Brennpunkte extragalaktischer Forschung

Silke Britzen

Max-Planck-Institut für Radioastronomie, Bonn

E-mail: sbritzen@mpifr-bonn.mpg.de
Web: www.mpifr-bonn.mpg.de/staff/sbritzen/

Auf ein Neues ...

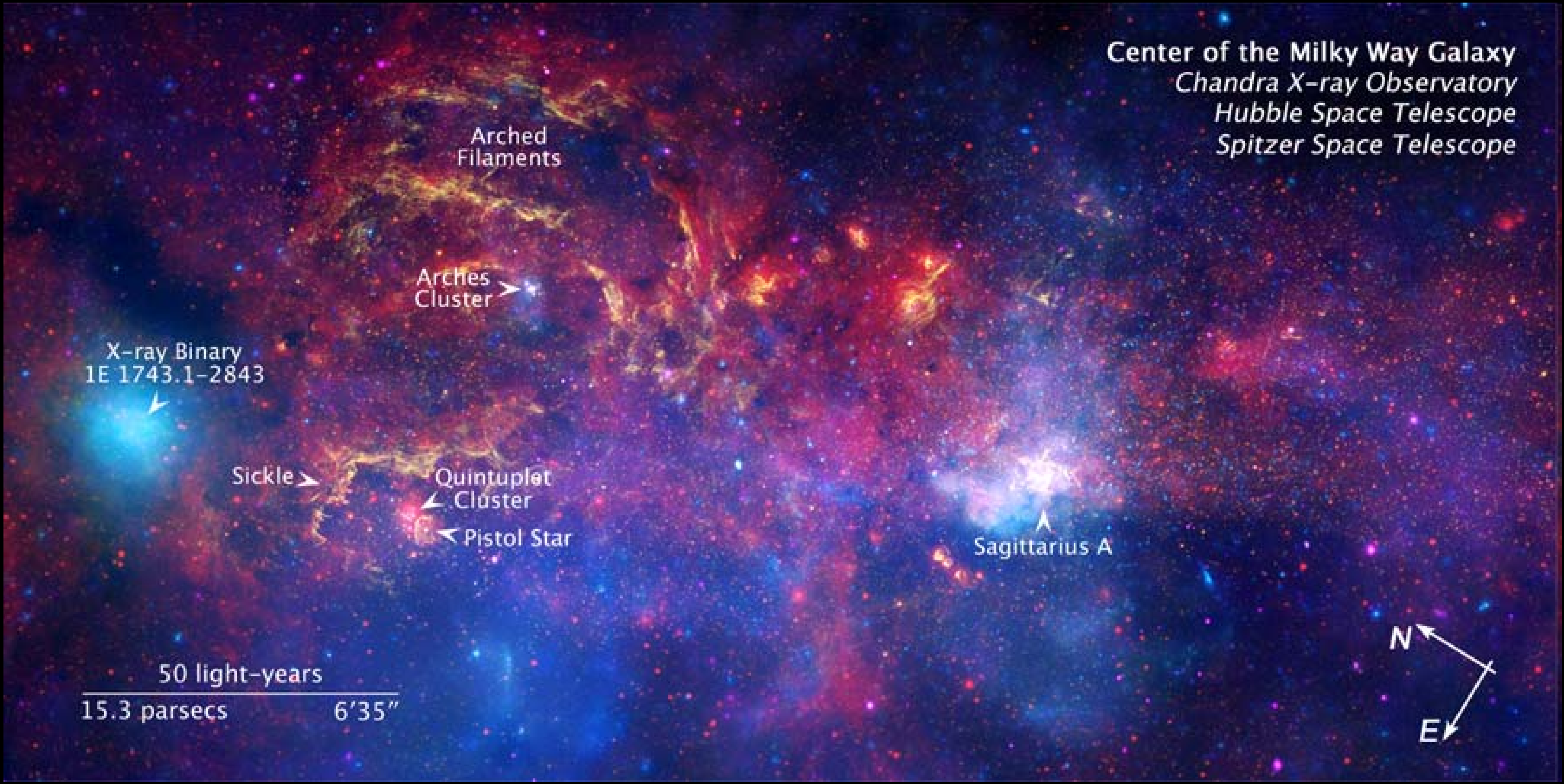
- 30.10. Gamma-Ray Bursts
- 13.11. GUT & TOE (Stringtheorie, etc.)
- 27.1l. LHC & Higgs
- 11.12. Higgs & die Physik jenseits des Standardmodells

Winterferien: 23.12.-06.01.10

- **08.01.10 Das Puzzle: Dunkle Materie, der LHC und die Frühphasen des Universums**
- 22.01.10 LHC: Materie & Antimaterie
- 05.02.10 Zeitfragen

Heute im Detail

- **11.12. Das Puzzle: Dunkle Materie, der LHC und die Frühphasen des Universums**
  - Nachtrag: Details zum Hubble Photo (und den Irritationen)
  - Dunkle Materie detektiert ?
    - Kurze Einführung
    - CDMS
    - PAMELA
    - DANA
  - Dunkle Materie, der LHC und die Frühphasen des Universums
    - Quark-Gluon Plasma
    - SUSY
    - ALICE

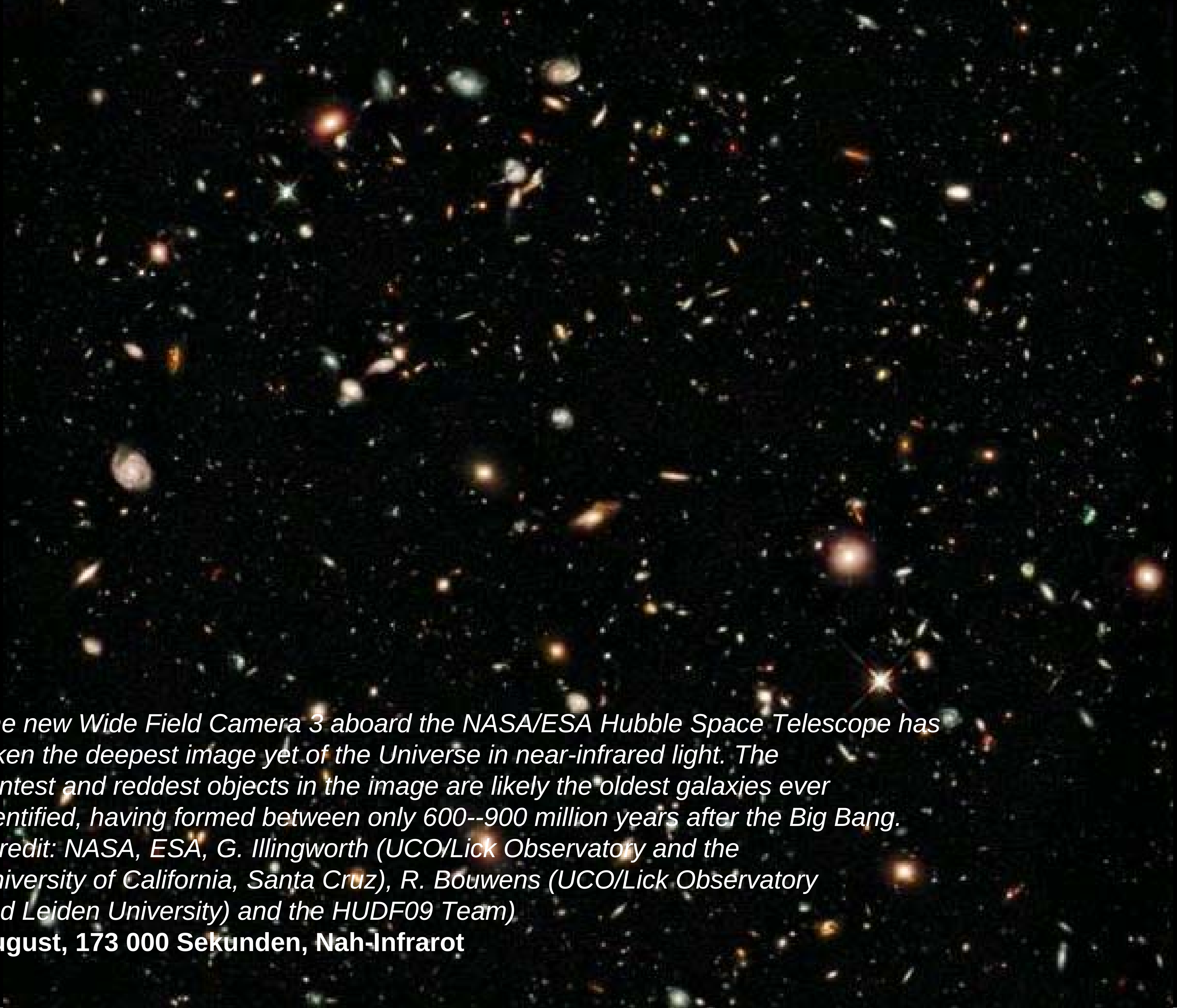


Center of the Milky Way Galaxy

Chandra X-ray Observatory

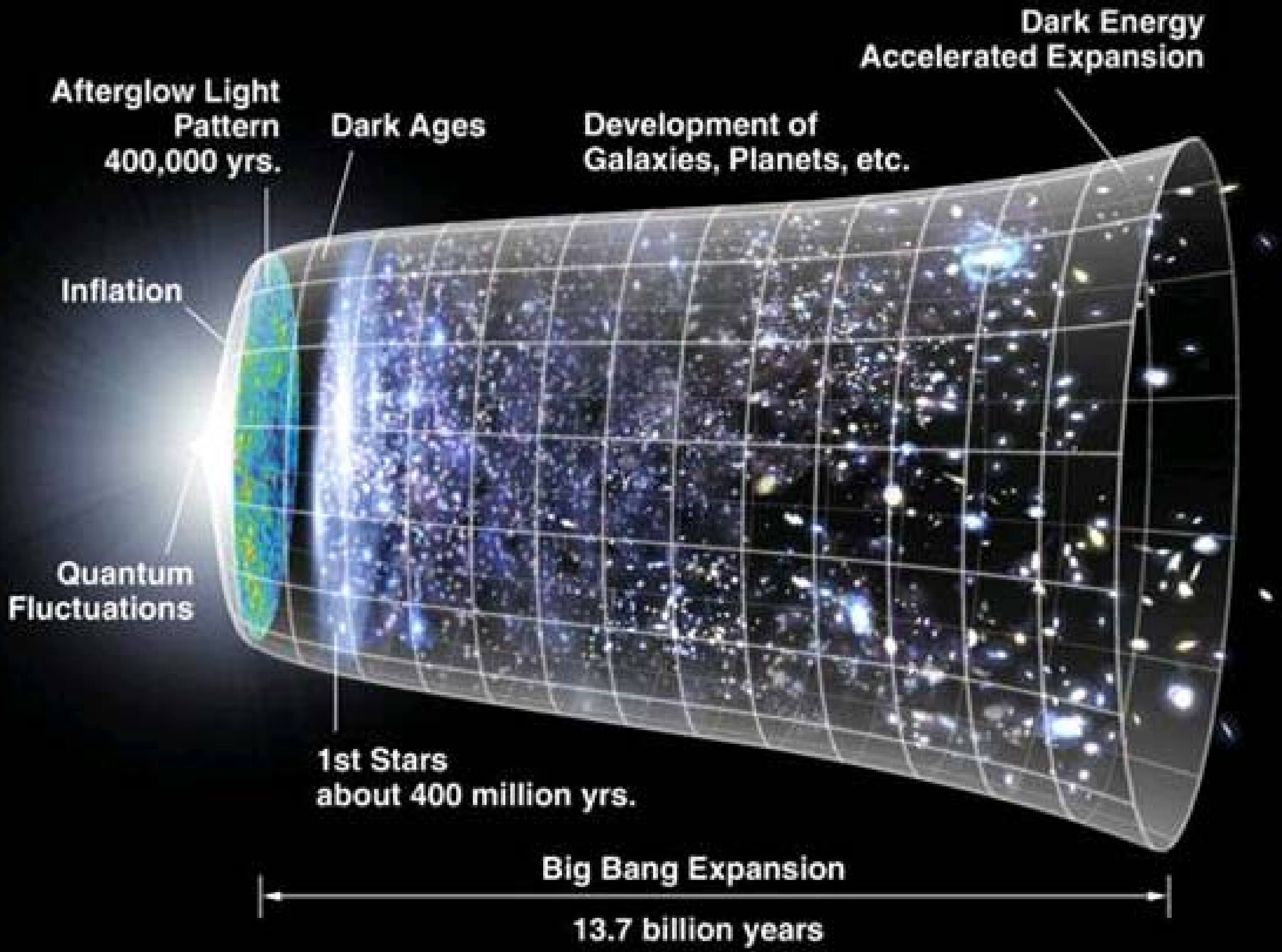
Hubble Space Telescope

Spitzer Space Telescope



The new Wide Field Camera 3 aboard the NASA/ESA Hubble Space Telescope has taken the deepest image yet of the Universe in near-infrared light. The faintest and reddest objects in the image are likely the oldest galaxies ever identified, having formed between only 600--900 million years after the Big Bang. (Credit: NASA, ESA, G. Illingworth (UCO/Lick Observatory and the University of California, Santa Cruz), R. Bouwens (UCO/Lick Observatory and Leiden University) and the HUDF09 Team)

August, 173 000 Sekunden, Nah-Infrarot



NASA/WMAP Science Team

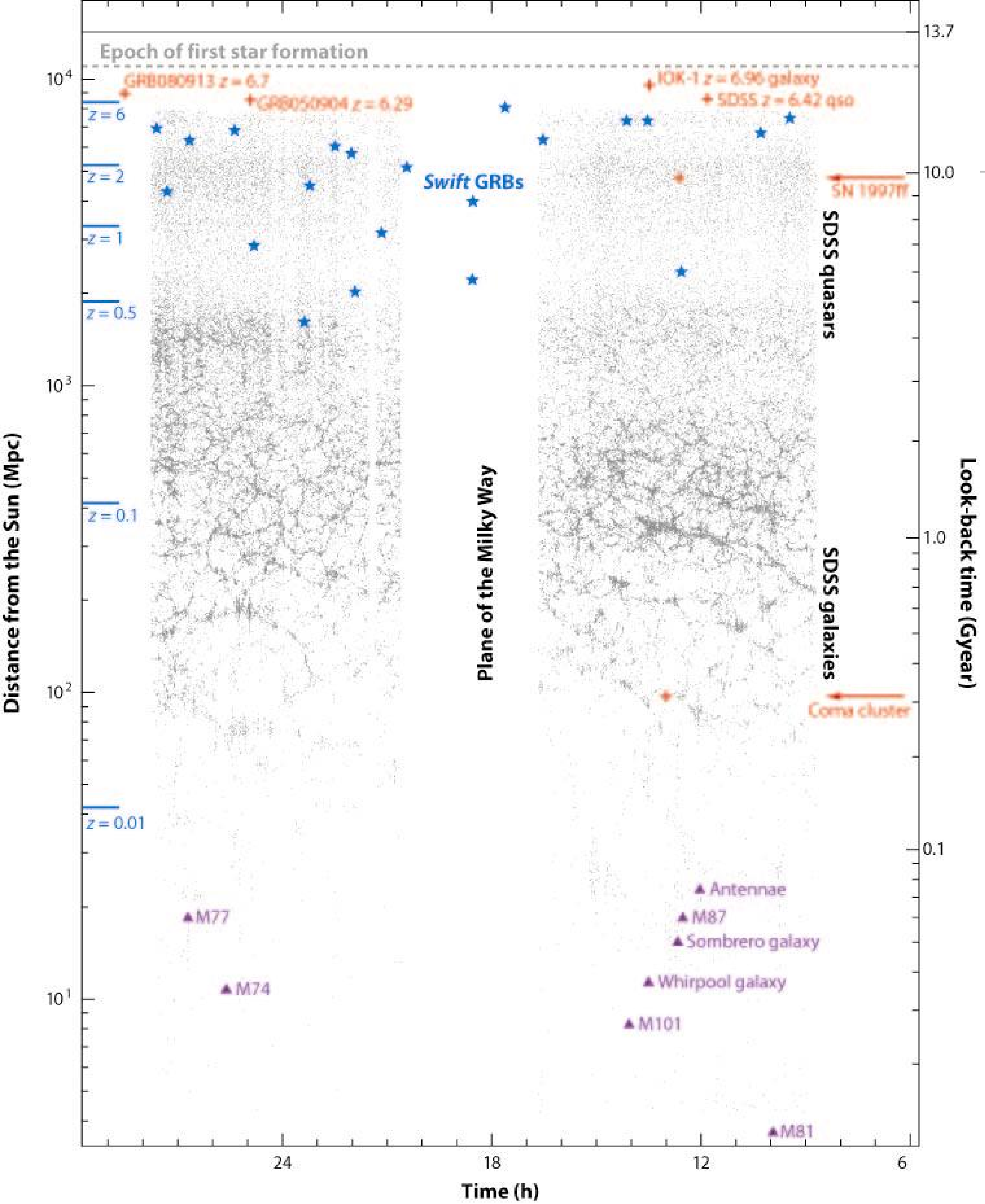
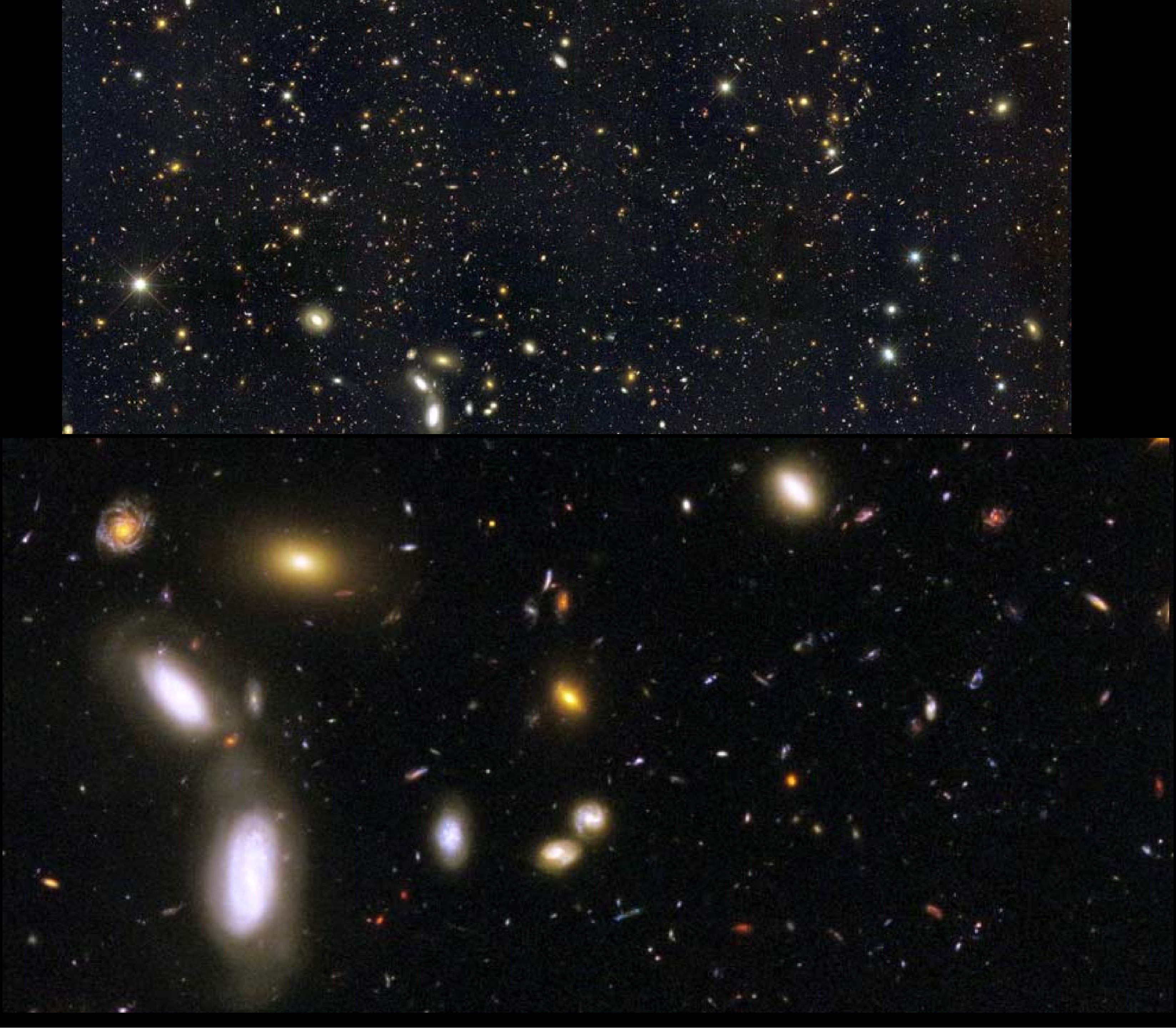
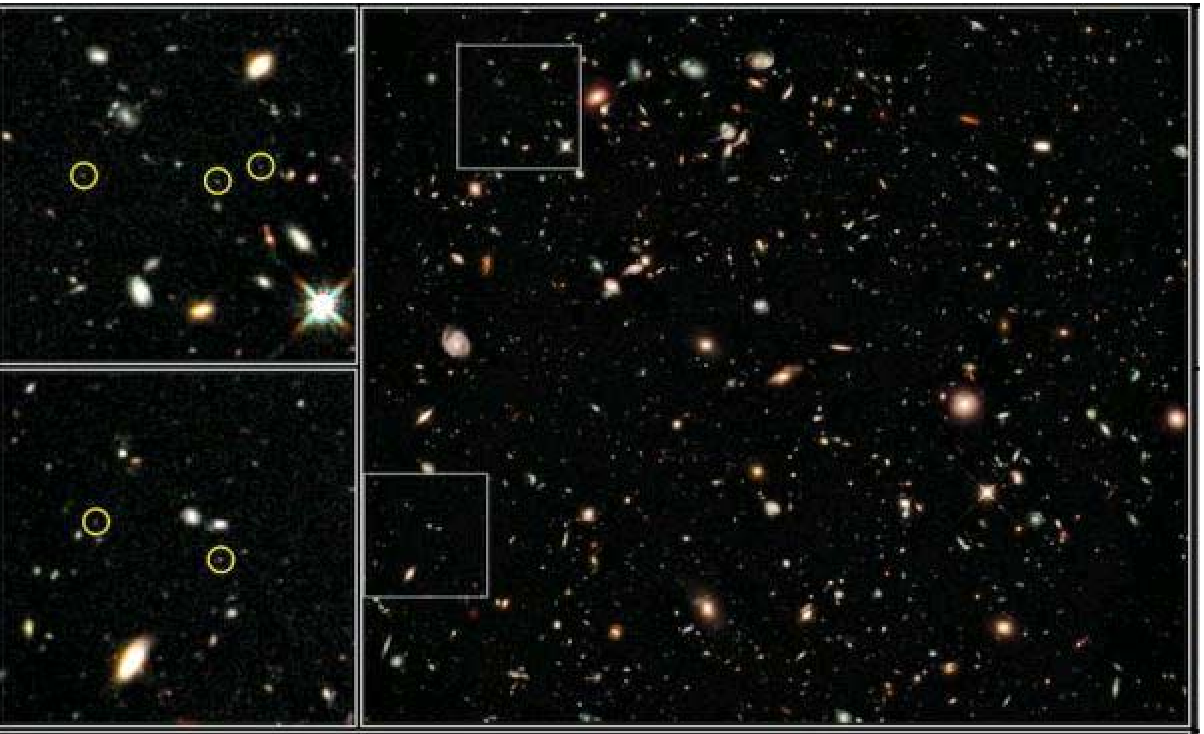


Figure 15 A 360° vista showing the entire sky, with visible structures stretching back in distance, time, and redshift. The most distant light we observe comes from the radiation leftover from the Big Bang: the CMB. As we descend the chart, we find the most distant objects known, followed by a web of Sloan Digital Sky Survey (SDSS) quasars and galaxies. Closer to home, we start to see a collection of familiar “near” galaxies (*purple triangles*). Also marked are all Swift GRBs with known distances (*blue stars*); SN 1997ff, the most distant type Ia supernova at $z = 1.7$; and the archetypal large galaxy cluster, the Coma cluster. The redshift distances of most distant GRBs are comparable to the most distant galaxies and quasars [adapted from Ramirez-Ruiz (2006a)].

Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617



Hubble: älteste Galaxien



Hubble Ultra Deep Field • Infrared

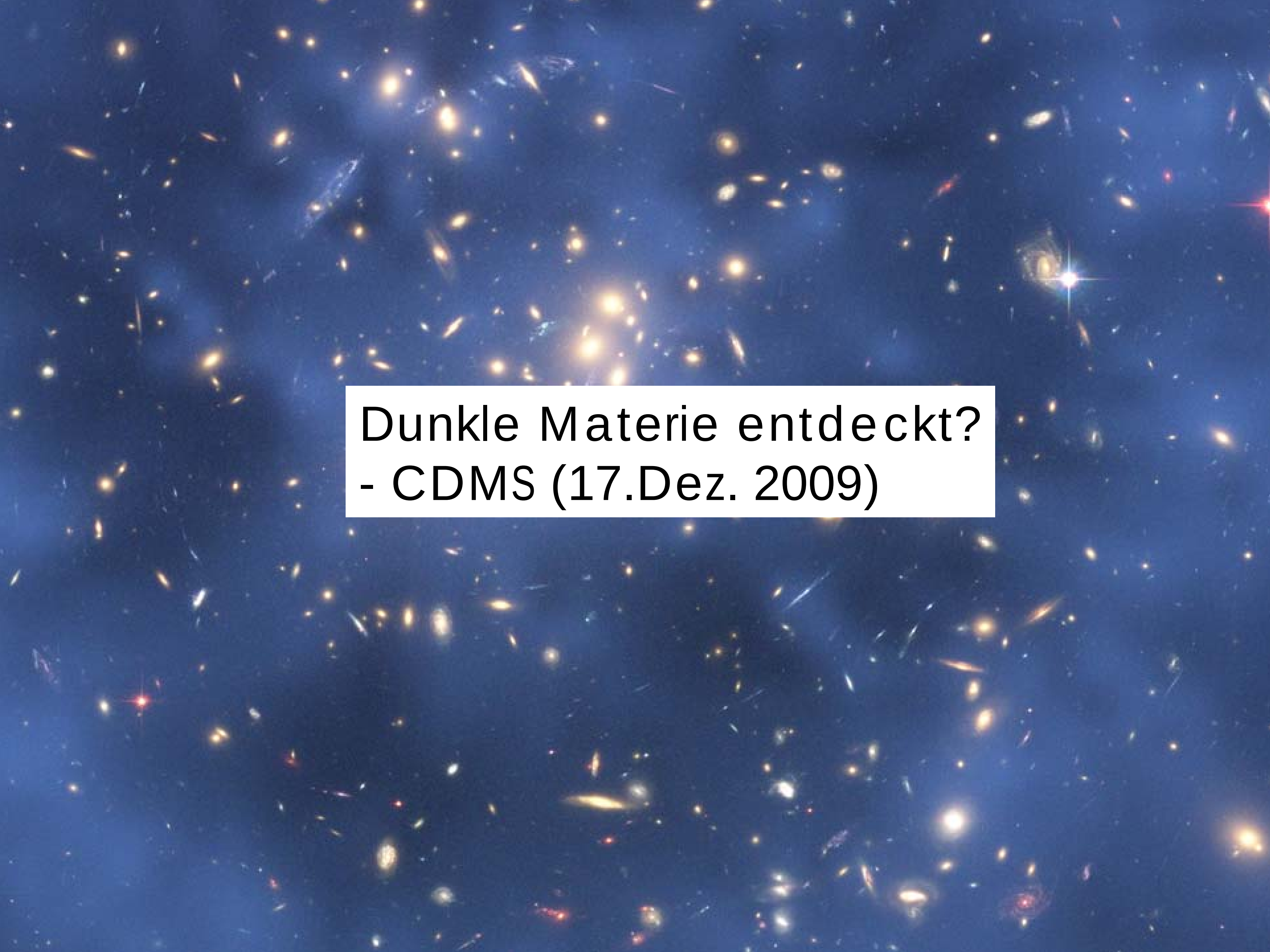
Hubble Space Telescope • WFC3/IR

NASA, ESA, G. Illingworth (UCO/Lick Observatory and University of California, Santa Cruz), and the HUDF09 Team STScI-PRC10-02

- Neue Panorama-Aufnahme zeigt 7500 Galaxien in den unterschiedlichsten Entwicklungsstadien – und aus fast allen kosmischen Epochen, die ältesten 600-800 Mio Jahre nach Urknall
- Höchste Rotverschiebungen vermutlich 7 - >8 (Ende der spektroskopischen Messmöglichkeiten – Objekte zu schwach)
- 5 Teams analysierten die Daten
- 15 paper bis zum 5.01.10
- Mit zunehmender Distanz werden die Formen der abgebildeten Galaxien immer
  - **irregulärer**
  - **blauer** (keine schweren Elemente)
  - **kleiner** (1/20 der Milchstraße)
  - **leichter** (1% der Milchstraße)

Das Problem

- Galaxien emittieren nicht genügend Strahlung, um Reionisation zu erklären!!
- Reionisation: zw. 400 und 900 Mio Jahre nach dem Urknall
- Galaxien liegen in dieser Reionisations-Epoche – reionisieren aber nicht genügend!!
- Vielleicht:
  - Hohe Dichte an schwachen Galaxien (unter Detektions-Grenze)
  - Frühere Welle an Galaxien-Bildung
  - Frühe Galaxien könnten extrem effizient in Reionisierung gewesen sein
  - Mini-Quasare? – noch unwahrscheinlicher …
  - Wir sehen das Ende der Ära der Reionisation, vielleicht sogar in die Ära der Reionisation (letzter wichtiger Gasphasenübergang im Universum)

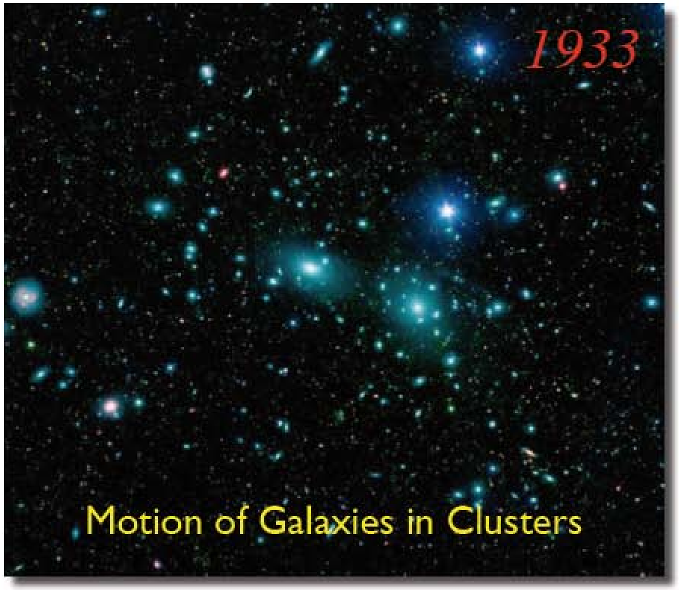


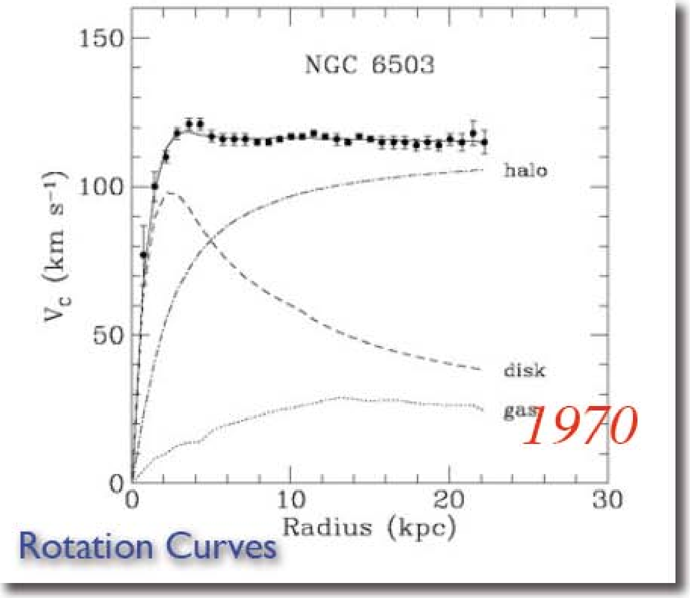
Dunkle Materie entdeckt?
- CDMS (17.Dez. 2009)

- **Thursday, 17 December 2009**
- **CDMS Live**

- 17:49. **It's official: 2 events**. One at 12 keV, the other at 15 kev.
- 17:49. There are additional 2 events very close to the cut window, approximately at 12 keV.
- 17:58. Now discussing the post-unblinding analysis and the statistical significance.
- 18:00. Both events were registered on weekends. Grad students having parties?
- 18:01. **The significance of the signal is less than two sigma.**
- 18:04. One of the events has something suspicious with the charge pulse. A long discussion unfolds.
- 18:12. **After post-unblinding analysis the signal significance drops to 1.5sigma (23 percent probability of the background fluctuation).**
- 18:14. The new limits on dark matter 4x10-44cm2 for a 70 GeV WIMP. Slightly better (factor 1.5) than the last ones.
- 18:17. Inelastic dark matter interpretation of the DAMA signal is not excluded by the new CDMS data.
- 18:18. **Nearing the end. The speaker discusses super-CDMS, the possible future upgrade of the experiment.**
- 18:20. **Summarizing, no discovery. Just a hint of a signal but with a very low statistical significance**. Was fun anyway.
- 18:20. So much for now. Good night and good luck. The first theory papers should appear on Monday

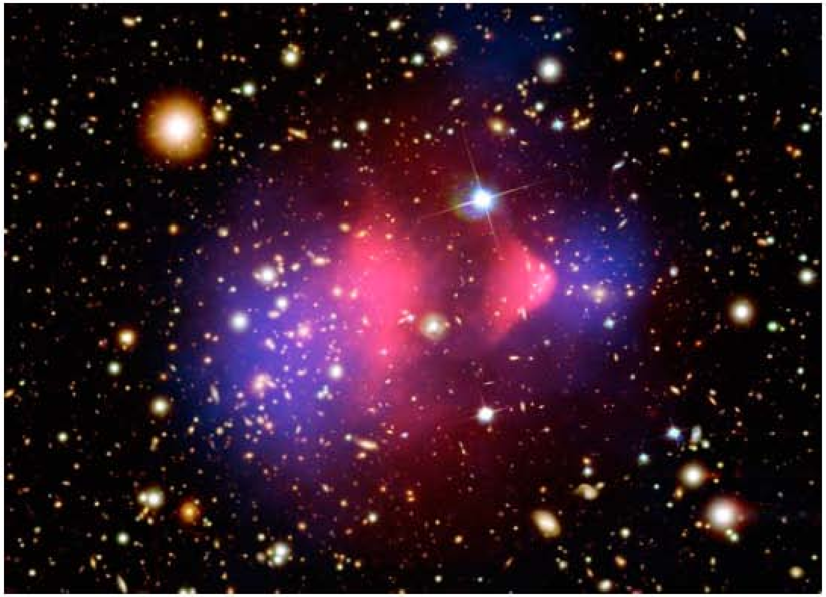
The Evidence for Dark Matter





The Bullet Cluster

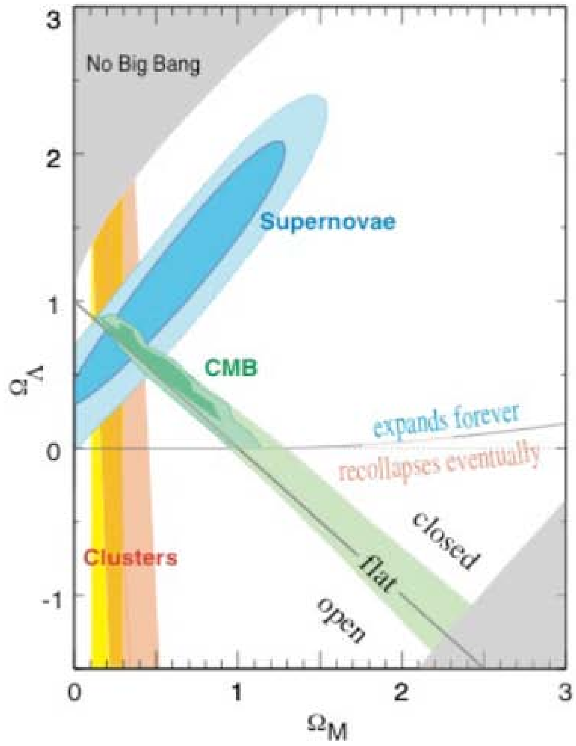
- Observations of the **Bullet Cluster** in the **optical** and **x-ray** fields combined with **gravitational lensing** provide compelling evidence that the dark matter is particles.
- Gravitational lensing tells us mass location
  - **No dark matter = lensing strongest near gas**
  - **Dark matter = lensing strongest near stars**

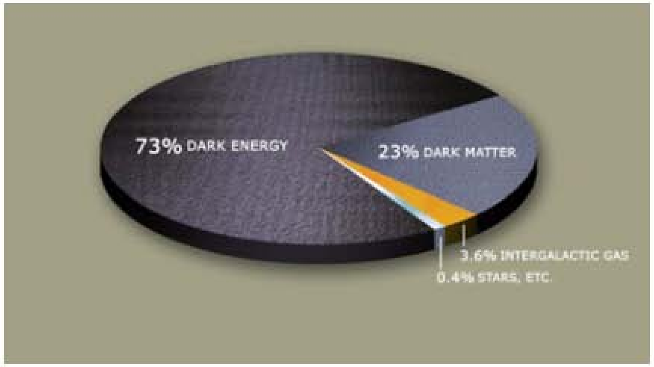


Clowe et al., ApJ, 648, 109

blue = lensing
red = x-rays

The Cosmic Pie





- Measurements from CMB + supernovae + LSS indicate that **~23% of our Universe is composed of dark matter**.

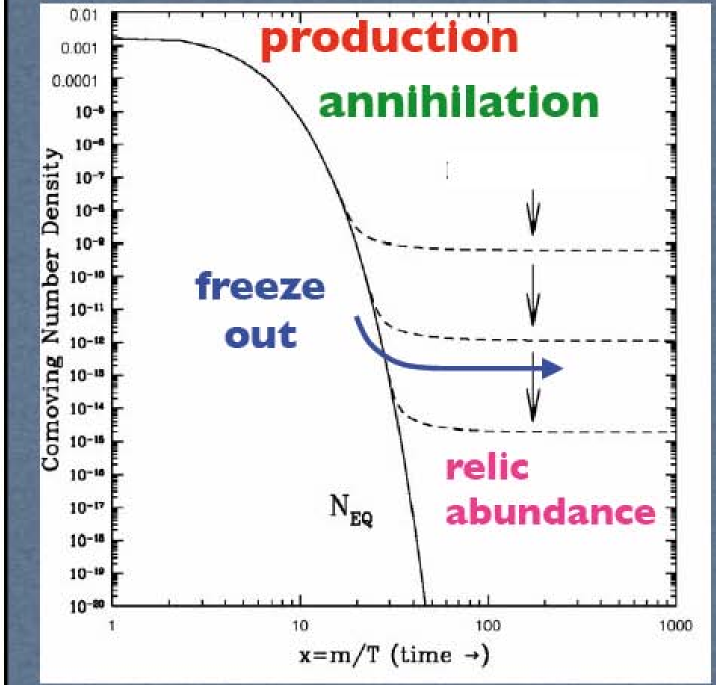
Kandidaten für dunkle Materie

- cold dark matter (über 90% der DM): <u>nicht-relativistisch</u>
  - wenn Rekombinationsrate abfällt (wg. Hubble-Expansion)
  - Zusammenhang σ – v bei Auskopplung
  - Teilchenmasse im GeV-Bereich
- hot dark matter (nur wenige %): <u>relativistisch</u>
  - also bspw. Neutrinos

- Um für DM in Frage zu kommen:
  - stabil auf kosmologischen Zeitskalen
  - sehr schwache Wechselwirkung mit elektromagnetischer Strahlung (wenn überhaupt)
  - Masse (bzw. Dichte) geeignet, um Phänomene zu erklären

- Möglichkeiten:
  - WIMPs (= weakly interacting massive particles)
  - Axion
  - primordial black holes (Stichwort MACHOs)
  - uneigentliche Kandidaten (MOND, kosm. Konstante, $G \sim t^{-1}$, siehe [2])

A Candidate is Born!



$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27}}{< \sigma_\chi v >}$$

Weakly Interacting Massive Particles

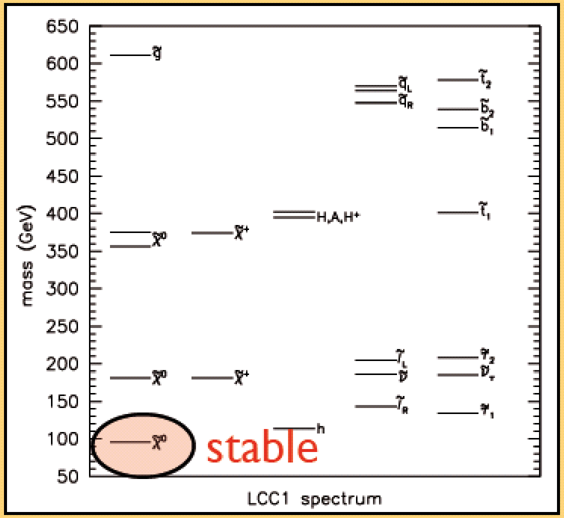
- New stable, **massive** particle produced thermally in early universe
- **Weak-scale** cross-section gives observed relic density

WMAP $0.095 < \Omega h^2 < 0.129$

$$\sigma_\chi \approx 10^{-37} cm^2$$

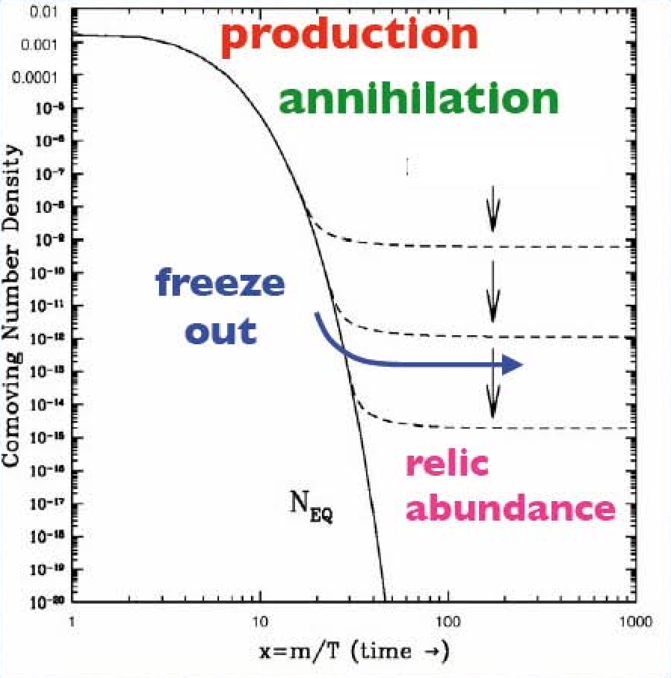
Motivated by Particle Physics Too!

- New TeV physics is required to explain radiative stability of weak scale.
  - SuperSymmetry
  - Extra Dimensions
  - ...
- These theories give rise to convenient dark matter candidates.
  - LSP, LKP

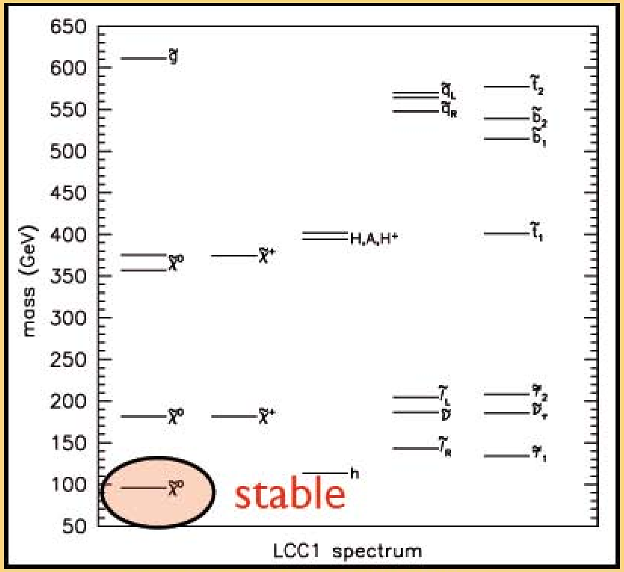


Baltz et al., PRD **74**, 103521 (2006)

Happy Coincidence!



$$\Omega_\chi h^2 \approx \frac{3\times10^{-27}}{<\sigma_\chi v>}$$



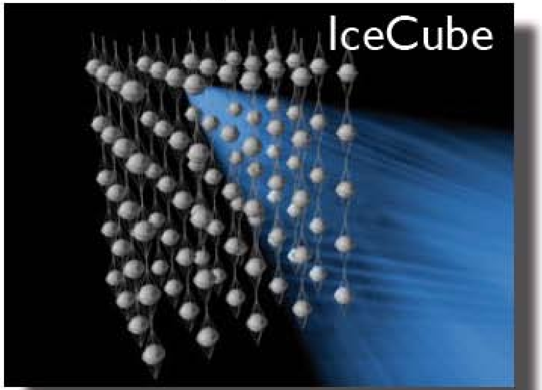
Baltz et al., PRD **74**, 103521 (2006)

$$\sigma_\chi \approx 10^{-37} cm^2$$

How Do We Detect WIMPs?

WIMP scattering on earth

WIMP production on earth

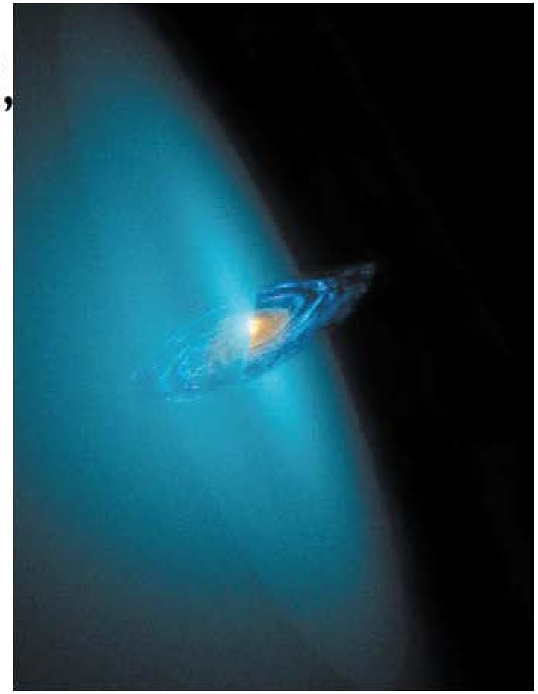


WIMP
annihilation in
the cosmos

Direct Detection Event Rates

"Spherical Cow" Halo Model

local density ($\rho_{o)}$ = 0.3 GeV/cm^3,
Maxwellian distrubution,
rms velocity ($v_{o)}$ = 220 km/s,
v_{esc} = 650 km/s



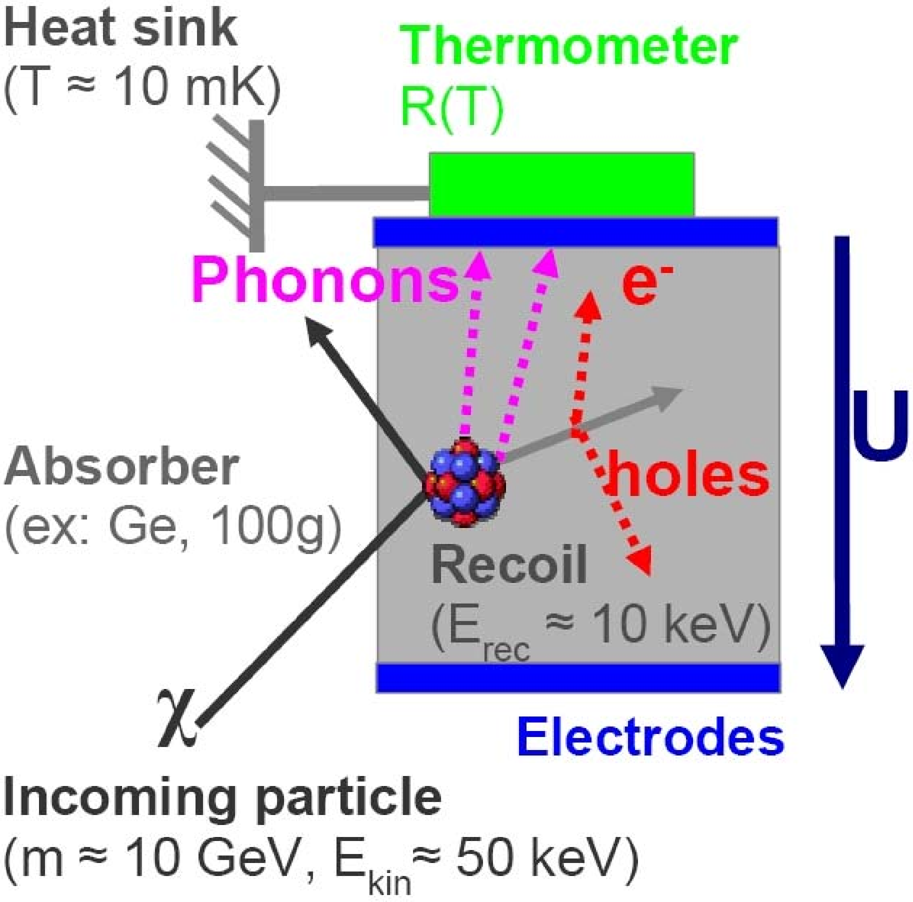
Interaction Details

spin-independent,
coherent scattering

→ $\sigma_\chi \propto A^2$

WIMPs

- weakly interacting massive particles
  - Masse ~ 10GeV bis einige TeV
  - Wirkungsquerschnitte ~schwache WW
  - cold dark matter
- mögl. Kandidat: LSP
  - „lightest super-symmetric particle“
- direkte Suche: „Hinsetzen und warten“
  - Zusammenstöße WIMP-Atomkern => Rückstoß-Energie des Kerns kann detektiert werden



Rückstoß-Kinematik

$$E_1 = \tfrac{1}{2} M_D \beta^2 \qquad r = 4 M_T M_D / (M_T + M_D)^2$$

mit:

M_D, M_T den Massen von WIMP und Target-Nukleus

β der WIMP-Geschwindigkeit

θ dem Streuwinkel im Schwerpunkts-System

Rückstoß-Energie:

$$E_R = E_1 r (1 - \cos\theta)/2$$

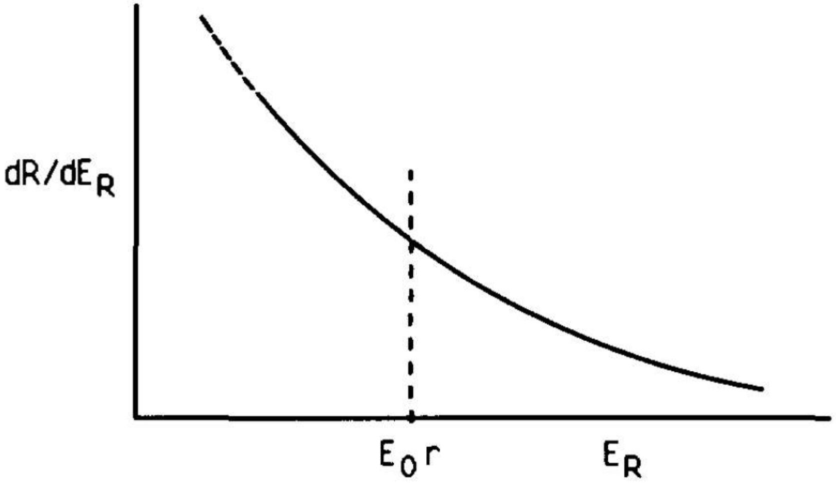
nimmt man eine galaktische Geschwindigkeitsverteilung an (Maxwell-Vert. um β_0):

$$\mathrm{d}n(\beta)/\mathrm{d}\beta = n_0 (\pi \beta_0^2)^{-3/2} 4\pi\beta^2 \exp[-(\boldsymbol{\beta} + \boldsymbol{\beta}_e)^2/\beta_0^2]$$

erhält man als diff. Ereignisrate (für β_e=0)

$$\mathrm{d}R/\mathrm{d}E_R = (R_0/E_0 r) \exp[-E_R/E_0 r]$$

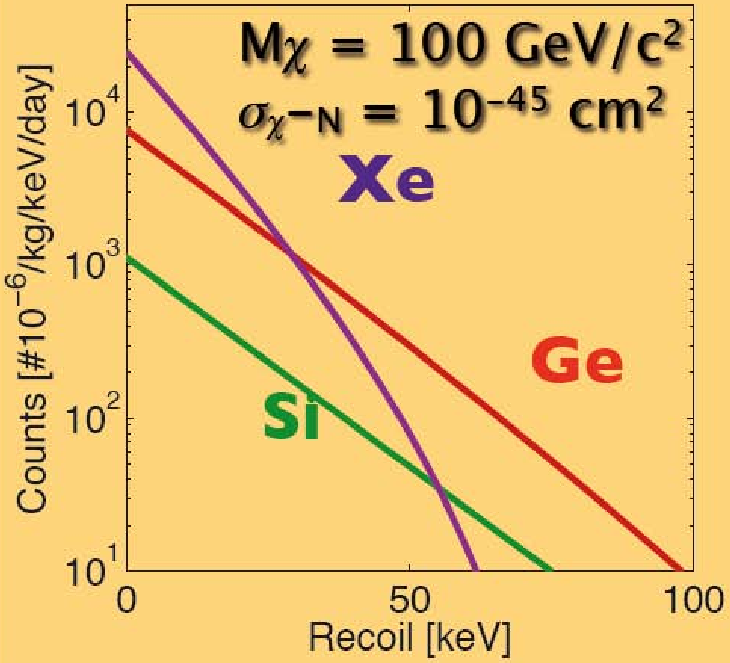
mit $R_0 = n_0 (2/\pi^{1/2}) \beta_0 c \sigma_T (6 \times 10^{26}/A)\ \mathrm{s}^{-1}\ \mathrm{kg}^{-1}$



Direct Detection Event Rates

- Elastic scattering of a WIMP deposits small amounts of energy into recoiling nucleus (~ few 10s of keV)
- Featureless exponential spectrum
- **Expected rate: < 0.01/kg-d**
- Radioactive background of most materials higher than this rate.

WIMP Differential Event Rate

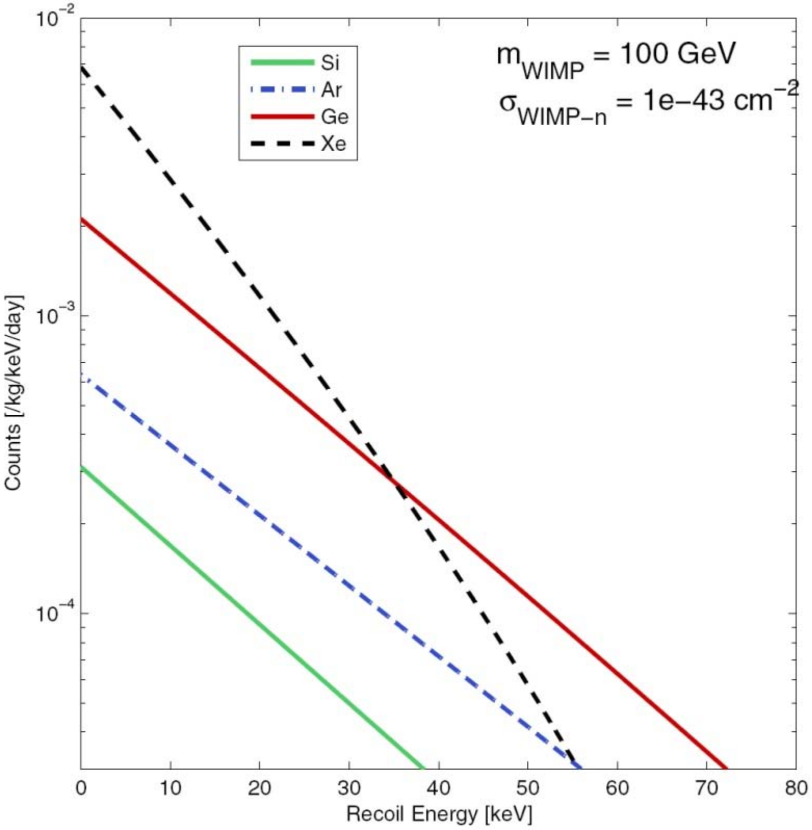


SLAC, Dec. 17, 2009

Jodi Cooley, SMU, CDMS Collaboration

WIMP-Signatur: Abhängigkeit von target

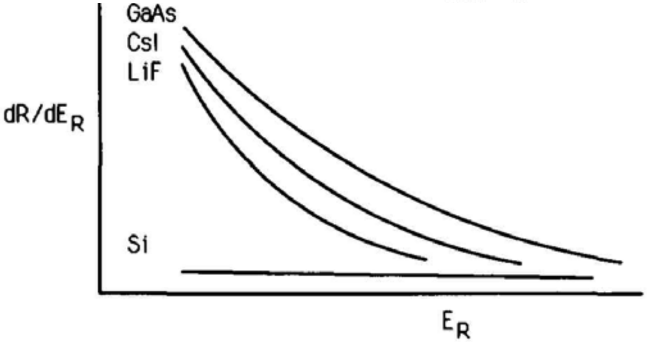
spin-unabhängige („coherent“) Streuquerschnitte dominieren:



aus [10]

spin-abhängige Wechselwirkung:

$$K_N = C\lambda_s^2 J(J+1)$$

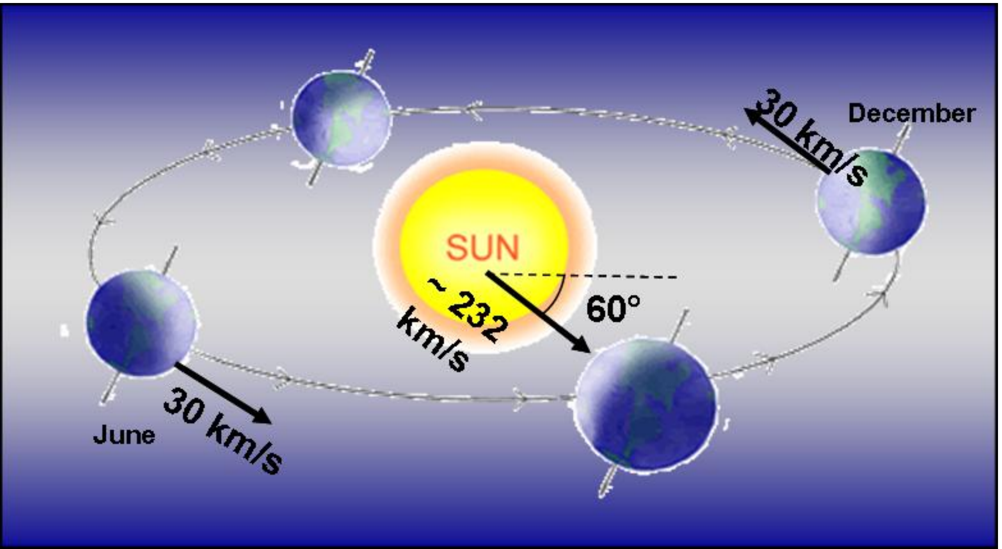


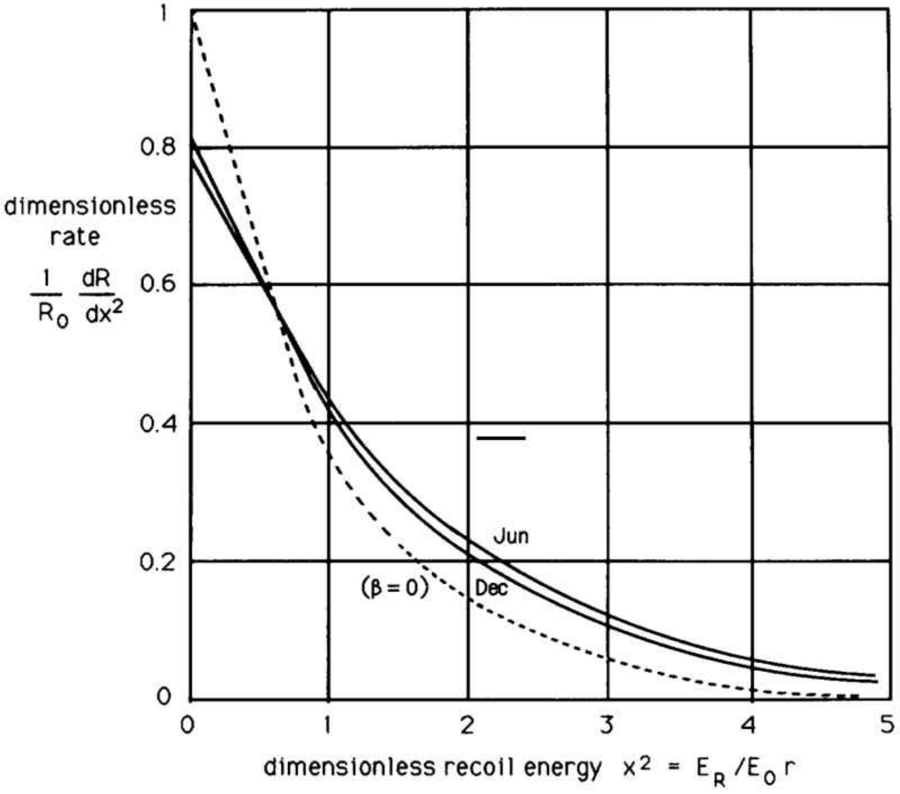
aus [4]

WIMP Signatur: jährliche Schwankungen

- Geschwindigkeitsverteilung
  - Annahme: Maxwell-Verteilung mit $\beta_e \neq 0$
  - β_e im galaktischen Koordinatensystem variiert 219-249 km/s (Maximum 2.-3. Juni)

=>Modulationen (um 4-18%) in Ereignisrate und Energie-Übertrag





Detection Challenges

- ✓ **Low energy thresholds** (~10 keV)
- ✓ Rigid **background controls**
  - ➡ Clean materials
  - ➡ shielding
  - ➡ discrimination power
- ✓ Substantial **Depth**
  - ➡ neutrons look like WIMPS
- ✓ **Long exposures**
  - ➡ large masses, long term stablility

The CDMS Collaboration

California Institute of Technology
Z. Ahmed, J. Filippini, S.R. Golwala, D. Moore, R.W. Ogburn

Case Western Reserve University
D. Akerib, C.N. Bailey, M.R. Dragowsky,
D.R. Grant, R. Hennings-Yeomans

Fermi National Accelerator Laboratory
D. A. Bauer, F. DeJongh, J. Hall, D. Holmgren,
L. Hsu, E. Ramberg, R.L. Schmitt, J. Yoo

Massachusetts Institute of Technology
E. Figueroa-Feliciano, S. Hertel,
S.W. Leman, K.A. McCarthy, P. Wikus

NIST *
K. Irwin

Queen's University
P. Di Stefano *, N. Fatemighomi *, J. Fox *,
S. Liu *, P. Nadeau *, W. Rau

Santa Clara University
B. A. Young

Southern Methodist University
J. Cooley

SLAC/KIPAC *
E. do Couto e Silva, G.G. Godrey, J. Hasi,
C. J. Kenney, P. C. Kim, R. Resch, J.G. Weisend

Stanford University
P.L. Brink, B. Cabrera, M. Cherry *,
L. Novak, M. Pyle, A. Tomada, S. Yellin

Syracuse University
M. Kos, M. Kiveni, R. W. Schnee

Texas A&M
J. Erikson *, R. Mahapatra, M. Platt *

University of California, Berkeley
M. Daal, N. Mirabolfathi, A. Phipps, B. Sadoulet,
D. Seitz, B. Serfass, K.M. Sundqvist

University of California, Santa Barbara
R. Bunker, D.O. Caldwell, H. Nelson, J. Sander

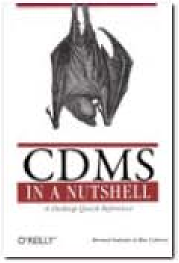
University of Colorado Denver
B.A. Hines, M.E. Huber

University of Florida
T. Saab, D. Balakishiyeva, B. Welliver *

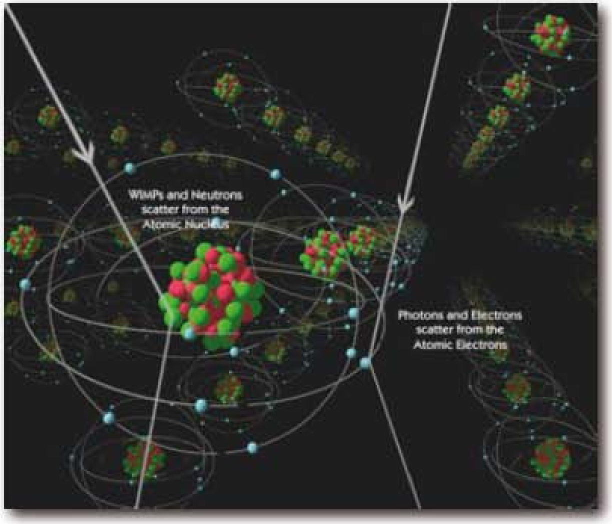
University of Minnesota
J. Beaty, P. Cushman, S. Fallows, M. Fritts,
O. Kamaev, V. Mandic, X. Qiu, A. Reisetter, J. Zhang

University of Zurich
S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

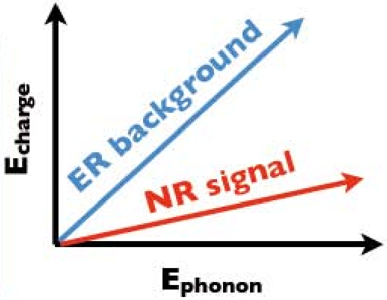
CDMS-II: The Big Picture



Use a combination of **discrimination** and **shielding** to maintain a **"<1 event expected background"** experiment with **low temperature** semiconductor detectors



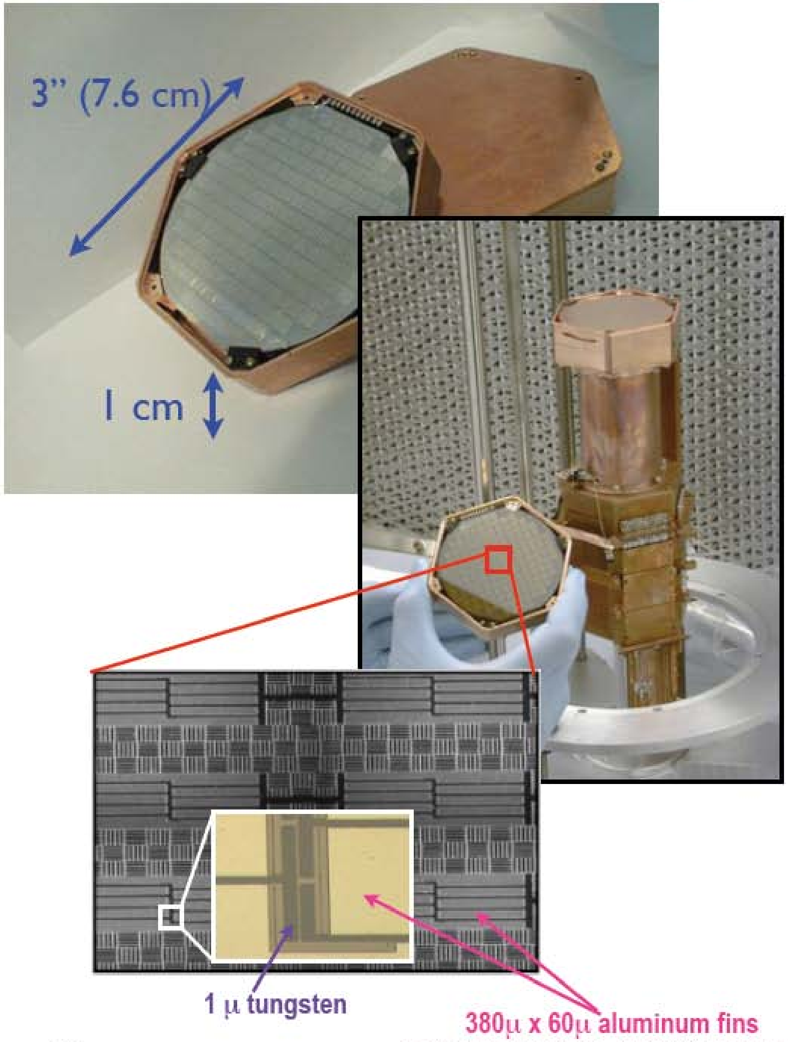
Discrimination from measurements of **ionization** and **phonon energy**.



Keep backgrounds low as possible through shielding and material selection.

CDMS-II ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- **230 g Ge** or **100 g Si** crystals (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to **collect athermal phonons** and **ionization signals**
  - xy-position imaging
  - Surface (z) event rejection from pulse shapes and timing
- **30 detectors** stacked into **5 towers** of 6 detectors



Signal erkennen?

- DM-Kern-Stoßvorgang von Untergrund unterscheiden
  - theoretisch höchstens 10 WIMP-Ereignisse/(kg*d)

- Leicht ausschließbar:
  - geladene Teilchen
    - zeichnen lange Spur
    - Veto außerhalb des Detektors möglich

- Problematisch:
  - Photonen
    - oberhalb ~100keV kurze WW-Strecken
    - einzelne Compton-Streuung hinterlässt E vergleichbar mit DM-Stoß
  - Neutronen
  - Elektronen
    - aus beta-Zerfällen im Detektor-Material (radioaktive Unreinheiten)

Erkennbare WIMP-Signatur

- Form des Energiespektrums
  - sollte abfallen mit E_{recoil} (also z.B. keine peaks)
  - aus Form auf E_0r und damit M_D schließen
- Abhängigkeit des Spektrums vom target-Material
- Jährliche Schwankungen des Signals
- Aufteilung der Rückstoßenergie auf verschiedene Prozesse

WIMP-Signatur: weitere hilfreiche Effekte

- Detektor aus kleinen Volumina
  - jedes WIMP nur eine Wechselwirkung
  - Teilchen mit langen Spuren somit ausschließbar
  - DM-Stöße ortsunabhängig
  - Photonen-Ereignisse nehmen mit Eindringtiefe in Detektor ab
- Myonen-Veto um das Target
  - nach Ausschluß kosmischer Neutronen: die meisten von Myonen erzeugt
- Richtung des Rückstoß-Kerns messen
  - bspw. über Messung ballistischer Phononen
  - sollte asymmetrisch bzgl. der Bewegung der Erde durch DM sein (vorwärts/rückwärts)

WIMP-Signatur: Quenching

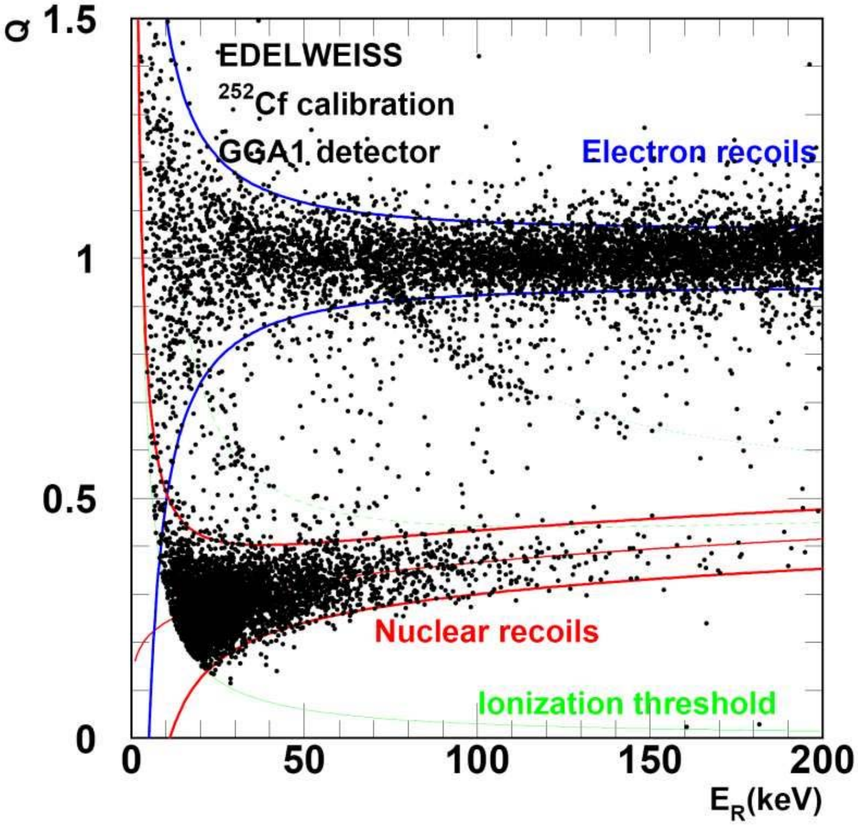
- **Gleichzeitig messen** von therm. E und Ionisation
  - Ionisation ist Energieübertrag auf Elektronen
  - bei Kern-Rückstoß: Energie nur zu ca. 30% als Ionisation

⇒ Verhältnis Ionisationsenergie zu Rückstoßenergie

1 für Photonen

kleiner für Kern-Rückstoß (materialabhängig)

- eine „aktive“ Reduktion des Hintergrunds
  - also von Fall zu Fall, für jedes gezählte Ereignis



Quenching-Faktor Q: Verhältnis von Ionisations- zu Rückstoß-Energie

Graphik aus: O. Martineau et al., „Calibration of the EDELWEISS…“, arXiv:astro-ph/0310657

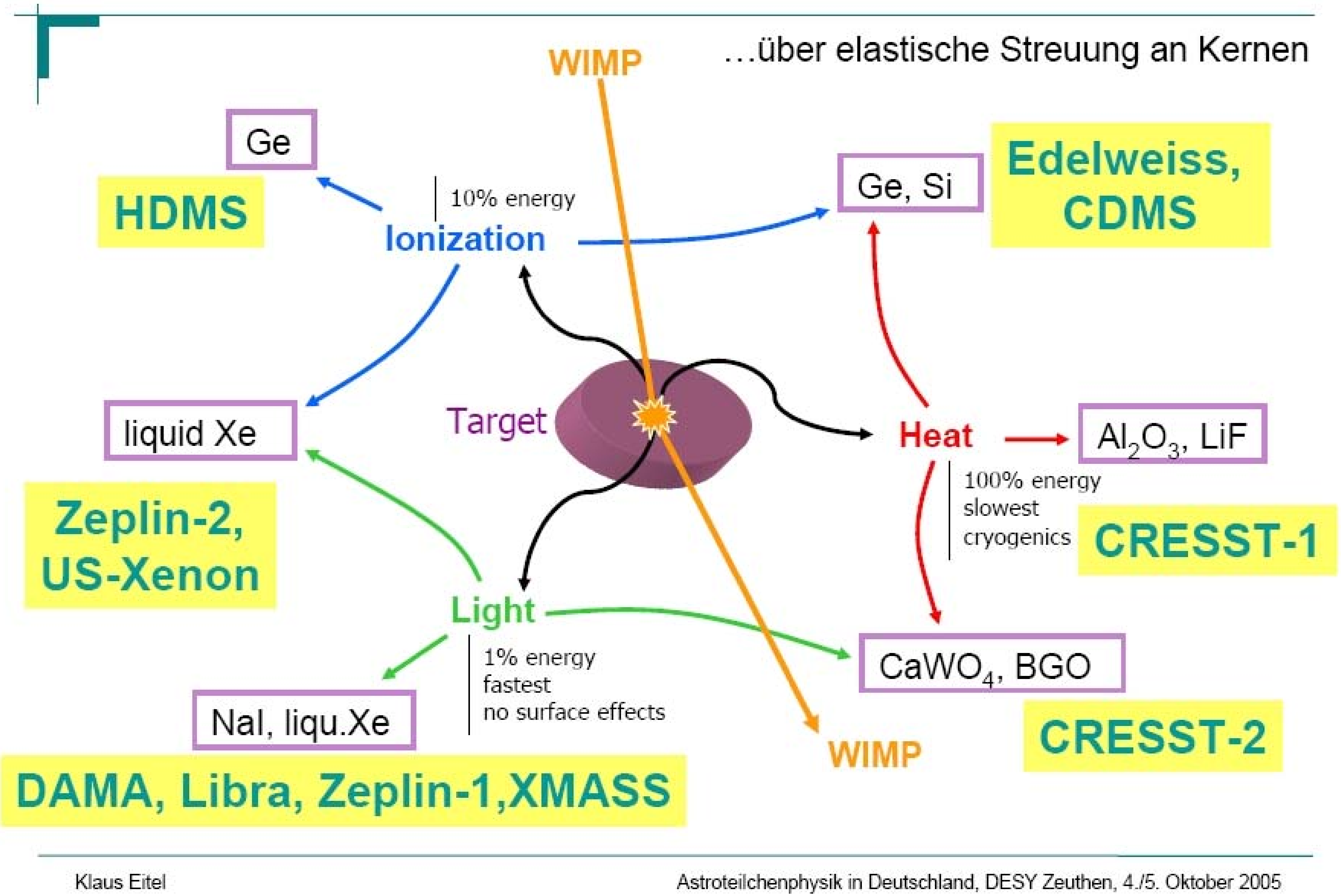
Wie misst man jetzt eigentlich?

- Ionisation in Halbleitern
  - e^- - Loch – Paare liefern Ionisations-Strom
  - Elektronenrückstoß ausschließen: Temperatur auch messen (Wärmekapazität mit T^3)
  - damit Fall-zu-Fall Untergrund ausschließbar
- Szintillation
  - in Kristallen wie NaI(Tl) mittels Photomultipliern messen
  - in Gasen wie Xe (strahlender Übergang von Angeregten zu Grundzuständen)
  - Pulsform (Zeitkonstante) unterschiedlich für Kern- und Elektronen-Rückstoß
  - statistische Unterdrückung des Untergrunds
- Temperaturanstieg
  - Phononen sofort messen (ballistische Ph.)
  - indem man in Supraleiter einkoppelt
    - Aufbrechen von Cooper-Paaren => Erzeugung von „Quasi-Teilchen“
  - thermalisierte Phononen mit Thermoresistor, SQUID o.ä. messen

? Supraleitende target-Materialien

- kleine Kügelchen, oder dünne Filme, auf T_{krit} gehalten
- winzige Erwärmung würde makroskopische Wirkung haben

Experimente



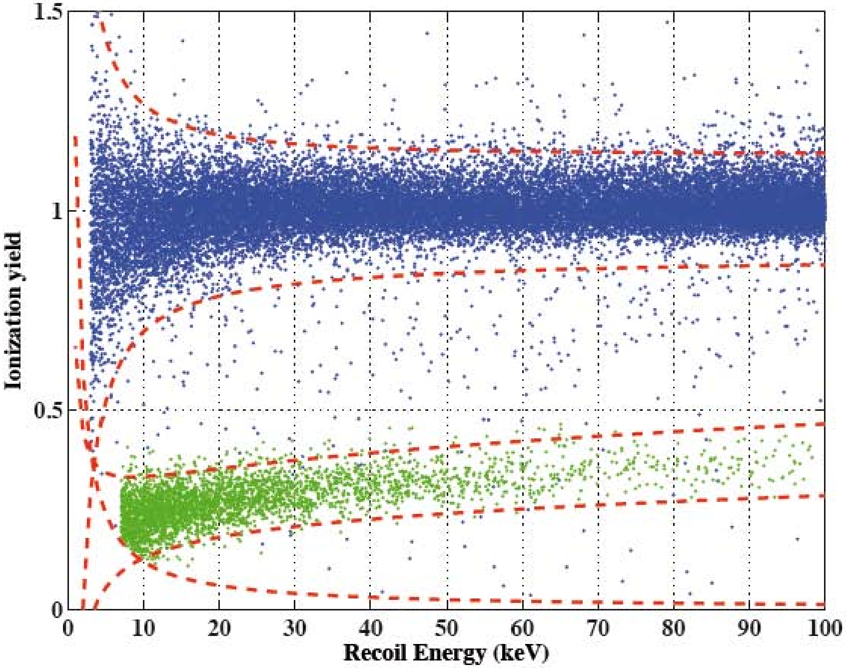
…über elastische Streuung an Kernen

Klaus Eitel

Astroteilchenphysik in Deutschland, DESY Zeuthen, 4./5. Oktober 2005

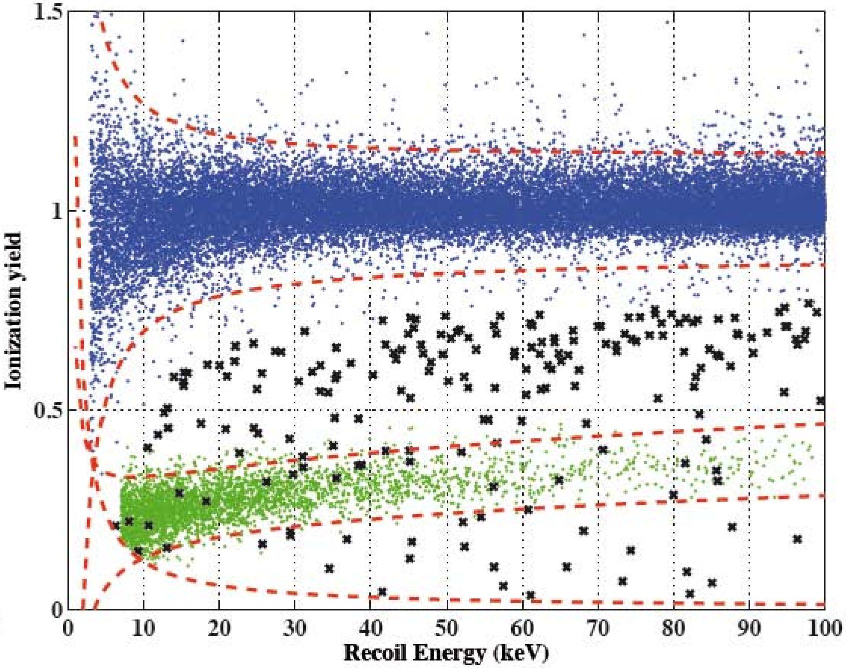
Background Rejection

- Most backgrounds (e, γ) produce electron recoils
- WIMPS and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit phonon energy) strongly depends on particle type.



Background Rejection

- Most backgrounds (e, γ) produce electron recoils
- WIMPS and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit phonon energy) strongly depends on particle type.
- Particles that interact in the "surface dead layer" result in reduced ionization yield.



Nord-Minnesota, Soudain

SOUDAN UNDERGROUND MINE STATE PARK

The Soudan Mine is designated a National Historic Landmark due to its significance in American history.

VISITOR FAVORITES

- Underground mine tour
- Interpretive center
- High energy physics lab

Since the early 1980s, scientists have conducted high energy experiments at the bottom of the Soudan Mine. The depth of the mine shields the experiments from cosmic rays found on the earth's surface. Information on current experiments is available in the Visitor Center.

FACILITIES AND FEATURES

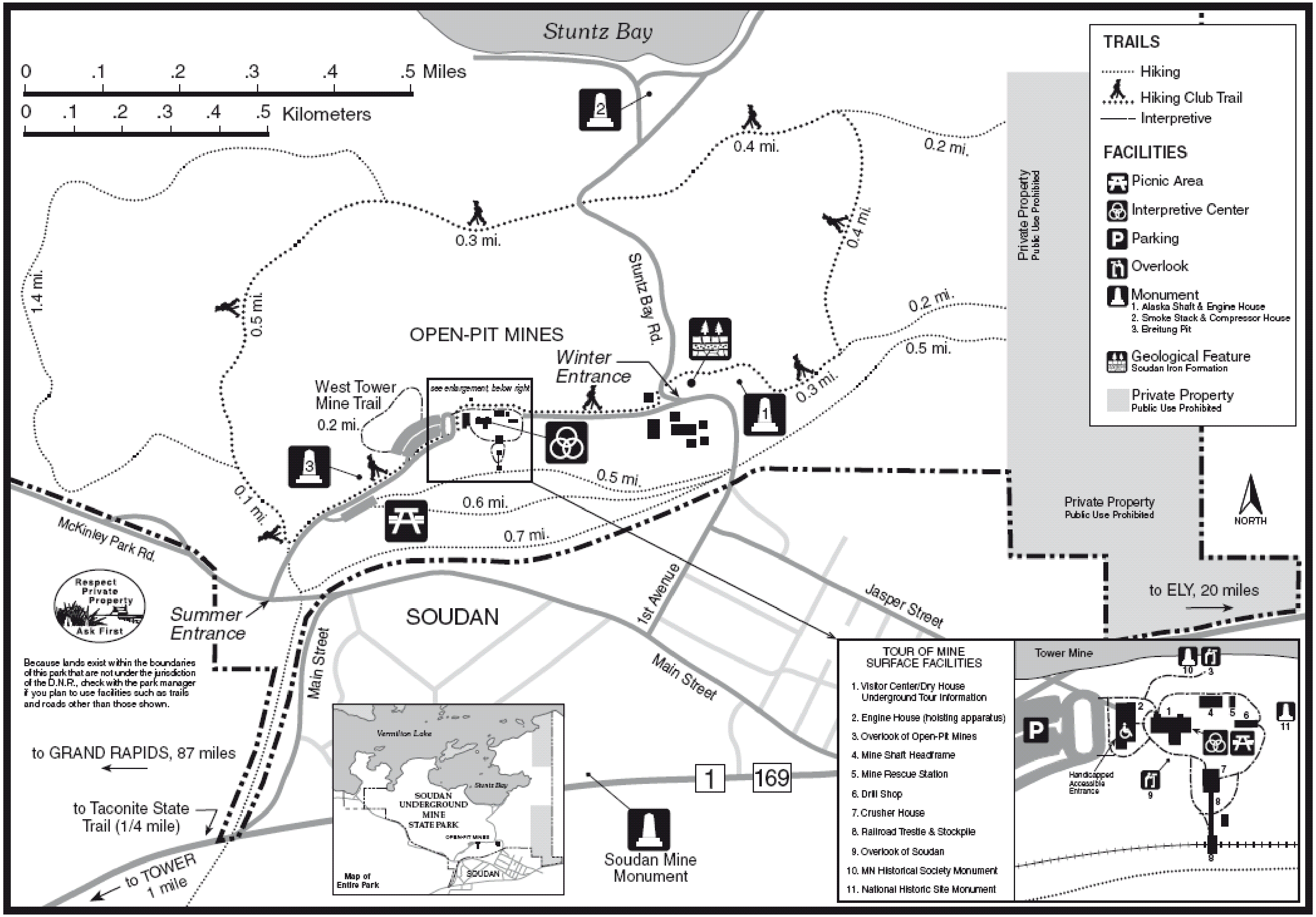
- Picnic area
- Interpretive trail
- Five miles of hiking trails among open-pit mines

LOOKING FOR MORE INFORMATION ?

The DNR has mapped the state showing federal, state and county lands with their recreational facilities.

Public Recreation Information Maps (PRIM) are available for purchase from the DNR gift shop, DNR regional offices, Minnesota state parks and major sporting and map stores.

Check it out - you'll be glad you did.

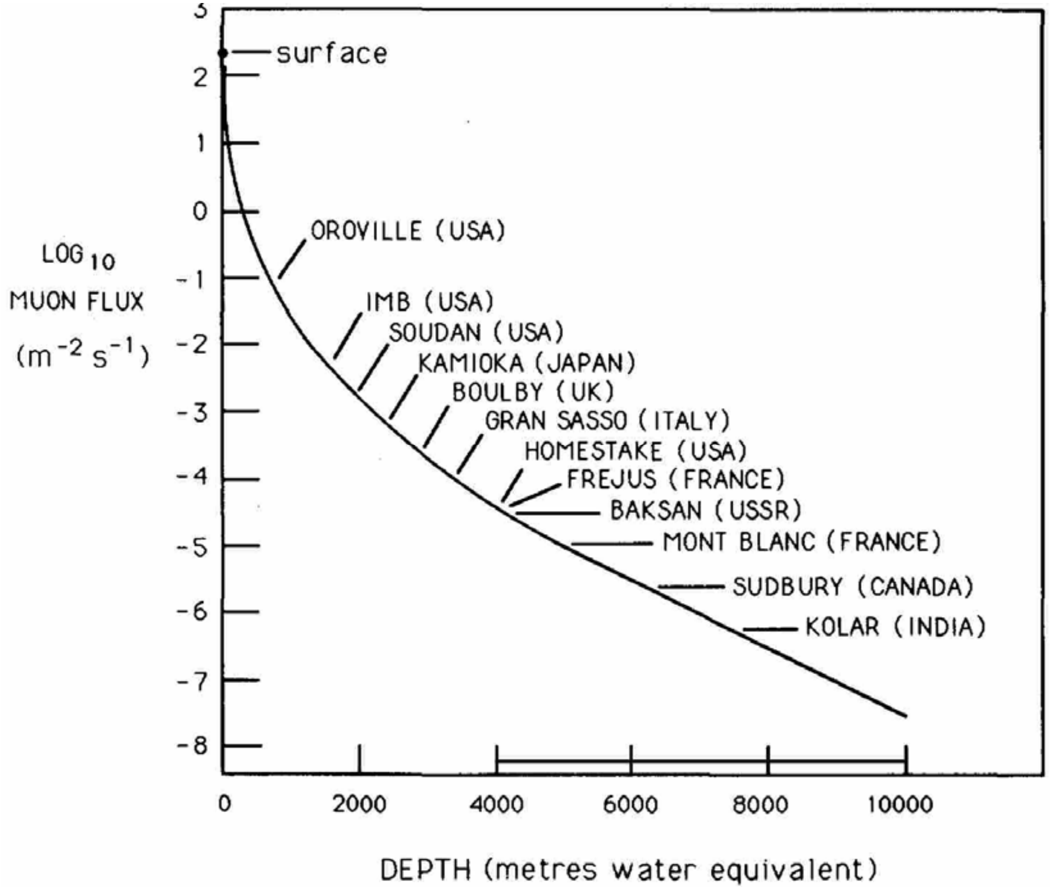


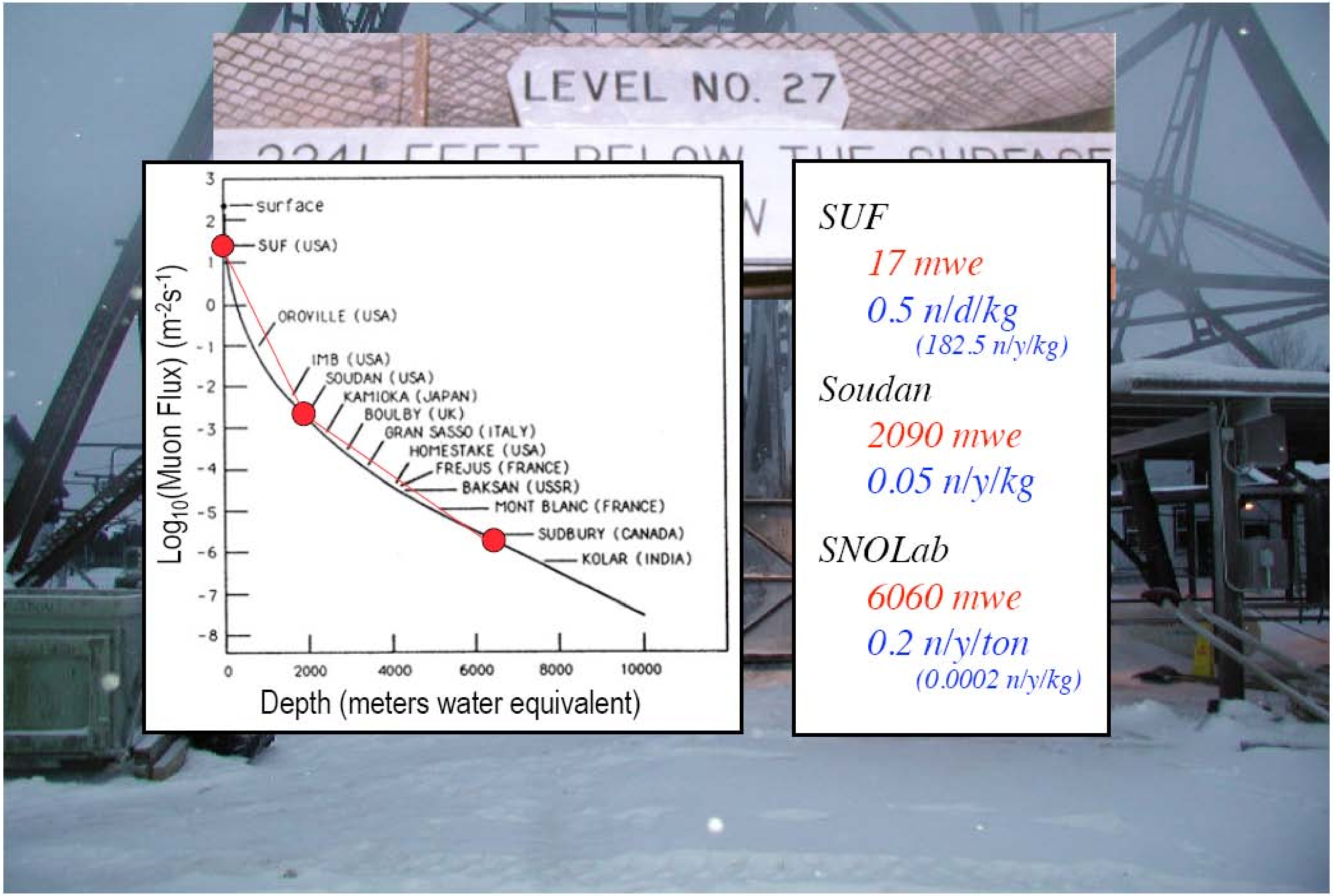

LEVEL NO. 27
2341 FEET BELOW THE SURFACE
689 FEET BELOW SEA LEVEL

Warum unterirdische Experimente?

- Kosmische Photonen und Neutronen
  - können abgeschirmt werden,
- ABER Myonen
  - **erzeugen**
    - **Photonen** (Kollision mit e^-, Bremsstrahlung)
    - **Neutronen** (Kollision mit Kernen)

  in der Abschirmung
- 2×10^{-3} bis 2×10^{-2} n/µ





SUF

17 mwe

0.5 n/d/kg

(182.5 n/y/kg)

Soudan

2090 mwe

0.05 n/y/kg

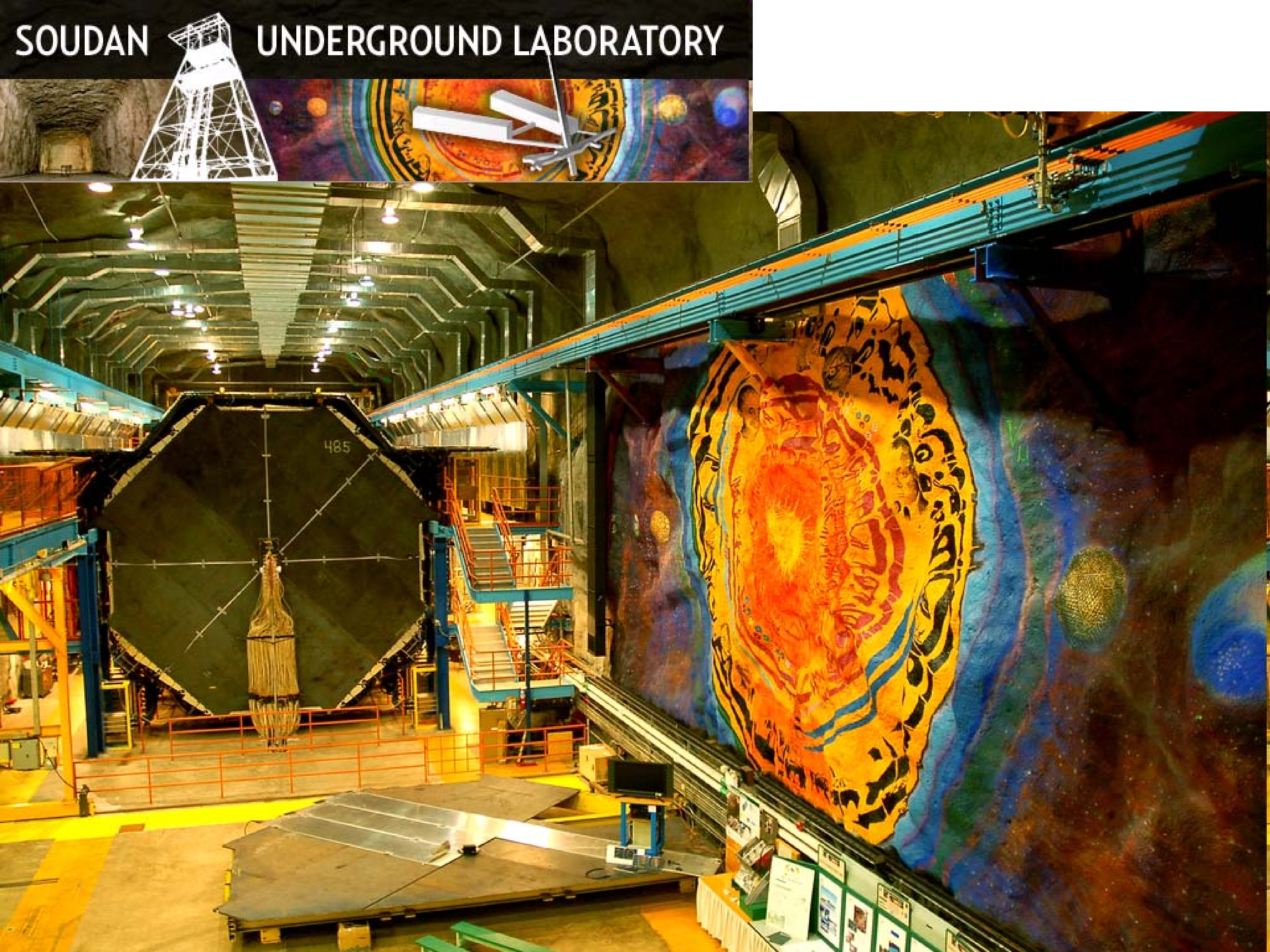
SNOLab

6060 mwe

0.2 n/y/ton

(0.0002 n/y/kg)

SOUDAN UNDERGROUND LABORATORY

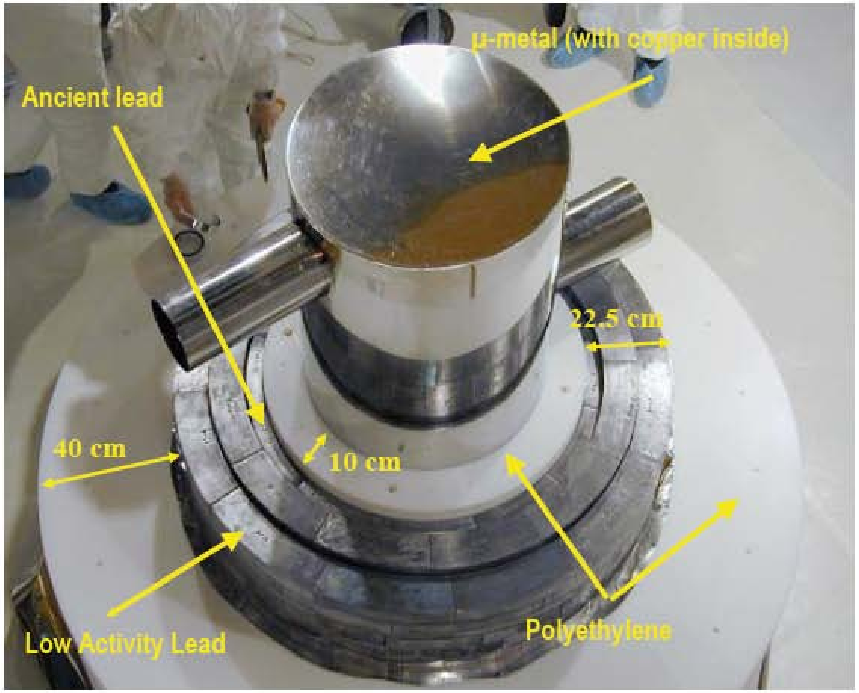


Peeling the Shielding Onion

Active Muon Veto: rejects events from cosmic rays

Pb: shielding from gammas resulting from radioactivity

Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays



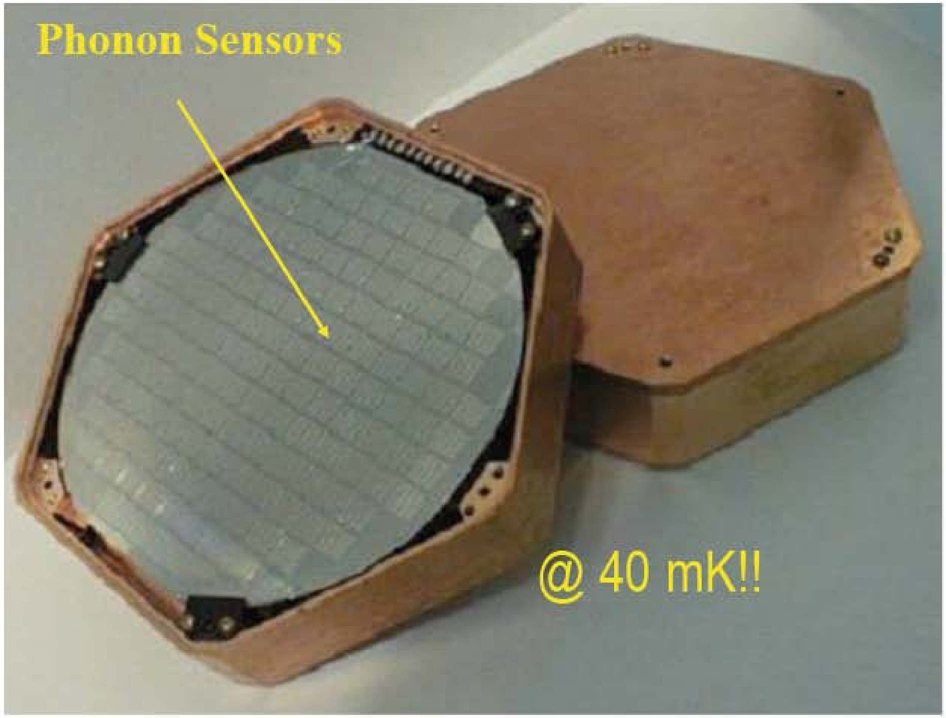
Peeling the Shielding Onion

Active Muon Veto: rejects events from cosmic rays

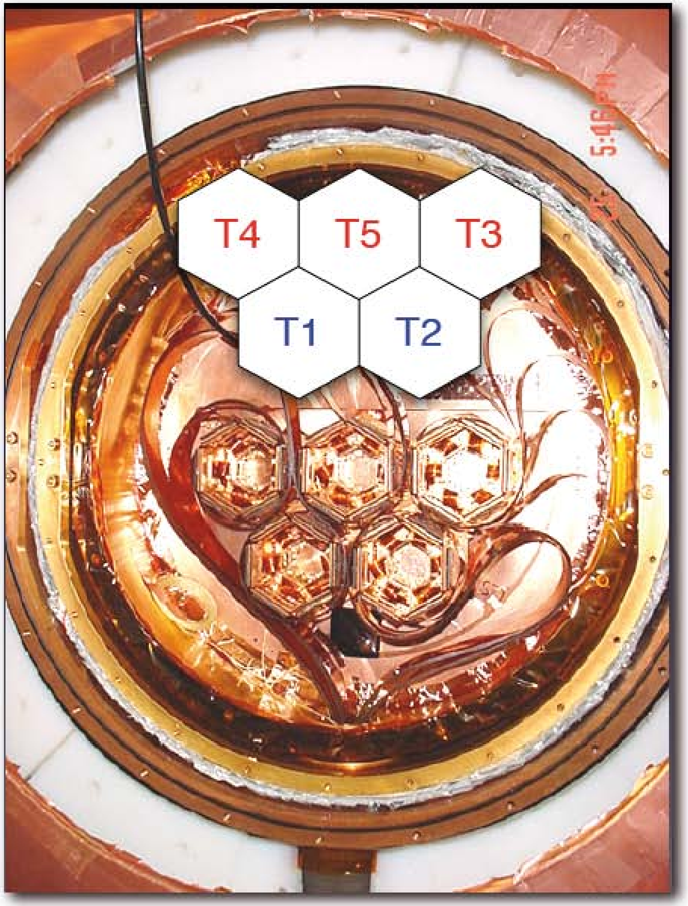
Pb: shielding from gammas resulting from radioactivity

Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays

Cu: shielding from gammas



CDMS II Experiment



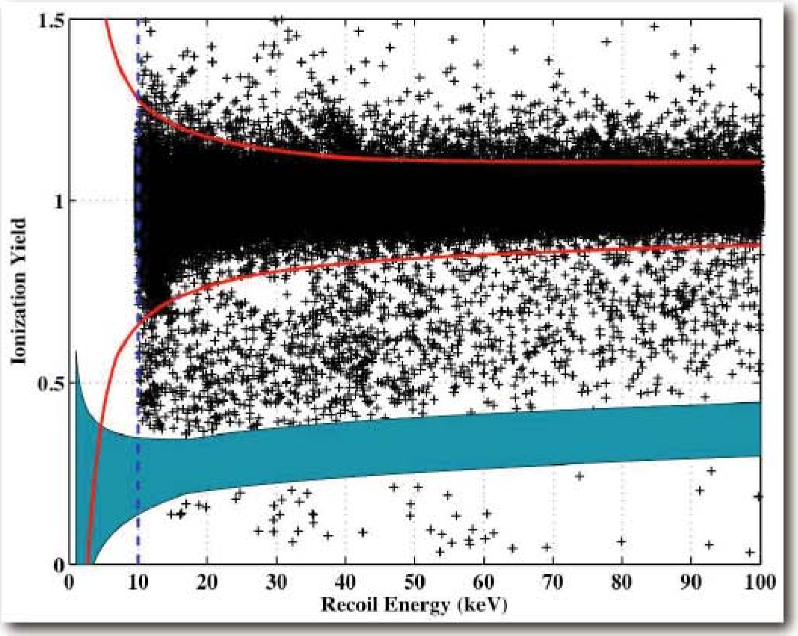
- **30 detectors installed and operating in Soudan since June 2006.**
  - **4.75 kg of Ge**, **1.1 kg of Si**

- **Seven Total Data Runs:**
  - ✓ **R123 - R124:**
    - **taken: (10/06 - 3/07) (4/07 - 7/07)**
    - **exposure: ~400 kg-d (Ge “raw”)**
    - **PRL 102, 011301 (2009)**
  - ✓ **R125 - R128**
    - **taken: (7/07 - 1/08) (1/08 - 4/08) (5/08 - 8/08) (8/08 - 9/08)**
    - **exposure: ~ 600 kg-d (Ge “raw”)**
  - ✓ **R129:**
    - **taken: (11/08 - 3/09)**

Results from Final Data

Blind Analysis:

Event selection and efficiencies were calculated without looking at the signal region of the WIMP-search data.



Event Selection:

- ☑ *Veto-anticoincidence cut*
- ☑ *Single-scatter cut*
- ☑ Q_{inner} *(fiducial volume) cut*
- ☑ *Ionization yield cut*
- ☑ *Phonon timing cut*

Surface Event Background

$$\text{Expected Surface “leakage”} = \frac{N^{\text{Sideband}}_{\text{pass cut}}}{N^{\text{Sideband}}_{\text{fail cut}}} * N^{\text{data}}_{\text{fail cut}}$$

Method 1

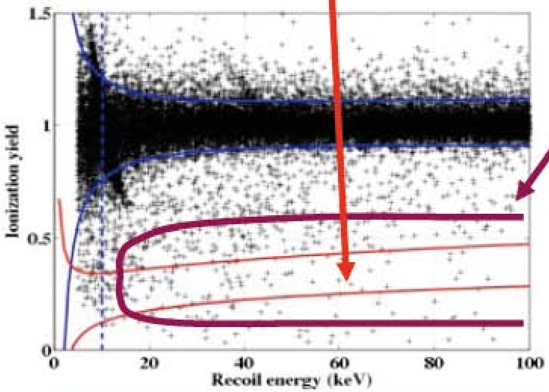
Use multiple-scatters in NR band

Method 2

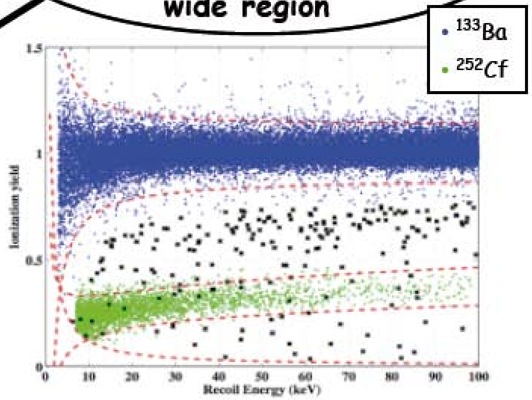
Use singles and multiples just outside NR band

Method 3

Use singles and multiples from Ba calibration in wide region



Correct for systematic effects due to different distributions in energy and face



Combined Estimate = $0.6 \pm 0.1(\text{stat.})$

Projected Sensitivity

612 raw kg-days
194.1 kg-d WIMP equiv.
@ 60 GeV/c^2
(10 -100 keV analysis
energy range)

Surface Background

$0.6 \pm 0.1(\text{stat.})$

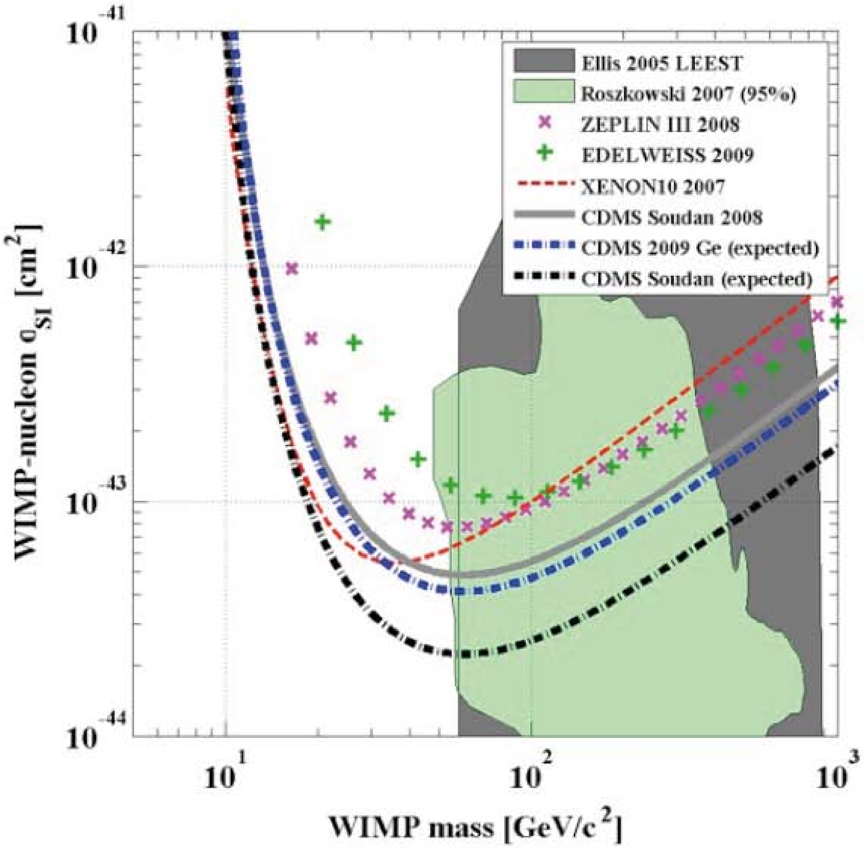
Neutron Background

Cosmogenic

$0.04^{+0.04}_{-0.03}(\text{stat.})$

Radiogenic

0.03 - 0.06



Opening the Box

Box opened November 5 , 2009 for 14 Ge ZIP detectors

Opening the Box

Box opened November 5 , 2009 for 14 Ge ZIP detectors

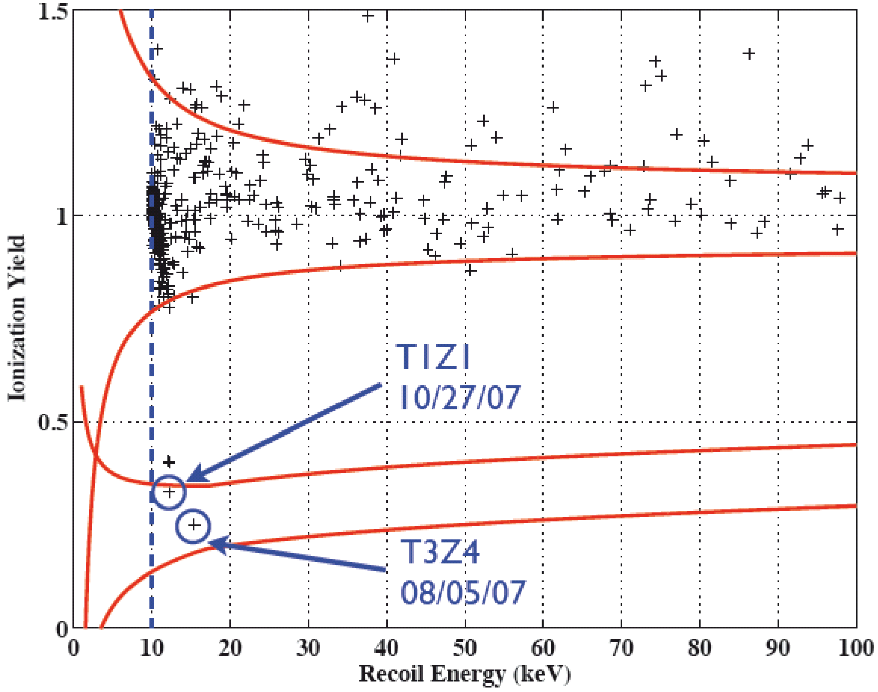
3σ region masked

- ☑ Hide unvetoed singles

Lift mask, see 150 singles failing timing cut

Apply the timing cut ...

2 EVENTS OBSERVED!



T1Z1
10/27/07

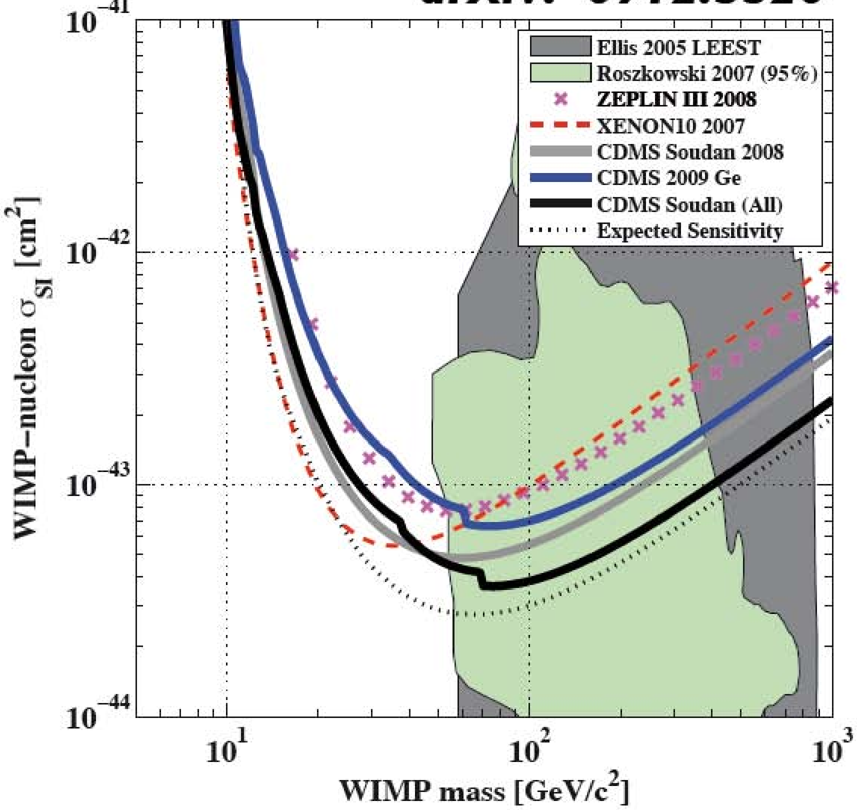
T3Z4
08/05/07

CDMS II Results

Upper limit at the 90% C.L. on the WIMP-nucleon cross-section is **3.8 x 10^{-44} cm^2** for a WIMP of mass **70 GeV/c^2**

Note: An improved estimate of our detector masses (~9% decrease) was used in calculating these limits.

arXiv: 0912.3320

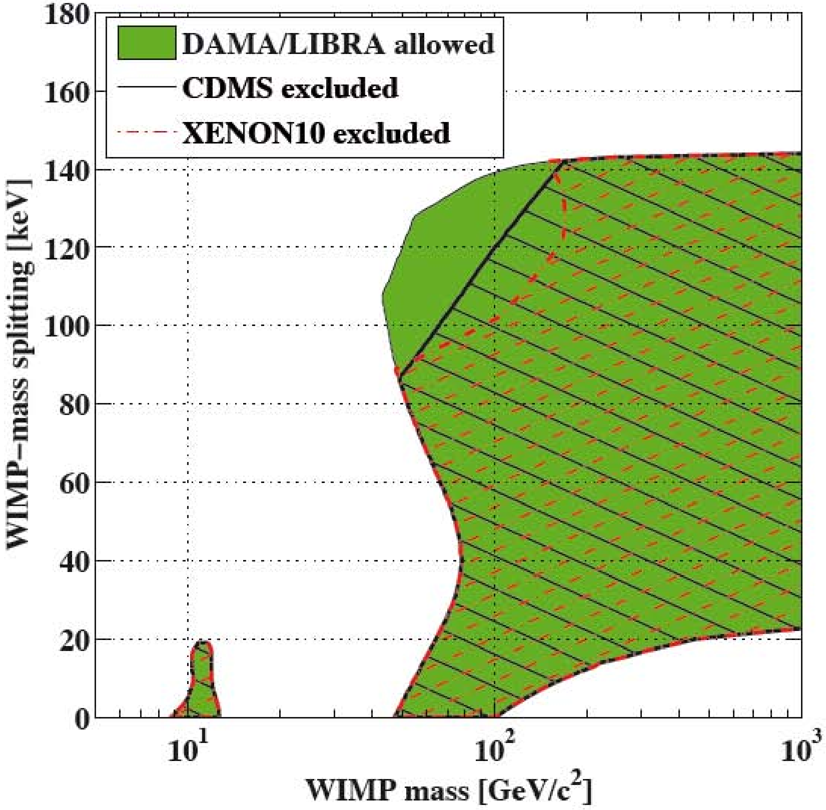


Inelastic Scattering

Disfavor all DAMA/LIBRA allowed region except for WIMPs of mass ~100 GeV with mass-splittings ~80-140 keV

Shown are only regions for which CDMS II and XENON10 are not compatible with DAMA/LIBRA at the 90% C.L.

arXiv: 0912.3320



What More Can We Say?

- The two events occur during a time of nearly ideal detector performance.
- They are separated in time by several months and occur on detectors in different towers (T1Z5 and T3Z4).
- They occur on inner detectors where we have a stronger handle on our background estimate.

Data Quality Item	Result
muon veto performance	*good*
neutralization	*good*
KS tests	*normal*
noise levels	*typical*
pre-pulse baseline rms	*typical*
background electron-recoil rate	*typical*
surface event rate	*typical*
radial position	*well-contained*
single-scatter identification	*good*
special running conditions	*no*
operator recorded issues	*no*

Final Comments on this Analysis

Our results cannot be interpreted as significant evidence for WIMP interactions.

However, we cannot reject either event as signal.

CDMS: **Latest Results in the Search for Dark Matter Thursday, December 17, 2009**

In this new data set **we indeed see two events with characteristics consistent with those expected from WIMPs. However, there is also a chance that both events could be due to background particles**. Scientists have a strict set of criteria for determining whether a new discovery has been made. **The ratio of signal to background events must be large enough that there is no reasonable doubt. Typically there must be fewer than one chance in a thousand of the signal being due to background. In this case, a signal of about five events would have met those criteria.** We estimate that there is about a one in four chance to have seen two backgrounds events, **so we can make no claim to have discovered WIMPs**.

Instead we say that the rate of WIMP interactions with nuclei must be less than a particular value that depends on the mass of the WIMP. The numerical values obtained for these interaction rates from this data set are more stringent than those obtained from previous data for most WIMP masses predicted by theories. Such upper limits are still quite valuable in eliminating a number of theories that might explain dark matter.

Results from the Final Exposure of the CDMS II Experiment

Z. Ahmed,19 D.S. Akerib,2 S. Arrenberg,18 C.N. Bailey,2 D. Balakishiyeva,16 L. Baudis,18 D.A. Bauer,3
P.L. Brink,10 T. Bruch,18 R. Bunker,14 B. Cabrera,10 D.O. Caldwell,14 J. Cooley,9 P. Cushman,17
M. Daal,13 F. DeJongh,3 M.R. Dragowsky,2 L. Duong,17 S. Fallows,17 E. Figueroa-Feliciano,5 J. Filippini,19
M. Fritts,17 S.R. Golwala,19 D.R. Grant,2 J. Hall,3 R. Hennings-Yeomans,2 S.A. Hertel,5 D. Holmgren,3
L. Hsu,3 M.E. Huber,15 O. Kamaev,17 M. Kiveni,11 M. Kos,11 S.W. Leman,5 R. Mahapatra,12 V. Mandic,17
K.A. McCarthy,5 N. Mirabolfathi,13 D. Moore,19 H. Nelson,14 R.W. Ogburn,10 A. Phipps,13 M. Pyle,10 X. Qiu,17
E. Ramberg,3 W. Rau,6 A. Reisetter,17, 7 T. Saab,16 B. Sadoulet,4, 13 J. Sander,14 R.W. Schnee,11 D.N. Seitz,13
B. Serfass,13 K.M. Sundqvist,13 M. Tarka,18 P. Wikus,5 S. Yellin,10, 14 J. Yoo,3 B.A. Young,8 and J. Zhang17
(CDMS Collaboration)

1Division of Physics, Mathematics & Astronomy,
California Institute of Technology, Pasadena, CA 91125, USA
2Department of Physics, Case Western Reserve University, Cleveland, OH 44106, USA
3Fermi National Accelerator Laboratory, Batavia, IL 60510, USA
4Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
5Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
6Department of Physics, Queen's University, Kingston, ON, Canada, K7L 3N6
7Department of Physics, St. Olaf College, Northfield, MN 55057 USA
8Department of Physics, Santa Clara University, Santa Clara, CA 95053, USA
9Department of Physics, Southern Methodist University, Dallas, TX 75275, USA
10Department of Physics, Stanford University, Stanford, CA 94305, USA
11Department of Physics, Syracuse University, Syracuse, NY 13244, USA
12Department of Physics, Texas A & M University, College Station, TX 77843, USA
13Department of Physics, University of California, Berkeley, CA 94720, USA
14Department of Physics, University of California, Santa Barbara, CA 93106, USA
15Departments of Phys. & Elec. Engr., University of Colorado Denver, Denver, CO 80217, USA
16Department of Physics, University of Florida, Gainesville, FL 32611, USA
17School of Physics & Astronomy, University of Minnesota, Minneapolis, MN 55455, USA
18Physics Institute, University of Zürich, Winterthurerstr. 190, CH-8057, Switzerland
19Division of Physics, Mathematics, and Astronomy,
California Institute of Technology, Pasadena, CA 91125, USA

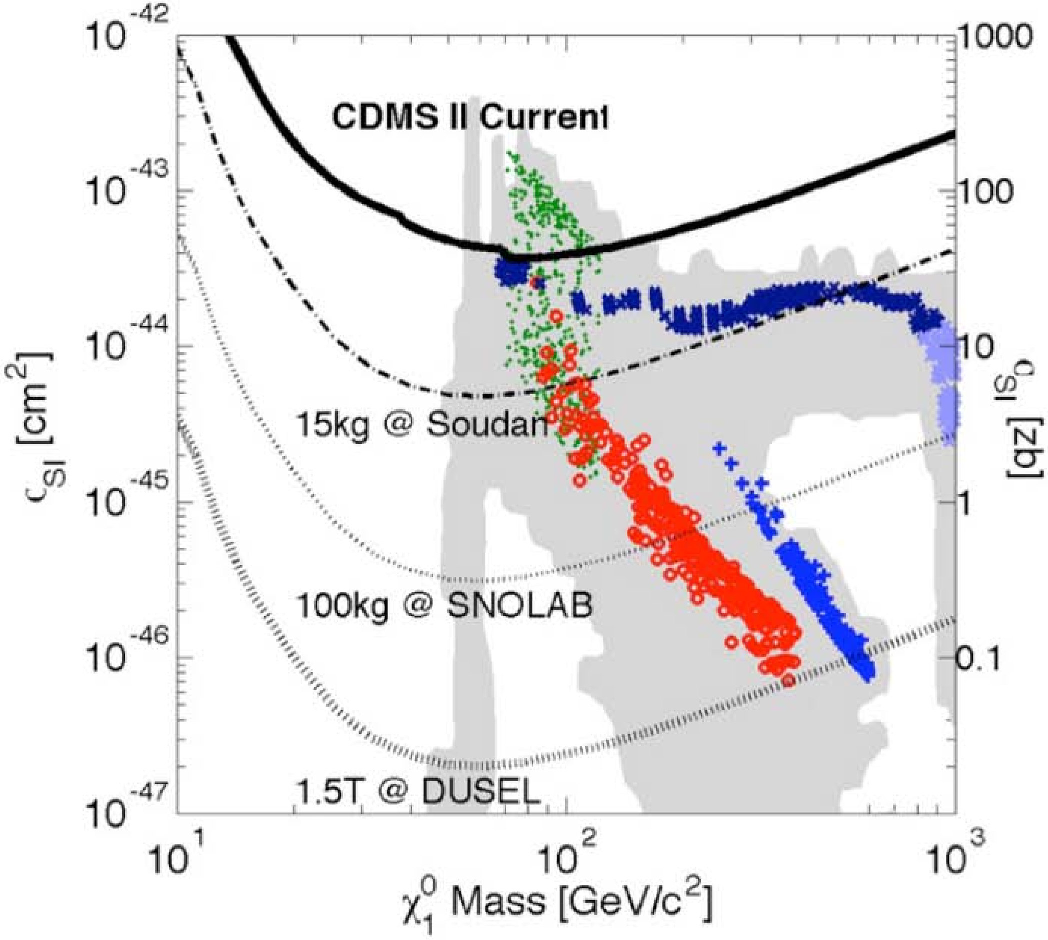
We report results from a blind analysis of the final data taken with the Cryogenic Dark Matter Search experiment (CDMS II) at the Soudan Underground Laboratory, Minnesota, USA. A total raw exposure of 612 kg-days was analyzed for this work. We observed two events in the signal region; based on our background estimate, the probability of observing two or more background events is 23%. These data set an upper limit on the Weakly Interacting Massive Particle (WIMP)-nucleon elastic-scattering spin-independent cross-section of 7:010 44 cm2 for a WIMP of mass 70 GeV/c2 at the 90% confidence level. Combining this result with all previous CDMS II data gives an upper limit on the WIMP-nucleon spin-independent cross-section of 3:810 44 cm2 for a WIMP of mass 70 GeV/c2. We also exclude new parameter space in recently proposed inelastic dark matter models.

PACS numbers: 14.80.Ly, 95.35.+d, 95.30.Cq, 95.30.-k, 85.25.Oj, 29.40.Wk

Next Step: SuperCDMS

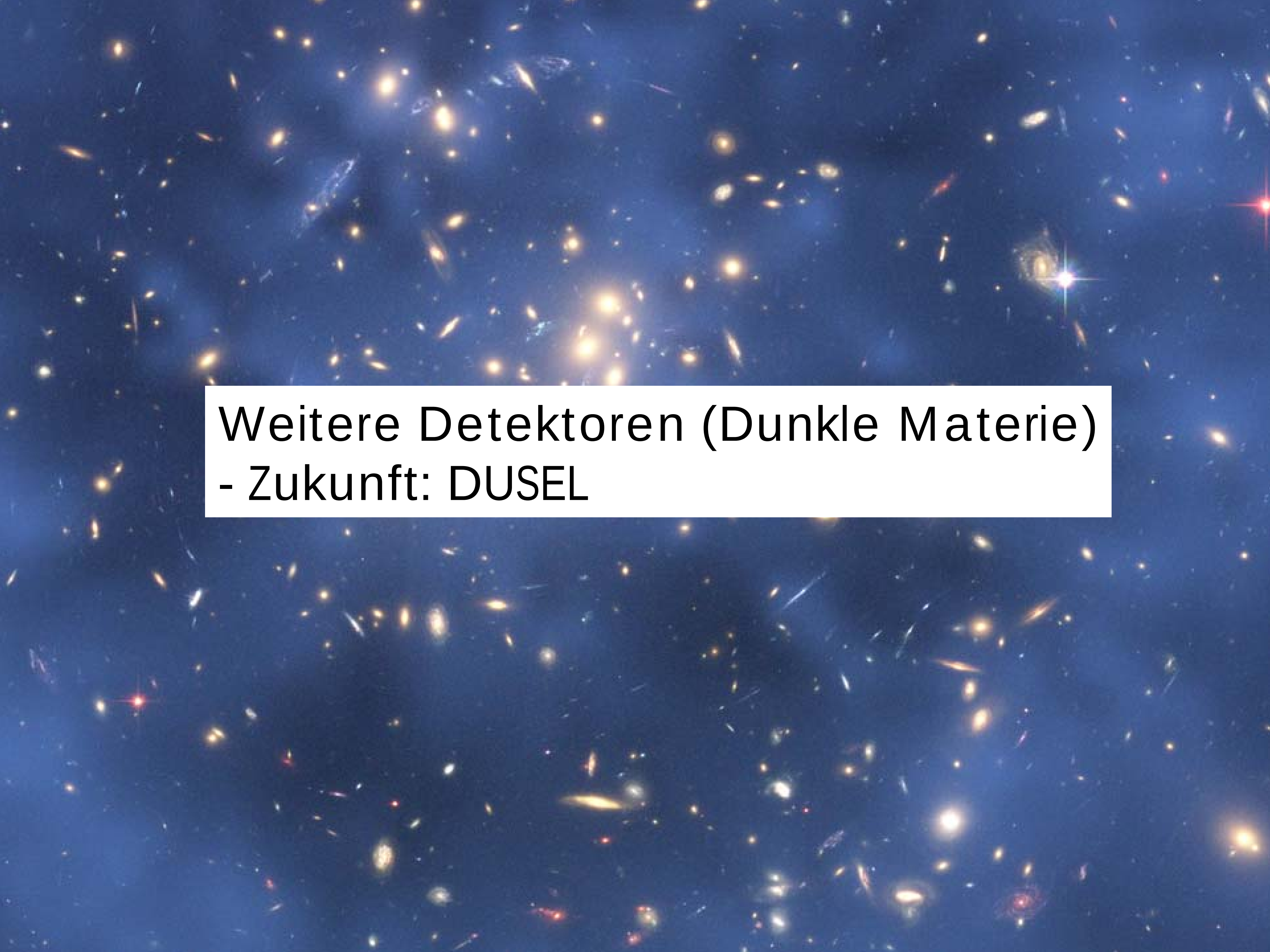
- Last CDMS II data taken on March 18, 2009
- March 19, 2009: Warm up to begin the installation and commissioning of the first SuperCDMS detectors. Commissioning runs of the first SuperCDMS tower is underway.
- Fabrication of remaining detectors for the SuperCDMS Soudan project (15 kg Ge deployed in existing Soudan setup) underway. Installation and commissioning summer 2010.
- Eventual goal: SuperCDMS SNOLAB (100 kg Ge deployed at SNOLAB)

Sensitivity of Future Detectors



Conclusions

- We observe 2 events in the first analysis of the final data taken by CDMS II between July 07 and Sept. 08. This yields a cross section limit of $< 3.8 \times 10^{-44} \mathrm{cm}^2$ (90% CL) for a WIMP of mass 70 $\mathrm{GeV/c}^2$ when combining this result with previous analyses.
- The results of this analysis cannot be interpreted as significant evidence for WIMP interactions, but we can not reject either event as a signal.
- The first SuperTower of detectors has been installed and is operating in the Soudan Underground Laboratory. Remaining SuperTowers of detectors are planned to be installed in Summer 2010.
- Stay tuned for this coming year. Several other promising technologies (liquid nobles, bubble chambers, ...) will have exciting results.

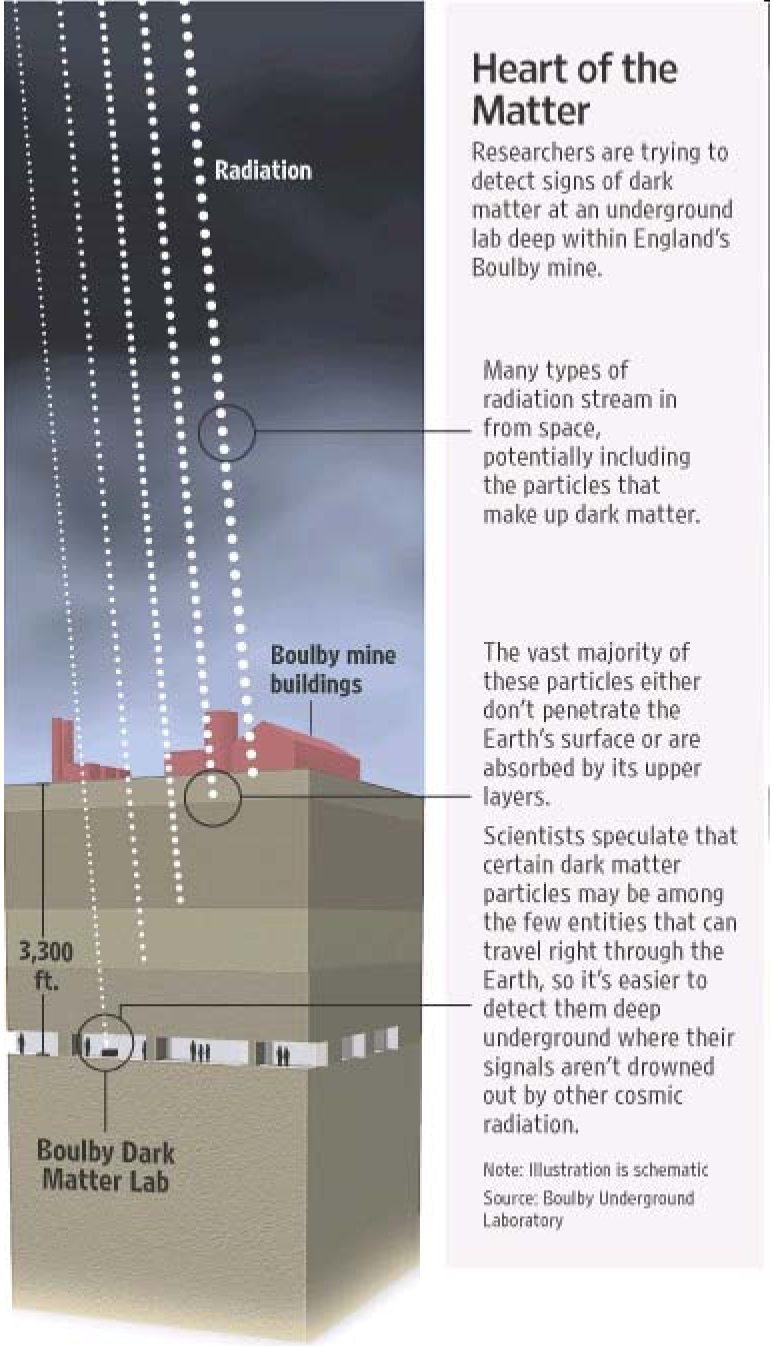


Weitere Detektoren (Dunkle Materie)

- Zukunft: DUSEL

WIMP Searches

- **CRESST** *at The Gran Sasso Laboratory*
- **CUORE** *at The Gran Sasso Laboratory*
- **DAMA** *at The Gran Sasso Laboratory*
- **EDELWEISS** *au Laboratoire Souterrain de Modane*
- **GENIUS** *at The Gran Sasso Laboratory*
- **HDMS** *at The Gran Sasso Laboratory*
- **MACHe3** *at the ISN*
- **PICASSO** *at the U. of Montreal*
- **UK Dark Matter Collaboration** *at the Boulby Mine*



Heart of the Matter

Researchers are trying to detect signs of dark matter at an underground lab deep within England's Boulby mine.

Many types of radiation stream in from space, potentially including the particles that make up dark matter.

The vast majority of these particles either don't penetrate the Earth's surface or are absorbed by its upper layers.

Scientists speculate that certain dark matter particles may be among the few entities that can travel right through the Earth, so it's easier to detect them deep underground where their signals aren't drowned out by other cosmic radiation.

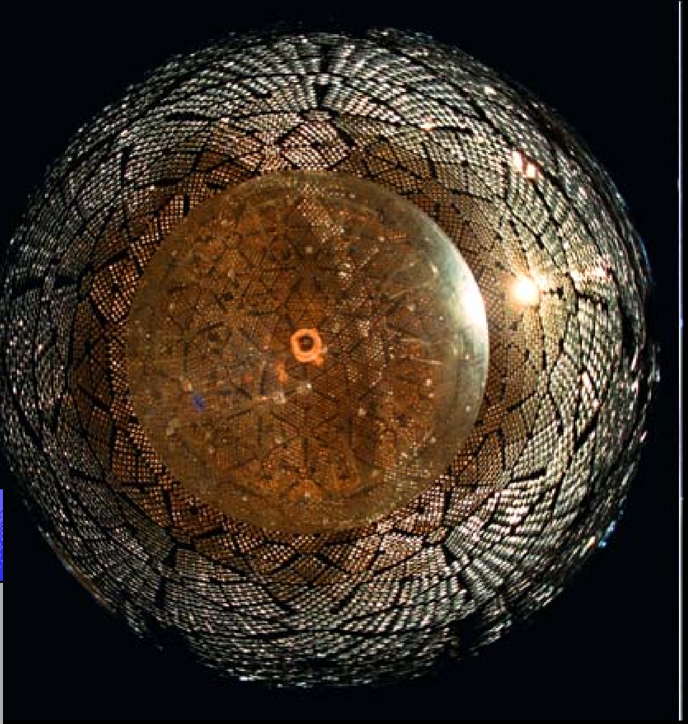
Note: Illustration is schematic

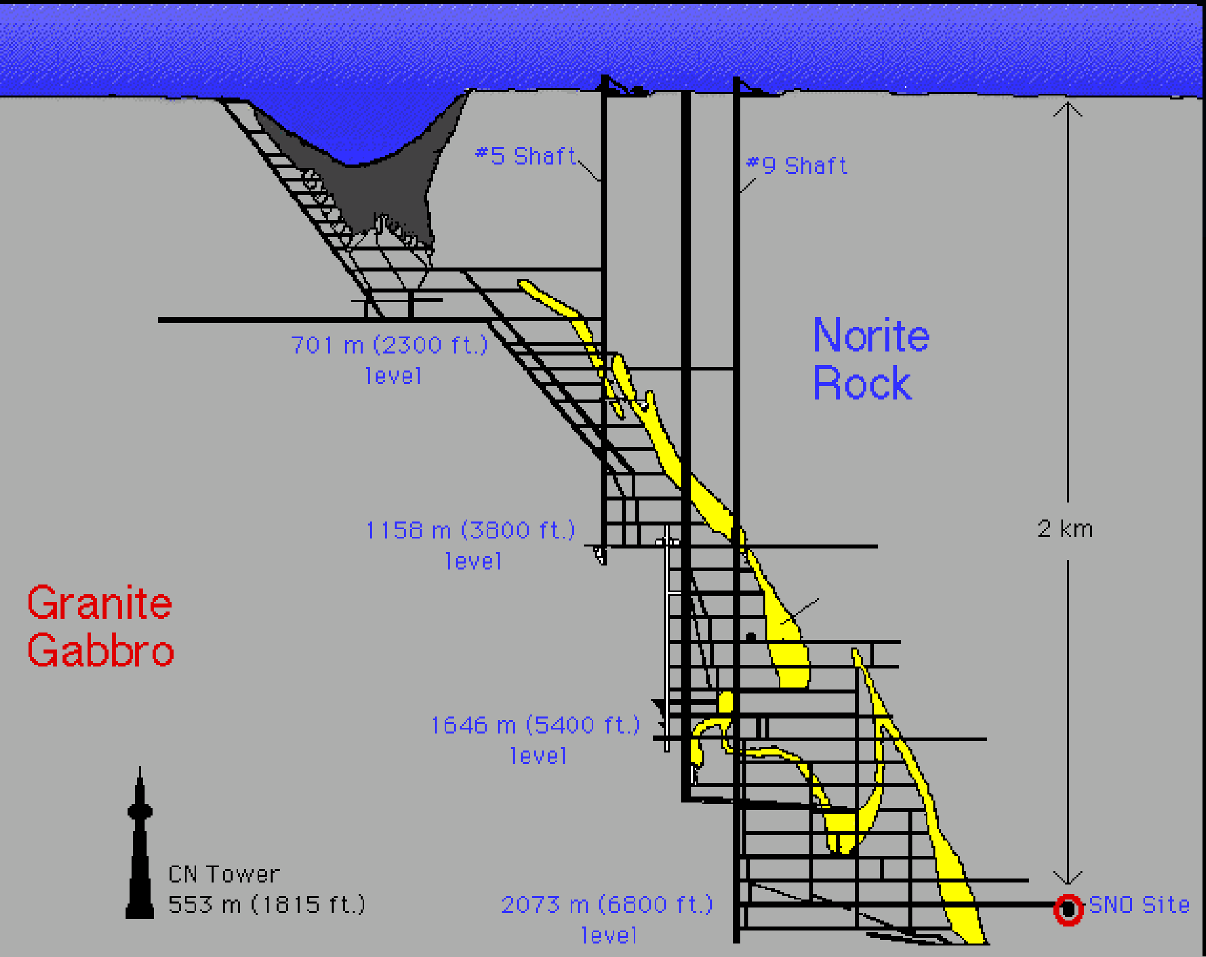
Source: Boulby Underground Laboratory

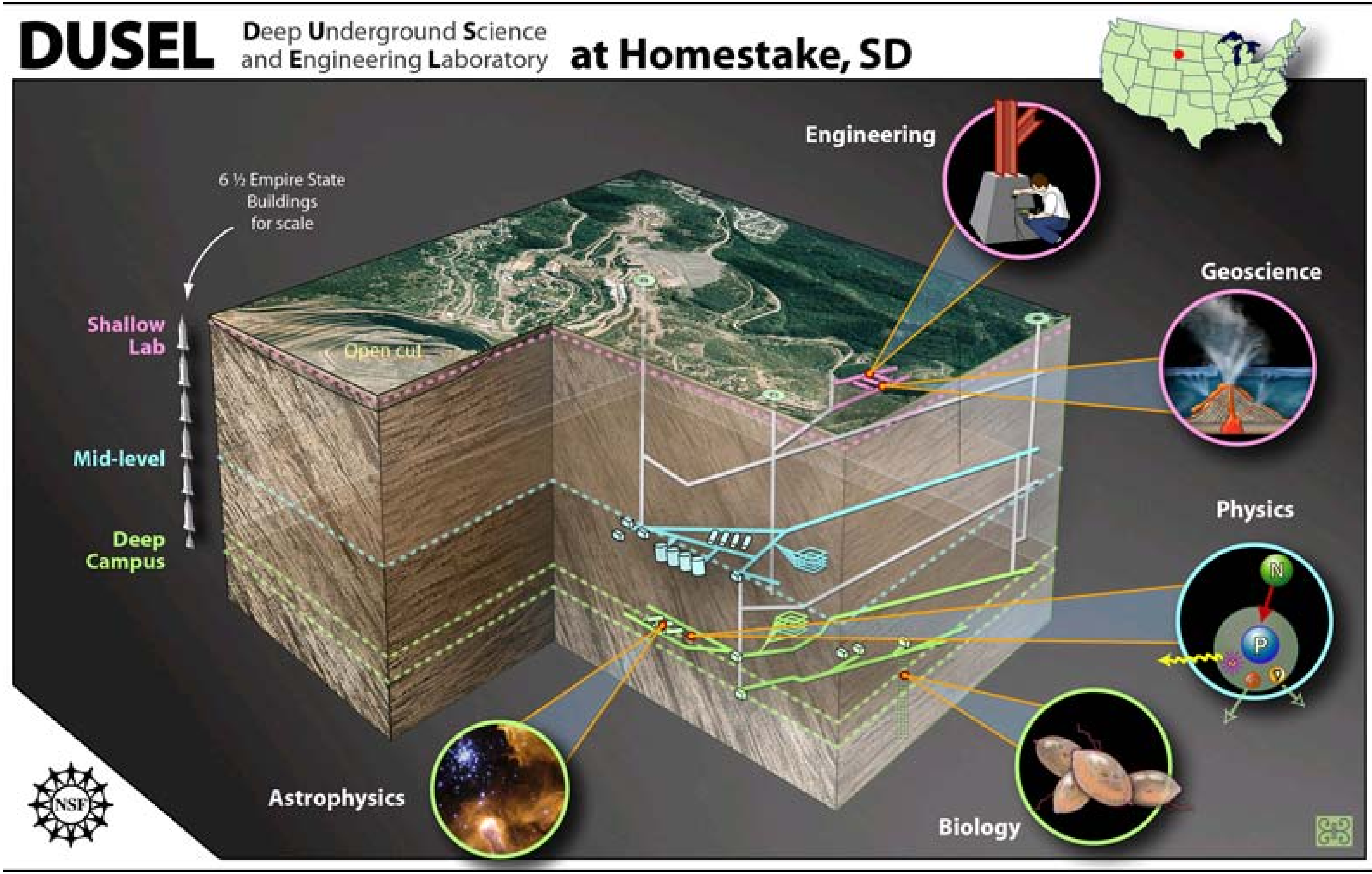
SNOLAB

MINING FOR KNOWLEDGE

CREUSER POUR TROUVER... L'EXCELLENCE





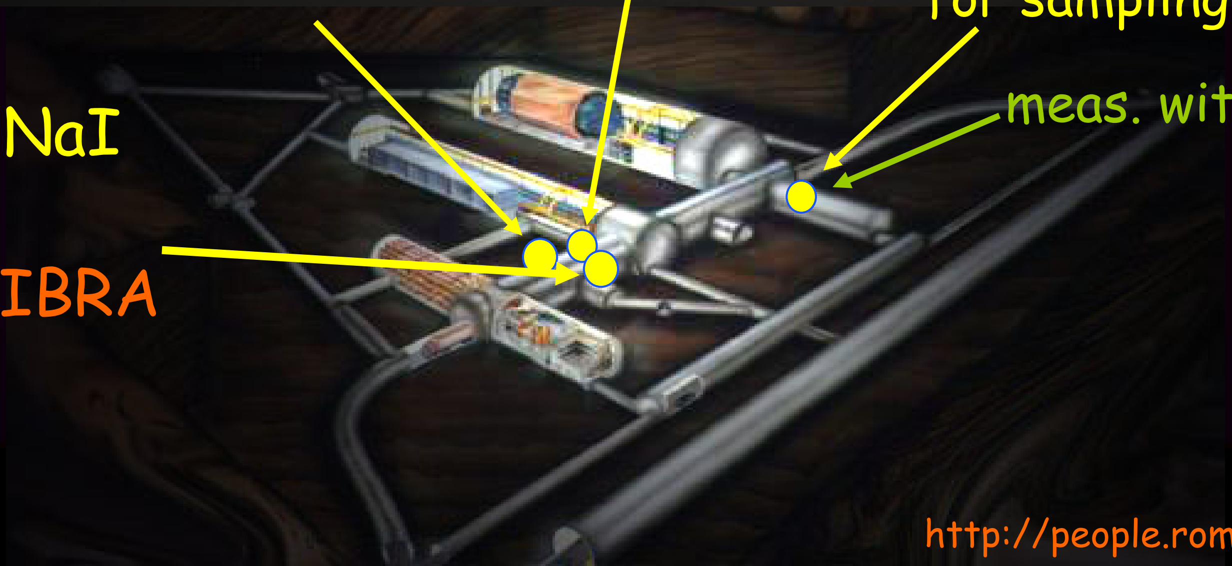


Extrem seltene kernphysikalische Prozesse studieren – Neutrino, Dunkle Materie 2007 vom NSF genehmigt – wird tiefstes Untergrundlabor der Welt sein (gerade geflutet …)

Dunkle Materie entdeckt?
- DAMA (2008)

Roma2,Roma1,LNGS,IHEP/Beijing

DAMA: an observatory for rare processes @LNGS



DAMA/R&D

DAMA/LXe

low bckg DAMA/Ge
for sampling meas.

meas. with ^{100}Mo

DAMA/NaI

DAMA/LIBRA

http://people.roma2.infn.it/dama

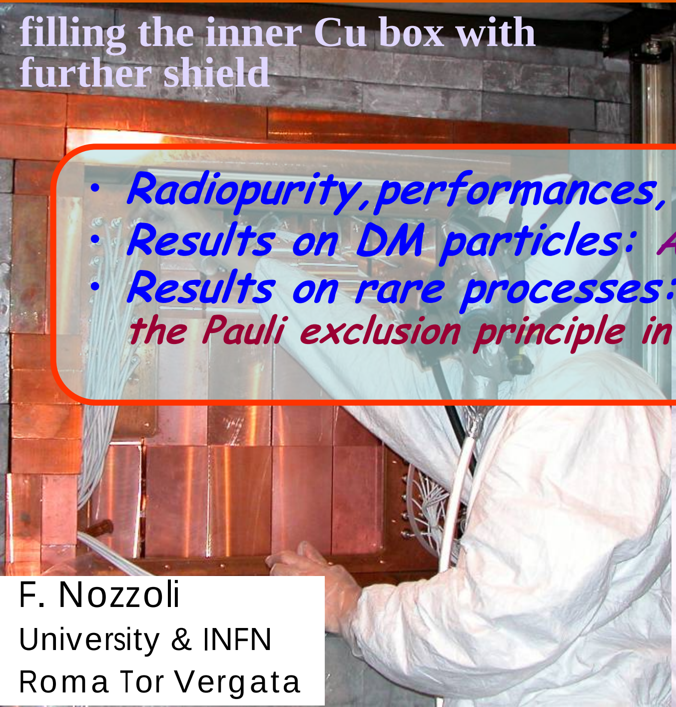
The new DAMA/LIBRA set-up ~250 kg NaI(Tl)
(Large sodium Iodide Bulk for RAre processes)

As a result of a second generation R&D for more radiopure NaI(Tl)
by exploiting new chemical/physical radiopurification techniques
(all operations involving crystals and PMTs - including photos - in HP Nitrogen atmosphere)

installing DAMA/LIBRA detectors

assembling a DAMA/ LIBRA detector

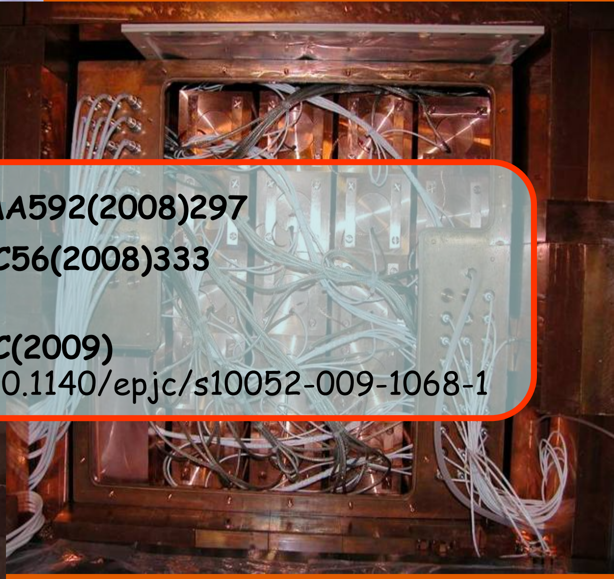
detectors during installation; in the central and right up detectors the new shaped Cu shield surrounding light guides (acting also as optical windows) and PMTs was not yet applied



filling the inner Cu box with further shield

- ***Radiopurity,performances, procedures, etc.:*** NIMA592(2008)297
- ***Results on DM particles:*** *Annual Modulation Signature:* EPJC56(2008)333
- ***Results on rare processes:*** *Possible processes violating the Pauli exclusion principle in Na and I:* EPJC(2009) doi 10.1140/epjc/s10052-009-1068-1

closing the Cu box housing the detectors

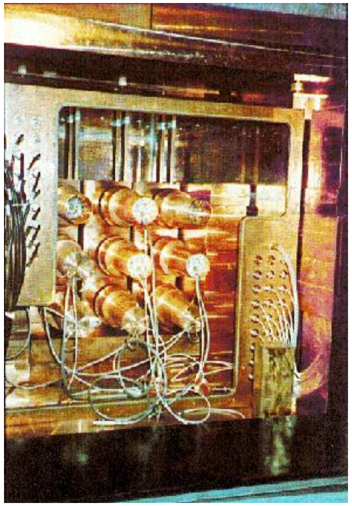


view at end of detectors' installation in the Cu box

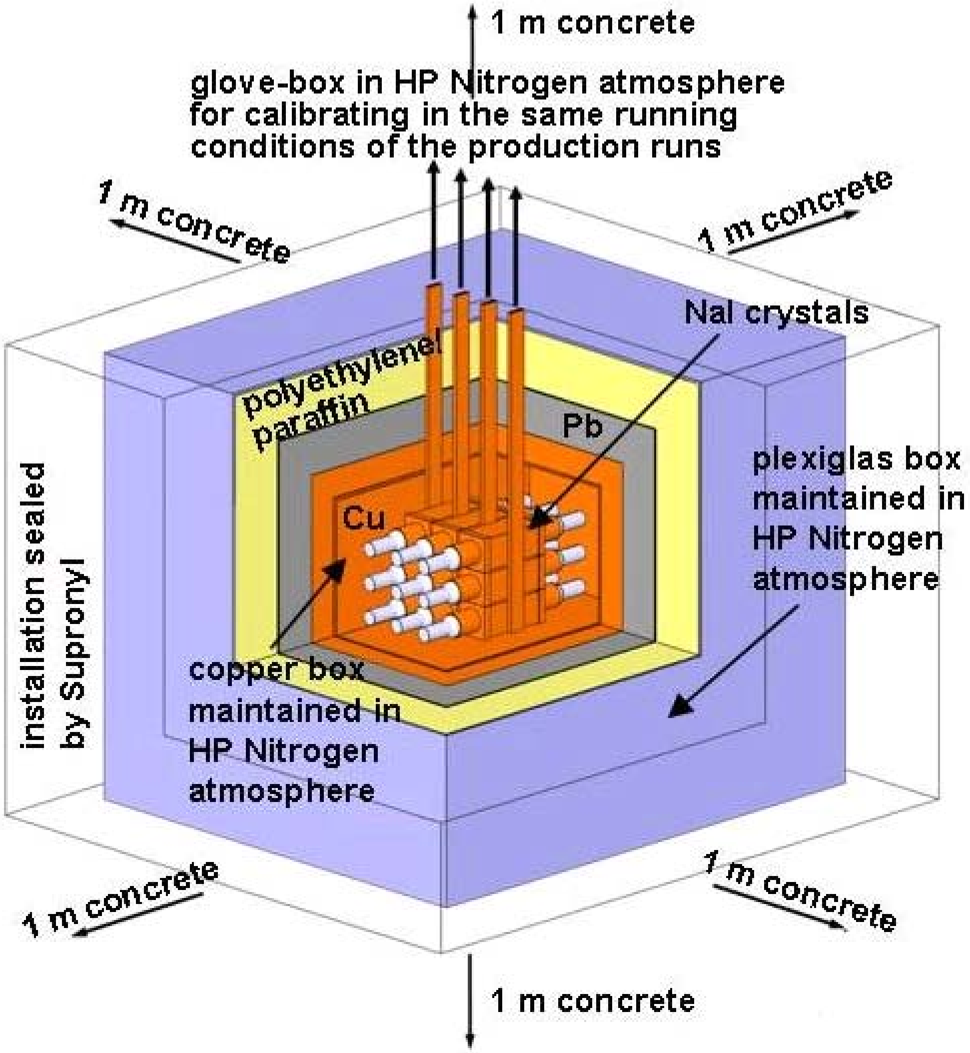
F. Nozzoli
University & INFN
Roma Tor Vergata

DAMA - Experiment

- 100kg NaI(Tl)-Kristalle
  - Energie durch Szintillation meßbar
  - erst direkt, dann proportional zu Ionisation
  - 10cm Lichtleiter von Kristall zu Photomultipliern
  - Abschirmung ähnlich Edelweiss
- Unterscheidung Kernrückstoß – Elektronrückstoß
  - Lichtpuls fällt unterschiedlich schnell ab (wg. quenching)
  - Unterdrückung des **Untergrund**s nur statistisch, **nicht** von Fall zu Fall
- Auflösung ca. 2keV

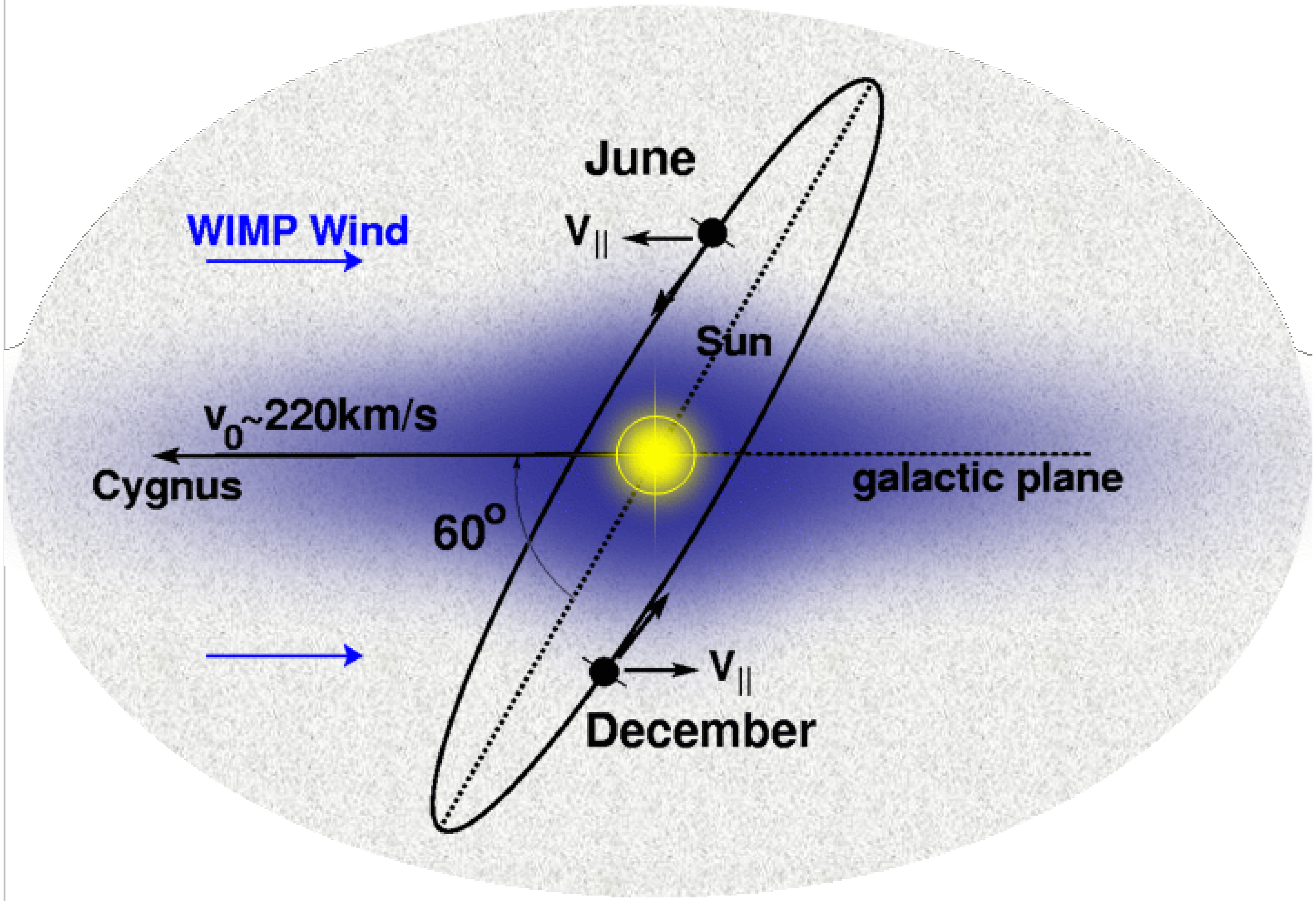


DAMA (Szintillator)



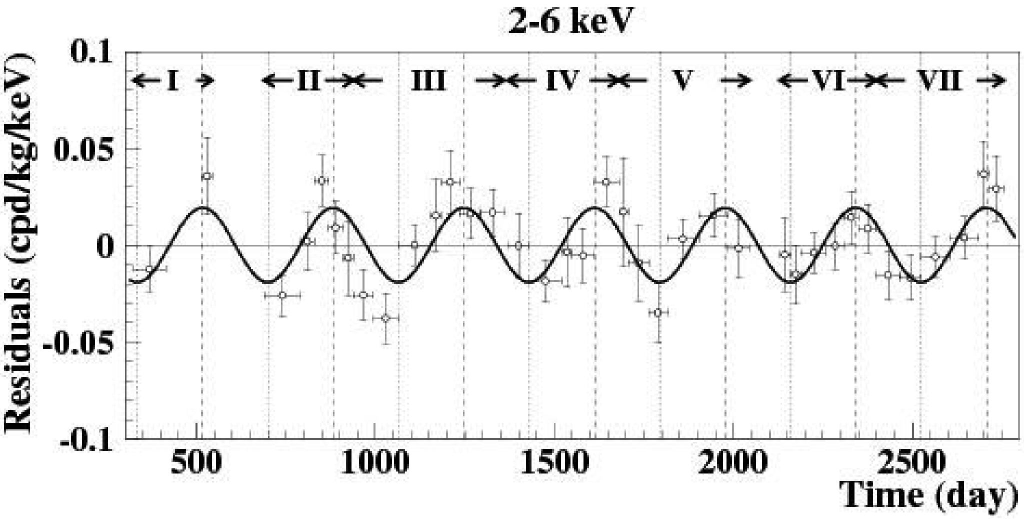
Simplified schema of ~ 100 kg NaI(Tl) set-up

- *Illustration of annual modulation in a WIMP signal.*



DAMA - Ergebnisse[1]

- Sie finden
  - nach 7 Jahren Laufzeit und insgesamt ca. 100 000 kg*d
  - Modulations-Signal (Signifikanz 6,3σ) E_{recoil}=2-6keV
  - müssten WIMPs mit M≈50GeV und $\sigma_{\chi p} \approx 7 \times 10^{-6}$ pb sein
- Aber Widersprüche:
  - Im Bereich 2-3keV sollten 50% der Ereignisse und in 4-6keV nur 7% liegen. Tun es aber nicht.
  - Verbleibender Hintergrund müsste mit E ansteigen. Wie das?



CDMS-results: für M≈60GeV ist

$\boldsymbol{\sigma_{\text{spin-independent}}}$ **≈1/10** von DAMA

(CDMS hauptsächlich für diese WW sensitiv, wg. Ge/Si)

D.S. Askerib et al., „Limits on spin-independent WIMP-nucleon interactions […] from CDMS“, arXiv:astro-ph/0509259

FAQ: ... DAMA/NaI "excluded" by others?

OBVIOUSLY NO

They give a single model dependent result using other target
DAMA/NaI gives a model independent result using ^{23}Na and ^{127}I targets

No direct model independent comparison possible

Even assuming their expt. results as they give them ...

Case of DM particle scatterings on target-nuclei

- In general? OBVIOUSLY NO

The results are fully "decoupled" either because of the different sensitivities to the various kinds of candidates, interactions and particle mass, or simply taking into account the large uncertainties in the astrophysical (realistic and consistent halo models, presence of non-thermalized components, particle velocity distribution, particle density in the halo, ...), nuclear (scaling laws, FFs, SF) and particle physics assumptions and in all the instrumental quantities (quenching factors, energy resolution, efficiency, ...) and theor. parameters.

- At least in the purely SI coupling they only consider? OBVIOUSLY NO

still room for compatibility either at low DM particle mass or simply accounting for the large uncertainties in the astrophysical, nuclear and particle physics assumptions and in all the expt. and theor. parameters.

Case of bosonic candidate (full conversion into electromagnetic radiation)

- These candidates are lost by these expts. OBVIOUSLY NO

....and more

(they usually quote in an uncorrect, partial and unupdated way the implications of the DAMA/NaI model independent result; they release orders of magnitude lower exposures, etc.)

aus „DAMA results&perspectives", Präsentation von R. Bernabei, gehalten in Zaragoza, 10/2006

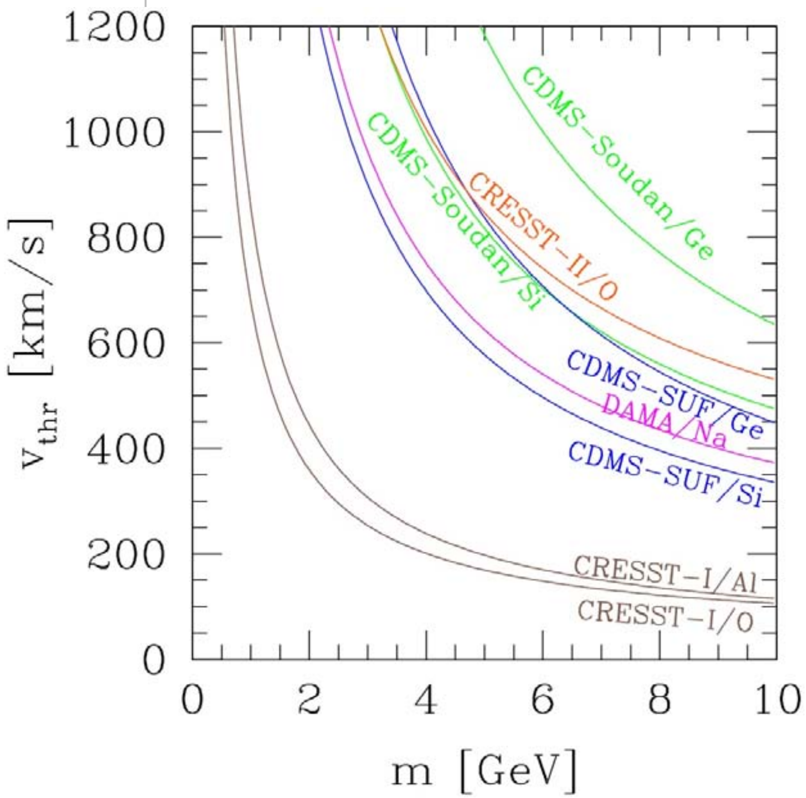
Kann DAMA doch auch richtig sein?

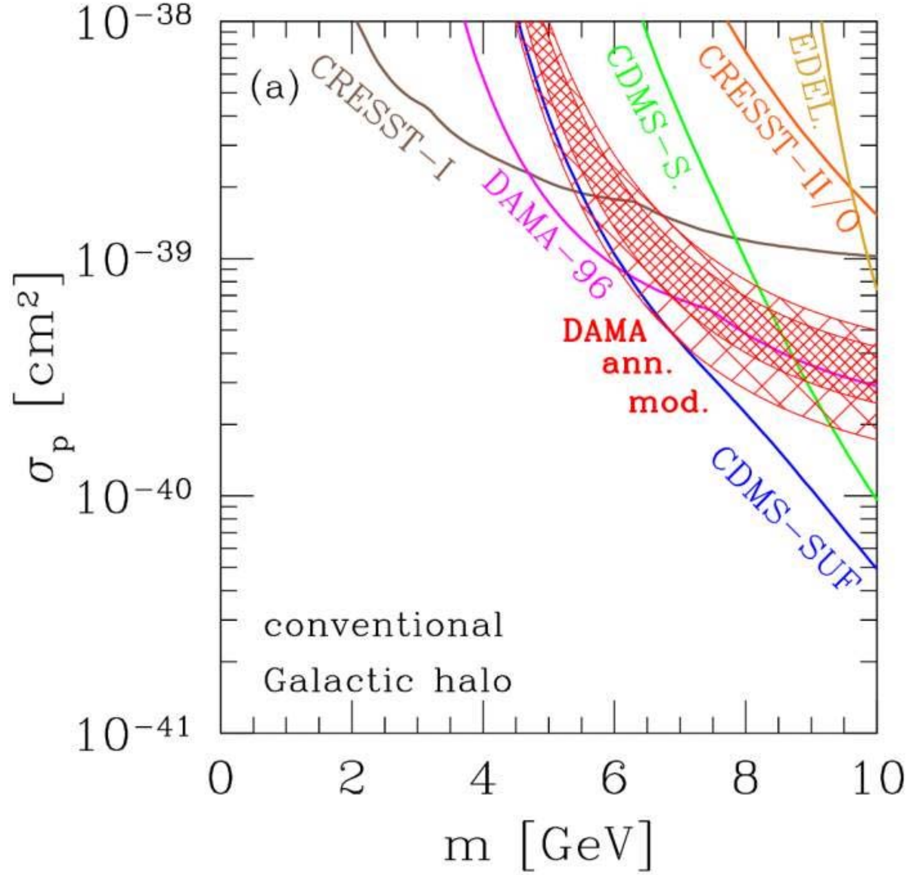
Übereinstimmung DAMA – andere Exp.

nur mit zusätzlichen Annahmen (und leichte WIMPs, etwa $5\mathrm{GeV}/c^2 < m_{\mathrm{WIMP}} < 9\mathrm{GeV}/c^2$)

besser, wenn man DM als halo mit Strömen beschreibt

WW spin-abhängig: dafür liefert CDMS mit ^{73}Ge (^{29}Si) auch Obergrenzen, aber natürlich geringe exposure.





aus: P. Gondolo, G. Gelmini, „Compatibility of DAMA dark matter detection with other searches“, Phys. Rev D 71, 123520 (2005)

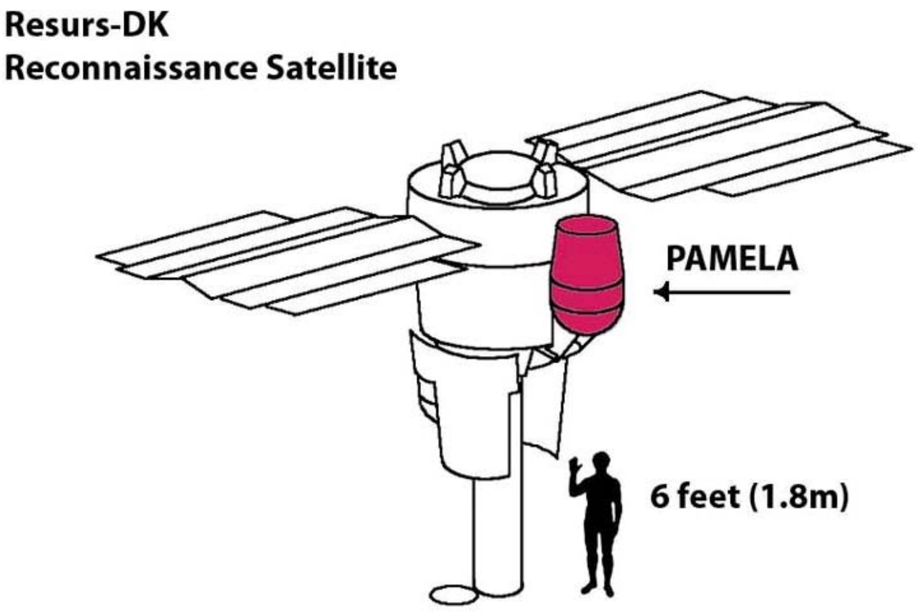
Hauptkritikpunkte an den DAMA-Resultaten

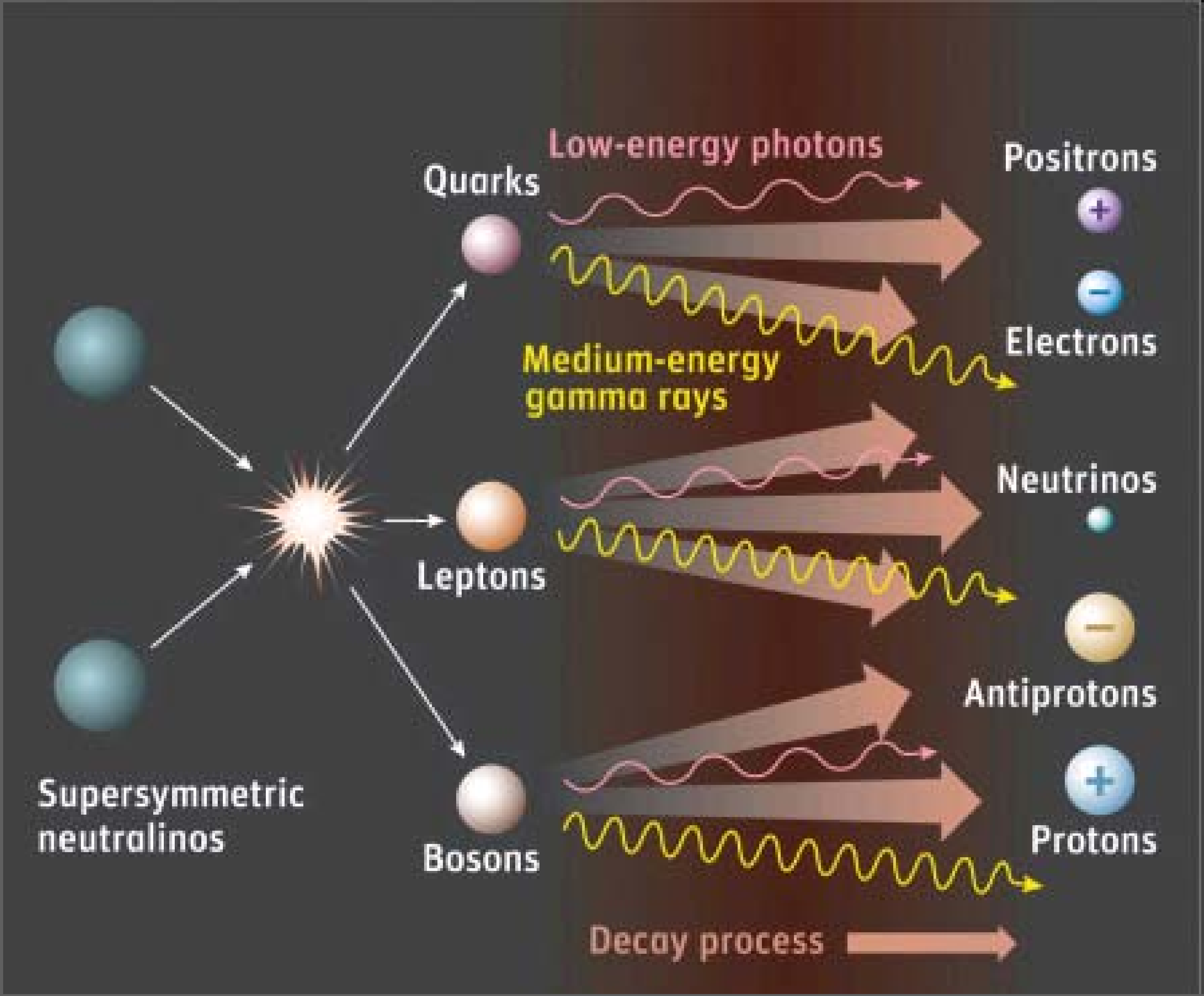
- Andere Gruppen sehen das Resultat nicht
- Systematische Fehler? Natürliche Strahlung, Elektronik?
- Radioaktivität?
- Zu kleine Kristalle?
- Stabilität der Detektoren?
- Eigenen „Kryostaten“ Kollegen finden nichts
- Gleiche Experimente 2. und 3. Generation zeigen die Resultate ebenfalls nicht
- Information der Community ist nicht ausreichend

- If the signal DAMA gets is dark matter, „it‘s certainly not the dark matter we were looking for“
- „I think it deserves to be checked.“
- „There are very good reasons to disbelieve the signal.“

Dunkle Materie entdeckt?
- PAMELA (2008)

- PAMELA is a space experiment carried on by the WiZard collaboration, devoted to the study of cosmic rays and carried on board of a Russian satellite, which was launched on 15th June, 2006.
- The main purpose of the experiment is the measurement of the antiproton and positron components of cosmic rays in a energy range and with a statistics never before achieved



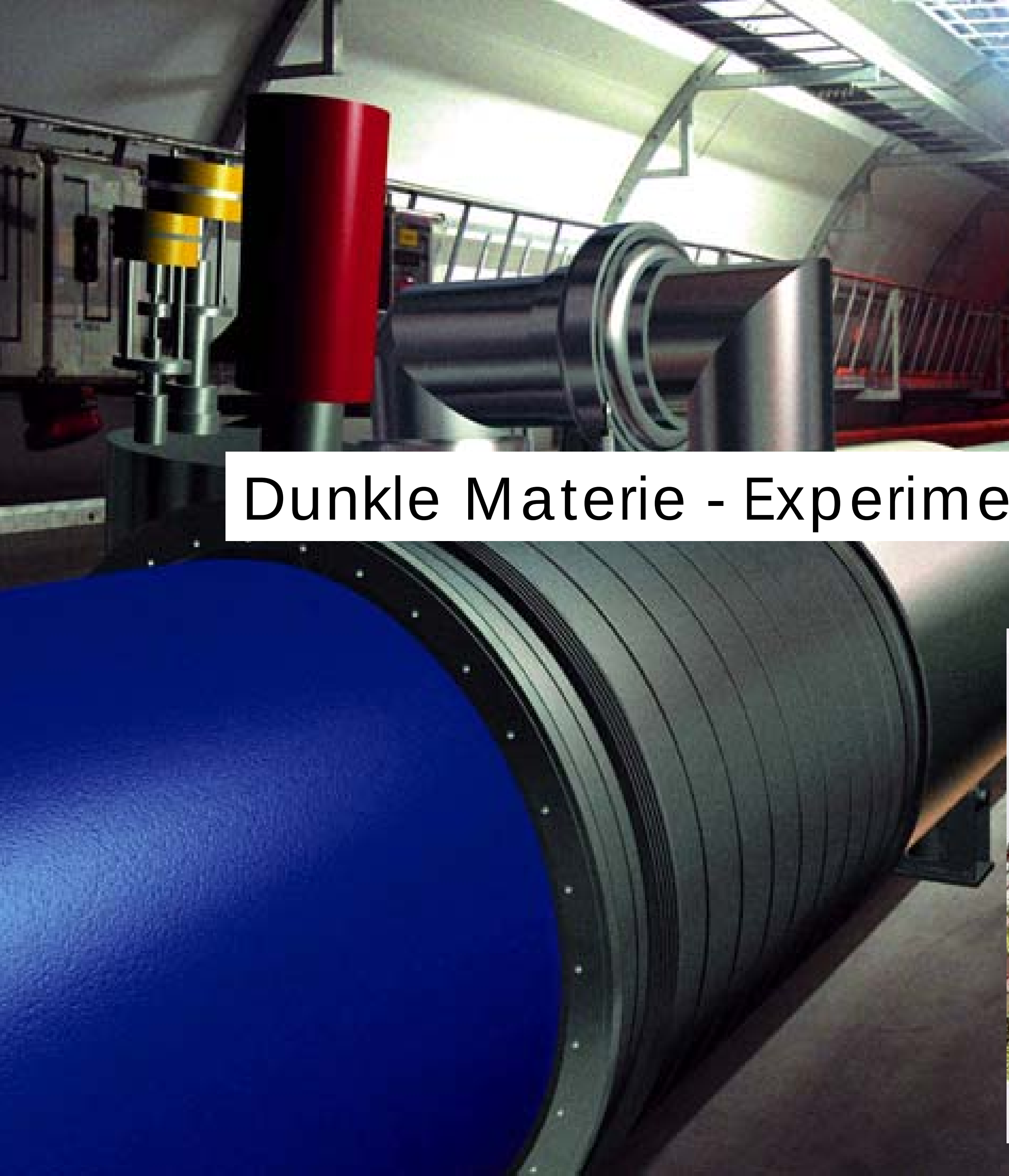

Low-energy photons
Quarks
Positrons
Electrons
Medium-energy gamma rays
Neutrinos
Leptons
Antiprotons
Supersymmetric neutralinos
Bosons
Protons
Decay process

Preliminary data (released Aug 2008, ICHEP Philadelphia) shows an **excess of positrons in the range 10-60 GeV**.

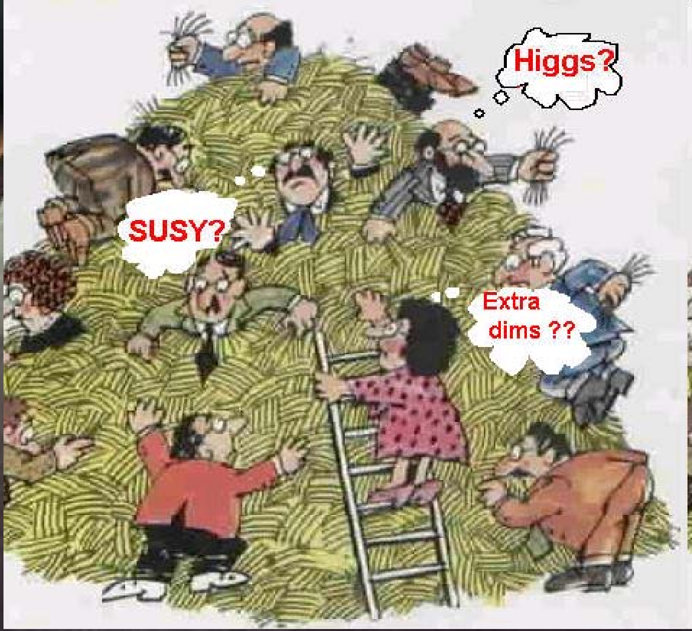
This is **thought to be a sign of dark matter annihilation:hypothetical WIMPs colliding with and annihilating each other to form gamma rays, matter and antimatter particles.**

The first two years of data were released in October 2008 in three publications. The positron excess was confirmed and found to persist up to 90 GeV.

Surprisingly, **no excess of antiprotons** was found. This is **inconsistent with predictions from most models of dark matter sources, in which the positron and antiproton excesses are correlated.**



Dunkle Materie - Experimente am LHC



Aufgabenstellungen für den LHC

- Was ist der Ursprung der Masse der Elementarteilchen,Higgs Teilchen ? (letztes Jahr)

- Ist unsere Welt supersymmetrisch ? (letztes Jahr)

- Woraus besteht die ‘dunkle’ Materie ? (**heutige Vorlesung**)
- Was sind die Eigenschaften der ‘Ur-Materie’ ?(**heutige Vorlesung**)

- Was ist der Grund für die die Materie-Antimaterie Asymmetrie im Universum ? (**nächste Vorlesung**)

Suche nach der DM / Kandidatenzoo

- Kandidatensuche für kalte dunkle Materie in SUSY-Teilchen:
  - Higgsino, Photino, Gravitino
  - Wino, Bino, Gluino (Gauginos)

  - Neutralinos und Charginos sind ein Zusammenspiel aus Higgsino, Wino und Bino Teilchen (über Massematrizen)

Axions, Neutralinos, Gravitinos, Axinos, Kaluza-Klein Photons,

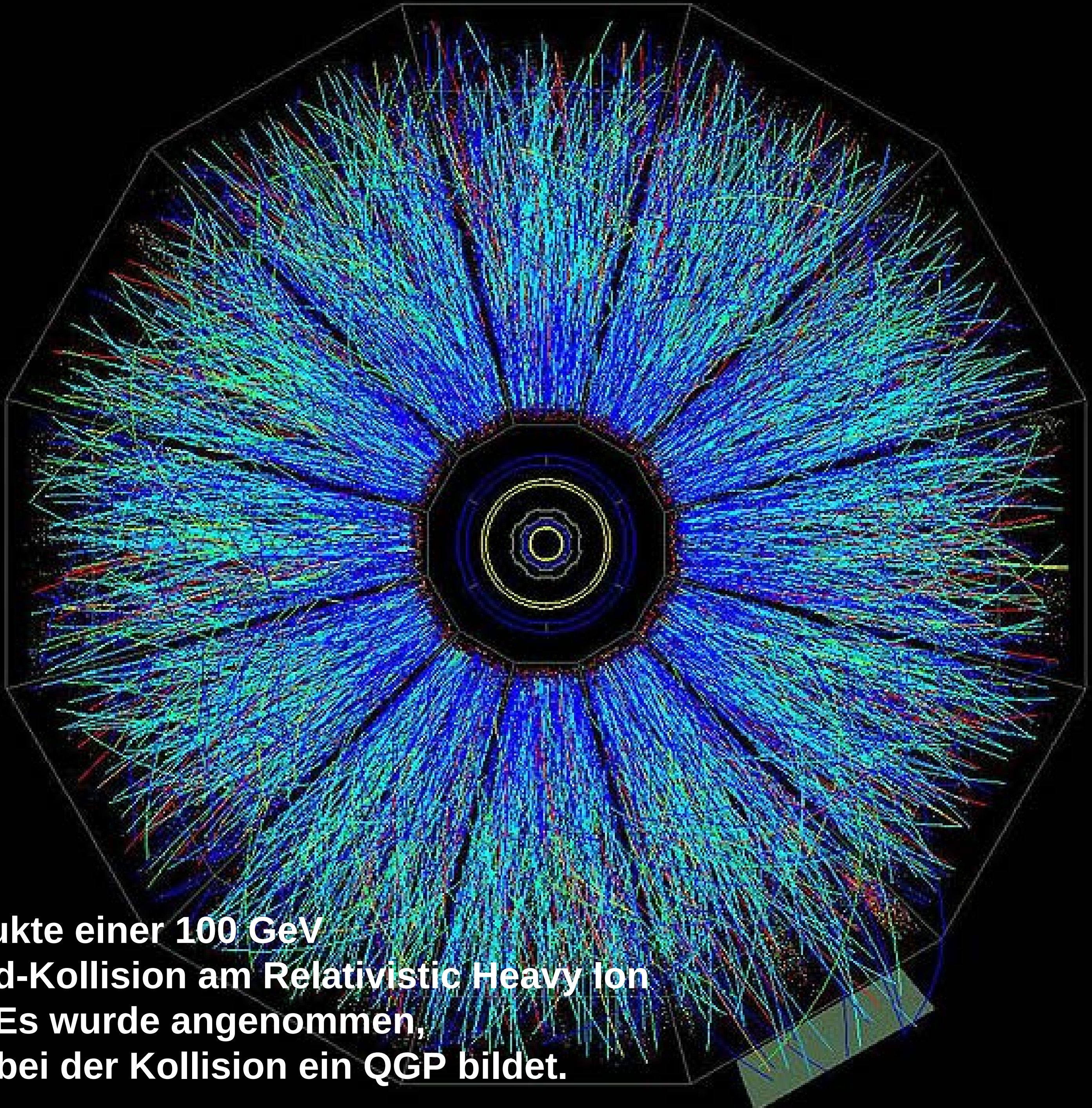
Kaluza-Klein Neutrinos,

Heavy Fourth Generation Neutrinos, Mirror Photons, Mirror Nuclei,

Stable States in Little Higgs Theories, WIMPzillas, Cryptons, Sterile Neutrinos,

Light Scalars, Q-Balls, D-Matter, Brane World Dark Matter,

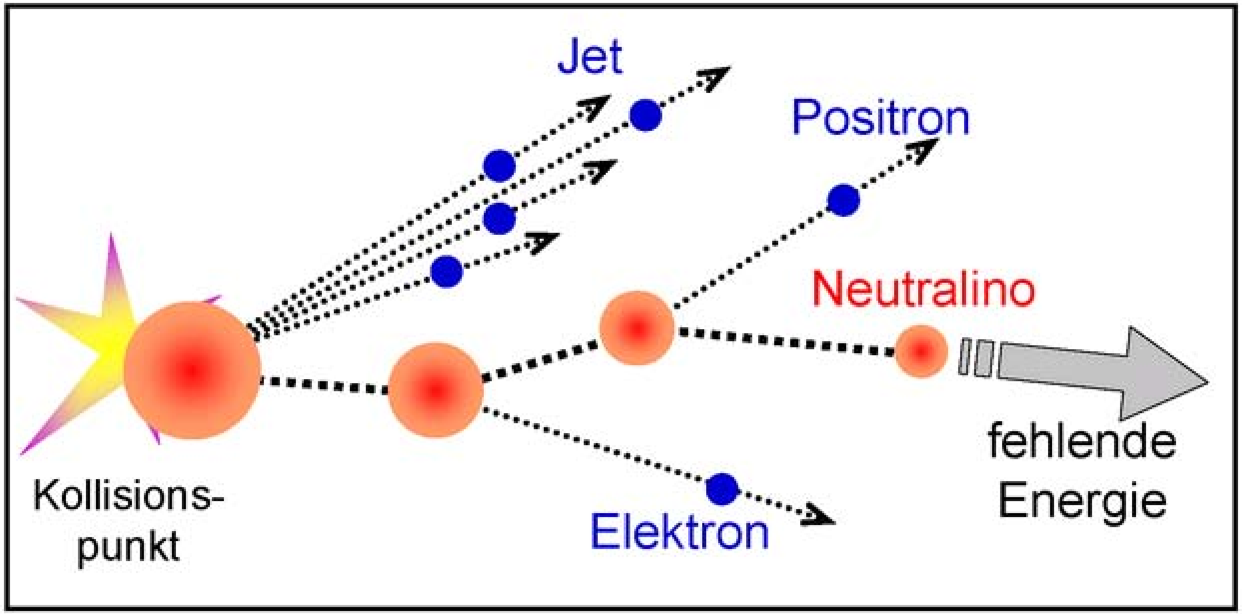
Primordial Black Holes, …



Endprodukte einer 100 GeV
Gold-Gold-Kollision am Relativistic Heavy Ion
Collider. Es wurde angenommen,
daß sich bei der Kollision ein QGP bildet.

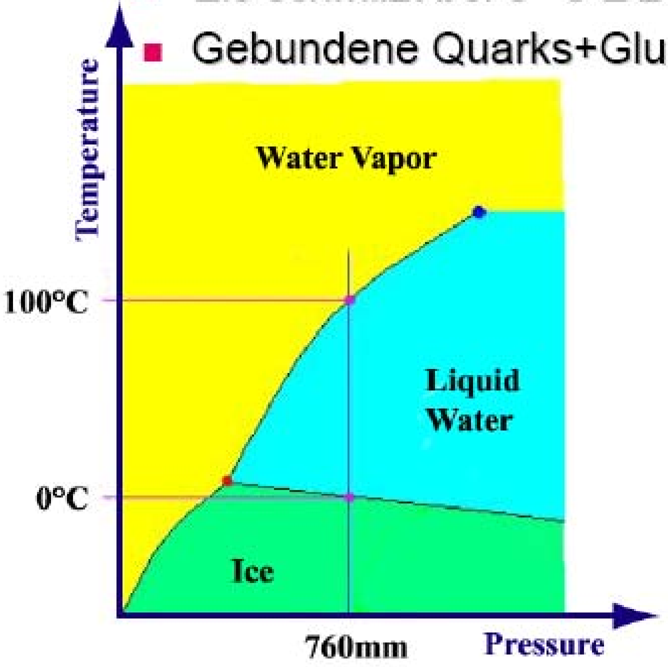
Zerfall schwerer supersymmetrischer Teilchen am LHC

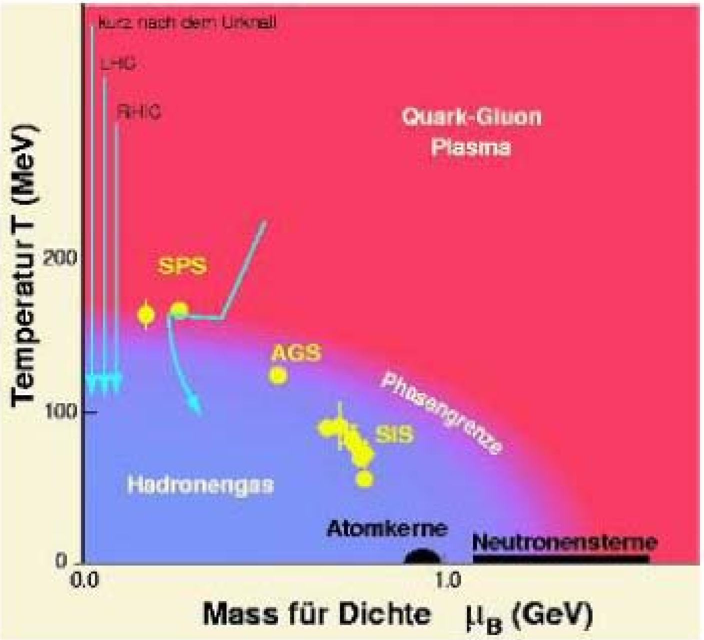
- Typischer Kaskadenzerfall von schweren supersymmetrischen Teilchen, die am LHC bevorzugt erzeugt werden. Der Endzustand besteht aus verschiedenen Teilchen des Standardmodells, begleitet durch fehlende Energie der unbemerkt entweichenden supersymmetrischen Endprodukte.



ALICE kocht die Ursuppe

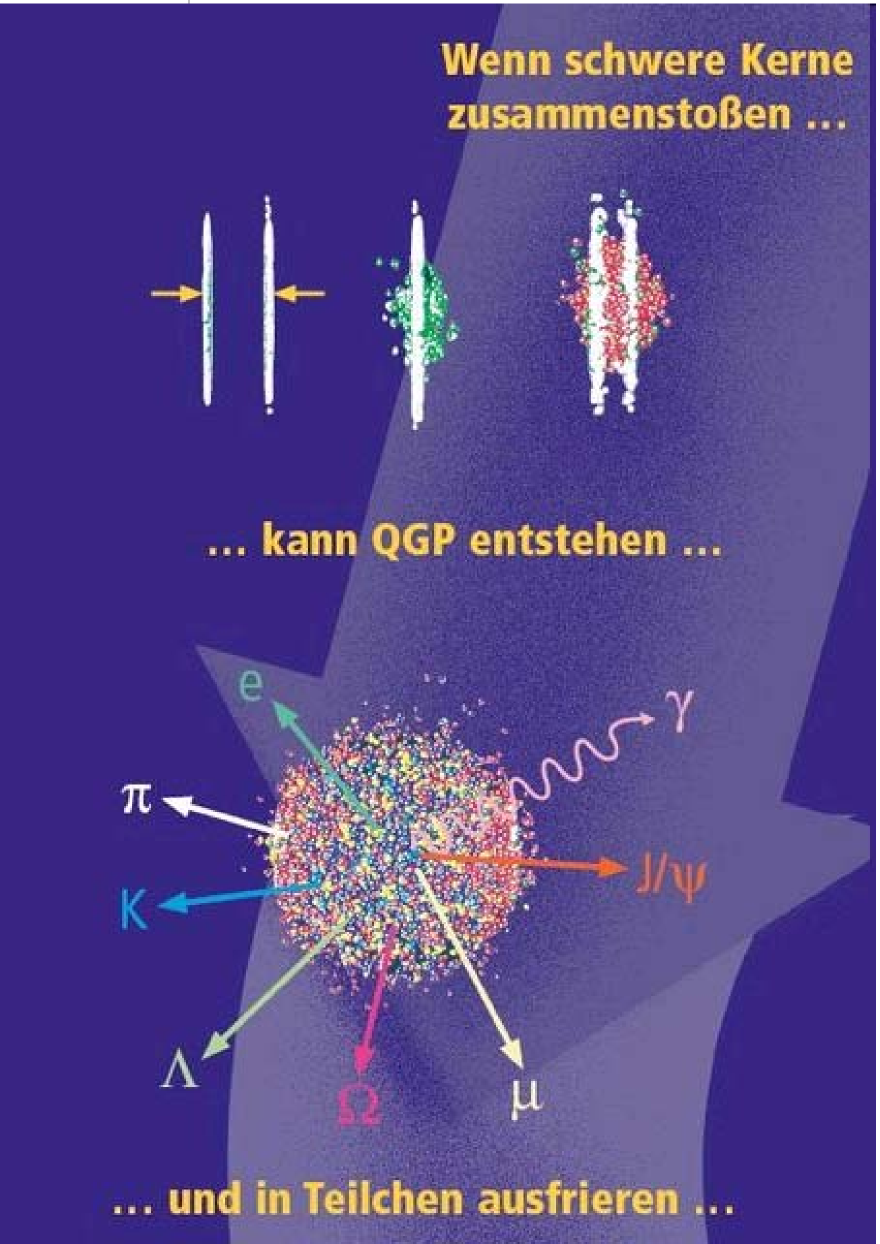
- Untersuchung des Quark-Gluon Plasmas
  - Neuer Zustand von Materie: „flüssige(?)“ Quarks und Gluonen
    - Eis schmilzt bei 0 °C ≅ 270 K
    - Gebundene Quarks+Gluonen schmelzen bei 170 MeV = 2x10^{12}K

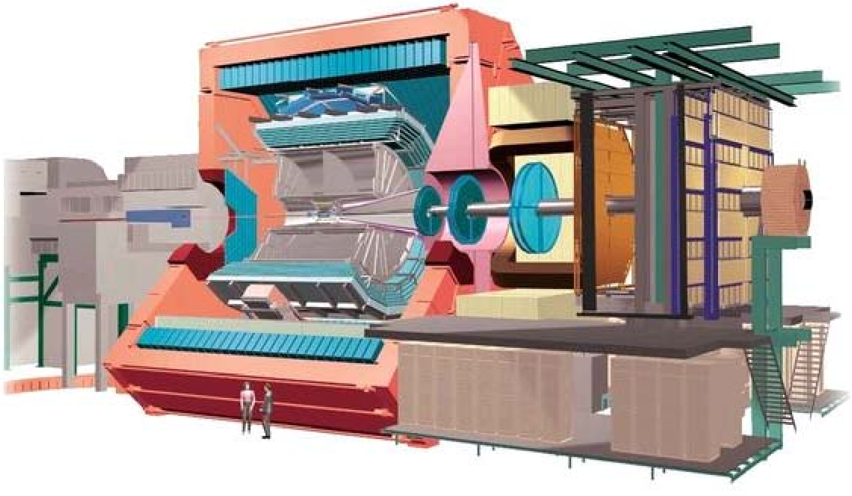




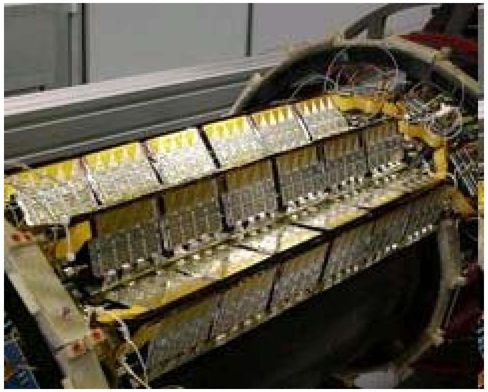
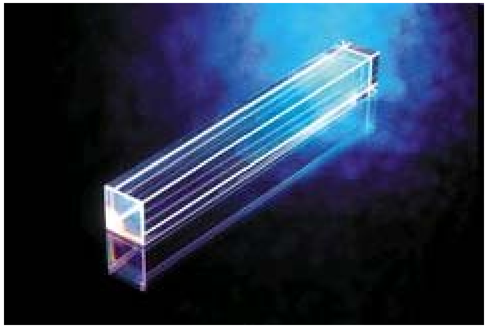
    - Beschleunige und Kollidiere „Hadronen“-Eis, um „Quark-Gluon“-Wasser herzustellen (erreiche > 200.000 fache Sonneninnentemperatur)
    - ALICE wird Eigenschaften dieses neuen Materiezustand untersuchen (Zustandsgleichung, Brechungsindex, Suszeptibilität, Viskosität, Wärmeleitfähigkeit, Schallgeschwindigkeit,…) → ideale Flüssigkeit?

Quark-Gluon Plasma (QGP) am LHC (ALICE)



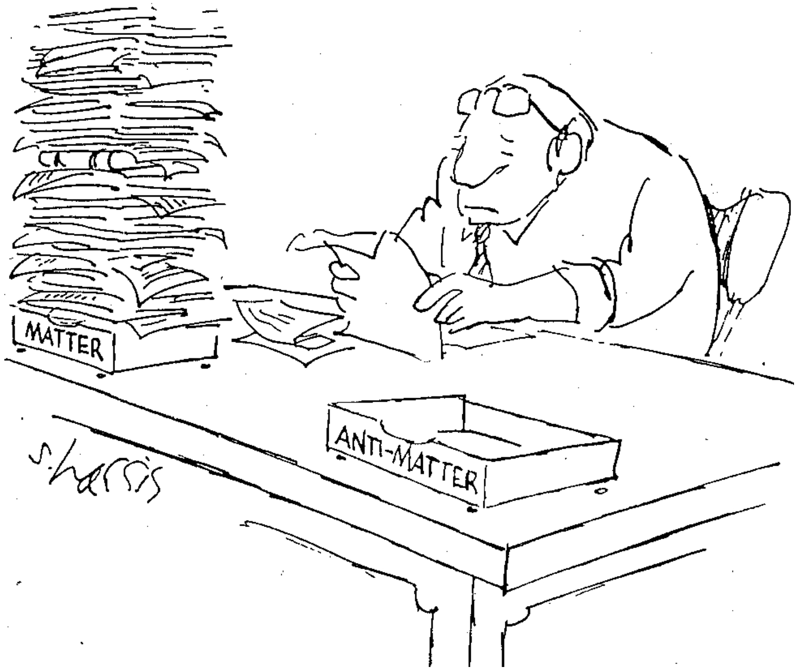


ALICE




In zwei Wochen ...



- **22.01.10 LHC: Materie & Antimaterie**
- 05.02.10 Zeitfragen