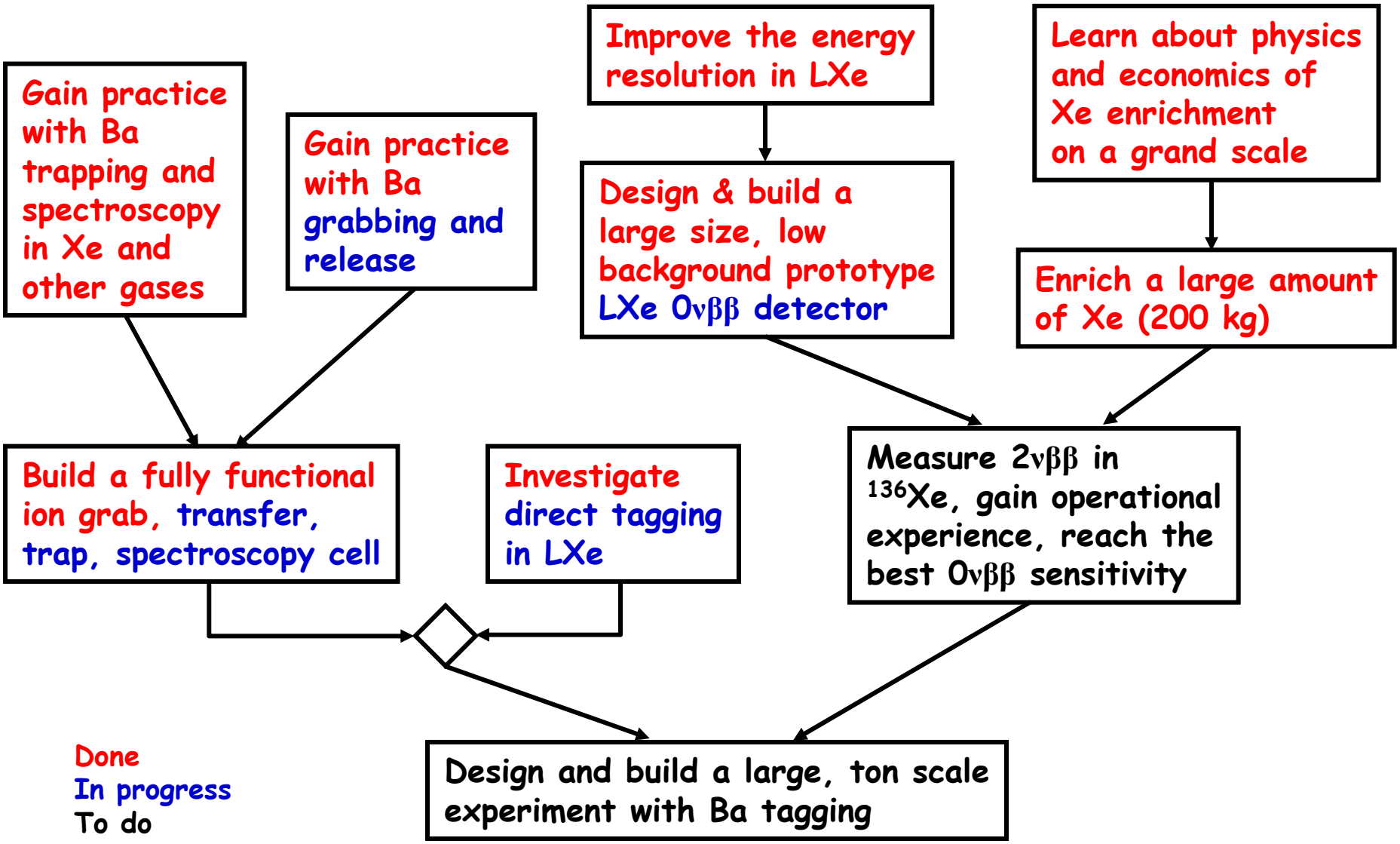
Xe offers a qualitatively new tool against background: $^{136}Xe \rightarrow {}^{136}Ba^{++}\, e^-\, e^-$ final state can be identified using optical spectroscopy (M.Moe PRC44 (1991) 931)

Ba^+ system best studied (Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)
Very specific signature "shelving"
Single ions can be detected from a photon rate of 10^7/s

- **Important additional constraint**
- **Drastic background reduction**



The roadmap to the background-free discovery of Majorana neutrinos and the neutrino mass scale



Done
In progress
To do

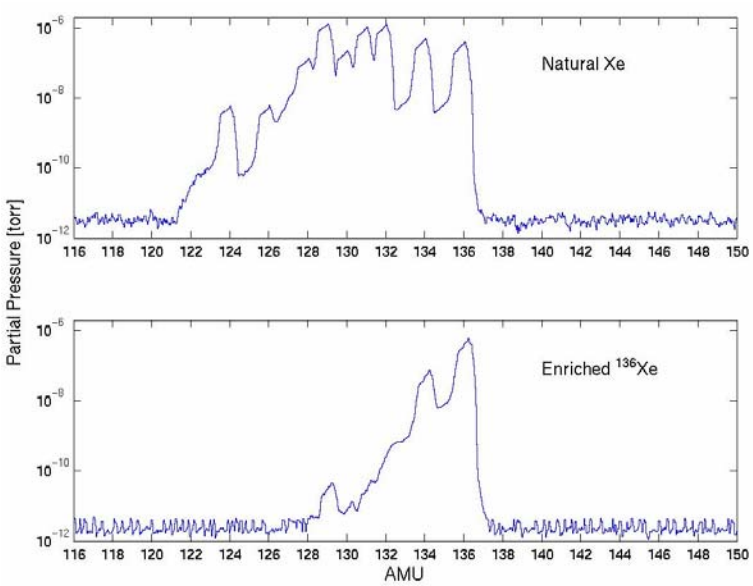
EXO-200:
an intermediate detector <u>without</u> Ba tagging

- **Need to test detector technology, particularly the LXe option:**
  A 200 kg chamber is close to the largest Xe detector ever built and hence good training ground
- **Essential to understand backgrounds from radioactivity:**
  200 kg is the minimum size for which the self-shielding is important and there is negligible surface inefficiency
- **Using ^{136}Xe can hope to measure the "background" $2\nu\beta\beta$ mode:**
  200 kg is needed to have a chance (if do not see the mode then is really good news for the large experiment !!)
- **The production logistics and quality of ^{136}Xe need to be tested:**
  Need a reasonably large quantity to test production

- **Already a respectable (20x) $\beta\beta$ decay experiment**

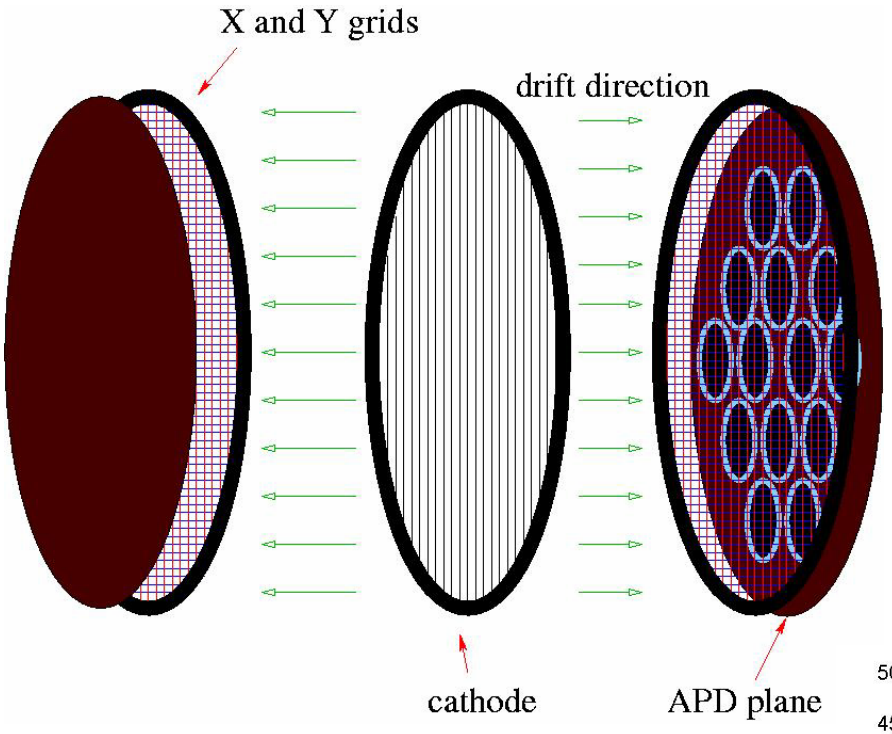
- **No need for Ba tagging at this scale**

200 kg ^{136}Xe test production completed in spring '03 (80% enrichment)

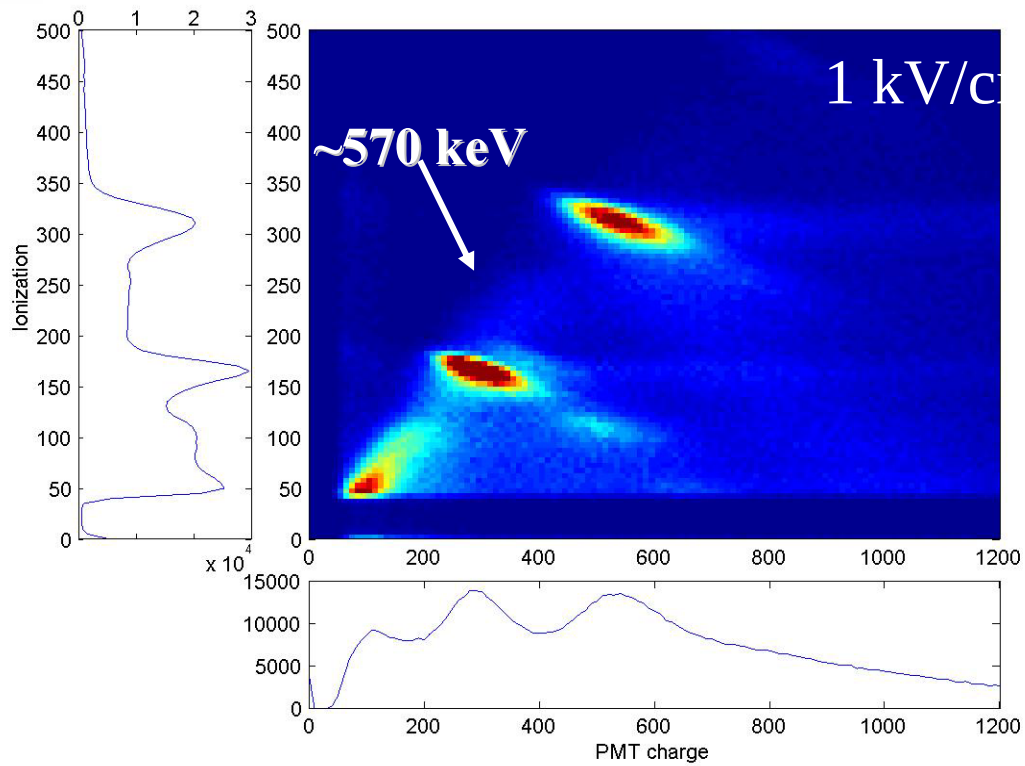


- Largest highly enriched stockpile not related to nuclear industry
- Largest sample of separated ββ isotope (by ~factor of 10)

EXO-200 TPC basics



Readout both scintillation and ionization to take full advantage of the anti-correlation found by our group and improve the energy resolution

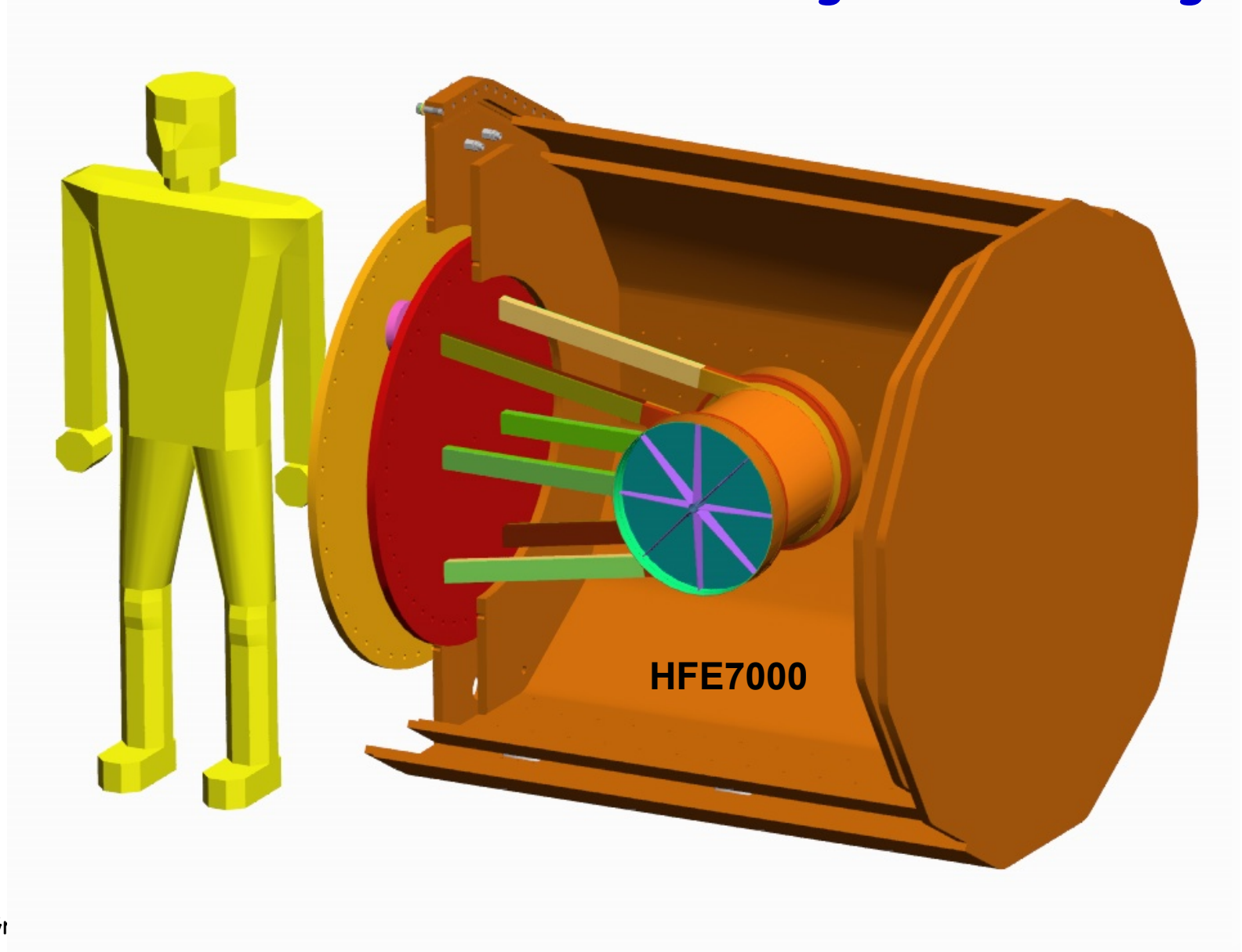


~40cm long, 40cm diameter cylinder with central cathode at ≤75kV

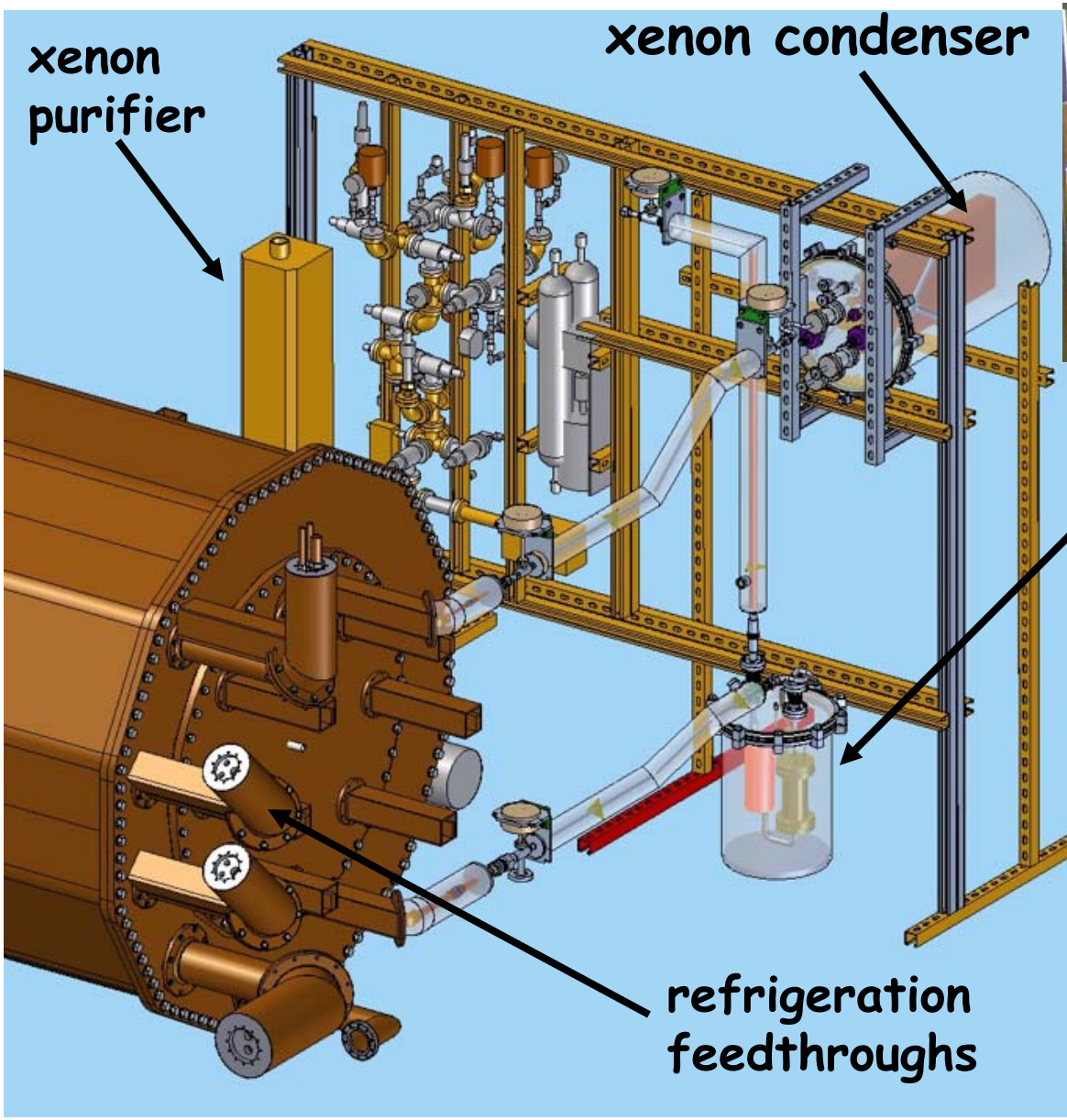
Scintillation readout with 2x259 bare LAAPDs (q.e.>1 @ 175nm)

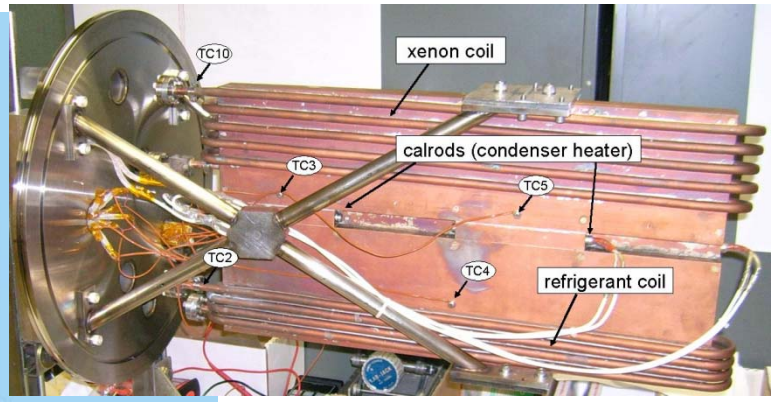
Charge readout with 60° crossed wire planes (96 ch on each side)

The TPC vessel sits in a low background, copper cryostat filled with ultra-clean HFE7000 refrigerant/shielding fluid



Cryogenics and Xenon Handling System



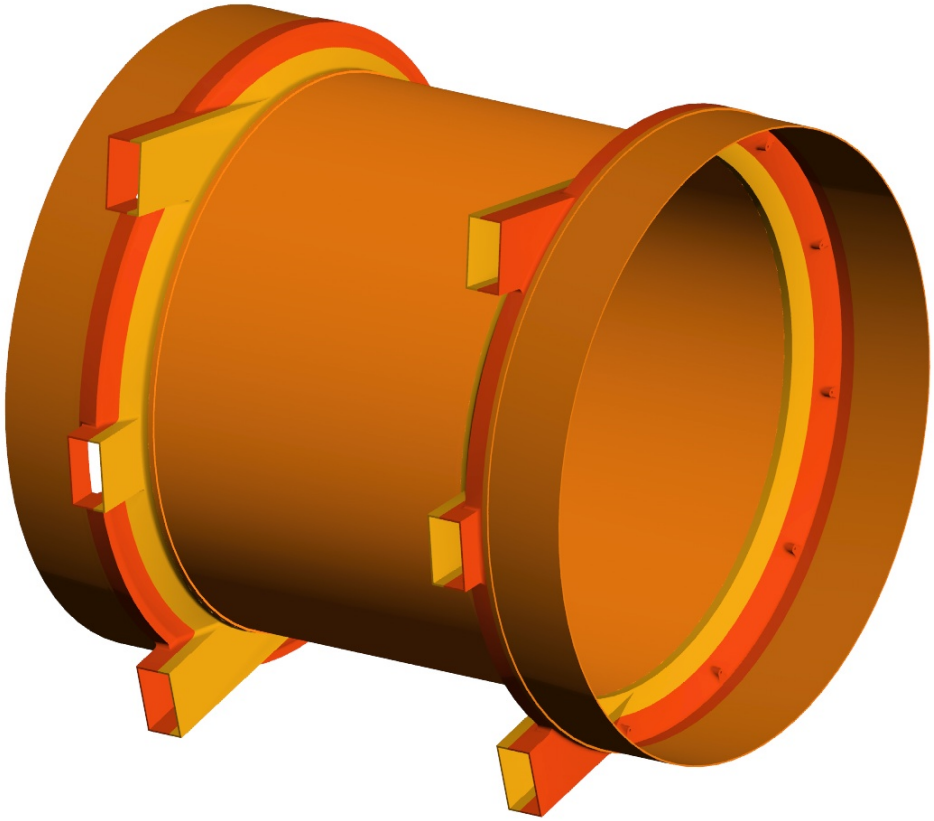


Cryostat was fabricated at SDMS (Grenoble)

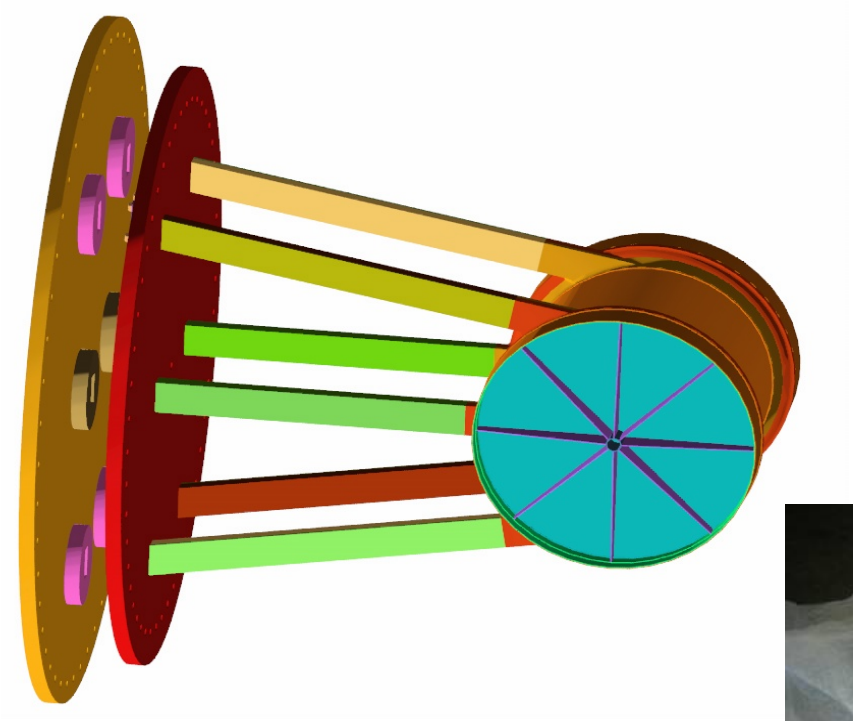
Extensive use of e-beam welding to reduce radioactive contamination

Ultra-low activity Cu vessel

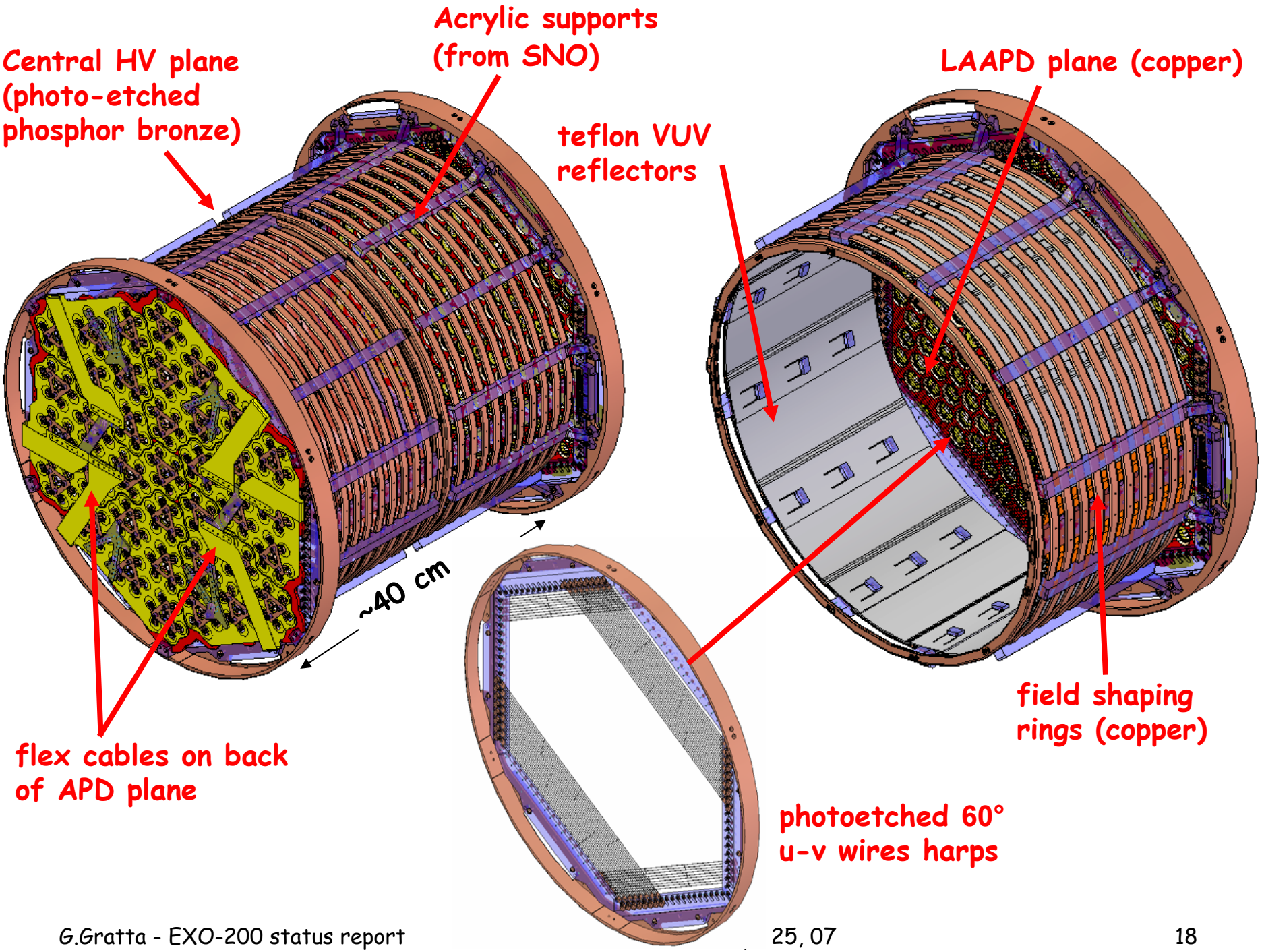
- Very light (~1.5mm thin, ~15kg) to minimize materials
- Low activity copper
- Different parts e-beam welded together
- Field TIG weld(s) to seal the vessel after assembly (TIG technology tested for radioactivity)
- All machining done by the Stanford Physics shop in the HEPL building (CR shielding)
- Complex shape to hug the fiducial volume and optimally utilize the ^{136}Xe



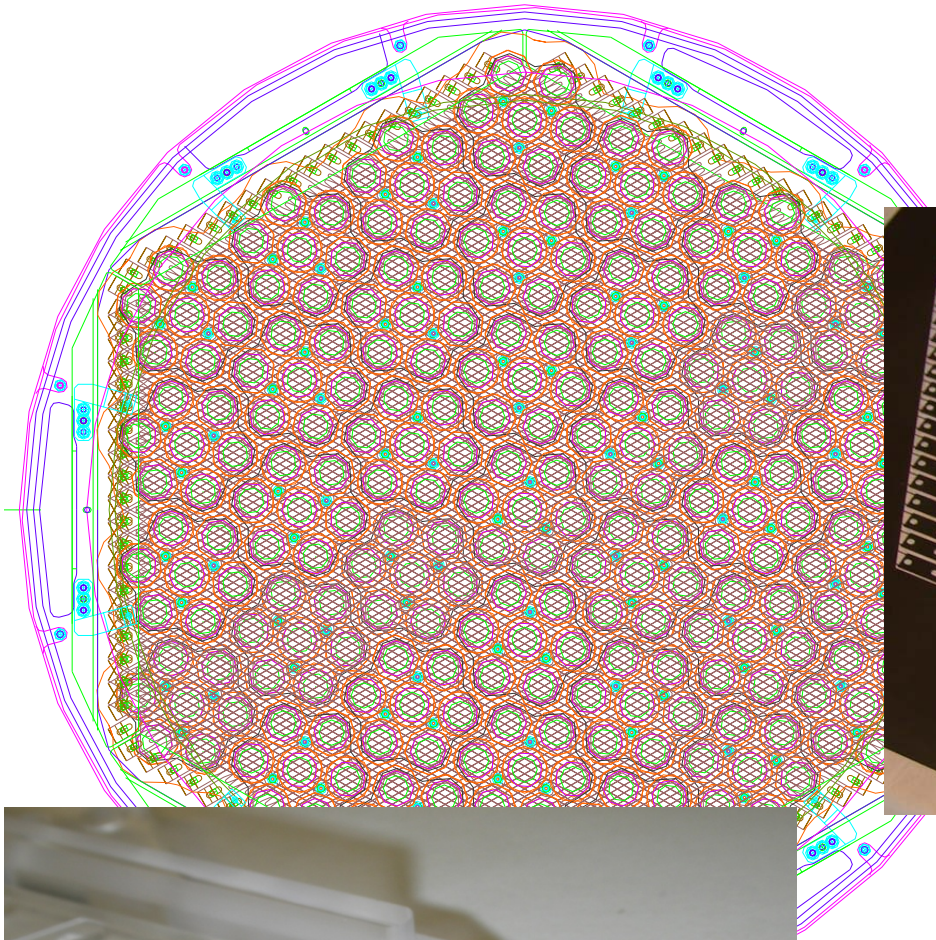
Low activity Copper arriving from Germany in a shielded container

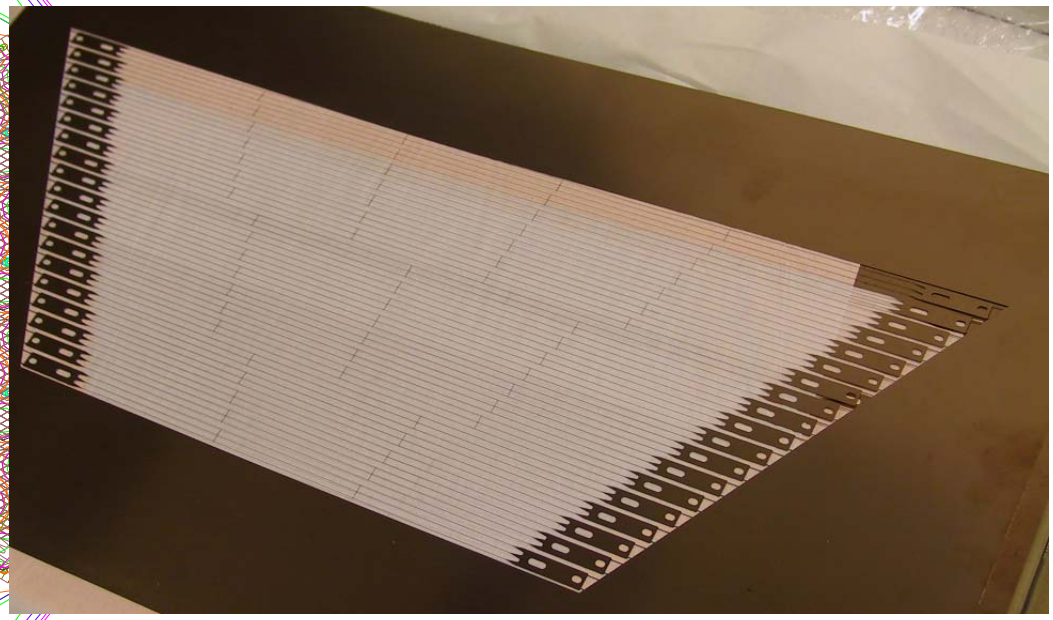


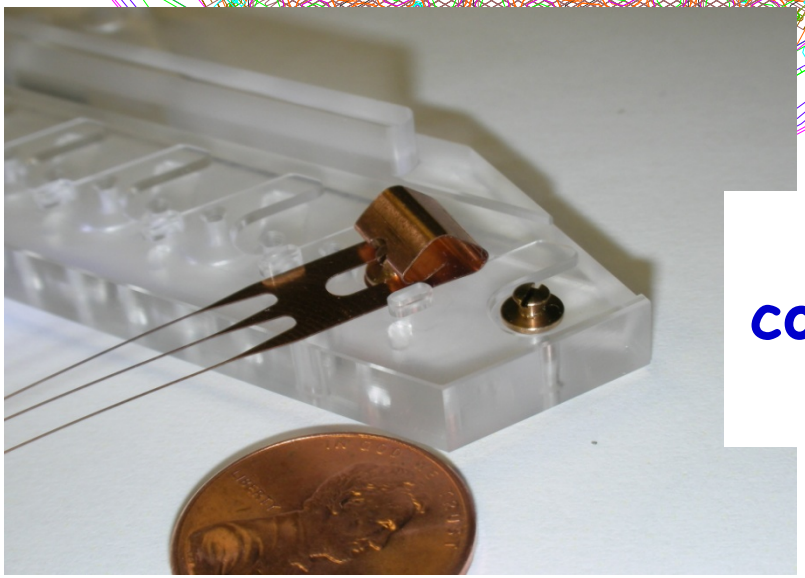
Copper vessel machined in shielded machine shop at Stanford


Central HV plane
(photo-etched
phosphor bronze)
Acrylic supports
(from SNO)
teflon VUV
reflectors
LAAPD plane (copper)
~40 cm
flex cables on back
of APD plane
field shaping
rings (copper)
photoetched 60°
u-v wires harps

Wire triplets are photoetched from low-activity phosphor bronze

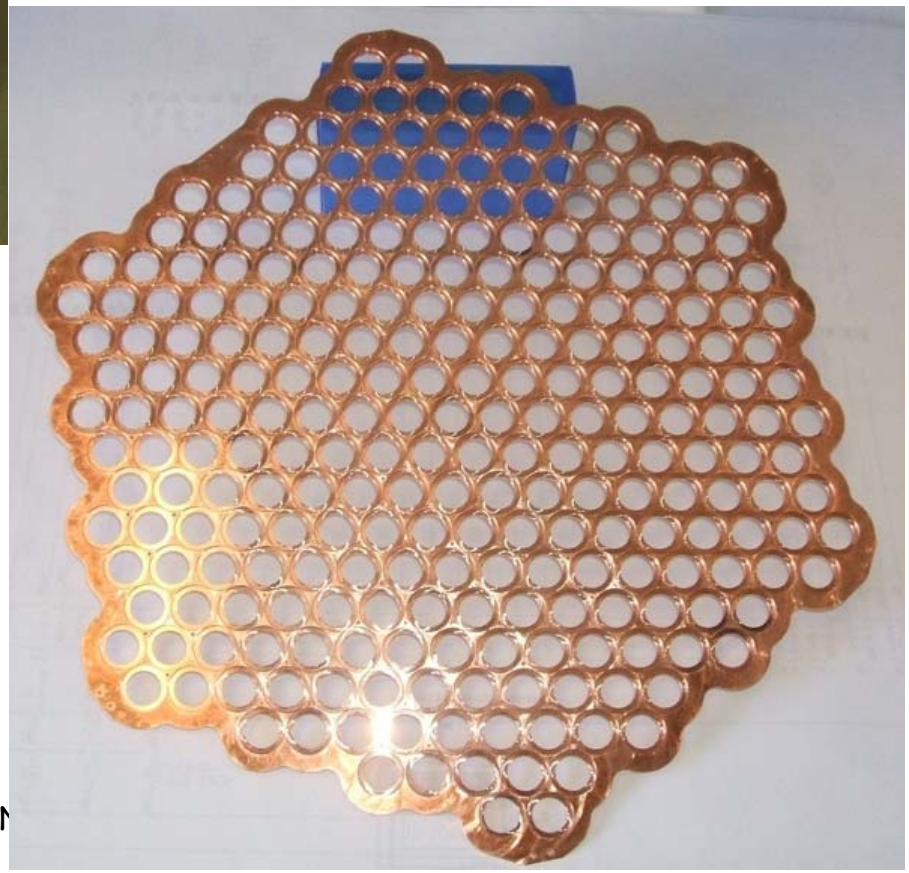






Built-in springs provide compliant mount for reliable temperature cycling

"Bare" LAAPDs are arranged in "gangs of 7" and contacted with photoetched phosphor bronze springs

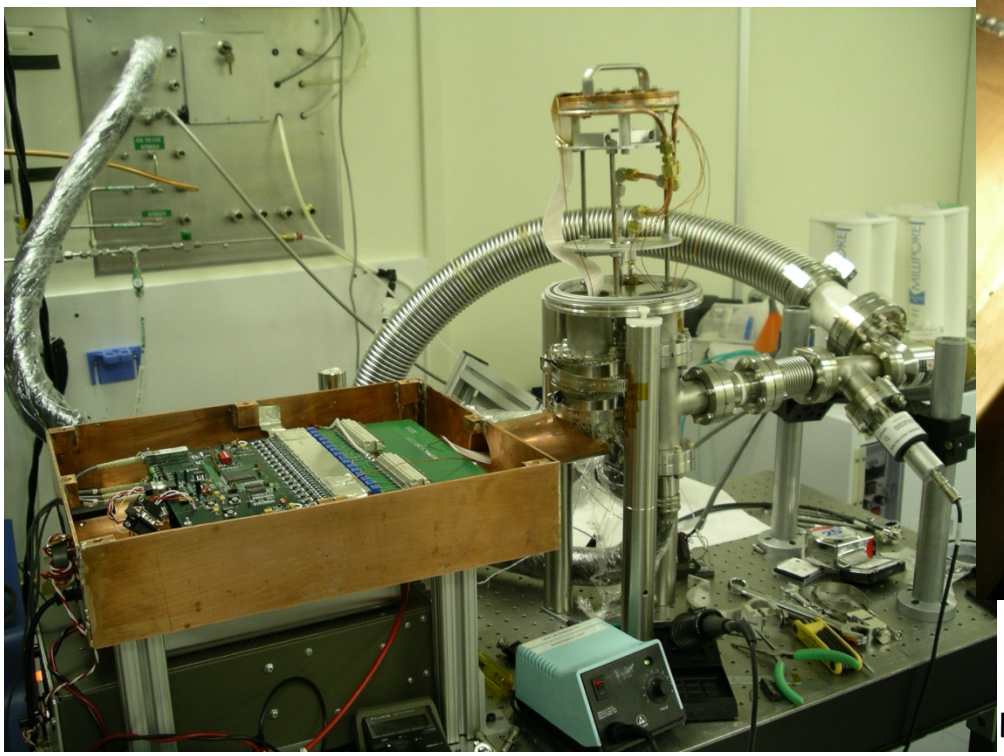


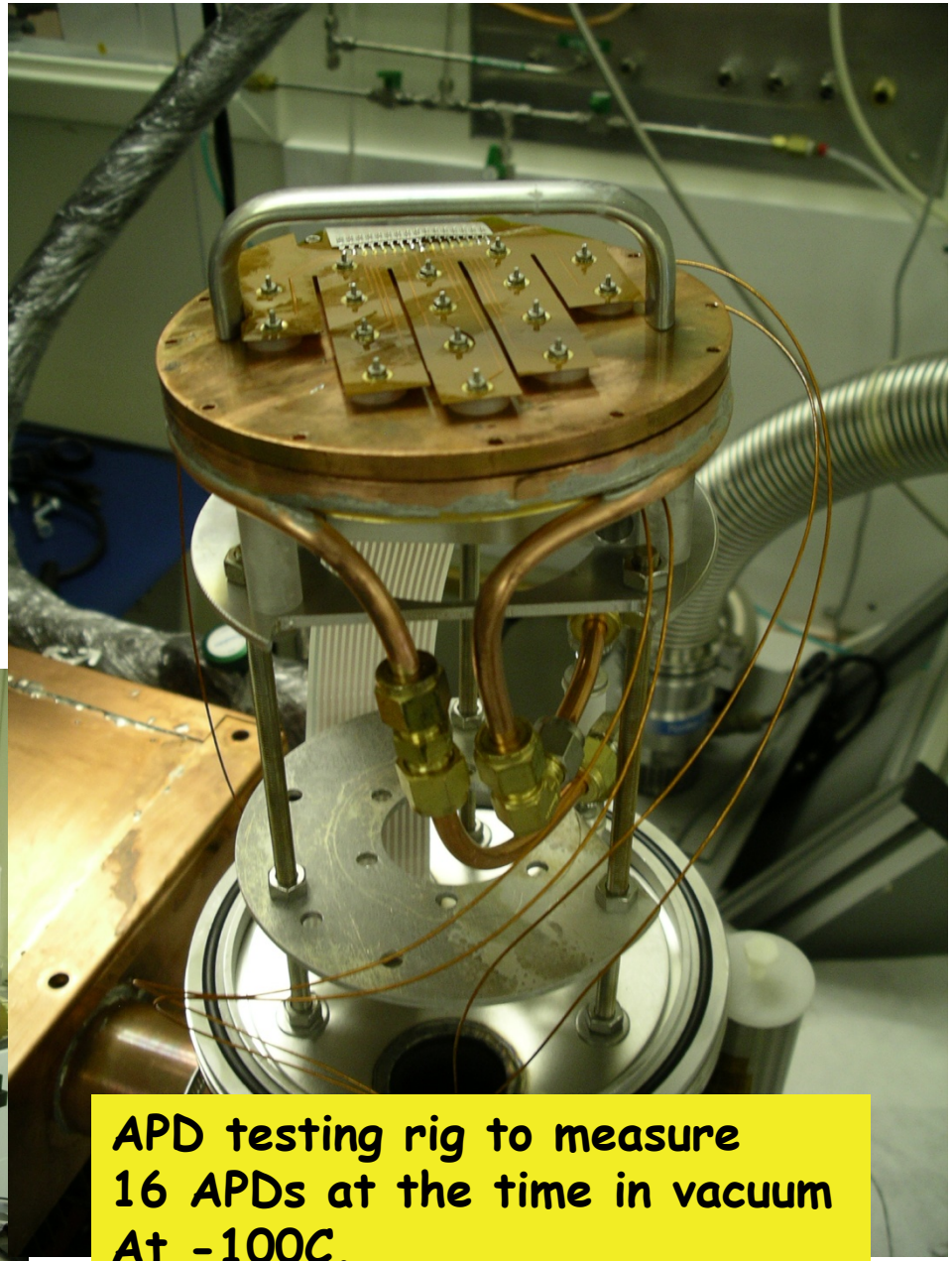
Two copper support platters hold 259 LAAPDs each

APDs are ideal for our application:
- very clean & light-weight,
- QE>1 @ 175nm

Gain set at 100-150

V~1500V
ΔV < ±0.5V
ΔT < ±1K APD is the driver for temperature stability
Leakage current OK cold





APD testing rig to measure
16 APDs at the time in vacuum
At -100C.
Readout using production
EXO-200 electronics (one card)

Bare LAAPD from Advanced Photonix

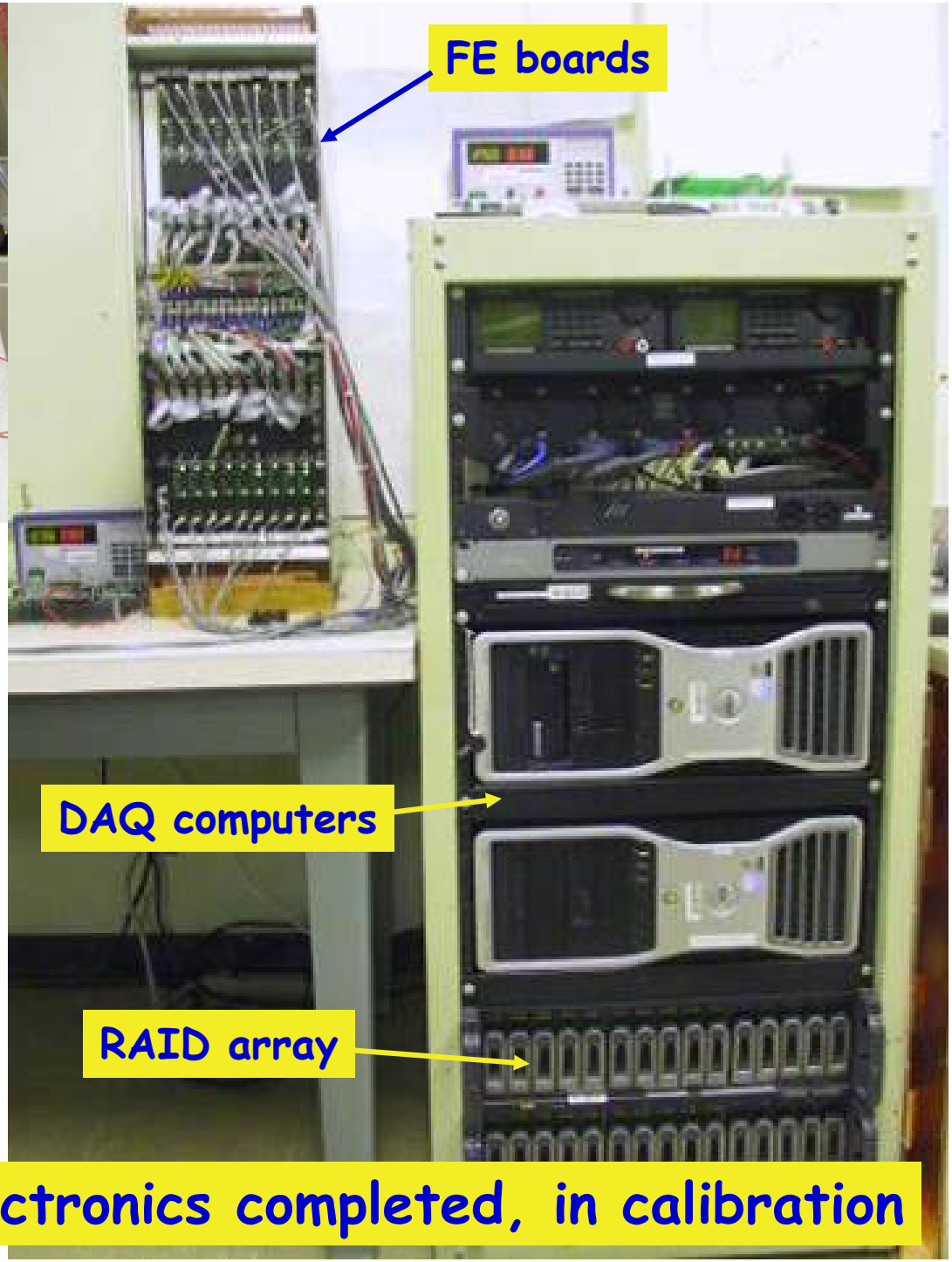
Have 150 devices tested

Yield problems at Adv Photonix factory in Camarillo CA

Restart production for EXO in Sept 2007, then shut down factory and move to Ann Arbor MI.

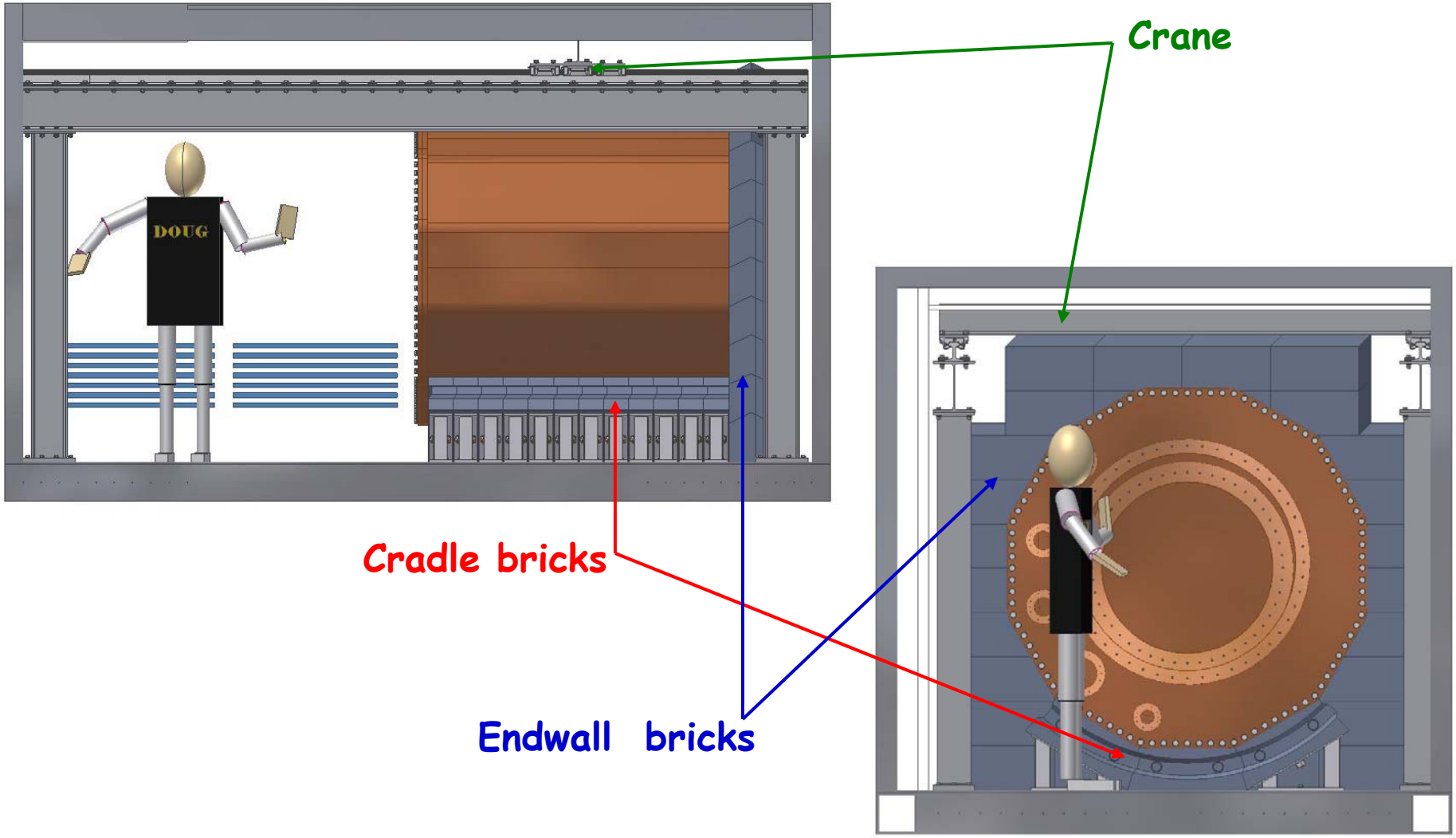
Delivery schedule:
- 45 on Sept 25, 07
- 200 on Oct 25, 07
- 225 on Nov 25, 07
- 101 on Dec 13, 07

First 110 good devices picked up Sept 24 (yesterday).
So they may be ahead of the (delayed) schedule

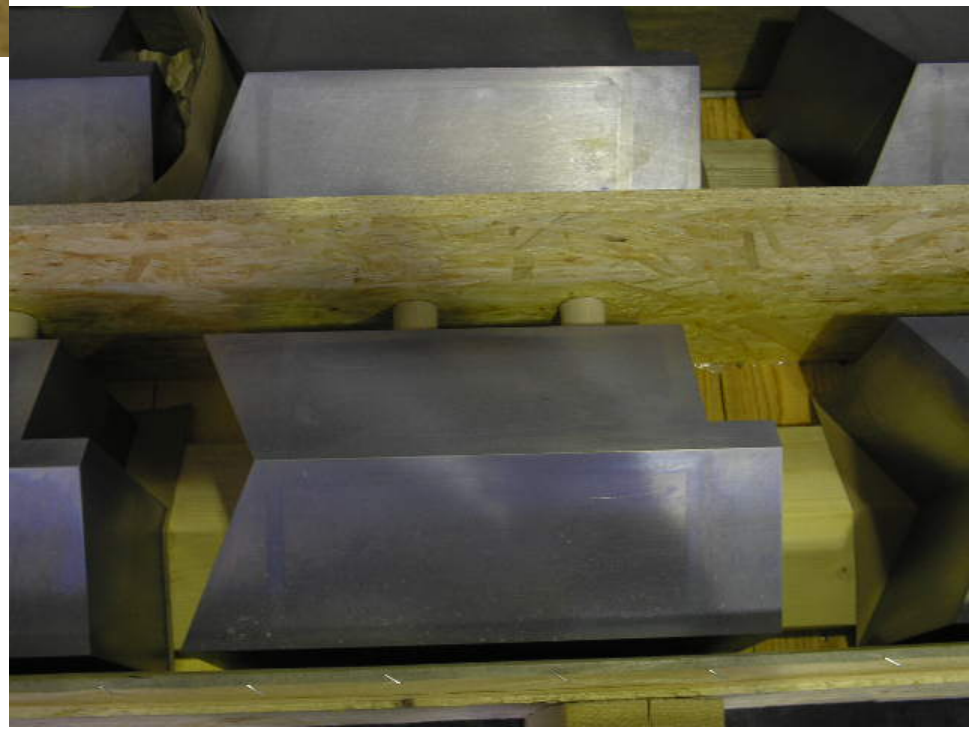


Electronics completed, in calibration

Lead Shielding



Each brick is epoxy painted at the factory in Germany to reduce Pb dust during assembly



All bricks and "arches" already at WIPP, except for the "front walls" that need to be ordered ASAP

Massive effort on material radioactive qualification using:

- NAA (MIT-Alabama)
- Low background γ-spectroscopy (Neuchatel, Alabama)
- α-counting (Alabama, Stanford, SLAC, Carleton)
- Radon counting (Laurentian)
- High performance GD-MS and ICP-MS (Canadian Inst. Standards)

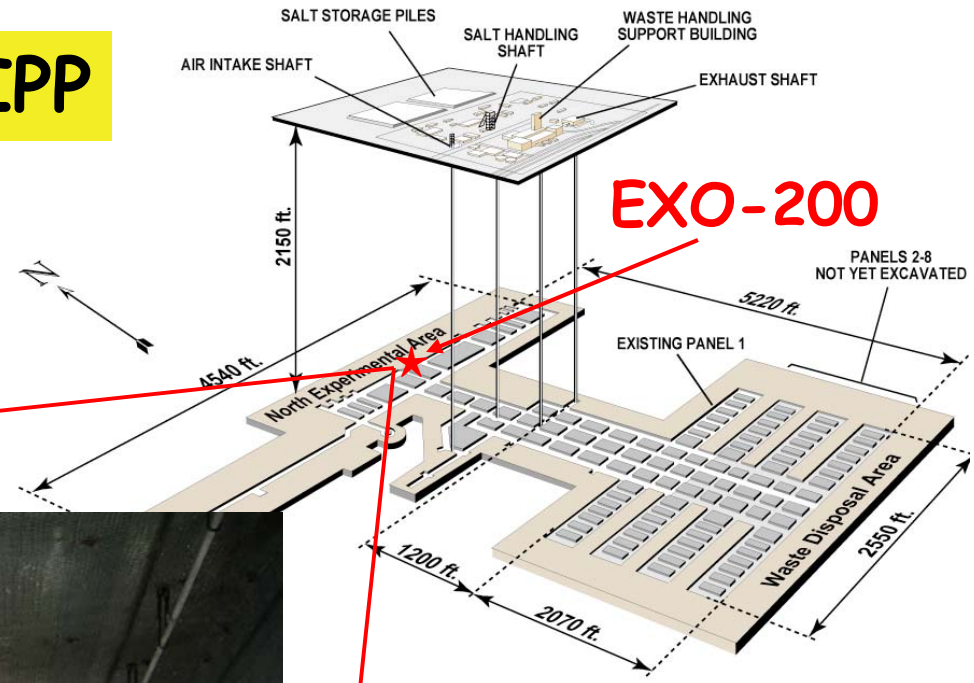
At present the database of characterized materials includes >300 entries

MC simulation of backgrounds at Alabama and Stanford/SLAC

The impact of every screw within the Pb shielding is evaluated before acceptance

NIM paper on material selection to be posted/submitted in the next 2 weeks

EXO-200 located at WIPP



Most EXO people have already completed the full WIPP/MSHA miner training ("inexperienced miner, metal/non-metal mines")

Summary EXO-200 funding FY02-07

Institution	Type	FY02	FY03	FY04	FY05	FY06	FY07	Total MY	Total M&S
DoE EM (WIPP)	labor			(a)	(a)	(a)	(a)	0	
	M&S	950	950	397	600	950			3847
Stanford DoE HEP	labor							0	
	M&S			70	300	300	200		870
Stanford Private	labor							0	
	M&S	100	350						450
SLAC	labor		0.5	2	2.6	5	6.9	17	
	M&S		350	121	75	307	522		1375
DoE NP (Alabama)	labor							0	
	M&S		9	7	22	23			61
Alabama State	labor							0	
	M&S	50	15		20	35	2		122
Neuchatel	labor			3	3			6	
	M&S			150	75	25	18		268
NSERC Canada	labor			1.5	1.5	1	1	5	
	M&S				50	37	103		190
ITEP Moscow	labor			1				1	
	M&S	100							100
Totals MY		0	0.5	7.5	7.1	6	7.9	29	
Totals M&S		1200	1674	745	1142	1677	845		7283

- **M&S funding in k$**
- **Labor is technical personnel only, in man yrs**
- **Stanford has had 1 mech engineer paid from M&S funds**

DoE-EM funding did not materialize in FY07 because of the continuing resolution

EXO first decided to proceed with operations that could be "swapped" between WIPP and Stanford with minor impact in the schedule:

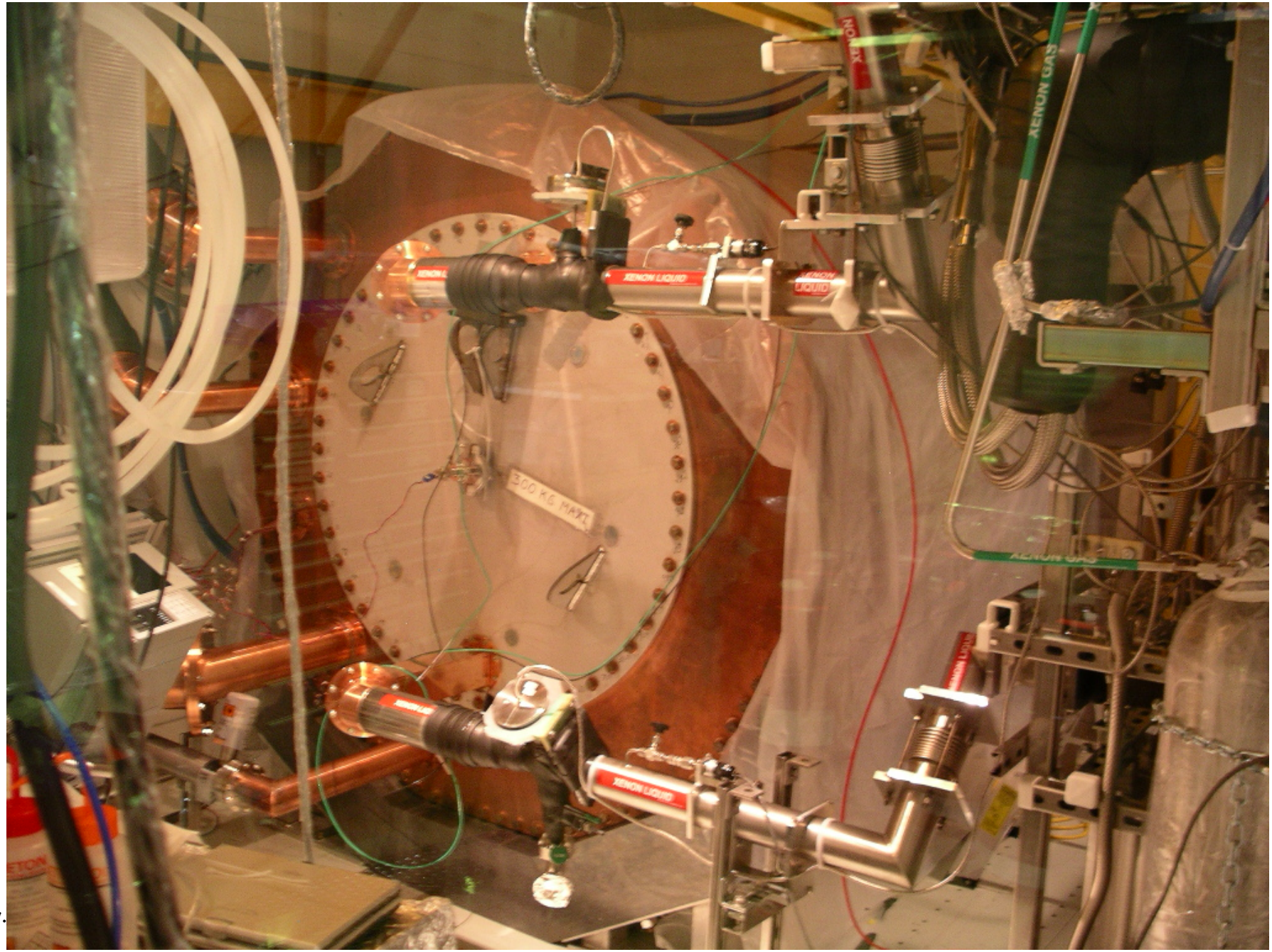
- *Pre-commission cryogenics, liquefy ~30kg Xe (Apr-May 2007)*
- *Replace superinsulation in the cryostat for lower background material and fewer layers (May 2007)*

In Jun 2007 EXO decided to proceed with the move to WIPP, to limit the delay to the project and minimize cost increases on the rigging, transportation and HVAC (de-/)re-commissioning contracts (then already awarded)

- *University of Neuchatel provided $58k towards installation costs*
- *NSERC-Canada provided ~$40k towards installation costs*
- *Stanford allowed the PI to overspend the WIPP/DoE-EM grant by up to $750k to proceed*

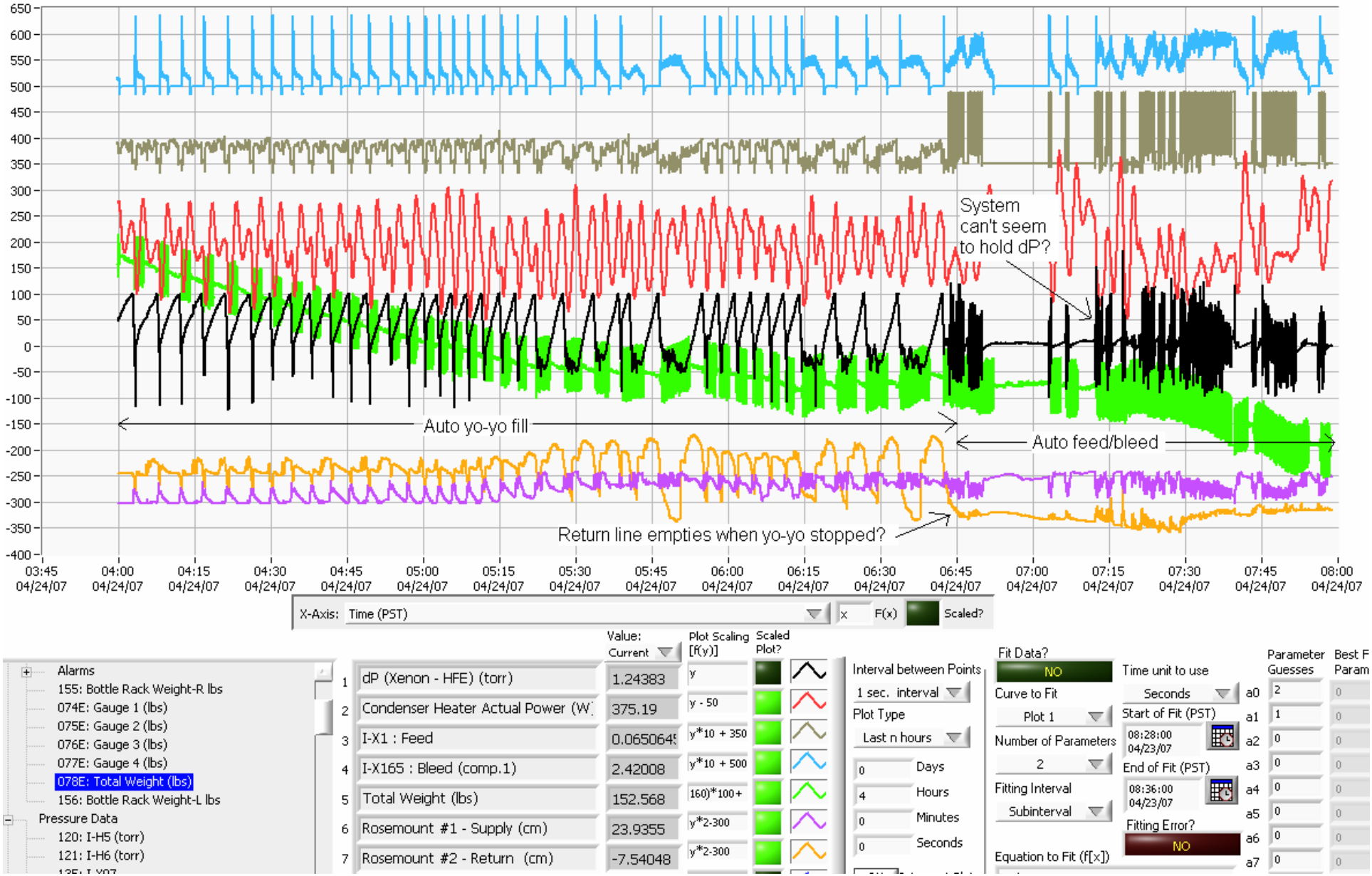
Commissioning LXe cryogenics and pressure control at Stanford

April 2007, ~30kg natural Xe

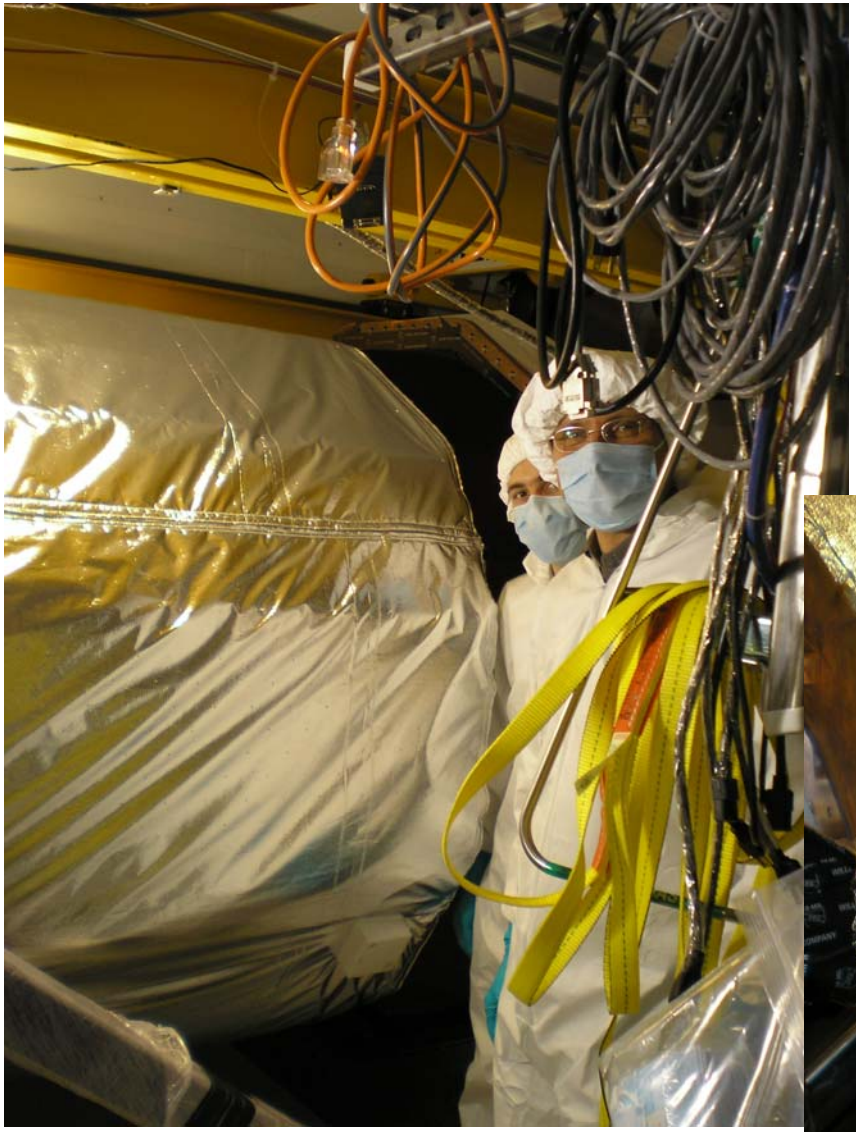


G.

Control and monitoring system at work, Apr 07



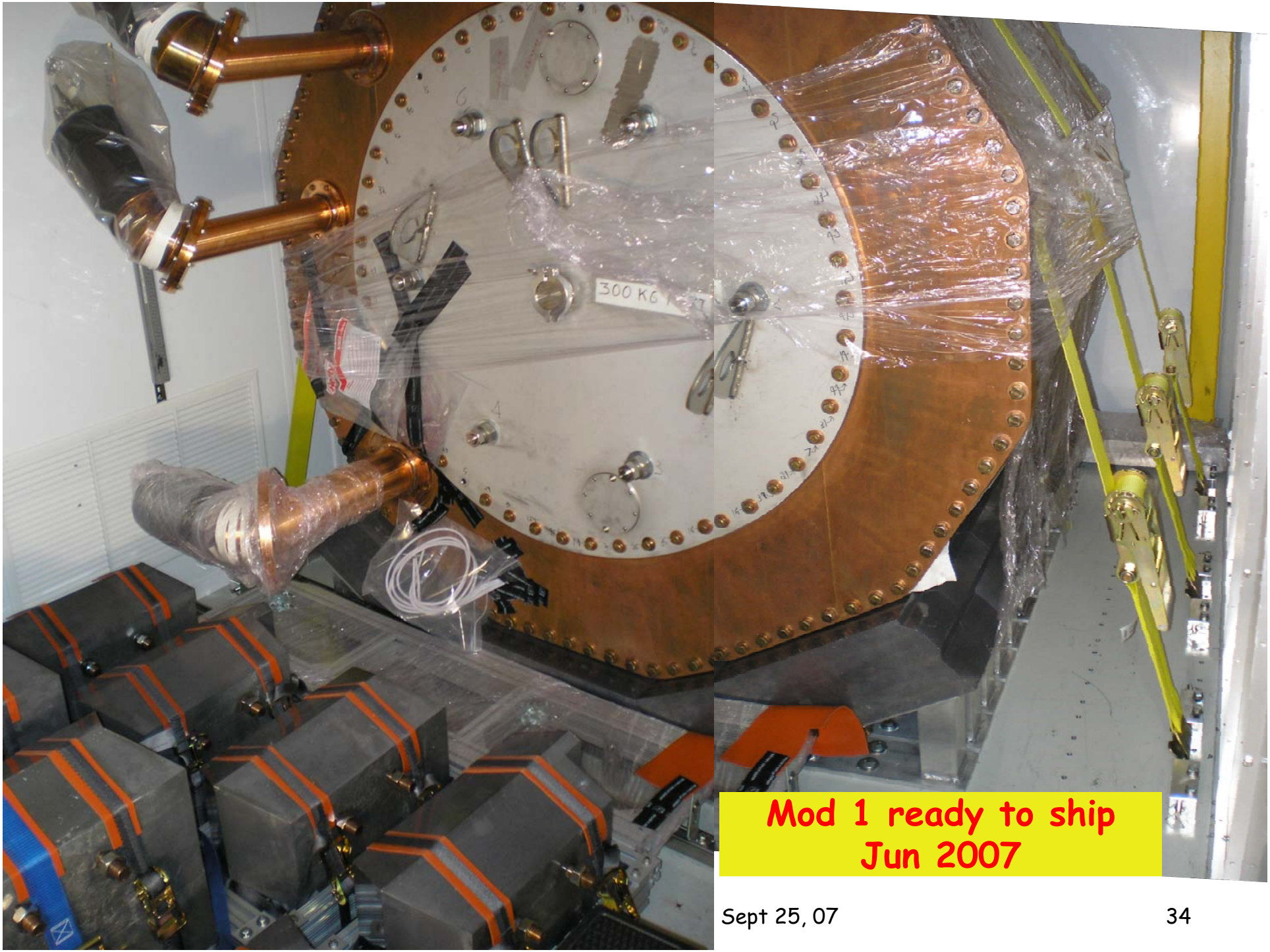
Superinsulation replacement May 2007



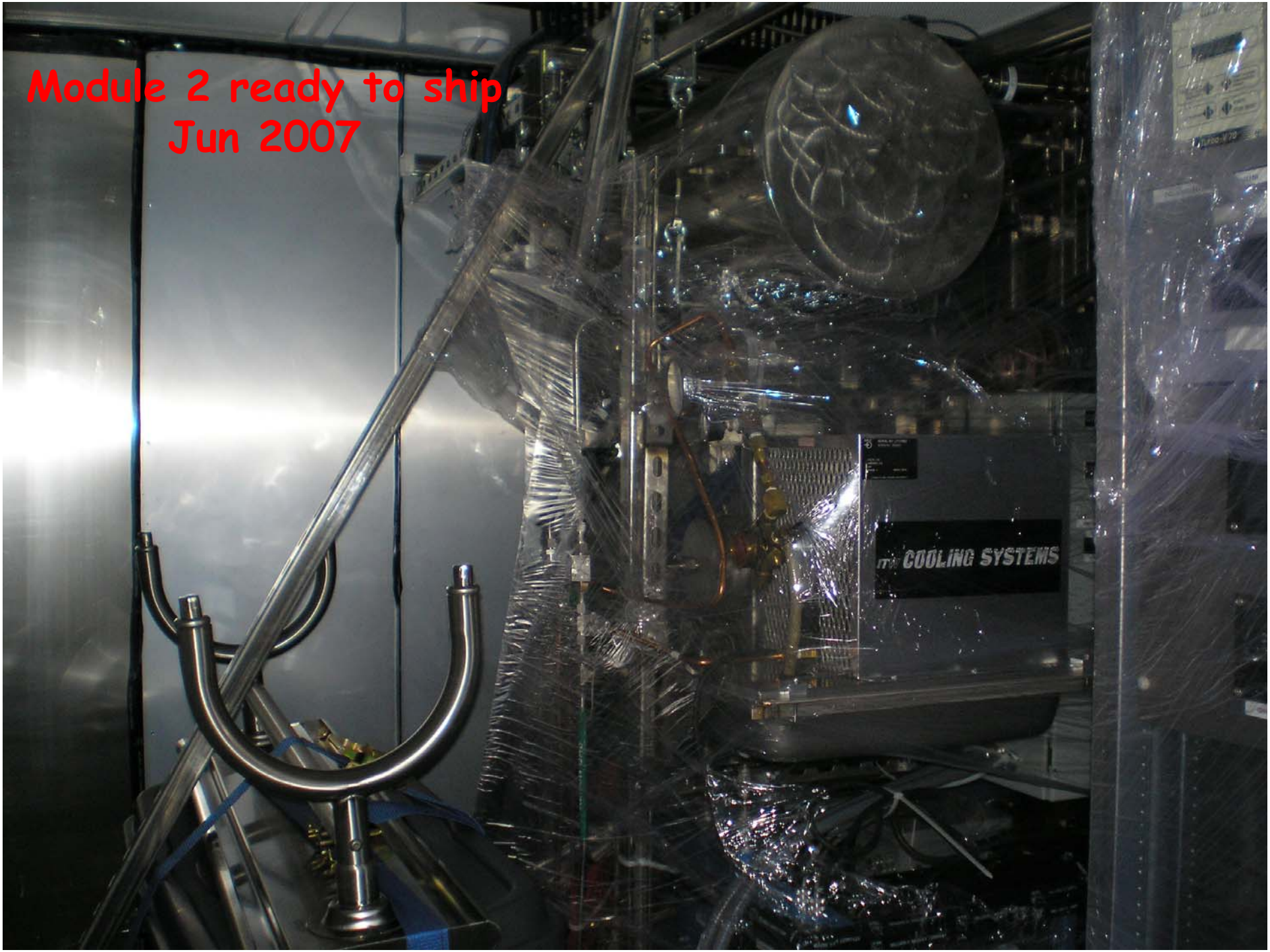
Shipping to WIPP, Schedule presented at the SLAC DoE review, June 2007

- May 28–Jun 8 Close Mod 1
  Secure equipment
- Jun 6-11 Dismount electrical
- Jun 12-24 Dismount HVAC ←
- Jun 25-Jul 6 Decouple and weigh modules
- Jul 9-13 Float
- Jul 13-16 Ship Mod 2-6 + containers
- Jul 20 Ship Mod 1

We may ship Mod 2-6 around Jul 1, 2 weeks ahead of schedule



Mod 1 ready to ship
Jun 2007


Module 2 ready to ship
Jun 2007
COOLING SYSTEMS

Late Jun 2007:
clean rooms are disconnected and weighted, ready to ship

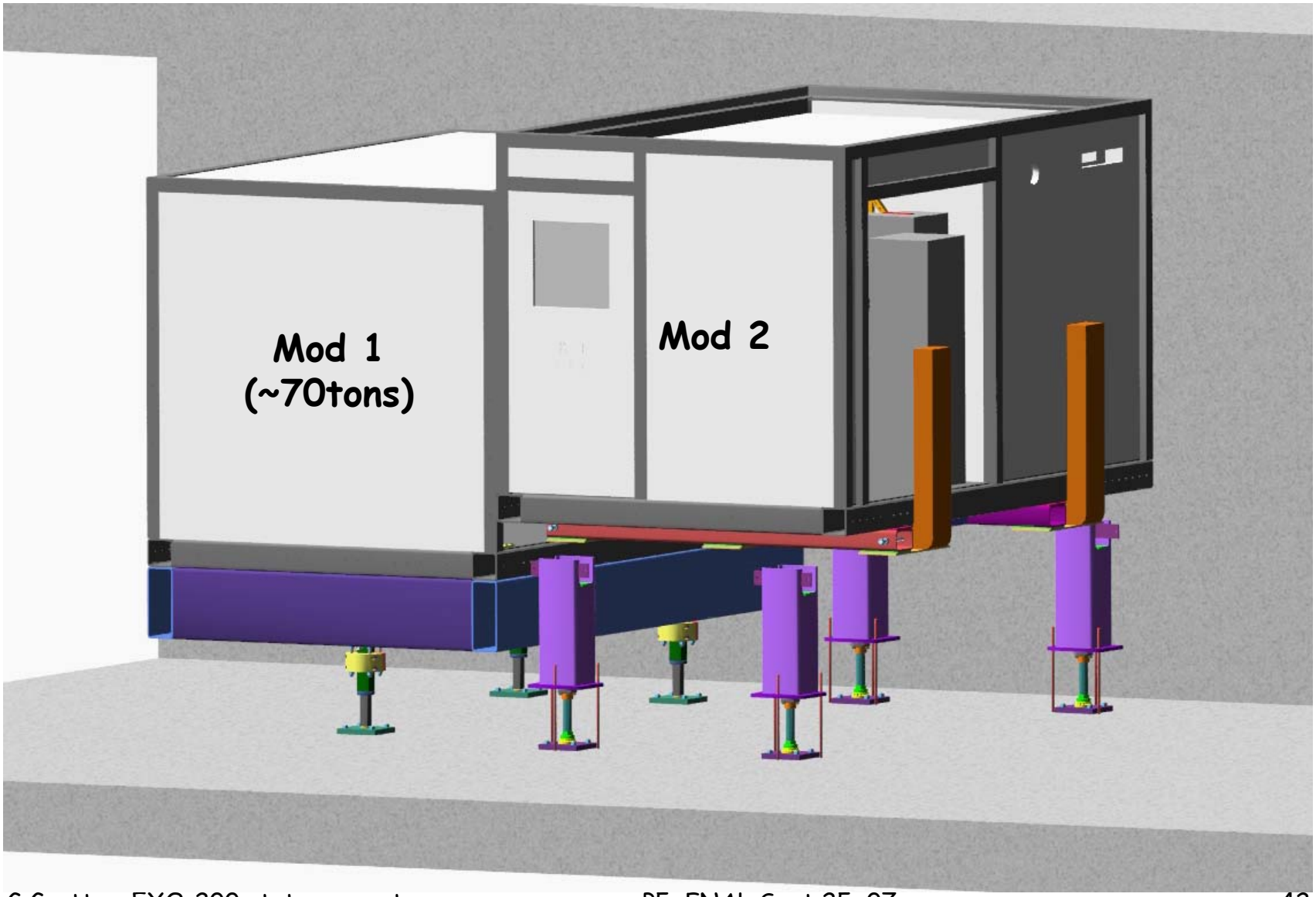
Jul 5, 07, the first shipment (Mods 5 & 6)

Aug 21, 07, 1AM PDT
Module 1 (last shipment) leaves Stanford

Aug 22, 07, 6PM MDT
Module 1 goes underground
Harness and Line
Required Around
Open Shaft
CAUTION

Aug 22, 07, 11:30 PM MDT
Module 1 in its final position

Because of salt creep over the years, a system of adjustable foundations maintains the EXO-200 cleanrooms level without the need for mining



Sept 6, 07 All clean rooms back together on their adjustable foundations

Sept 18 HVAC reassembly starts

EXO-200 Milestones
(from Jul 07 Installation proposal to the Office of HEP)

- Reconnect EXO-200 cleanrooms, HVAC and electric — Oct 31, 2007
- Re-commission EXO-200 cryogenics — Dec 31, 2007
- Ship TPC to WIPP — Mar 1, 2008
- Commission TPC with Natural Xe — May 31, 2008

Stanford overdraft reaches $750k

It is unlikely that the project will be able to continue without new funding past Dec 31, 07

Budget to complete the detector and run until FY10*
(from the Jul 07 installation, commissioning and operations proposal)

Item	Description	FY07*	FY08	FY09	FY10
1	Adjustable salt foundations for Module 1	50	-	-	-
2	Engineering	103	95	28	-
3	Casting, machining and painting of the front lead walls	100	-	-	-
4	TPC vessel machining and ebeam welding	100	55	-	-
5	HVAC dismounting (Stanford) and re-commissioning (WIPP)	65	-	-	-
6	Avalanche photodiodes re-order (250 at $670)	168	-	-	-
7	Spares for cryogenic seals	-	25	-	-
8	Low radioactivity silicone warms cryostat seals	10	-	-	-
9	Compressed gases, LN2 and other consumables	-	15	10	10
10	Underground electrical hookup, isolation transformer	50	-	-	-
11	Clean room supplies	25	25	15	10
12	Electric fork lift (6,000 lbs) for assembly at WIPP	8	-	-	-
13	Additional UPS batteries	-	100	-	-
14	Veto scintillators	-	200	-	-
15	Extra cards for the veto HV power supply	-	25	-	-
16	Mechanical technician in Carlsbad (inch benefits and indir)	-	135	140	145
17	Domestic travel to WIPP (incl indir)	37	51	19	19
	Total	716	726	212	184

**** Expected data taking period with enriched Xe is 3 to 5 years***

Conclusions

Over its glorious history neutrino physics has provided plenty of surprises and has required forays in many different areas of science and technology

EXO really belongs to this tradition!

Isotope enrichment at an unprecedented scale (for science) is a reality

EXO-200 is underground!

Ba tagging for EXO is using bag of tricks borrowed from nuclear and particle physics, AMO and surface science

We are still ahead of the competition and would like to remain this way !