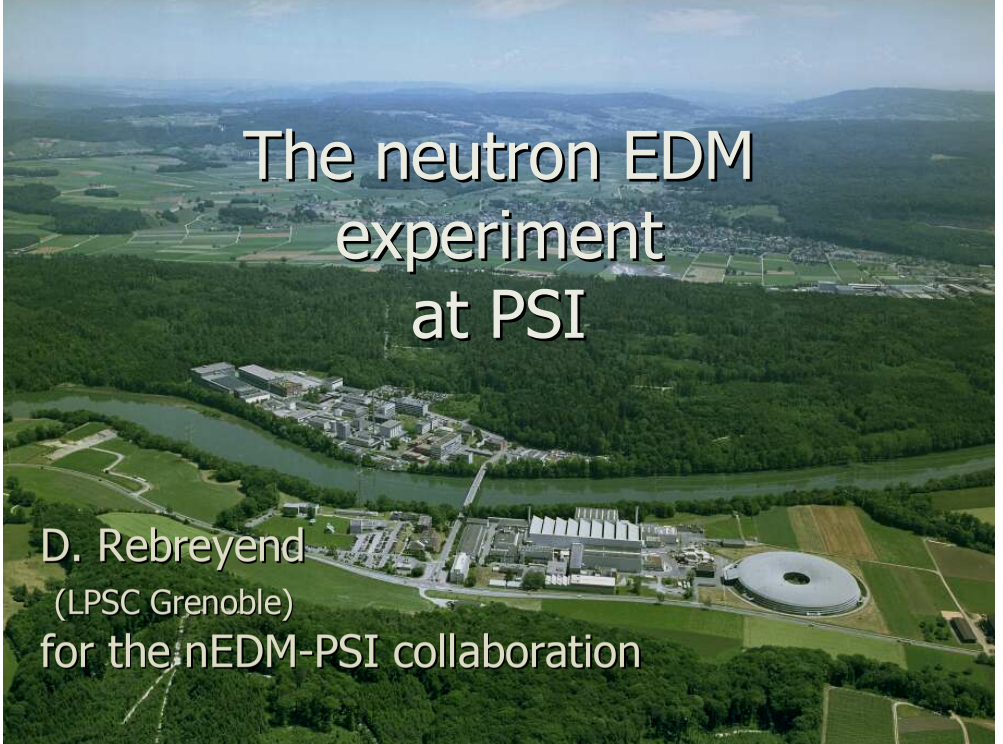

The neutron EDM
experiment
at PSI
D. Rebreyend
(LPSC Grenoble)
for the nEDM-PSI collaboration

Overview

- Motivations
- The experimental technique
- Our approach
- Other experiments
- Summary

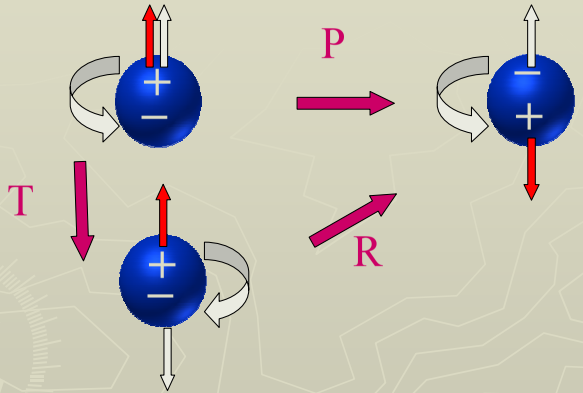
An other form factor...

$$\langle N|\hat{\mathcal{J}}^{\gamma}_{\mu}|N\rangle = \overline{\mathcal{U}}_N \left[F_1^{\gamma}(q^2)\,\gamma_\mu + \frac{i\sigma_{\mu\nu}\,q^\nu}{2M_N} F_2^{\gamma}(q^2) + \frac{G_F}{M_N^2} F_A^{\gamma}(q^2) \left(q^2\gamma_\mu - q^\nu\gamma_\nu q_\mu\right)\gamma_5 - \frac{i\sigma_{\mu\nu}\,q^\nu\,\gamma_5}{2M_N} F_e(q^2) \right] \mathcal{U}_N$$

- F_1 and F_2 : Dirac FF
- F_A : anapole FF
- F_e : electric dipole FF
  $F_e(q^2 = 0) = 2\ M_N\ d_N$

  d_N : Electric Dipole Moment (EDM)

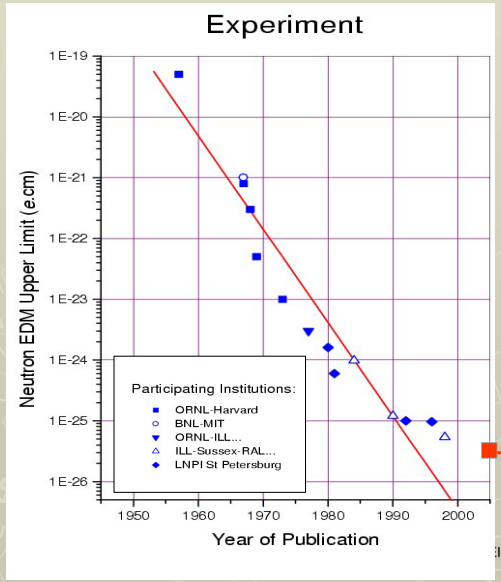
...which violates P and T

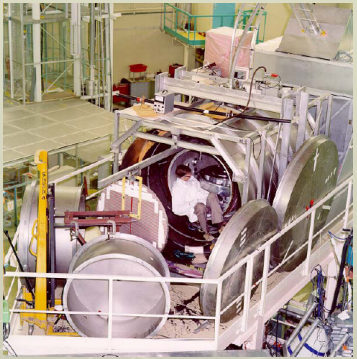


nEDM ≠ 0 → ~~P~~ and ~~T~~

+ CPT Theorem → ~~CP~~

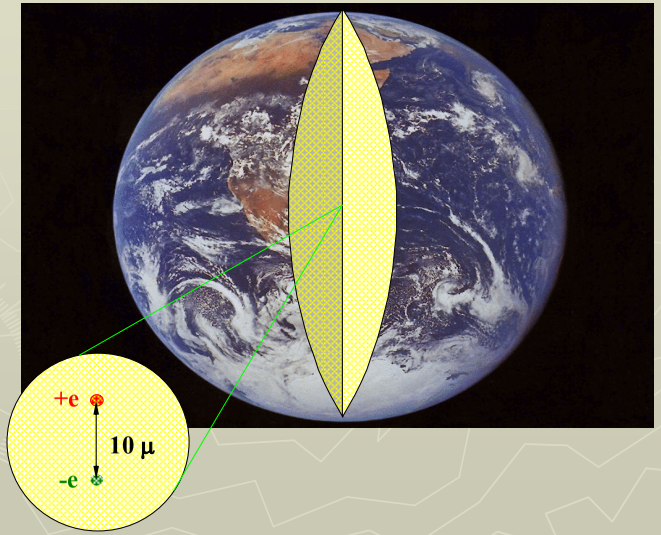
Best limit: the RAL-Sussex experiment at ILL





$|d_n| \leq 2.9\ 10^{-26}$ e.cm (90 % CL)
(PRL 97(2006)131801)

If the neutron were the size…
of the earth



WANTED: more $\not{CP}$

- Sources of CP violation in SM:
  - δ phase of CKM matrix → explains K *and* B physics
  - θ term in QCD

    $d_n \sim \theta \times 10^{-15}$ e.cm → $\theta < 10^{-11}$

    → strong CP problem
- δ phase much too small to explain baryon asymmetry of the universe:

  $BA^{obs.} \sim 10^{-10}$ but $\sim 10^{-17}$ in SM !
- Additional $\not{CP}$ mechanisms exist in extensions of SM (SUSY, LR...)

→Intensive Search for new sources of CP violation:
- Precision frontier → EDM of particles: n, e, μ, d...
- High energy frontier → LHCb

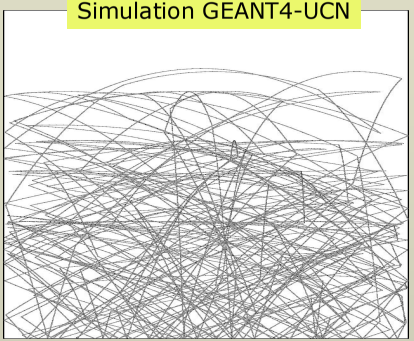
The Ultra Cold Neutrons (UCN)

Typical UCN numbers

- E ~ 100 neV (δ z ~ 1 m)
- V ~ 5 m/s
- T ~ mK
- λ ~ 1000 Å

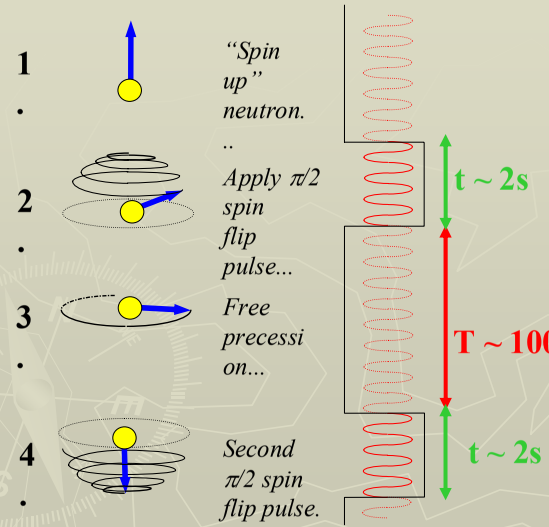
→ Can be stored in vessels!

Simulation GEANT4-UCN



- Numerous applications : neutron lifetime, nnbar oscillations, nEDM,...
- UCN sources:
  - PF2@ILL (the best to date) : ρ ~ 40 UCN/cm^3 (Fission)
  - UCN@PSI (2008→) : ρ ~ 3 10^3 UCN/cm^3 (Spallation)
  - + other projets (Munich, Japan…)

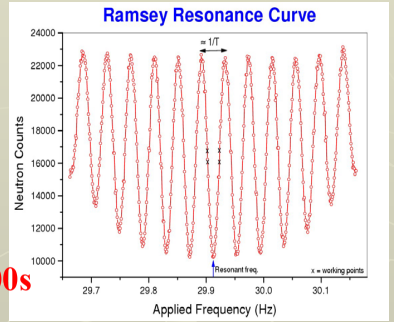
The Ramsey method of separated oscillatory fields



D. Rebreyend, EINN07

$H = -2 (\mu_n \mathbf{B} \pm d_n \mathbf{E})$

$\Delta \nu_L (\uparrow\uparrow - \uparrow\downarrow) = 4 d_n E / h$



RAL-Sussex-ILL experiment:

- $B_0 = 1\ \mu T$
- $\nu_n \approx 30$ Hz
- $\delta\nu_n \approx 25\ \mu Hz$

Statistics versus Systematics (I)

- Statistical error: $$\delta d_n = \frac{h}{4\pi\alpha} \cdot \frac{1}{T \cdot E \cdot \sqrt{N_0}}$$

α : visibility (polarization product) ~ 0.7

E : E-field strength ~ 10 kV/cm

T : storage time ~ 130 s

N_0 : total number of detected neutrons

→ Higher UCN densities

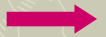
Statistics versus Systematics (II)

- Systematics :

$$h(\nu_{\uparrow\uparrow} - \nu_{\uparrow\downarrow}) = -2\mu_n (B_{\uparrow\uparrow} - B_{\uparrow\downarrow}) - 4d_n E$$
$$= -4d_n E \qquad \text{only if } B_{\uparrow\uparrow} = B_{\uparrow\downarrow}$$

Exple: for $d_n = 10^{-27}$ e.cm in E=10 kV/cm
$\rightarrow \Delta\nu \approx 10^{-8}$ Hz corresponding to $\delta B \approx 0.3$ fT

Most of systematics connected with control of B-field
Beware of false nEDM : GPE $\propto \partial B/\partial z$



Need improved magnetometry

Our approach

- Sensitivity goal : 5×10^{-28} e.cm
  (MS prediction: $d_n \sim 10^{-(31\text{-}32)}$ e.cm)
- In vacuum technique with external UCN source
- Room temperature
- Combination of co-magnetometry and external magnetometry with Cs LsOPM (for monitoring and stabilization)

The Neutron EDM Collaboration

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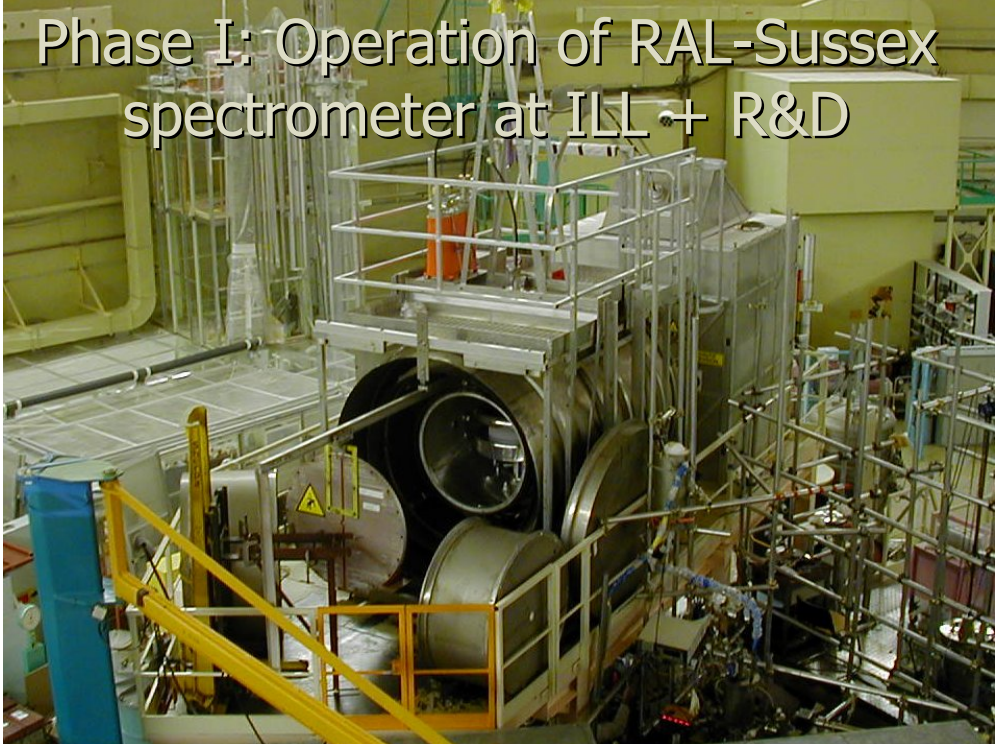
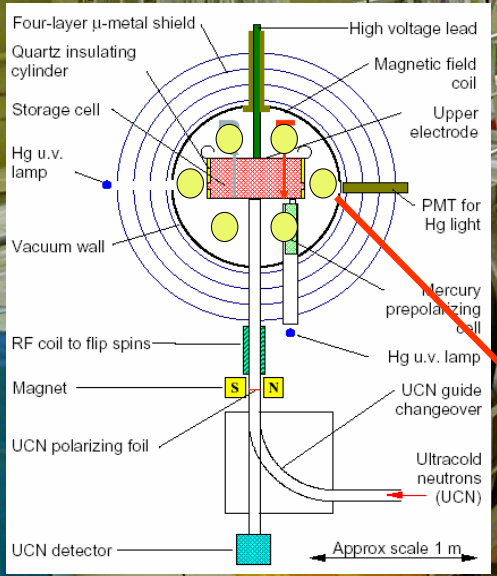
The roadmap

- Phase I (2005-2008)
  - Operation and improvement of the RAL-Sussex spectrometer at ILL
  - R&D on magnetometry, materials, UCN detection...
  - Design of a new spectrometer
- Phase II (2009-2010)
  - Data taking with upgraded version of RAL-Sussex apparatus at PSI
    → sensitivity of 5×10^{-27} e.cm
  - Construction of the new spectrometer
- Phase III (2011-2015)
  - Data taking with the new spectrometer
    → sensitivity of 5×10^{-28} e.cm

Phase I: Operation of RAL-Sussex spectrometer at ILL + R&D

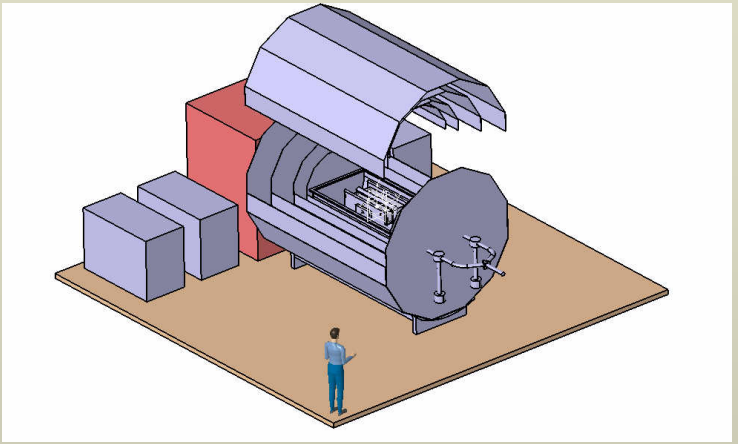


Phase I: Operation of RAL-Sussex spectrometer at ILL + R&D



- New materials and coatings: guides, chamber, shutter
- New HV system: power supply, cable, feed-through...
- New detection system and polarization analysis
- Improved Hg co-magnetometer
- Array of Cs magnetometers

Phase III: n2EDM@PSI



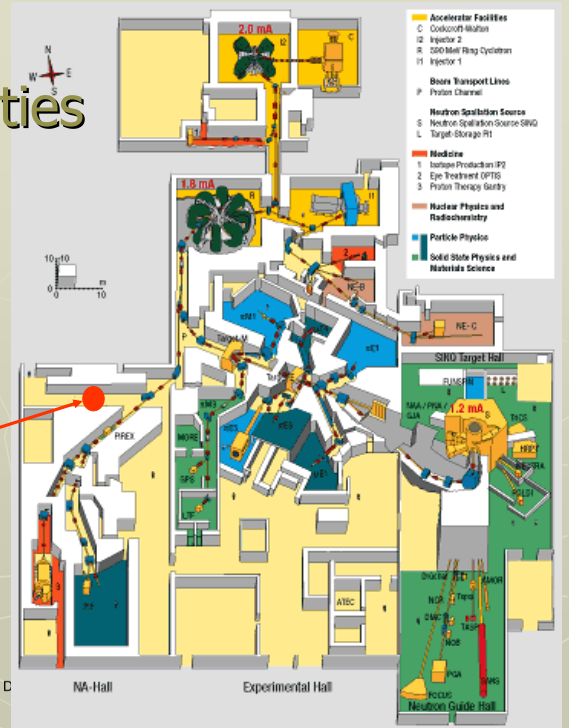
- Double chamber with increased storage volume
- At least one co-magnetometer (R&D on Hg, He, Xe)

→Sensitivity goal: **5×10^{-28} ecm**

The PSI accelerator facilities

- Proton beam :
  600 MeV, 1.2 mA
  → 1.2 MW

UCN source



PAUL SCHERRER INSTITUT

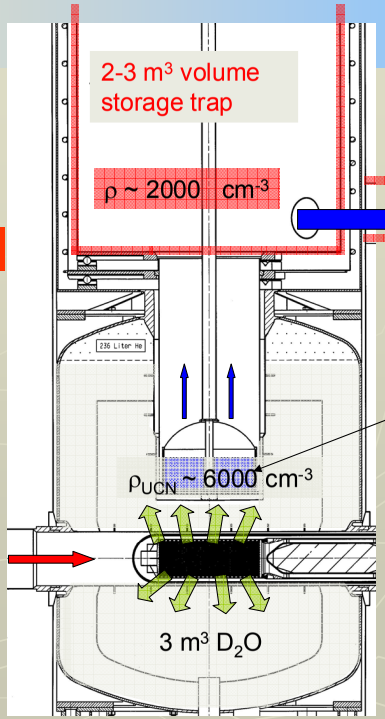
PSI

Ultra Cold Neutron Source

The PSI UCN source

First UCN : end 2008

http://ucn.web.psi.ch

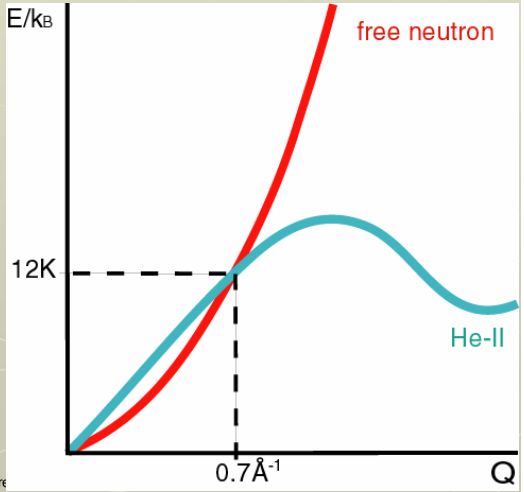


2 mA, 600 MeV
proton beam
1% duty cycle

Production of UCN in superfluid He

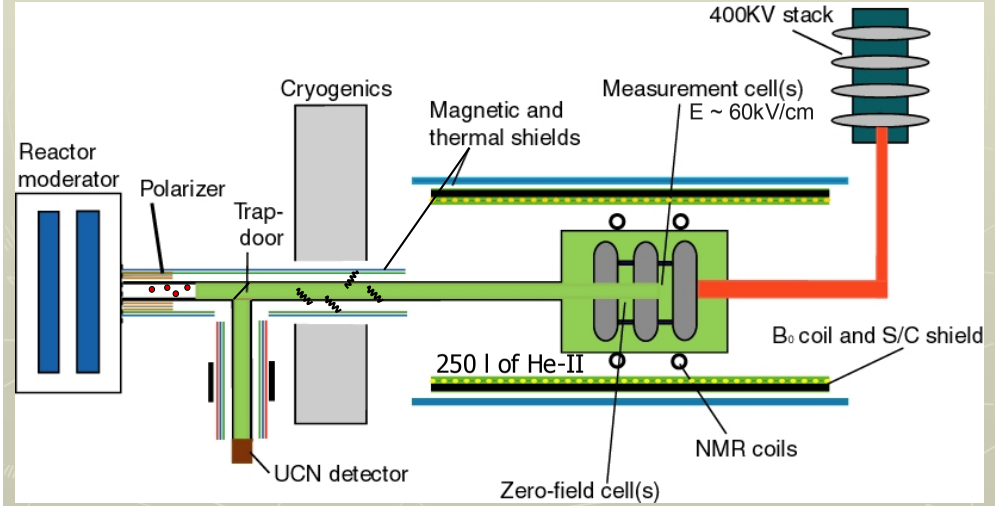
- Proposed by Golub and Pendlebury in 1970's
- Cold neutrons (0.89 nm) lose all their energy by phonon emission → UCN.
- Upscattering suppressed by very low temperature of He (0.5 K)

Dispersion curves for He-II and free neutrons

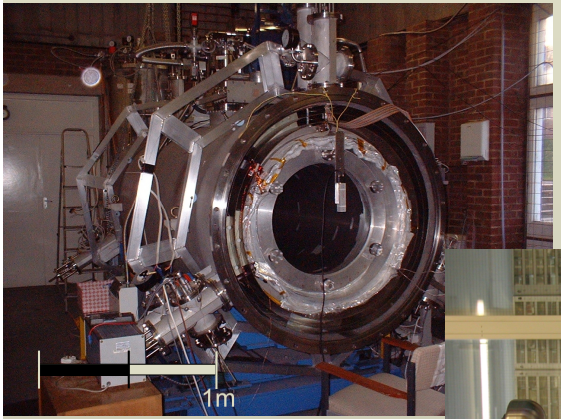


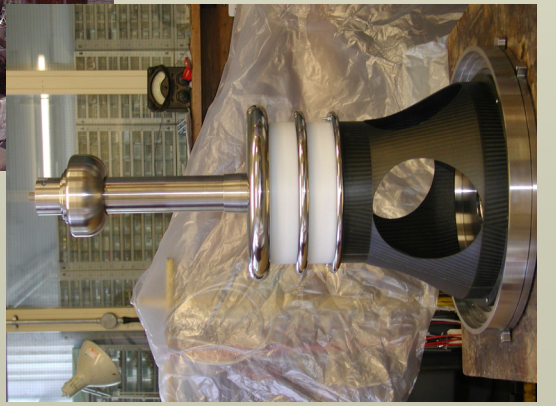
The CRYO-EDM experiment at ILL

(RAL-Sussex collaboration)



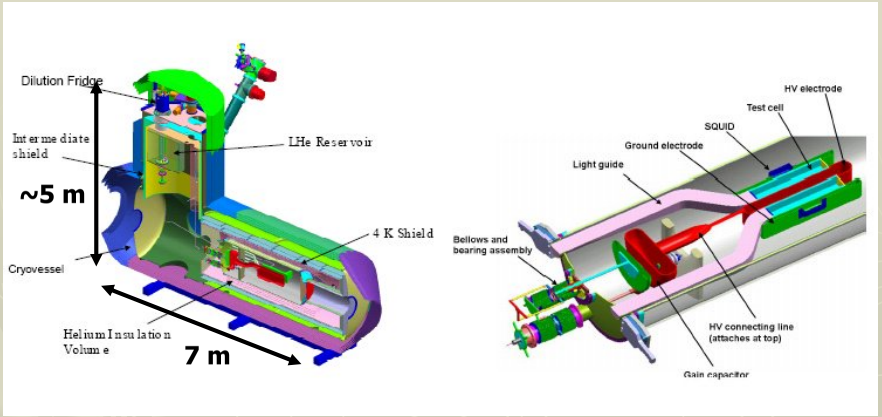
CRYO-EDM : Status and plans





- Commissioning started
- First results~2010

The SNS-EDM experiment at ORNL



- 1000 l of superfluid He (300 mK) !
- Co-magnetometry with ^{3}He
- Start of operation expected~2013

Summary

- The neutron EDM provides a sensitive test of physics beyond the SM.
- An experiment will be running at PSI with a sensitivity goal $\sim 5 \times 10^{-28}$ e.cm at horizon 2015 (5×10^{-27} e.cm in 2011).

Thanks for you attention !