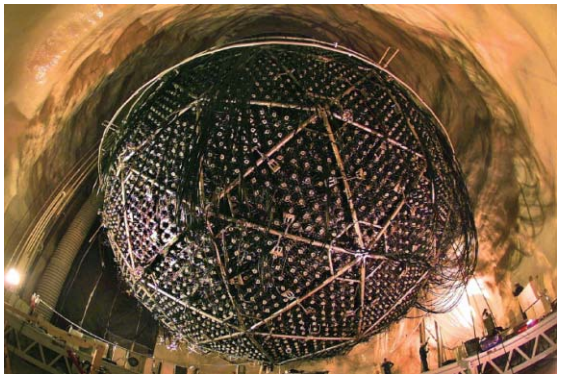
Facilities and Infrastructure for Fundamental Symmetries and Neutrinos

Brad Plaster, University of Kentucky

+ thanks to innumerable members of the community (U.S. and international)



Town Meeting – Chicago – September 29, 2014

Outline

I. Underground Labs

II. Neutrino Physics: Reactors, SNS

III. Muon Physics: FNAL, PSI

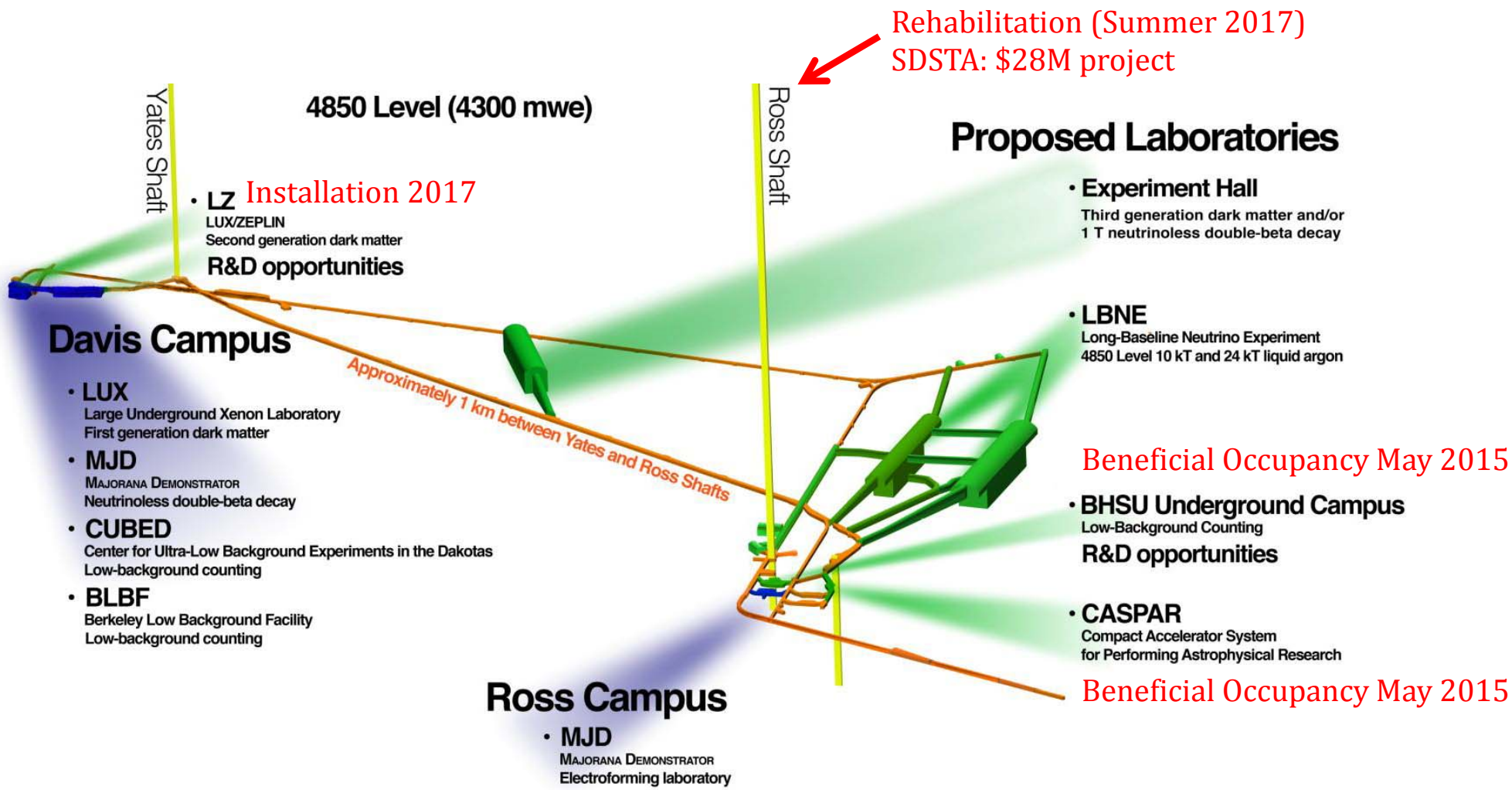
IV. Infrastructure for PVES at JLab

V. Neutron Physics

I. Underground Labs

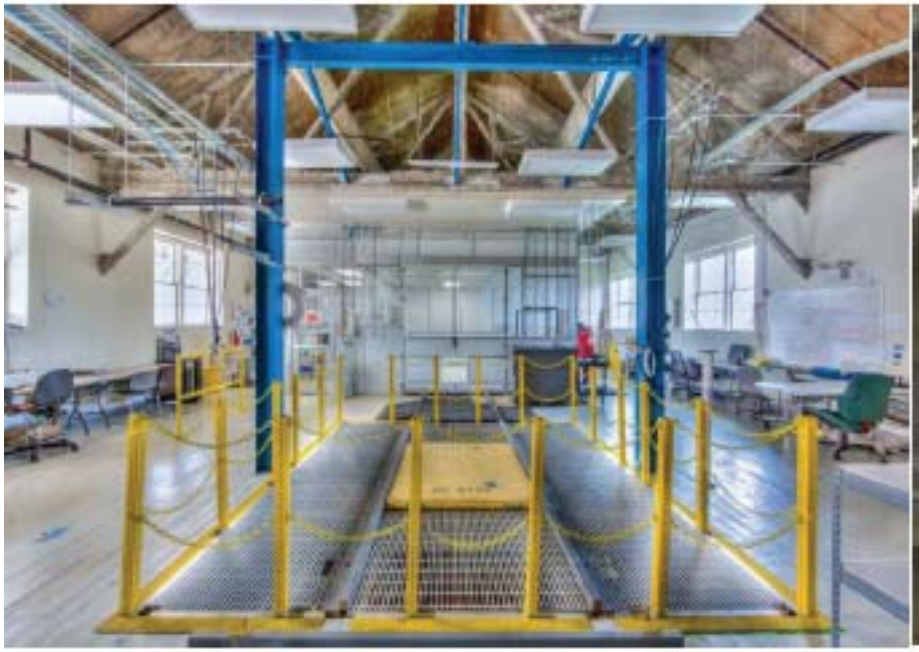
Sanford Underground Research Facility

- Deep (4850 ft, 4300 mwe) underground facility with expansion possibilities
- Redundant safe access with two principal shafts



SURF Space for R&D Opportunities

- Surface Laboratory:
  - 190 m^2 lab space (lower 3 levels not fully developed)
  - Cleanroom (incl anteroom, 9' ceiling), water shield tank (~3-m diameter)
- 4850L Davis Campus and Vicinity:
  - Inside Davis Campus clean space, Lower Davis room: ~17 m^2 (14' ceiling height)
  - Two cutouts outside clean space: ~33-50 m^2 (with 12' avg ceiling height)



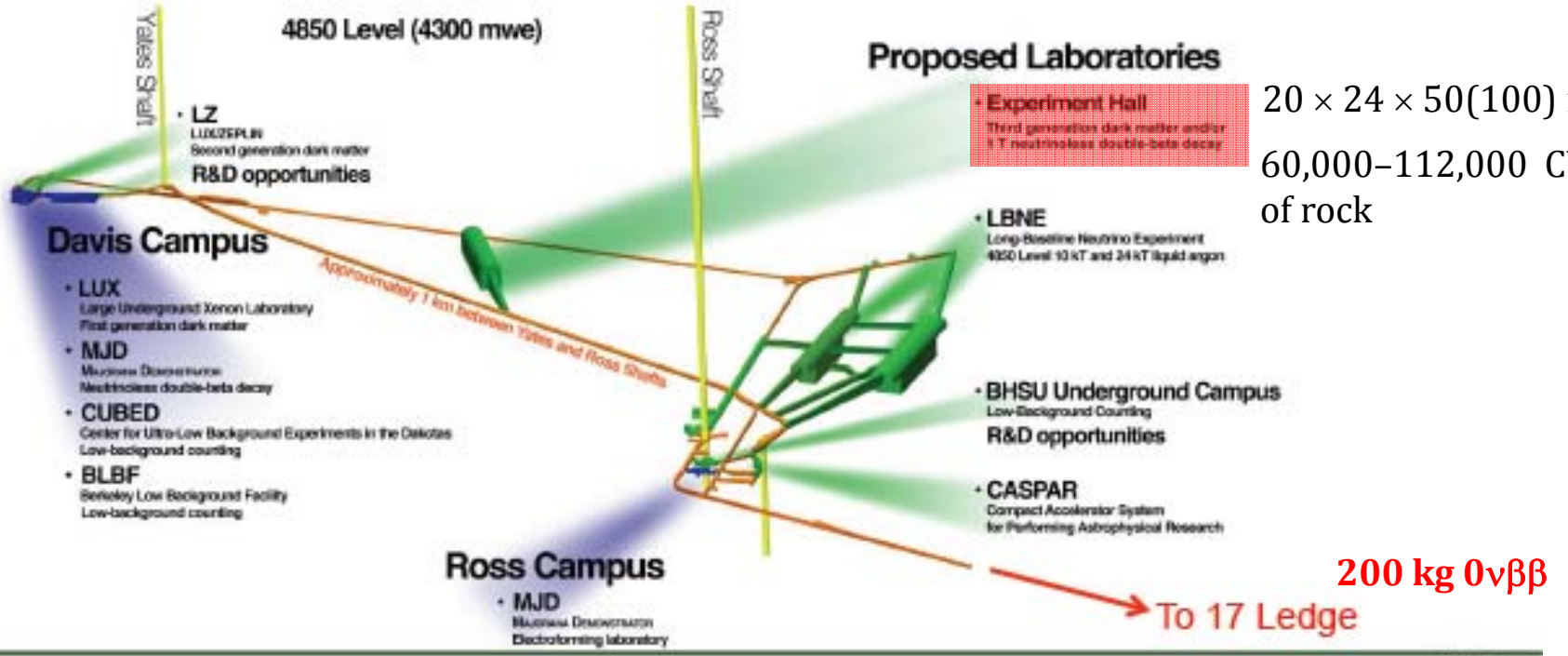
Sanford Underground Research Facility

Courtesy: M. Headley (SURF)

Expansion Options

Spaces Available

- LUX, then LZ will occupy the Davis Cavern until the mid 2020's
- MAJORANA will occupy their cavern until ~2019, at which time that space may be available, depending on whether their next generation could fit. It is a tight fit for a 1 tonne scale DBD detector
- There are existing large (~40'x60'x15' tall) spaces available both on the 4850L and other levels that were historically used for shops. Securing (rock bolting) access to these spaces is required for their use. In some cases, expanding the cross section of the access is also advisable. The space SURF would consider most attractive is know as the 17 ledge shop, ~ 1mile from the Ross shaft (below)



$20 \times 24 \times 50(100)$ m^3

60,000–112,000 CY of rock

200 kg 0νββ

Sanford Underground Research Facility

Courtesy: M. Headley (SURF)

Limitations to Expansion in Near-Term

- Existing space for disposal of rock at the 4850 level is limited
  → Space for ~15,000 cubic yards (CY)

- New excavations > 15,000 CY will be challenging if undertaken before completion of the Ross Shaft rehabilitation (2017)

- After the rehabilitation, but before LBNE has installed a waste rock handling system (2017–2019), removal possible via trucks
  - Order of magnitude: ~50,000 CY requires 3,000 30-ton truckloads

- **Post LBNE waste rock handling system (> 2019), very large excavations will be possible**

Berkeley Low Background Facility

BLBF
LBNL γ SURF

http://lbf.lbl.gov

BLBF Group (LBNL and UC Berkeley)
A.R. Smith, K.J. Thomas, A.W.P. Poon, Y.D. Chan, E.B. Norman, K.T. Lesko

Provides low background, gamma spectroscopy services to a wide variety of projects/experiments
115% n-type, 85% p-type HPGe, +others

- passive counting for U, Th, K (and common man-made/cosmogenics)
- active assay via neutron activation analysis
- Neutron flux measurements (beam characterization, etc.)

Long History of Low Background Counting (>60 years experience)

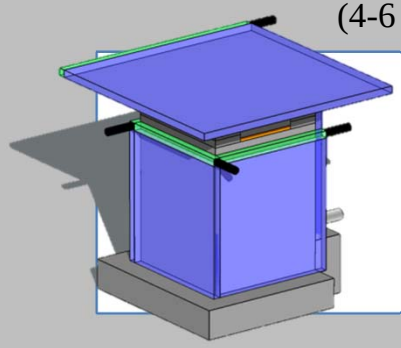
- SNO, KamLAND, CUORE, DoubleCHOOZ, Daya Bay, Majorana, Katrin, Sanford Lab, LUX/LZ, + more.

**** BLBF Open to any project/experiment**

- Requests for service can be made at website. http://lbf.lbl.gov
- Samples typically screened first at LBNL, then those requiring additional sensitivity are sent to SURF.

BLBF@LBNL
4850L (4300 m.w.e.)

Specially selected, low activity concrete used in lab construction. (4-6 feet thick on all sides.)



HPGe w/muon veto system
2-3 HPGe detectors in use.

*not to scale

Facility Characteristics

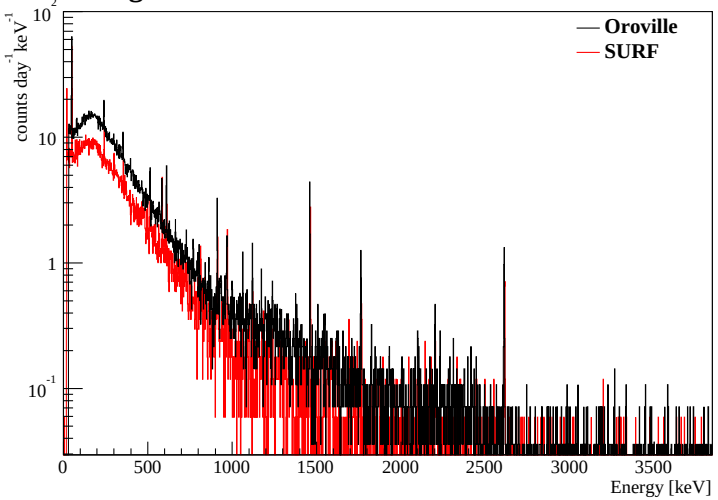
Local Site LBNL	Remote Site SURF 4850 L
low activity construction 1.5m minimum thickness	4300 m.w.e. overburden
backgrounds dominated by cosmic ray muons, Muon Veto in use	backgrounds dominated by residual activity in detector and shielding
1 x 115% n-type & 1 x 85% p-type	1 x 85% p-type (soon to be 2x)

Counting Sensitivities [for ~1kg samples]	Berkeley Site [~1 day]	SURF Site [~1 week]
U series	0.5 ppb (6 mBq/kg)	50 ppt (0.6 mBq/kg)
Th series	2.0 ppb (8 mb/kg)	200 ppt (0.8 mBq/kg)
K	1.0 ppm	100 ppb
Co-60	0.04 pCi/kg (1.5 mBq/kg)	0.004 pCi/kg (0.15 mBq/kg)

BLBF@SURF
4850L (4300 m.w.e.)

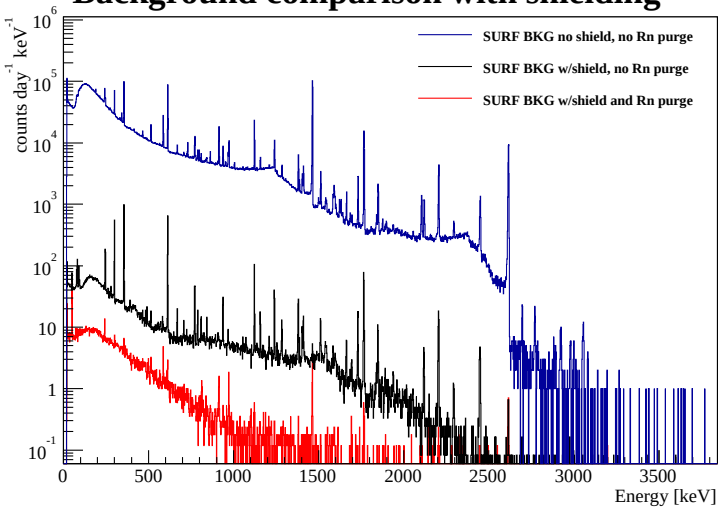
BLBF LBNL γ SURF Berkeley Low Background Facility

Backgrounds Reduced in re-installation at SURF.



Comparison of backgrounds at Oroville and SURF. The backgrounds at SURF are ~30% *lower* than Oroville, due to shield configuration improvements.

Background comparison with shielding



Detector backgrounds in the detector at SURF without shielding (top), with shielding (middle), and last with a nitrogen radon purge running (bottom).

Remote BLBF counting site (Oroville) relocated to SURF

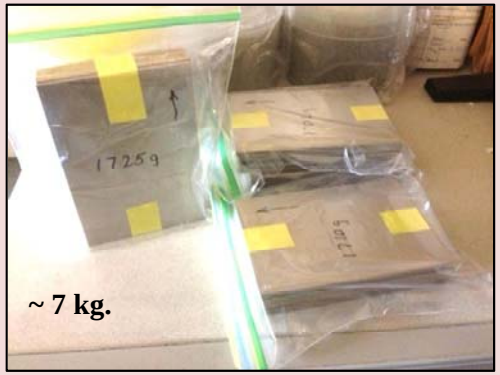
- **Feb 1, 2014**: End of counting operations at Oroville Dam (originally the UCSB/LBL double-beta experiment site from late 1980's).
- **Early March 2014**: Detector relocated to SURF
- **Late March**: Oroville Site decommissioned, shielding and equipment shipped to SD.
- **May 2014**: Detector and shielding installed underground at SURF.
- **June 2014**: Background testing and equipment diagnostics.
- **July 1, 2014**: Counting station back online for receiving of samples.

< 6 months total!

First Sample Results – MAJORANA Ag epoxy

		2013 Oroville	2014 SURF
mass	g	62.1	56.5
U	ppb	< 1	< 0.8
Th	ppb	< 3	< 2.2
K	ppm	< 2	< 1.4
^{238}U	mBq/kg	< 12	< 10
^{232}Th	mBq/kg	< 12	< 8.9
^{40}K	mBq/kg	< 62	< 43
^{108m}Ag	mBq/kg	23(4)	20(2)
^{110m}Ag	mBq/kg	15(3)	17(3)

Second Sample Results – LZ Titanium plate



U_e:	0.65(15)	ppb U
U_l:	< 0.01	ppb U
Th:	< 0.03	ppb Th
K:	< 20	ppb K
^{46}Sc:	2.1(1)	mBq/kg
^{44}Ti:	0.09(3)	mBq/kg

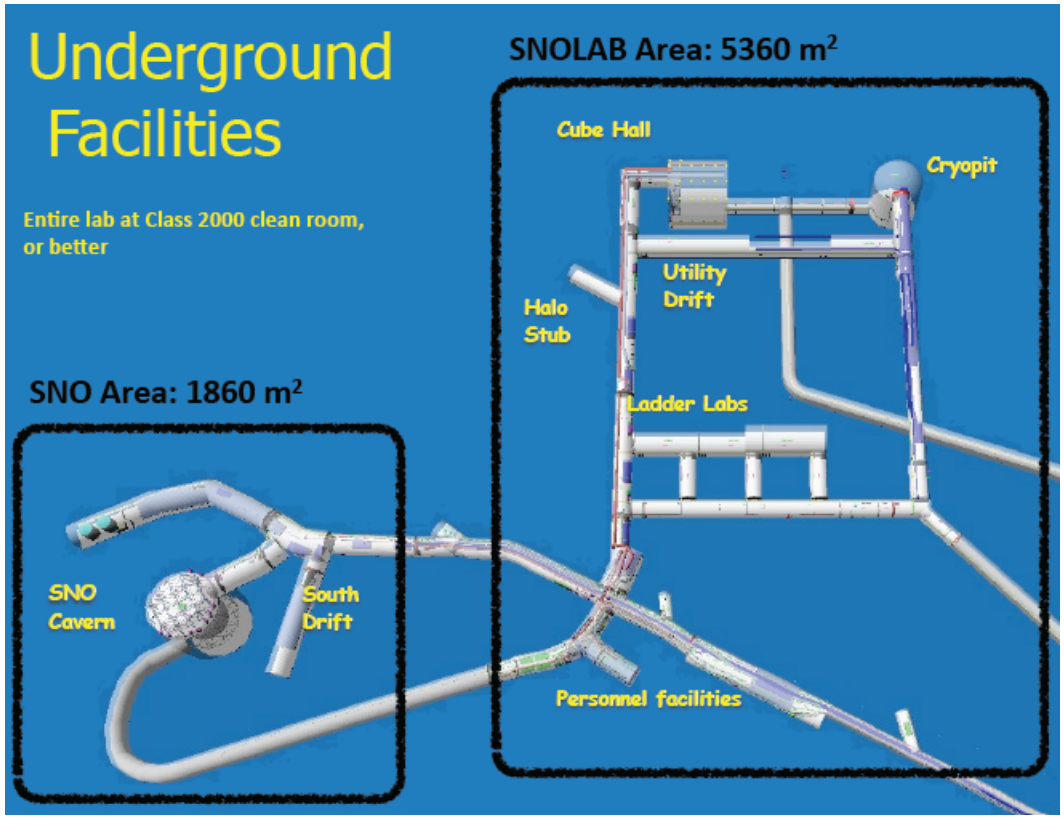
SNOLAB

Underground campus
6800 feet, 6010 mwe

Entire lab Class-2000 clean room, or better

Surface Facilities (3100 m^2)

440 m^2 Class-1000 clean room



Underground Facilities

SNO+ Cavity: 1860 m^2

Underground Construction: 5360 m^2

Two large cavities: Cube Hall, Cryopit (+ support drifts)

Additional linear drifts for smaller scale experiments

Materials handling/cleaning areas, personnel areas, tram transportation, …

The SNOLAB Science Programme

Experiment	Solar ν	0νββ	Dark Matter	S/Nova ν	Geo ν	Other	Space allocated	Status
CEMI						Mining Data Centre	Surface Facility	In Construction
COUPP-4			√				"J"-Drift	Completed
COUPP-60			√				Ladder Labs	Operational
DAMIC			√				"J"-Drift	Operational
DEAP-1			√				"J"-Drift	Completed
DEAP-3600			√				Cube Hall	In Construction
DEAP-50T/CLEAN			√				Cube Hall	Letter of Intent
Ge-1T		√					Cryopit	Letter of Intent
nEXO		√					Cryopit	Request
HALO				√			Halo Stub	Operational
MiniCLEAN			√				Cube Hall	In Construction
PICASSO-III			√				Ladders Labs	Completed
PICO-2			√				"J"-Drift	Operational
PICO-500			√				Ladder Labs	Letter of Intent
PUPS						Seismicity	Various	Completed
SNO+	√	√		√	√		SNO Cavern	In Construction
SuperCDMS			√				Ladder Labs	Commitment
U-Toronto						Deep Subsurface Life	External Drifts	Completed

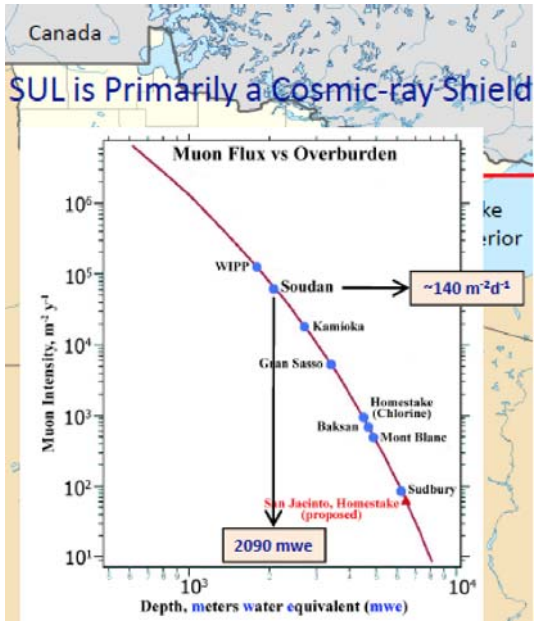
Courtesy: N. Smith

Additional Development - Experiments

- Existing Space will become available as projects complete
  - "J" drift anticipated for R&D/rapid deployment at all times
  - Ladder labs: SuperCDMS area committed; PICO for next few years
  - Cube Hall: argon programme for next five++ years
  - SNO+ cavity: occupation over next decade
  - Cryopit: process underway to select project:
- Planned projects for Cryopit
  - No commitment yet made, several projects presented to 2011 Cryopit review and 2013 Future Projects Planning Workshop
  - DEAP-CLEAN, EXO, GeoDM, COUPP, PICASSO, (PICO), 1TGe
  - Process continues in tandem with EAC and external agencies

Courtesy: N. Smith

Soudan Underground Laboratory



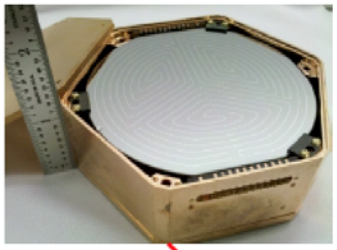
710 m, 2090 mwe

40000 m^3 volume in two large detector rooms

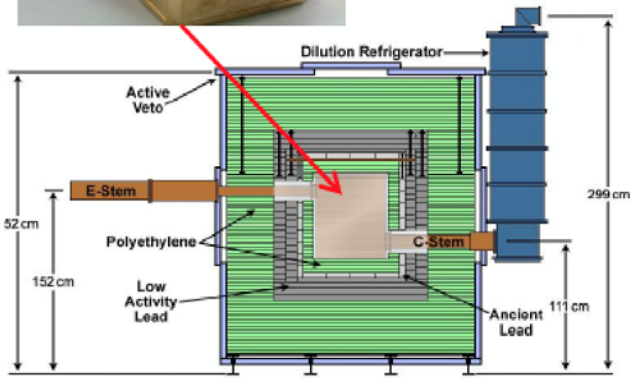
U. Minnesota committed to operation for ≥ 5 years

Running Experiments: MINOS+, SuperCDMS

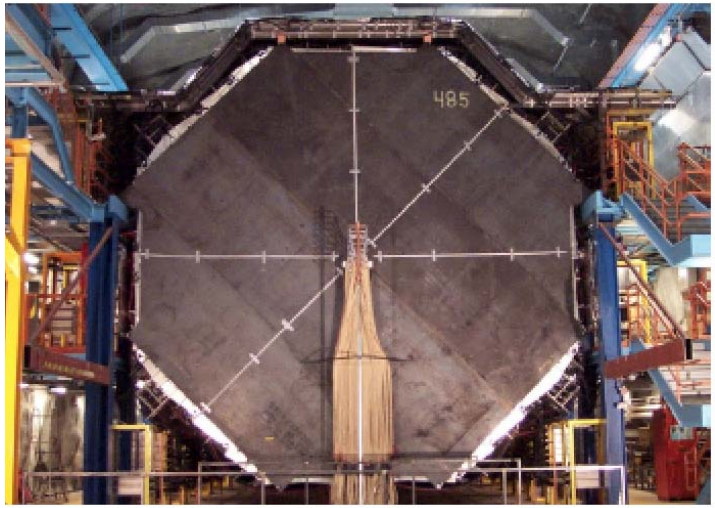
Also: CoGeNT, Low Background Counting Facility, Gamma Screeners, Neutron Detectors



SuperCDMS continues to operate at Soudan



MINOS+ : on-axis for NuMI beam



Kimballton Underground Research Facility

30 minutes from Va. Tech.

Limestone mine (active)

Horizontal access

50+ miles of drifts

Facilities at: 1450 mwe, and 300 mwe

1450 m.w.e. Lab

A. mini-LENS (Low Energy Neutrino Spectroscopy)
   Virginia Tech, Louisiana State University, BNL
B. 2nd Order Weak Nuclear Decay to Excited State
   Duke University
C. HPGe Low-Bkgd Screening
   North Carolina State University, University of North Carolina, Virginia Tech
D. MALBEK (Majorana 0νββ and Darkmatter)
   University of North Carolina
F. Office

Completed experiments

E. Darkside – ^{39}Ar Depleted Argon
   Princeton University, Temple University, Virginia Tech
G. Neutron Spectrometer
   University of Maryland, NIST

II. Neutrino Physics Facilities: Reactors, SNS

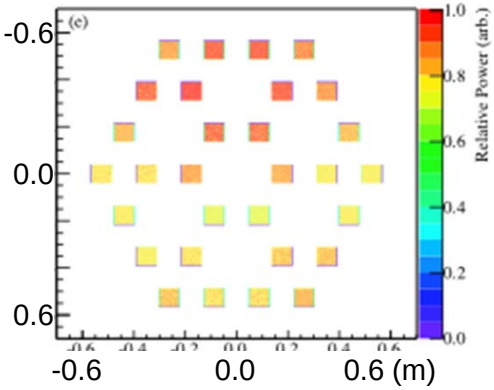
Courtesy: P. Mumm

Highly-enriched Compact Core Research Reactors: 3 US Sites $\gtrsim$ 20 MW_{th}

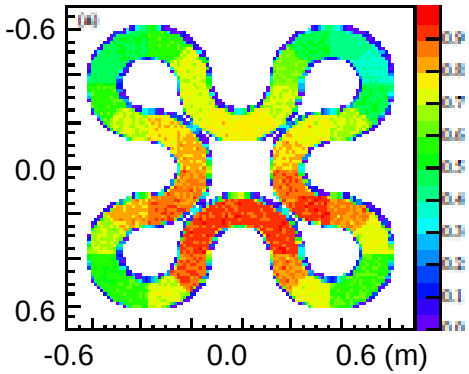
commercial core

Site	Power (MW_{th})	Duty Cycle	Near Detector		Far Detector	
			Baseline (m)	Avg. Flux	Baseline (m)	Avg. Flux
NIST	20	68%	3.9	1.0	15.5	1.0
HFIR	85	41%	6.7	0.96	18	1.93
ATR	120	68%	9.5	1.31	18.5	4.30

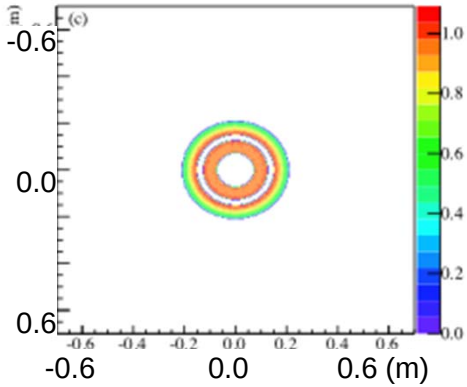
NBSR, NIST



ATR, INL

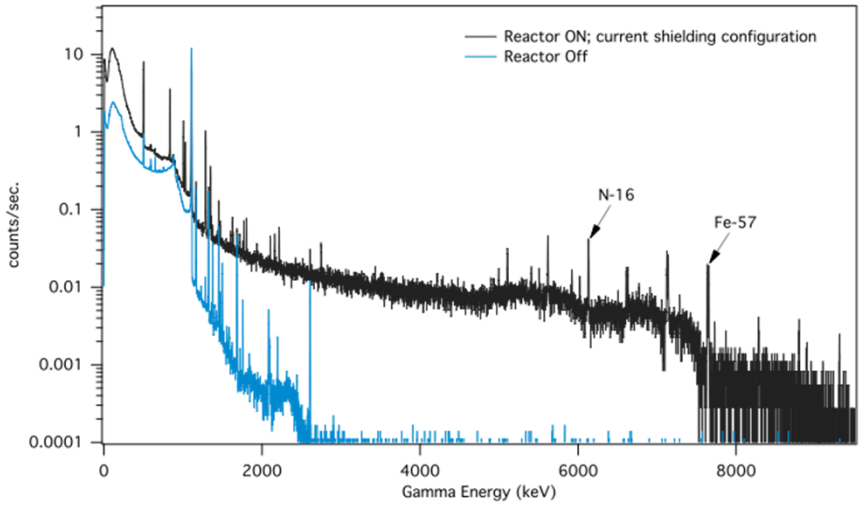


HFIR, ORNL



- Compact cores (~1m)
- Shortest possible baselines ~ few meters
- HEU fuel, simpler, spectrum constant in time
- Reactor off periods (background measurement)
- Ability to reconfigure/run for extended periods

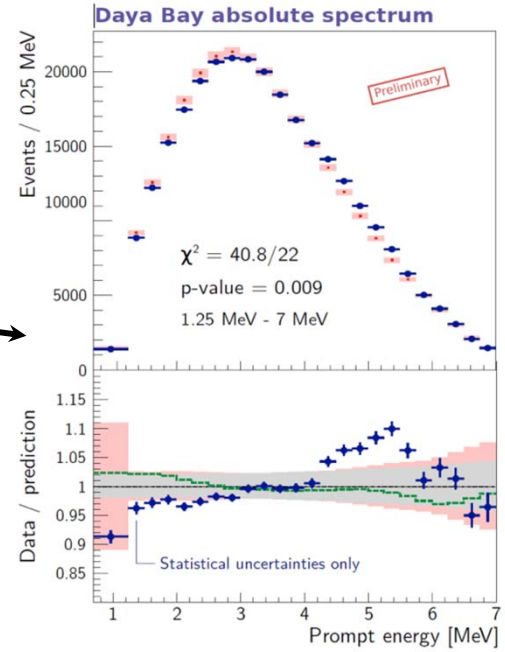
Backgrounds have been well characterized



Opportunities at High-power US research reactors

Precision measurement of reactor spectrum

Address recent anomalies in spectral shape at ~ 5-6 MeV
Possible first measurement of spent fuel

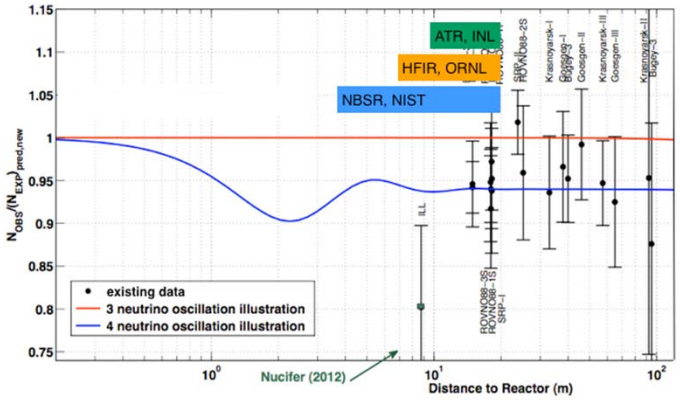


Spectral Shape as a Function of Energy and Baseline

Definitively address the possibility of sterile neutrino oscillation as an explanation of observed electron antineutrino deficits

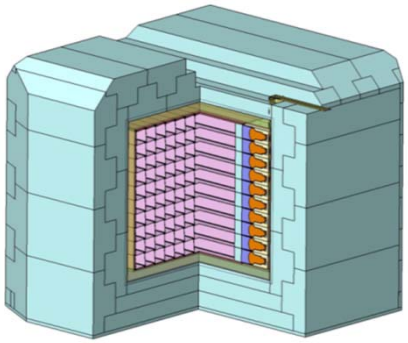
Safeguards - a passive standoff capability

Provides a remote, non-intrusive reactor power and Pu production monitoring capability

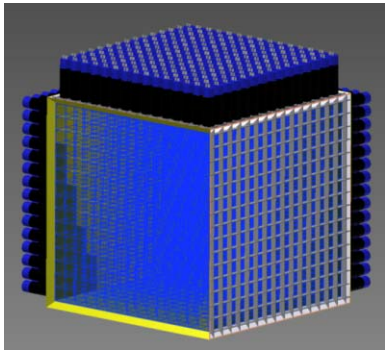


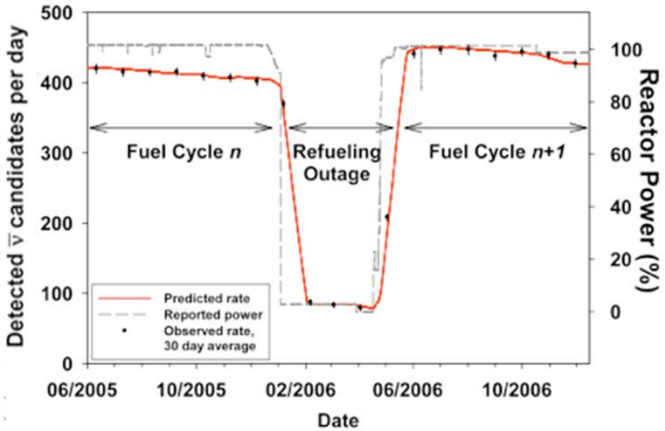
Two projects in advanced R&D phase:

PROSPECT (HFIR)



nuLat (NIST, Navy)





Courtesy: P. Mumm

SNS: Neutrino Physics

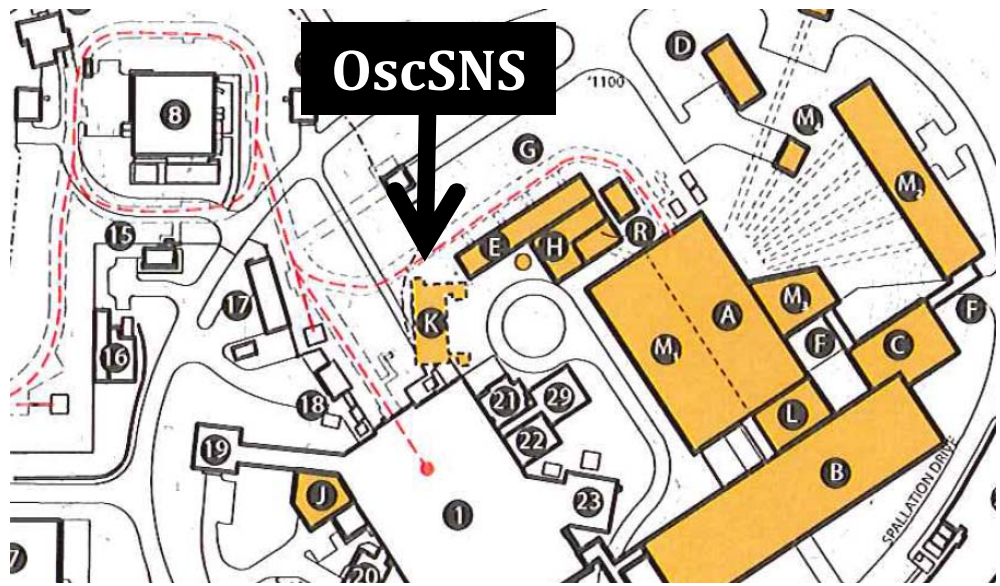
SNS: World's most intense pulsed source of neutrinos

First Target Station
1.4 MW, 60 Hz, 695 ns

Second Target Station (CD-0 2009)
10 Hz, optimized for cold neutrons

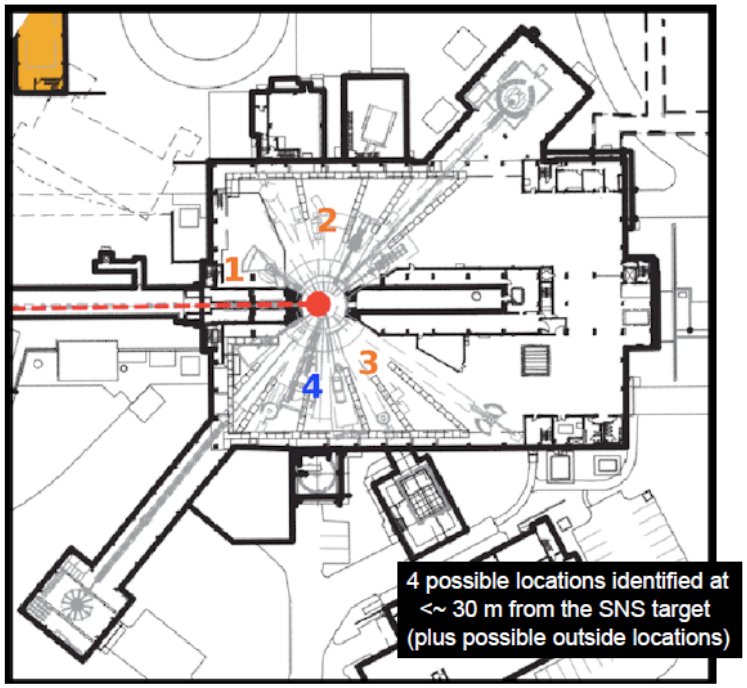
Cylindrical detector
8 m diameter, 20.5 m long
Underground concrete enclosure
12 m × 12 m × 25 m

Civil engineering probable cost:
$5.5M

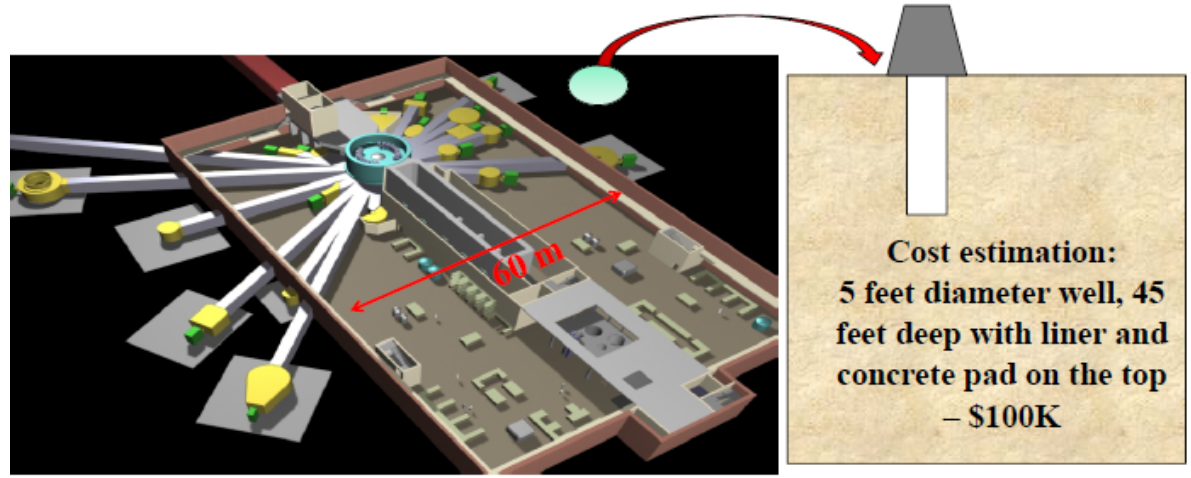


SNS: Neutrino Physics

COHERENT Collaboration: CENNS experiment at the SNS



detectors ~15-35 m from target



Such a location can completely eliminate SNS neutron background and strongly suppress cosmic rays background

III. Muon Physics

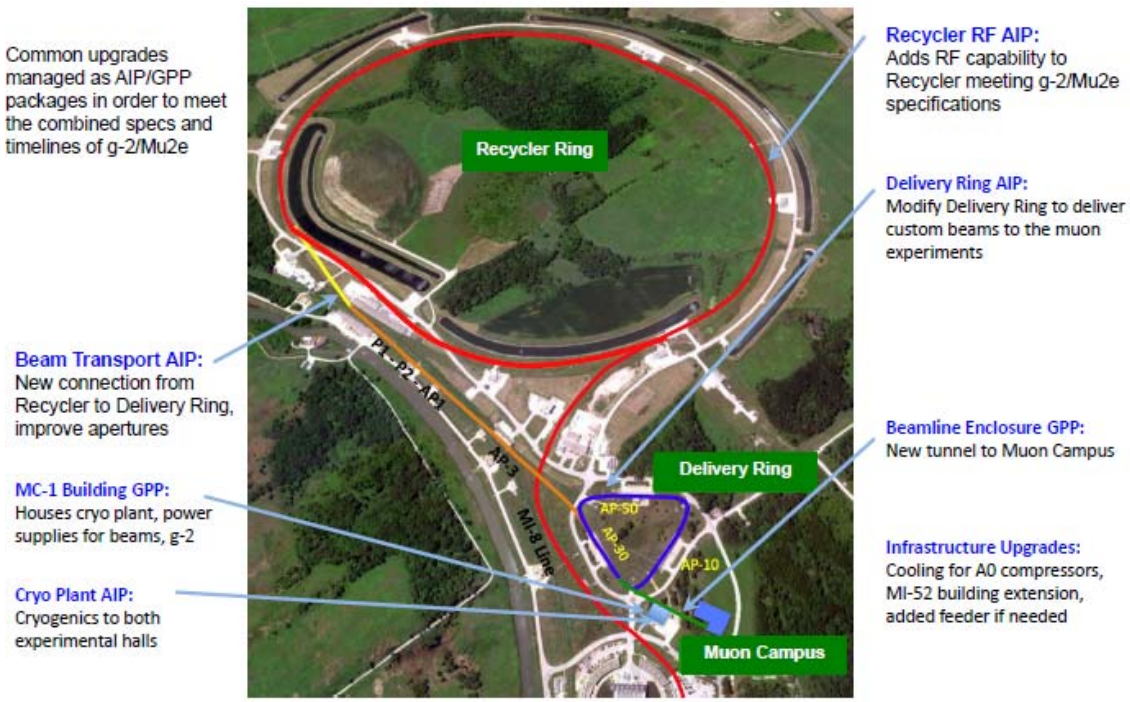
Muon Campus at FNAL

New FNAL Muon Campus
→ HEP-funded (~$350M)

Although HEP facility, **physics leadership from NP**

g–2: D. Hertzog, B.L. Roberts

Mu2e: D. Glenzinski, J. Miller



Coordinated effort to meet both the g–2 and Mu2e needs

Booster upgrade: 8 GeV p @ 15 Hz
→ Recycler Ring (instead of Main Injector)

For g–2:

$p \rightarrow$ muon source (previous $\bar{p}$ source) $\rightarrow \pi \rightarrow \mu$

Delivery Ring → g–2 ring

Current Status

MC-1 Building Complete

- Houses g-2 experiment, cryo plant and beamline power supplies for g-2 and Mu2e

Cryo Plant 60% complete

- Ready to cool g-2 storage ring in March 2015

Tunnel construction starts in 2015

Conversion of pbar source to muon source underway

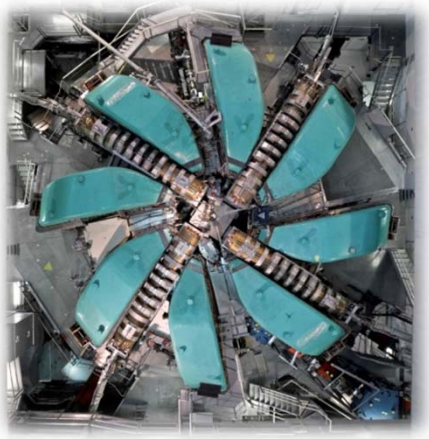
Courtesy: C. Polly, D. Hertzog

Concept to reality…g-2 building

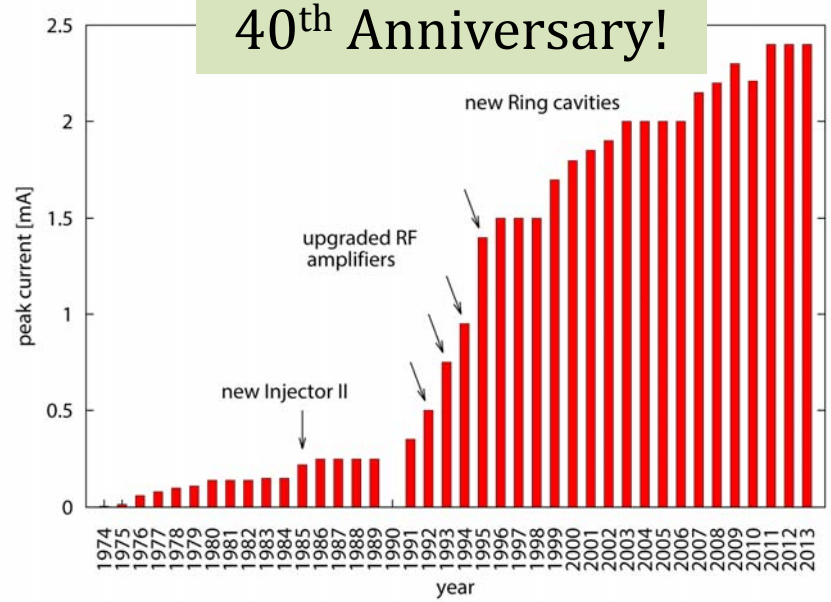
Courtesy: C. Polly, D. Hertzog

PSI

1.4 MW Ring Cyclotron
590 MeV

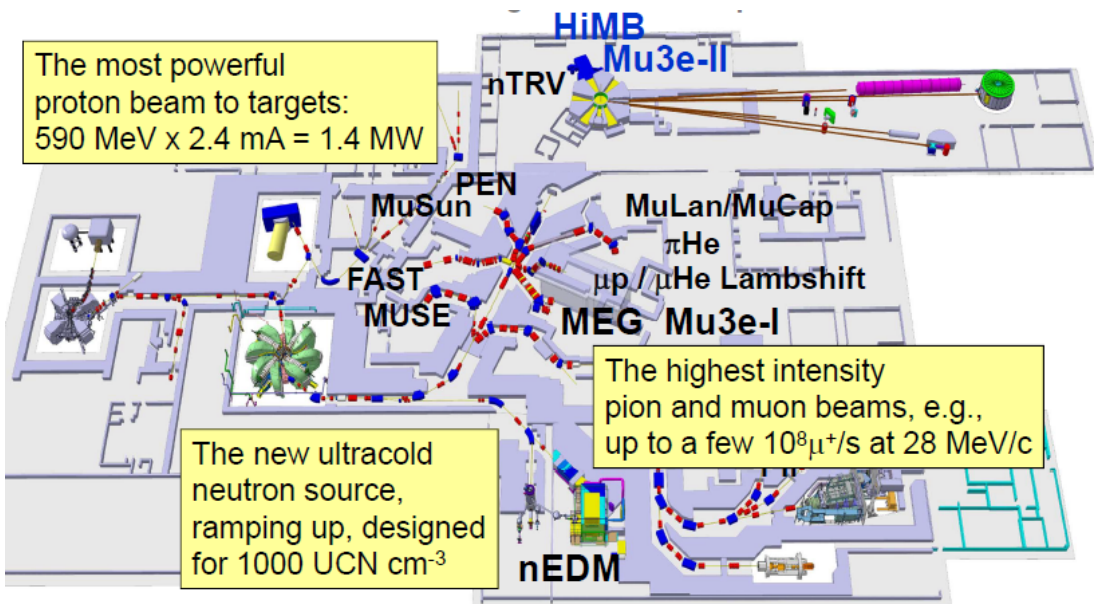


40th Anniversary!



2.6 mA possible in few years

Expected to run at least until the ESS is up to full power (~10 years)



World's highest intensities of :

Mesons: π^+, π^-, π^0

Leptons: μ^+, μ^-

Ultracold Neutron source :

Neutron EDM experiment

PSI

- HiMB: Feasibility study for a high-intensity "surface muon" beam

SINQ Spallation Source → π^+ Stopped in Target Material (near surface) → "Monochromatic" μ^+ p_μ = 29.8 MeV/c (100% polarized)

→ **Aiming at ~ 10^{10} μ^+/s**

- Muon Cooling: Phase Space Compression

PRL 112, 224801 (2014) PHYSICAL REVIEW LETTERS week ending 6 JUNE 2014

Muon Cooling: Longitudinal Compression

Yu Bao,[1] Aldo Antognini,[2,*] Wilhelm Bertl,[1] Malte Hildebrandt,[1] Kim Siang Khaw,[2] Klaus Kirch,[1,2] Angela Papa,[1] Claude Petitjean,[1] Florian M. Piegsa,[2] Stefan Ritt,[1] Kamil Sedlak,[1] Alexey Stoykov,[1] and David Taqqu[2]
[1]*Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland*
[2]*Institute for Particle Physics, ETH Zurich, 8093 Zurich, Switzerland*
(Received 11 February 2014; published 4 June 2014)

A 10 MeV/c positive muon beam was stopped in helium gas of a few mbar in a magnetic field of 5 T. The muon "swarm" has been efficiently compressed from a length of 16 cm down to a few mm along the magnetic field axis (longitudinal compression) using electrostatic fields. The simulation reproduces the low energy interactions of slow muons in helium gas. Phase space compression occurs on the order of microseconds, compatible with the muon lifetime of 2 μs. This paves the way for the preparation of a high-quality low-energy muon beam, with an increase in phase space density relative to a standard surface muon beam of 10^7. The achievable phase space compression by using only the longitudinal stage presented here is of the order of 10^4.

10 MeV/c μ^+ stopped in He gas
16 cm → few mm

Potential 10^7 increase in density

Muonium spectroscopy, g–2, EDM, …

IV. JLab PVES

MOLLER Hall A Compatibility

MOLLER Experiment: JLab Hall A

- 11 GeV longitudinally polarized beam
- 150-cm long, liquid hydrogen target
  - P = 80%, I = 75 μA (approved)
  - P = 90%, I = 60 μA (compatible with other halls)

Hall A Infrastructure:

HRS-L, HRS-R, BigBite, SBS

MOLLER will be designed so that it can be removed from the beamline for compatibility with other Hall A experiments

Courtesy: K. Kumar, C. Keppel

Requirements for MOLLER Experiment

For experiment to proceed, MIE is needed

Infrastructure needs beyond the scope of the MIE:

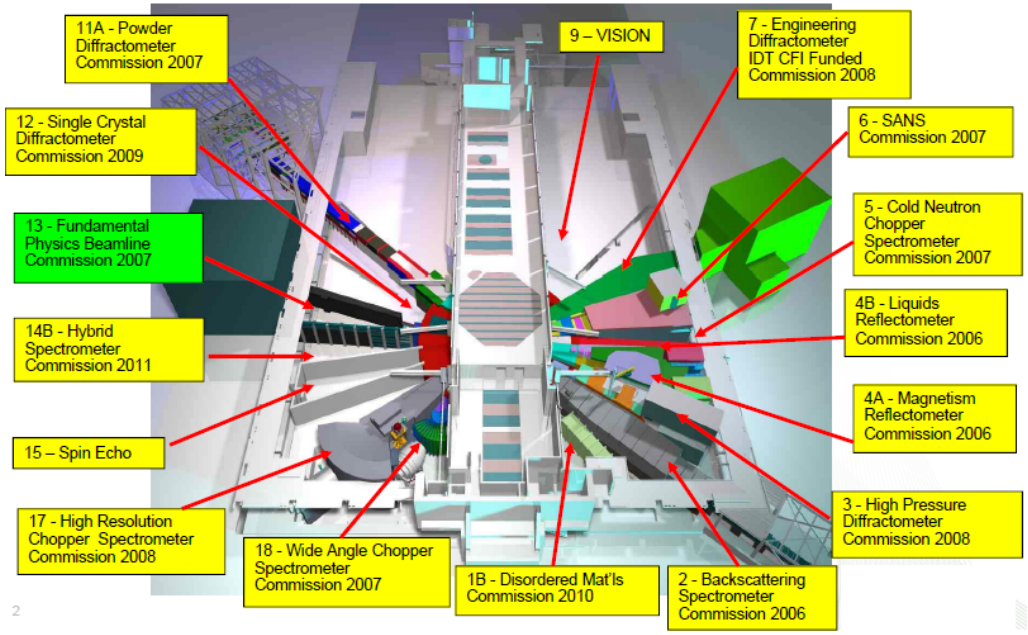
- Ability to measure the beam polarization to 0.4% uncertainty
  - Upgrades to the Moller and Compton polarimeters for 11 GeV beam
- Successful development of a conceptual design for a 150-cm long LH_2 target system capable of handling a heat load of 5 kW [DOE Early Career Award: S. Covrig (JLab)]
- Replacement of aging End Station Refrigerator with new 4 kW End Station Refrigerator (ESR-2) to ensure adequate cryogenic capacity for all Halls
- Upgrades to the JLab injector and accelerator and development of configuration tools (e.g., planned injector test facility upgrade) to deliver sub-100 nm helicity-correlated position differences in the injector, and other beam delivery parameters, to achieve 0.15 ppb helicity-correlated systematics
- Hall A beamline instrumentation capable of ensuring helicity-dependent position measurements of 3 μm or better, and helicity-dependent charge measurements of 10 ppm or better

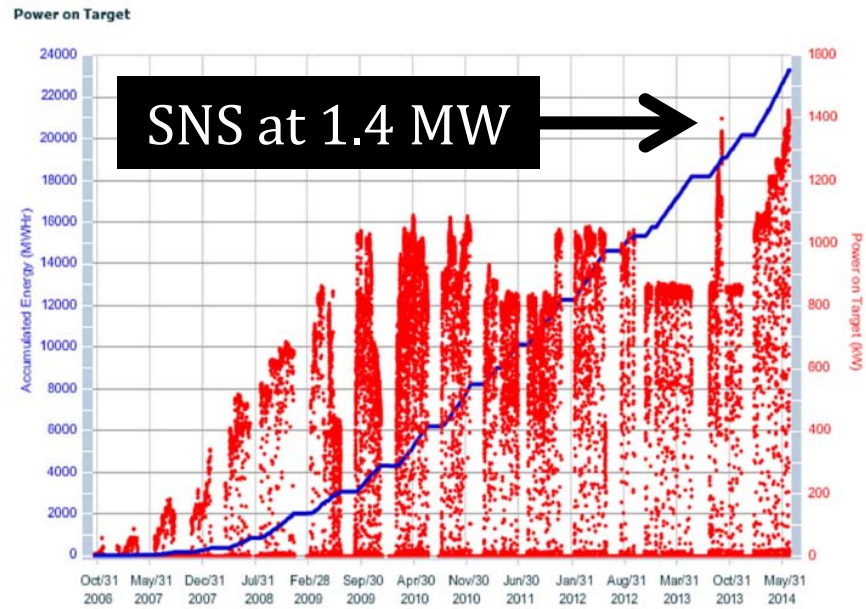
All these requirements, especially the first one on polarimetry, will help the PVDIS SoLID Experiment

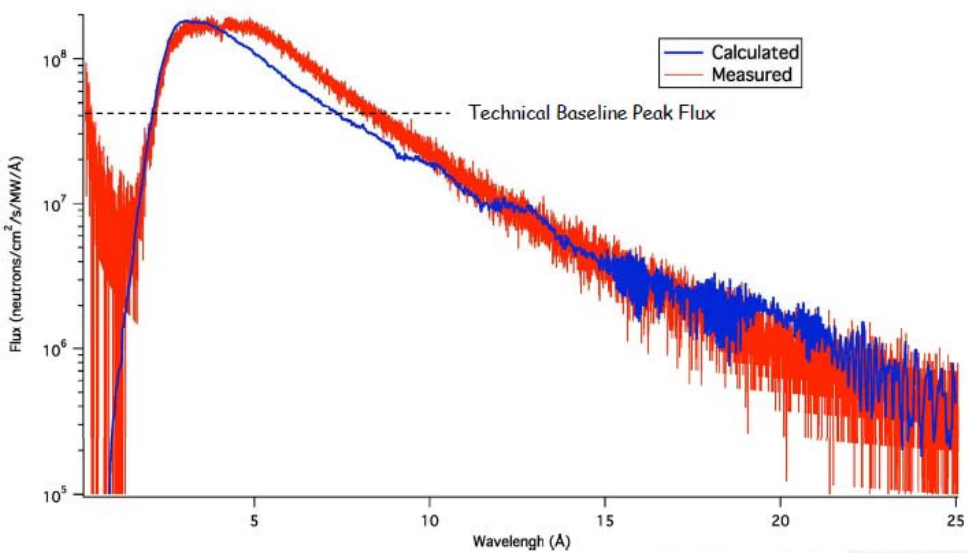
Courtesy: K. Kumar, C. Keppel

V. Neutron Physics

SNS Fundamental Neutron Physics Beamline







FNPB flux well understood

Consistent with initial physics design

First major experiment successfully completed (NPDGamma)

Program: hadronic PV (n-^{3}He), neutron β-decay (Nab), nEDM

SNS Fundamental Neutron Physics Beamline

First Target Station
1.4 MW, 60 Hz, 695 ns

Second Target Station (CD-0 2009)
10 Hz, optimized for cold neutron production

nEDM Building

Long-term: Potential significant increase in the 8.9 Å flux needed for the nEDM Experiment

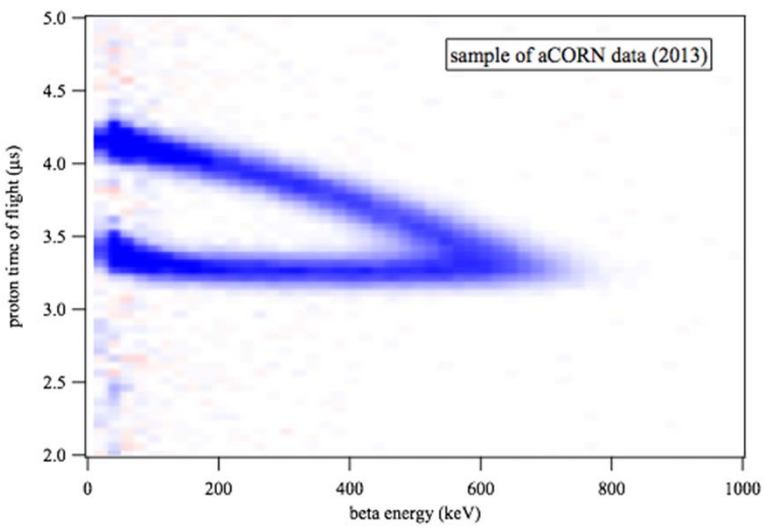
NIST Center for Neutron Research (NCNR)

20 MW research reactor

Guide hall expansion December 2012

New high-flux NG-C beamline
Highest integrated flux in U.S.

Liquid D_2 cold source upgrade in 2016
Factor of ~1.5–2 increase for all beams



Broad NG-C physics program:
- Neutron β-decay (aCORN, beam lifetime)
- PV spin rotation in ^{4}He

Monochromatic beams: interferometry, scattering lengths, charge radius, beam lifetime counting, lifetime in magnetic trap, …

LANL UCN Source

Source	Converter	Density in storage vol UCN/cm^3	Useful current 10^4 UCN/s	Source storage time (s)
Available now:				
LANL area B [79]	SD_2	52	10	40
ILL turbine [76]	liq. D_2	>39	100	Few sec
ILL LHe [80]	LHe	>55	0.14	67
RCNP [81]	LHe	26	2	81
PSI [82]	SD_2	23	4.2	90
Mainz [83]	SD_2	25	0.12	Few sec
Planned (date)	Target parameters:			
PULSTAR [84] (2014+)	SD_2	>30	>10	Few sec
FRM II [85] (2015+)	SD_2	5000	3000	N/A
TRIUMF [86] (2016)	LHe	1500*	100*	150
WWR-M [87] (2016)	LHe	12000	7000	10

Only operating UCN source in North America

β-decay (UCNA, UCNτ, UCNB), SNS nEDM R&D

LDRD-funded source upgrade underway

High-statistics β-decay

Possible nEDM with ~10^{-27} e-cm

LANSCE accelerator will continue to operate for foreseeable future

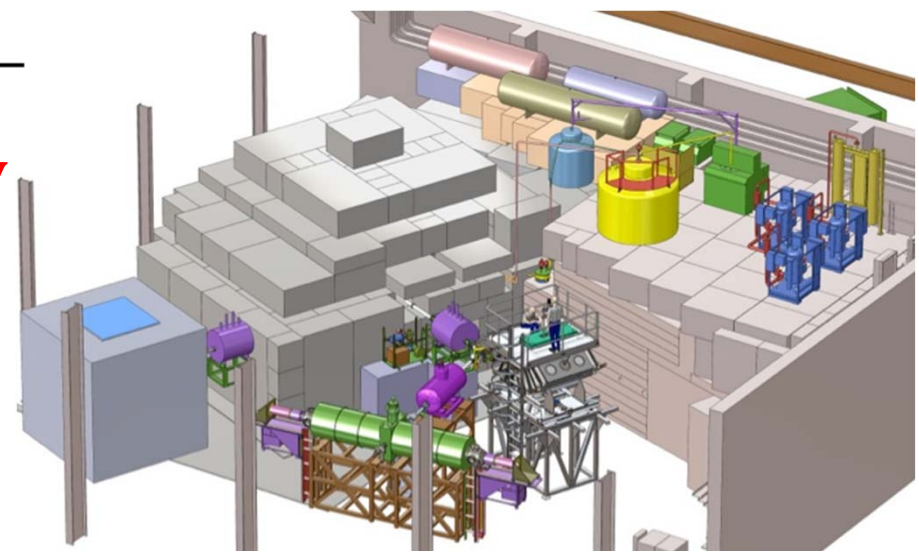
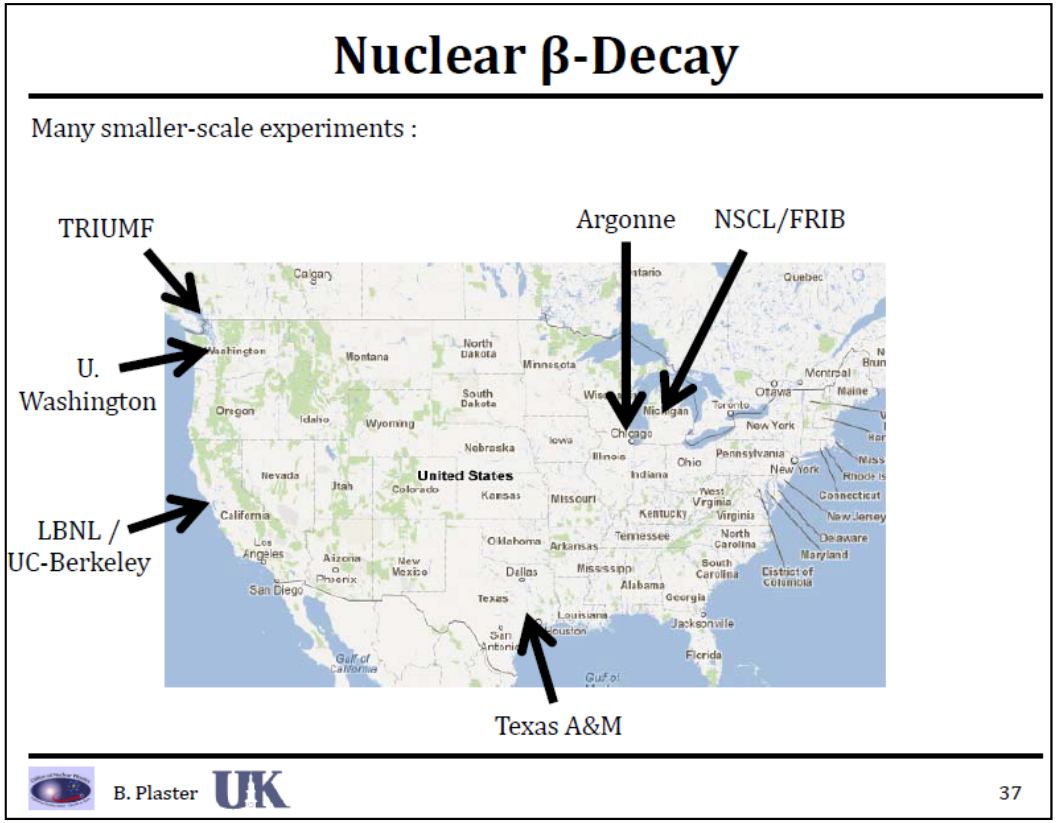


Table from: A.R. Young et al., J. Phys. G (in press)

VI. Nuclear β-Decay



No time !

However, was summarized in the "Facilities" talk I gave at the 2012 FS/Neutrinos Working Group Meeting:

http://www.phy.ornl.gov/funsym/talks/Plaster_NSAC_Facilities_Chicago_August2012_v3.pdf

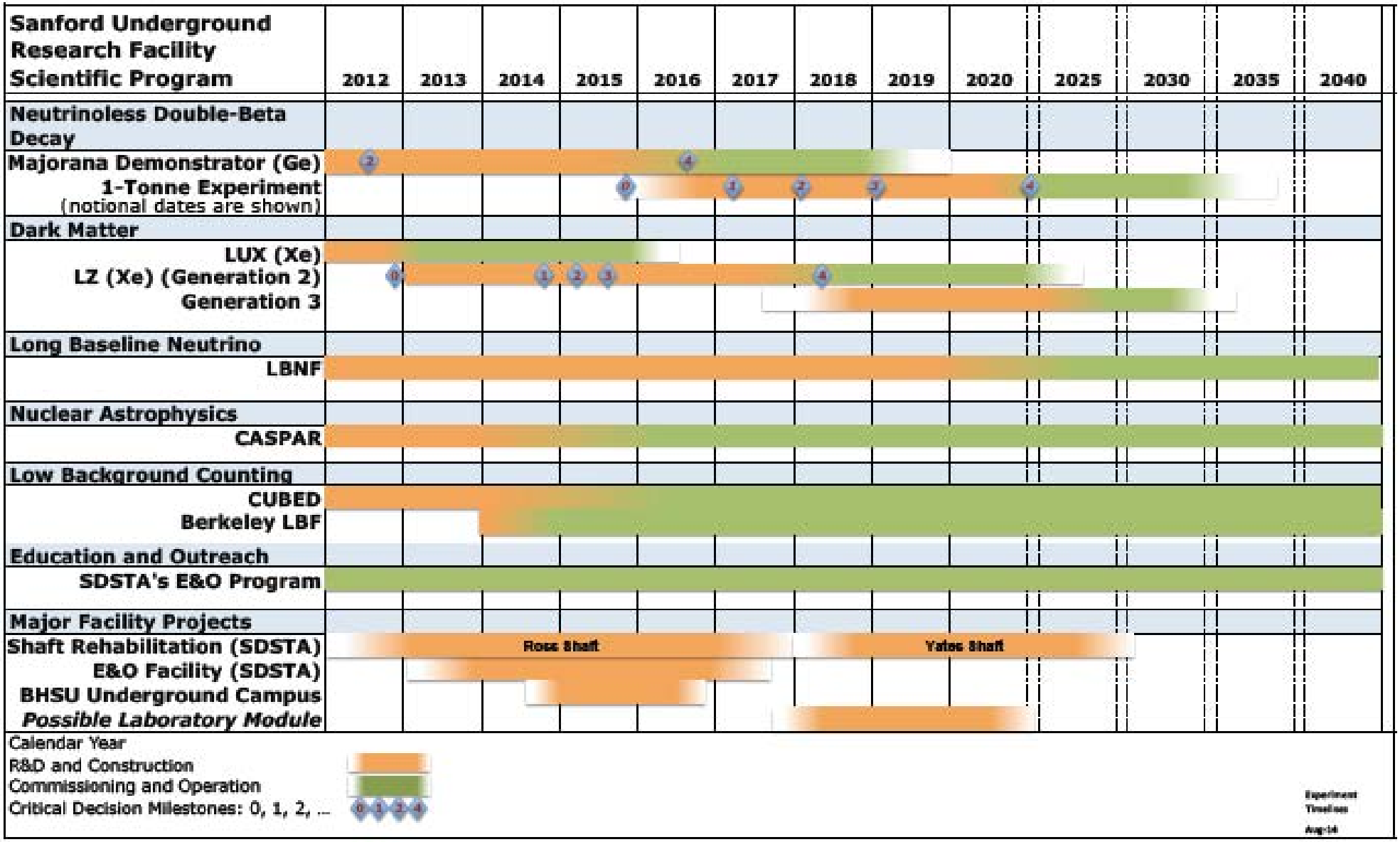
Summary

We are a community with experiments operating at / planned for a diverse array of facilities !

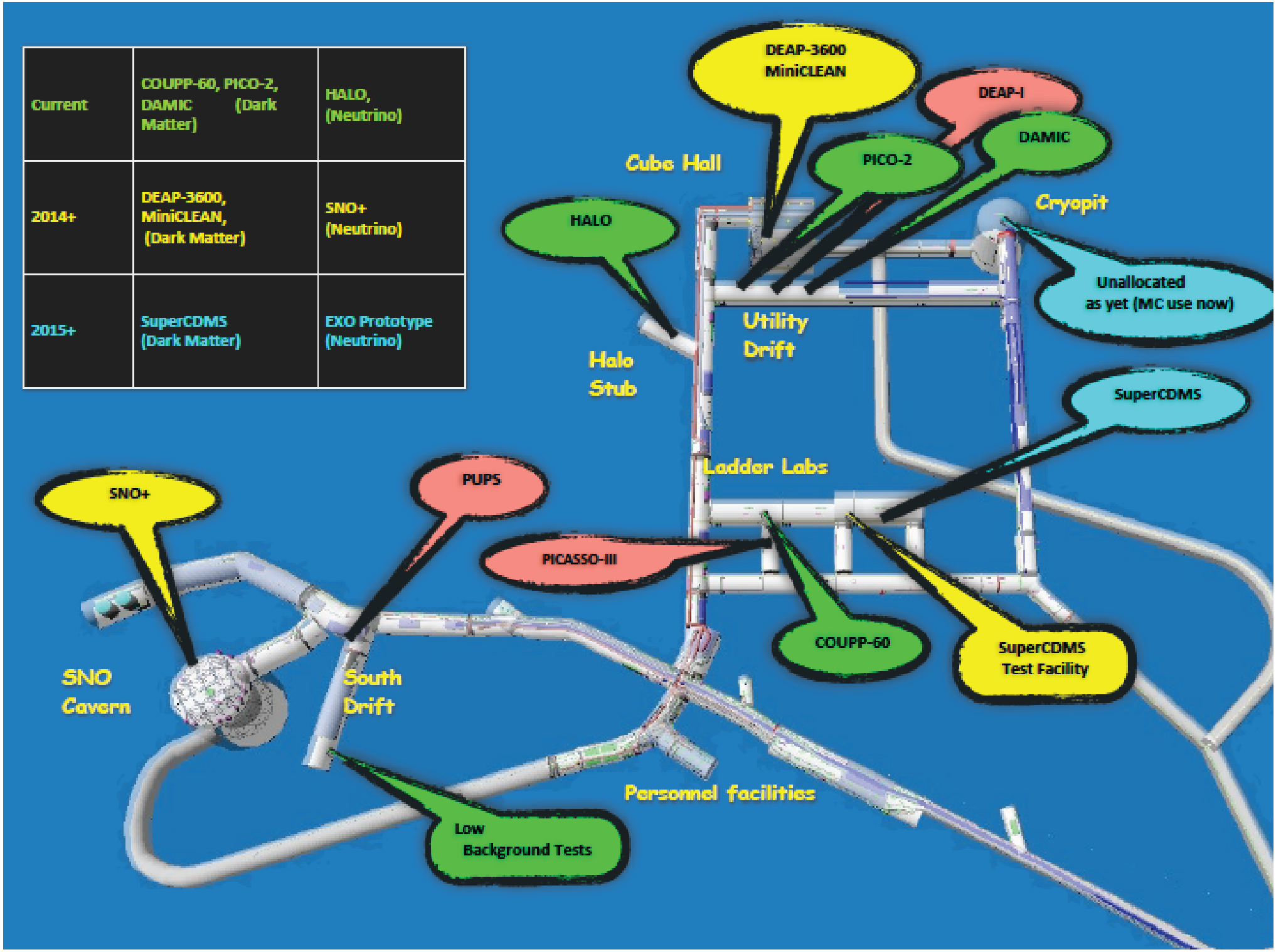
Continued and strong support for these facilities is needed to realize our physics goals !

Backup Slides

Development Timeline



Current	COUPP-60, PICO-2, DAMIC (Dark Matter)	HALO, (Neutrino)
2014+	DEAP-3600, MiniCLEAN, (Dark Matter)	SNO+ (Neutrino)
2015+	SuperCDMS (Dark Matter)	EXO Prototype (Neutrino)



MOLLER Workforce

✦ MOLLER: IV Generation JLab PVES project

★ III Generation Experiments Qweak and PREX

- *critical evolutionary development of all technical requirements*
- *majority of both collaborations are committed to MOLLER*
- *combined Hall A/C PVES: 12 PD FTE's and 25 Ph.D. students at peak*
- *funding from DOE NP, NSF and NSERC (Canada)*

★ 7-8 faculty/lab staff positions in last decade in US NP

- *Critical training and expansion of expert workforce*

✦ MOLLER Workforce Outlook:

★ Estimate 12-15 PD FTEs and 25 Ph.D. students at peak

- *A majority of the User funding would be redirected from existing grants*
- *Restore PVES User funding to 2010-11 levels; it is down ~20%*
- *New foreign participation will help offset losses at the ~10% level*