Results and Prospects of Direct Dark Matter Detection

CHIPP Plenary Meeting
Lausanne, September 8-9, 2009

Laura Baudis
University of Zurich
Goal of Direct Detection Experiments

• Detect new, yet undiscovered particles, which may be responsible for the dark matter in our galaxy. Example: WIMPs = heavy (few GeV - few TeV), color and electrically neutral; in thermal equilibrium with the rest of the particles in the early universe, freeze out when $M_W >> T_F$

(B. Moore at all, 2008)

(Klypin, Zhao & Somerville 2002)
Strategy for WIMP Direct Detection

- Elastic collisions with atomic nuclei
- The recoil energy is:

\[ E_R = \frac{\bar{q}^2}{2m_N} = \frac{\mu^2 v^2}{m_N} (1 - \cos \theta) \leq 50 \text{ keV} \]

- and the expected rate:

\[ R \propto N \rho_\chi \frac{\sigma_\chi N \cdot \langle v \rangle}{m_\chi} \]
Expected Scattering Cross Sections

• A general WIMP candidate: fermion (Dirac or Majorana), boson or scalar particle
• The most general, Lorentz invariant Lagrangian has 4 types of interactions (S, P, V, A)
• In the extreme NR limit relevant for galactic WIMPs \(v_{\text{WIMP}} \sim 10^{-3} \text{c}\), the interactions leading to WIMP-nuclei elastic scattering are classified as:

**scalar interactions** (WIMPs couples to nuclear mass; from the scalar and vector part of \(L\))

\[
\sigma_{SI} = \frac{m_N^2}{4\pi(m_W + m_N)^2} \left[ Z f_p + (A - Z) f_n \right]^2 \quad f_{p,n} = \text{effective couplings to } p, n
\]

**spin-spin interactions** (WIMPs couples to nuclear spin \(J_N\), from the axial part of \(L\))

\[
\sigma_{SD} = \frac{32}{\pi} G_F^2 \frac{m_W^2 m_N^2}{(m_W + m_N)^2} \frac{J_N + 1}{J_N} \left( a_p \left< S_p \right> + a_n \left< S_n \right> \right)^2 \quad \left< S_{p,n} \right> = \text{expectation values of the spin content of the } p, n \text{ in the target nucleus}
\] \(a_{p,n} = \text{effective couplings to } p, n\)
Expected Interaction Rates

- Integrate over WIMP velocity distribution; in general assumed to be of Maxwell-Boltzmann type, which so far is a pretty good approximation (isothermal halo with ideal WIMP gas):

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2m_\chi \mu^2} F^2(E_R) \int_{v_{min}}^{v_{max}} \frac{f(v)}{\sqrt{v}} dv$$

$$f(v) dv = \frac{4 v^2}{\sqrt{v_0^3/\pi}} e^{-v^2/v_0^2} d^3v$$

- with WIMP-nucleon cross sections $< 10^{-7}$ pb, the expected rates are

$$< 1 \text{ event/100kg/day}$$

Differential rates for different targets

- $M_{\text{WIMP}} = 100 \text{ GeV}$
- $\sigma_{WN} = 4 \times 10^{-43} \text{ cm}^2$

Laura Baudis, University of Zurich, CHiPP Plenary Meeting, September 9, 2008
Expected WIMP Signatures

- **WIMP interactions in detector should be:**
  - nuclear recoils
  - single scatters, uniform throughout detector volume

- **Spectral shape** (exponential, however similar to background)

- **Dependence on material** ($A^2$, $F^2(Q)$, test consistency between different targets)

- **Annual flux modulation** (~ 3% effect, most events close to threshold)

- **Diurnal direction modulation** (larger effect, requires low-pressure gas target)
Evidence for annual modulation?

- DAMA/LIBRA at LNGS (0.82 ton x year in NaI); $A = (0.0215 \pm 0.0026)$ cpd/kg/keV (8.3 $\sigma$ CL)
- Severe tension with other experiments!

Savage, Gelmini, Gondolo, Freese

Spin-independent

Spin-dependent

Savage, Gelmini, Gondolo, Freese
Direct WIMP Detection Experiments and Results

Spin-independent cross section (normalized to nucleons)

- COUPP, PICASSO, ULTIMA
- CDMS, EDELWEISS
- CRESST, ROSEBUD
- DRIFT (+direction)
- ZEPLIN, XENON, LUX, ArDM, WARP
- DAMA/LIBRA, XMASS, CLEAN, ANAIS, KIMS

WIMP-nucleon $\sigma_{SI}$ [cm$^2$]

WIMP Mass [GeV]
Cryogenic Experiments at mK Temperatures

- **Advantages:** high sensitivity to nuclear recoils
  - measuring the full nuclear recoil energy in the phonon channel
  - low energy threshold (keV to sub-keV), good energy resolution
  - light/phonon and charge/phonon: nuclear vs. electron recoil discrimination

---

**CRESST at LNGS**

- **CRESST CaWO₄ Light vs. Phonons**
  - Efficiency: > 99.9%
  - E > 20keV

**EDELWEISS at LSM**

- Ionization/Recoil Ratio
  - Neutron calibration
  - GGA1

**CDMS at Soudan**

- Electron recoils
- Nuclear recoils

---

Laura Baudis, University of Manchester
IP Plenary Meeting, September 9, 2022
Cryogenic Experiments at mK Temperatures

10 kg array of 33 CaWO₄ detectors; 66 SQUID channel array now cool-down (5 kg)

10 kg (30 modules) of NTD and NbSi Ge detectors in new cryostat
- 100 kg d under analysis
- data taking in progress

30 Ge (4.75 kg) and Si (1.1) detectors in 5 towers
Run 123+124: 654 kg d Ge
Run 125+126: 740 kg d Ge
Run 127: ongoing

Run 30 Verena/SOS21 25.1 kg days

commissioning run
25 kg d

CRESST at LNGS

Prototype ≈ 4 kg.d

Ge: 397 kg d

CDMS at Soudan
Future mK Cryogenic Dark Matter Experiments

- **EURECA (European Underground Rare Event Calorimeter Array)**
  - Joint effort: CRESST, EDELWEISS, ROSEBUD, CERN,...
  - Mass: 100 kg - 1 ton, multi-target approach

- **SuperCDMS (US/Canada):** 3 phases 25 kg - 150 kg - 1 ton
  - 640 g Ge detectors with improved phonon sensors
  - 4 prototype detectors built and tested

**R&D for SuperCDMS:**
- 1” thick SuperZIPs (0.64 kg)
- 2 SuperTowers at Soudan
- 7 SuperTowers at SNOLAB
Noble Liquids as Dark Matter Detectors

Dense, homogeneous targets/detectors
High scintillation/ionization yields
Commercially easy to obtain and purify

<table>
<thead>
<tr>
<th></th>
<th>Scintillation Light</th>
<th>Intrinsic Backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne (A=20)</td>
<td>85 nm requires wavelength shifter</td>
<td>Low BP (20 K), all impurities frozen out. No radioactive isotopes</td>
</tr>
<tr>
<td>$60/kg</td>
<td>$60/kg</td>
<td></td>
</tr>
<tr>
<td>100% even-even nucleus</td>
<td>85 nm requires wavelength shifter</td>
<td></td>
</tr>
<tr>
<td>Ar (A=40)</td>
<td>128 nm requires wavelength shifter</td>
<td>Natural Ar contains $^{39}$Ar at 1Bq/kg, corresp. to ~150 ev/kg/day/keV at low energies</td>
</tr>
<tr>
<td>$2/kg</td>
<td>$2/kg</td>
<td></td>
</tr>
<tr>
<td>100% even-even nucleus</td>
<td>128 nm requires wavelength shifter</td>
<td></td>
</tr>
<tr>
<td>Xe (A=131)</td>
<td>175 nm UV quartz PMT window</td>
<td>No long lived isotopes. $^{85}$Kr can be removed by active charcoal filter or distillation</td>
</tr>
<tr>
<td>$800/kg</td>
<td>$800/kg</td>
<td></td>
</tr>
<tr>
<td>50% odd nuclei ($^{129}$Xe, $^{131}$Xe)</td>
<td>175 nm UV quartz PMT window</td>
<td></td>
</tr>
</tbody>
</table>

Differential rates

Integrated rates

$M_{WIMP} = 100$ GeV
$\sigma_{WIMP-N} = 4 \times 10^{-43}$ cm$^2$

Laura Baudis, University of Zurich, CHIPP Plenary Meeting, September 9, 2008
Charge and Light in Noble Liquids

Kubota et al., PRB 20, 1979

Ionizing charged particles

holes R⁺

electrons

escape

localized ions R⁺²

thermalized electrons

recombination

τ ≈ 15 ns

time constants:

few ns/15.4 μs Ne
10 ns/1.5 μs Ar
3/27 ns Xe

excited molecular states

1Σ⁺ u
3Σ⁺ u

fast
slow

luminiscence
VUV light

λ_{LNe} \sim 77.5 \text{ nm}
λ_{LAr} \sim 128 \text{ nm}
λ_{LXe} \sim 175 \text{ nm}

Laura Baudis, University of Zurich, CHIPP Plenary Meeting, September 9, 2008
Noble Liquid Detectors: Existing Experiments and Proposed Projects

<table>
<thead>
<tr>
<th></th>
<th>Single Phase (liquid only) PSD</th>
<th>Double Phase (liquid and gas) PSD and Charge/Light</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neon (A=20)</strong></td>
<td>miniCLEAN (100 kg) CLEAN (10-100 t)</td>
<td>SIGN (high P Ne gas)</td>
</tr>
<tr>
<td><strong>Argon (A=40)</strong></td>
<td>DEAP-I (7 kg) miniCLEAN (100 kg) CLEAN (10-100 t)</td>
<td>ArDM (1 ton) WARP (3.2 kg) WARP (140 kg)</td>
</tr>
<tr>
<td><strong>Xenon (A=131)</strong></td>
<td>ZEPLIN I XMASS (100 kg) XMASS (800 kg) XMASS (23 t)</td>
<td>ZEPLIN II + III (31 kg, 8 kg) XENON10 (15 kg), XENON100 (170 kg) LUX (300 kg), XENON1t (3t)</td>
</tr>
</tbody>
</table>

- **Single phase**: $e^-$-ion recombination occurs; singlet/triplet ratio is 10/1 for NR/ER
- **Double phase**: ionization and scintillation; electrons are drifted in $\sim$ 1kV/cm E-field
- **Complementarity between Ar and Xe targets** (nuclear mass, spin vs. no spin,...)
The Double-Phase Detector Concept

- **Prompt (S1) light signal** after interaction in active volume; charge is drifted, extracted into the gas phase and detected either *directly with LEMs*, or as *proportional light (S2)*
- **Challenge**: ultra-pure liquid + high drift field; efficient extraction + detection of $e^-$
Two-phase Argon Detectors

WARP at LNGS
3.2 kg LAr operated at LNGS; results from zero events > 55 keVr

140 kg LAr, 41 3” PMTs under construction active LAr shield: ~ 8t, viewed by 300 PMTs

1 t LAr prototype under construction direct electron readout via LEMs (thick macroscopic GEM) S1 with 14 x 8” PMTs
The ArDM Experiment

- 1 ton liquid argon TPC/calorimeter, in construction phase at CERN
- Goals: $E_{th} \approx 30$ keV, 3D imaging, event-by-event identification of interaction type
- Background rejection by: topology, localization, ionization density (ratio of ionization/scintillation and time distribution of the scintillation light)
- Expected signal rate: 1 WIMP event/ton/day at $10^{-8}$ pb
The ArDM Experiment: Status at CERN

- Cryostat and liquid purification and recirculation built and tested
- HV generator (Greinacher circuit) to reach $\approx 4 \text{ kV/cm (} V_{\text{tot}} = 500 \text{ kV)}$ placed in liquid
- Slow Control has been implemented
- Double phase LEMs successfully operated in double phase Ar mode (stable gain of $10^4$); with final LEM charge readout segmented; A/D conversion and DAQ system being developed
- 14 bialkali 8” PMTs (TPB coated) installed at the bottom
- 15 light reflector/shifter foils produced and installed

C.Amsler et al., “Luminescence quenching of the triplet excimer state by air traces in gaseous argon” arXiv:0708.2621

- Double-sided copper-clad (35 µm layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu ($<~ 1$ µm layer) to avoid oxidization
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 µm
- Distance between centers of neighboring holes = 800 µm

Hamamatsu R5912-02MOD
The ArDM Experiment: Assembly and Plans

• Assembled at CERN: Sept. 2007 - May 2008
• First cool down in May 2008 successful, PMTs work well
• To understand light collection: movable source + blue LED installed
• Purity monitoring cell and neutron calibration in progress
• Goals: operate full scale prototype at surface (and evtl. at shallow depth) at CERN
• Consider deep underground operation, for instance at the Canfranc Lab
Two-phase Xenon Detectors

ZEPLIN III at Boulby

8 kg LXe (fiducial)
31 x 2” cm PMTs
analysis of WIMP search run in progress

XENON10 at LNGS

15 kg (5.4 fiducial), 89 2” PMTs
136 kg d (after cuts) of WIMP search data

a total of 30% of WIMP search data unblinded => no events in the signal region
rest (70%) will be unblinded soon

10 events observed, all BG
Results: PRL100, PRL101
The XENON Program

XENON R&D
ongoing

XENON10
2006-2007
in commissioning

XENON100

in commissioning

2009-2013
studies in progress

XENON1t

ongoing

Laura Baudis, University of Zurich, CHIPP Plenary Meeting, September 9, 2008
The XENON100 Detector

- TPC (total of 170 kg LXe) with active veto (100 kg LXe) installed underground since February 2008
- New cryostat design: PTR and feed-throughs outside the low-background shield
- All (detector/shield) materials were screened for their radio-purity: MC predictions of backgrounds
- Test runs showed that background is at the expected level
- Xe is now being purified to ppt $^{85}\text{Kr}$-levels ($T_{1/2} = 10.7 \text{ y}$, $\beta^-$ 678 keV) with dedicated column at LNGS
- **Expect to start WIMP search run in November 2008**
XENON100 PMTs

- 242 (Hamamatsu R8520) 1”x1”, low radioactivity PMTs; 80 with high QE of 33%
- 98 top: for good fiducial volume cut efficiency
- 80 bottom: for optimal S1 collection efficiency (thus low threshold); 64 in active LXe shield
- PMT gain calibration with blue LEDs; the SPE response is measured
Responsibilities of UZH Group in XENON

- PMT testing, calibrations and gain monitoring (+ PMT database)
- Material screening with ultra-low BG HPGe detector at LNGS and identification of low-background materials
- MC geometry (Geant4) and simulations of gamma/alpha/beta and neutron backgrounds
- Calibration (sources/data/MC) with gamma and neutron sources
- Charge and light yield measurements (+ R&D) with small prototype detector at UZH lab
- Various hardware components (inner PTFE TPC structure + PMT holder built at UZH)
- 3 postdocs (A. Ferella, R. Santorelli, E. Tziaeri), 4 graduate students (A. Askin, A. Kish, A. Manalaysay, M. Haffke)
Preliminary Background from XENON100 Data

Data and Monte Carlo predictions are in good agreement for overall rate

light yield: 2.6 pe/keV

Data (S1 only)

Monte Carlo simulations

single scatter only with ∼46 kg fiducial mass cut

all single/multiple scattering events

edge events with poor light collection, will be removed by radial position cut
Expected Sensitivity for WIMPs and SUSY Predictions

Spin-independent

\[ \text{Cross-section [cm}^2\text{] (normalised to nucleon)} \]

\begin{align*}
10^{-41} & \quad 10^{-42} \\
10^{-43} & \quad 10^{-44} \\
10^{-45} & \quad 10^{-46}
\end{align*}

\begin{align*}
10^1 & \quad 10^2 \\
10^3 & \quad 10^4
\end{align*}

Many SUSY models

XENON10

XENON100

Spin-dependent (pure n-couplings)

\[ \text{SD pure neutron cross section [cm}^2\text{]} \]

\begin{align*}
10^{-34} & \quad 10^{-35} \\
10^{-36} & \quad 10^{-37} \\
10^{-38} & \quad 10^{-39} \\
10^{-40} & \quad 10^{-41}
\end{align*}

\begin{align*}
10^2 & \quad 10^3
\end{align*}

XENON10

XENON100

CMSSM

XENON10 SD limit: PRL101 091301 (2008)

XENON10 SI limit: PRL100, 021303 (2008)
Expected sensitivity for heavy Majorana Neutrinos

XENON100:
expected number of events in **50 kg x 300 days**

XENON10:
expected number of events in **5.4 kg x 58.6 days**
⇒ $M_{\nu_M} < 9.4$ GeV and $> 2.2$ TeV

arXiv: 0805.2939
PRL101 091301 (2008)
Expected Sensitivity for WIMPs and UED Predictions

Spin-independent

LHC reach in 4l+E_{T} channel

Spin-dependent

WMAP5 region
(WIMPs make 100% of the dark matter)

S. Arrenberg, L. Baudis, K.C. Kong,
K. Matchev, J. Yoo,
PRD2008 (arXiv:0805.4210)
Next Step: XENON1t

- Studies in progress for 3 ton (1 ton fiducial) LXe detector
- Possible location: inside LVD SN neutrino detector at LNGS -> active veto for μ-induced neutrons
- Gamma flux inside LVD structure: 10-20 times lower than in main halls (detailed mapping of gamma and neutron background in progress)
Summary

Many different techniques/targets are being employed to search for dark matter particles. Experiments are probing the theoretically interesting regions. 

In CH: complementarity between the LAr and LXe WIMP targets!

Next generation projects: should reach the \( \lesssim 10^{-10} \) pb level \( \implies \) WIMP (astro)-physics.

Theory example: CMSSM (Roszkowski, Ruiz, Trotta) 
see also: Balz, Baer, Bednyakov, Bottino, Cirelli, Chattopadhyay, Ellis, Fornengo, Giudice, Gondolo, Massiero, Olive, Profumo, Santoso, Spanos, Strumia, Tata,...+ many others

1 event/kg/yr
CDMS-II, XENON100, ArDM, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

1 event/t/yr
SuperCDMS1t, WARP1t, ArDM XENON1t, EURECA, XMASS, ...
End
The LUX Experiment

- 300 kg dual phase LXe TPC (100 kg fiducial), with 122 PMTs in large water shield with muon veto
- 50 kg LXe prototype with 4 R8778 PMTs being assembled and tested at CWRU
- full detector to be installed at Homestake Davis Cavern, 4850 ft in 2008-2009 (in 8 m \( \phi \) water tank)
- WIMP sensitivity goal: \( 7 \times 10^{-10} \) pb after 10 months
The KIMS Experiment

- At the Yangyang Lab in Korea (2000 mwe)
- 4 x 8.7 kg CsI(Tl) crystals for 3407 kg yr
- background reduction by PSD
- best SD limit for pure-p

Current status:
12 detectors (104.4 kg) installed
- muon veto (liquid scintillator+56 PMTs)
- optimization runs finished (BG ~ 1 dru)
**stable operation in progress**
- probe the DAMA modulation signal
- study annual modulation of ‘muon tail ‘ events

*PRL 99, 091301(2007)*
Bubble Chambers as WIMP Detectors

- **COUPP**: superheated liquid -> detects single bubbles induced by high dE/dx nuclear recoils;  
  **advantage**: large masses, low costs, SD, SI (I, Br, F, C), high spatial granularity, ‘rejection’ of ERs \(10^{10}\) at 10keV;  
  **challenge**: reduce alpha background

n-induced event (multiple scatter)

WIMP: single scatter

2 kg detector at 300 mwe in 2006: \(\alpha\) BG from walls  
\(^{222}\)Rn decays -> \(^{210}\)Pb plate-out + \(^{222}\)Rn emanation  
run with 2 kg in 2007 (reduced backgrounds)  
80 kg module approved by FNAL -> \(3 \times 10^{-8}\) pb

Laura Baudis, University of Zurich, CHIPP Plenary Meeting, September 9, 2008

(Plot showing energy vs. dE/dx for various elements, with a graph comparing WIMP mass vs. cross-section for different experiments.)
Directional Detector: DRIFT

- **Negative ion (CS$_2$) TPC**: 1 m$^3$ 40 Torr CS$_2$ gas (0.17 kg); 2 mm pitch anode + crossed MWPC grid→2D
- NR discrimination via track morphology in gas (gamma misidentification probability < 5 x 10$^{-6}$)
- **3D track reconstruction** for recoil direction: find head-tail of recoil based on dE/dx
- **DRIFT IIa operated at Boulby in 2005**: background from Rn emanation of detector components (recoiling nuclei from alpha-decays on cathode wires); 6 kd-d of data being analyzed
- **DRIFT IIb: installed in 2006/07, new run with strongly reduced Rn backgrounds**
- **WIMP Telescope!**
New measurements of the Light Yield in LXe

- Columbia + Zurich: at RaRAF (Nevis Labs), 1 MeV n-beam
- Detector: XeCube, 6 R8520 PMTs, 2.5 cm$^3$ LXe, zero field
- New experiment for charge/light under preparation at UZH (using D-D neutron generator)

Publication to be submitted to PRD
Reminder: Backgrounds in XENON10

- Dominated by contribution from detector materials:
  - steel (~ 180 kg, $^{60}$Co), PMTs (89 R8520, U/Th/K/Co) and ceramic HV feed-throughs (U/Th/K)

\[ \text{2 cm radial cut (+ z-cut)} \rightarrow 5.4 \text{ kg LXe mass} \]

\[ \Rightarrow \text{background rate of 0.6 events/(kg d keV)} \]

\[ \text{dru = events/(kg day keV)} \]
XENON100 Material Screening

- Ultra-low background, 100 % efficient (2 kg) HPGe-spectrometer, operated at LNGS (plus detectors from LNGS screening facility)

- **Shield**: 5 cm of OFRP Cu (Norddeutsche Affinerie); 20 cm Pb (Plombum, inner 5 cm: 3 Bq/kg $^{210}$Pb), air-lock system and nitrogen purge against Rn, slow control for online monitoring of HV, N$_2$ flow rate, leakage current and LN level

- **Background spectrum**: $< 1$ event/(kg d keV) above 40 keV

- Screened all XENON100 detector/shield components for a complete BG model
# XENON100 Material Screening

<table>
<thead>
<tr>
<th>Material*</th>
<th>$^{238}\text{U}$</th>
<th>$^{232}\text{Th}$</th>
<th>$^{40}\text{K}$</th>
<th>$^{60}\text{Co}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel 1.5 mm (316Ti, Nironit; cryostat)</td>
<td>$&lt;2$ mBq/kg</td>
<td>$&lt;2$ mBq/kg</td>
<td>10.5 mBq/kg</td>
<td>8.5 mBq/kg</td>
</tr>
<tr>
<td>Stainless Steel 25 mm (316Ti, Nironit, cryostat)</td>
<td>$&lt;1.3$ mBq/kg</td>
<td>$&lt;0.9$ mBq/kg</td>
<td>$&lt;7.1$ mBq/kg</td>
<td>1.4 mBq/kg</td>
</tr>
<tr>
<td>PMTs (R8520-AL)</td>
<td>$&lt;0.24$ mBq/PMT</td>
<td>0.18 mBq/PMT</td>
<td>7.0 mBq/PMT</td>
<td>0.67 mBq/PMT</td>
</tr>
<tr>
<td>PMT Bases</td>
<td>0.16 mBq/pc</td>
<td>0.10 mBq/pc</td>
<td>$&lt;0.16$ mBq/pc</td>
<td>$&lt;0.01$ mBq/pc</td>
</tr>
<tr>
<td>Teflon (TPC)</td>
<td>$&lt;0.3$ mBq/kg</td>
<td>$&lt;0.16$ mBq/kg</td>
<td>$&lt;2.3$ mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Poly I (shield)</td>
<td>$&lt;3.8$ mBq/kg</td>
<td>$&lt;2.7$ mBq/kg</td>
<td>$&lt;5.88$ mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Poly II (shield)</td>
<td>2.43 mBq/kg</td>
<td>$&lt;0.67$ mBq/kg</td>
<td>$&lt;4.66$ mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Polish Pb (outer shield)</td>
<td>$&lt;5.7$ mBq/kg</td>
<td>$&lt;1.6$ mBq/kg</td>
<td>14 mBq/kg</td>
<td>$&lt;1.1$ mBq/kg</td>
</tr>
<tr>
<td>French Pb (inner shield)</td>
<td>$&lt;6.8$ mBq/kg</td>
<td>$&lt;3.9$ mBq/kg</td>
<td>$&lt;28$ mBq/kg</td>
<td>$&lt;0.19$ mBq/kg</td>
</tr>
</tbody>
</table>

* only a selection is shown here, all PMTs are screened and show consistent values; also screened: copper, cables, screws, ...

** thanks also to Matthias Laubenstein (LNGS screening facility)

Laura Baudis, University of Zurich, CHIPP Plenary Meeting, September 9, 2008
# Gamma Background Predictions from MC Simulations

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate [mdru]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel (cryostat, 65 kg)</td>
<td>2.01 ± 0.22</td>
</tr>
<tr>
<td>Teflon (TPC, 10.7 kg)</td>
<td>0.18 ± 0.02</td>
</tr>
<tr>
<td>PMTs (including bases, 242)</td>
<td>4.91 ± 0.60</td>
</tr>
<tr>
<td>Polyethylene (shield, 2t)</td>
<td>2.50 ± 0.29</td>
</tr>
<tr>
<td>Copper (shield, 2t)</td>
<td>0.026 ± 0.002</td>
</tr>
<tr>
<td>Total*</td>
<td>9.63 ± 0.70</td>
</tr>
</tbody>
</table>

* dominant background rate before S2/S1 discrimination in fiducial mass
dru = events/(kg day keV)
Gamma Background Predictions from MC Simulations

Total single scatters in fiducial volume

Count rate [events/(kg day keV)]

- total rate
- Stainless steel
- Teflon
- PMT
- Polyethylene

Average rate in 4.5-30 keV, Veto Threshold > 20 keV [DRU]
Neutron Backgrounds: MC Simulations

- Internal neutron BG from detector materials + shield, from \((\alpha,n)\) and fission reactions
- Numbers based on detailed MC, with measured U/Th activities of all materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Total n-rate [yr(^{-1})]</th>
<th>Single NR rate [(\mu)dru]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>15.0</td>
<td>0.18</td>
</tr>
<tr>
<td>Teflon</td>
<td>10.1</td>
<td>0.58</td>
</tr>
<tr>
<td>PMTs</td>
<td>7.0</td>
<td>0.32</td>
</tr>
<tr>
<td>LXe</td>
<td>0.81</td>
<td>0.007</td>
</tr>
<tr>
<td>Copper</td>
<td>1.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Poly shield</td>
<td>416.3</td>
<td>0.49</td>
</tr>
<tr>
<td>Polish Pb</td>
<td>5805</td>
<td></td>
</tr>
<tr>
<td>French Pb</td>
<td>1579</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>~ 1.6</td>
<td>~ 0.6 single NRs/year in FV</td>
</tr>
</tbody>
</table>

\(\sim 44\%\) of events are singles.

=> ~ 0.6 single NRs/year in FV

**Neutron Spectrum from U in Polyethylene**

- U total
- U spont. fission
- U \((\alpha,n)\)

**Poly: for 10 ppb U**

**Neutron Spectrum from U in SS**

- U total
- U spont. fission
- U \((\alpha,n)\)

**Steel: for 10 ppb U**
WIMP rate versus neutron background

- assumptions:
  - spin-independent WIMP-nucleon cross section: $2 \times 10^{-45} \text{ cm}^2$
  - local WIMP density: $0.3 \text{ GeV/cm}^3$