Обзор экспериментов по поиску WIMP.

Д.Ю. Акимов
ИТЭФ

- Мотивация поиска Темной Материи
- Методы поиска
- Фоны и основные принципы построения детекторов
- Эксперименты:
  - DAMA/LIBRA
  - Directional experiments
  - Пузырьковые камеры
  - Низкотемпературные болометры
  - Детекторы на жидких благородных газах
  - Hi-Tech разработки для детекторов ТМ

Физическая мотивация

Сегодня свидетельства в пользу существования Темной Материи намного сильнее, чем когда-либо!

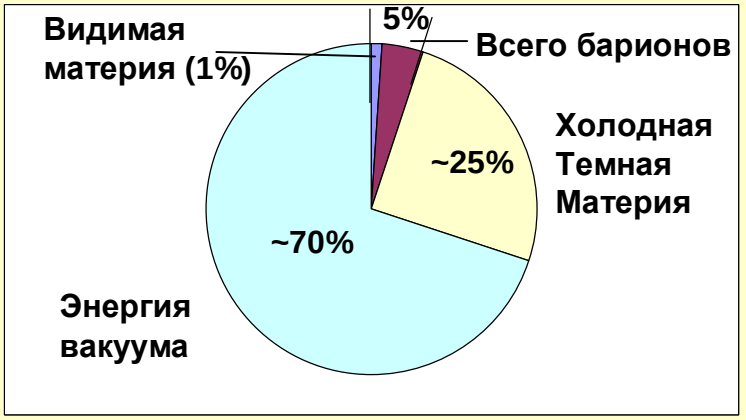
Астрофизическая мотивация

- Кривые вращения спиральных галактик
- Гравитационное линзирование скоплениями галактик

Космологическая мотивация

- Крупномасштабная структура Вселенной
- Анизотропия реликтового излучения (CMB)
- N-body симуляция
- Замечательное согласие выводов по CMB and SN Ia
- Теория нуклеосинтеза

Современная космологическая модель

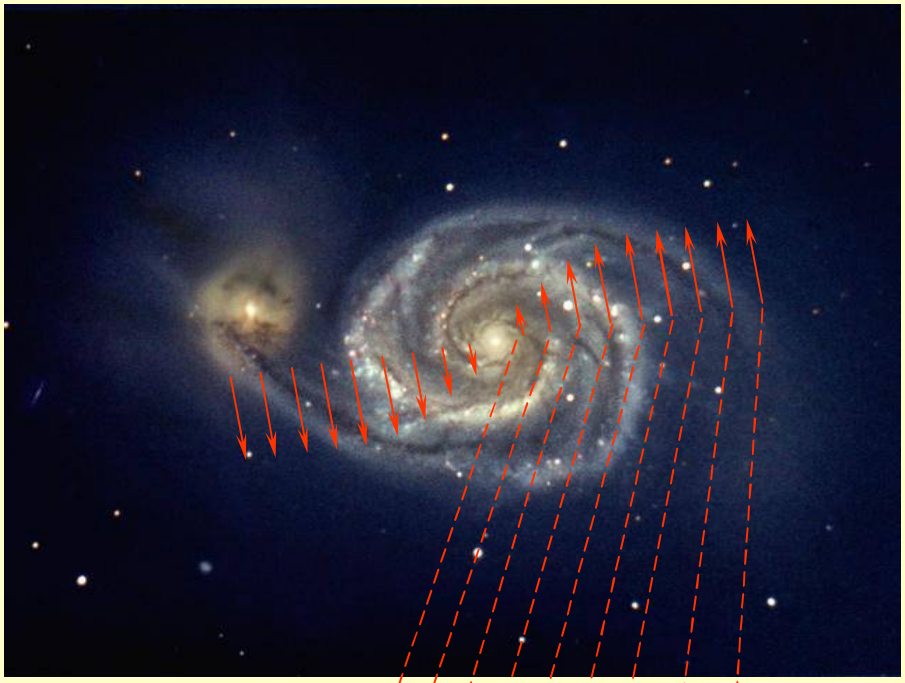


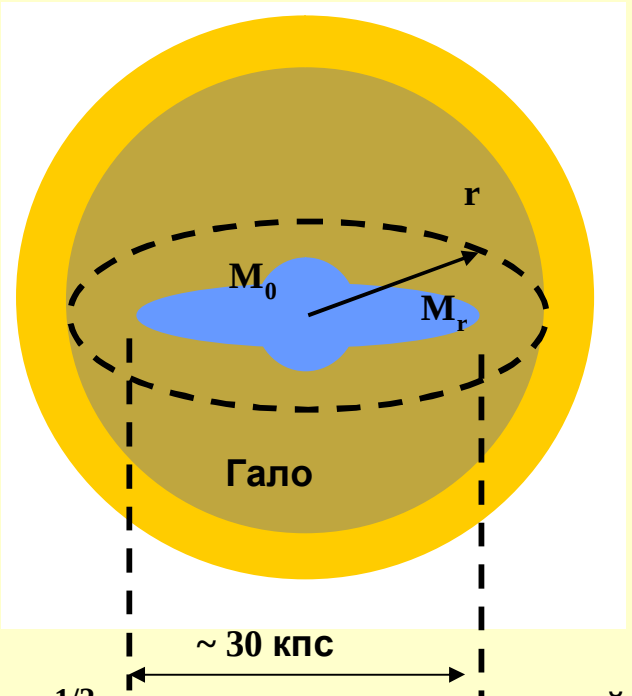
$\rho \approx \rho_{cr} \Rightarrow$

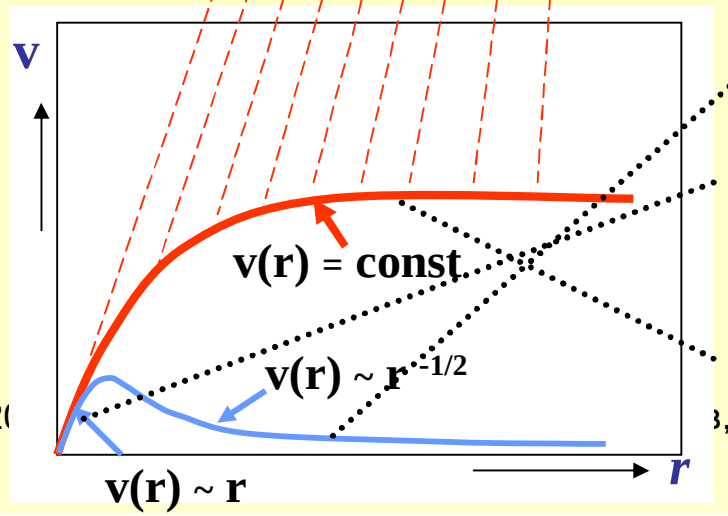
$W = \rho / \rho_{cr} \approx 1$

Астрофизические свидетельства

Что же наблюдается на галактических масштабах?







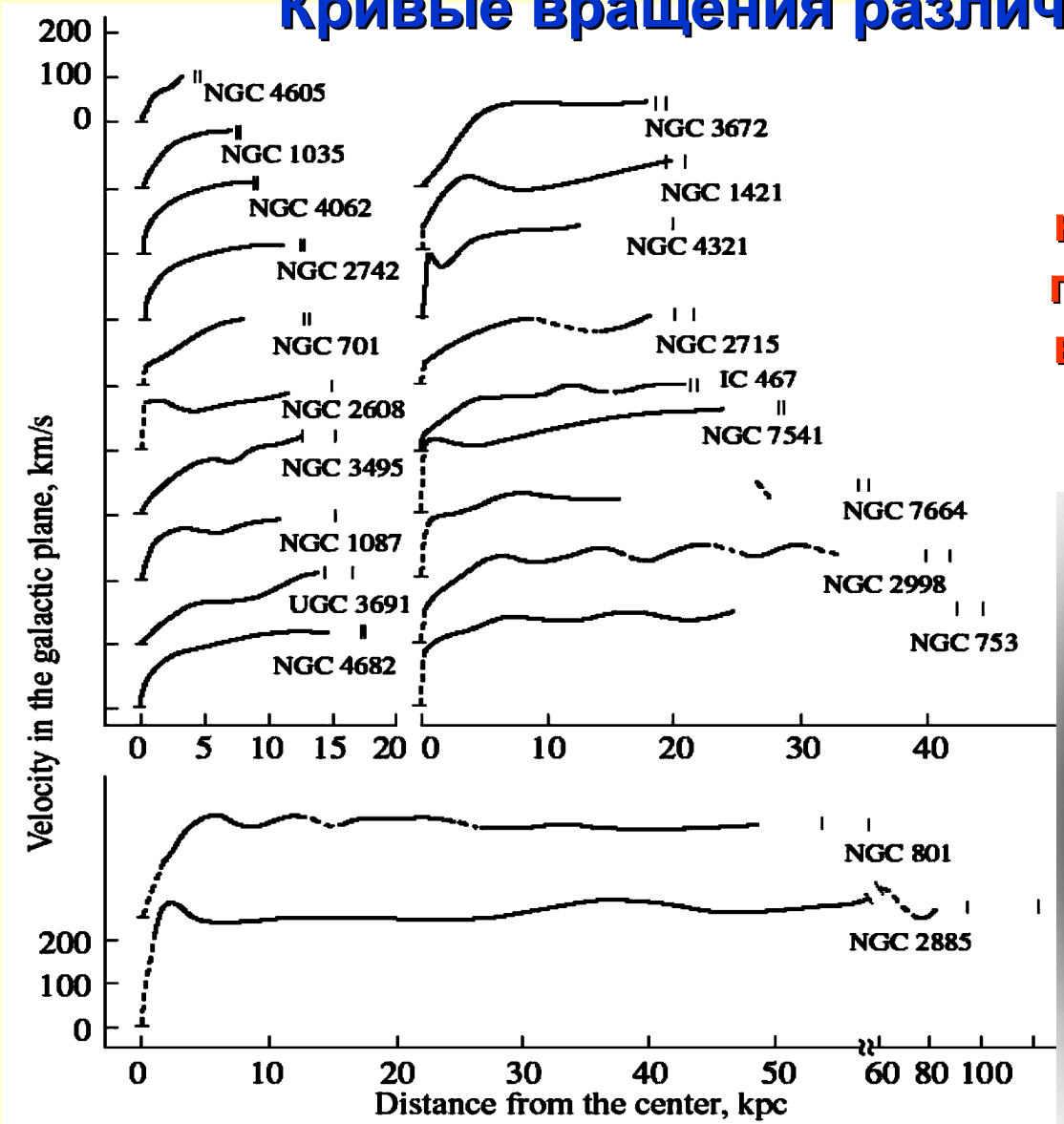
$v(r) \sim r^{-1/2}$ для случая центральной массы M_0

$v(r) \sim r$ для случая равномерного распределения массы ($M_r \sim r^3$)

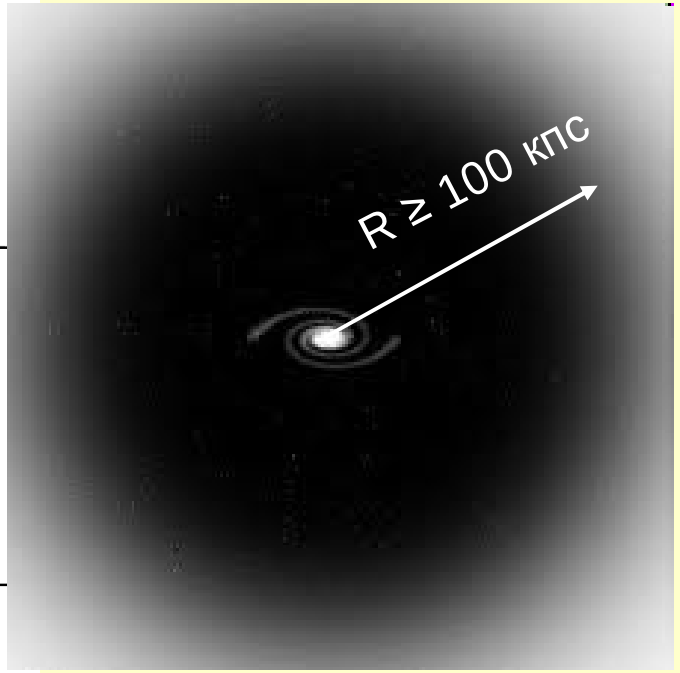
$v(r) = const$ для случая $M_r \sim r$

Астрофизические свидетельства

Кривые вращения различных галактик

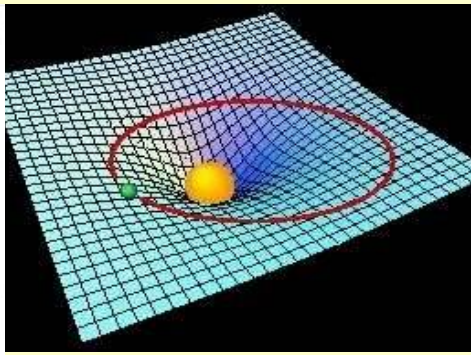


Для объяснения такого поведения кривых необходимо количество гравитирующей материи в ~10 раз превышающее количество видимой!

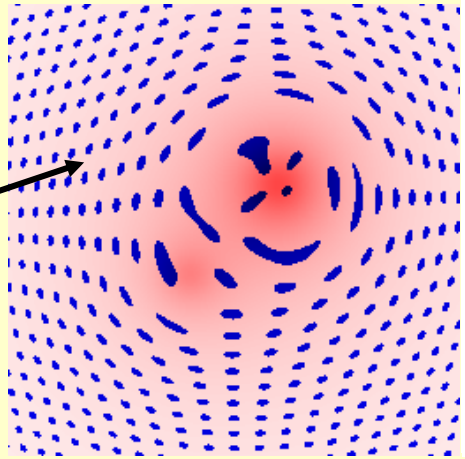


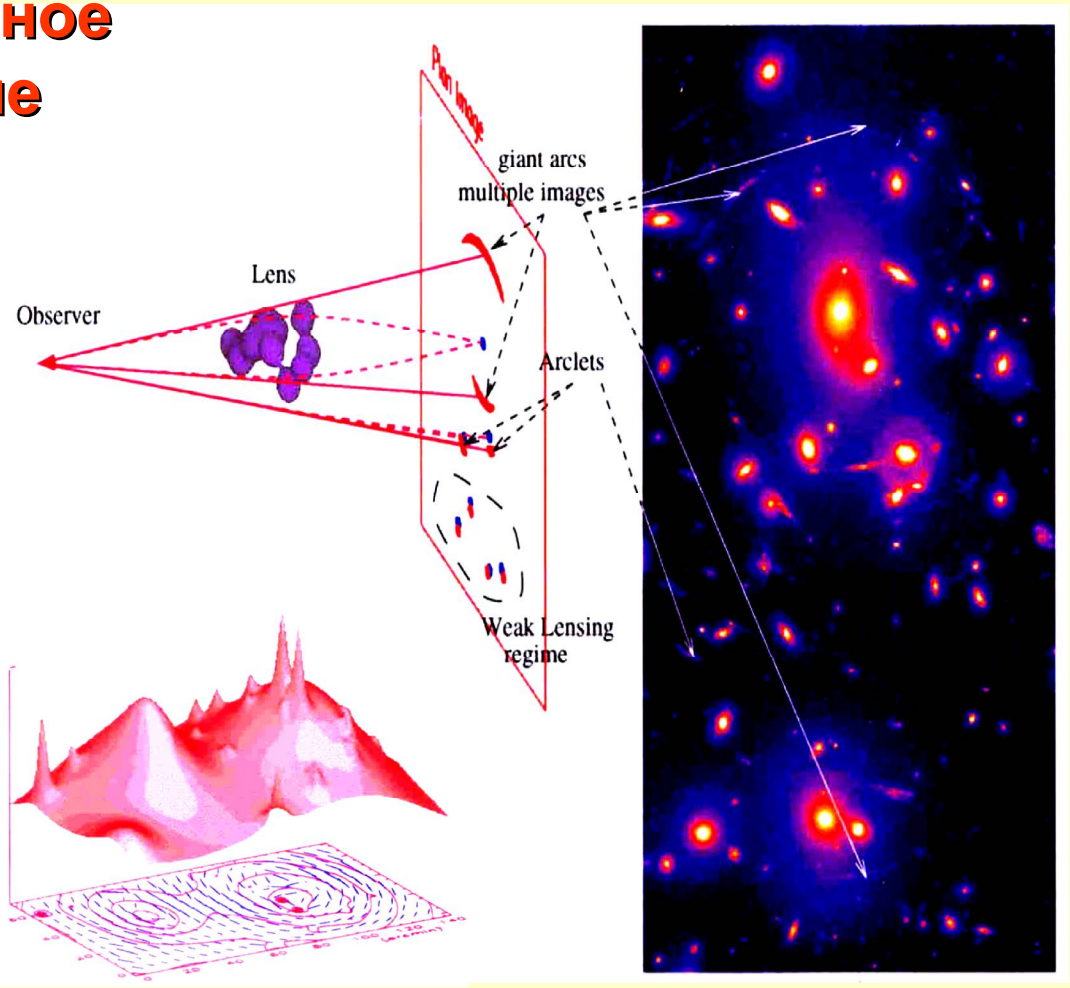
Астрофизические свидетельства

Гравитационное линзирование



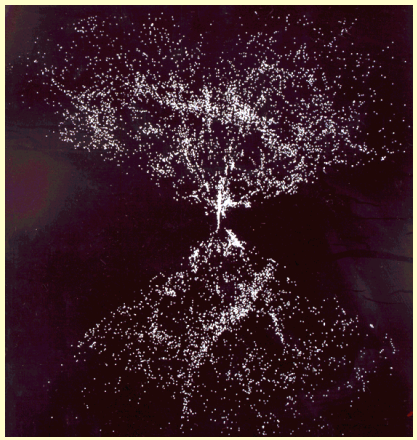
Так выглядел бы регулярный паттерн, находящийся за "размазанным" массивным объектом



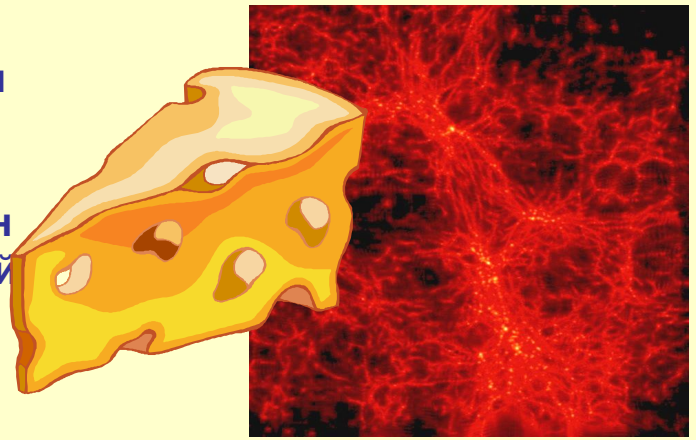


Также требуется в ~10 раз большая масса

Космологическая мотивация



Крупномасштабная структура Вселенной, реконструированная из измерений красного смещения объектов



Результат N-body симуляции, проведенный на суперкомпьютерах

Главный результат симуляции – Темная Материя должна быть холодной (нерелятивистской)

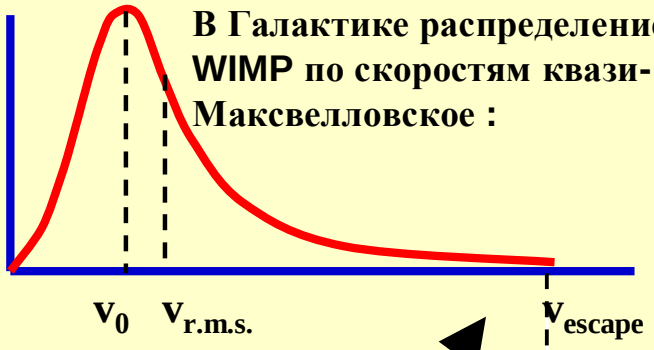
Теория Суперсимметрии SUSY предоставляет нам новый класс частиц.

Нейтралино – наиболее вероятный кандидат в WIMP - (Weakly Interacting Massive Particles)

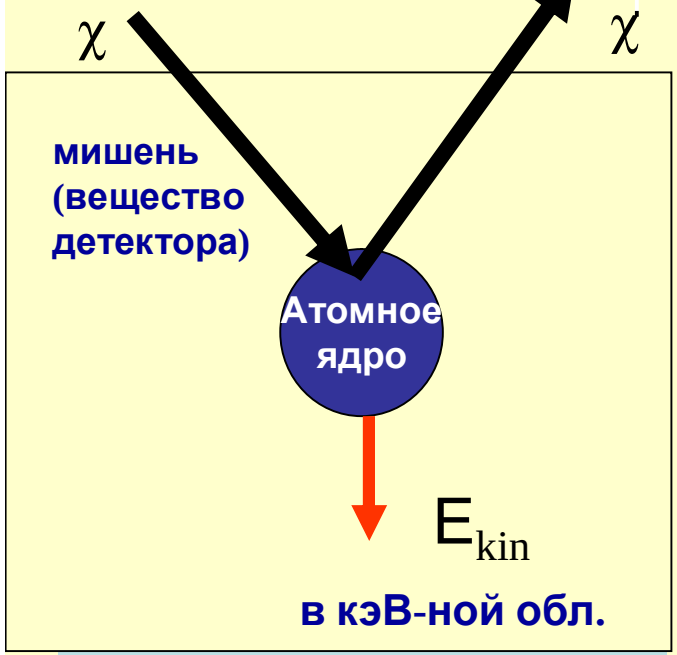
Диапазон масс от неск. дес. до неск. сотен ГэВ

Местная галактическая плотность ~ 0.3 ГэВ/см^3 ~неск. частиц в литре!

Регистрация WIMP: прямое детектирование



$$\frac{dn_w}{dv} = 4p\left(\frac{1}{pv_0^2}\right)^{3/2} v^2 \exp\left(-\frac{v^2}{v_0^2}\right)$$



$$\frac{dN}{dE} = \frac{r}{M_c} sN_N \frac{M_N c^2}{4m_{red}^2 v_0} \frac{g(h,E)}{h} F_N^2(E))$$

$$g(h,E) = \begin{cases} \mathrm{erf}(x+h) - \mathrm{erf}(x-h) - \frac{4}{\sqrt{p}} h e^{-z^2} & x \le z-h \\ \mathrm{erf}(z) - \mathrm{erf}(x-h) - \frac{2}{\sqrt{p}}(z+h-x)he^{-z^2} & z-h \le x \le z+h \\ 0, & x \ge z+h, \end{cases}$$

M_χ, M_N и m_{red} – masses of WIMP and target nucleus, and their reduced mass, respectively;

$$x_i = \sqrt{\frac{M_i E_i}{2m_{red}^2 v_0^2}} \qquad h = \frac{v_{Earth}}{v_0} \qquad z = \frac{v_{escape}}{v_0}$$

v_{Earth} = 232 km/s – Earth velocity,

$v_0 = \sqrt{2/3}\, v_{r.m.s.}$ – Quasi-Maxwell distribution parameter,

N_N – number of target nuclei,

ρ = 0.3 GeV/cm³ – WIMP density in Galactic halo,

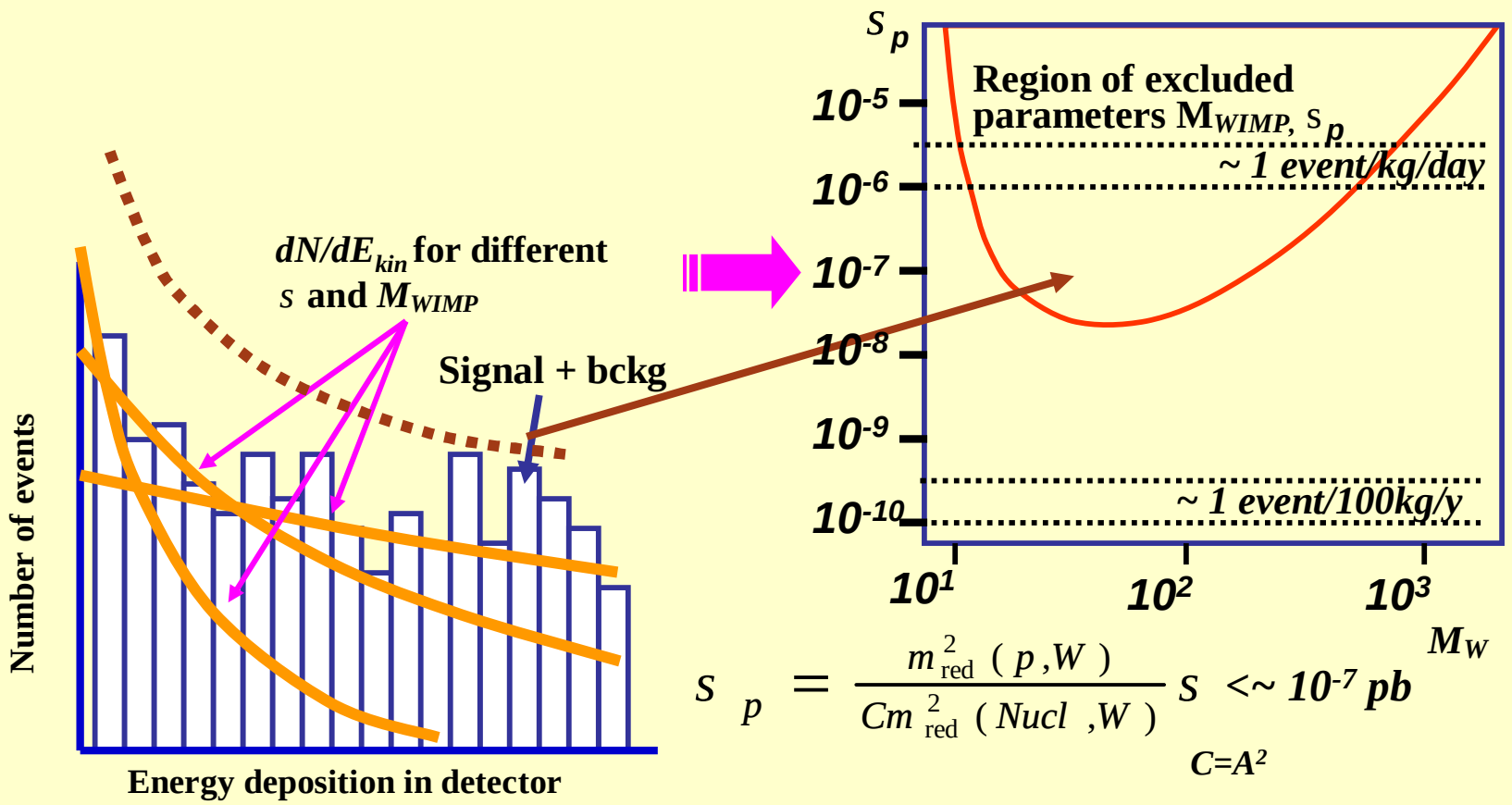
s – WIMP interaction cross-section,

$F_N^2(E)$ – nuclear form factor

$s \sim A^2$	**- spin-independent (SI) interaction**
$s \sim J(J+1)$	**- spin-dependent (SD) interaction**

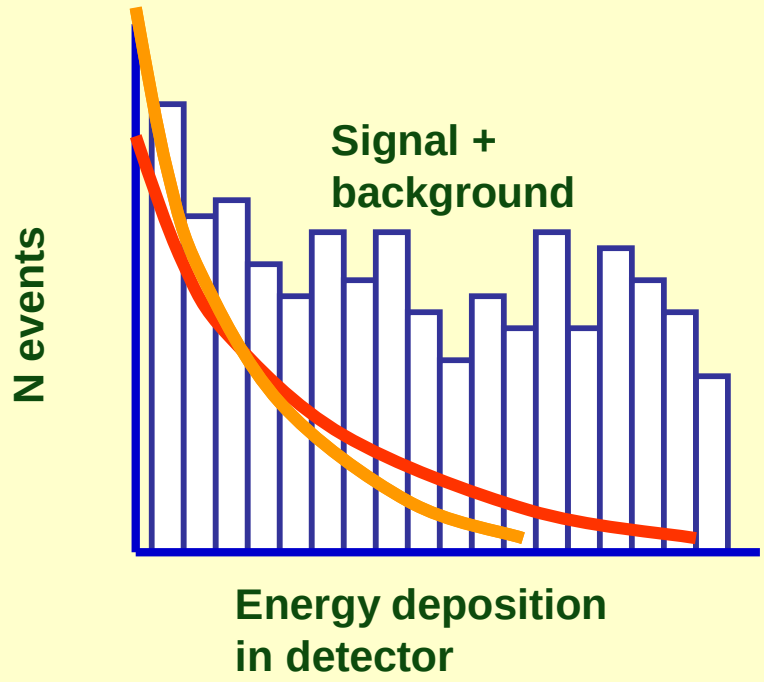
Д.К

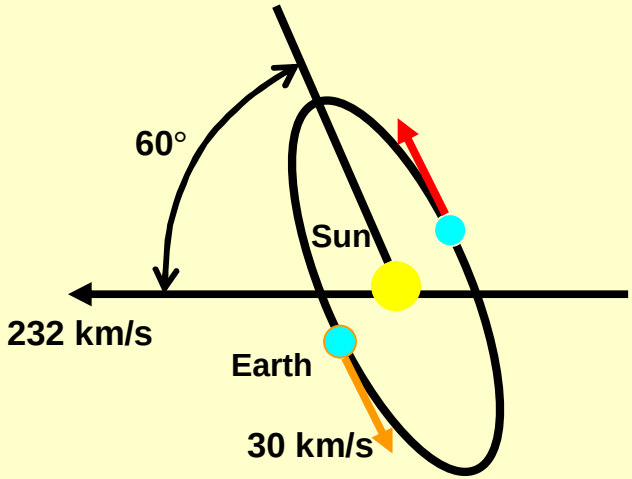
Регистрация WIMP: прямое детектирование



Exponential behavior is very similar to that of bckg of various origins.

Регистрация WIMP: годичная модуляция





Ожидаемая вариация темпа счета WIMP ~ 5%

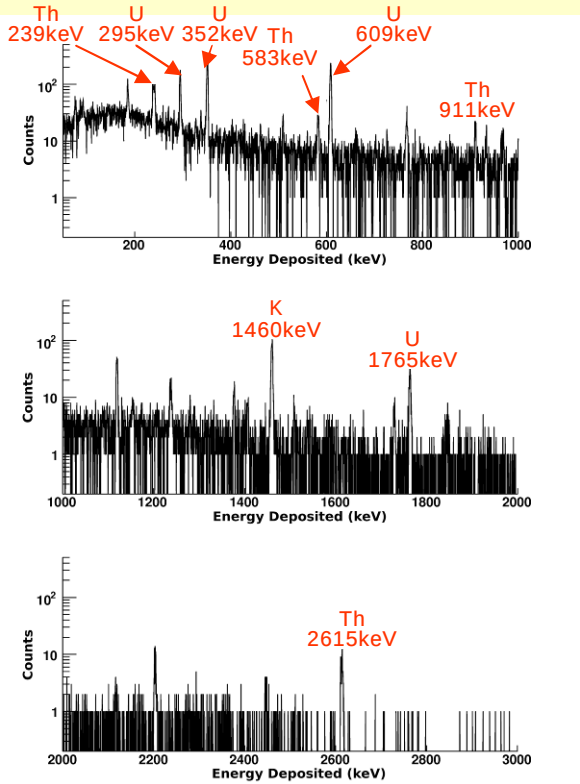
(с максимумом 2 го июня)

Регистрация WIMP: фоновые условия

The use of low-radioactive materials ONLY !

Every component must be screened with Ge detector or MS or NAA!

The main contaminants are the isotopes of U/Th chains and ^{40}K



Construction materials:

Teflon U <0.7 10^{-9}, Th <2.3 10^{-9}, K<2.2 10^{-6}

Electrolytic copper - U<1.2 10^{-11}, Th<1.1 10^{-11}, K<5.6 10^{-9}

Detection media used for DM search:

Ge – U <10^{-14}, Th < 1.5 10^{-13}

LXe U/Th <~10^{-13} (XMASS)

technogenic ^{85}Kr (beta)

Can be removed : K. Abe et al., arXiv:0809.4413v3 [physics.ins-det] by distillation (XMASS)
A.I. Bolozdynya et al., NIM A, 579 (2007), p. 50 by chromatographic separation (Xenon, LUX)

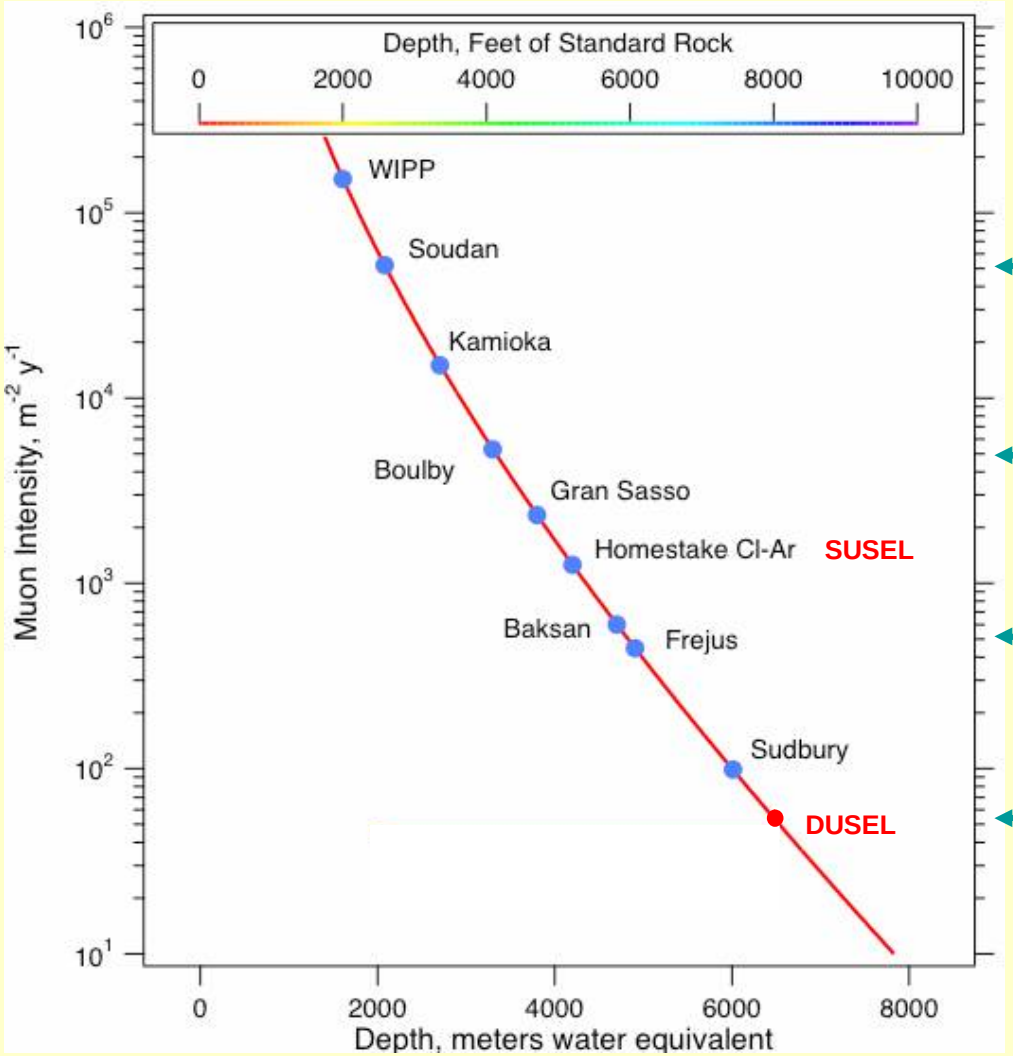
LAr – cosmogenic ^{39}Ar (beta)

Depletion, Ar from underground reservoirs.

Rn – should be removed from the vicinity of setup: overpressuring by dry pure nitrogen.

Регистрация WIMP: фоновые условия

The experiments are carried out in the underground labs



reduction of muon flux by:

10^5

10^6

10^7

10^8

Muon flux at sea level:

~ 1 cm^{-2} min^{-1}

=

~ $5 \cdot 10^9$ m^{-2} y^{-1}

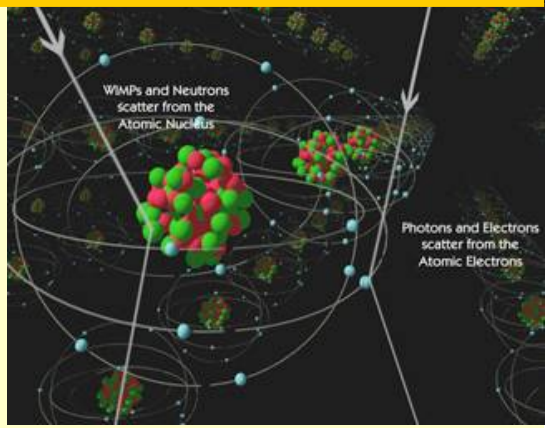
Регистрация WIMP: как зарегистрировать?

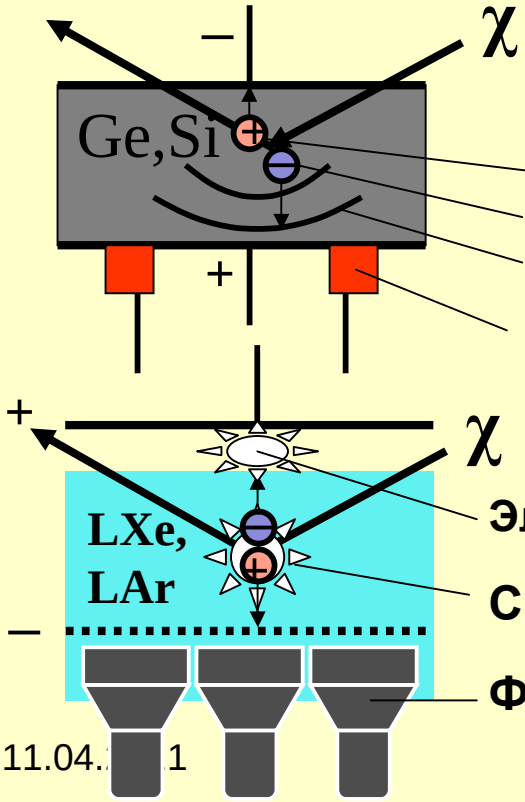
Специализированные детекторы WIMPов

ЗАДАЧА: выключить фоновые взаимодействия – сильное и электромагнитное!

Основные свойства:

- **одновременное измерение выделенной энергии по 2 и более независимым каналам. Ядро отдачи и гамма-кв. разделяются по соотношению сигналов. Либо детектор должен быть не чувствителен к электромагнитному фону.**
- **низкий порог регистрации (на уровне неск. кэВ)**





Низкотемпературные болометры

Частицы производят ионизацию и тепло; нагревая кристалл на ~10^{-6} K (теплоемкость при низких т-рах падает как T^3)

Работают при т-рах нес. дес. мК

Двухфазные детекторы на благородных газах

Частицы производят сцинтилляцию и ионизацию. Работают при T ~ 100 K

Регистрация WIMP: эксперименты

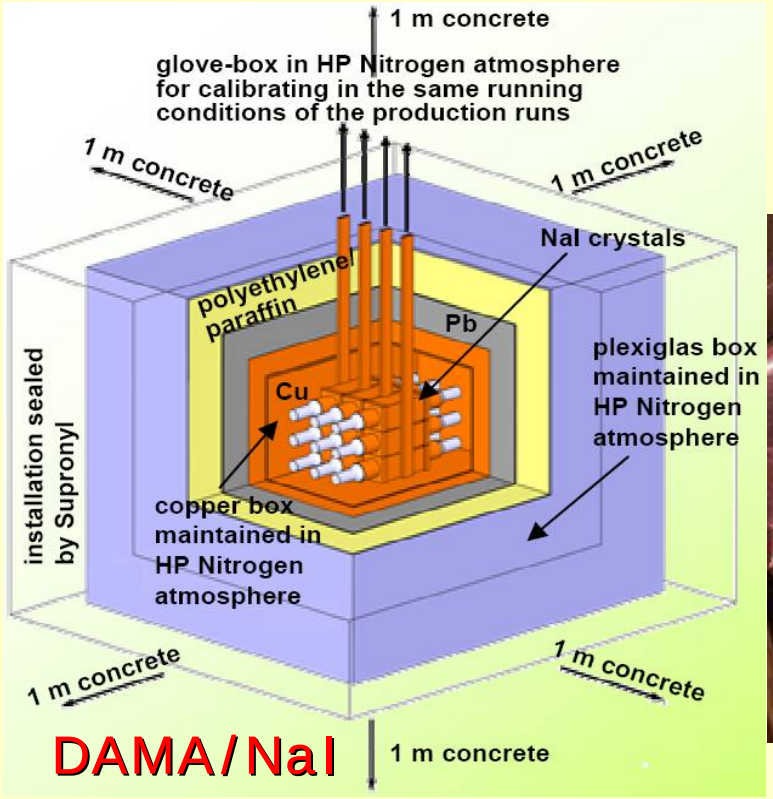
Experiment	Target
ANAIS	NaI
DAMA/NaI	NaI
DAMA/LIBRA	NaI
DAMA/1 ton	NaI
NAIAD	NaI
HDMS	Ge
KIMS	CsI
Caf2-Kamioka	CaF2
CDMS	Ge
CRESST	CaWO4
EDELWEISS	Ge
EURECA	Ge
ROSEBUD	Ge, sapphire
COUPP	FSH
PICASSO	FSH
SIMPLE	FSH
NEWAGE	CF4
DM-TPC	CF4
Drift	CS2
MIMAC	3He gas

Experiment	Target
DAMA/LXe	LXe
WARP	LAr
XENON 10	LXe
XENON 100	LXe
Zeplin I	LXe
Zeplin II	LXe
Zeplin III	LXe
ArDM	LAr
LUX	LXe
LZS/LZD	LXe
MAX	LXe/LAr
CLEAN	LNe
DEAP	LAr
XMASS	LXe
MIMAC	3He gas

Experiments: DAMA/LIBRA

Experiments: DAMA/LIBRA

9 crystals NaI(Tl) 9,7 kg each, placed in a copper box, then lead, polyethylene, paraffin and enclosed in a plexiglas box filled with HP N2 to protect from Rn



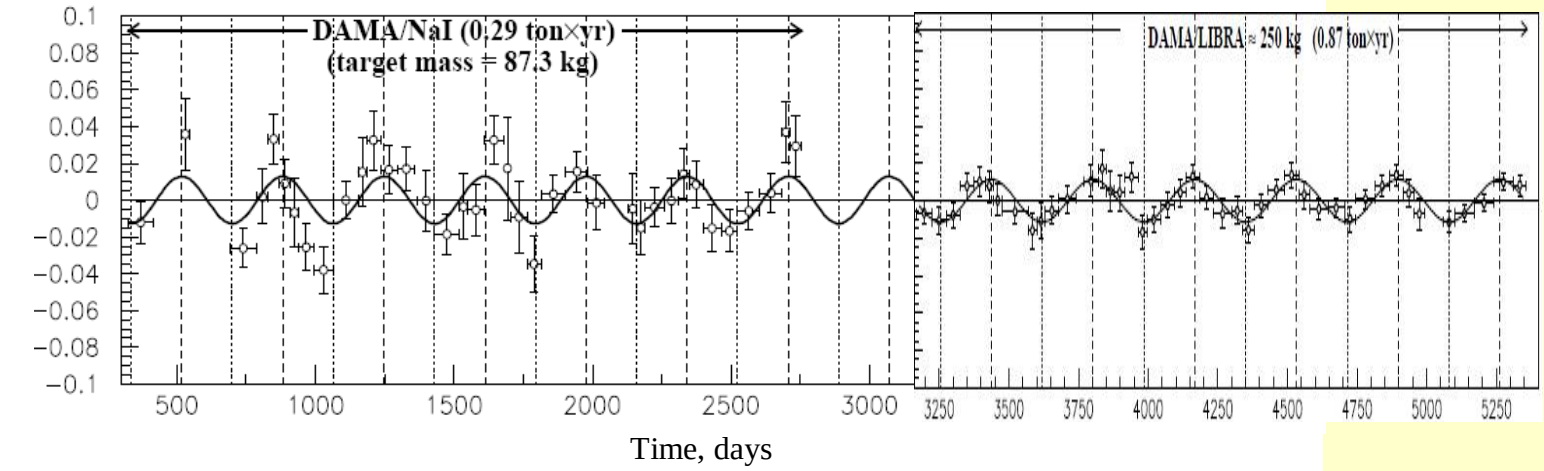
LIBRA- 25 of the same type in the same shield; 250 kg.
Data taking with LIBRA 2003 - 2008

Experiments: DAMA/LIBRA

Deviation of the count rate from the mean value (2 – 6 keV only) during the whole exposure time on both setups DAMA and LIBRA

arXiv:1002.1028v1 [astro-ph.GA]

Total exposure ~1.17 t·y

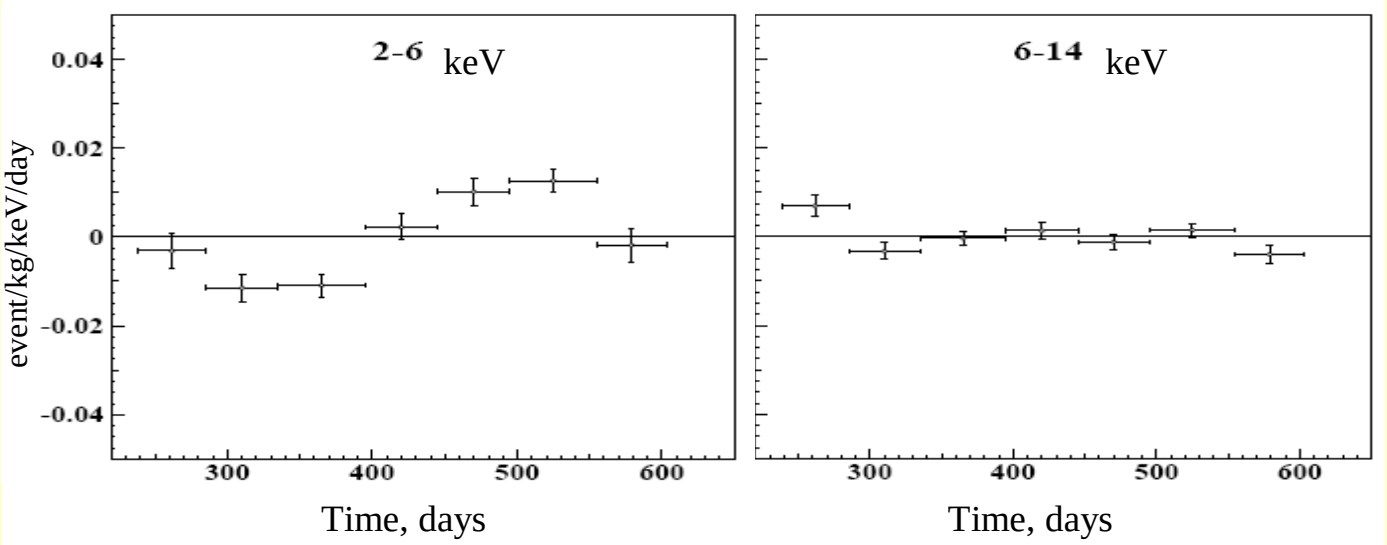


$A \cdot \cos \omega(t - t_0)$ with a period $T = 2\pi/\omega = 0.999 \pm 0.002$ y,
and a phase $t_0 = 146 \pm 7$ day, which is very close to the expected: 152,5 days (2 June)

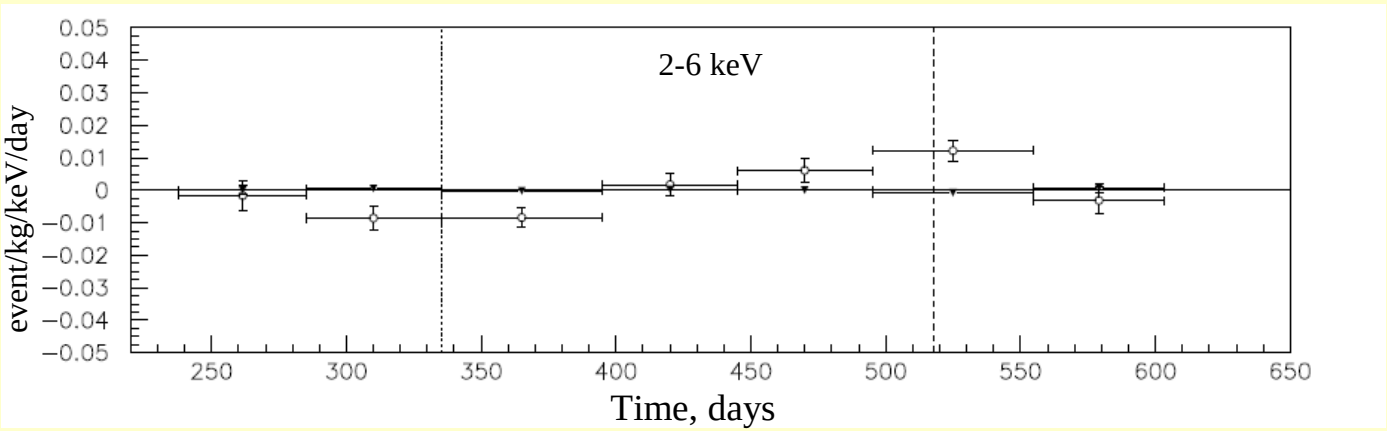
$A = (0.0114 \pm 0.0013)$ event/kg/keV/day, C.L. = 8.8σ

Experiments: DAMA/LIBRA

Data reduced to one period:

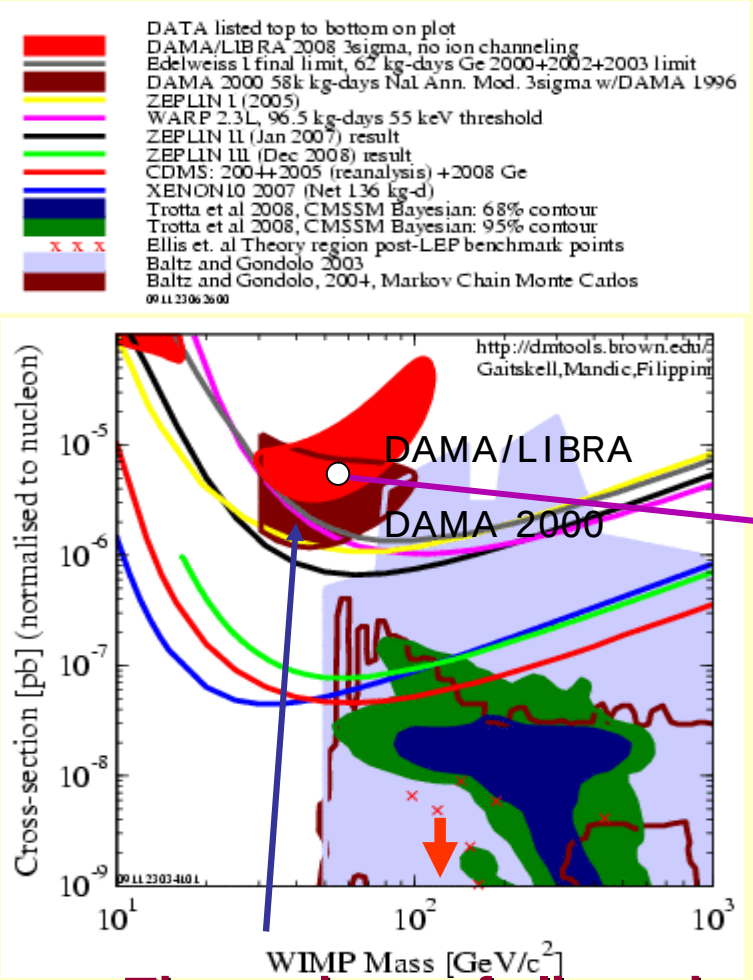


The effect takes place only in 2-6-keV interval



The effect takes place only for single "hits"!

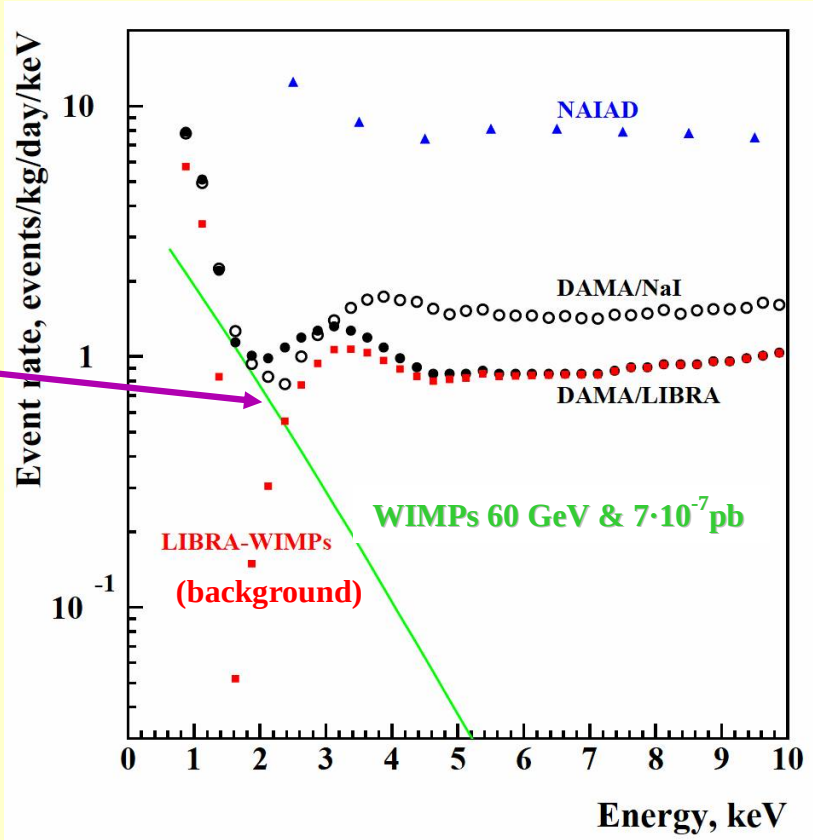
Experiments: DAMA/LIBRA



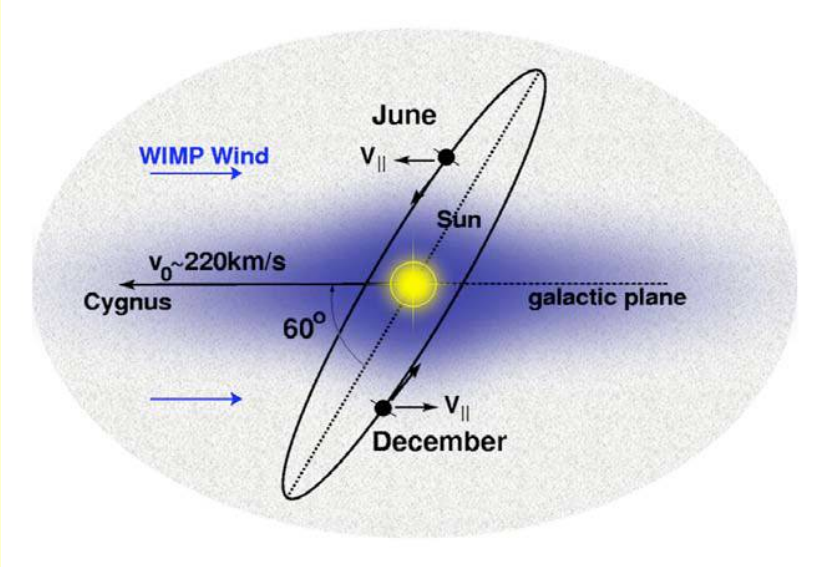
The regions of allowed σ_p, M_w

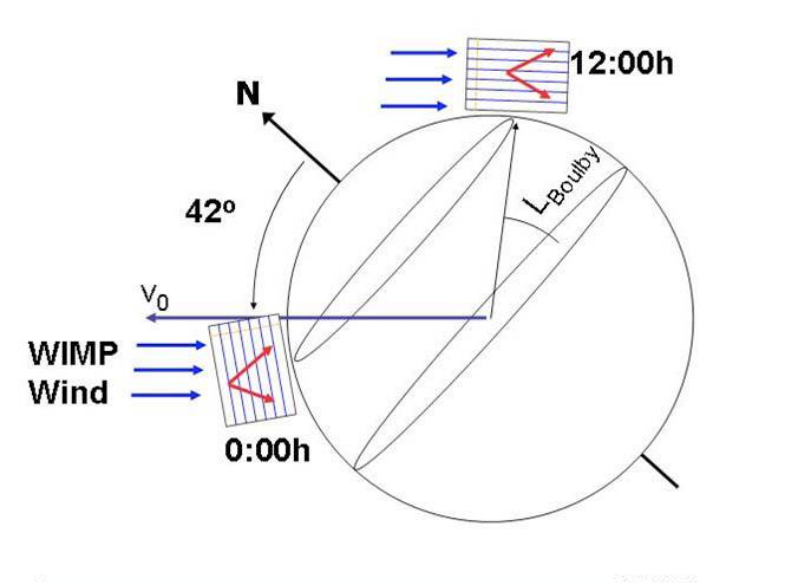
But there is a significant discrepancy!

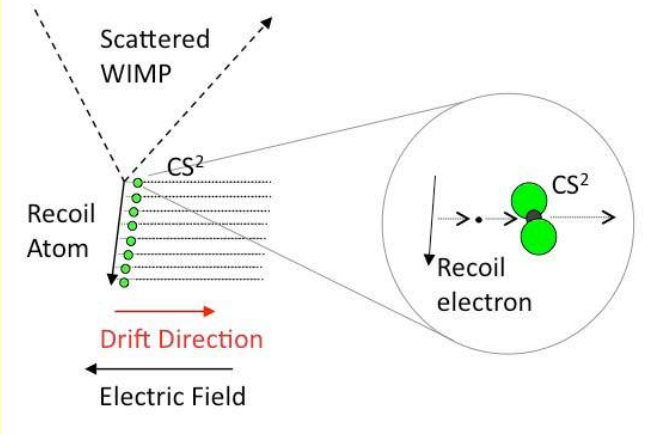
arXiv:0912.2983v1 [hep-ex]

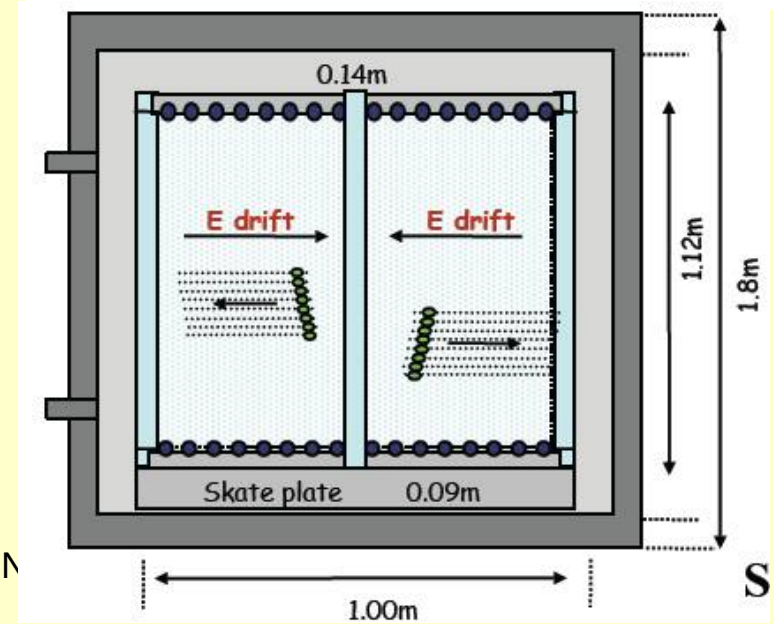


Directional Experiments





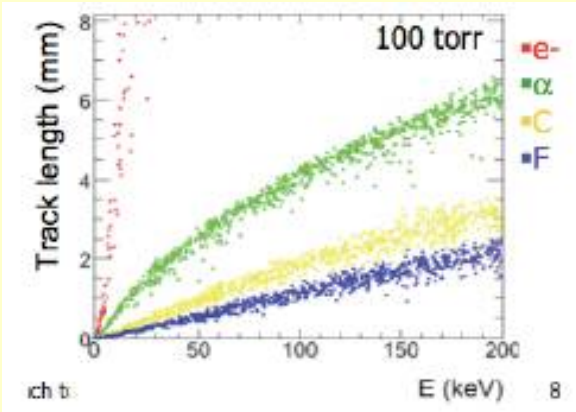


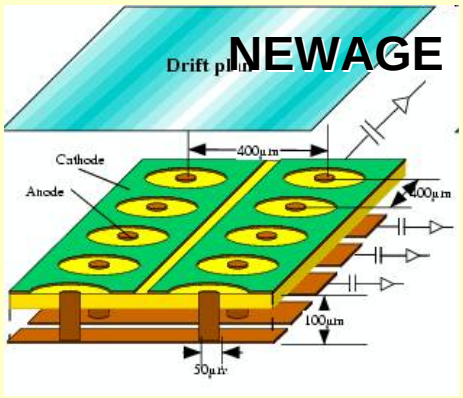


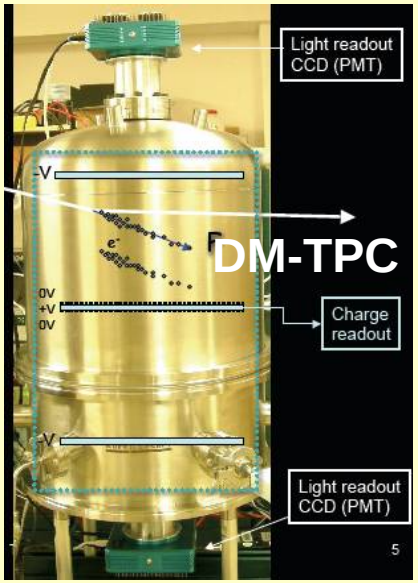
Directional Experiments

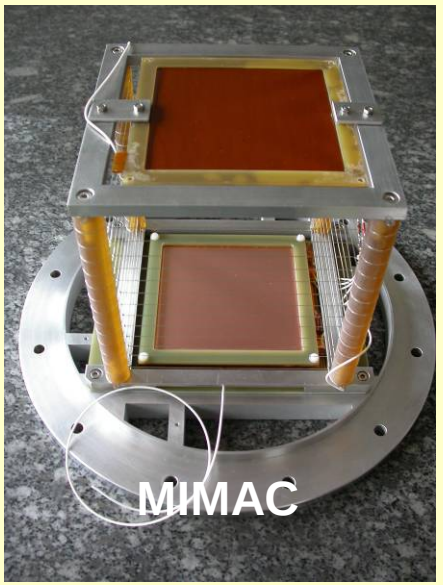
Directional detectors with low pressure gas (large volume)
Challenge is to measure 3D tracks of low energy recoils

•DRIFT-II @ Boulby mine: 1 m3 MWPCs with 40 torr CS2 (167 g)
•DM-TPC @ MIT: 2x 10-2 m3 with 50 torr CF4 (PMTs + CCD readout for 3D + E)
•NEWAGE @ Kamioka: 23 x 28 x 30 cm3 TPC with 150 torr CF4 and microwell readout
•MIMAC @ Saclay : 3 He & CF4 TPC modules (3 x 3 cm Micromegas with pixellized anode)

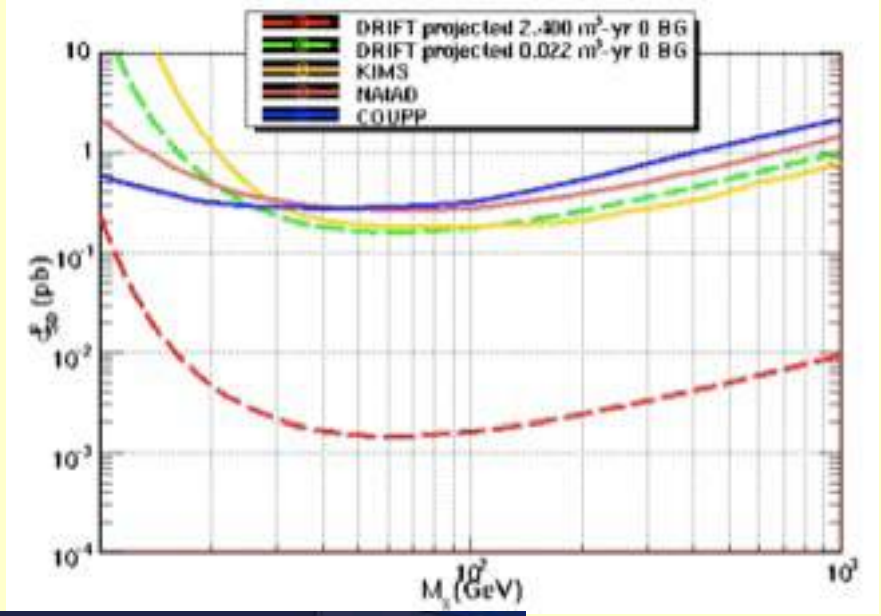






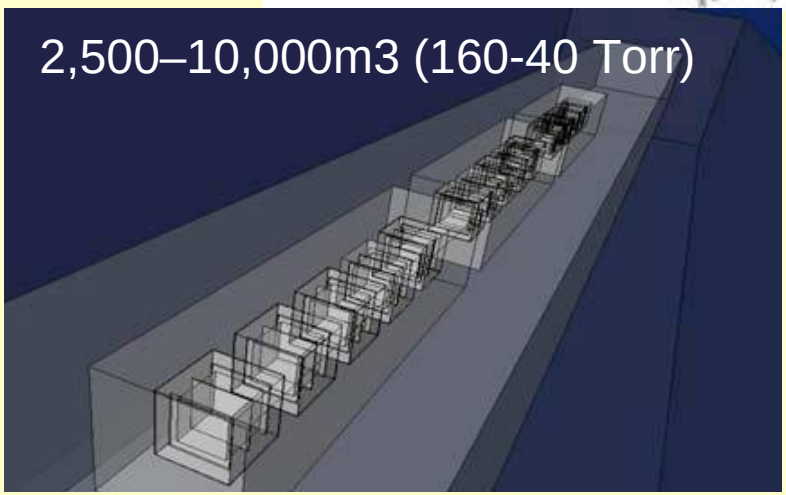


DRIFT-IId SD limits

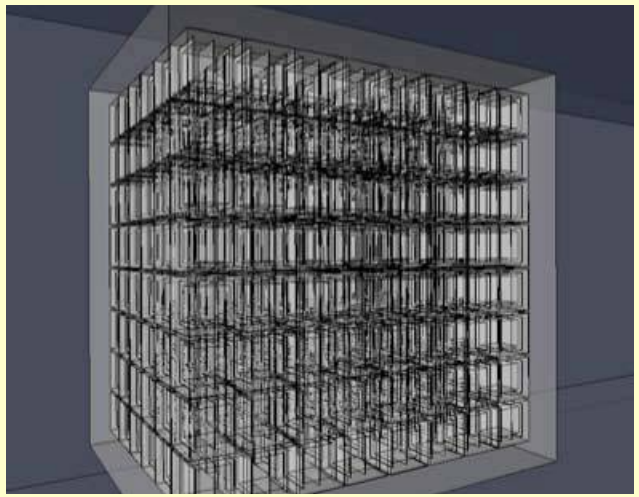


1 m³ x 2.5 y

~ 1 t



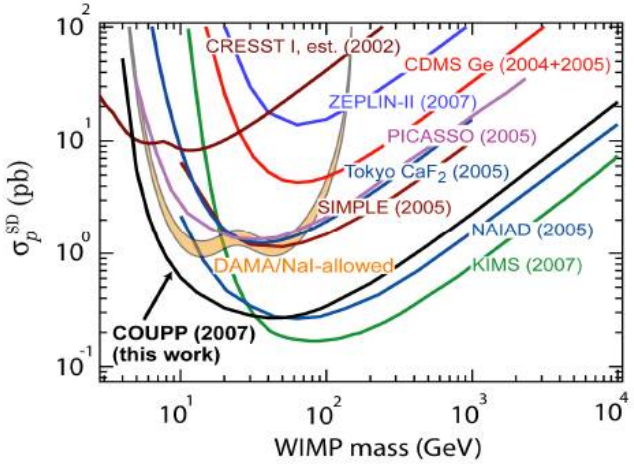
up 10 t!

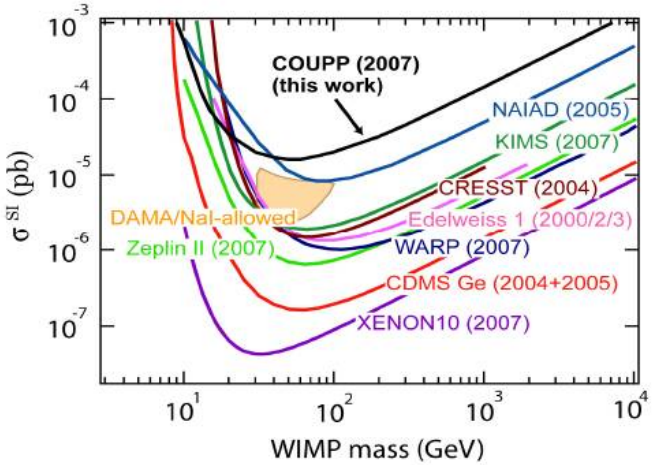


COUPP - Chicagoland Observatory for Underground Particle Physics

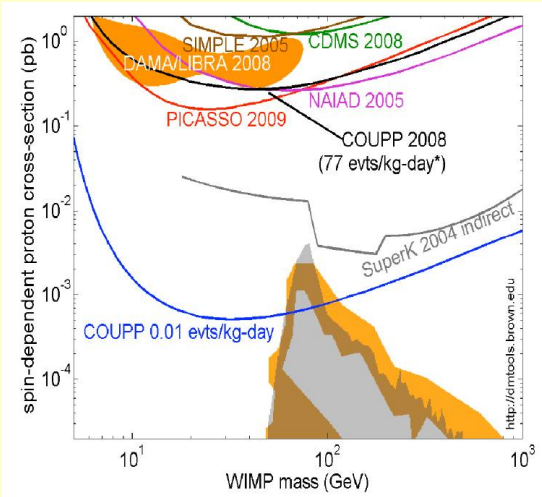
A bubble chamber; superheated CF_3I

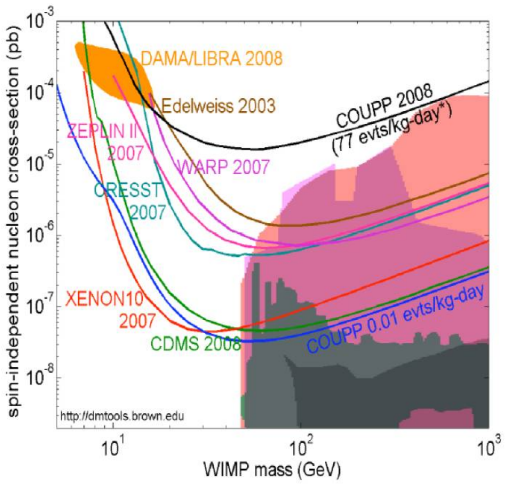
The limits obtained with 1.5-kg at Fermilab E. Behnke, *et al. Science* 319, 933 (2008):





60kg chamber being commissioned at Fermilab
Proposed to SNOLAB



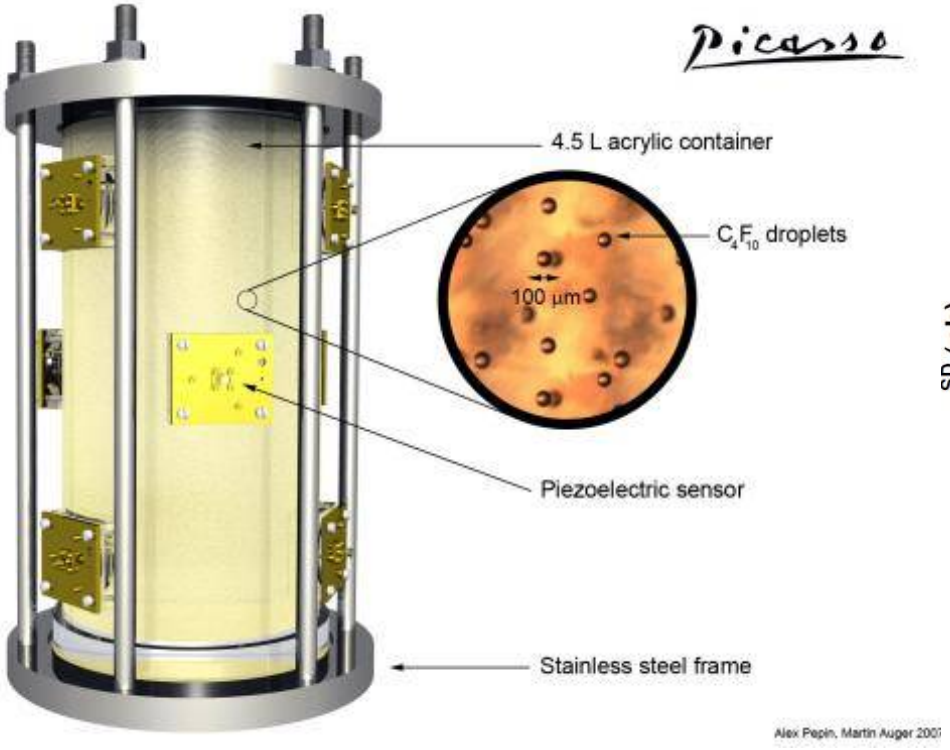


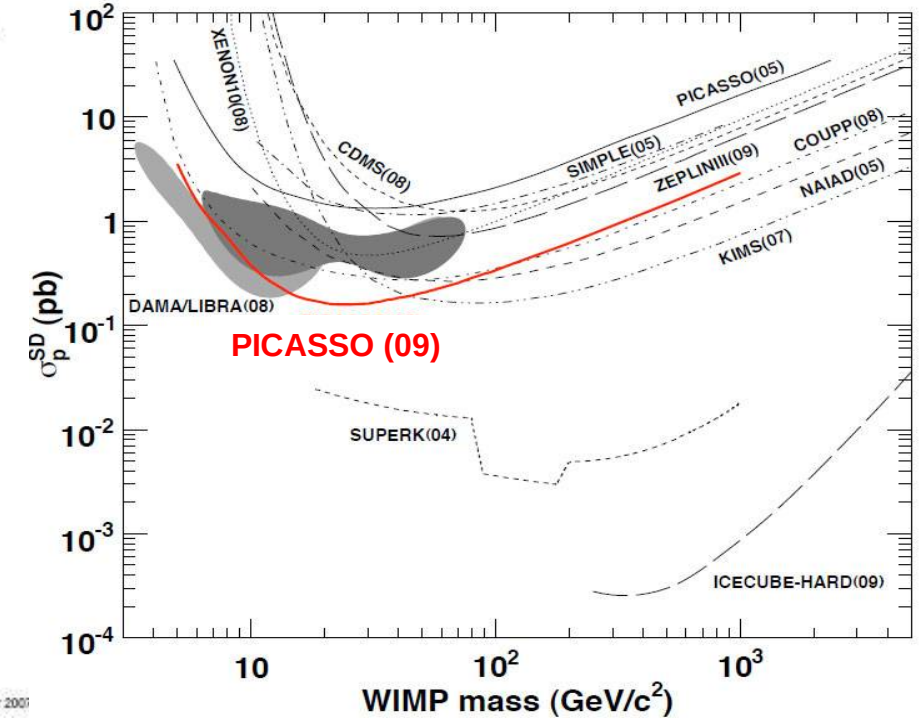
PICASSO

Experiment at SNOLAB

4.5l module with 80g of active mass of C4F10.
Superheated droplets are suspended in an elastic polymer
Signals are recorded by 9 piezo electric sensors. Events are localised by GPS-like triangulation.

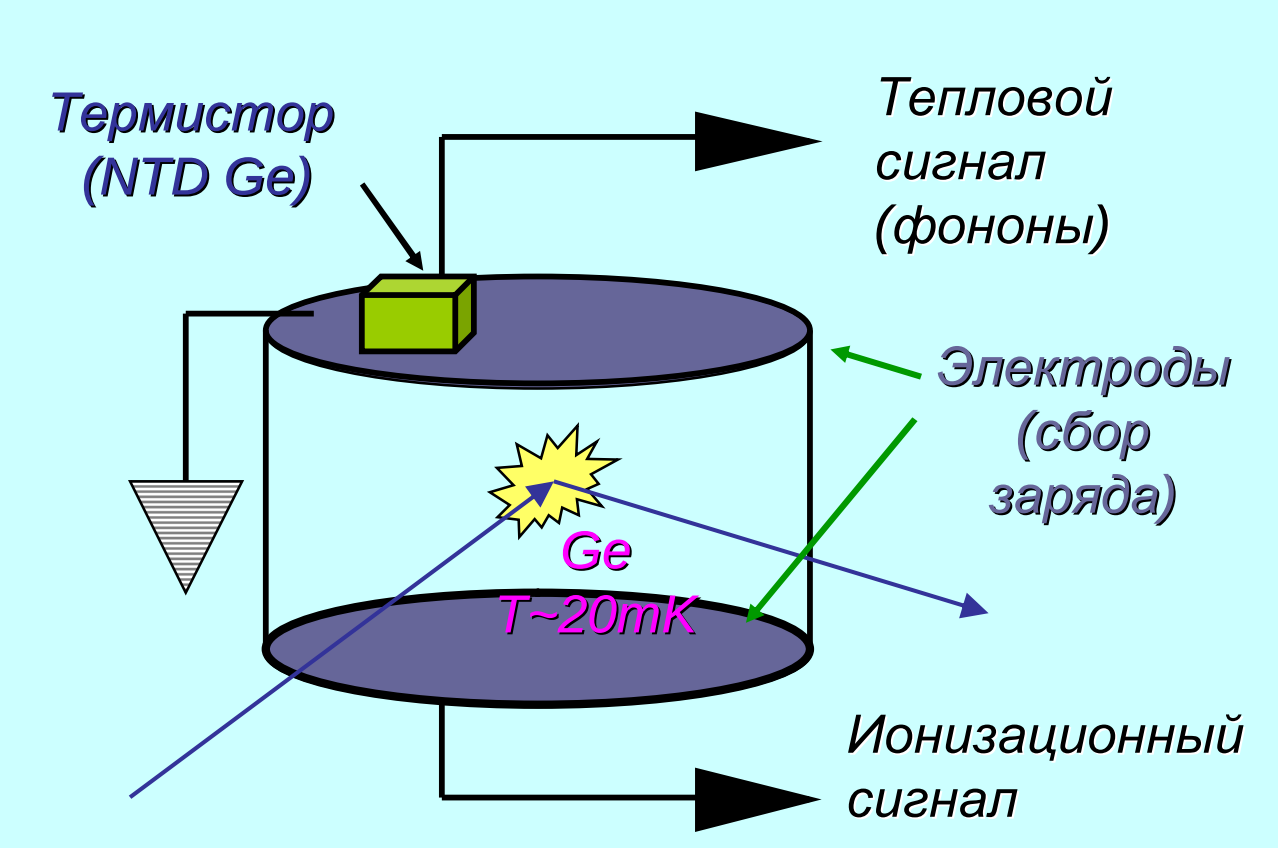
Presently PICASSO is installing a new experiment with 32 detector modules as shown to the left and with an active mass of 2.6 kg.





Низкотемпературные болометры

Детектирование с помощью низкотемпературных болометров



NTD - neutron transmutation doping ~150 нВ/кэВ

Теплоёмкость диэлектрика определяется согласно закону Дебая:

$$C = l_D \left(\frac{T}{\Theta_D}\right)^3,$$

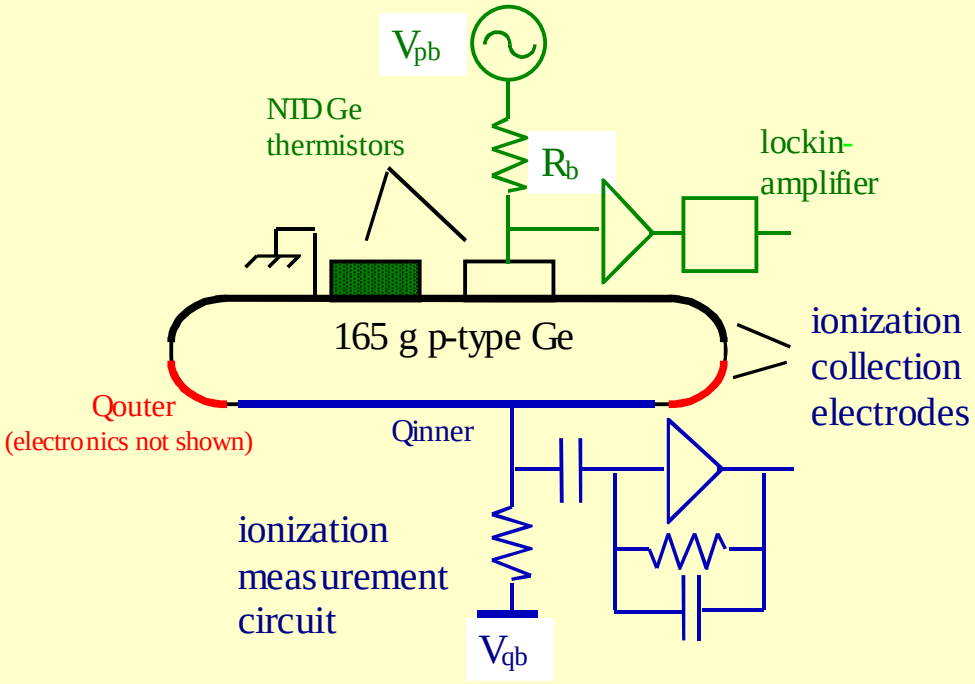
где l_D=1944 Дж/моль/К,
T – температура (К),
Q_D – температура Дебая.

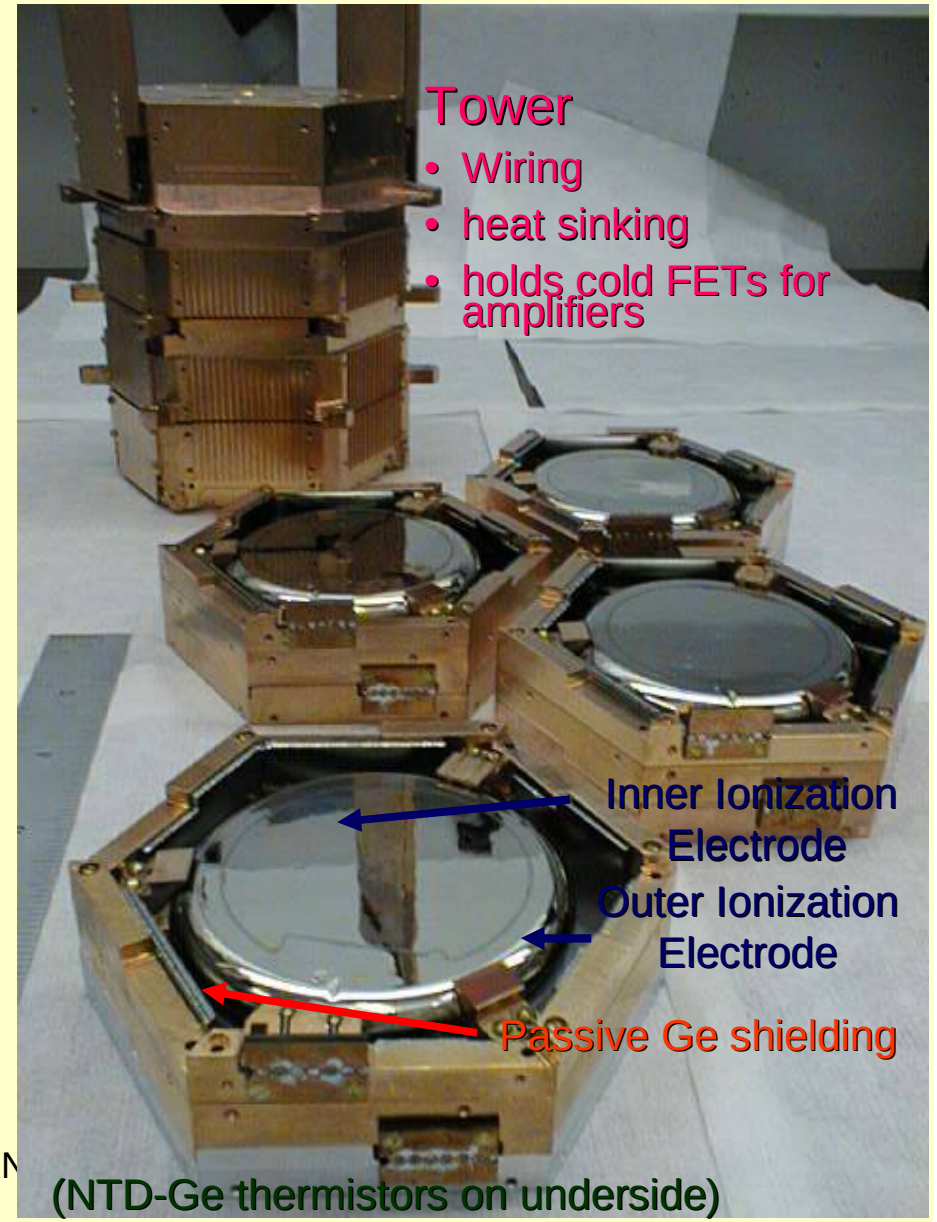
Для Ge, например,
Q_D равна 374К.
При T ~ 20 мК
C_{Ge} ~ 20 кэВ/моль/мкК.

Коллаборация по поиску Тёмной Материи CDMS – Cryogenic Dark Matter Search

Ge BLIP Detectors

Berkeley Large Ionization- and Phonon-mediated Detectors

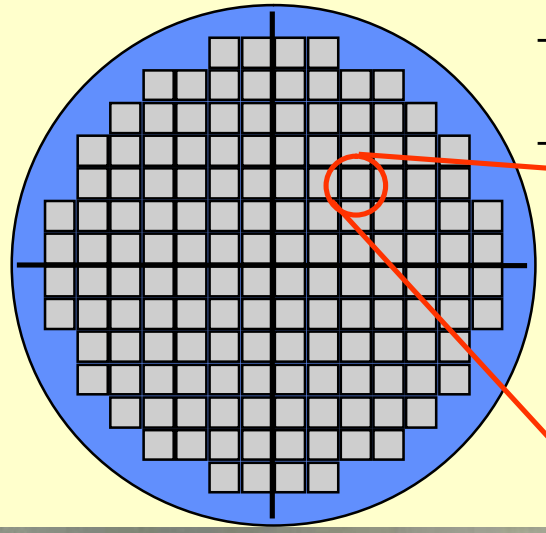


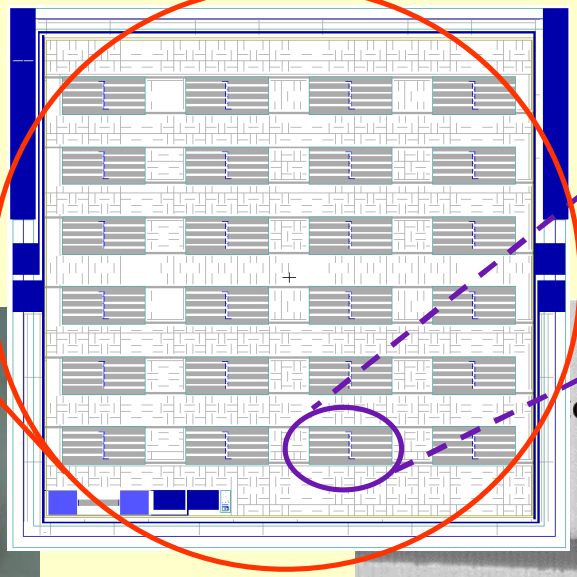


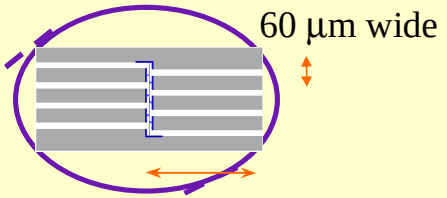
(NTD-Ge thermistors on underside)

ZIP detector phonon sensor technology

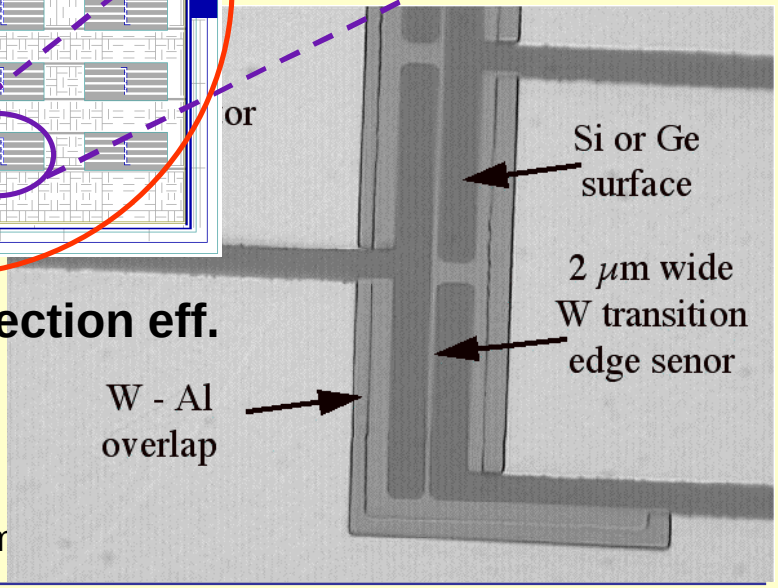
- TES's patterned on the surface measure the full recoil energy of the interaction
- Phonon pulse shape allows for rejection of surface recoils (with suppressed charge)
- 4 phonon channels allow for event position reconstruction







~25% QP collection eff.



). Акимов, INR sem

Experiments: CDMS

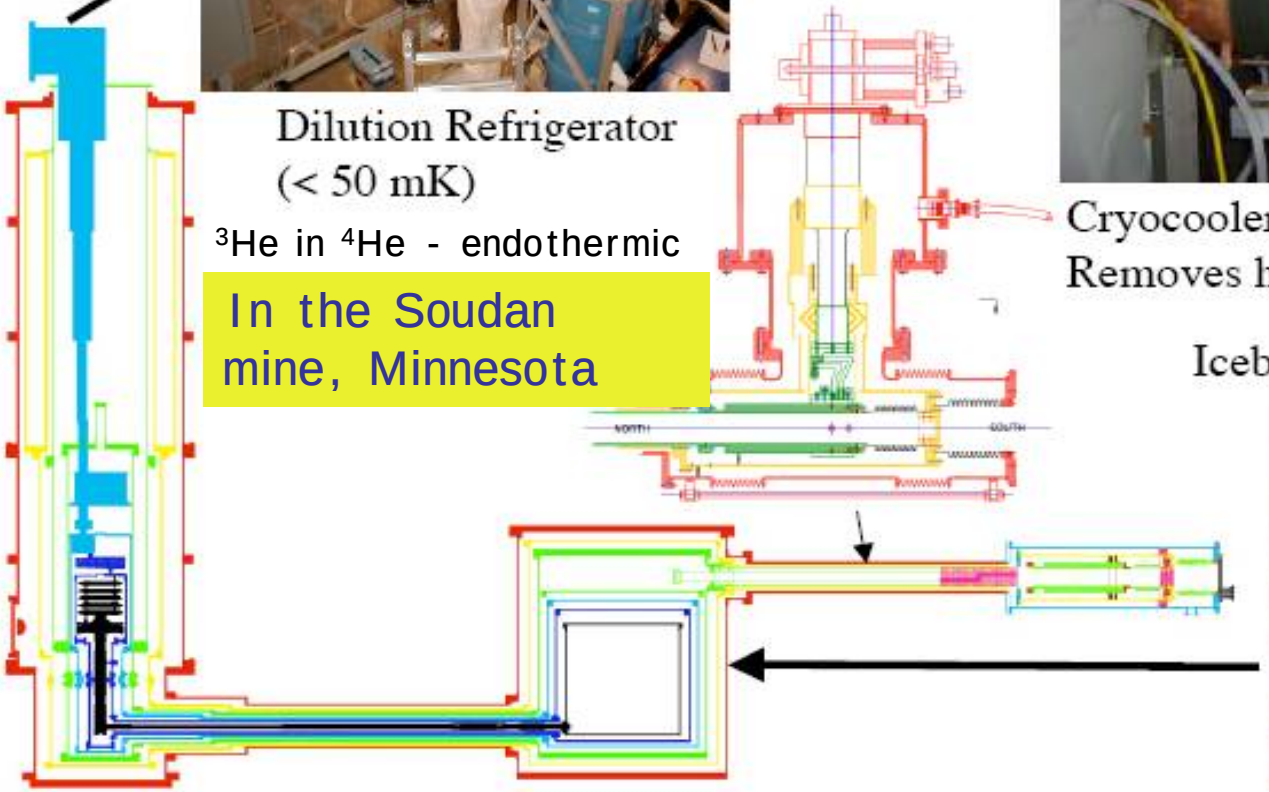
Dilution Refrigerator
(< 50 mK)

^{3}He in ^{4}He - endothermic

In the Soudan mine, Minnesota

Cryocooler (77K and 4K)
Removes heat load from signal cables.

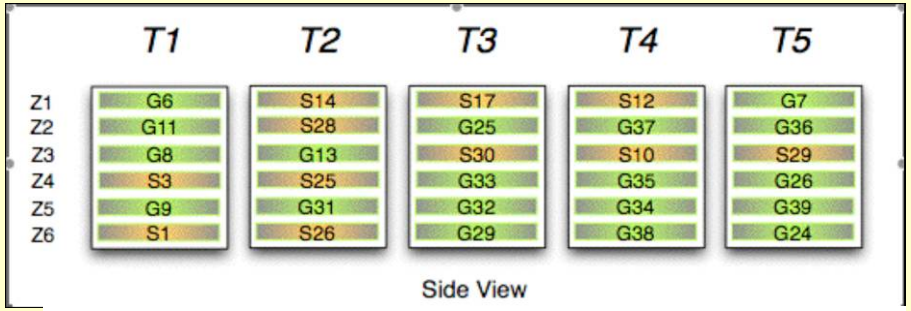
Icebox (Detector Cold Volume)

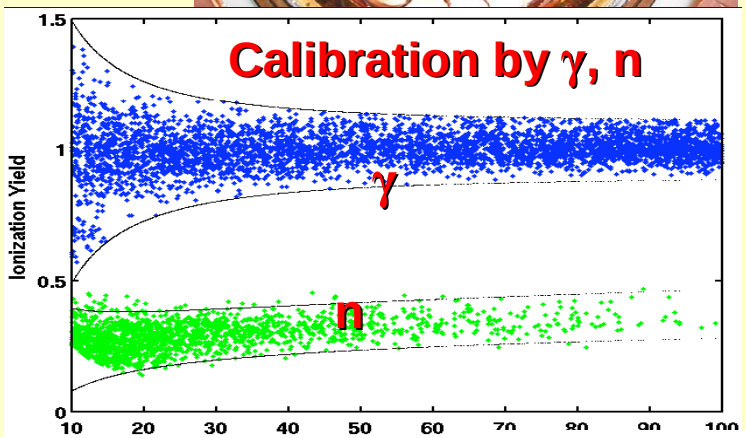


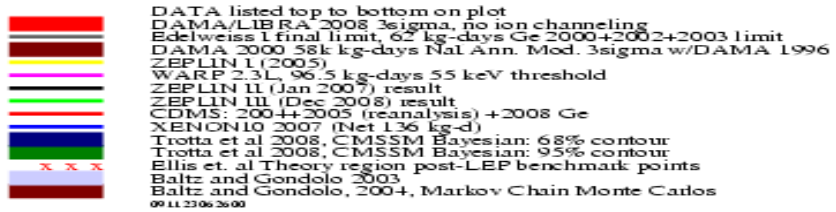
Experiments: CDMS

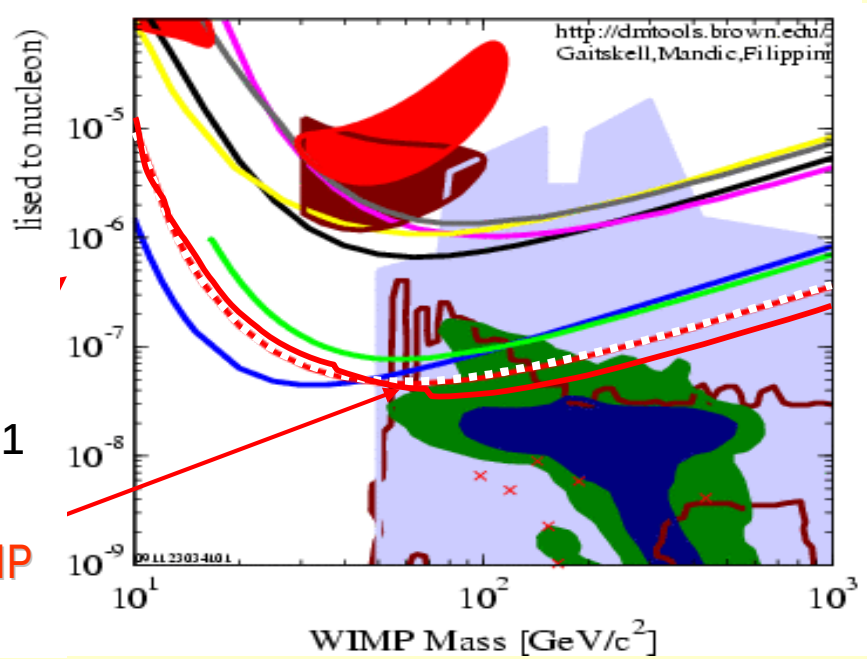
4.75 kg Ge,
1.1 kg Si

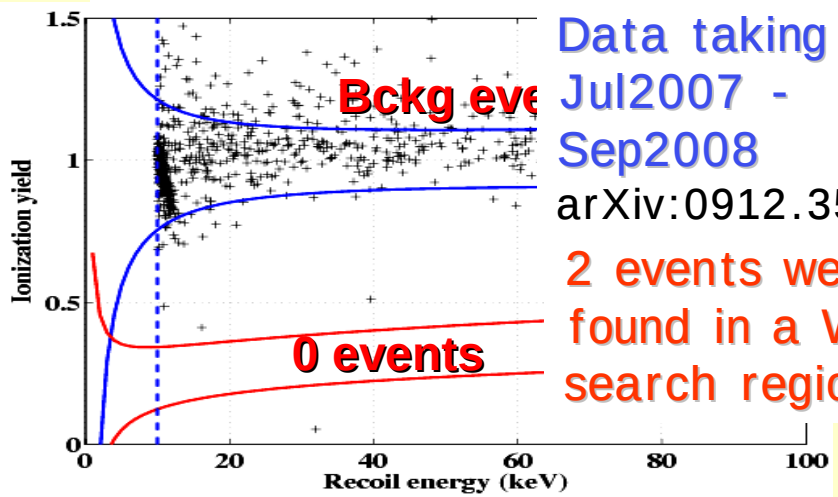
Data taking
Oct2006 - Jul2007
arXiv:0802.3530v2







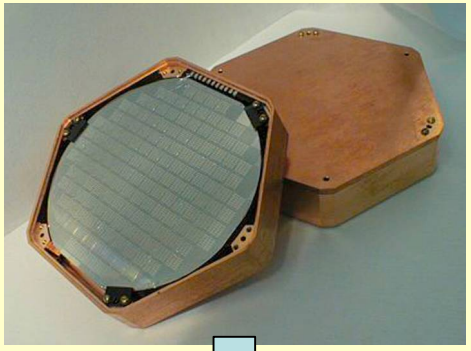


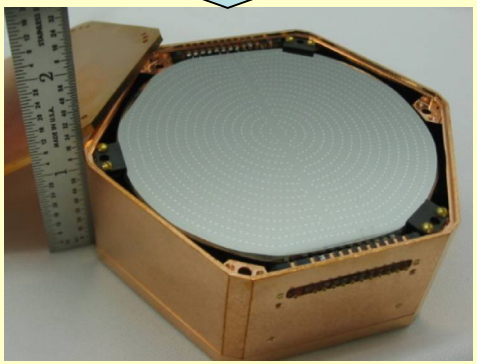


Data taking
Jul2007 - Sep2008
arXiv:0912.3592v1

2 events were found in a WIMP search region

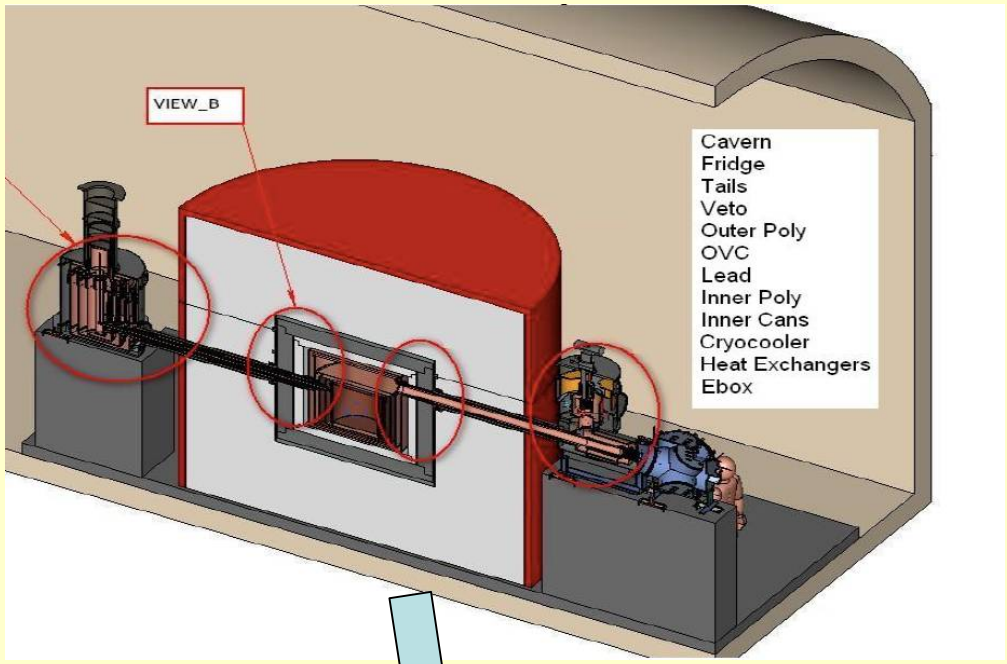
Experiments: SuperCDMS





Элемент детектора SuperCDMS
Ge : диам.76 мм, толщ. 25 мм, вес 607 г.

SuperCDMS в SNOLAB
150 кг – 3×10^{-10} пб

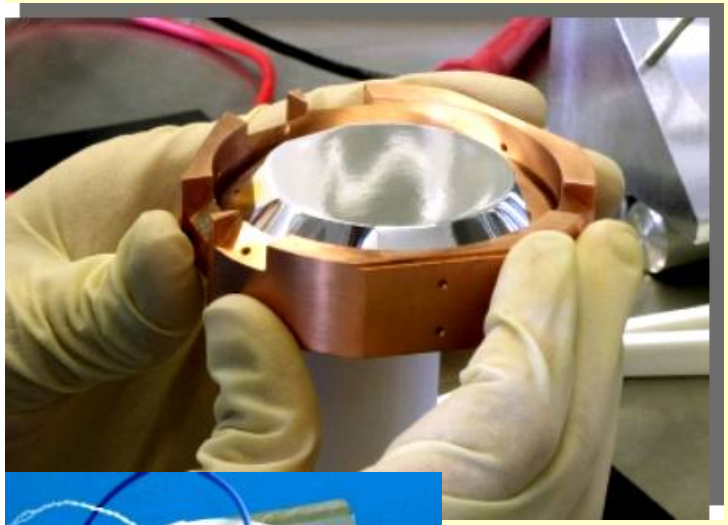


SuperCDMS в Soudan
15 кг – 5×10^{-9} пб

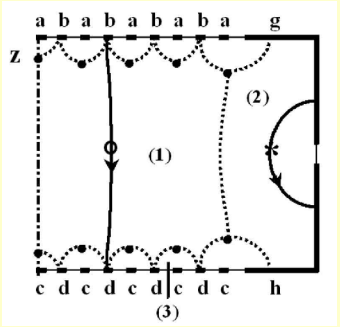
GEODM в DUSEL
1.5 т – 2×10^{-11} пб

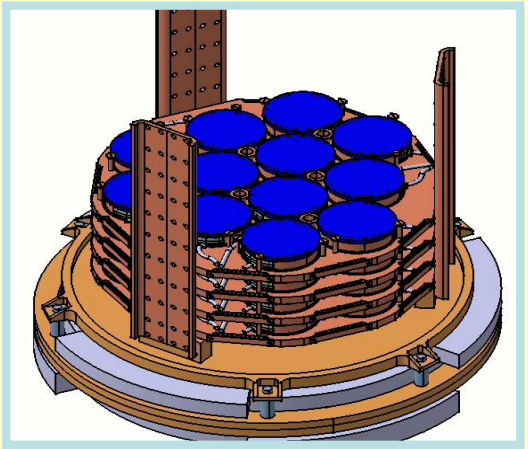
Эксперимент EDELWEISS

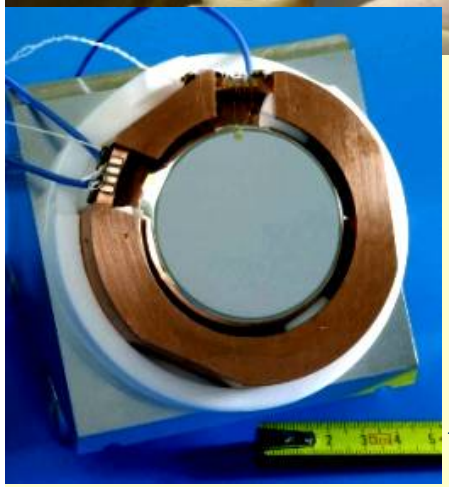
Laboratoire Souterrain de Modane (LSM)



320 grams







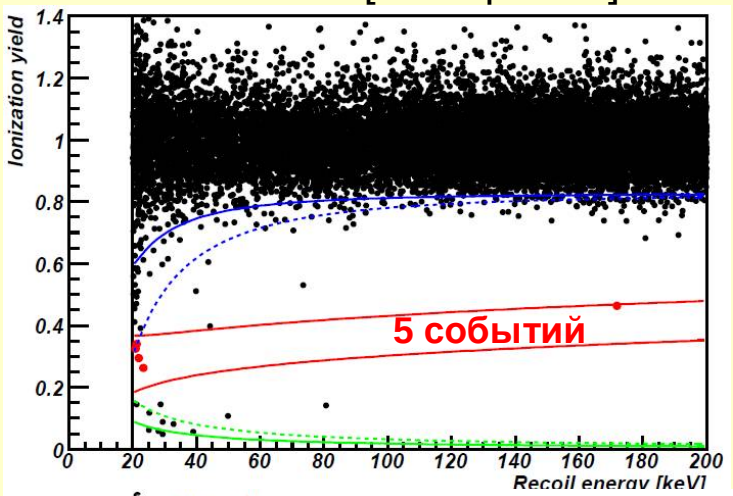
- *heat and ionisation Ge detector*
- *aluminium interlaying electrodes*
- *NTD sensor on guard ring electrode*

Resolutions @ 10 keV	*@ 122 keV)*
• ionisation : 1.3 keV	*2.2 keV*
• heat :1.0 keV	*3.0 keV*

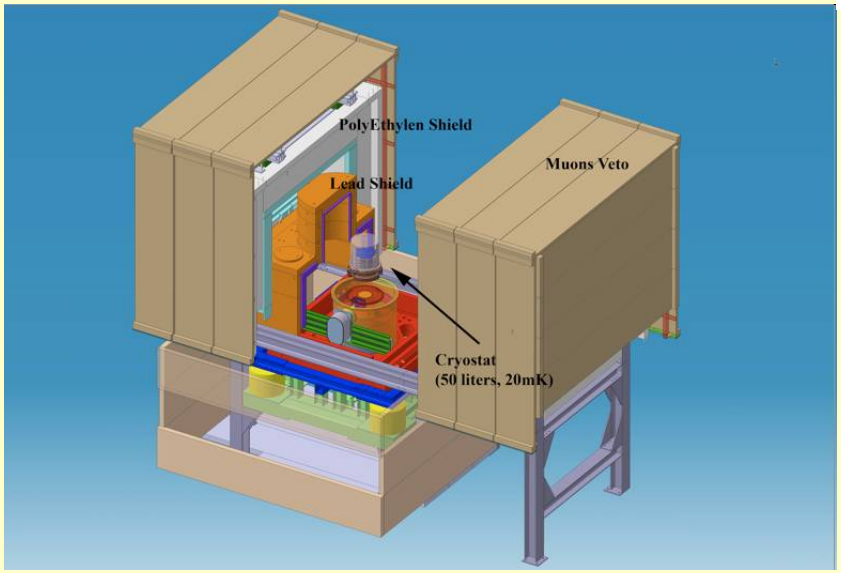
Эксперимент EDELWEISS

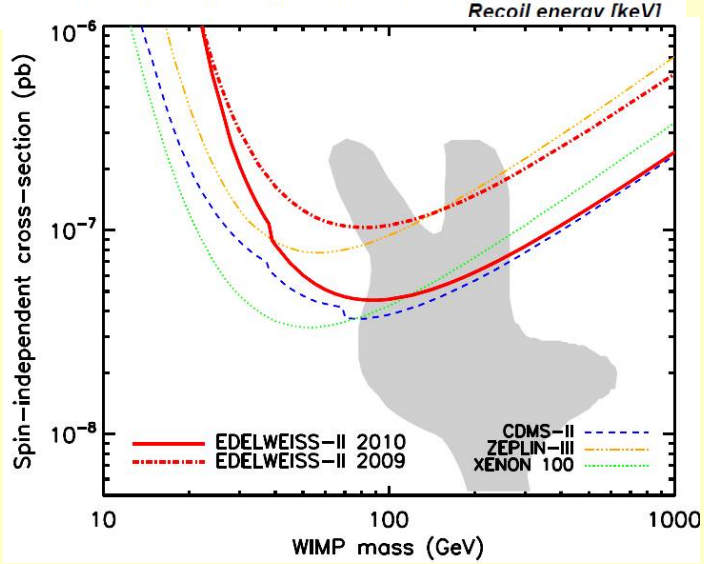
апрель 2009 по май 2010 384 кг сут

arXiv:1103.4070 [astro-ph.CO]



5 дет. 410 г
5 дет. 370 г





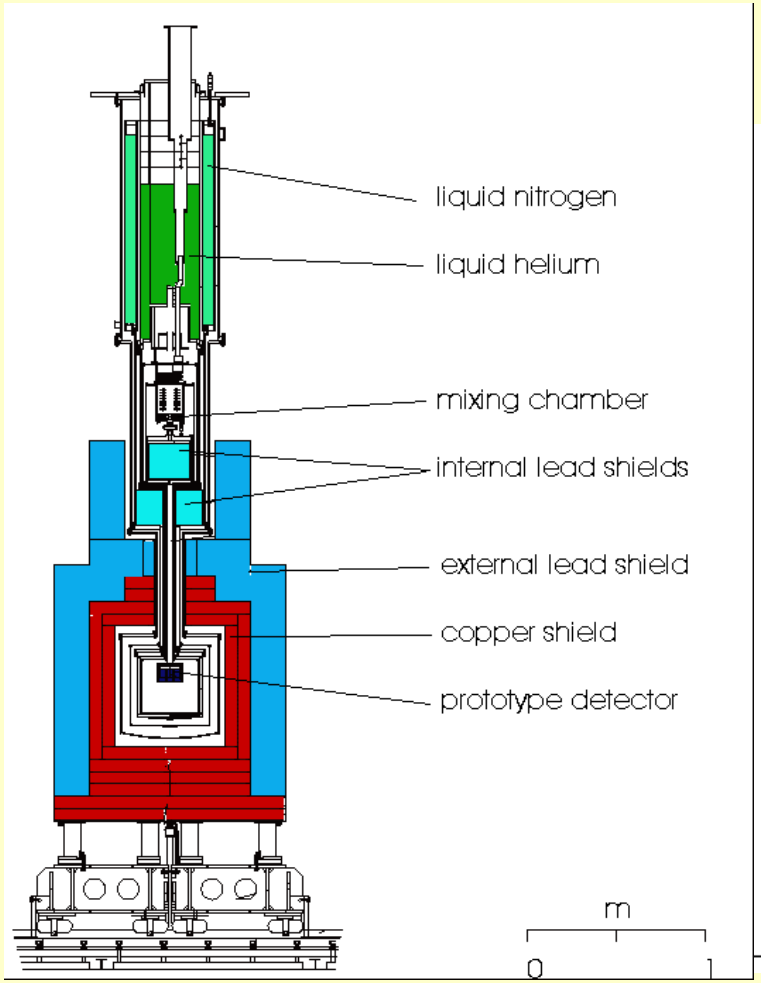
4.4×10^{-8} пб для M_W=85 ГэВ

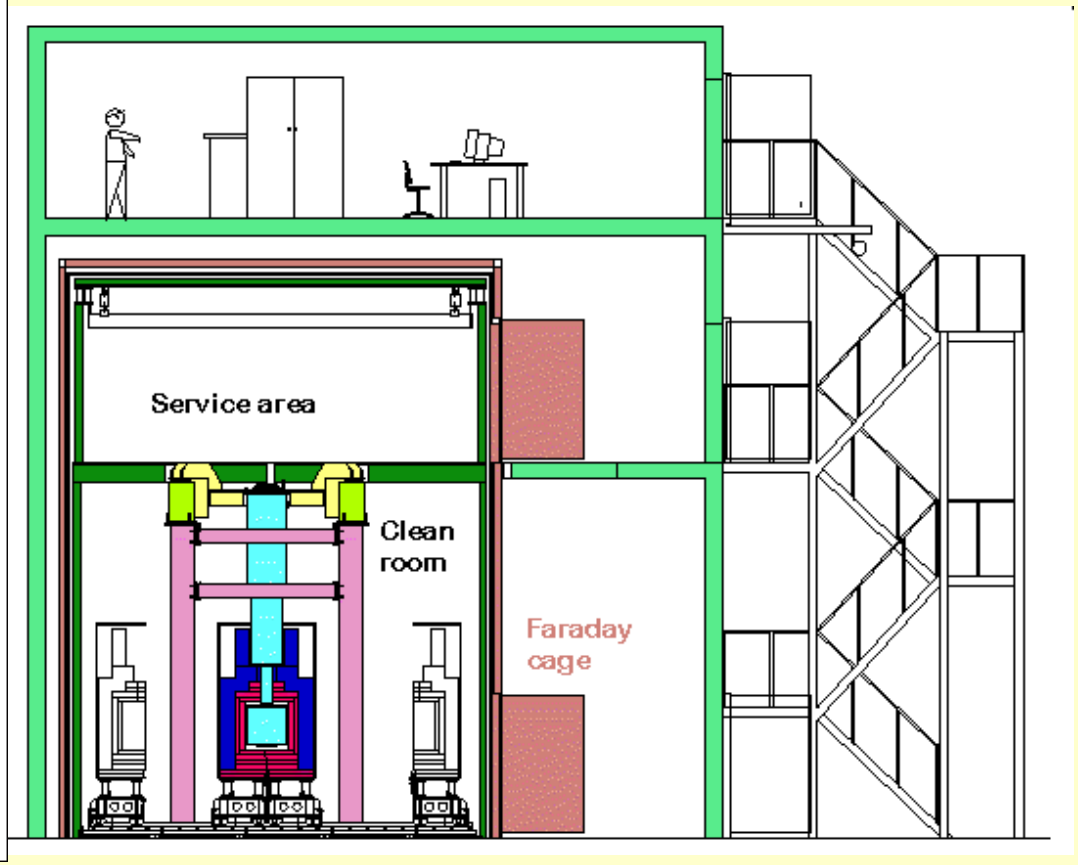
след. этап – 40 кг; 10^{-9} пб

Эксперимент CRESST

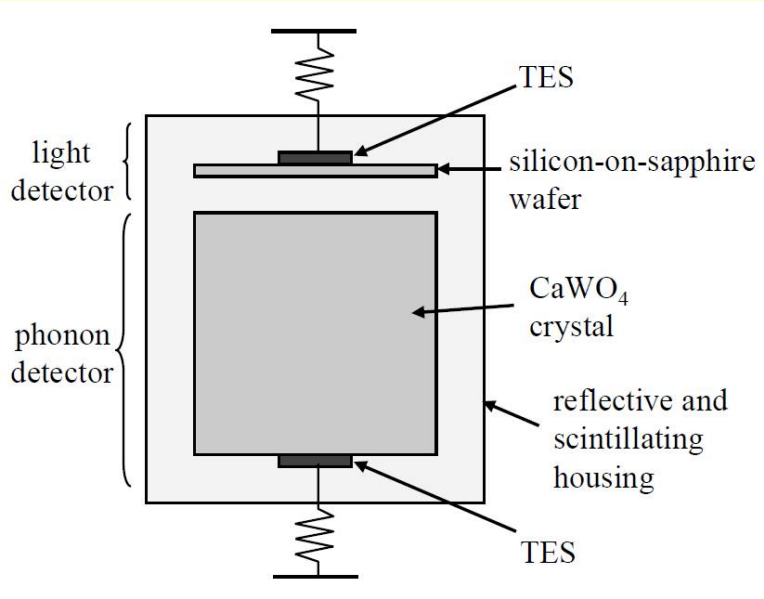
Cryogenic Rare Event Search with Superconducting Thermometers

- **Laboratori Nazionali Gran Sasso**
- **Max-Planck-Institut für Physic**
- **Technische Universität München**
- **University of Oxford**





CRESST-II



TES – Transition Edge Sensor

- Сеанс измерений начался в 2009, сейчас продолжается.
- Работают 10 детекторов общей массой 3 кг.
- Набранная экспозиция (после катов) ~700 кг сут.

NPPD 2011 4-7 April (Glasgow):

57 событий в области ядер отдачи,

из которых 22.6 идентифицируются как сигнал на уровне 4.6 σ

M_W ~ 13 ГэВ,

σ ~ 5 10^{-3} пб

EURECA

The EURECA Collaboration

CRESST, EDELWEISS, ROSEBUD + CERN, others

United Kingdom
- Oxford (H Kraus, coordinator)

Germany
- MPI für Physik, Munich
- Technische Universität München
- Universität Tübingen
- Universität Karlsruhe
- Forschungszentrum Karlsruhe

International
- JINR Dubna
- CERN

France
- CEA/IRFU Saclay
- CEA/IRAMIS Saclay
- CNRS/Neel Grenoble
- CNRS/CSNSM Orsay
- CNRS/IPNL Lyon
- CNRS/IAS Orsay

Spain
- Zaragoza

Ukraine
- Kiev

EURECA

Timeline:

2009/10: Design Study → TDR

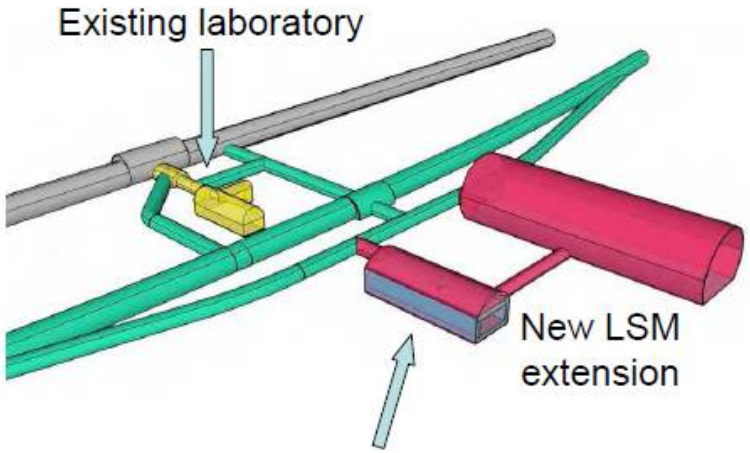
2011/12: Digging out of LSM extension begins. In parallel, begin construction of EURECA components away from LSM. Aim for ~100kg stage (10^{-9} pb).

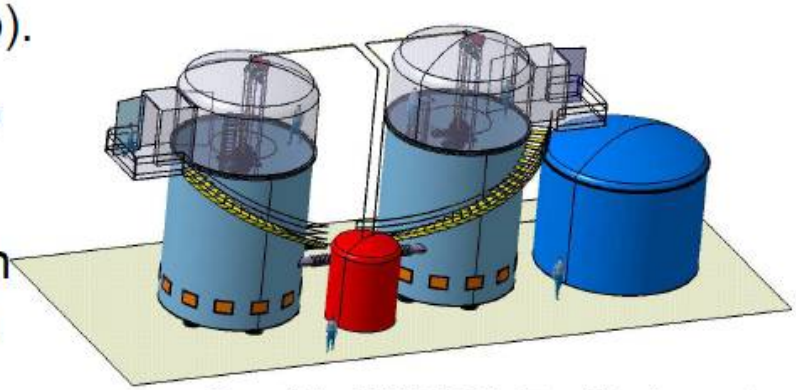
2014: LSM extension ready to receive EURECA.

2015: Begin data taking and in parallel improve and upgrade.

2018: One tonne target installed.

EURECA in LSM

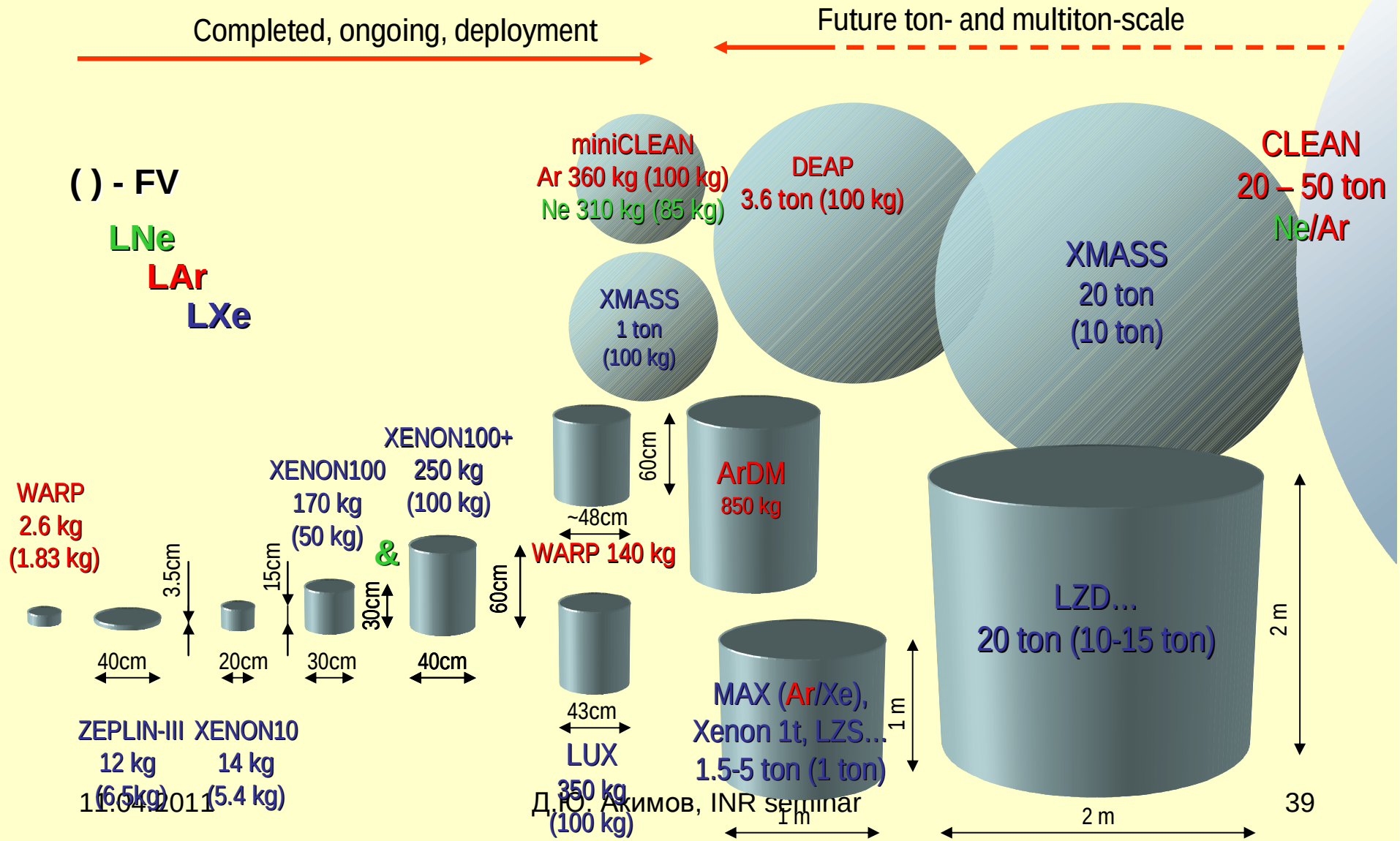




Possible EURECA Facility Layout

Детекторы на жидких благородных газах

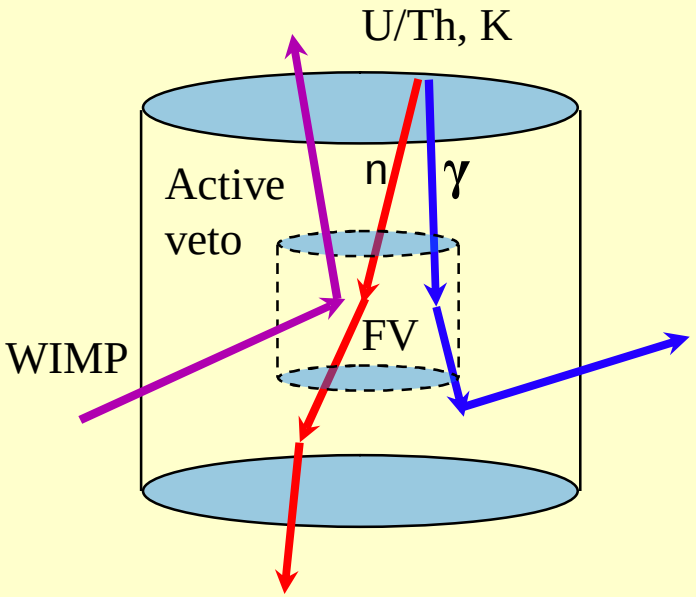
Family of noble-liquid DM detectors



Experiments: Liquid noble-gas detectors

Liquid noble gases are increasingly used as a detection medium for WIMPs

- **very low contamination by U/Th, K (can be easily purified by filtering)**
- **possibility of discrimination by simultaneous measurements of scintillation and ionization signals in a two-phase mode**
- **possibility to build large and even very large (ton-scale) detectors**
- **3D position sensitivity => "WALL-LESS" detector!!!**



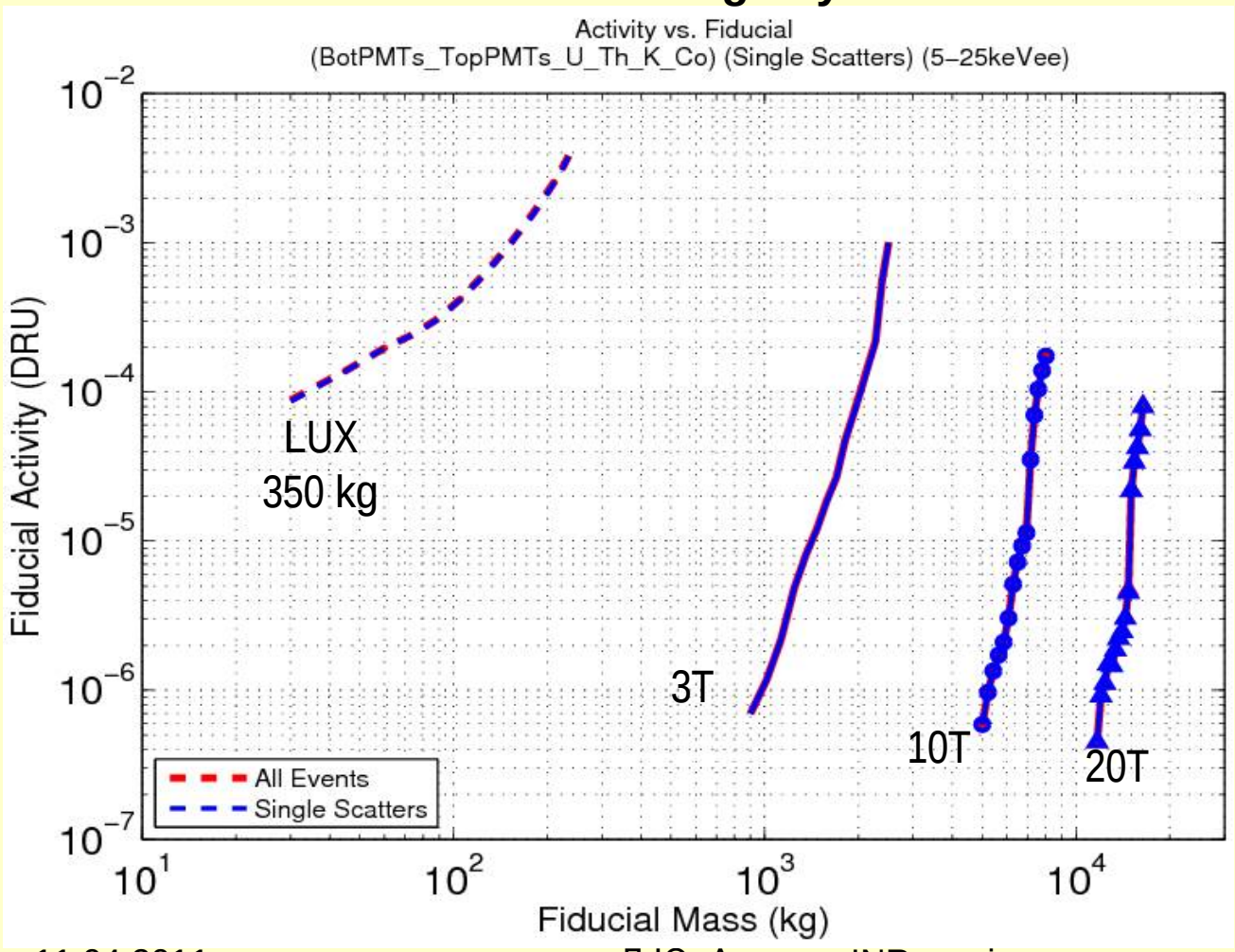
LAr, LXe: at the same mass LXe detectors have by an order of magnitude higher sensitivity:

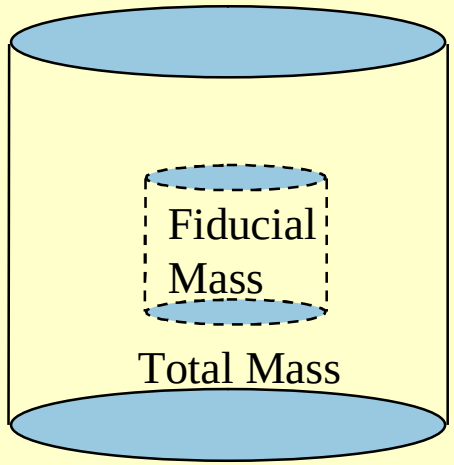
$\sigma_{SI} \sim A^2$, **higher density and Z => better self-shielding**

But to use different targets is very important!

Experiments: Liquid noble-gas detectors

Example of self-shielding effect. *Simulation by LUX*
Single scatter events from PMTs gammas
DRU – event/keV/kg/day



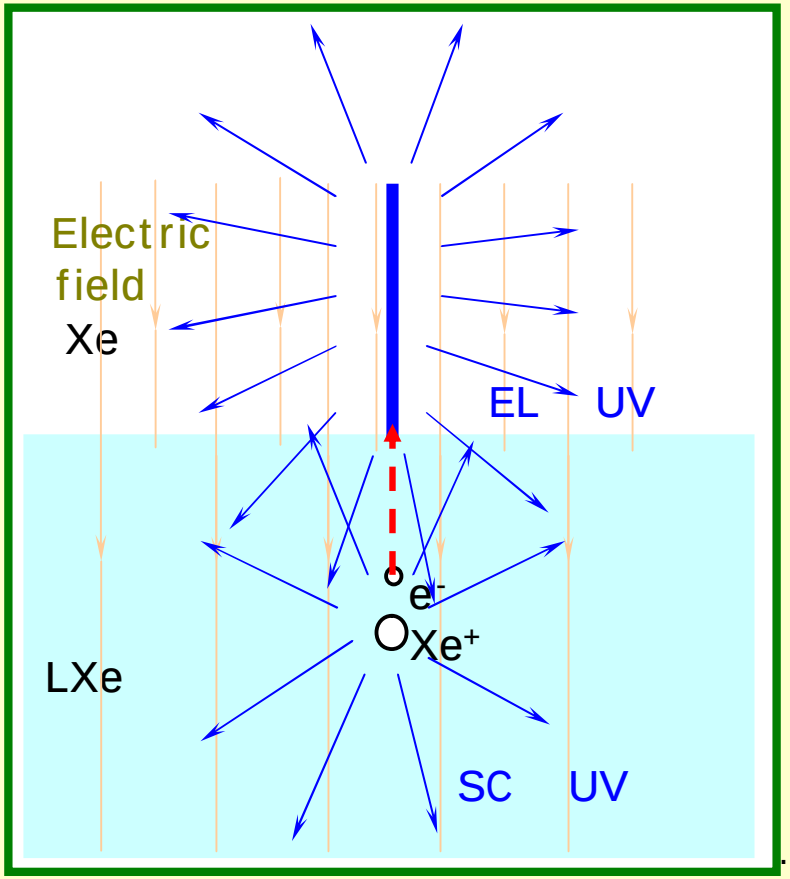


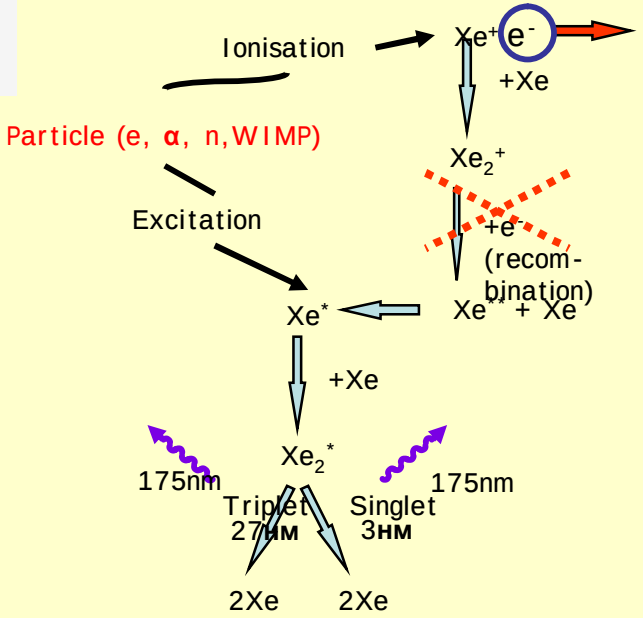
Experiments: LXe detectors

Discrimination of particles in a two-phase detector (Xe)

B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETF Letters (in Russian), 1970, v. 11, p. 513

For the Dark Matter search:
A.S. Barabash and A.I. Bolozdynya, JETF Letters (in Russian), 1989, v.49, p. 359

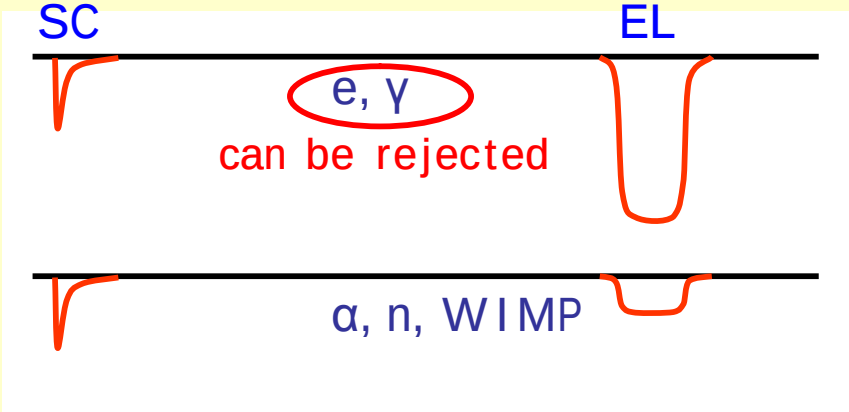




Electrons are partly extracted from the track: recombination is suppressed

Suppression depends on dE/dX

Ratio of SC/EL is different for different kind of particles



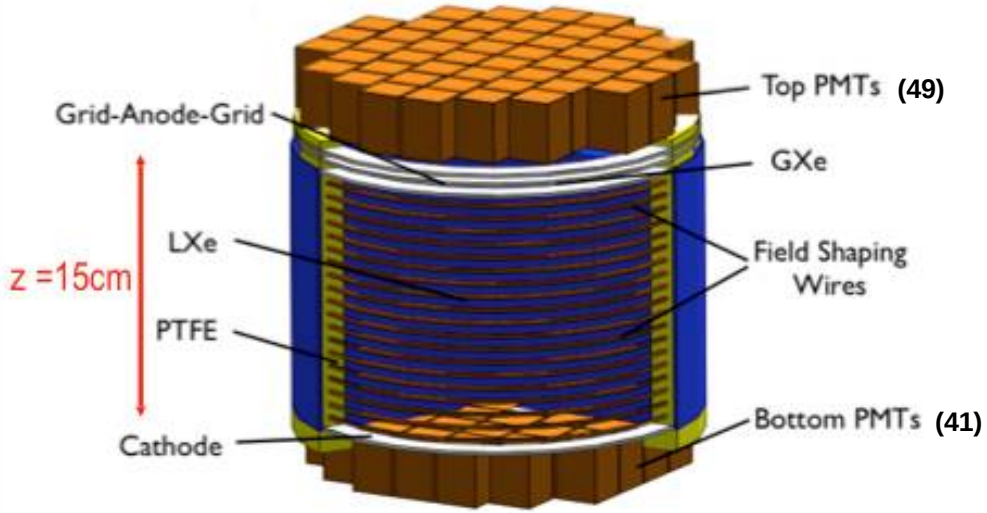
Experiments: Xenon collaboration

Xenon collaboration

- Columbia University
- Universität Zürich
- Brown University
- University of Coimbra
- CWRU
- Livermore National Laboratory
- Rice University
- Yale University
- Nazionali del Gran Sasso

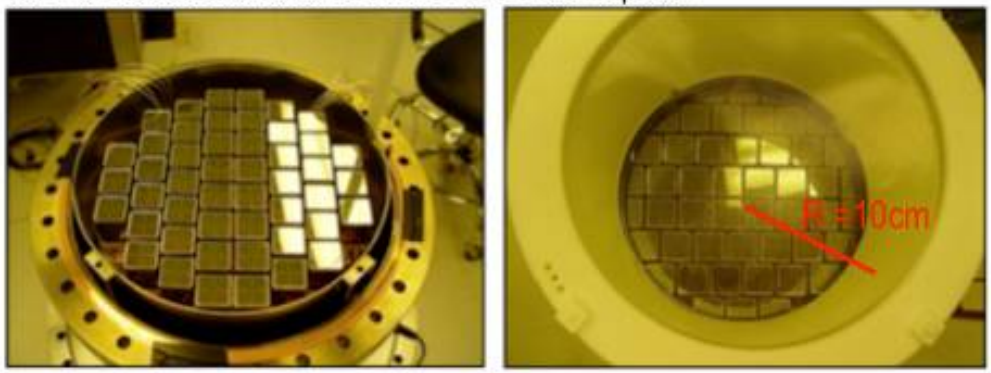
Xenon10 - Gran Sasso

Experiments: Xenon10



3.0 pe/keV at 122 keV gammas

89 PMTs: Hamamatsu R8520-AL 2.5 cm square



diam.~ 20 cm; drift gap= 15 cm
LXe - 25 kg (15 kg active)

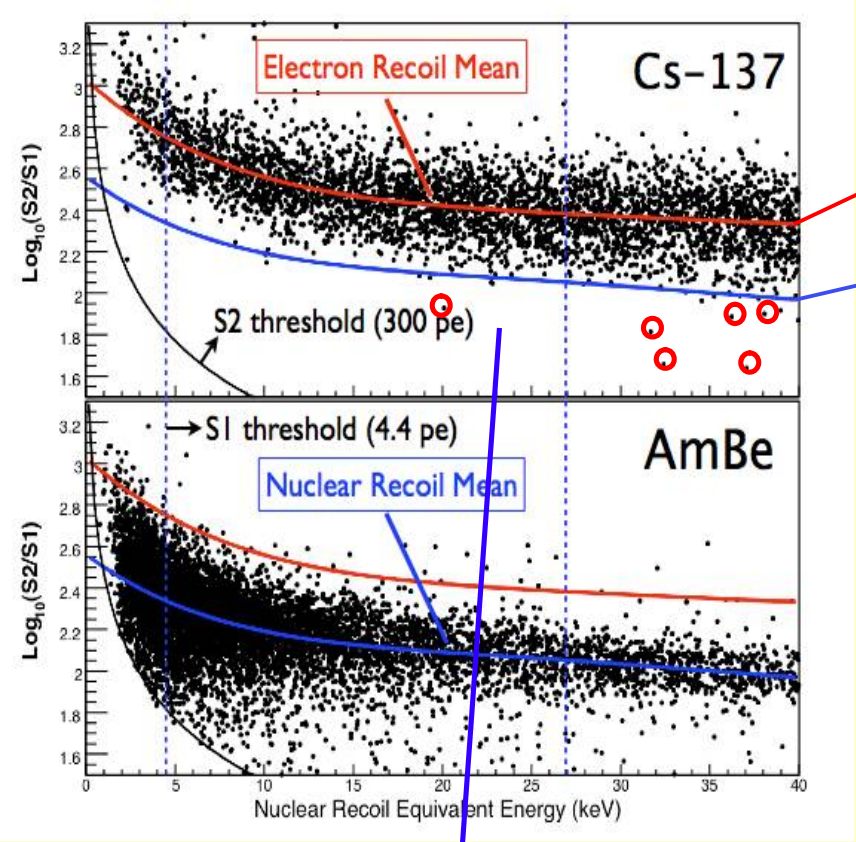
Low Radioactive PMTs:

U	-	0.17±0.04 mBq/PMT
Th	-	0.20±0.09 mBq/PMT
K	-	10±1 mBq/PMT
Co	-	0.56±0.05 mBq/PMT

Experiments: Xenon10

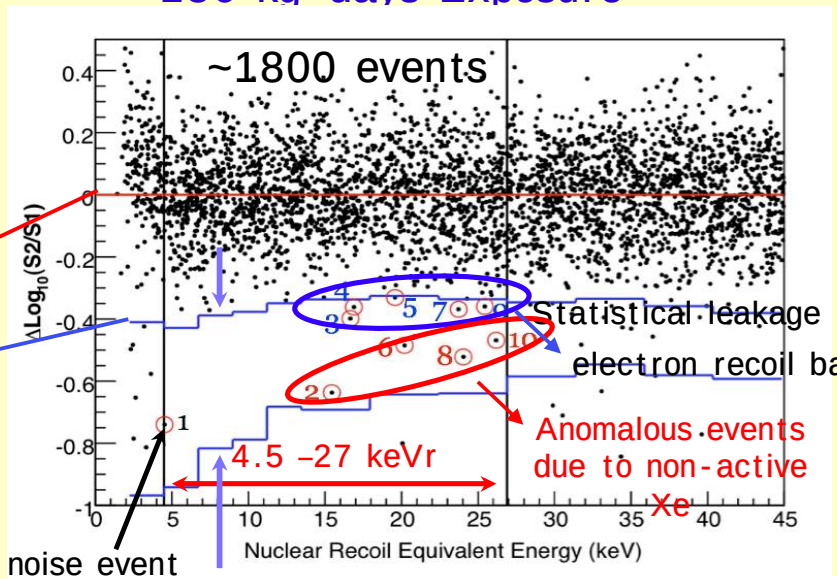
E.Aprile TAUP2007:

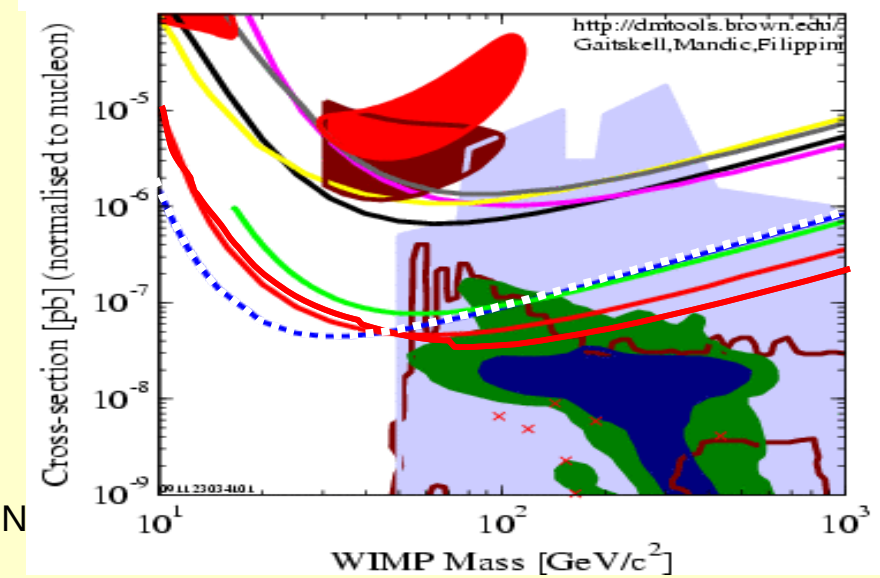
Gamma/Neutron calibration



~ 99.5 % gamma events
are rejected below
nuclear recoil mean

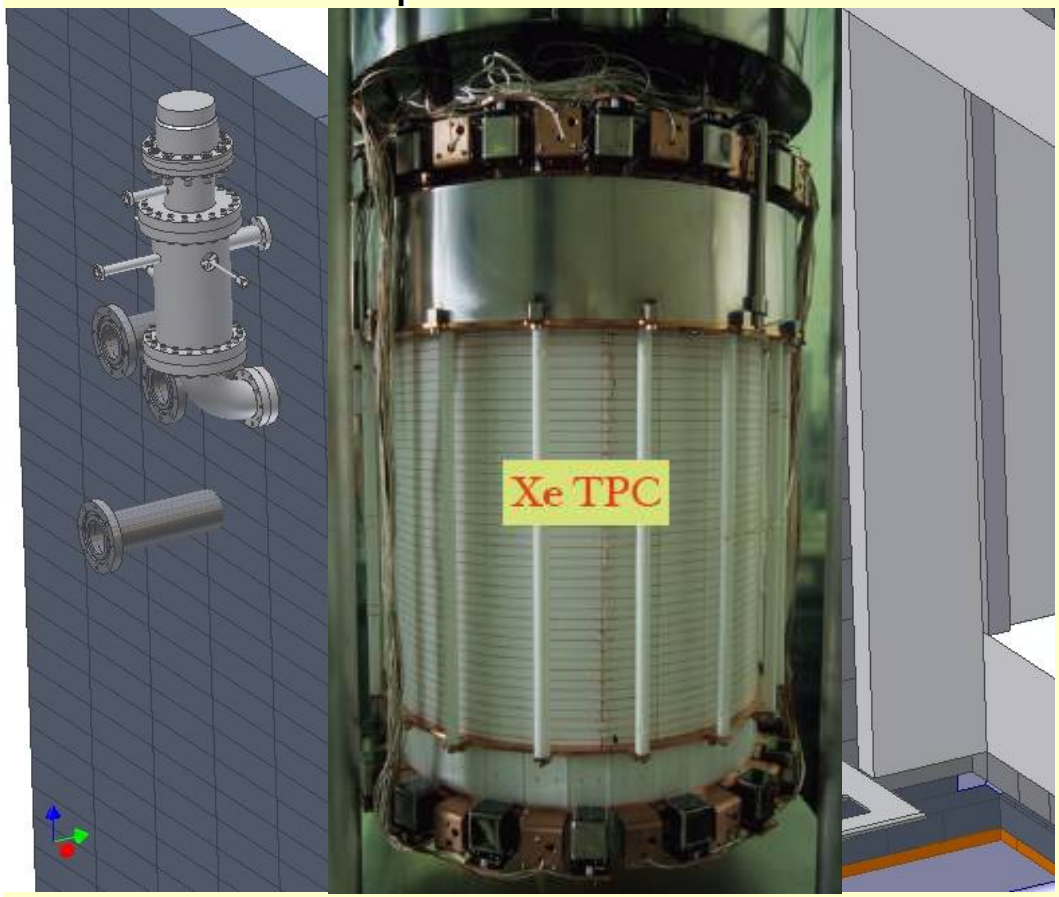
Blind Analysis
136 kg-days Exposure





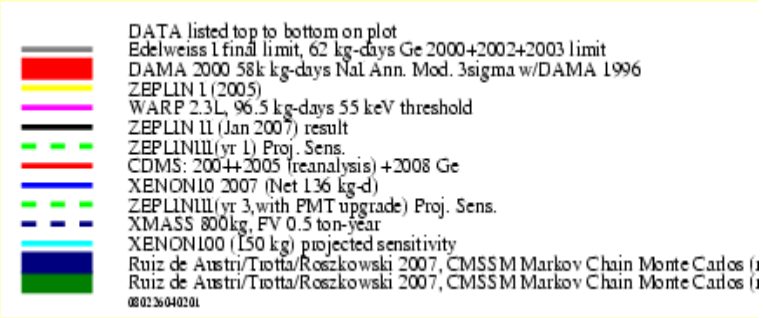
Experiments: Xenon100

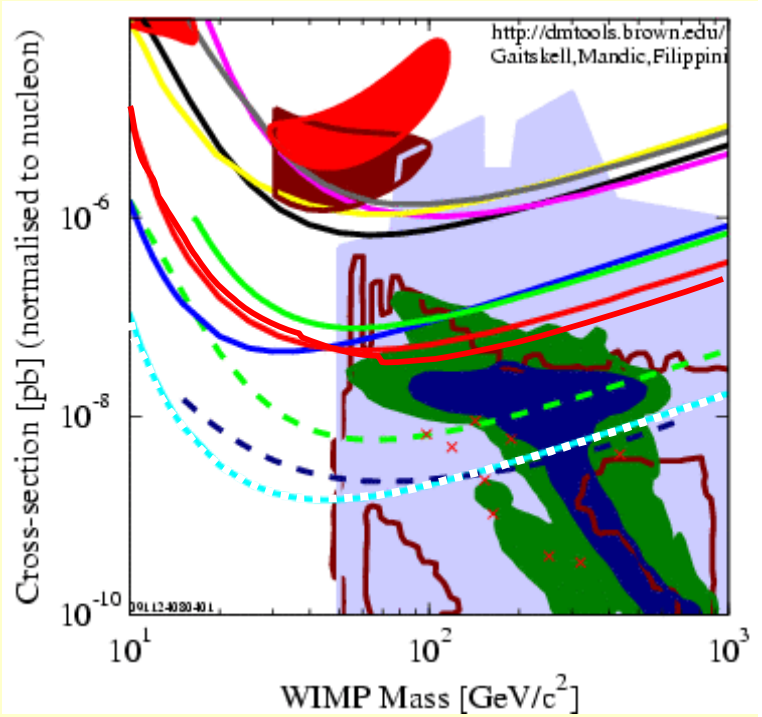
Scaled-up Xenon10 detector



150 kg total (70 kg in target)

started data taking in mid Jan 2010





Experiments: ZEPLIN

ZEPLIN (UKDMC) collaboration

ZEPLIN I (single phase)

- CCLRC Rutherford Appleton Laboratory
- Imperial College London
- University of Sheffield
- University of London Queen Mary

ZEPLIN II (two-phase)

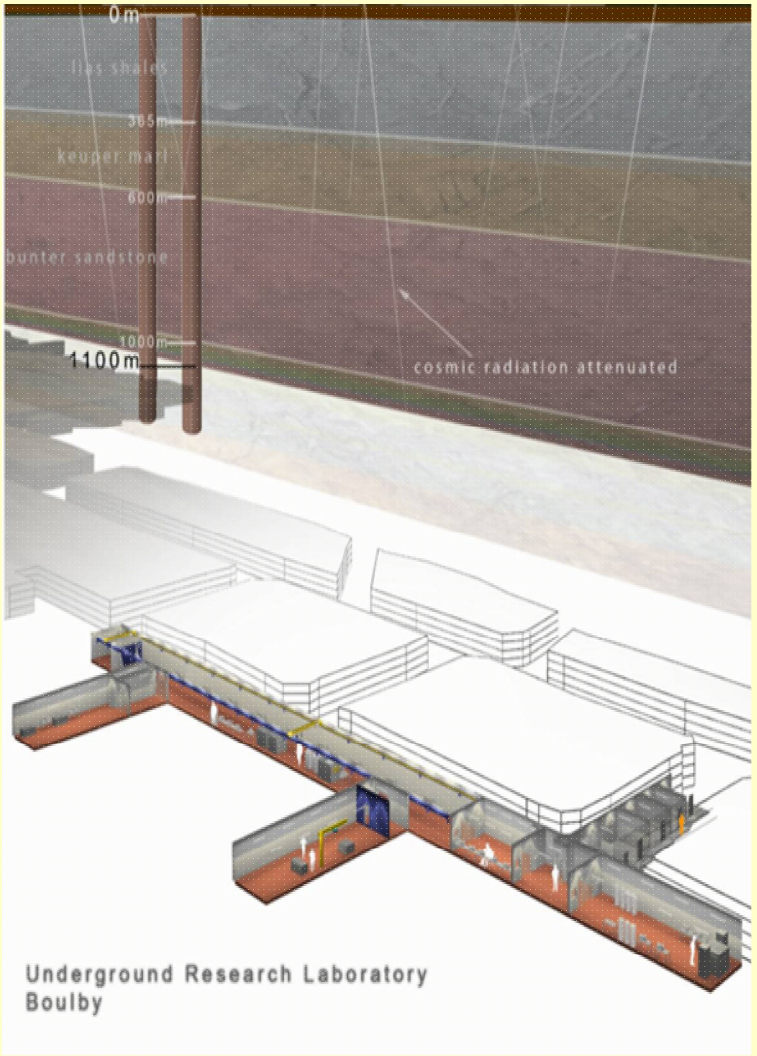
- CCLRC Rutherford Appleton Laboratory
- Imperial College London
- University of Sheffield
- University of Oxford
- University of Edinburgh
- University of California (UCLA)
- Texas A&M University
- University of Rochester
- LIP- Coimbra (Coimbra Univ.)
- INFN Pisa

ZEPLIN III (two-phase)

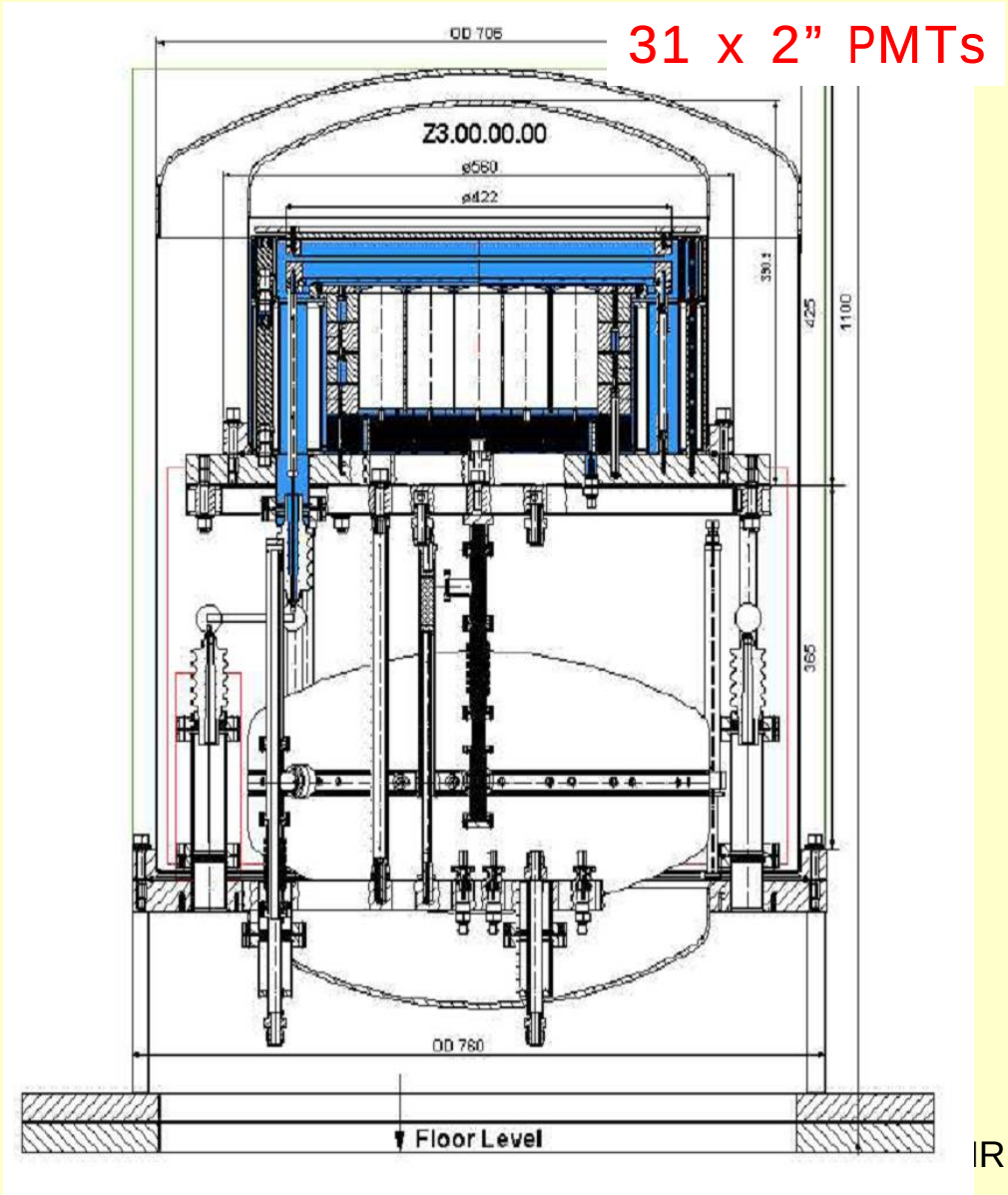
- CCLRC Rutherford Appleton Laboratory
- Imperial College London
- University of Edinburgh
- LIP- Coimbra (Coimbra Univ.)
- ITEP

Experiments: ZEPLIN

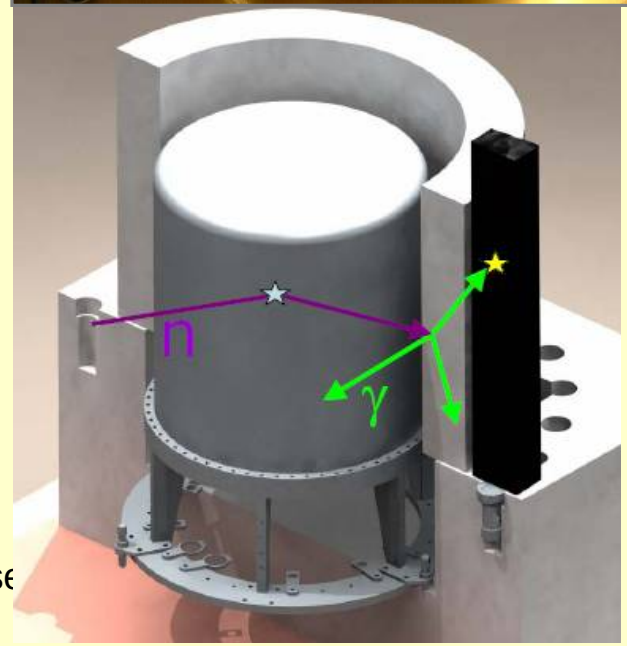
Boulby, U.K. site (‘Palmer lab’)
1100m, 2.8km water equiv.
10^6 reduction in muon flux



Experiments: ZEPLIN III



31 x 2” PMTs



IR se

Experiments: ZEPLIN III

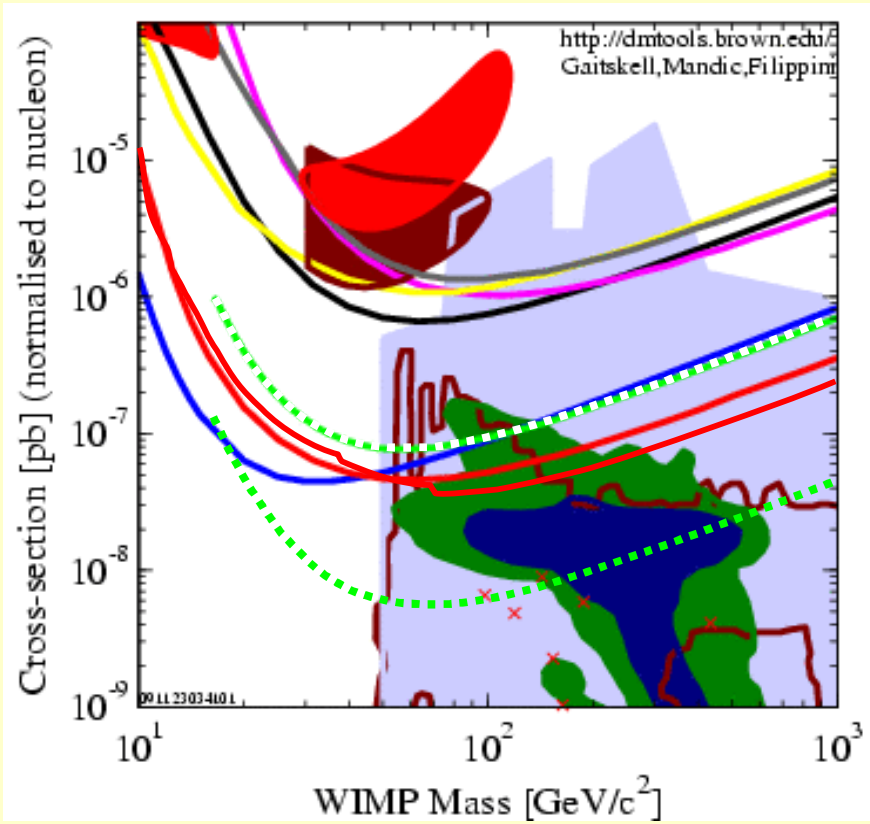
Phase 1

Completed
453.6 kg days
à 8.1 x10^{-8} pb
astro-ph:0812.1150

Phase 2

Upgrade completed:
• 30 times less radioactive PMTs
•Active neutron Veto

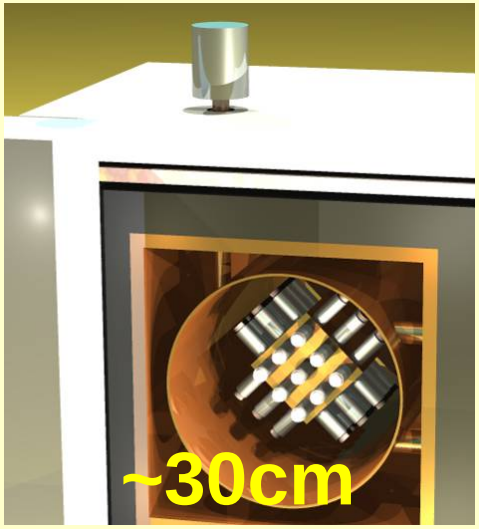
Collect 1 year of data
à 5.6 x10^{-9} pb



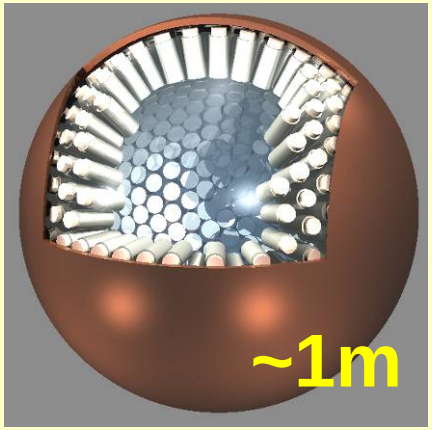
Experiments: XMASS

XMASS – multipurpose detector

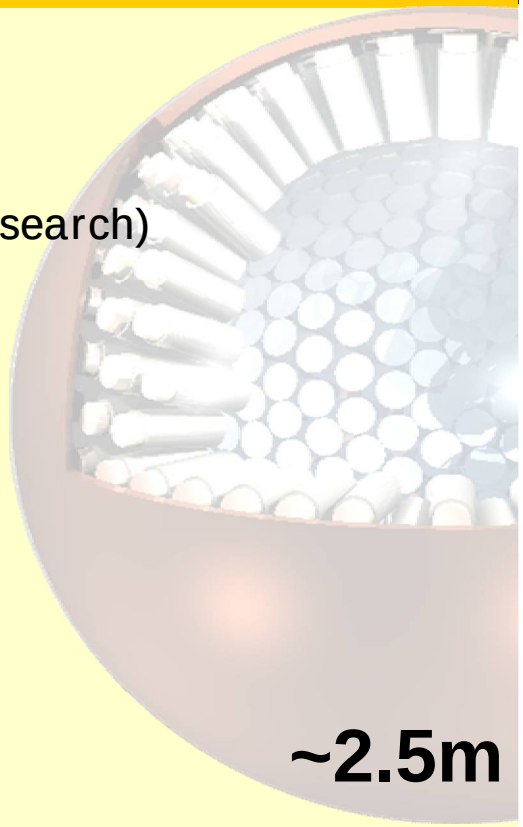
Xenon MASSive detector for Solar neutrino (pp/^{7}Be)
Xenon neutrino MASS detector (double beta decay)
Xenon detector for Weakly Interacting MASSive Particles (DM search)



Prototype detector (FV 3kg) R&D



~1 ton detector (FV 100kg) Dark matter search



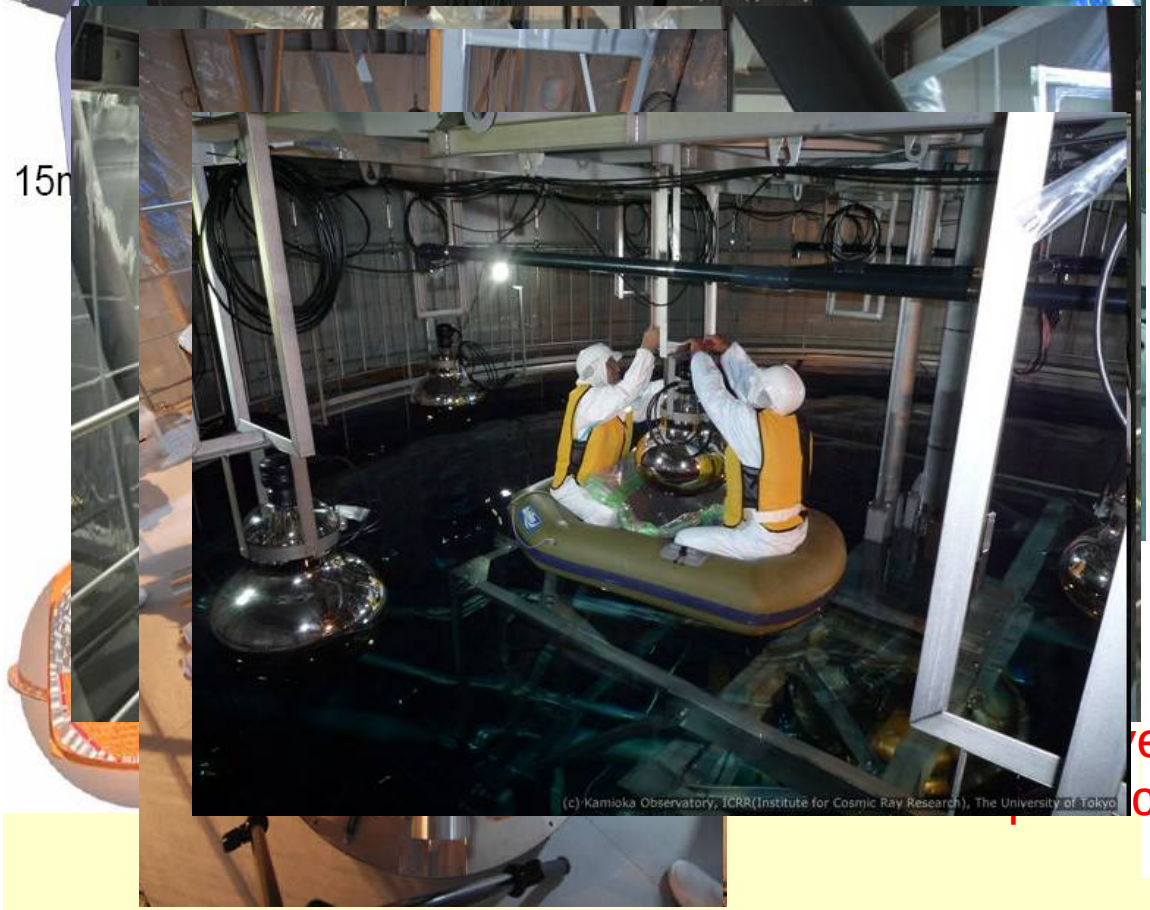
~20 ton detector (FV 10ton) Solar neutrinos Dark matter search

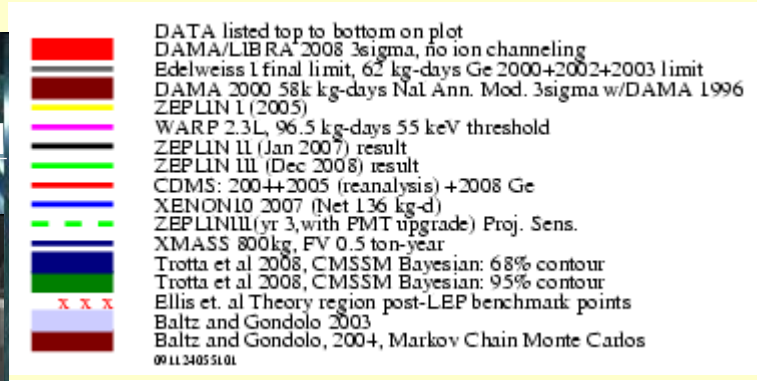
Confirmation of feasibilities of the ~1ton detector

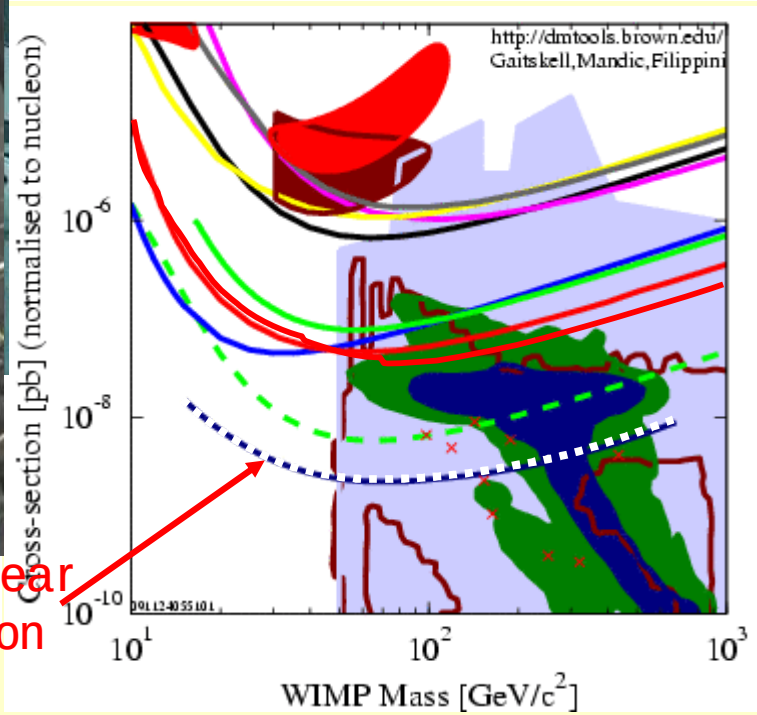
Experiments: XMASS

Assembling of XMASS can be tracked:

http://www-sk.icrr.u-tokyo.ac.jp/xmass/status-e.html



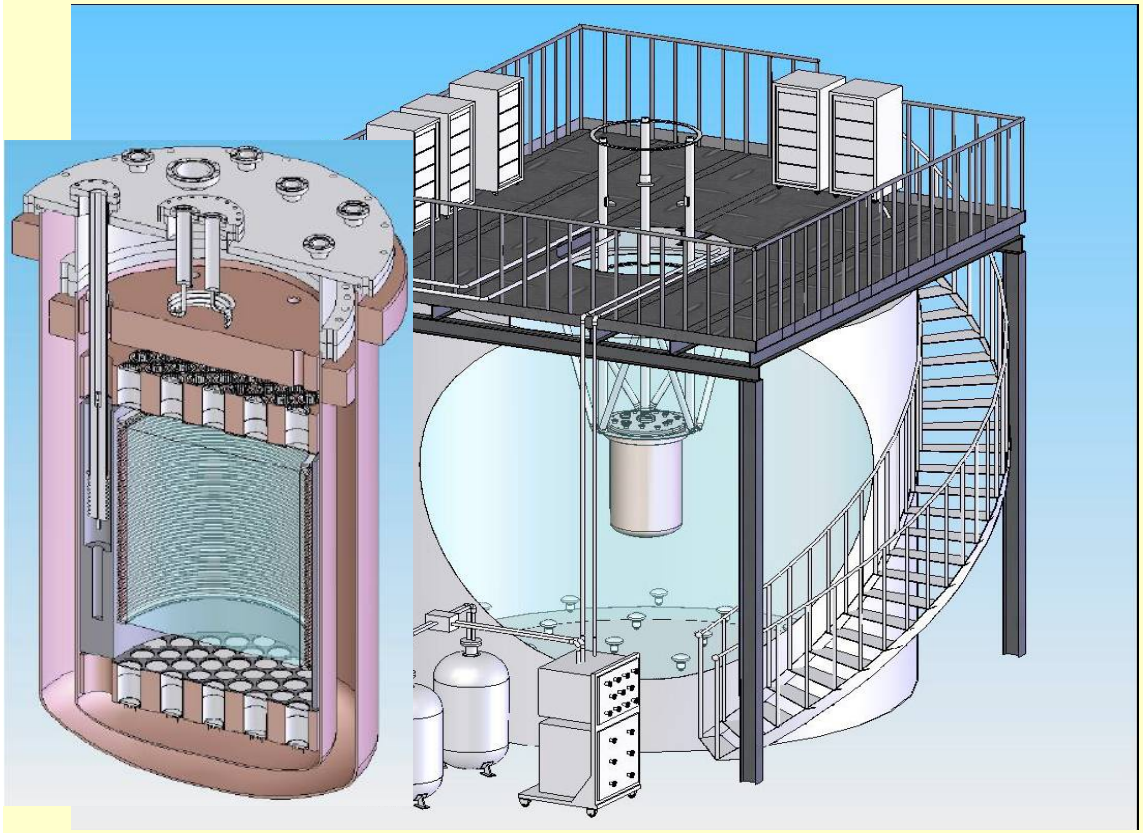


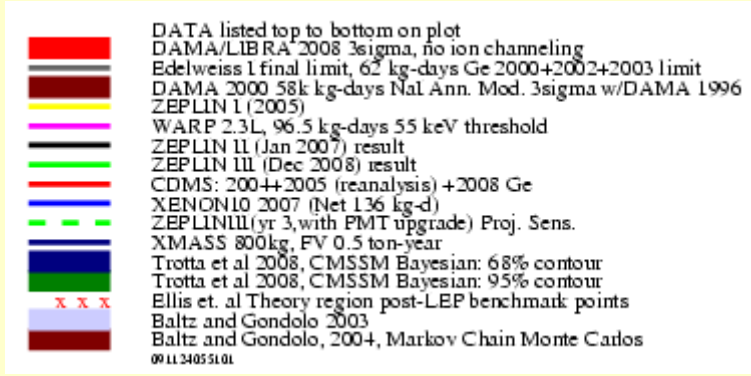


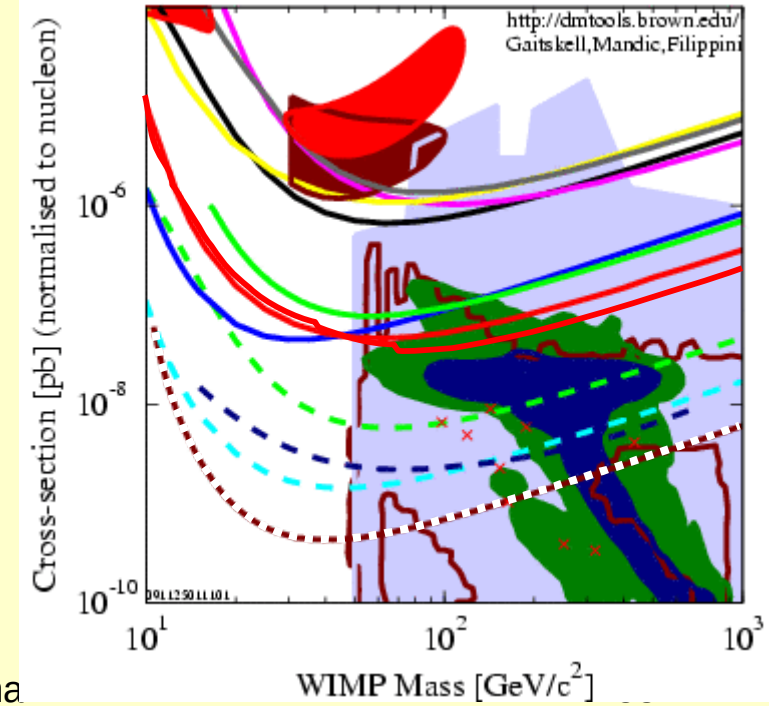
Future experiments: LUX

Large Underground Xenon detector

SUSEL – at Homestake; South Dakota





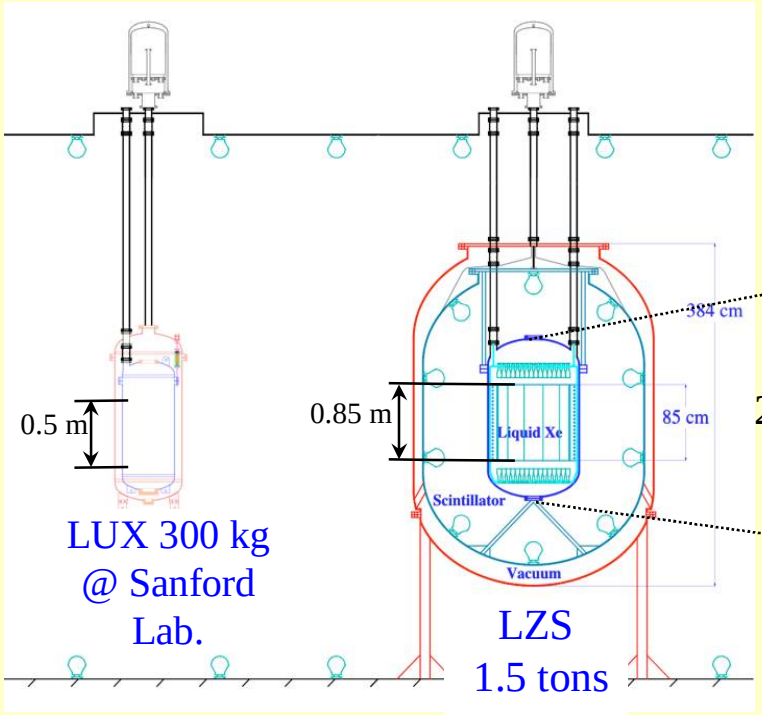


350 kg total (150 kg in target)

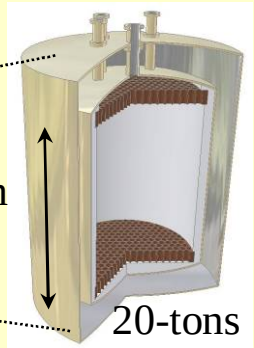
Large water shield Cherenkov readout - muon veto. **10-month exposition**

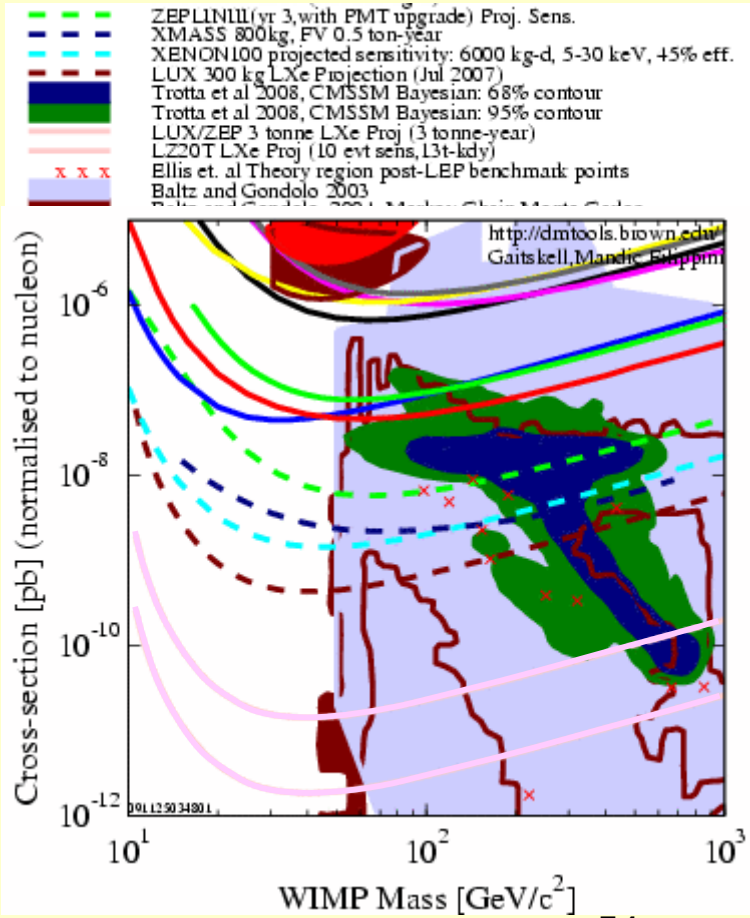
Projects: LZ

LZS@SUSEL – Sanford Underground Science and Engineering Lab. 4850 feet
LZD@DUSEL – Deep Underground Science and Engineering Lab. 8000 feet



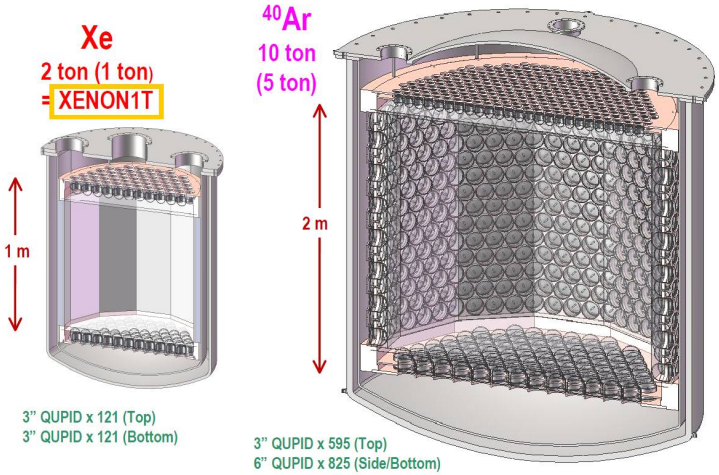
LZD



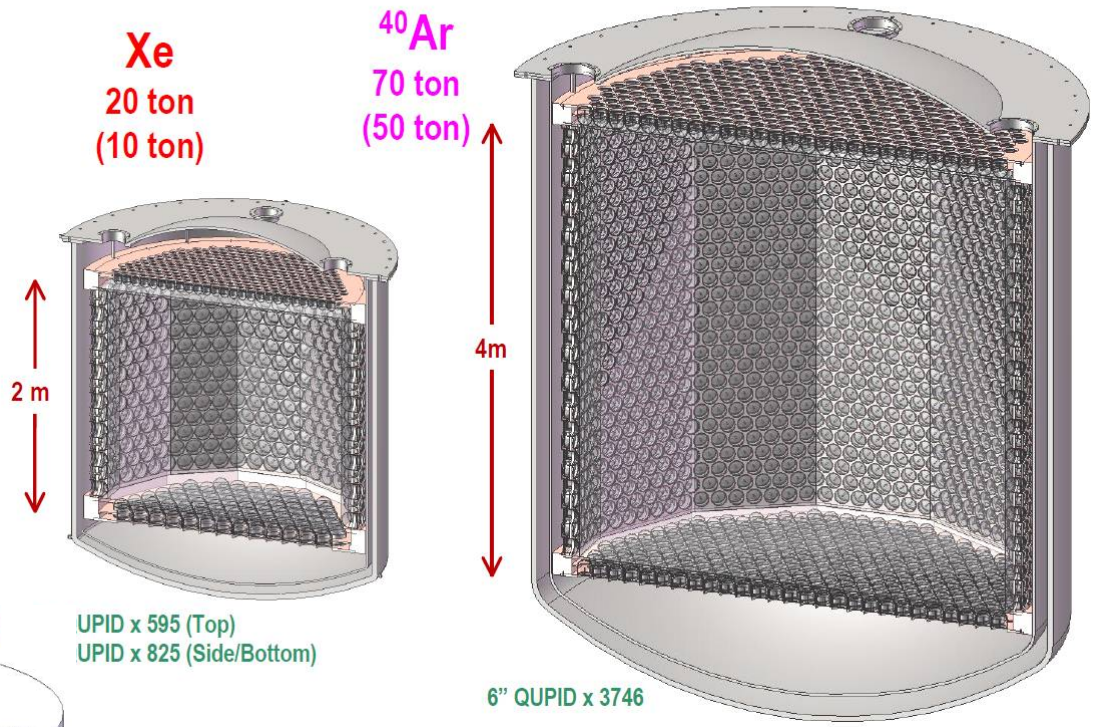


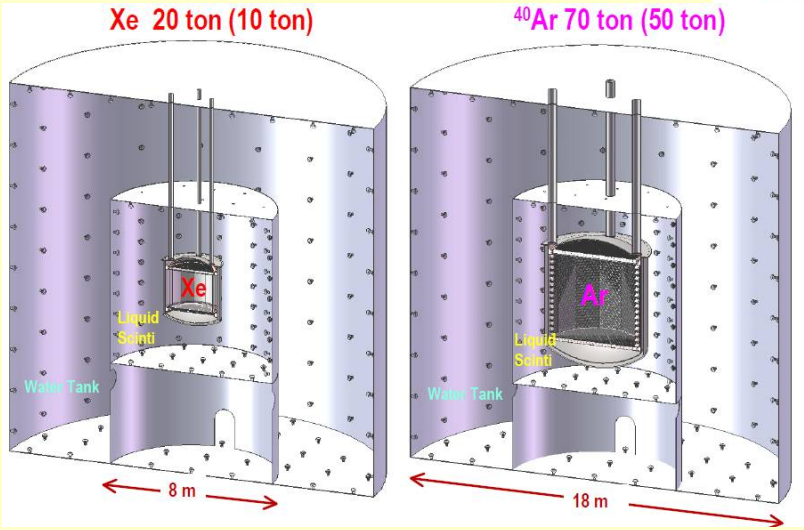
Projects: эксперимент MAX

MAX – G2 Detector



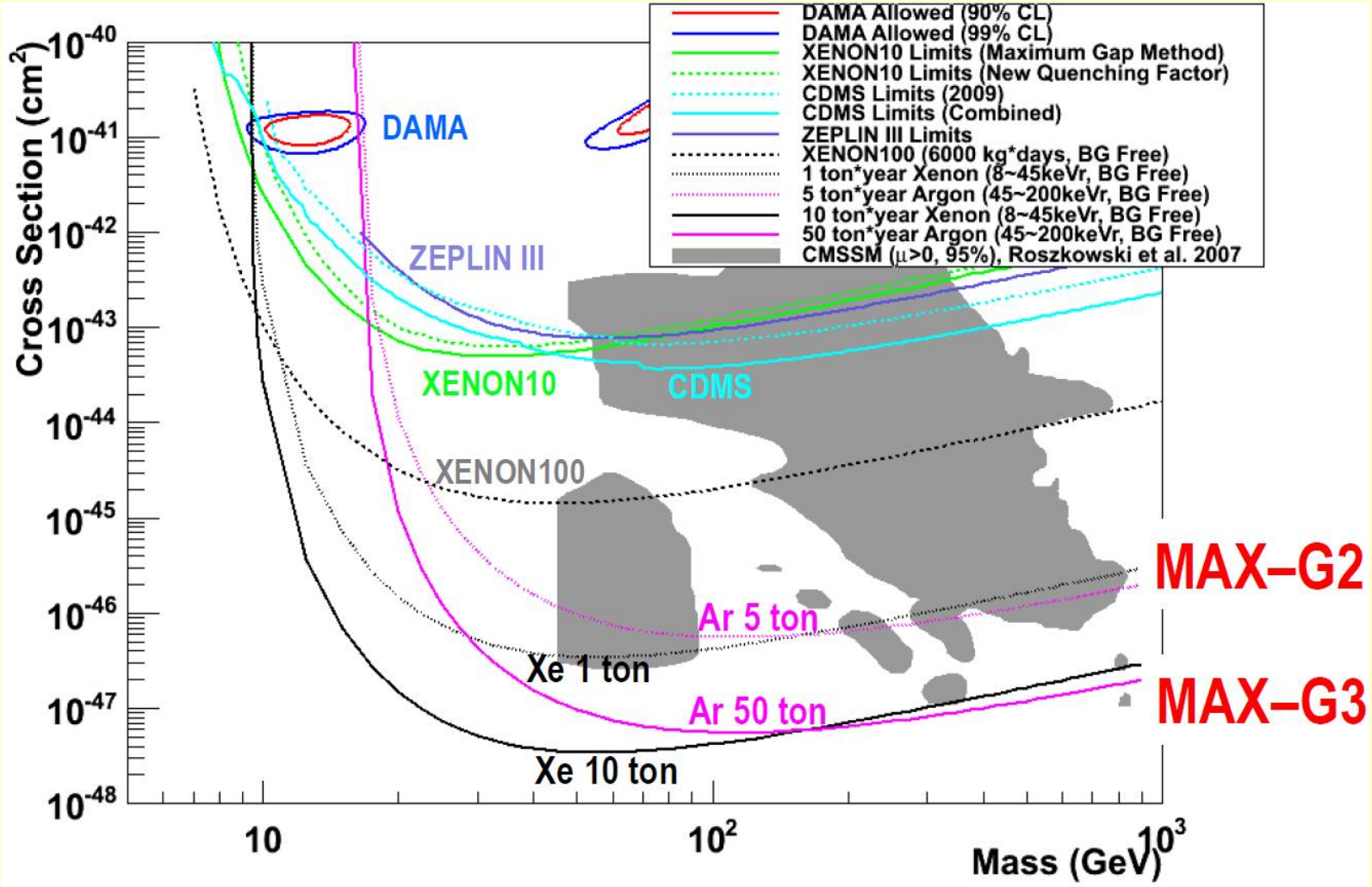
MAX – G3 Detector





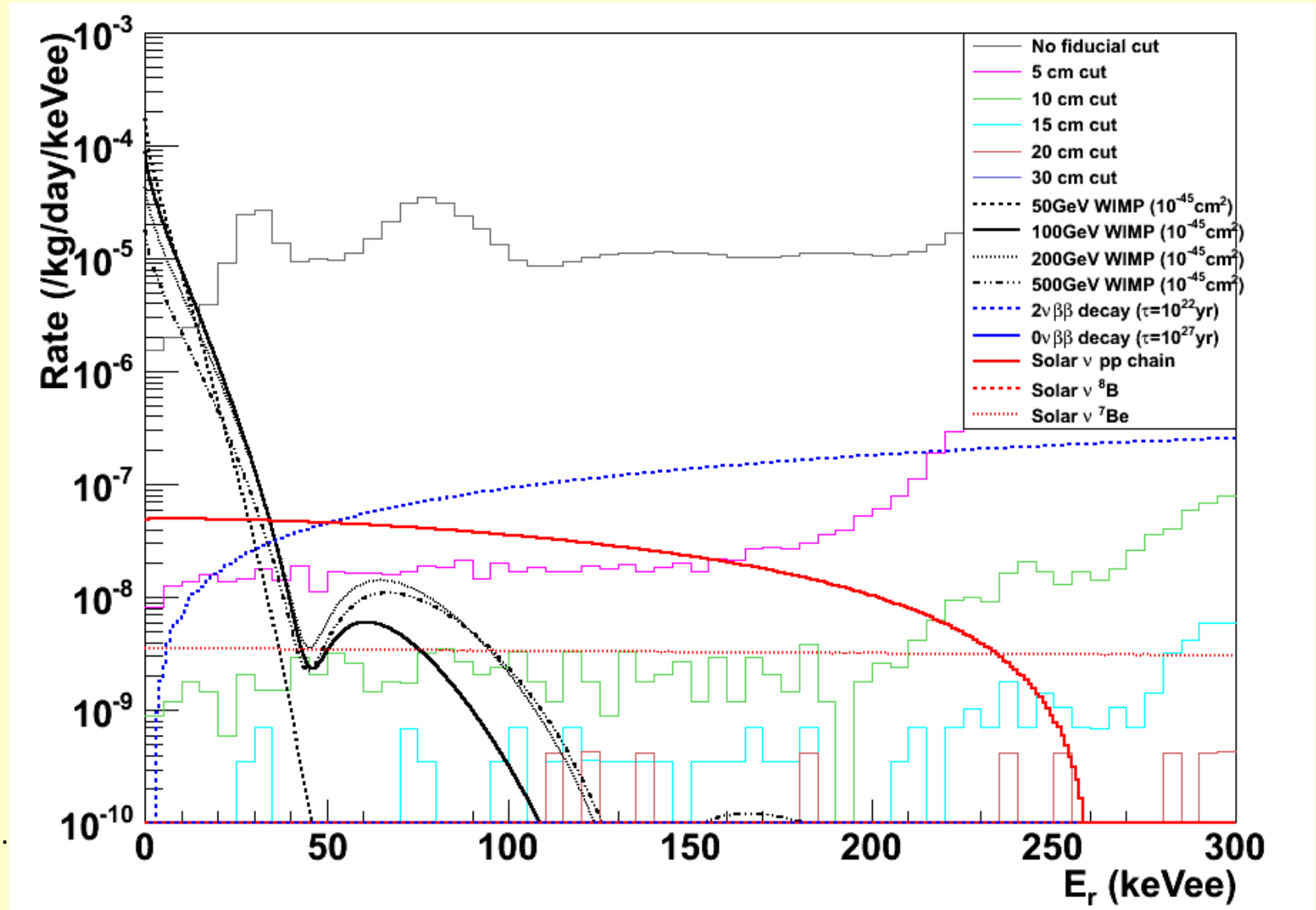
DUSEL –
Deep Underground Science and Engineering Laboratory
8000 feet ≈ 2500 м!
Южная Дакота, США

Projects: эксперимент MAX

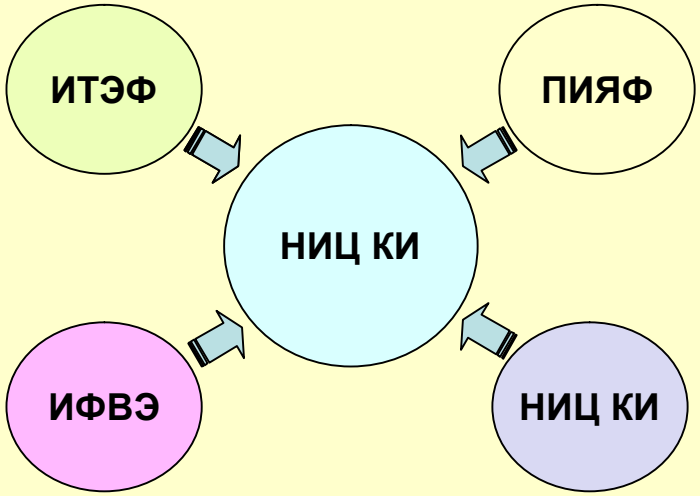


Projects: эксперимент MAX

After multi-hit cut and S2/S1 cut



Projects: что в России?



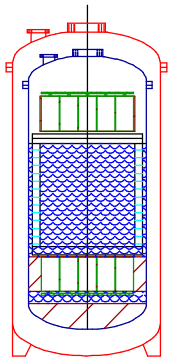
Коллаборация РЭД:
ИТЭФ, ПИЯФ, НИЦ КИ – НИЦ КИ
МИФИ, ИЯФ, НИИЯФ МГУ

В настоящее время идет разработка детекторов

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

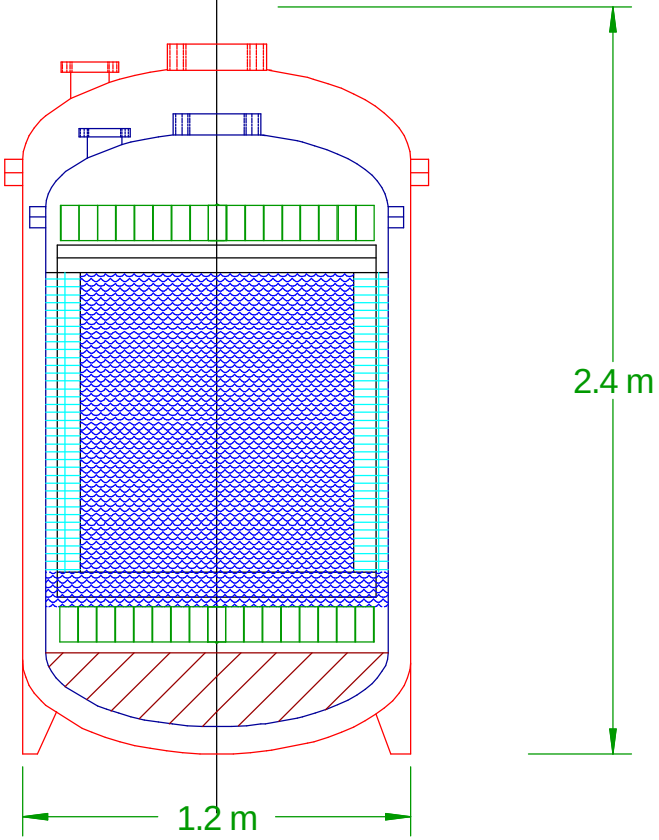
Для поиска ν-N когерентного рассеяния

RED-100



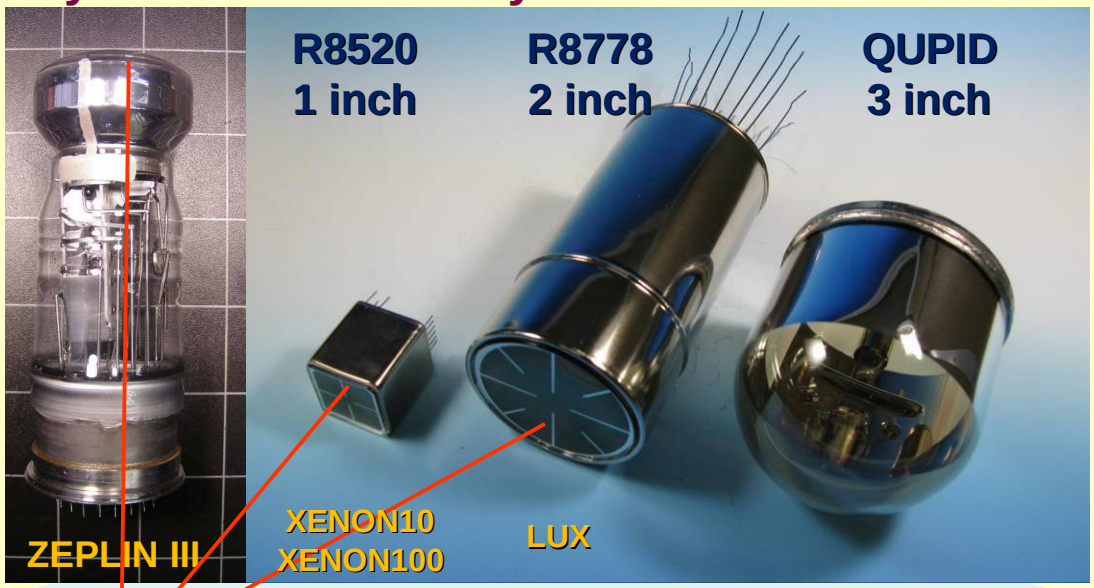
RED-3000

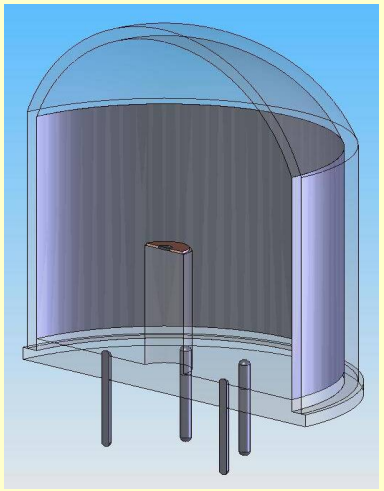
Для поиска Темной Материи



Special development: low-radioactive photodetectors

by ETL: **by Hamamatsu:**





A. Fukasawa et al., talk at TIPP 09

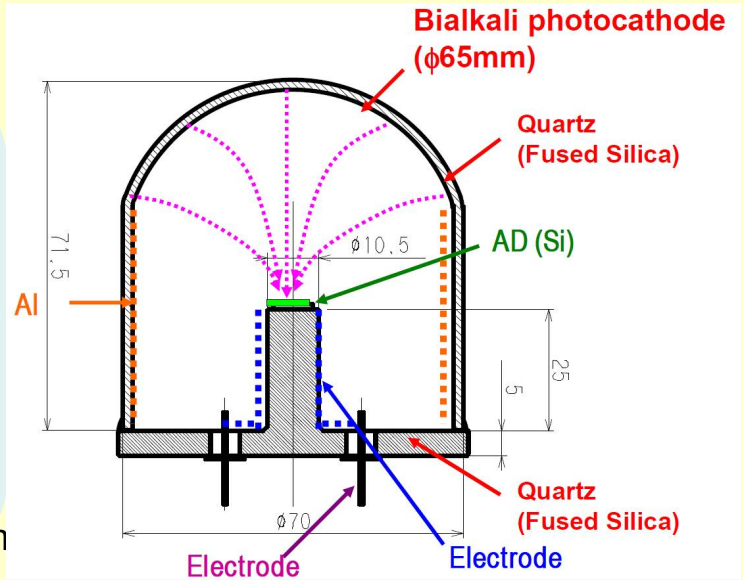
U - 0.17±0.04 mBq/PMT
Th - 0.20±0.09 mBq/PMT
K - 10±1 mBq/PMT

Metal strips to increase conductivity of photocathode at low temp.

LUX (R8778):
U - 9 mBq/PMT
Th - 3 mBq/PMT

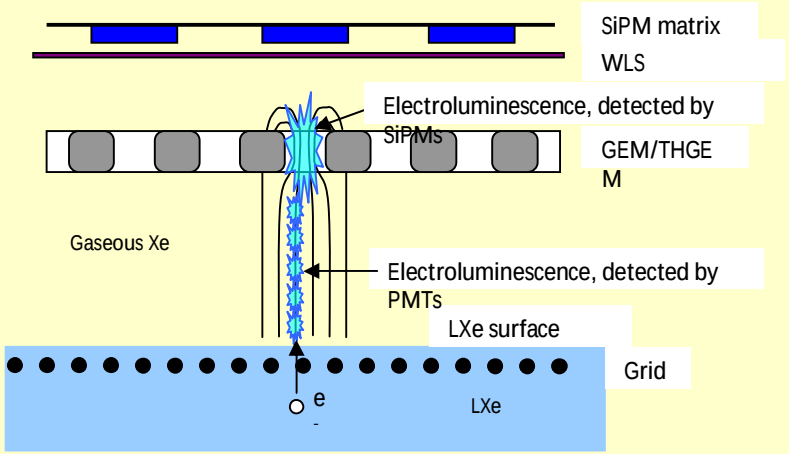
QUPID:
U - <0.3 mBq/PMT
Th - <0.3 mBq/PMT

XMASS (R8778mod):
U - 1.8 mBq/PMT
Th - 0.7 mBq/PMT
K - 1.4 mBq/PMT

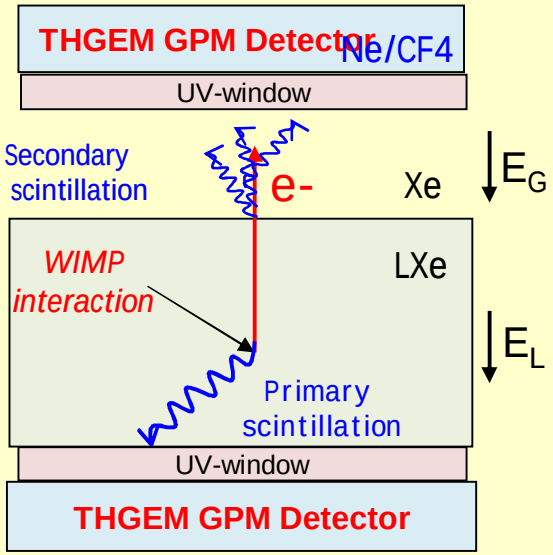


Special development: charge readout with THGEM (LEM)

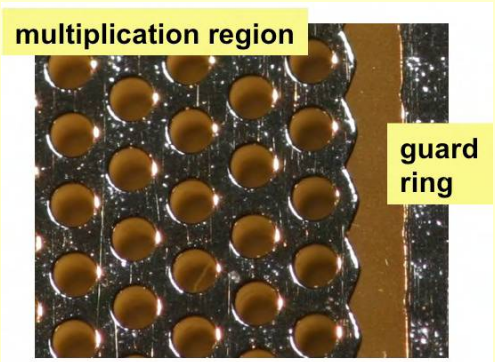
ITEP&INP

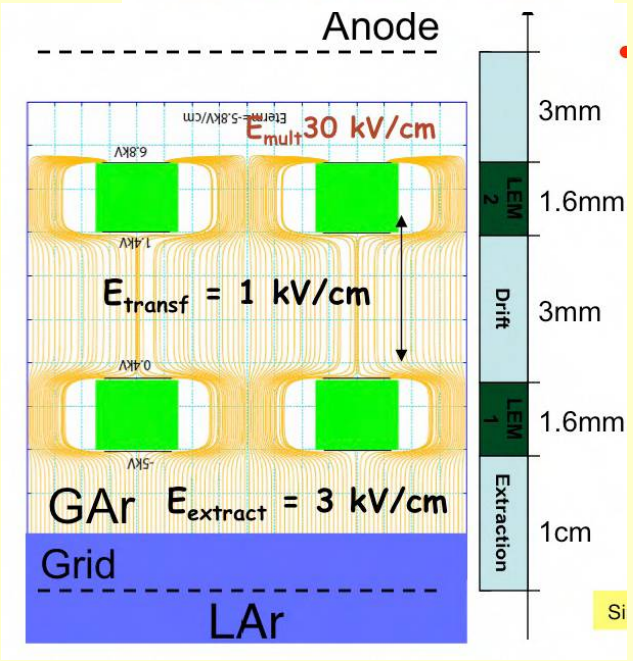


RD51: Weizmann/Nantes/Coimbra



accepted as a base option for ArDM





Заключение

- **Имеются очень сильные свидетельства существования Темной Материи.**
- **Эксперименты по прямому детектированию идут полным ходом.**
- **Благодаря прогрессу в технологиях, с начала экспериментов по настоящее время фон в установках уменьшен на 5 порядков величины!**
- **Супердетекторы (с массой более тонны) пройдут практически весь диапазон предсказаний SUSY.**

BACKUP SLIDES

Useful bibliography resources

- Internet recourses:
  - Dark Matter (**DM)** and DM related conferences: DM (http://www.physics.ucla.edu/hep/dm10/presentations.html), idm, Dark, TAUP, NANP
- Public pages of the DM experiments/collaborations: EDELWEISS, CDMS, ZEPLIN, Xenon, DAMA …
- Wikipedia: http://en.wikipedia.org/wiki/Dark_matter and many related topics therein
- http://elementy.ru/lib/25560/25563 - very good video lecture of V.A. Rubakov
- T.J. Sumner, Experimental Searches for Dark Matter – on-line review http://relativity.livingreviews.org/Articles/lrr-2002-4/
- Teilchenastrophysik (translated to Russian: **Астрофизика элементарных частиц**) H.V. Klapdor-Kleingrothaus, K. Zuber, published by Teubner B.G. GmbH (1997)
- D. Yu. Akimov, Experimental Methods for Particle Dark Matter Detection-Review, Instrum. Exp. Tech. 44 (2001) 575-617
- D. Akimov, Techniques and results for the direct detection of dark matter (review). Nuclear Instruments and Methods in Physics Research A 628 (2011) 50–58

Астрофизические свидетельства

Открыта галактика, состоящая из Тёмной Материи!

В феврале 2005 (arXiv:astro-ph/0502312)
астрономы из Cardiff University открыли галактику VIRGOHI21 практически полностью состоящую из Тёмной Материи!
В ней нет звёзд, только один водород видимый в линии 21 см; водород вращается, и его скорость не убывает с расстоянием
M_H:M_{total} = 1:1000

Projects: эксперимент MAX