THE NEWS-SNO PROJECT

Search for low mass Dark Matter with spherical TPCs

Sabine Roth & Gilles Gerbier

Queen's University, Kingston, Canada

on behalf of the NEWS Collaboration

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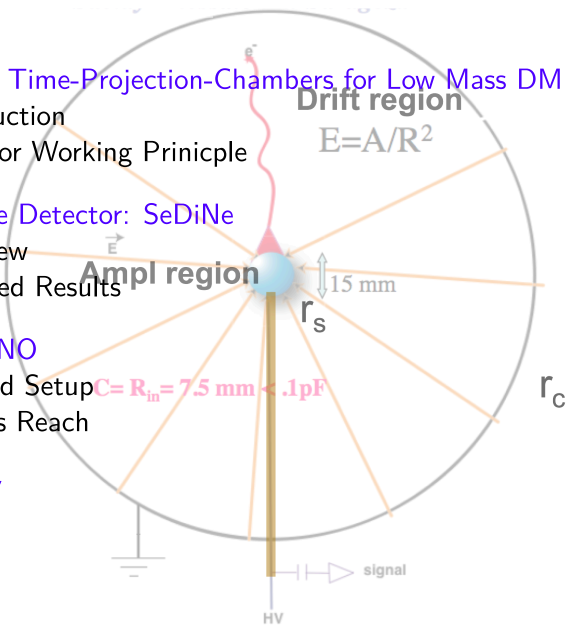
Prospects on Low Mass Dark Matter
Munich, Germany

Contents

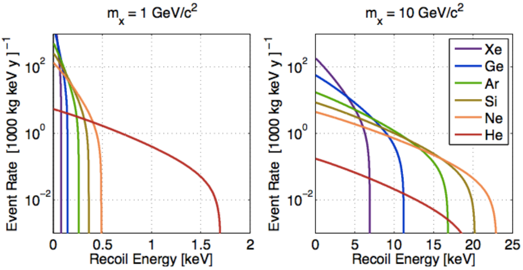


Physics goal:

- Search for very low mass ($0.1 - 5 GeV/c^2$) SI and SD coupling WIMPs using very light nuclei
- Search for Kaluza-Klein Axions through their 2-photon decay

Spherical Time Projection Chamber as detector:

- Usage of light taget nuclei - kinematical match
  $\Rightarrow$ H, He and Ne gases/gas mixtures



Recoil event rate for 1 and 10 GeV/c^2 WIMPs for various target materials

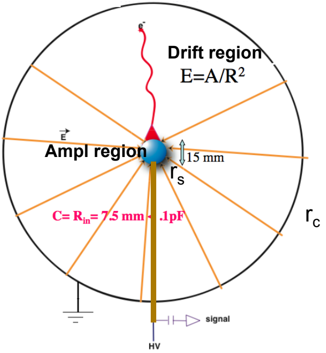
Physics goal:

- Search for very low mass ($0.1 - 5 GeV/c^2$) SI and SD coupling WIMPs using very light nuclei
- Search for Kaluza-Klein Axions through their 2-photon decay

Spherical Time Projection Chamber (STPC) as detector:

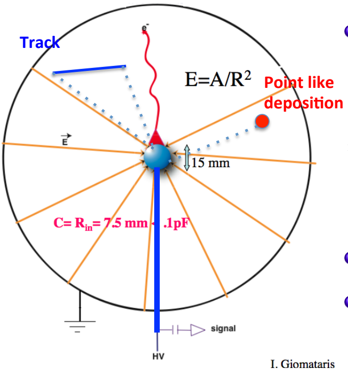
- Usage of light taget nuclei - kinematical match
  $\Rightarrow$ H, He and Ne gases/gas mixtures
- Very low energy thresholds: single electron ionization threshold!
  $\Rightarrow$ 3 e^--equiv. nucl. E_{th}: 500eV (Ne), 360eV (He), 200eV (H)
  600eV for Ne demonstrated
- 1.4m Cu sphere, operated at up to 10 bar
  $\Rightarrow$ $m_{Ne} = 12.5$kg, $m_{He} = 2.5$kg, $m_H = 0.25$kg (90%He/10%CH_4 mix)
- Simple detector design
  $\Rightarrow$ Small number of materials $\rightarrow$ very low radioactive background
- Planned location: SNOLAB

Spherical Gas Detectors:



- Large spherical cavity (r_c) on ground potential
  Small spherical sensor (r_s) on high voltage (typ. $\gtrsim$ 1kV)
  $\Rightarrow$ Energy deposition $\rightarrow$ ionization
  $\Rightarrow$ Electrons drift inwards
  $\Rightarrow$ Close to sensor $\rightarrow$ avalanche ionization
  $\rightarrow$ signal amplification
- Small sensor $\rightarrow$ small capacitance
  $\Rightarrow$ very low energy threshold
- Energy threshold $\not\propto$ size
  $\Rightarrow E(r) \approx \frac{V}{r^2} \cdot r_s \not\propto r_c$ for $r_c \gg r_s$
  $\Rightarrow$ Large mass with single read-out channel
- Simple sealed mode

Spherical Gas Detectors:



Standard operation mode, high pressure:

- High pressure → large mass
- Radius of event e^- → e^- diffusion times
  ⇒ e^- diffusion times depend on r_{ev}
  ⇒ Event risetime t_{rt} depends on r_{ev}

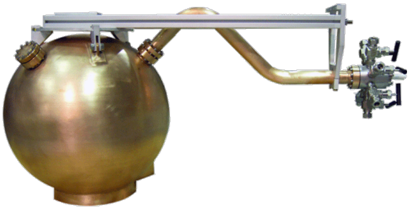
⇒ Risetime distribution ⇒ fiducialization

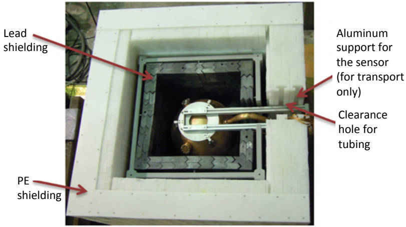
Low pressure ($\lesssim$ 50mbar)/High energies:

- Electron recoil → track-like energy deposition
- Nuclear recoil → point-like energy deposition
  ⇒ e^- diffusion times depend on particle type
  ⇒ Event risetime t_{rt} depends on particle type

⇒ Risetime distribution ⇒ particle identification

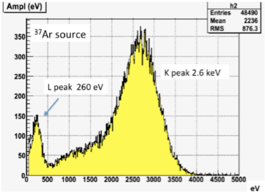
SeDiNe: Spherical Detection of Neutrons

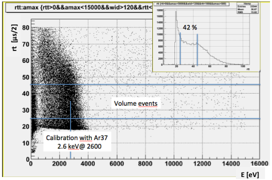


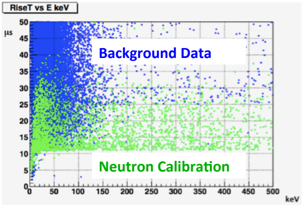


- Set-up at LSM
- First STPC optimized for low countrates
- ⌀ 60cm with 6mm ⌀ sensor
- Out of low radioactivity copper
- Shielding: 5cm Cu (not shown), 10cm Pb, 30cm PE
- Originally: high sensitivity thermal neutron flux measurement (^{3}He)
  $\Rightarrow$ Successfully performed
- Currently, WIMP search:
  Use 3bar Ne/CH_4 mixture
- BUT not yet optimized wrt to:
  Surface cleanliness (Rn daughters)
  Shielding composition/thickness

SeDiNe: Preliminary Results







- Commissioning runs with Ar
  - $\Rightarrow$ Tuning of operation parameters
- WIMP search run with Ne+0.7%CH_4
  - $\Rightarrow$ 300g target mass
  - $\Rightarrow$ $\sim$ 12kg d exposure
- ^{37}Ar calibration (260eV, 2.6keV)
  - $\Rightarrow$ $E_{th} \approx$ 120eV (electron equiv.)
  - $\Rightarrow$ Fiducial cut efficiency: 42%
- Neutron calibration
  - $\Rightarrow$ Fiducial volume definition

$\Rightarrow$ Capability of concept demonstrated

$\Rightarrow$ Data analysis ongoing (background model)

$\Rightarrow$ Preliminary result: Limit equivalent to DAMIC 2012

No background subtraction

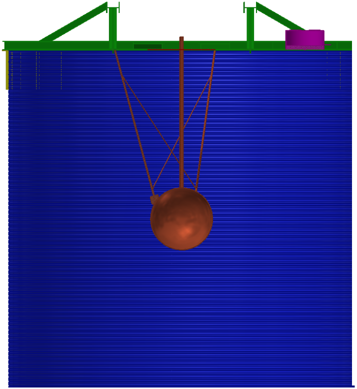
NEWS-SNO (New Experiments with Spheres at SNOLab)

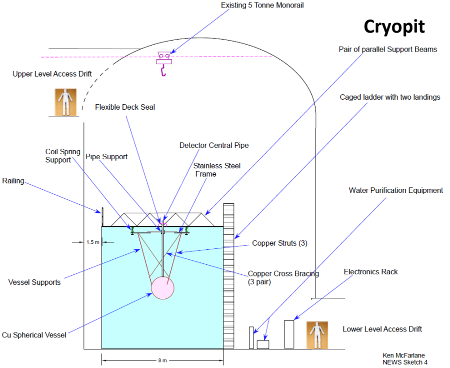
From the SeDiNe prototype to NEWS-SNO:

- Use of optimized materials wrt radiopurity:
  $\Rightarrow$ High purity Cu ($\sim 1\frac{\mu\text{Bq}}{\text{kg}}$ ^{238}U, ^{232}Th) for Sphere & Sensor
  $\Rightarrow$ Highly reduced cosm. act.: ^{63}Cu(n,α)^{60}Cu (use protection)
- Larger size of 1.4m $\oslash$ & higher pressure (up to 10bar):
  $\Rightarrow$ Improved self-shielding (decreased low energy event rate)
- Optimized inner surface cleaning/etching procedure:
  $\Rightarrow$ Efficient reduction of Rn-daughter plate-out
- Improved shielding - 2 options:
  $\Rightarrow$ 8m $\oslash$ water tank (excellent 4π low radioactivity shield)
  $\Rightarrow$ Optimized compact shield (i.a., inner archaeol. Pb layer)
- Application of lighter nuclei: H (from CH_4 gas) He and Ne
  $\Rightarrow$ Optimized for low mass DM search
- Use of Xe gas and MC-simulations
  $\Rightarrow$ Dedicated, precise background understanding

NEWS-SNO (New Experiments With Spheres at SNOlab)

Water-tank option:





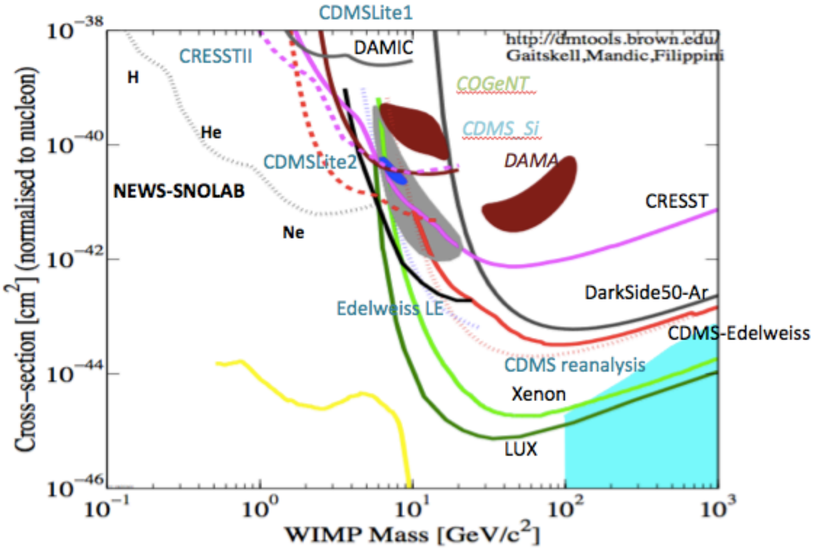
Plan: Start data taking in $\sim$ 2 years!

NEWS-SNO: Projected background count rates

Radioactive background budget	Goal / estimation / measurement	Rate Ne ev/kg.keV.d in 0-1 keV in Neon 10b	Relative weight %	Rate He ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %	Rate H ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %
U Copper	1 µBq/kg	0,006	5,0	0,006	4,2	0,055	4,2
Th Copper	1 µBq/kg	0,004	3,7	0,004	3,1	0,041	3,1
Co60 Copper	30 µBq/kg integrated exposure to CR	0,046	41,6	0,046	35,2	0,460	35,2
External radiation from rock	208Tl and 40K flux underground	0,002	1,8	0,002	1,5	0,020	1,5
Radon in water	1 mBq/m3 from polyurea 2 at/m2.h	0,001	0,9	0,001	0,8	0,010	0,8
Radon in gas	Rn emanation within sphere/pipes/ valve (0.3 mBq)	0,005	4,5	0,005	3,8	0,050	3,8
Rod/sensor	Max 0.01 mBq	0,005	4,5	0,005	3,8	0,050	3,8
Electronics	2 CREMAT no components 10 cm shield	0,020	18,1	0,020	15,3	0,200	15,3
Holding structure	Steel 1mBq/kg 6 kg : 3 rods 3 cm diam	0,012	10,8	0,012	9,2	0,120	9,2
Flanges/screws	Steel 1mBq/kg 1 kg	0,005	4,5	0,005	3,8	0,050	3,8
Pb210 Surface	Max exposure= 2 Bq/m3*h	0,005	4,5	0,025	19,1	0,250	19,1
Total	dru	**0,111**	100,0	0,131	100,0	**1,306**	100,0
Nb evts in 0.2 keV	in 100 kg.d	**2,212**		**2,612**		**26,124**	

& Dedicated QF-measurements (down to 0.5keV) at LPSC (Grenoble)!

NEWS-SNO: Projected background-free limits



+ Next step: background subtraction ⇒ Improve limits further!

Summary

- **Spherical gaseous time-projection-chambers are particularly suited for low mass DM search**
  $\Rightarrow$ Light nuclei
  $\Rightarrow$ Large target mass
  $\Rightarrow$ Very low radioactive backgrounds
  $\Rightarrow$ Fiducialization
- **Prototype detector SeDiNe running and taking data**
  $\Rightarrow$ Detector concept proved: E_{th} and fiducialization
  $\Rightarrow$ Data analysis ongoing
  $\Rightarrow$ Expect limits soon!
- **NEWS at SNOLAB**
  $\Rightarrow$ In CDR/TDR phase
  $\Rightarrow$ Largely improved background levels
  $\Rightarrow$ Unique WIMP detection capability down to $\sim 0.1\mathrm{GeV}/c^2$

NEWS Collaboration

Queen's University – Gilles Gerbier, Philippe di Stefano, Tony Noble, Sabine Roth, Bei Cai, Alvine Akamaha, Alexis Brossard, Paco Vasquez dSF, Philippe Camus + Summer Students + 3 new MsC/PHD (2016)

Copper vessel and gas set-up specifications, project follow up, calibration set up
Gas characterization at Queen's, laser calibration, on smaller scale prototype…
Simulations/Data analysis

SNOLAB – Ken Mc Farlane, Brian Morisette

Water shielding and infrastructure at SNOLAB

(TRIUMF – Fabrice Retiere

cosmic ray protection for sphere fabrication at PAVAC, light detection, sensor**)**

IRFU/Saclay – Ioannis Giomataris, Michel Gros, Thomas Papaevangelou, Patrick Magnier, Jean Paul Bard

Sensor/rod (low activity, optimized wrt field with 2 electrodes)
Electronics (low noise preamps, digitization, stream mode)
DAQ/soft

LSM (Laboratoire Souterrain de Modane) – **Fabrice Piquemal , Michel Zampaolo, Ali Dastgheibi Fard**

Low activity archelogical lead for close electronics/valve shield
Compact Shield Design and Setup

Tessaloniki University – Ilias Savvidis, Ioannis Katsioulas

Simulations, neutron calibration
Studies on sensor

LPSC Grenoble - Daniel Santos, Jean-Francois Muraz, Olivier Guillaudin

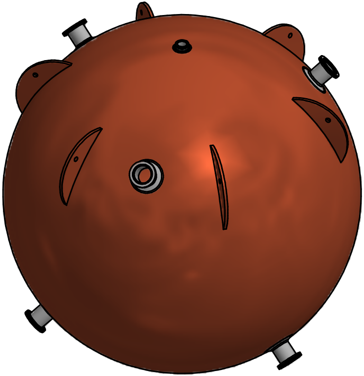
Quenching factor measurements < 1 KeV with ion beams

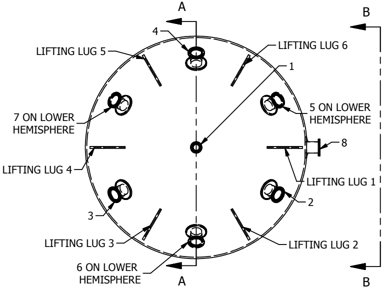
TU Munich – Andreas Ulrich

Gas properties and ionisation process for Pening mixtures

… more collaborators welcome!

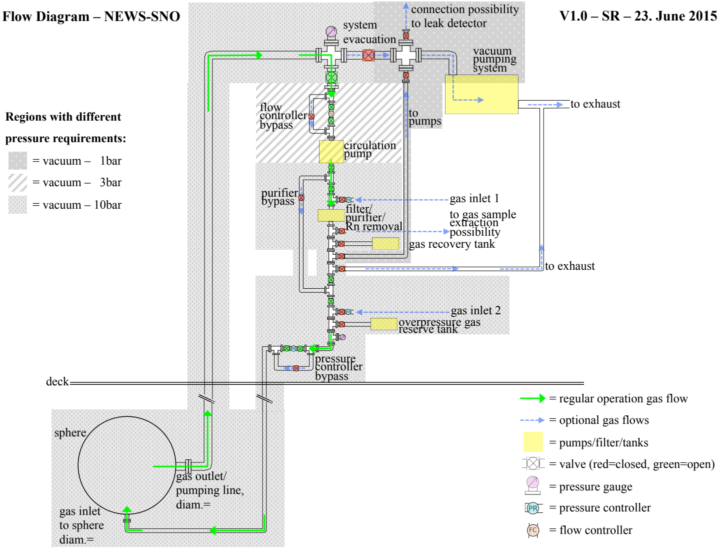
Sphere Production





PALN VIEW

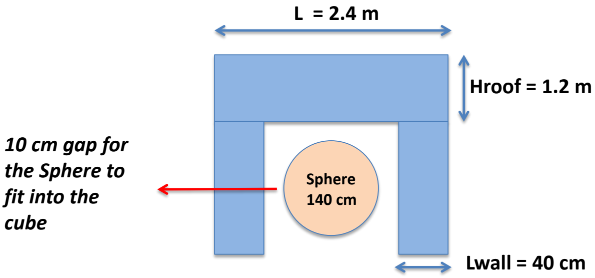
Setup


Flow Diagram – NEWS-SNO
V1.0 – SR – 23. June 2015
connection possibility
to leak detector
system
evacuation
vacuum
pumping
system
to exhaust
flow
controller
bypass
to
pumps
circulation
pump
purifier
bypass
gas inlet 1
filter/
purifier/
Rn removal
to gas sample
extraction
possibility
gas recovery tank
to exhaust
gas inlet 2
overpressure gas
reserve tank
pressure
controller
bypass
deck
sphere
gas outlet/
pumping line,
diam.=
gas inlet
to sphere
diam.=
Regions with different
pressure requirements:
= vacuum – 1bar
= vacuum – 3bar
= vacuum – 10bar
= regular operation gas flow
= optional gas flows
= pumps/filter/tanks
= valve (red=closed, green=open)
= pressure gauge
PR
= pressure controller
FC
= flow controller

Setup

Copper protection from atmospheric neutrons (at sea level)

- **Shielding Material -> Concrete**



Hroof and Lwall for a reduction of the ^{60}Co by a ~5.5 factor

- **Cubic geometry**
- ***Gordon et al* neutron spectrum (1 MeV - 220 MeV neutrons)**

Projected KK-axion Limits

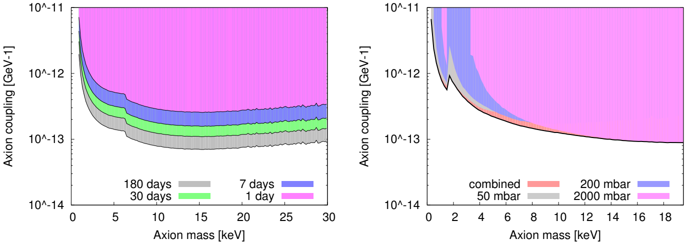


Figure 4: Sensitivity limit estimation for the axion-photon coupling in case of zero background. (left) Coupling limit for different exposure times (sphere radius 65 cm) in an argon+10%CH_4 at 100 mbar. (right) Coupling limit for neon+2%CH_4 gas mixture (sphere radius 30 cm) at different pressures for a 180 days exposure period and the combined result.

Projected KK-axion and H-SDLimits

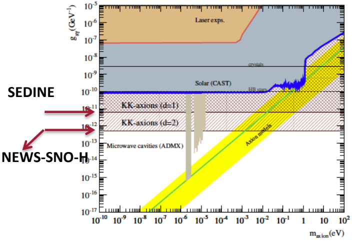
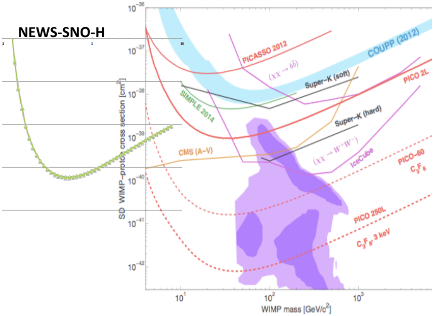


FIG. 7. Sensitivity limits obtained with SEDINE detector in this work versus other axion searches [4].

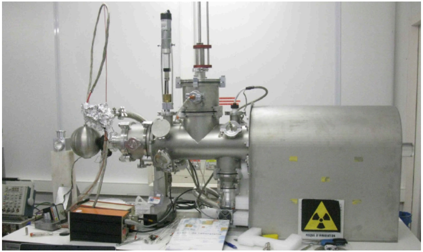


KK axions
2 photon decays of solar axions
NB : here need volume
Paper in preparation

Spin dependent couplings with H
H is best nucleus with Fluor

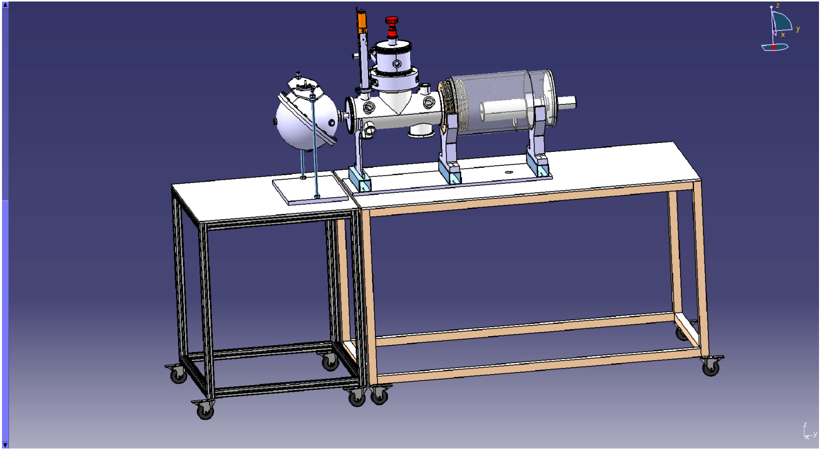
Ionization Quenching Factor Measurement

QF measurement at LPSC in Grenoble at COMIMAC line
Use Ion beam injected to detector through massless window
Trick : 1 μm hole
Use same setup for electron injection (of same energies)
=> Direct measurement of ionization QFs!



Ion and Electron energies between $\sim 0.5 - 30\text{keV}$

Ionization Quenching Factor Measurement



New, optimized setup - currently planned and to be ready mid 2016!

Ionization Quenching Factor Measurement