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Dark Matter at DUSEL

Based on a community wide white paper

- http://dmtools.brown.edu/DMWiki/images/c/c8/DMWG_DUSEL_White_Paper_April_2010.pdf
- One of the inputs to the facility PDR

The Science

Proposed program

- Two Generation-3 experiments

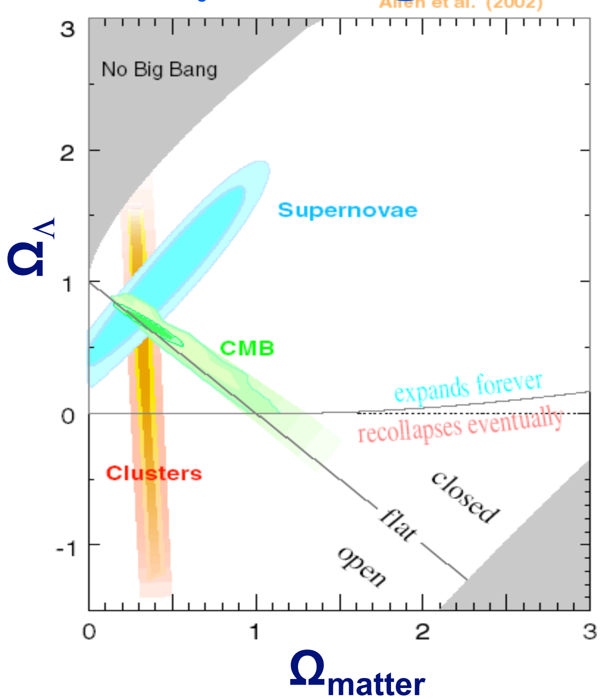
Implementation

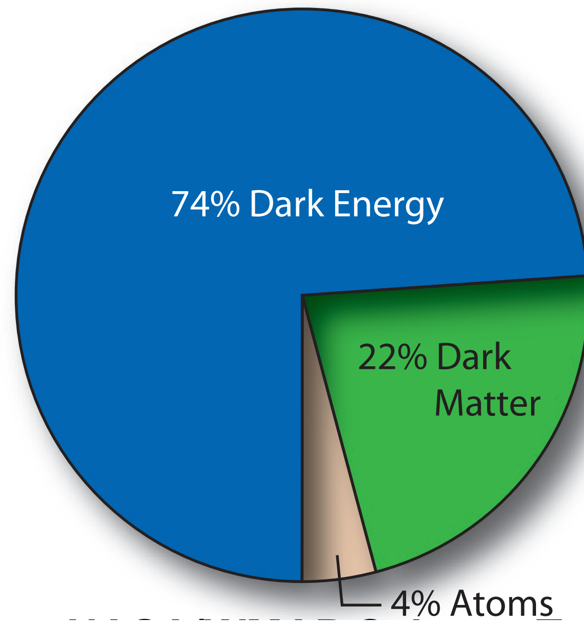
- If beneficial occupancy in 2017, Technology choice mid 2013

Convergence of the community

The Dark Matter Puzzle

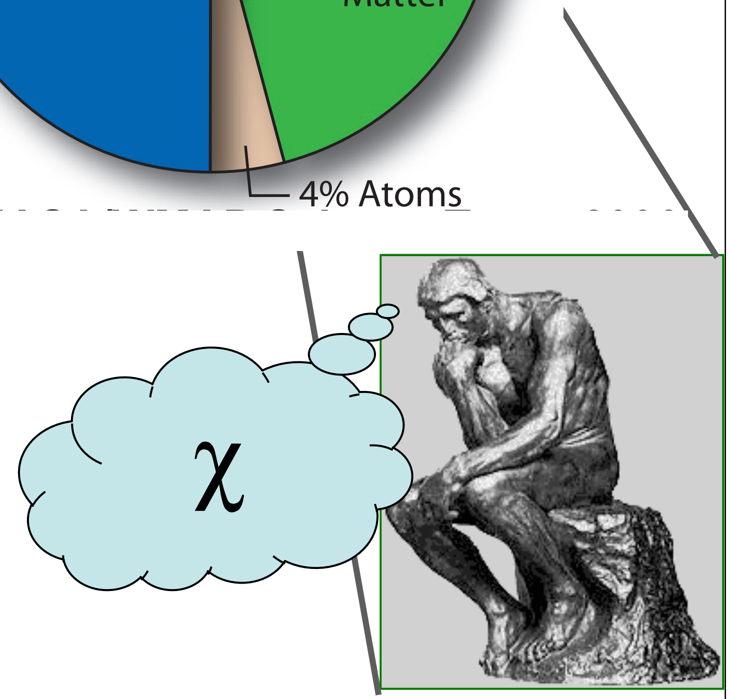
A surprising but consistent picture





Not ordinary matter (Baryons)

$$\Omega_m >> \Omega_b = 0.047 \pm 0.006 \text{ from} \left| \begin{array}{c} \text{Nucleosynthesis} \\ \text{WMAP} \end{array} \right.$$



Not light neutrinos ≠ small scale structure

Dark Matter Could Be Due to New Physics at the TeV Scale!

A remarkable coincidence

Particles in thermal equilibrium + decoupling when nonrelativistic

$$\Rightarrow \Omega_x h^2 = \frac{3\cdot 10^{-27}\, cm^3 / s}{\langle \sigma_A v \rangle} \approx 0.12 \quad \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale
(e.g. supersymmetry, global symmetry or additional dimensions)
=> significant amount of dark matter

Weakly Interacting Massive Particles

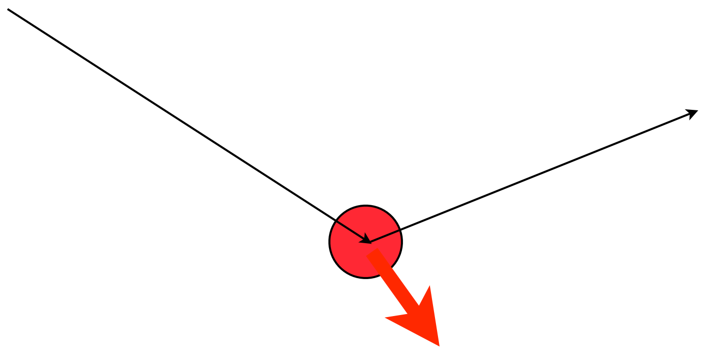
Three methods:

- **Direct Detection in the Cosmos**= Halo WIMP elastic scattering
- **Indirect Detection in the Cosmos**= Annihilation products $\gamma, e^+, \overline{p}, \nu$
- **Production at the large Hadron Collider**

Historical opportunity: 3 methods ≈ same sensitivity + complementarity

General Principles of Direct WIMP Search

Halo WIMP scattering on nucleus



Detect recoil of a nucleus

Essential to identify nuclear recoil
in order to distinguish such rare events from e, γ background
-> electron recoils

Get rid of the neutrons
- Depth
- Water moderator
- Active veto

A variety of techniques

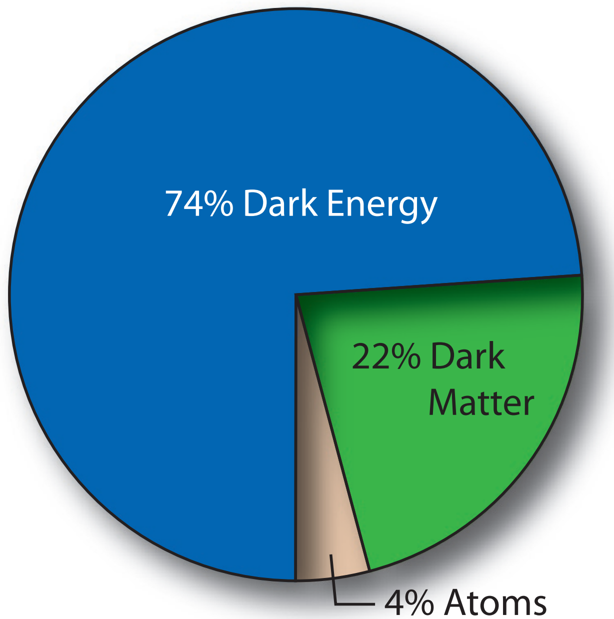
- Exquisite energy sensitivity
- Ultra low background, shield
- 3 D reconstruction
- At least two measurements to distinguish nuclear recoil from electron recoils

	Liquid Xenon	Liquid Argon	Low temp. Ge	Bubble Chamber
Ionization	√	√	√	high density
Scintillation	√	√		
Phonons			√	
Other		Pulse shape	Pulse shape	Acoustic

Dark Matter @DUSEL

Among all discoveries that could possibly happen at DUSEL, no one would be more transformational than the discovery of dark matter

- We do not understand what constitutes more than 80% of the mass in the Universe



A discovery would provide

- A direct proof of a fundamental component of our understanding of cosmology
- A direct door to a new sector of physics at the TeV scale
- Potentially: One of the most fundamental contributions of the DUSEL initial program

Dark Matter @ DUSEL

Even if a discovery is made before DUSEL, we need a Dark Matter Observatory

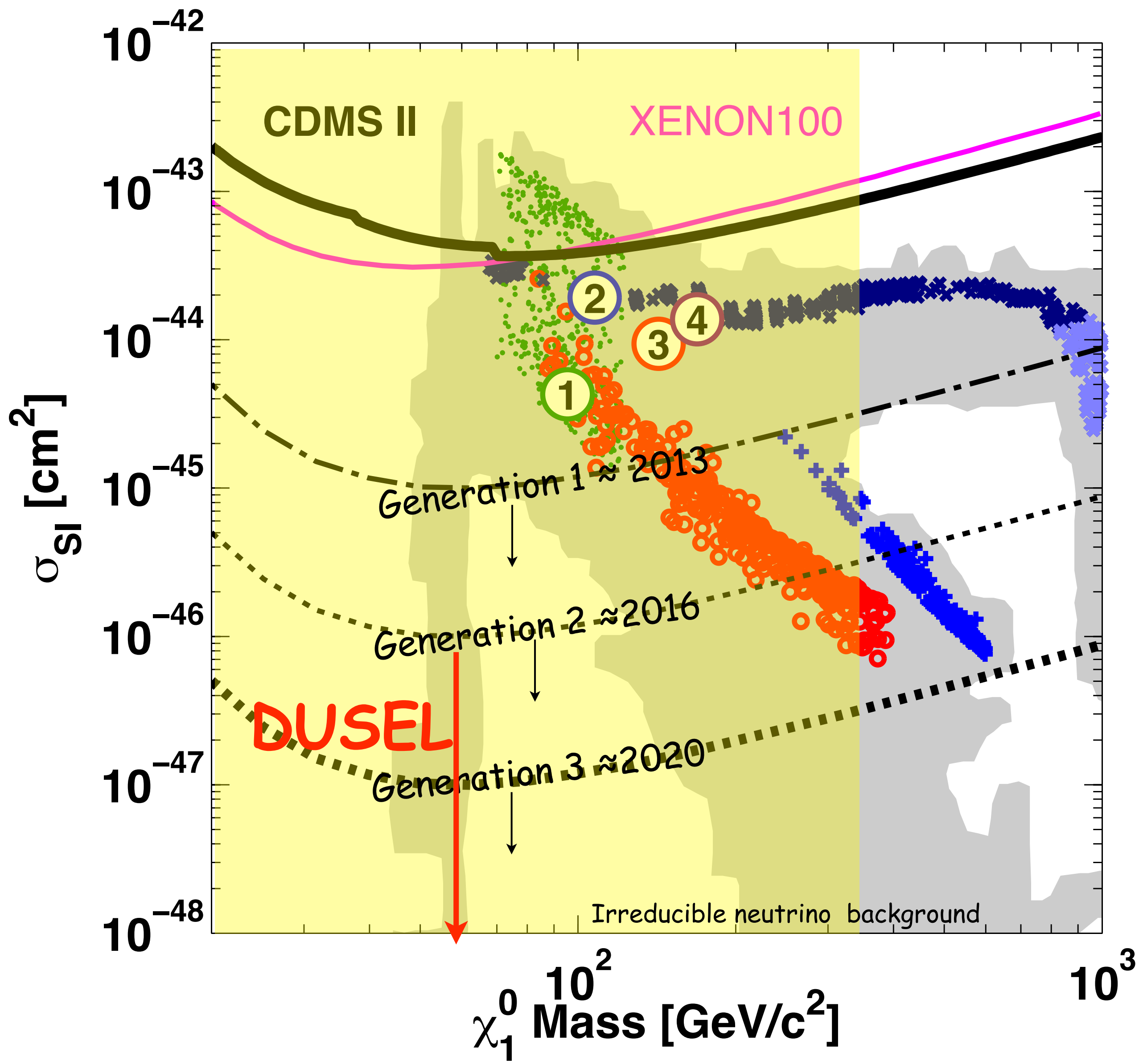
- To get large statistics to measure mass and cross section: complementary information between direct detection, LHC and indirect detection to fully understand the nature of the new interaction
- To get detailed information about the velocity spectrum of the dark matter (and check modulation)
- Eventually, directionality: we need strong R&D for this difficult task!

Technologies are rapidly reaching the needed level of sensitivity/background rejection

- Bubble Chamber
- Ar
- Ge
- Xe

This should be a cornerstone of the DUSEL program

No less than two generation-3 Expts



Proposed Program at DUSEL

In order to have a program

- at the frontier of the field worldwide
- resilient to potential political and technical delays of the facility
- with strong flexibility

the US WIMP search community proposes no less than two generation-3 experiments with a cost envelope of $150M -$200M.

- 2 different technologies, with at least 2 nuclei
  - with different technological risks
  - with different backgrounds
- Technology choice to be made later on view of current and generation 2 results (flexibility)
- Depth: the deeper the better, but adapt to facility availability

This presupposes a vigorous pre-DUSEL G2 program

Why two Generation 3 Experiments?

Vital to maintain US leadership

Science is essential

- Requires several targets
- Maximize impact, minimize technical risk of US program
- => at least two techniques

Timing is natural for Generation-3

- DUSEL comes too late for generation-2
- Robust program, not too sensitive to minor delays

Strategy within the worldwide context

- Likely to be 3-5 experiments
- Maintain US leadership
- Size of the community: Likely to be strong participants in at least 3 experiments worldwide
- Having only 1 expt at DUSEL: not a lot of savings, but clear loss of the leadership

Collocation:

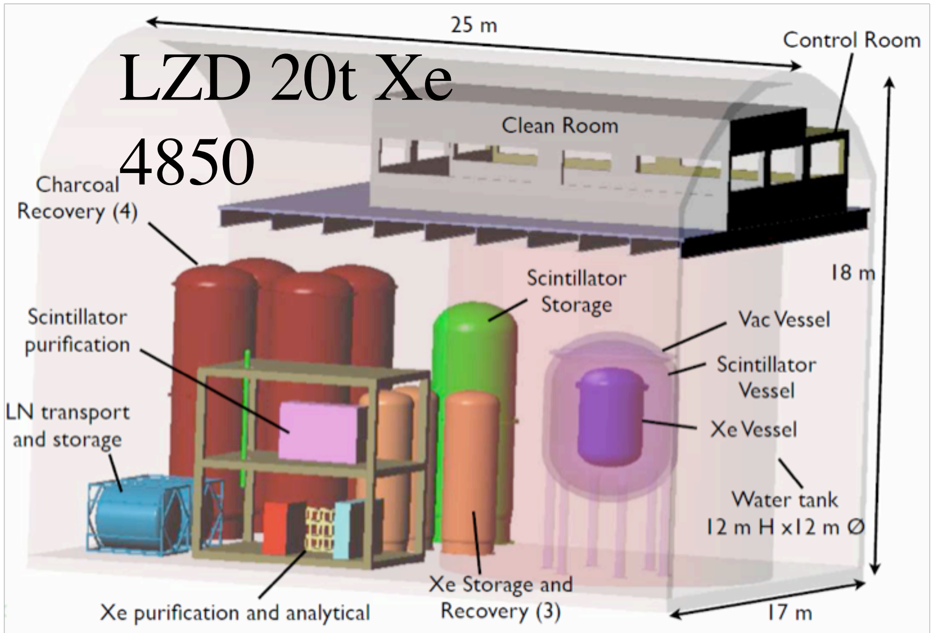
- Scientific exchanges
- Technological sharing

DUSEL Dark Matter Experiments

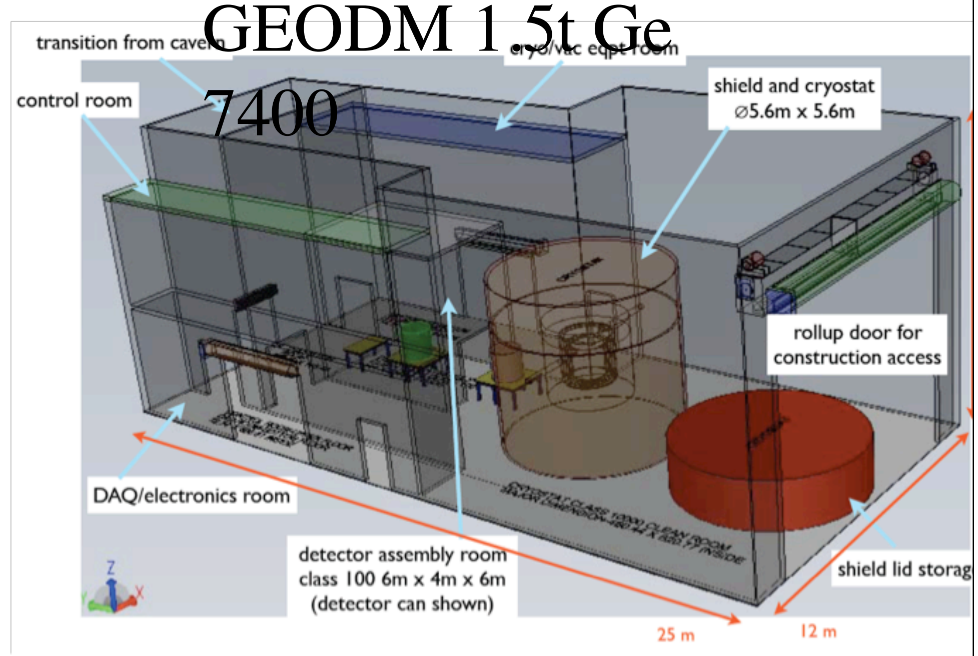
Experiment	Mass Target	Sensitivity Scalar cm^2	Location Install. Date	Strengths	Challenges R&D	Estimated Costs
COUPP	16x500kg CF3I bubble ch.	dependent on α contamination	4850 ft 2017	γ rejection Cheap SD target	α (Acoustic Discrim.) Threshold detector	$21+11M
LZD	20t Xe dual phase	10^{-48}	4850 ft 2017	3D imaging Self shielding Scalable	Liquid purity HV	$55+28M
Max	20t depleted Ar 6t Xe dual phase	10^{-47}	4850 ft 2017	3D imaging Self Shielding QUPID Pulse shape rejection (Ar)	Liquid purity HV ^{39}Ar depletion	$70+35M
GEODM	1.5 t Ge phonons +ionization	$2\ 10^{-47}$	7400 ft 2017	Rejection + Background demonstrated 3D imaging	Cost/yield for large # of detectors high Ø Ge	$55+28M
CLEAN	50 t Ar single phase	few 10^{-47}	7400 ft 2017	Pulse shape rejection n self shielding Scalable	Rn contamin. Liquid purity	$60+30M

Dark Matter @DUSEL

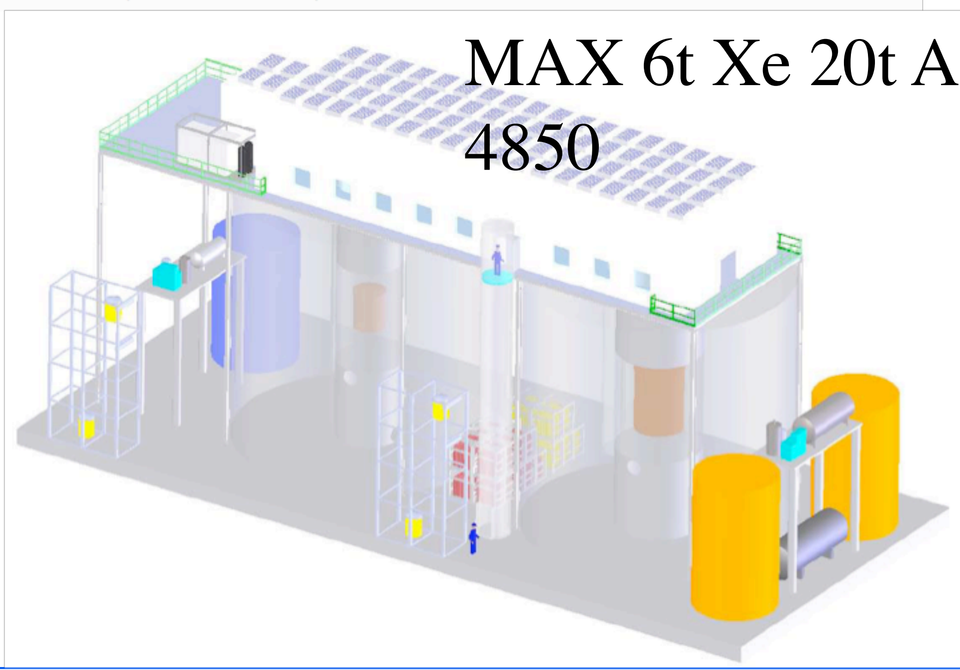
LZD 20t Xe
4850



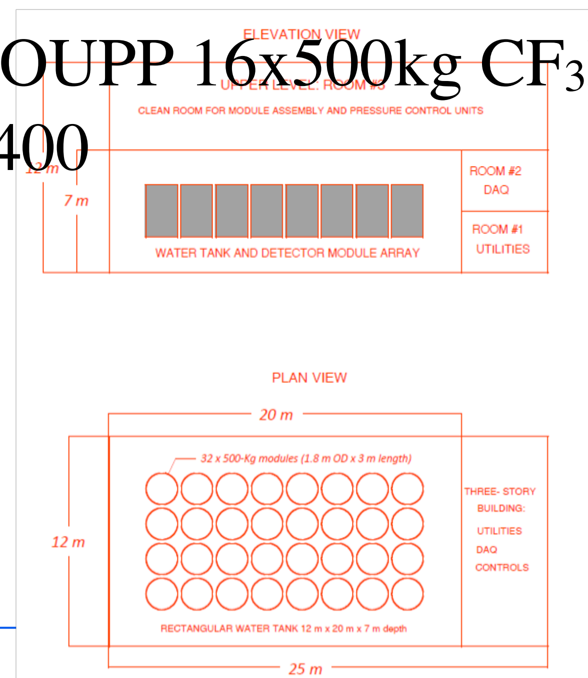
GEODM 1.5t Ge
7400



MAX 6t Xe 20t Ar
4850



COUPP 16x500kg CF_3I
7400



What would it take?

A major mobilization of the community

- Unified

Strong collaboration between NSF and DOE

Important role of DOE National Laboratories

Complement S4 moneys

- Otherwise, can not be technically ready for technological choice in 2013 and installation in 2017.

Strong R&D

- Example: Directionality
  - Not ready for initial suite of experiment
  - Need for aggressive R&D before DUSEL at the $1m^3$
  - Likely major R&D at DUSEL

Generic Schedule (2017 beneficial occupancy)

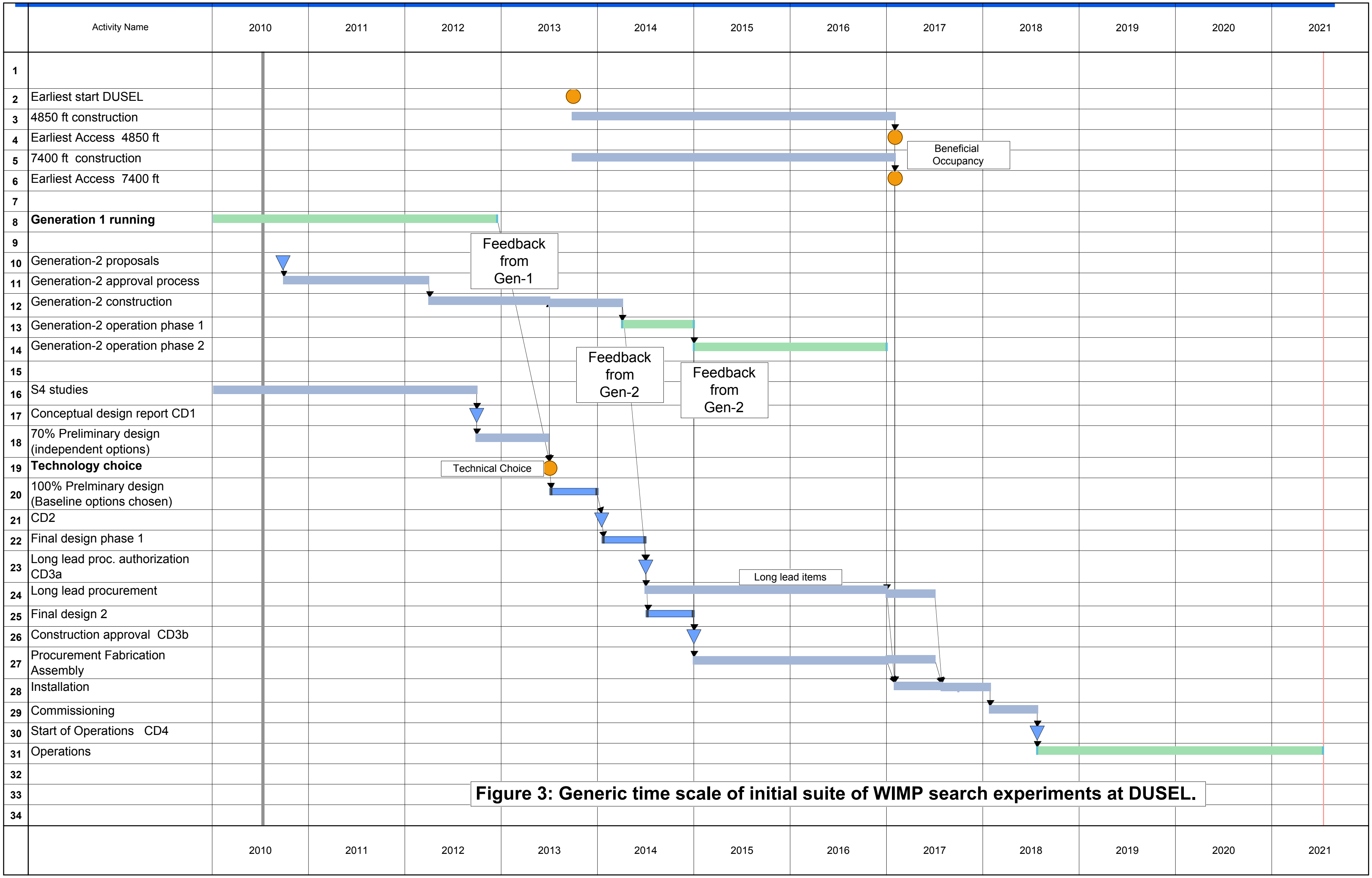


Figure 3: Generic time scale of initial suite of WIMP search experiments at DUSEL.

Date of Technology Choice

3 principles

- The choice of technology for the initial suite of experiments at DUSEL should not be made before DUSEL is approved and its time scale established.
- At least two dark matter experiments should be ready at the time of beneficial occupancy of the laboratory.
- In order to take optimum account of the latest scientific results, maximize the scientific reach and minimize risk for the initial suite of dark matter experiments, the technology choice should be made at the latest date compatible with the second goal above.

Compromise: 3.5 years before beneficial occupancy

with DUSEL available Jan 2017 **1 July 2013**

but

need better estimate of experiment construction time
keep monitoring procurement time and impact on costs (e.g., Xe)
7400 ft availability

Unification of the Community

Shared goals

- Develop a common vision for a powerful WIMP search/study program for the 2015–2025 timeframe, using several complementary targets and technologies.
- Ensure world leadership for the dark matter search program at DUSEL .
- Continue the emphasis on strong R&D to maintain leadership in the field

Strategy to shift from competition to collaboration

- Start studies on issues of common interest
- Eventual merging of S4 studies
  - Start with noble liquids then open to others
  - Goal: one design for each of the four targets: Xenon, Argon, Germanium, High spin nuclei (e.g.Fluorine)
- Compile->coordinate information from the competing generation-1 and generation-2, as input for generation-3 decisions.

A new collaboration (8/9/10)

We have agreed to form **a new collaboration** that will address common challenges faced by the US dark matter community engaged in developing the best possible program for DUSEL, along with our international partners. We recognize the efficacy of collaborative effort, along with its enhanced efficiency in technical advancement, and bringing clarity in representing the community's dark matter program for DUSEL.

This group consists initially of members drawn from the existing **liquid noble projects** including LZD, MAX and CLEAN. This new organization, however, is **open to other technologies** and will be structured so that it can lead to a larger collaboration involving other efforts involved in dark matter searches.

Immediate actions for this group fall into the following areas:

(1) **Develop a co-ordinated technical strategy** for the direct detection of dark matter at the DUSEL.

(2) **Initiate working groups** under the new collaboration structure. Areas of collaboration, common to all dark matter experiments, include shielding, radiogenic and cosmogenic neutron backgrounds, radon suppression/emanation and materials procurement and assay. Areas available for immediate cooperative work related to the liquid noble elements include safety, purification, cryogenic systems, photodetectors, DAQ, electronics, high voltage, and rare gas procurement and storage.

(3) **Develop a management structure** to govern the collaboration covering both the scientific and project aspects of the program. We expect the **project manager to be an appointed position.** This person will be charged with managing an open process to arrive at the technical definition of the G3 experiments.

Conclusions

Dark Matter: A central scientific question!

Understanding the nature of Dark Matter would be transformational

Weakly Interactive Massive Particles: An attractive candidate, where we can make a discovery fundamental for cosmology and particle physics.

A cornerstone of the DUSEL initial program

≥ 2 Generation-3 experiments in initial suite

R&D space also needed

An ongoing effort of the community to converge

Broad consensus on roadmap

Agreement on time scale of G-3 technological choice

- to be refined to take into account the date of beneficial efficiency and S4 studies (procurement, construction times)

Beginning of organization -> S4 coordination /merging-> full collaboration

- Working groups
- Development of a management structure: important role of project manager in technological choice.
- Start with noble liquids -> extend to others

Additional Material

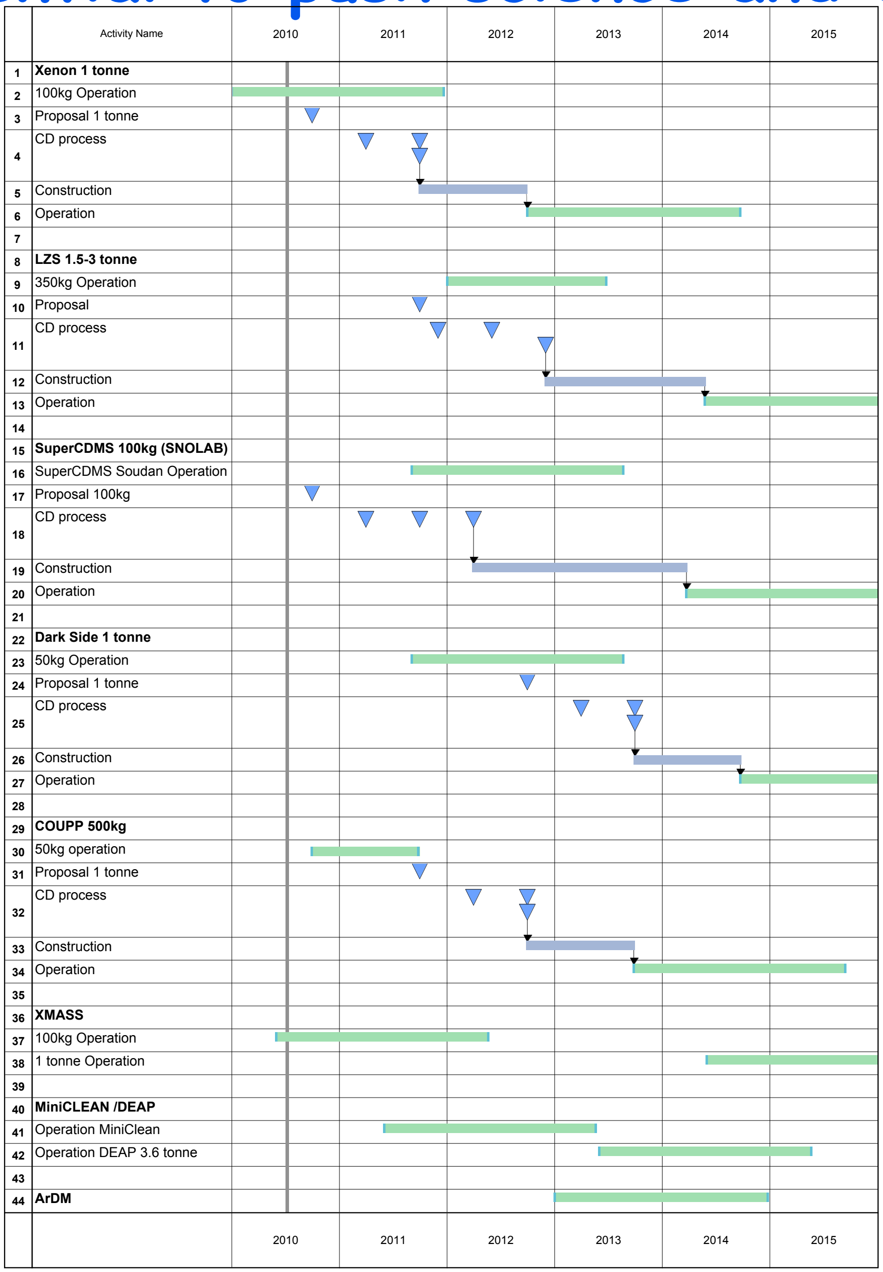
International Context

Region	Current Generation (Gross Mass)	Current Status	Generation 2 (Gross Mass)	Current Status	Generation 3	Current Status
US	LUX 350kg Xe Sanford Lab	Assembly 2011 Install	LZS 1.5-3t Xe Sanford Lab	Design Same water tank as LUX	LZD 20t Xe DUSEL	S4, R&D 2017
UK/Portugal /Russia	ZEPLIN III 10 kg Xe Boulby, UK	Running (2009-2010)				
US	Darkside 50kg Ar LNGS	Design DAr under procurement 2011-2012	1t	Design Same shield of DarkSide-50	MAX 6t Xe 20t DAr DUSEL	S4, R&D 2017 Install
US/Europe /China	XENON100 80kg Xe Gran Sasso	Running	XENON1t 2.4t Xe	Designing 2012 Install		
US/Canada	SCDMS 10kg Ge Soudan	Construction 2011 Install	SCDMS 100kg Ge SNOLAB	R&D 2014 Install	GEODM 1.5t DUSEL	S4, R&D 2018
US	COUPP 60kg CF3 SNOLAB	Construction NUMI test 2010	500 kg	2011 Design 2013 Install	16t scale	S4 R&D
Canada	PICASSO 2.6 kg SNOLAB	Running	PICASSO II 25kg	2010/11 Install	PICASSO III > 500 kg	2012/13 Install
US/Canada	MiniCLEAN 500kg Ar	Construction 2011 Install	DEAP-3600 3.6t	Funded 2012 Install	CLEAN 50t Ar/Ne	Planning R&D
Europe	Edelweiss Now 3 kg =>24 kg Ge 2011 Modane	Running 24kg funding secured	EURECA 100kg Ge Interleaved Ge/ scintillator Modane Extension *Merging of CRESST and Edelweiss*	Active R&D 2013 Install	EURECA 1t Ge / scintillator LS Modane Extension	Planning 2016
Europe	CRESST 5 kg of CaWO- Gran Sasso	Running				
Europe	ArDM 800kg Ar Canfranc	Construction 2011 Install				
Europe/US	WARP 140kg Ar Gran Sasso	Running				
Japan	XMASS 800kg Xe Kamioka	Installation Running 2010	XMASS II 5t	R&D 2014 Install	XMASS III 10t	Planning 2016
China	Jin-Ping lab. Ge and/or Xe	Planning	100kg	2015 R&D	>1t	2020

Table I: International Context (non-directional detectors): Compilation of the plans of various WIMP search collaborations across the world. All masses shown are the active masses of the central detectors. (DAr means Ar depleted in 39Ar.)

Generation 2 Experiments

Essential to push science and explore limit of technologies



Come too late to limit extrapolation

Major impact on DUSEL

Engineering studies

Fold in experience

Validate DUSEL choices

Experiment	US Cost	Remarks
Xenon 1 tonne	$4M	Shielding paid by Europe
LZ 3 tonne	$11.5M	Same shield as LUX
SuperCDMS SNOLAB	$26M	
DarkSide 1 tonne	$4M	Same shield as 50kg
COUPP 500kg	$7M	

Projected costs of generation-2 experiments proposed in the US (equipment+ engineering/technical staff, DOE+NSF)

Space Requirements and Costs

Table II: Experimental Space Requirements

Experiment	Detector Size	Depth	Footprint (W x L x H) m^3	Staging needed
R&D		4850	17 x 25 x 18	
COUPP	32 x 500 kg 16 ton	7400	12 x 25 x 12	
GEODM	1.5 ton Ge	4850 7400	17 x 25 x 14 12 x 25 x 14	25m
LZ20	20 ton LXE	4850	17 x 25 x 18	25m
MAX	20 ton LAr 6 ton LXe	4850	17 x 50 x 21	25m
CLEAN	50 t LAr or LNe	4850	15m ϕ x 15m water tank in pit Facilities above tank	25m
Directionality	TBD		17 x50x 18?	

d. Costs

Table III indicates the estimated costs provided by the various projects. The scale of a program including two generation-3 experiments is such that, in order to be successful, it requires a major mobilization of the community, strong support from NSF and DOE and a sustained engineering involvement of the national laboratories.

Experiment	Size	Cost
CLEAN	50 t LAr /10 t LNe	$60M (+$30M Contingency)
COUPP	16t CF_3I	$21M (+$11M Contingency
GEODM	1.5t Ge	$55M (+$28M Contingency)
LZD	20t Xe	$50M (+$25M Contingency)
MAX	6t Xe, 20t DAr	$70M (+$35M Contingency)

Table III: Estimated cost of the various experiments proposed for the initial suite of WIMP search experiments at DUSEL (equipment + engineering/technical personnel).