LNGS
a laboratory with the vocation of the Dark Matter

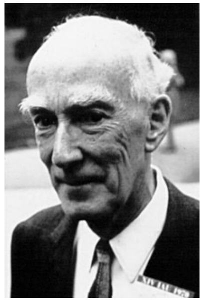
Marcello Messina

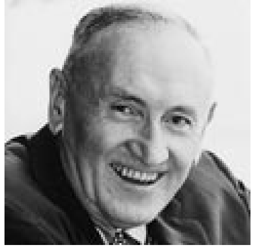
Columbia University and LNGS

25/05/2016

Dark Matter: a brief history

- 1922: Jacobus Kapteyn coined the name "dark matter", while studying stellar motions in our galaxy. He found that the Galaxy had a center of rotation
- 1932: Jan Oort, student of Kapteyn, did a Ph.D. whose title was *High velocity stars*. He suggested that there would be more dark than visible matter in the vicinity of the Sun (later the result turned out to be wrong)
- 1933: F. Zwicky found "dunkle Materie" in the Coma cluster - the redshift of galaxies were much larger than the escape velocity due to luminous matter alone





The Dark Matter puzzle

The bulk of the matter in the Universe (about 85%) is observable only through its gravitational effects.

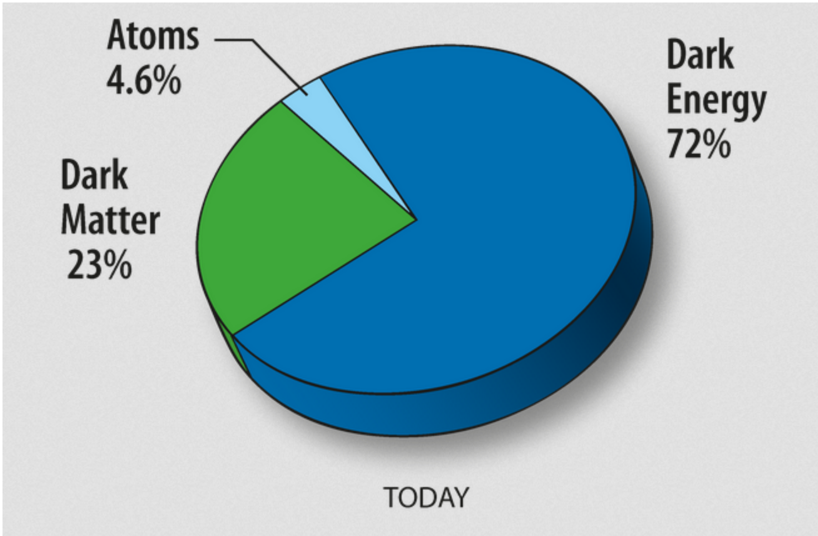
DARK MATTER

Credit: NASA/WMAP Science Team

The Dark Matter puzzle

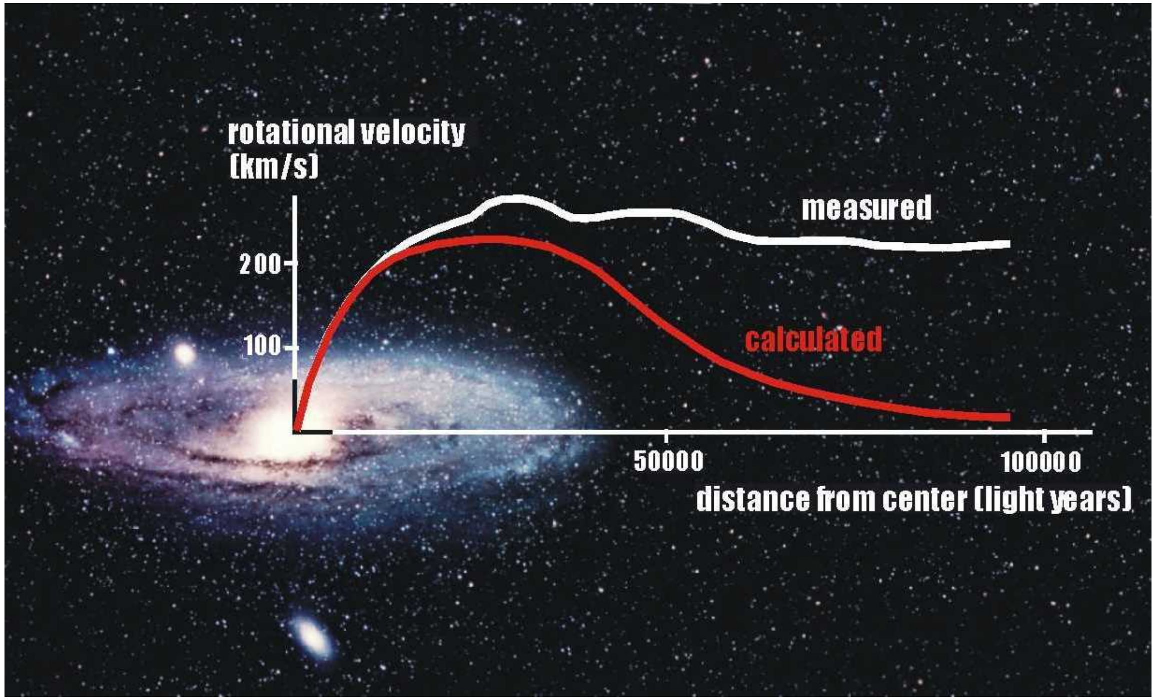
The bulk of the matter in the Universe (about 85%) is observable only through its gravitational effects.

DARK MATTER



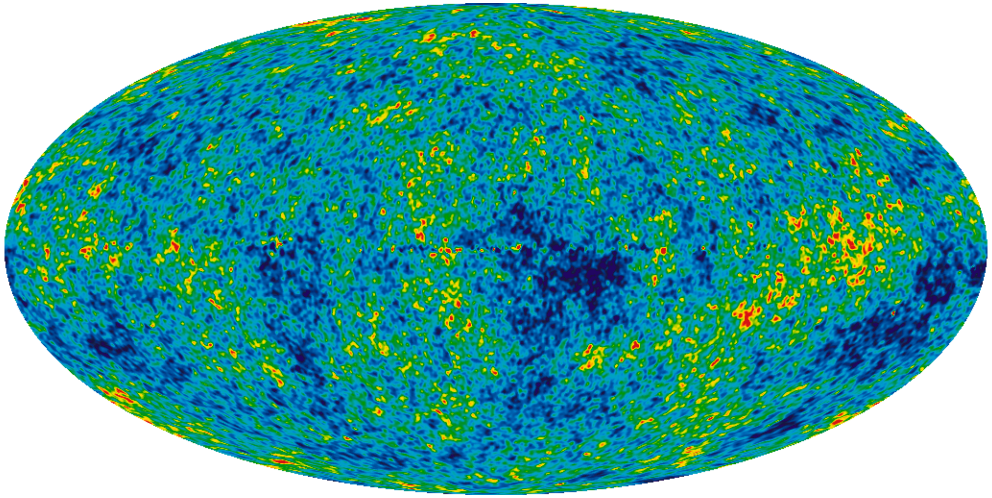
Credit: NASA/WMAP Science Team

Evidence for Dark Matter, Galaxy rotation curves



Spiral galaxies show $\frac{M}{L} \sim 30 - 40 \frac{M_\odot}{L_\odot}$.

Evidence for Dark Matter, Cosmic Microwave Background

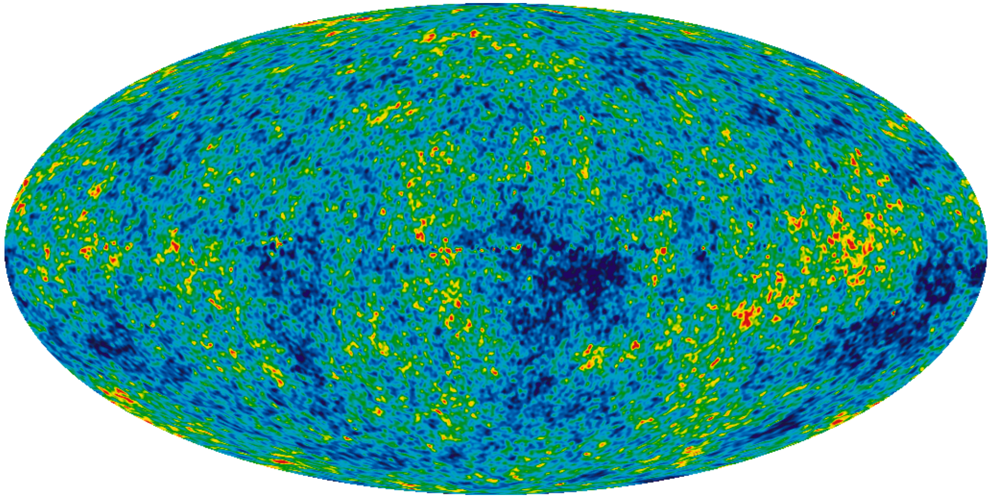


Credit: NASA/WMAP Science Team

Detailed measurements of the Cosmic Microwave Background (CMB) temperature fluctuations.
They support ΛCDM model with a flat Universe.

$$\Omega_\Lambda \sim 0.72,\ \Omega_{CDM} \sim 0.23,\ \Omega_B \sim 0.046,\ \Omega_{Tot} = 1$$

Evidence for Dark Matter, Cosmic Microwave Background



Credit: NASA/WMAP Science Team

Detailed measurements of the Cosmic Microwave Background (CMB) temperature fluctuations.
They support ΛCDM model with a flat Universe.

$$\Omega_\Lambda \sim 0.72,\ \Omega_{CDM} \sim 0.23,\ \Omega_B \sim 0.046,\ \Omega_{Tot} = 1$$

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

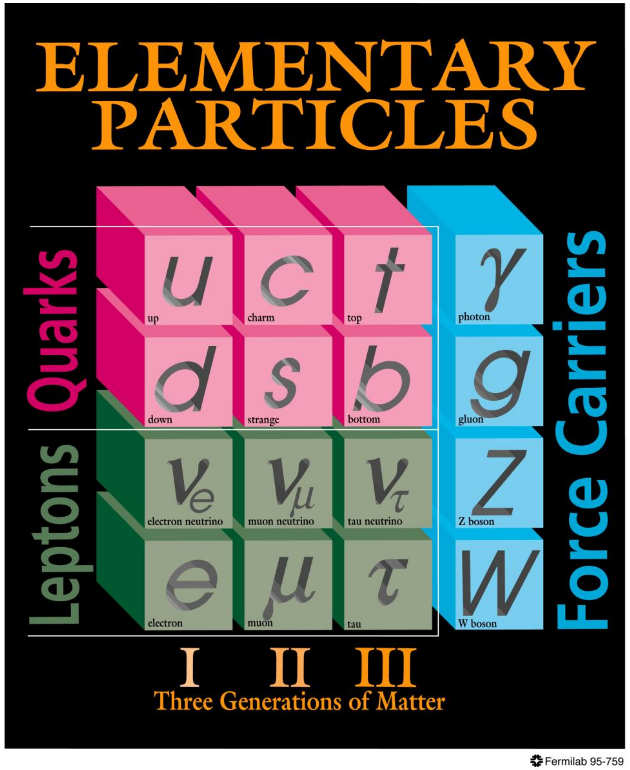
- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

Properties of Dark Matter

Dark Matter is a component of the Universe with these features:

- It's DARK, neither emitting nor absorbing light. No electric charge.
- It's massive, gravitational effects.
- Small interaction between DM particles, basically collisionless.
- Small interaction with baryons.
- It's COLD, non relativistic.
- It's stable, its mean decay time is much longer than the age of the Universe.

A Standard Model particle as Dark Matter candidate?

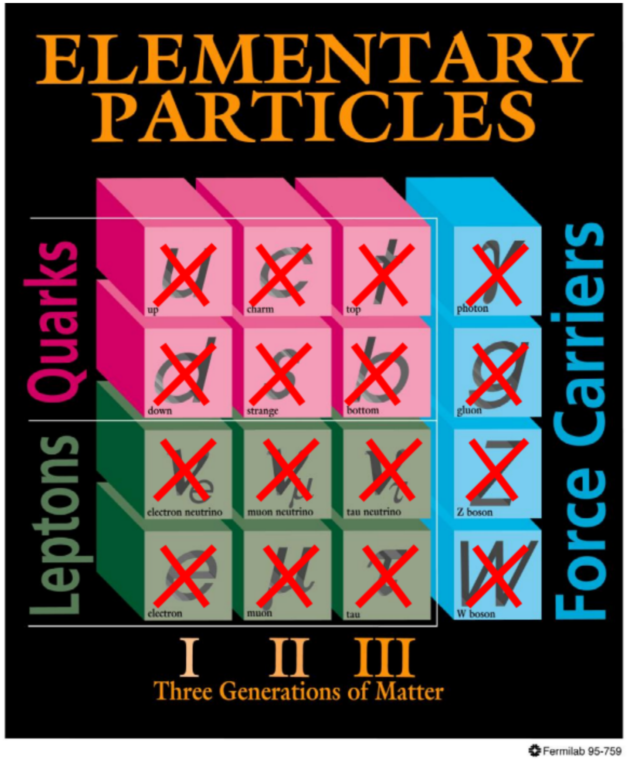


- Massive
- Stable
- No electric charge
- Non relativistic

No SM particle is a suitable DM candidate.

Study of DM $\rightarrow$ Study of physics beyond the SM.

A Standard Model particle as Dark Matter candidate?

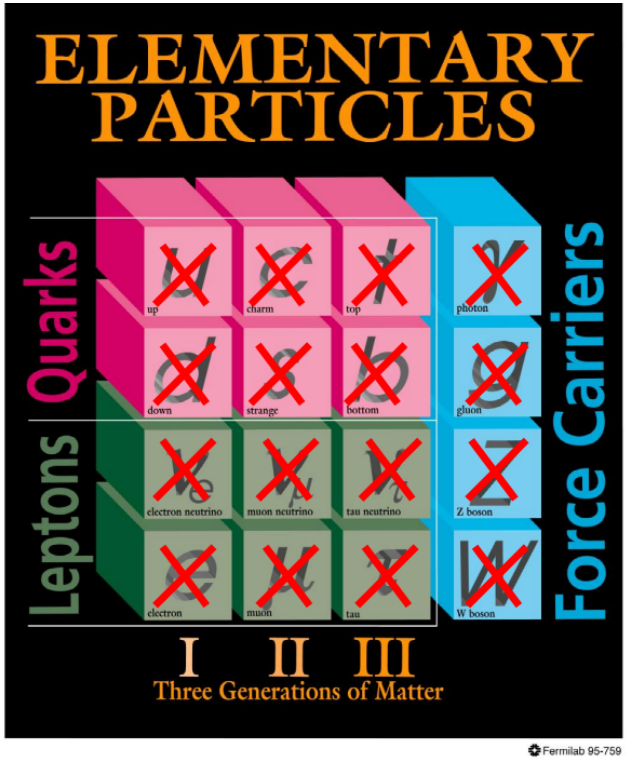


- Massive
- Stable
- No electric charge
- Non relativistic

No SM particle is a suitable DM candidate.

Study of DM $\rightarrow$ Study of physics beyond the SM.

A Standard Model particle as Dark Matter candidate?



- Massive
- Stable
- No electric charge
- Non relativistic

No SM particle is a suitable DM candidate.

Study of DM $\rightarrow$ Study of physics beyond the SM.

Weakly Interacting Massive Particles

Weakly Interacting Massive Particles (WIMPs) are a class of DM candidates.

A new stable neutral particle, with feeble interaction and O(100 GeV) mass.

This kind of particles arises in a few theories beyond SM, as Supersimmetry (SUSY).

Weakly Interacting Massive Particles

Weakly Interacting Massive Particles (WIMPs) are a class of DM candidates.

A new stable neutral particle, with feeble interaction and O(100 GeV) mass.

This kind of particles arises in a few theories beyond SM, as Supersimmetry (SUSY).

Weakly Interacting Massive Particles

Weakly Interacting Massive Particles (WIMPs) are a class of DM candidates.

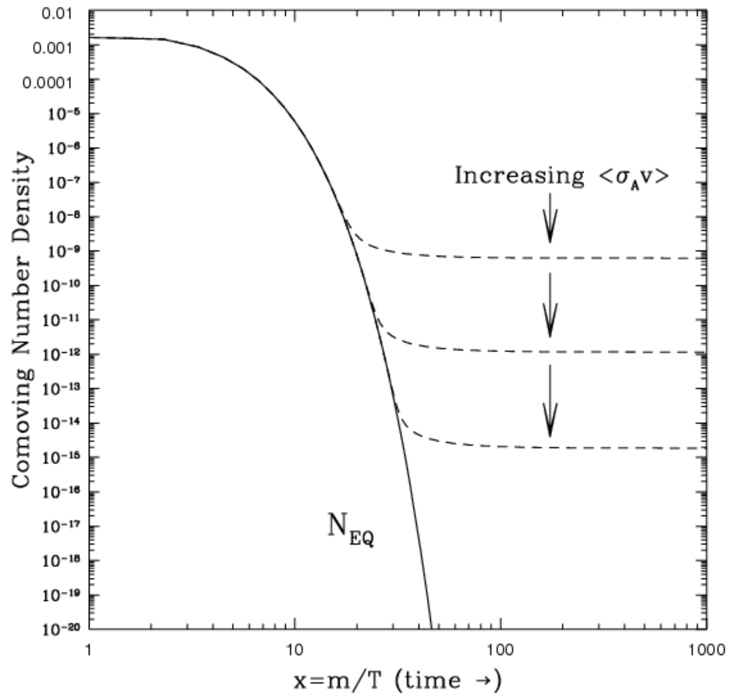
A new stable neutral particle, with feeble interaction and O(100 GeV) mass.

This kind of particles arises in a few theories beyond SM, as Supersimmetry (SUSY).

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

- Initial thermal equilibrium: $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down: $\chi\chi \rightarrow q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



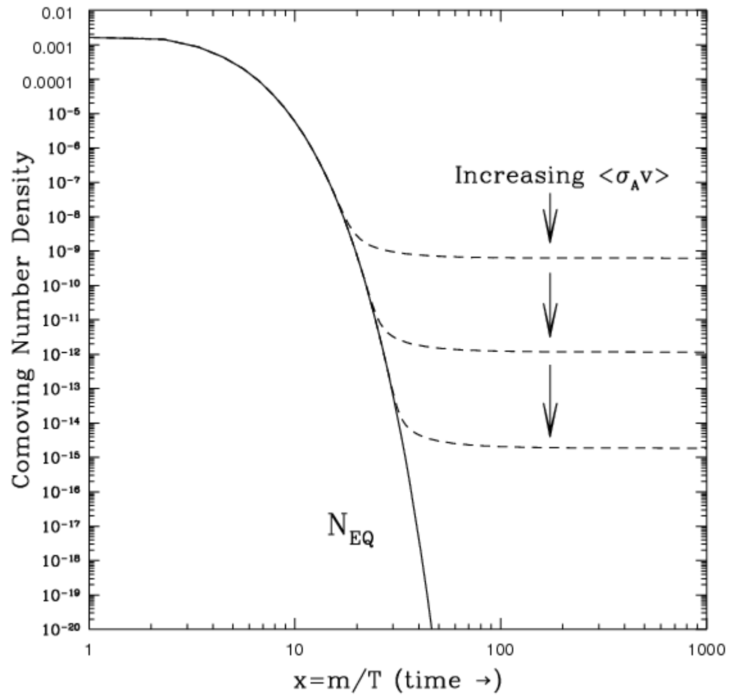
Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

- Initial thermal equilibrium: $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down: $\chi\chi \rightarrow q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



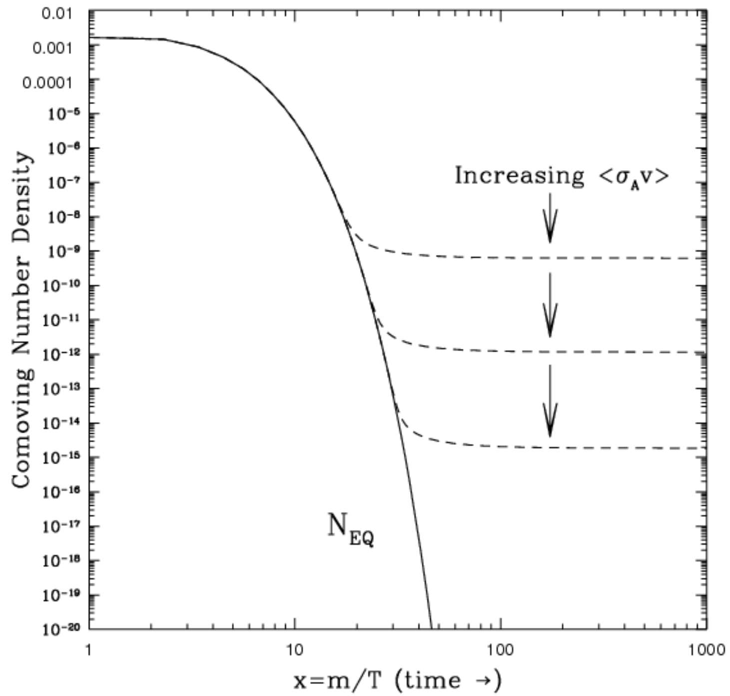
Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

- Initial thermal equilibrium:
  $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down:
  $\chi\chi \to q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



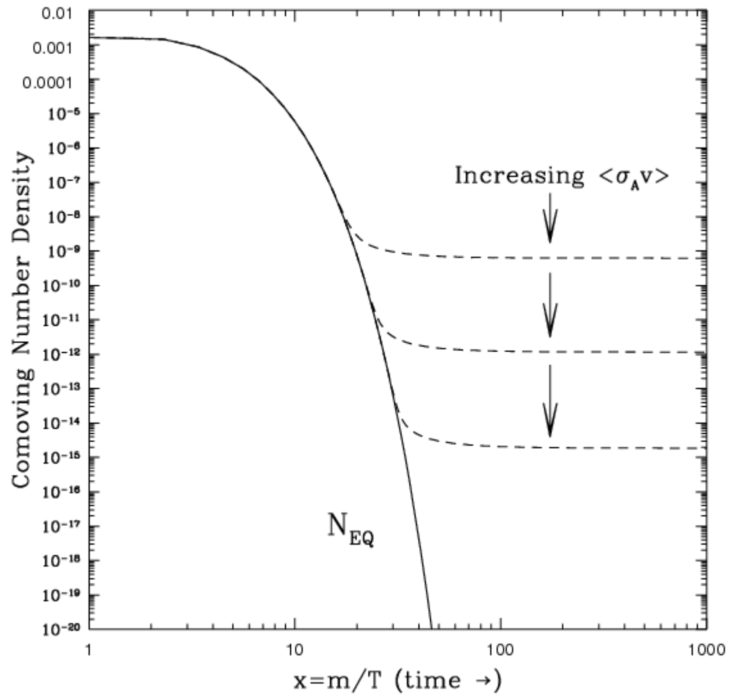
Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

- Initial thermal equilibrium: $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down: $\chi\chi \to q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



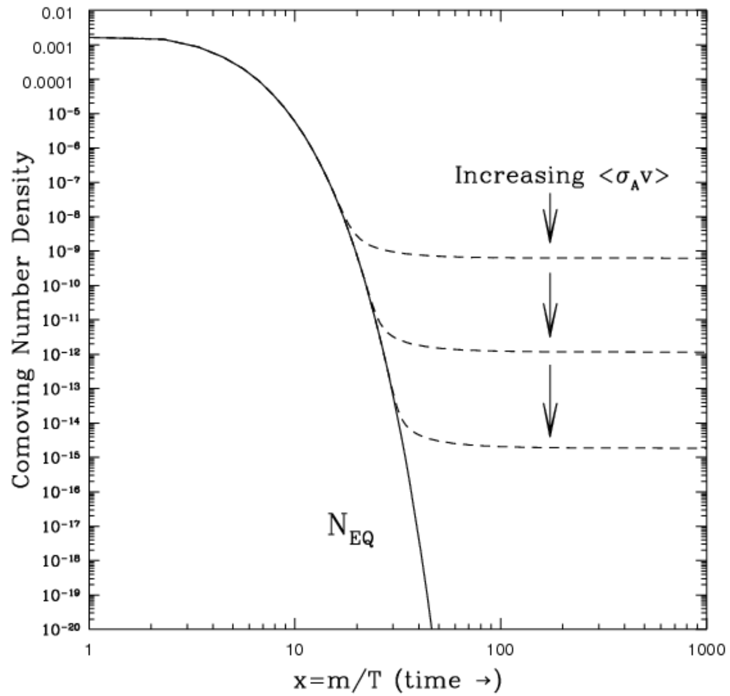
Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

- Initial thermal equilibrium: $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down: $\chi\chi \rightarrow q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



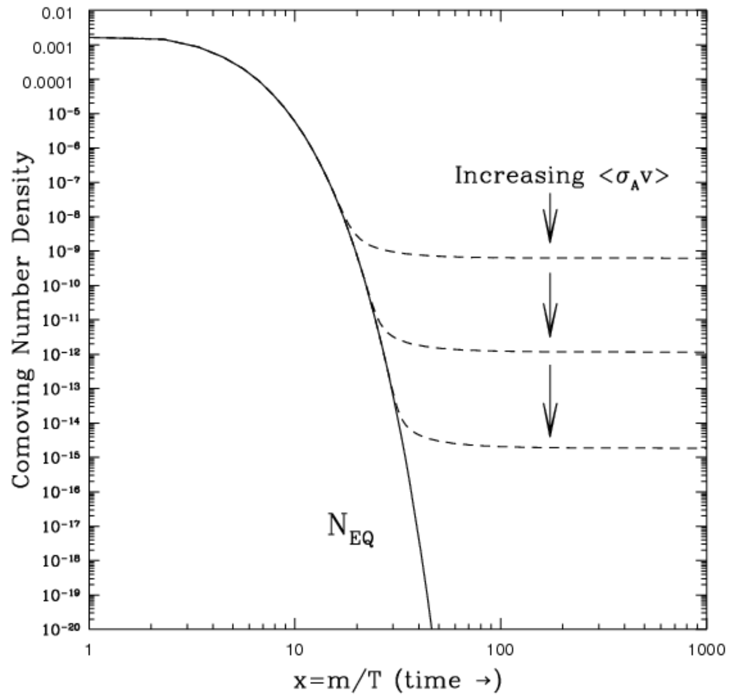
Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

Weakly Interacting Massive Particles

WIMPs are relic particles from the Big Bang.

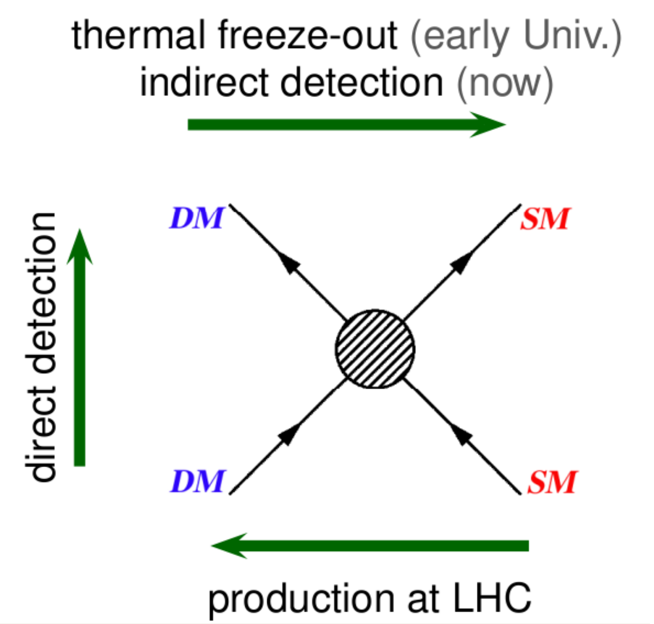
- Initial thermal equilibrium: $\chi\chi \rightleftarrows q\bar{q}, l\bar{l}$
- Universe cools down: $\chi\chi \to q\bar{q}, l\bar{l} \Rightarrow N_\chi \propto e^{-M_\chi/T}$
- Freeze out: $N \sim const.$



Final abundance determined by annihilation cross section σ_A. For WIMPs this is at the electroweak scale. This naturally gives the correct relic abundance $\Omega_{CDM} \sim 0.1$.

WIMP miracle

WIMPs detection channels



Independent and complementary approaches

Indirect detection

Products of DM particles annihilation: e^+, $\bar{p}$, γ, energetic νs.

Production in colliders

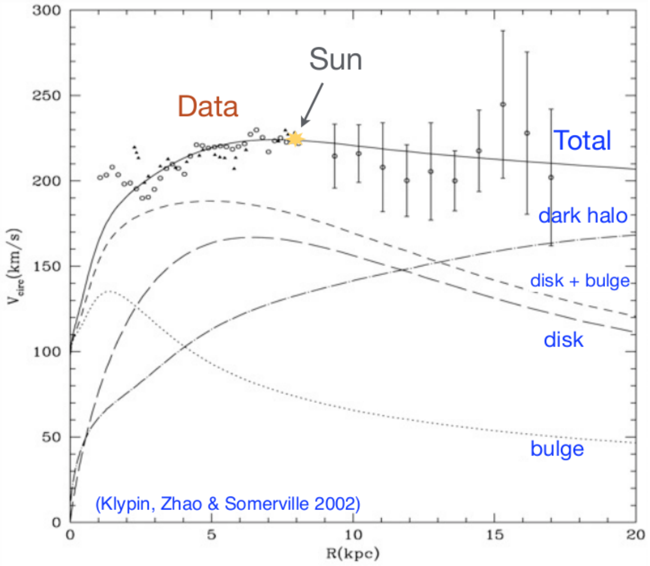
Missing energy in LHC collisions

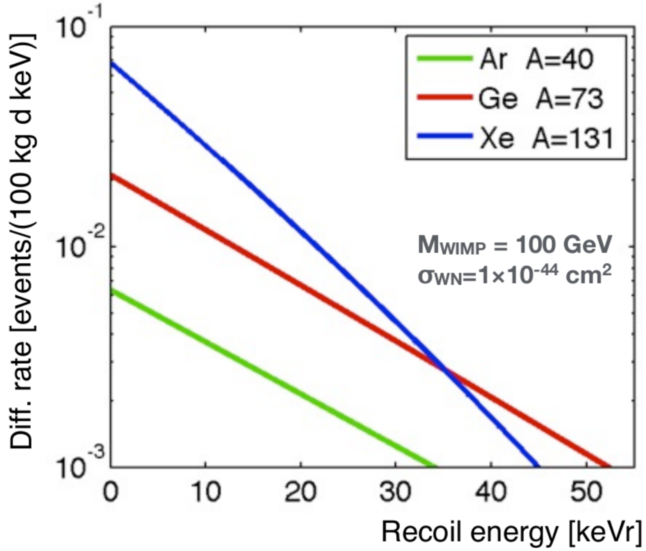
Direct detection

WIMPs interactions with target nuclei

Direct detection: effect of WIMPs interactions

WIMPs induce *nuclear recoils* in a terrestrial detector.

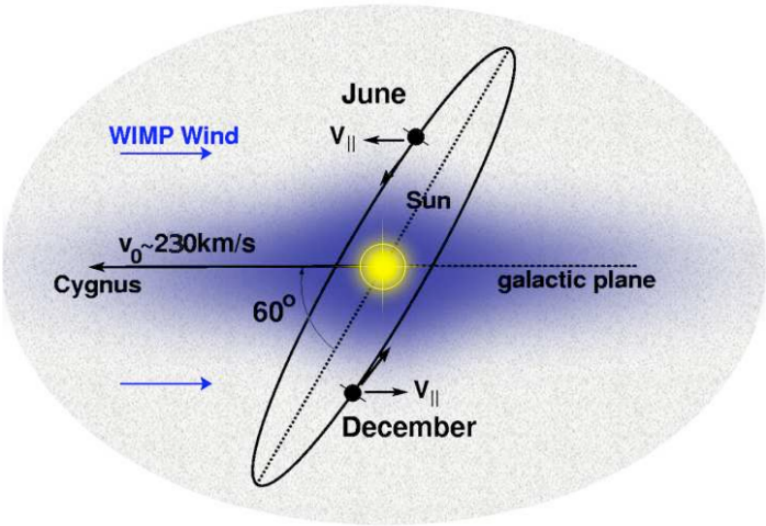




$\rho_0 \sim 0.3\,\mathrm{GeV} \cdot cm^{-3}$ (few particles per liter) at the Sun position. Standard assumption is a Maxwellian velocity distribution with $v_0 = 220$ km/s

Nuclear recoil energies O(10 keV)
Total recoil rate as low as 1-10^{-3} events / (day · kg)

Direct detection: annual modulation

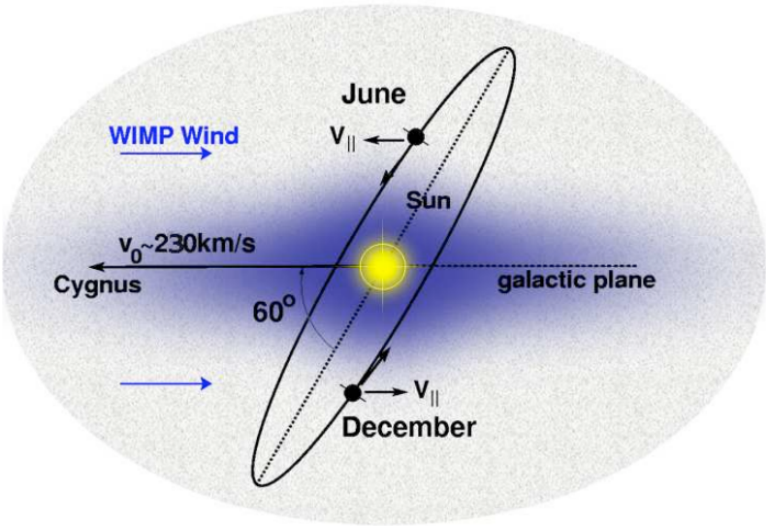


Annual modulation of the recoil rate:

- Modulation present only in a definite energy region
- Modulation ruled by a cosine function
- Period of 1 year
- Phase is 152.5^{th} day in the year (June 2^{nd})
- Amplitude of the modulation order few percents

Strong signature.

Direct detection: annual modulation

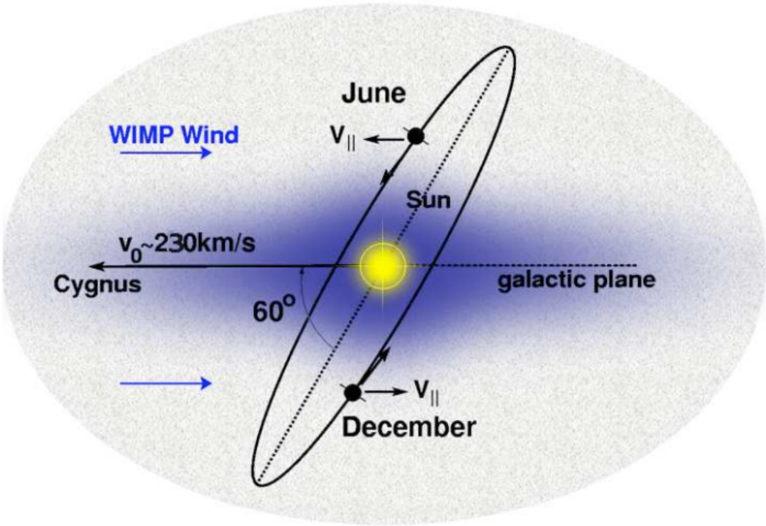


Annual modulation of the recoil rate:

- Modulation present only in a definite energy region
- Modulation ruled by a cosine function
- Period of 1 year
- Phase is 152.5^{th} day in the year (June 2^{nd})
- Amplitude of the modulation order few percents

Strong signature.

Direct detection: annual modulation



Annual modulation of the recoil rate:

- Modulation present only in a definite energy region
- Modulation ruled by a cosine function
- Period of 1 year
- Phase is 152.5^{th} day in the year (June 2^{nd})
- Amplitude of the modulation order few percents

Strong signature.

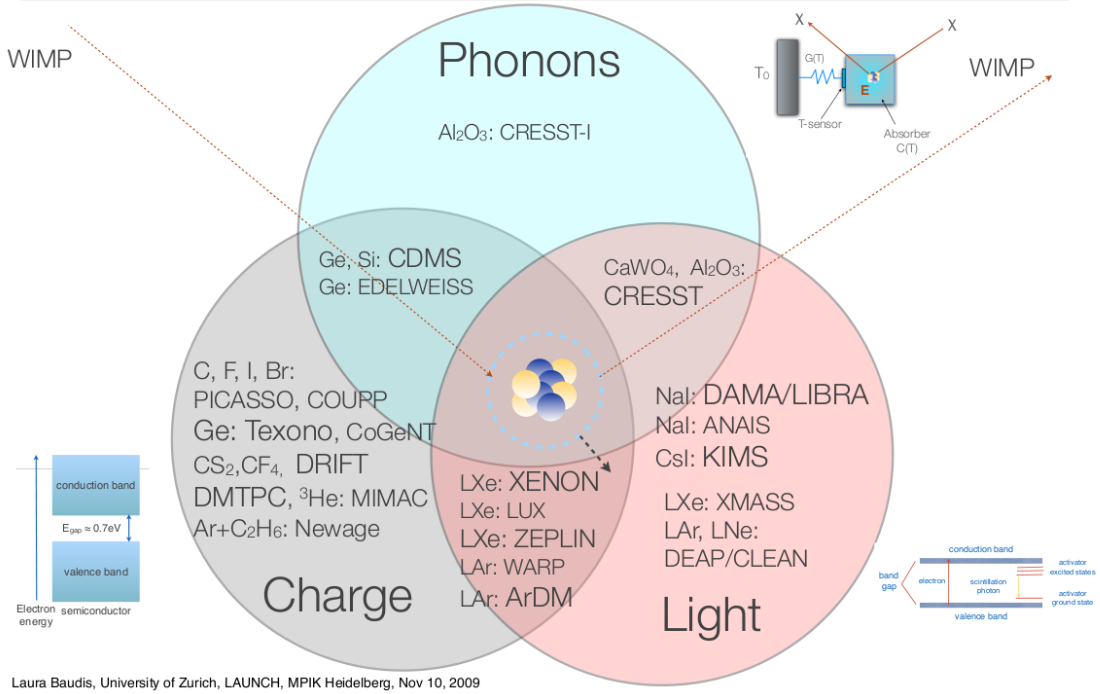
Direct detection: design of a WIMP detector

- Very low energy threshold for nuclear recoils, O(1 keV)
- Underground site to avoid cosmic rays (LNGS)
- Very low radioactive background at low energies, with careful material selection and detector design
- Sensitivity to a recoil, i.e. specific observable, to reject the abundant γ and β background
- Space resolution to reject multiple-hit events (induced by neutrons)
- Sensitivity to a WIMP specific observable: annual modulation, rate scaling with A of target.

Direct detection: design of a WIMP detector

- Very low energy threshold for nuclear recoils, O(1 keV)
- Underground site to avoid cosmic rays (LNGS)
- Very low radioactive background at low energies, with careful material selection and detector design
- Sensitivity to a recoil, i.e. specific observable, to reject the abundant γ and β background
- Space resolution to reject multiple-hit events (induced by neutrons)
- Sensitivity to a WIMP specific observable: annual modulation, rate scaling with A of target.

Direct detection: different techniques

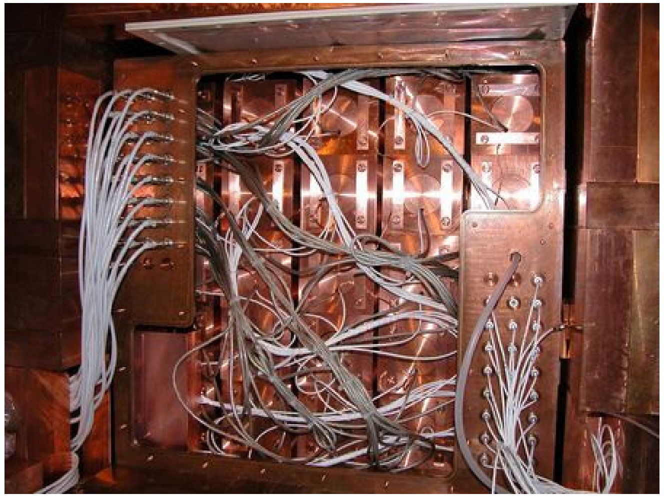


Laura Baudis, University of Zurich, LAUNCH, MPIK Heidelberg, Nov 10, 2009

Double Read-Out: use of two signals to discriminate nuclear and electronic recoils

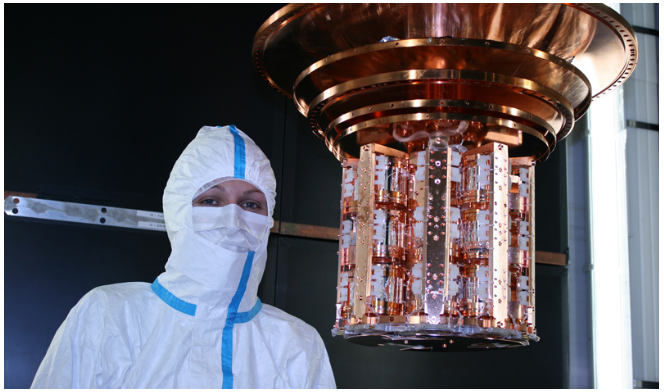
$$\left(\frac{CHARGE}{PHONONS}\right)_{nuclear} \ll \left(\frac{CHARGE}{PHONONS}\right)_{electron},$$
$$\left(\frac{LIGHT}{PHONONS}\right)_{nuclear} \ll \left(\frac{LIGHT}{PHONONS}\right)_{electron},$$
$$\left(\frac{CHARGE}{LIGHT}\right)_{nuclear} \ll \left(\frac{CHARGE}{LIGHT}\right)_{electron}$$

Direct detection: LNGS experiments

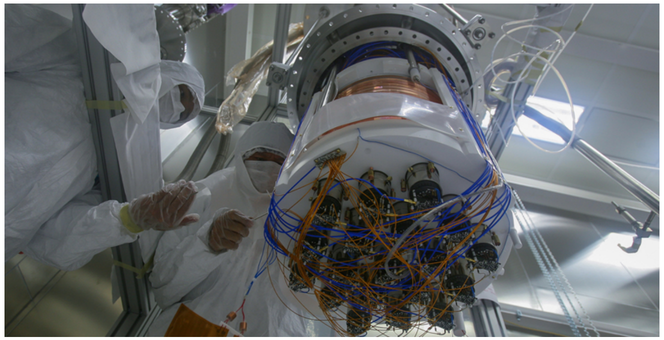


DAMA: light (annual modulation)

XENON: light + charge



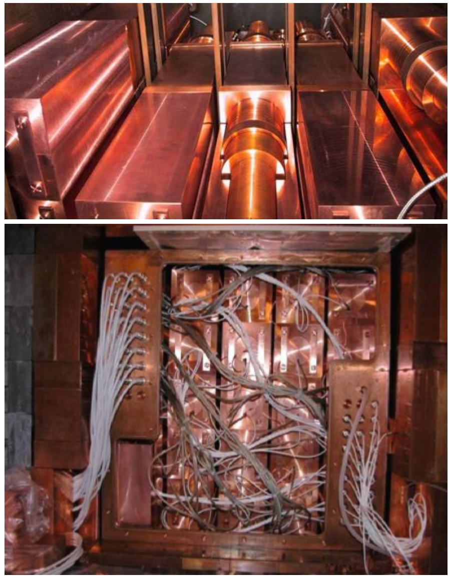
CRESST: light + phonons

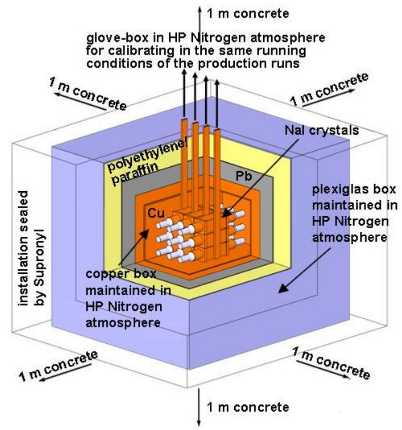


DARKSIDE: light + charge

DAMA

Array of radiopure sodium iodine (NaI) scintillating crystals. Light is detected by means of PMTs. Look for *annual modulation* in single-hit events.





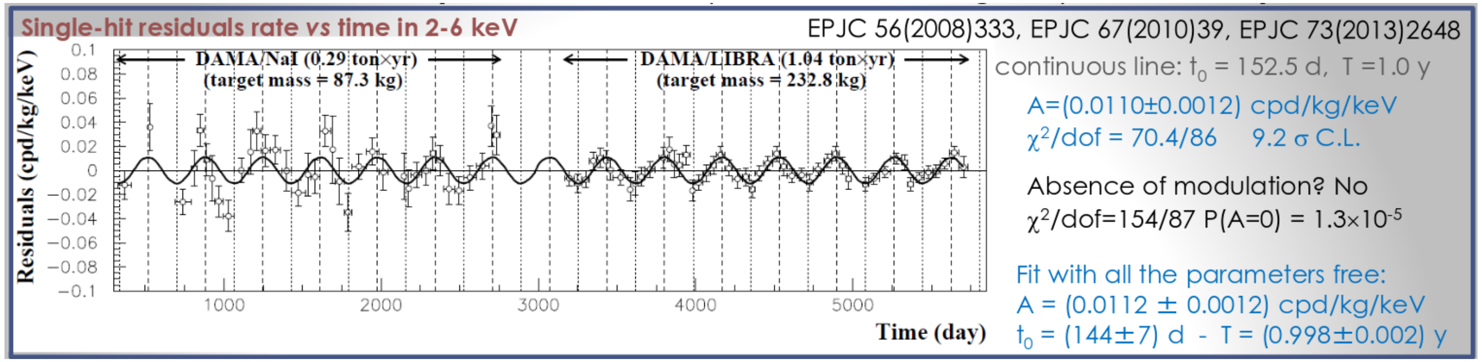
Simplified schema of ~ 100 kg NaI(Tl) set-up

DAMA/NaI: 87.3 kg of NaI, completed data taking in July 2002, total exposure 0.29 ton $\times$ year.

DAMA/LIBRA: 232.8 kg of NaI, first phase ended August 2013, total exposure 1.04 ton $\times$ year.

DAMA

Total exposure (NaI+LIBRA): 1.33 ton $\times$ year (14 annual cycles). 9.3 σ evidence for annual modulation in single-hit events, 2-6 keV energy range (electron calibration).



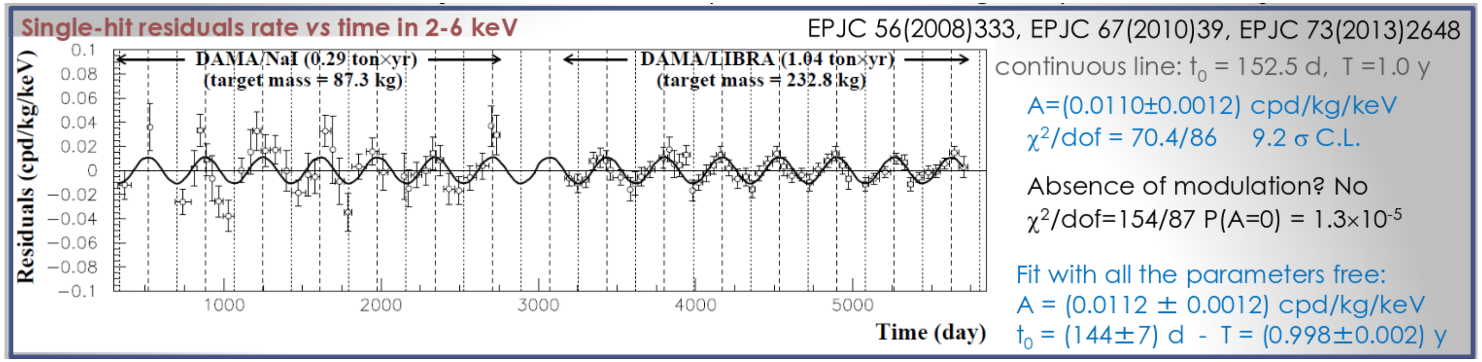
From R.Cerulli's talk @ MG14-ICRA, Roma

Compatible with annual modulation expected from DM particles in the halo of the Galaxy. No modulation in multiple-hit events and in the energy range above 6 keV.

Interpretation as WIMP with M$\sim$10 GeV and $\sigma \sim 10^{-40}$ cm^2 is challenged by other experiments.

DAMA

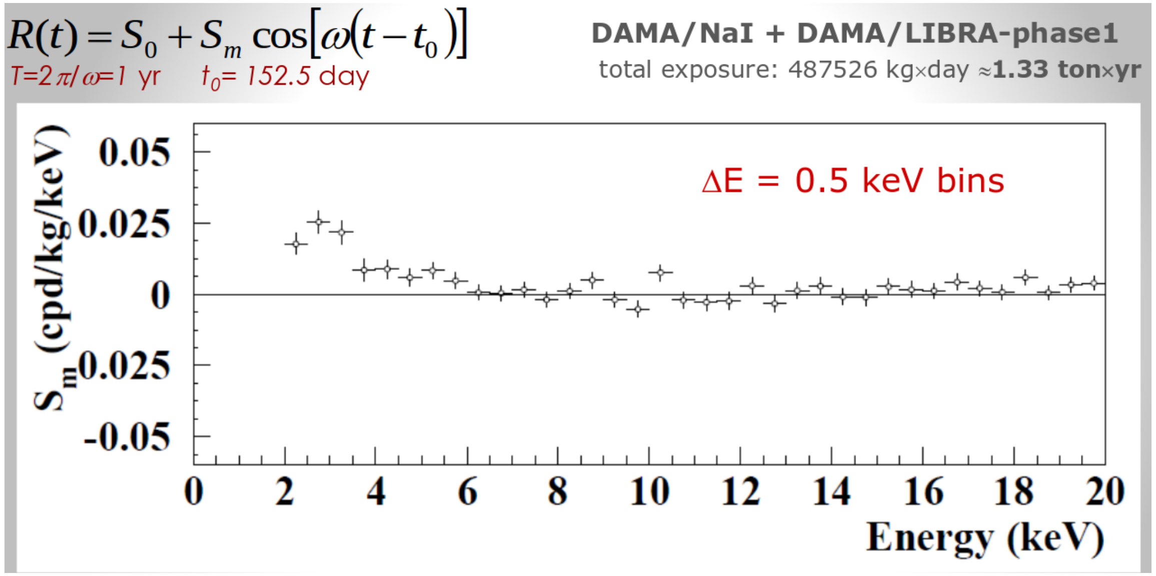
Total exposure (NaI+LIBRA): 1.33 ton $\times$ year (14 annual cycles). 9.3 σ evidence for annual modulation in single-hit events, 2-6 keV energy range (electron calibration).



From R.Cerulli's talk @ MG14-ICRA, Roma

Compatible with annual modulation expected from DM particles in the halo of the Galaxy. No modulation in multiple-hit events and in the energy range above 6 keV.
Interpretation as WIMP with M$\sim$10 GeV and $\sigma \sim 10^{-40}$ cm^2 is challenged by other experiments.

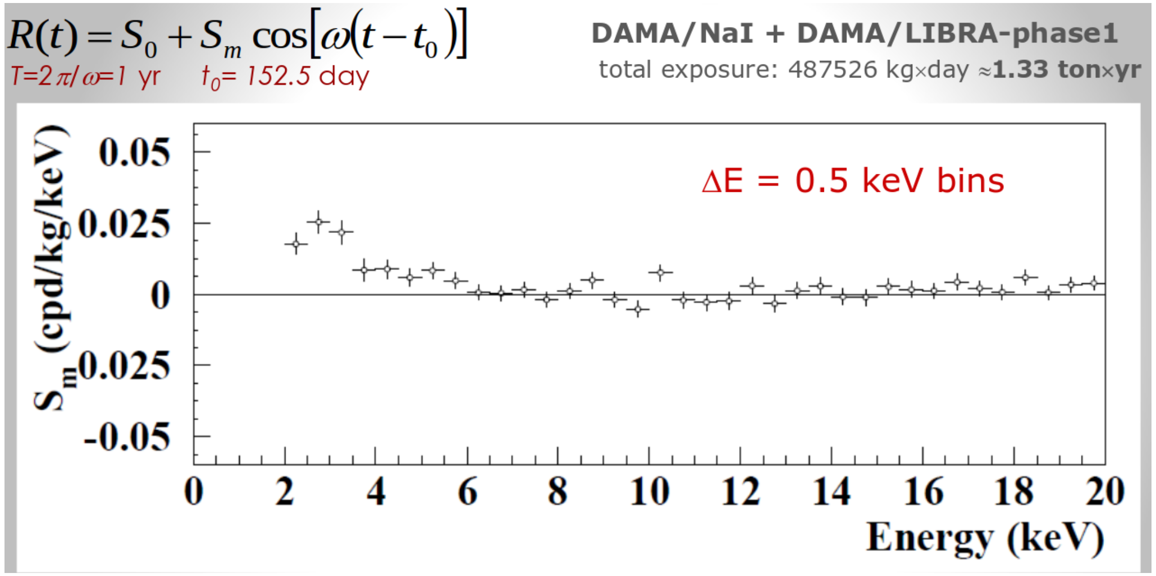
DAMA



From R.Cerulli's talk @ MG14-ICRA, Roma

- DAMA/LIBRA phase 2 in data taking at lower energy threshold (below 2 keV).
- DAMA/LIBRA phase 3 under study (increasing light collection and with new high q.e. PMTs).
- R&D for a possible DAMA/1 ton setup.

DAMA

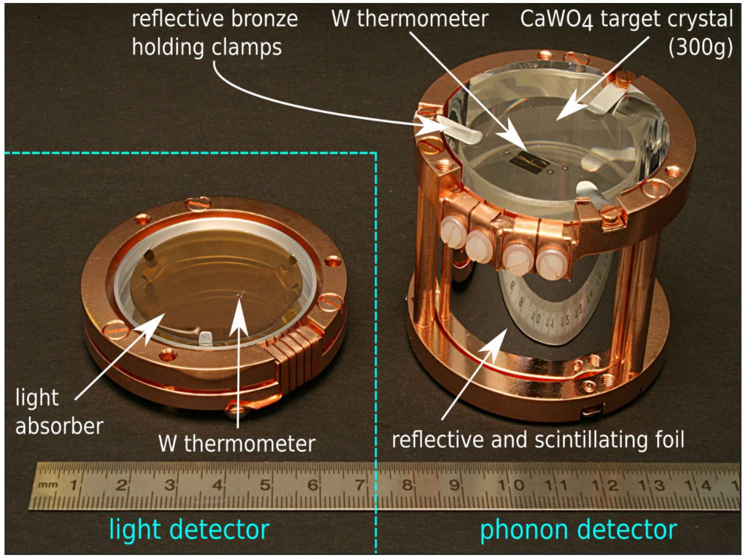


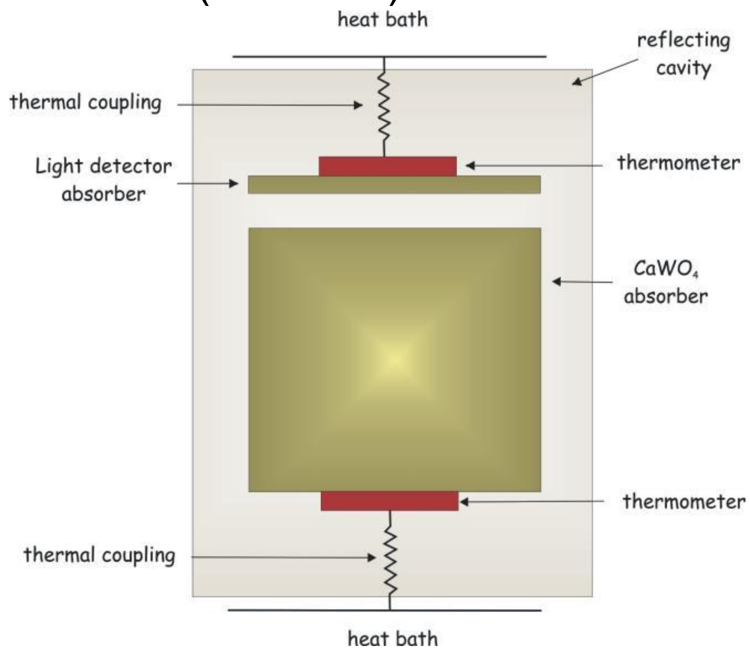
From R.Cerulli's talk @ MG14-ICRA, Roma

- DAMA/LIBRA phase 2 in data taking at lower energy threshold (below 2 keV).
- DAMA/LIBRA phase 3 under study (increasing light collection and with new high q.e. PMTs).
- R&D for a possible DAMA/1 ton setup.

CRESST

It uses scintillating $CaWO_4$ crystals (300 g each) as target at cryogenic temperatures ($\sim$10 mK). Very low threshold (0.4 keV).





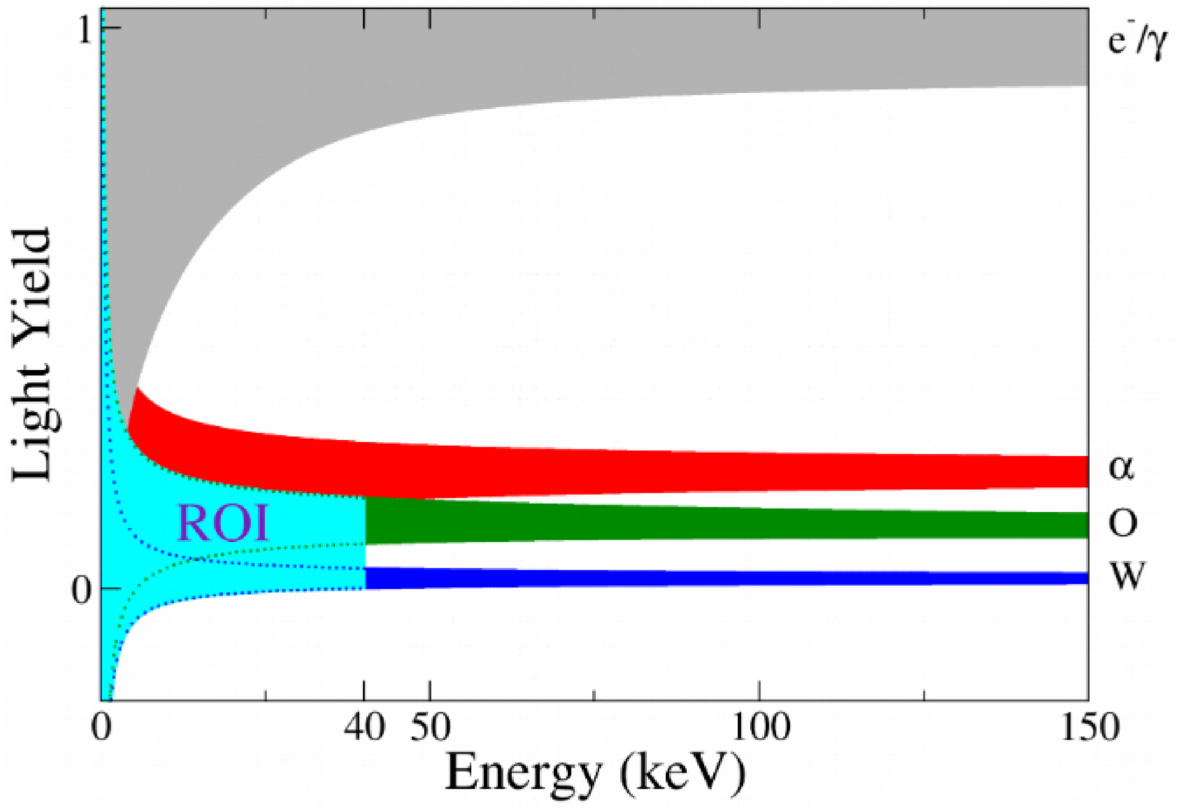
$$\Delta T = \frac{E}{C(T)} e^{-\frac{t}{\tau}}, \tau = \frac{C(T)}{G(T)}$$

Phonon signal (heat) $\rightarrow$ deposited energy

Scintillation light $\rightarrow$ particle discrimination

CRESST

Light Yield = $\frac{\textit{light signal}}{\textit{phonon signal}}$

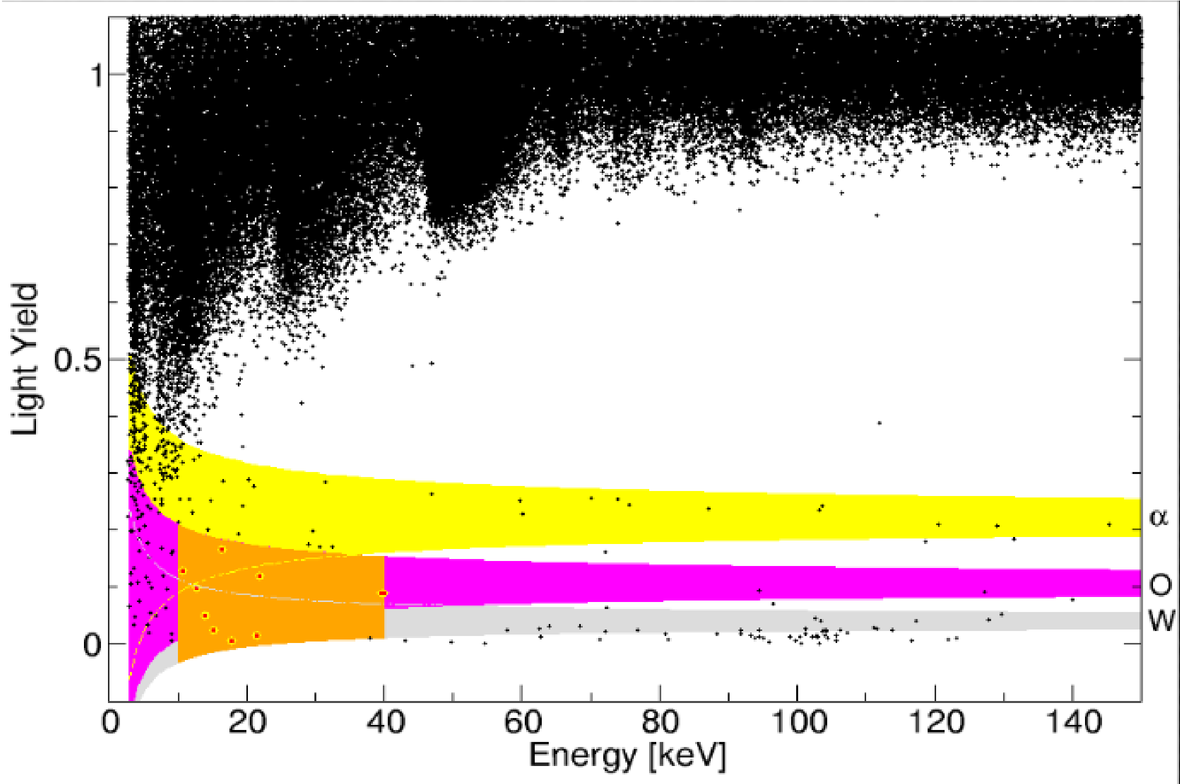


From F.Reindl's talk @ NDM 2015, Jyvaskyla

Very good electronic recoil discrimination.

CRESST

Light Yield = $\frac{\textit{light signal}}{\textit{phonon signal}}$

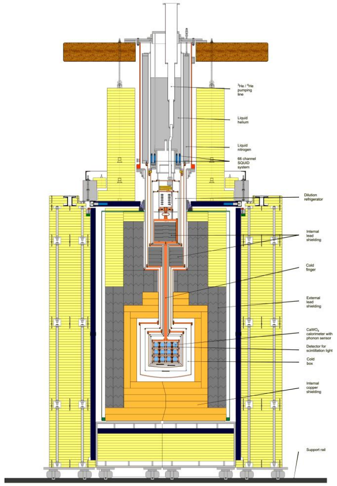


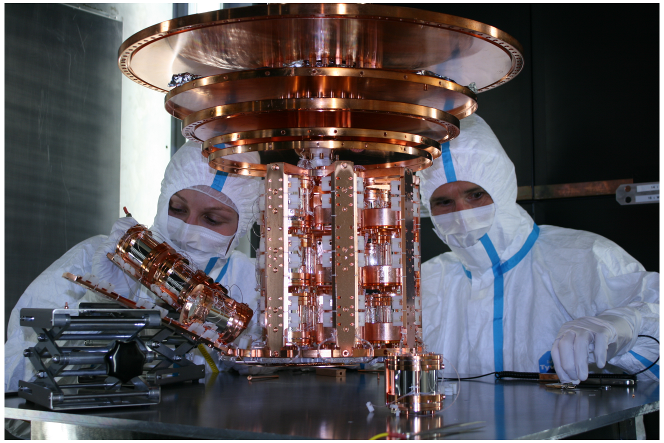
From F.Reindl's talk @ NDM 2015, Jyvaskyla

Very good electronic recoil discrimination.

CRESST

An array of 33 modules (10 kg target mass).





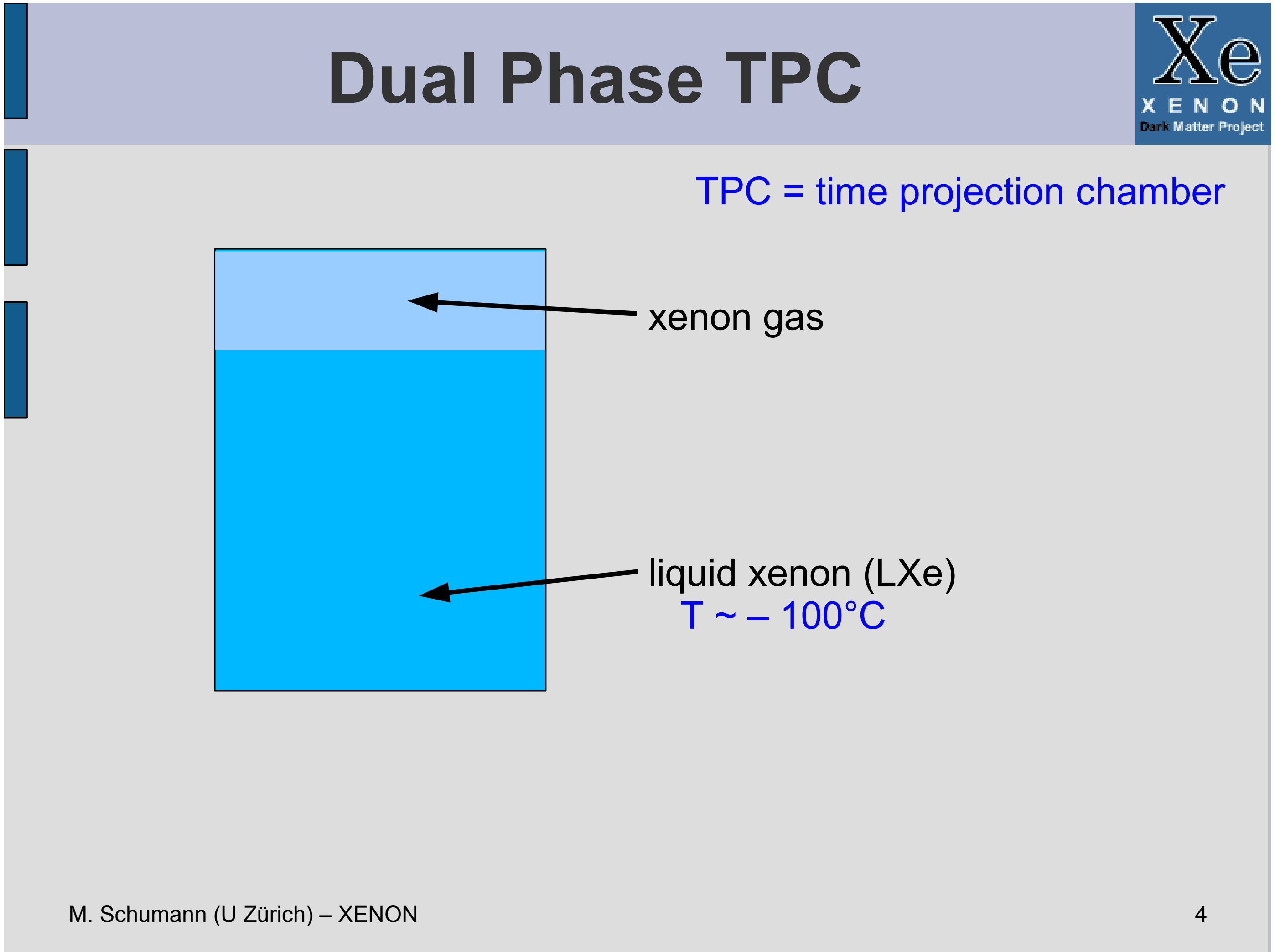
CRESST-II Phase 1 (2009-2011): excess above known background, mild tension with previous data.

CRESST-II Phase 2 (since July 2013): background reduction, currently running. Very good performance at low WIMP mass (<3 GeV).

CRESST-III: smaller crystals (24 g), lowering threshold (100 eV). Starting this year.

XENON

Dual-phase Xenon Time Projection Chamber (TPC).

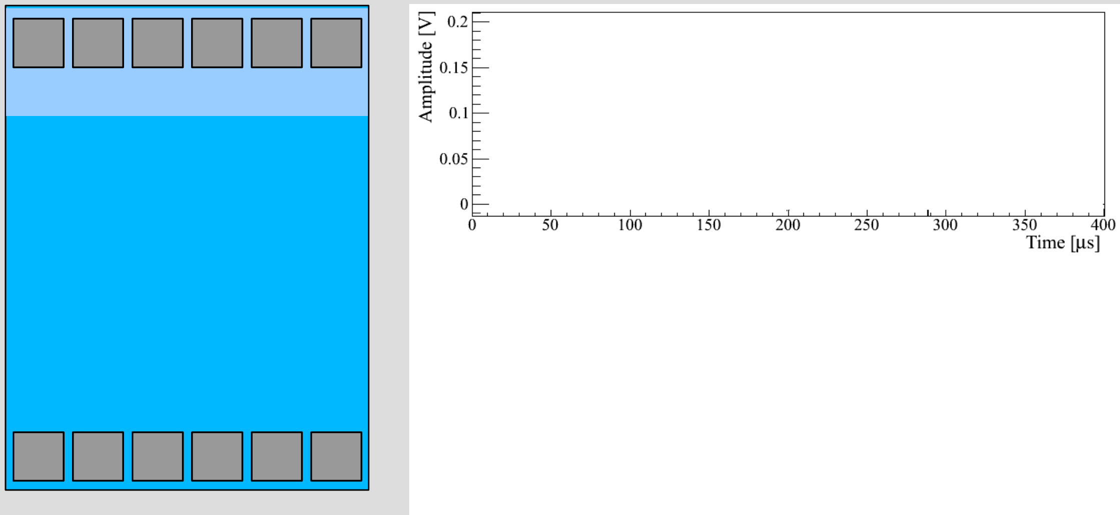


XENON

Dual-phase Xenon Time Projection Chamber (TPC).

Dual Phase TPC

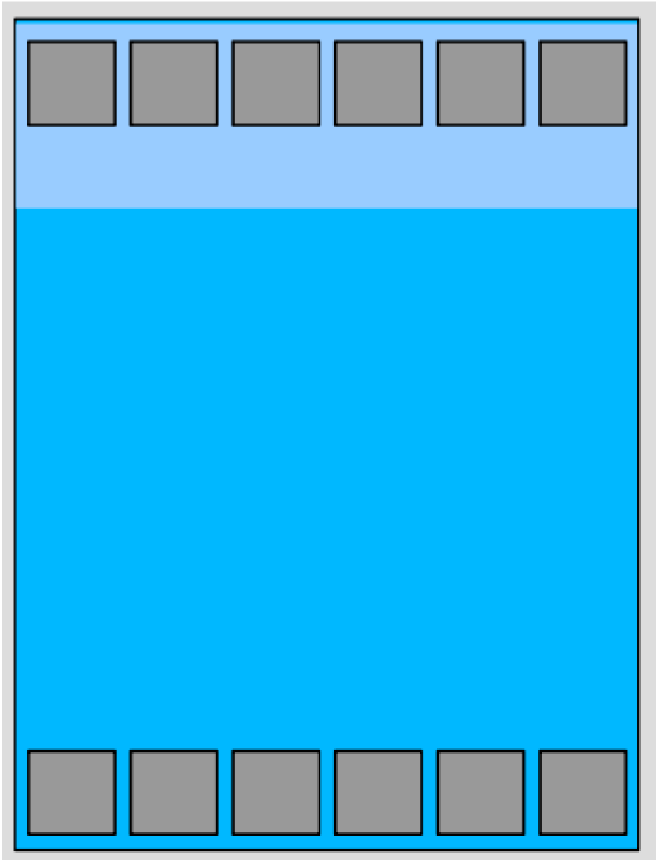
XENON
Dark Matter Project

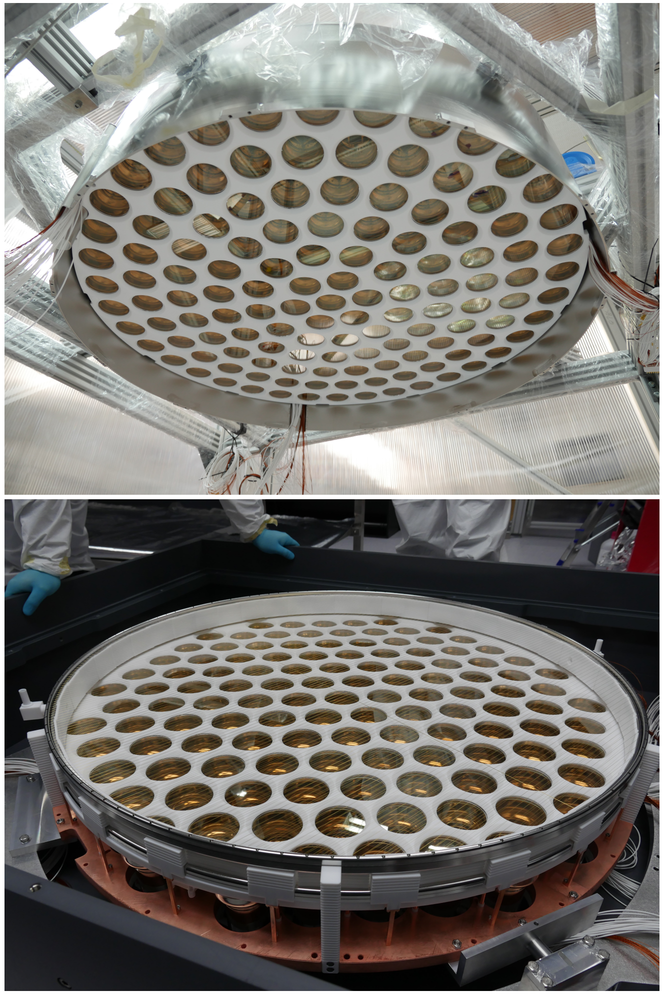


M. Schumann (U Zürich) – XENON 5

XENON

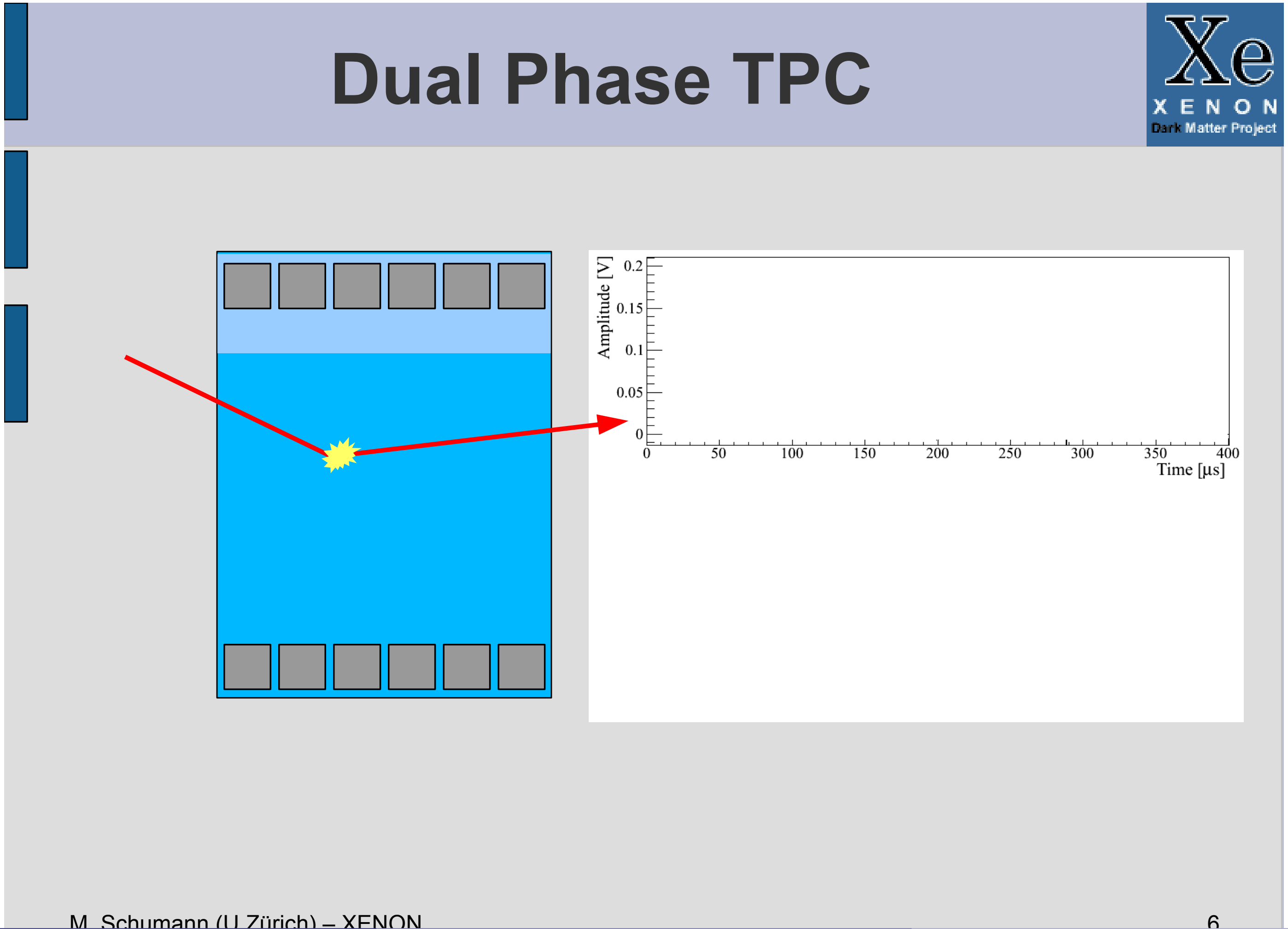
Dual-phase Xenon Time Projection Chamber (TPC).





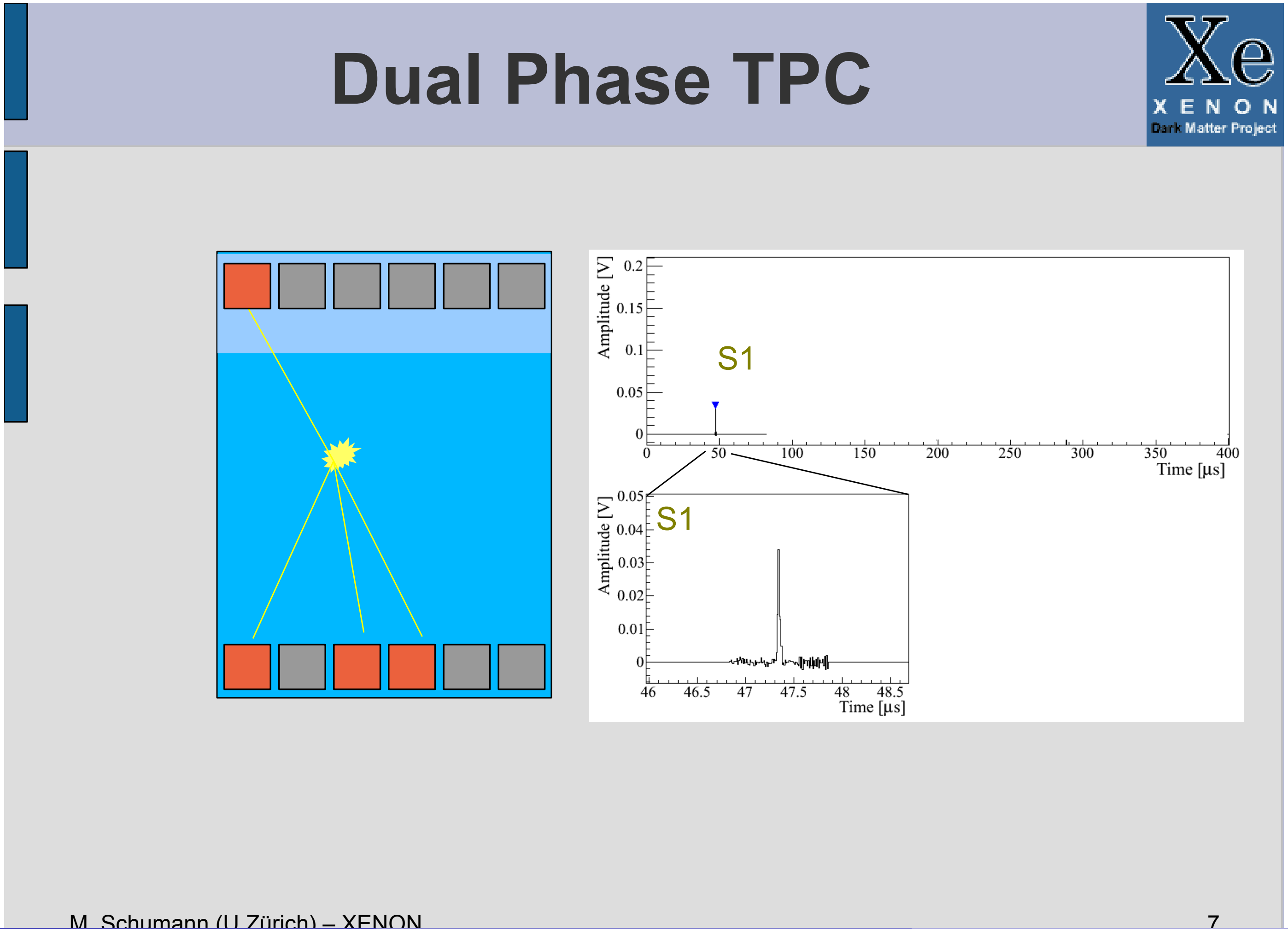
XENON

Dual-phase Xenon Time Projection Chamber (TPC).



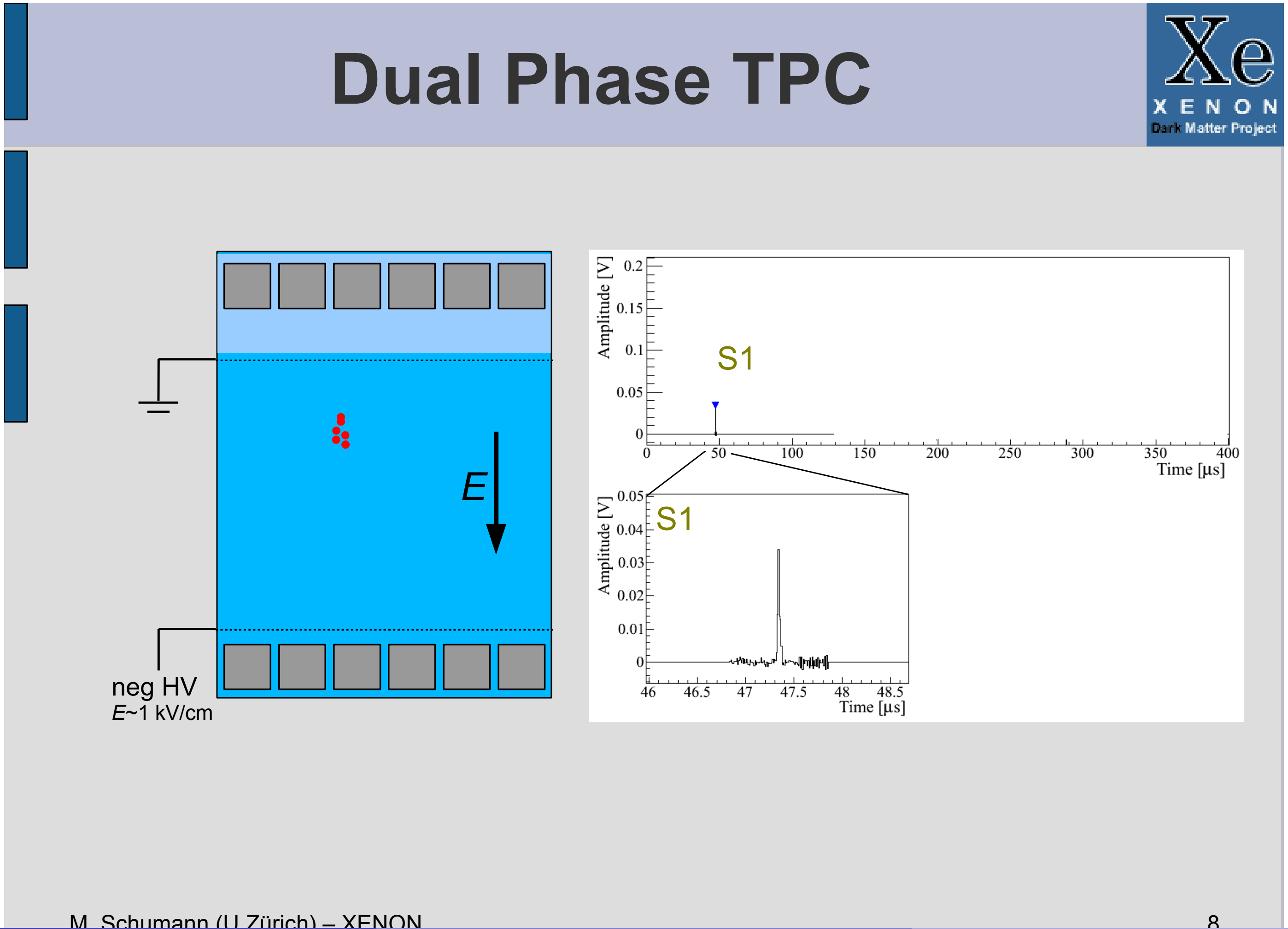
XENON

Dual-phase Xenon Time Projection Chamber (TPC).



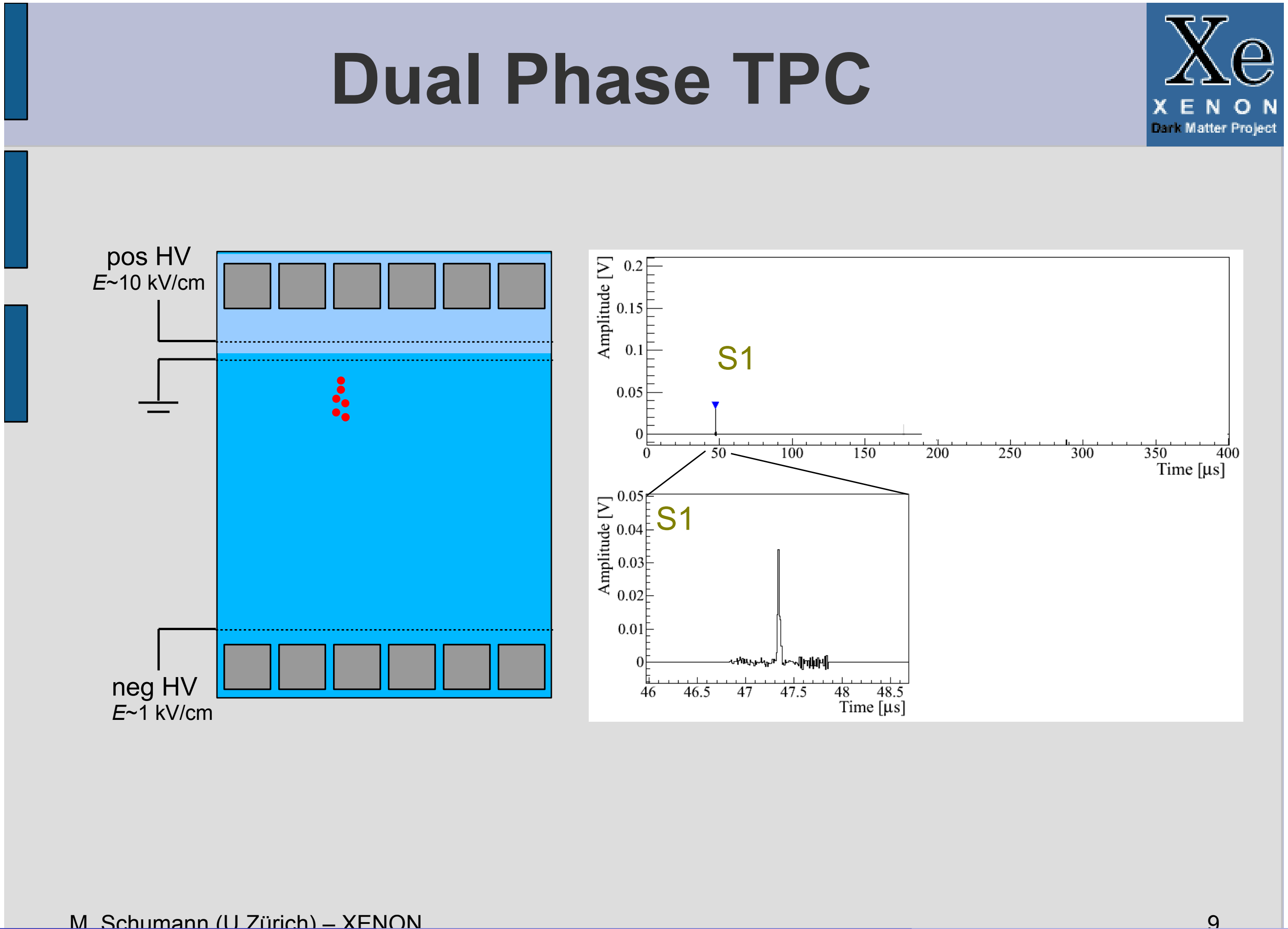
XENON

Dual-phase Xenon Time Projection Chamber (TPC).



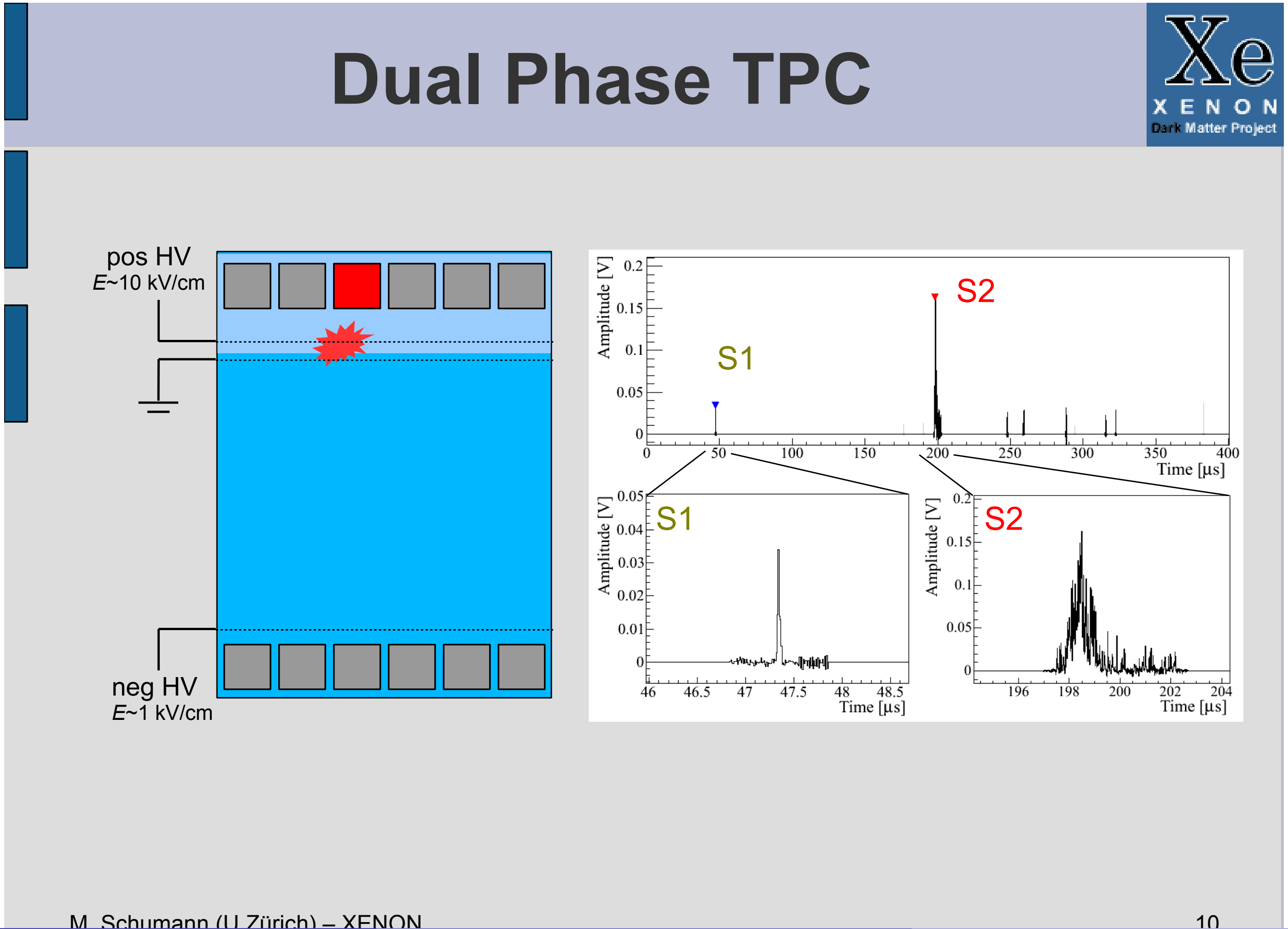
XENON

Dual-phase Xenon Time Projection Chamber (TPC).

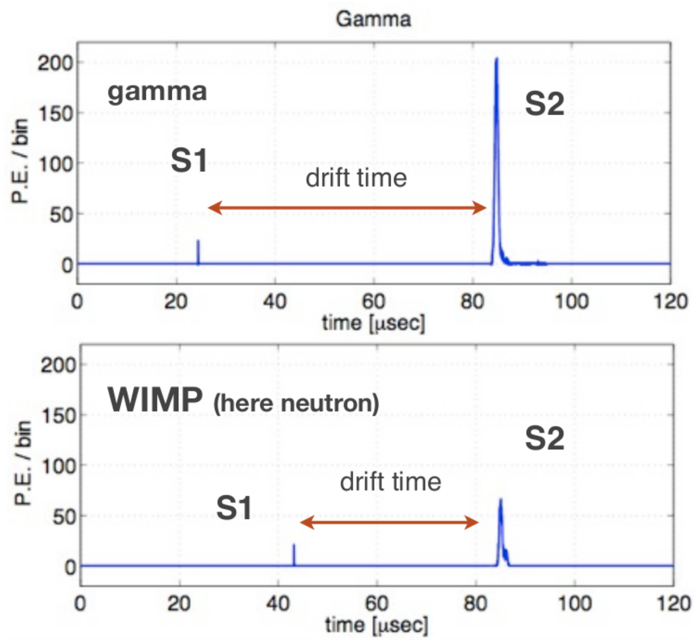


XENON

Dual-phase Xenon Time Projection Chamber (TPC).

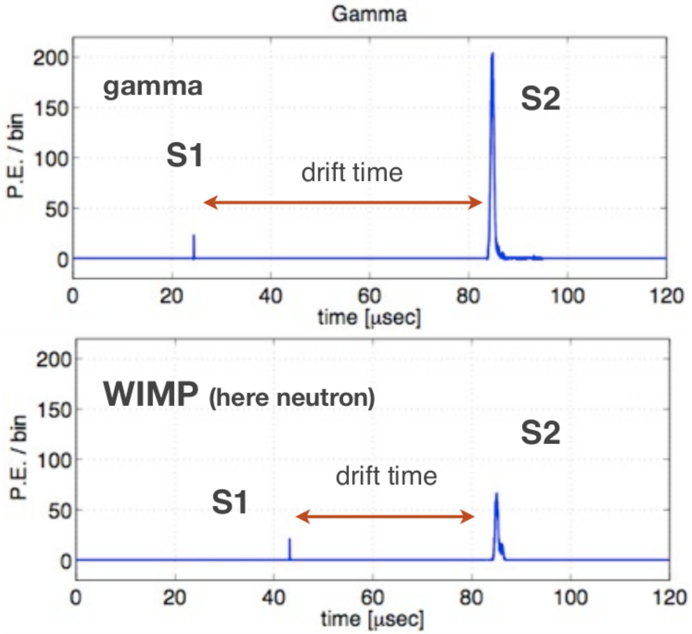


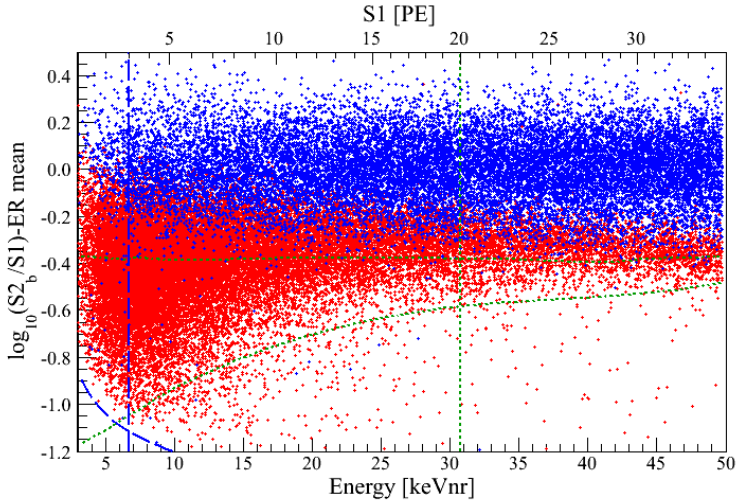
XENON



Charge/Light ratio to discriminate electronic recoils.
3D reconstruction of the position of the interactions (drift time + light pattern on the PMTs).

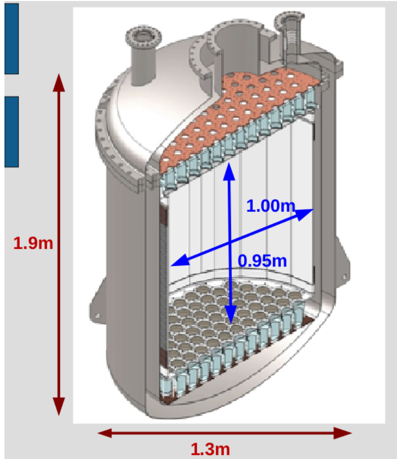
XENON

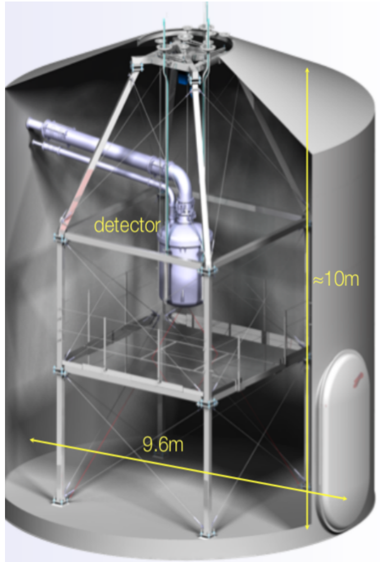




Charge/Light ratio to discriminate electronic recoils.
3D reconstruction of the position of the interactions (drift time + light pattern on the PMTs).

XENON



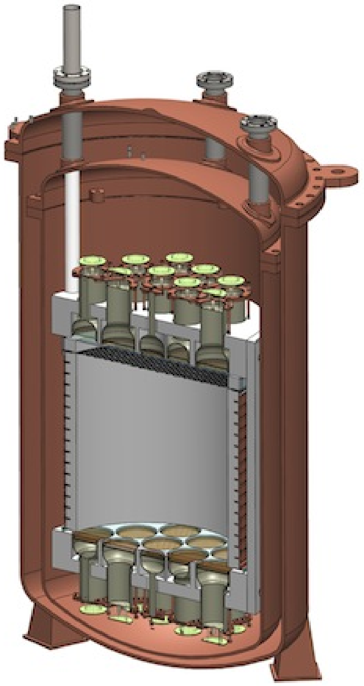


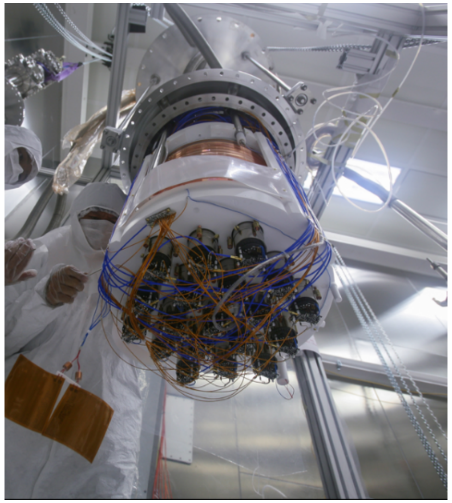
XENON100: 62 kg Xenon target mass (161 kg total) started data taking in 2007, still running. Led the field for many years with longest run (i.e. 225 days).
XENON1T: 1 ton Xenon fiducial volume (3.3 tons total) just stared the data taking. Complemented by a Cherenkov detector for μ.

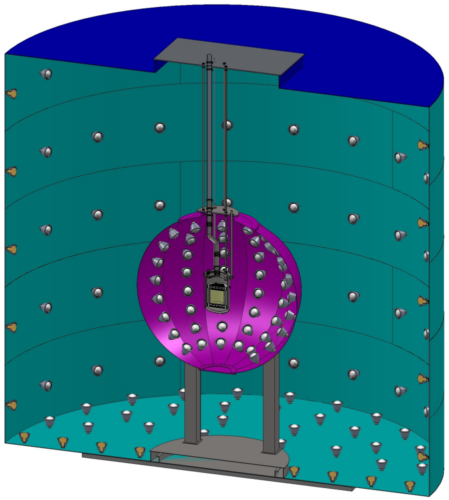
The design embeds already the upgrade at larger mass $\sim$7 tonnes, larger detector in a larger vessel, where all the infrastructures will be exploited while only the inner vessel of the cryostat and a new TPC will be re-built.

DarkSide

Dual-phase Argon TPC.



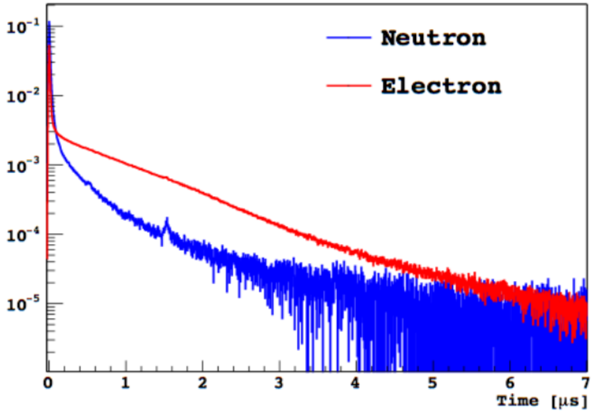


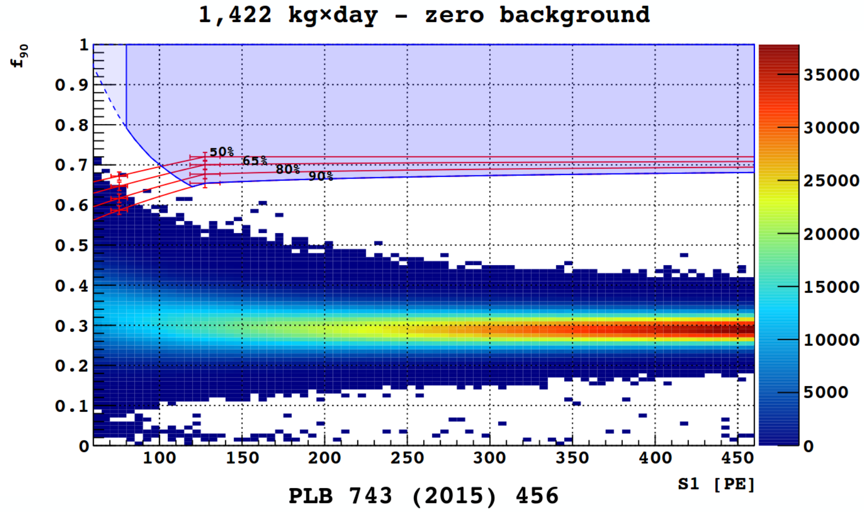


Use of Underground Argon (UAr) to get rid of the radioactive ^{39}Ar isotope.
Borated Liquid Scintillator Veto for neutrons, Water Cherenkov detector for μ.

DarkSide

Discrimination with charge/light ratio + Pulse Shape Discrimination.





f_{90}: fraction of S1 in the first 90 ns

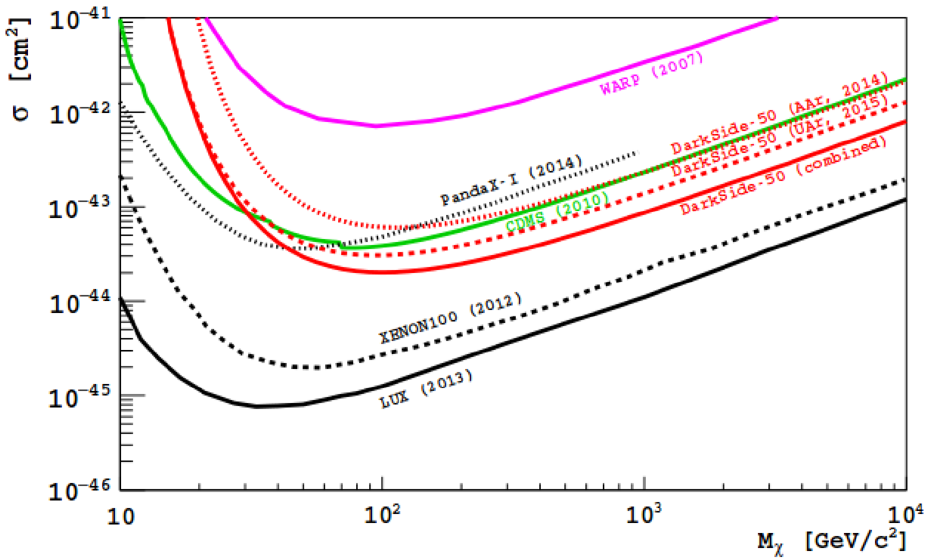
From S.Davini's talk @ TAUP 2015, Torino

DarkSide

Currently running is DarkSide-50, with 46 kg Ar active mass, total mass 153 kg.

- Started data taking in late 2013 using atmospheric Argon.
- Filled with UAr in April 2015, 70 days data taking. ^{39}Ar reduced by a factor 1400. No evidence of DM interactions.

Future: DS-20k, 20 tons fiducial volume mass (30 tons total). Use of SiPMs.



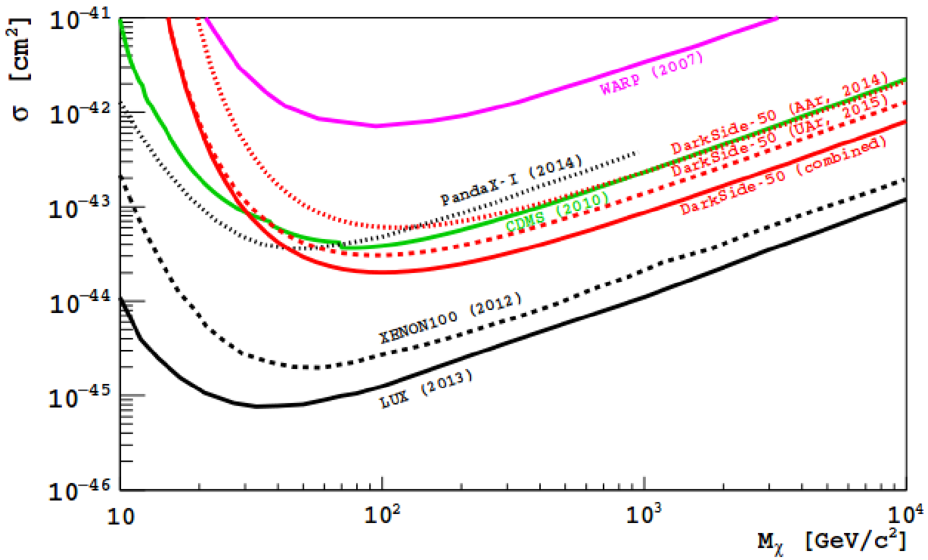
arXiv:1510.00702

DarkSide

Currently running is DarkSide-50, with 46 kg Ar active mass, total mass 153 kg.

- Started data taking in late 2013 using atmospheric Argon.
- Filled with UAr in April 2015, 70 days data taking. ^{39}Ar reduced by a factor 1400. No evidence of DM interactions.

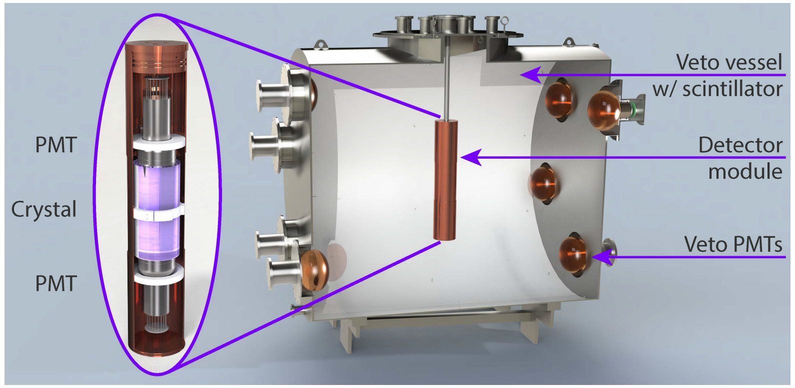
Future: DS-20k, 20 tons fiducial volume mass (30 tons total). Use of SiPMs.



arXiv:1510.00702

What about future

SABRE: It was motivated to definitively proof or disproof the controversial DAMA/LIBRA results.

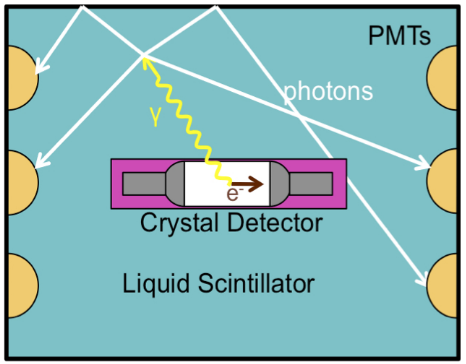


- Crystal NaI $\sim$ 5 kg
- Crystal PMTs: 3 inch flat Hamamatsu R11065-20
- Vessel: 1.3 m diameter, 1.5 m length
- 2 tonnes of LS 2.25 m^3
- LS veto PMTs: 8 inch semi-spherical PMTs R5912

Experimental installation for the proof of principle (PoP) setup is ongoing in the HallB

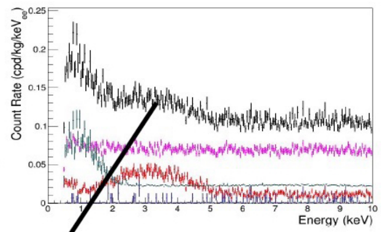
SABRE's strategy to lower BG

- Grow NaI(Tl) crystal with improved radio-purity: cleaner powder, higher-purity growth method, and low radioactivity enclosure, plus veto LS detector, mainly vetoing ^{40}K and $^{22}N_a$
- High QE PMTs directly coupled to the crystals and lower HV to reduce dynode afterglow.
- Twin detectors in northern and southern hemisphere to reduce seasonal effect (LNGS Italy, & SUPL, Australia)

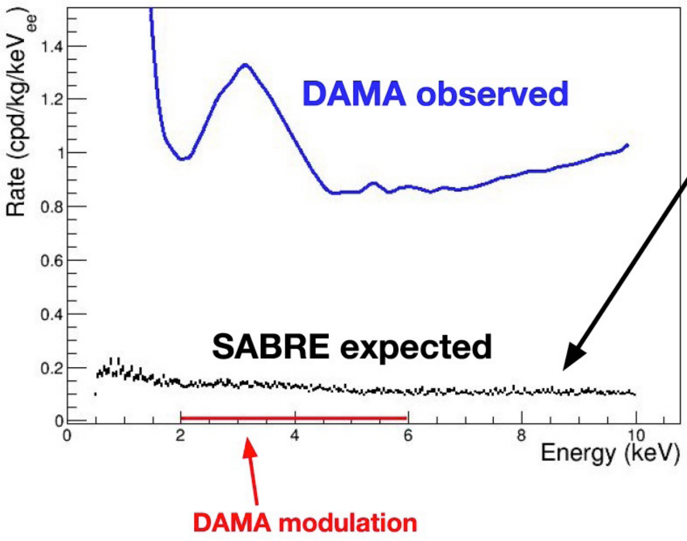


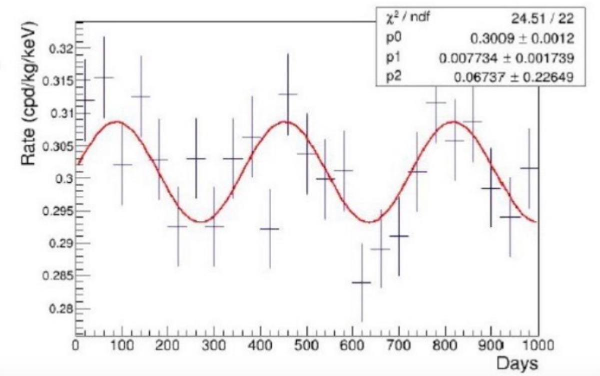
Crystal	SABRE measure	DAMA measure
mass (so far)	1.5 kg	
OD/length	88 mm / 50 m	
light yield	41 pe/keV	
pe yield	14	7 pe/keV
^{nat}K in crystal	9 ppb	13 ppb
Rb	<0.1 pb	0.35 ppb
Th	0.5 ppt	0.5-7.5 ppt
U	0.6 ppt	$\sim$ppt

SABRE's BG and sensitivity



- K
- Rb
- Total < 0.13 cpd/kg/keV (DAMA 1 cpd/kg/keV)



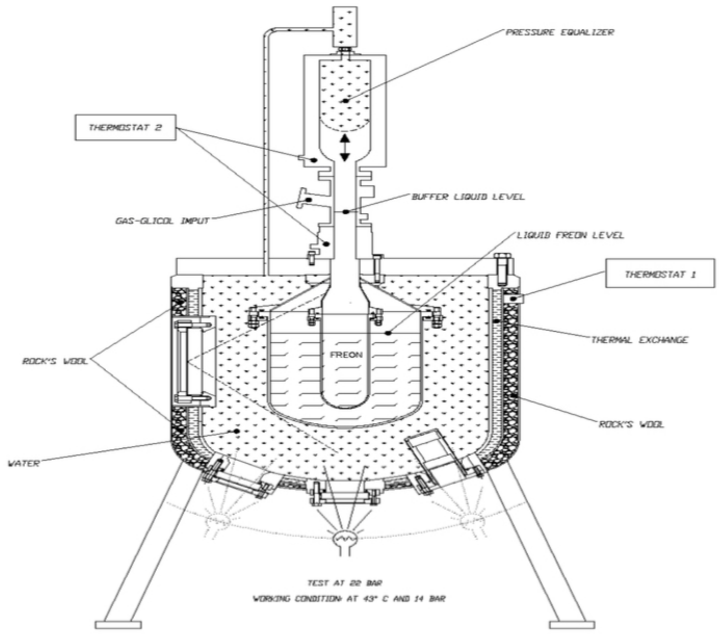


With a BG of 0.13 cpd/kg/keV a

6σ Dama/Libra signal can be tested with 50 kg x 3 yrs

MoscaB a promising R&D

A detector technology based on superheated liquid (C_3F_8). When an energy release, above a certain threshold (E_c and dE/dx), take place, a micro-bubble can grow to become visible.

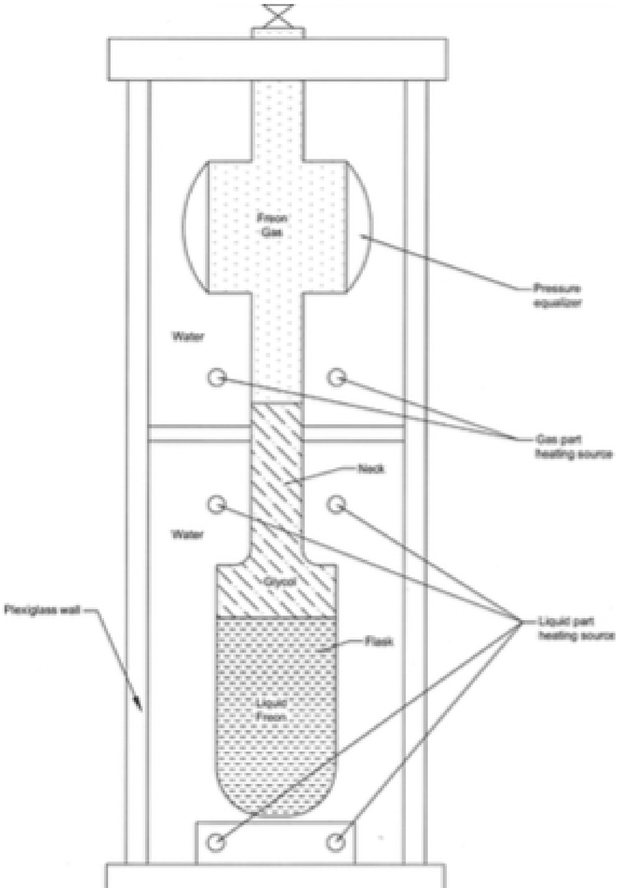


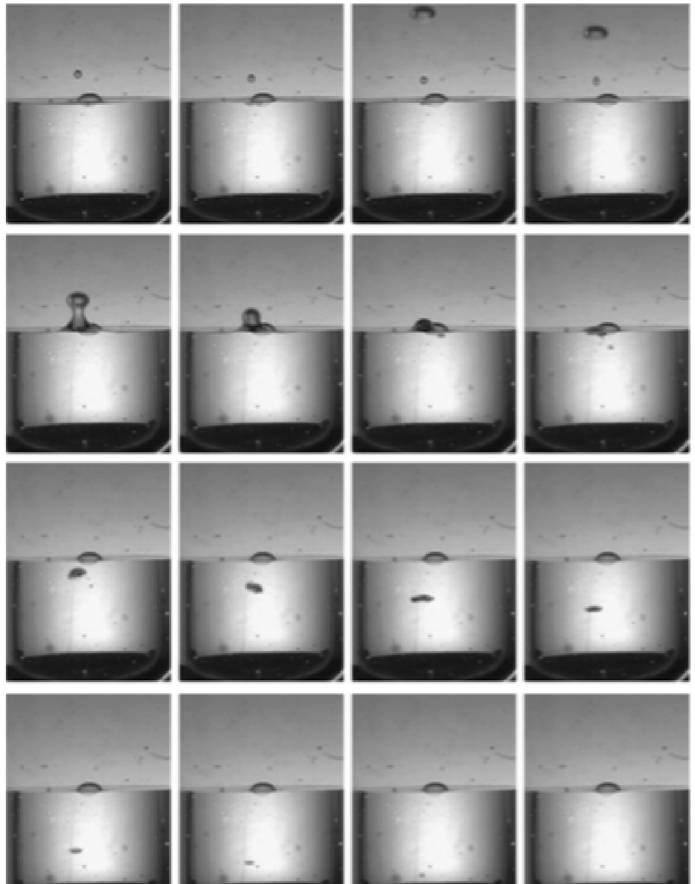
The read out is done by means of the high quality cameras, (50 frames/s). A trigger is generated when a pixel detects a signal above threshold. This happen when a micro-bubble is generated. Then 50 frames before and after he trigger are recorded.

In the next months a 40 kg target mass detector will be installed at the LNGS. This is one module out of 10 foreseen if the expected performance are achieved.

MoscaB working principle:

When a bubble is generated in the liquid phase (at given T_{liq}) it grows to become visible while migrating to the liquid-glycol interface. Once the droplet leaves the glycol-vapour interface at T_{vap}>T_{liq} it re-liquify and goes back to the liquid phase restoring the equilibrium

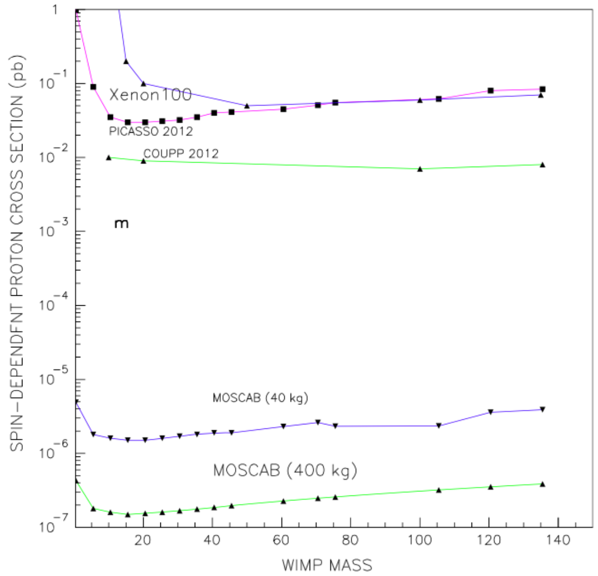




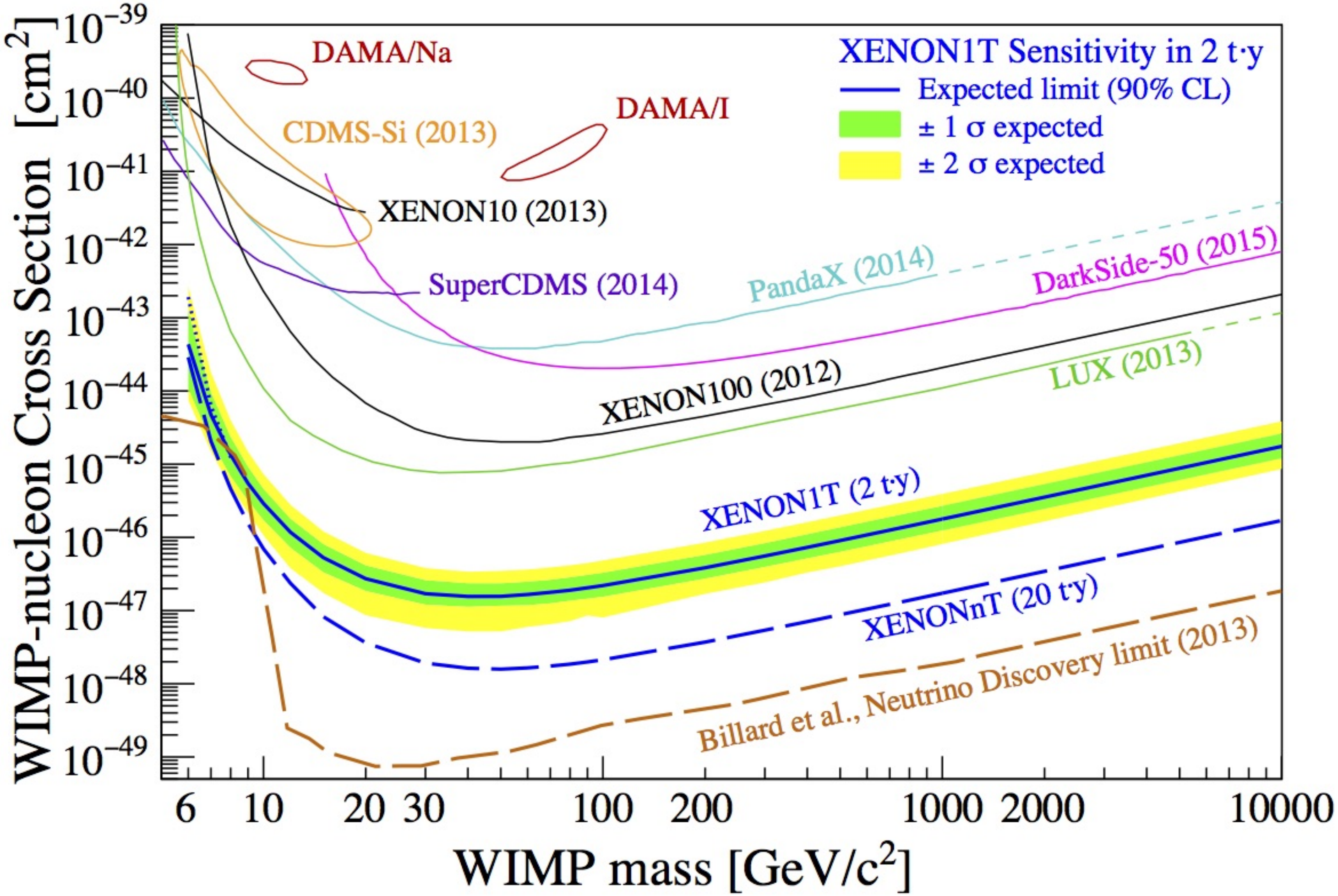
MoscaB BG and exclusion plot for SD interactions with 1 year exposure

The working parameters are tuned such that electrons (or gammas) do not start nucleation process at level of 10^{10}. So the electrons are not really a background.
A significant source of BG can be the spontaneous nucleation started on the surface of the vessel. This can be largely reduced with a surface treatment.

Another relevant source of BG are α particles from contaminants. However, acoustic measurements are under development where α and nuclear recoils can be distinguished by means of the sound signal fe



NIM A 744 (2014) 61-68


WIMP-nucleon Cross Section [cm^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
DAMA/Na
DAMA/I
CDMS-Si (2013)
XENON10 (2013)
SuperCDMS (2014)
PandaX (2014)
DarkSide-50 (2015)
XENON100 (2012)
LUX (2013)
XENON1T (2 t·y)
XENONnT (20 t·y)
Billard et al., Neutrino Discovery limit (2013)
XENON1T Sensitivity in 2 t·y
Expected limit (90% CL)
± 1 σ expected
± 2 σ expected
6
10
20
30
100
200
1000
2000
10000
WIMP mass [GeV/c^2]

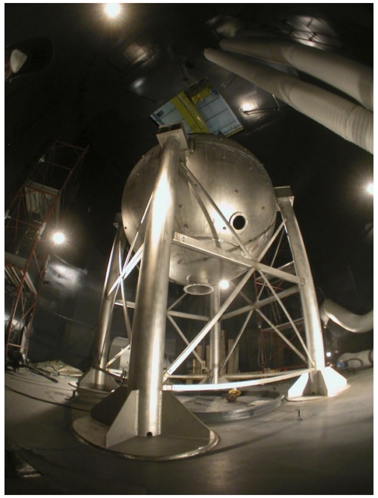
Conclusions

LNGS are leading the field of Dark Matter direct detection.

4 different experiments are ongoing, using different techniques and a variety of targets. More is already planned for the near future.

Important results already achieved and good prospects for the near future.

STAY TUNED FOR NEXT RESULTS!



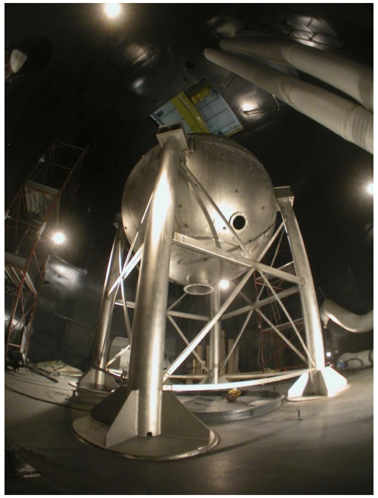
Conclusions

LNGS are leading the field of Dark Matter direct detection.

4 different experiments are ongoing, using different techniques and a variety of targets. More is already planned for the near future.

Important results already achieved and good prospects for the near future.

STAY TUNED FOR NEXT RESULTS!



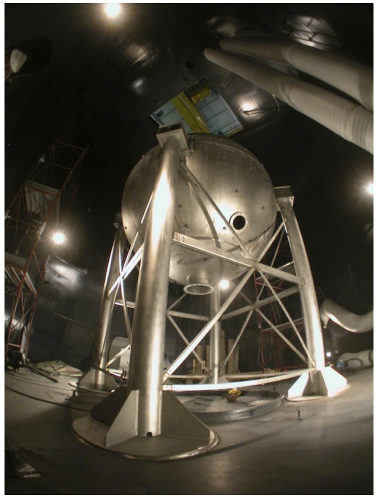
Conclusions

LNGS are leading the field of Dark Matter direct detection.

4 different experiments are ongoing, using different techniques and a variety of targets. More is already planned for the near future.

Important results already achieved and good prospects for the near future.

STAY TUNED FOR NEXT RESULTS!



Conclusions

LNGS are leading the field of Dark Matter direct detection.

4 different experiments are ongoing, using different techniques and a variety of targets. More is already planned for the near future.

Important results already achieved and good prospects for the near future.

STAY TUNED FOR NEXT RESULTS!