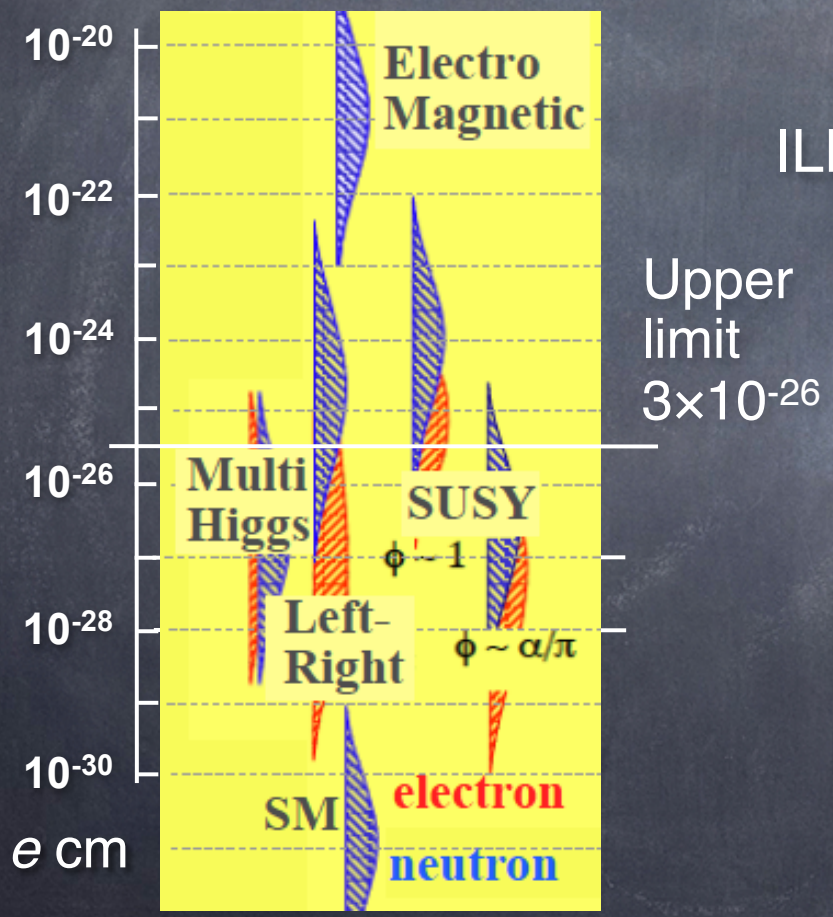
A nEDM measurement by using a spallation UCN source of He-II

Y. Masuda (KEK), Sep. 9, 2013, PSI2013



Upper limit 3×10^{-26}

ILL

Statistical error

1.5×10^{-26} →

Systematic error

0.7×10^{-26} →

Our approach

Superfluid helium (He-II) UCN source to reduce it

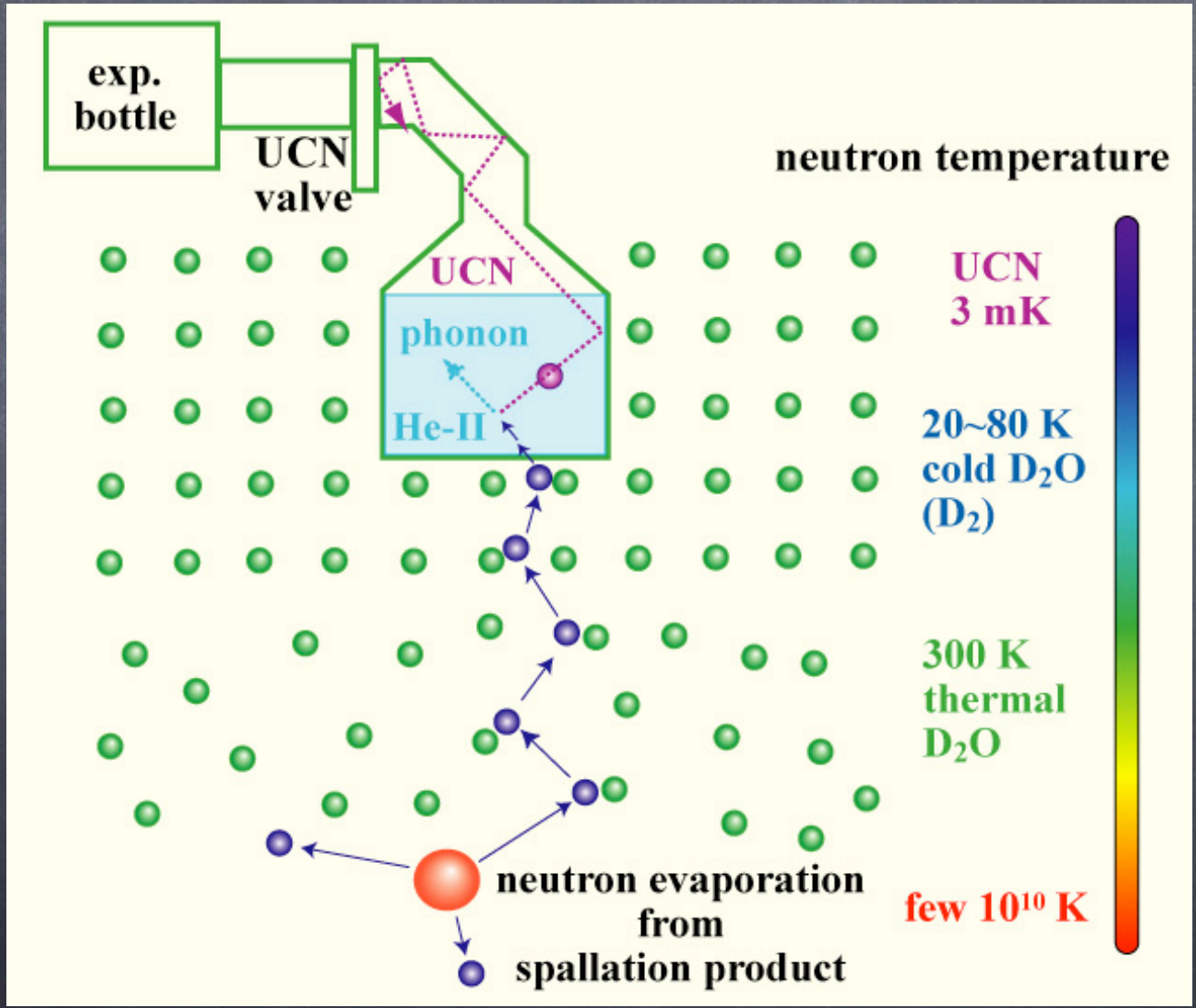
10^{-26}~10^{-27} *e* cm at RCNP

10^{-27}~10^{-28} *e* cm at TRIUMF

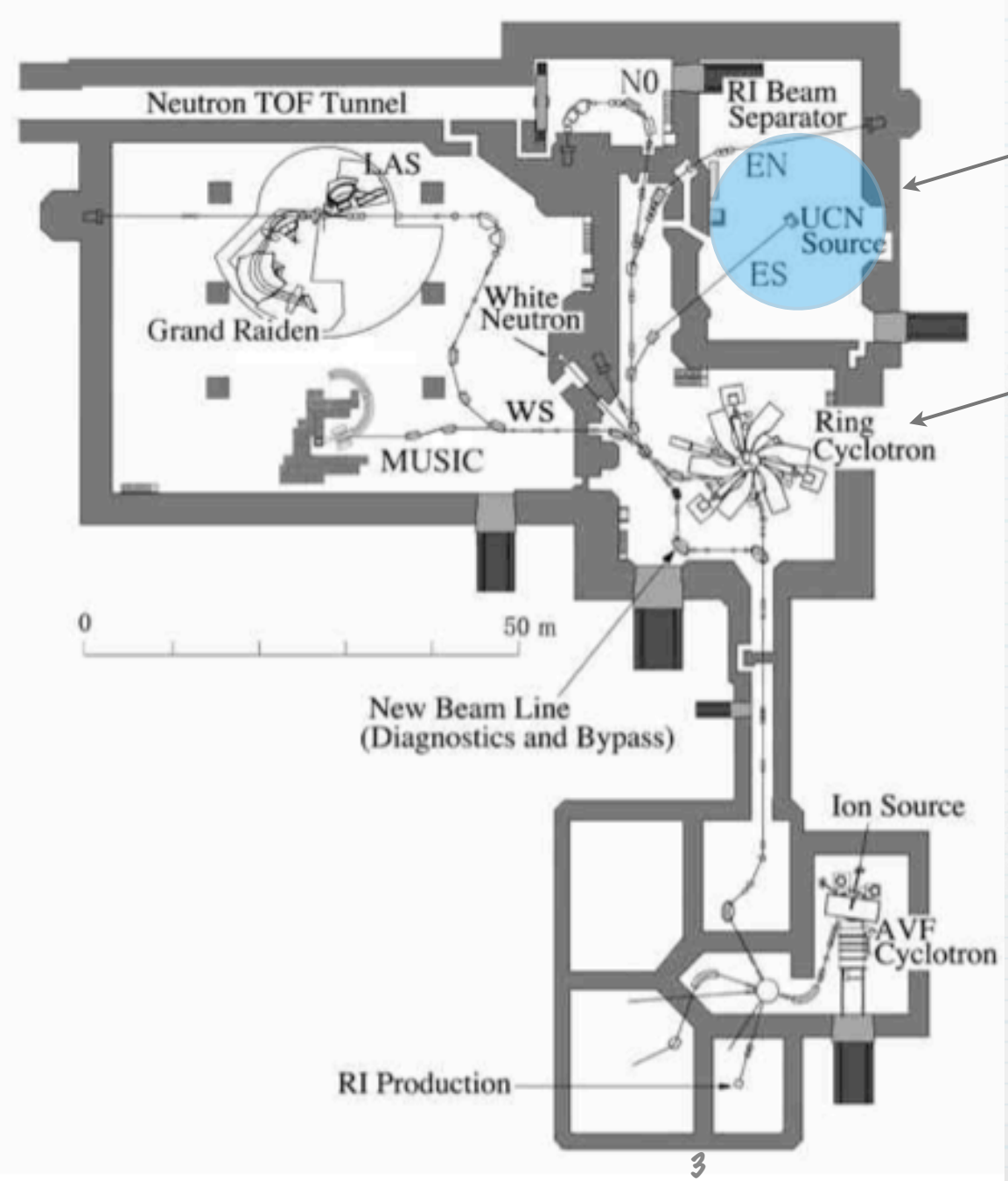
^{129}Xe co-magnetometer to reduce it

~10^{-28} *e* cm

We have placed He-II in a spallation neutron source



We have placed the UCN source at RCNP, Osaka



4 m concrete wall

Ring Cyclotron
E_p=400 MeV
I_p=1 μA → 10 μA

We have produced UCN 東

P = 4 UCN/cm^3·s at E_c = 210 neV for 0.4 kW p beam

T_s = 81 s

Phys. Rev. Lett. 108(2012)134801

240 s irradiation

26 UCN/cm^3 at E_c = 90 neV,

75 ($\propto E_c^{3/2}$) 180

Primary biological shielding
iron and concrete

closed

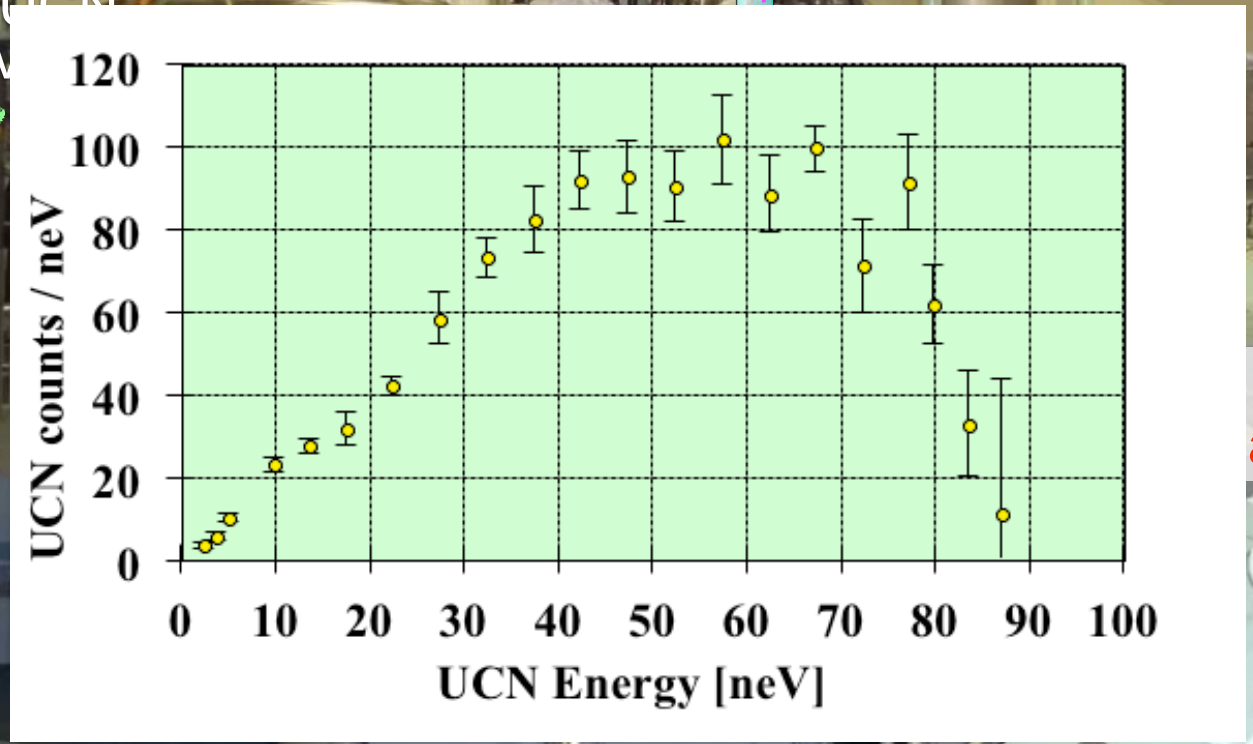
UCN guide

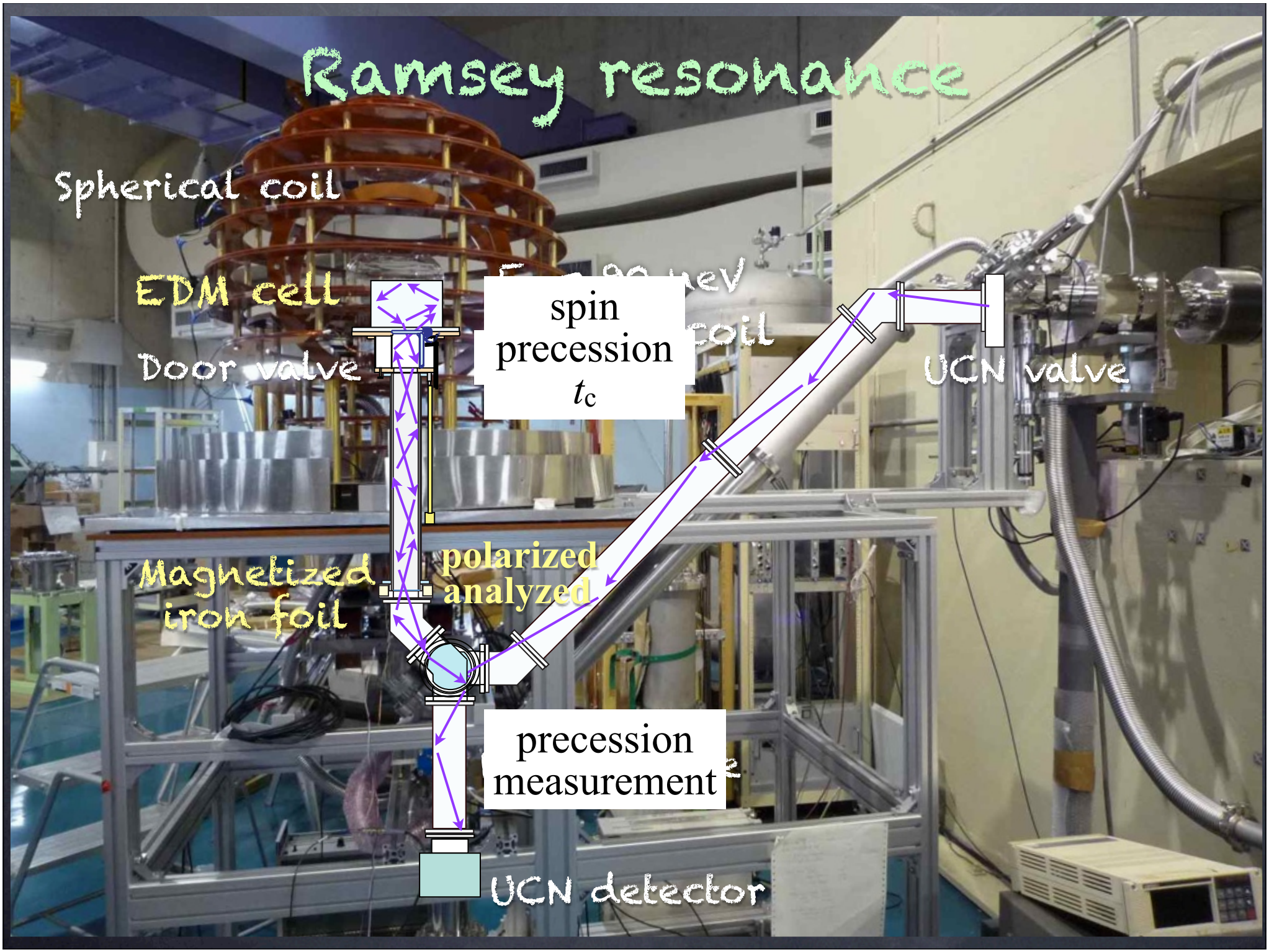
^{4}He pump

^{3}He pump

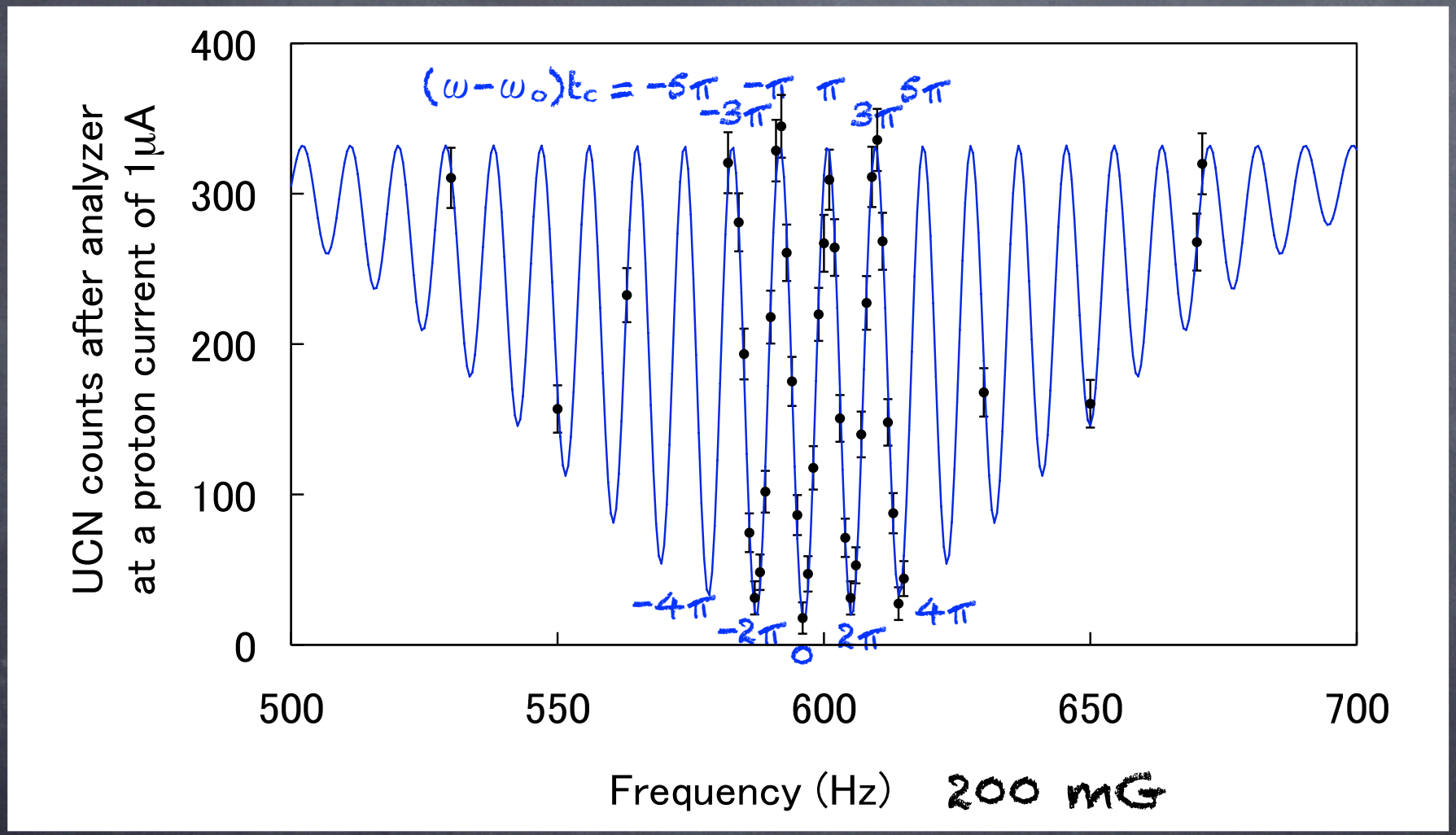
^{3}He circulator

UCN detector




Ramsey resonance
Spherical coil
EDM cell
Door valve
spin
precession
t_c
UCN valve
Magnetized
iron foil
polarized
analyzed
precession
measurement
UCN detector

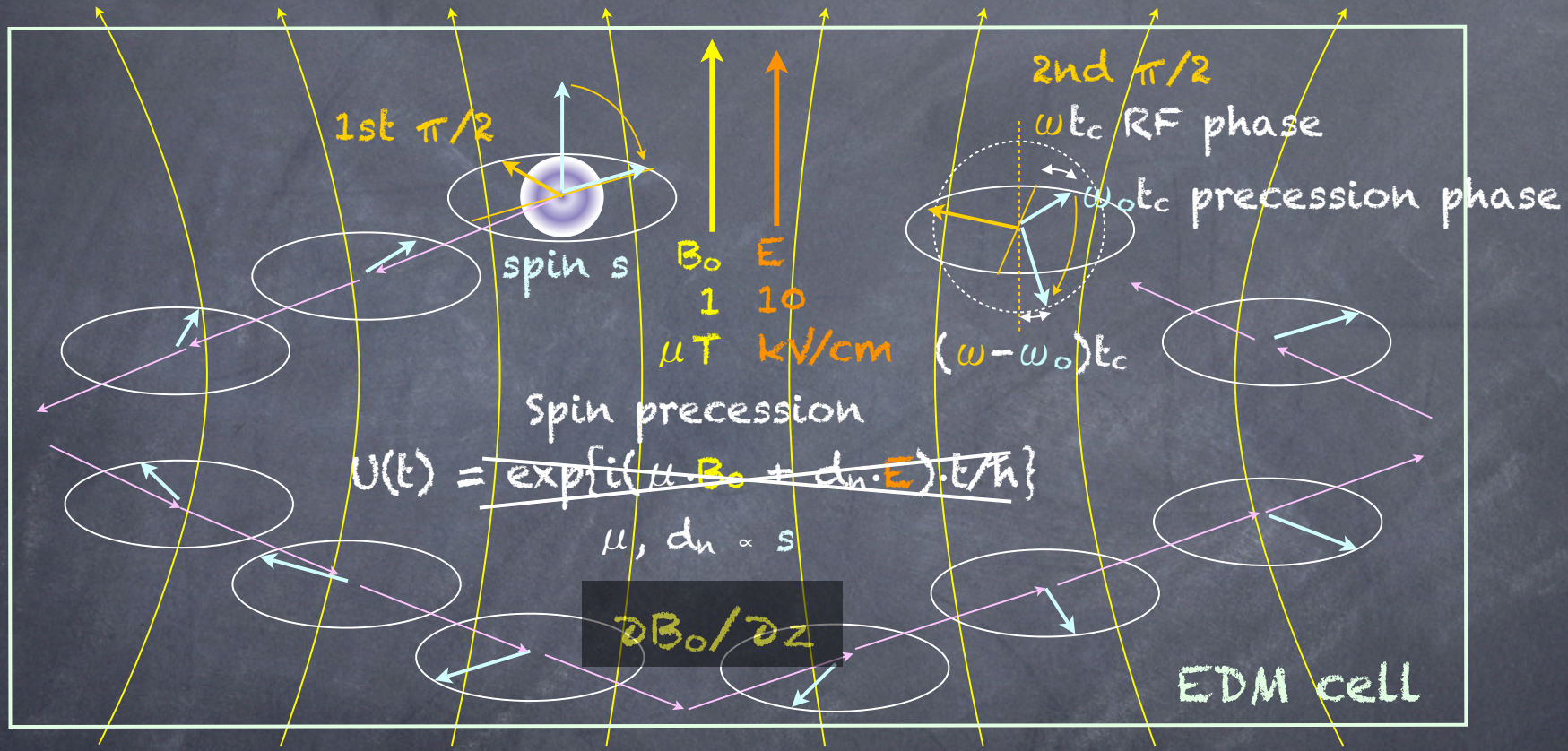
Result of Ramsey resonance



EDM is obtained from a phase shift upon E reversal

$\Delta d_{sta} = \hbar/\{2P_n E t_c \sqrt{N}\}$ P_n : UCN polarization, N : $\rho_{UCN} V_{cell}$

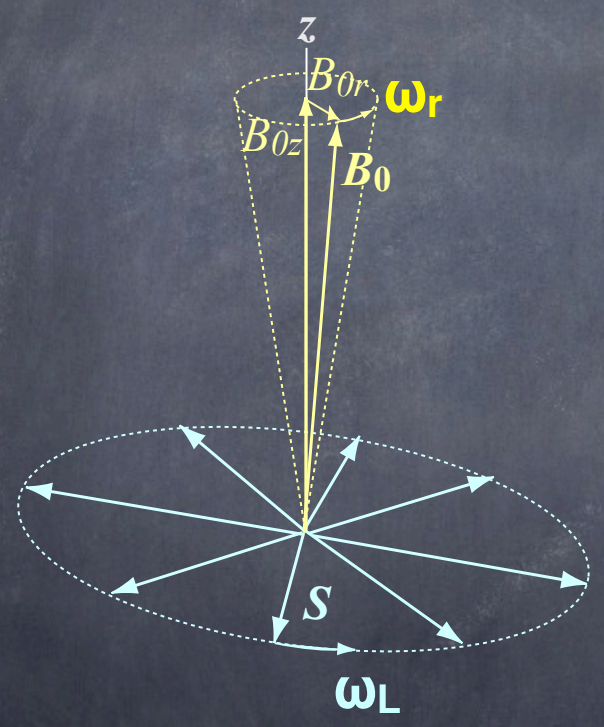
Effect of particle motion



Transverse fields, $(\partial B_0/\partial z)r/2$ and $E\times v/c^2$ rotate upon particle motion

Effect of time dependent interaction
Geometric phase effect

Phys.Lett. A376(2012)1347



$$H_0 = -\boldsymbol{\mu}\cdot\boldsymbol{B}_0 - \boldsymbol{d}_n\cdot\boldsymbol{E}$$

$$U(t) = \exp(-iH_0 t/\hbar)$$

$$H = H_0 + V(t)$$

$$V(t) = -\boldsymbol{\mu}\cdot\boldsymbol{B}_{xy}(t)$$

$$= -\gamma\boldsymbol{s}\cdot\left\{\underline{\boldsymbol{E}\times\boldsymbol{v}(t)/c^2 - (\partial B_{0z}/\partial z)\boldsymbol{r}(t)/2}\right\}$$

$$U_I(t) = 1 + \left(\frac{-i}{\hbar}\right)\int_0^t dt' V_I(t')$$

$$+\left(\frac{-i}{\hbar}\right)^2\int_0^t dt'\int_0^{t'} dt'' V_I(t')V_I(t'') + \cdots$$

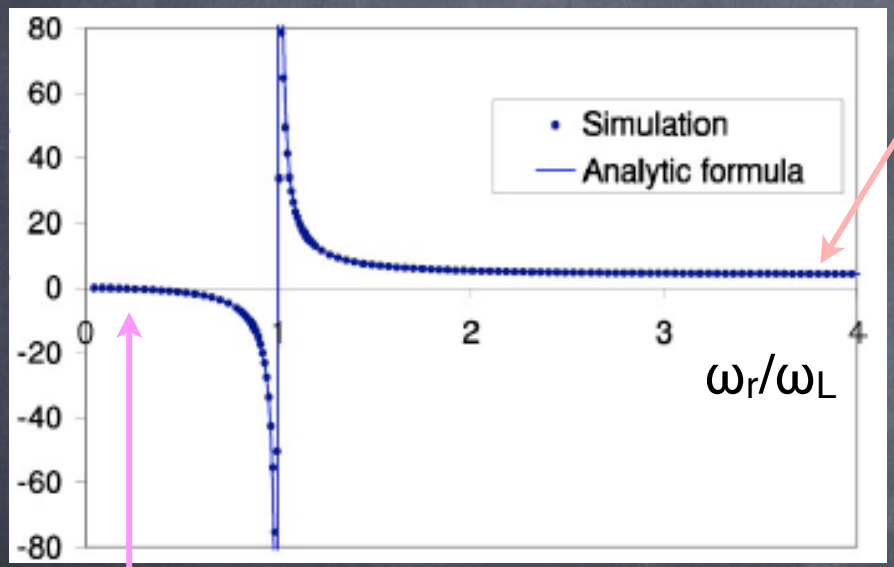
$$V_I(t) = e^{iH_0 t/\hbar}\{-\boldsymbol{\mu}\cdot\boldsymbol{B}_{xy}(t)\}e^{-iH_0 t/\hbar}$$

$E\times v/c^2 \cdot (\partial B_0/\partial z)r/2$ cross terms induce false effect

GPE suppression of Xe co-magnetometer

$$U_I(t) = 1 + \frac{is_z}{\hbar}\frac{1}{4}\gamma^2 \frac{E}{c^2}\frac{\partial B_{0z}}{\partial z}\int_0^t dt' \int_0^{t'} d\tau \cos(\omega_0 \tau)$$

$$\{x(t')v_x(t'-\tau) - x(t'-\tau)v_x(t') + y(t')v_y(t'-\tau) - y(t'-\tau)v_y(t')\}$$



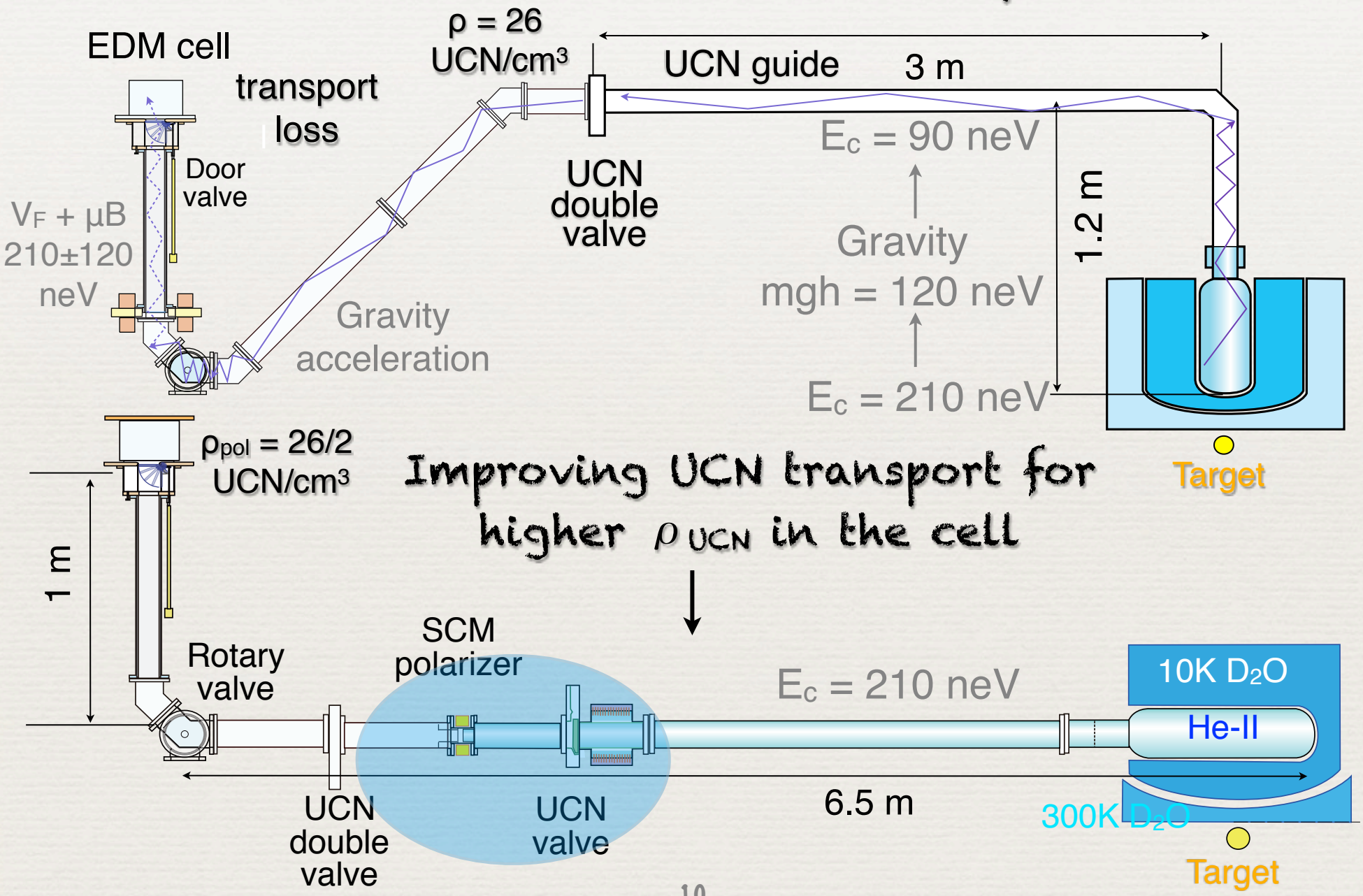
Atomic co-magnetometer:
Non-adiabatic regime $\omega_r >> \omega_L$
$d_{afXen} = \hbar/8 \cdot \gamma_n \gamma_{Xe} (\partial B_{0z}/\partial z) R^2/c^2$
$= 8\times10^{-26}$ e cm at R = 25 cm

$\langle r(t)v(t-\tau)\rangle \rightarrow << 1$
for short mean free path λ
r(t) is almost constant
v(t-τ) rapidly changes

UCN: Adiabatic regime $\omega_r << \omega_L$
$d_{afn} = -\hbar/4 \cdot (\partial B_{0z}/\partial z)/B_{0z}^2 \cdot v_{xy}^2/c^2$
$= 1\times10^{-27}$ e cm
at $\partial B_{0z}/\partial z$ = 1nT/m, B_{0z}=1μT

Diffusion velocity is in $\omega_r << \omega_L$
$v_{xy}\lambda/(2R)^2$ = 8Hz $<< \omega_L/2\pi$ =120Hz
at B_{0z} = 10μT
Suppression $[\{v_{xy}\lambda/(2R)^2\}/(\omega_L/2\pi)]^2$
$d_{afXen} \rightarrow 4\times10^{-28}$ e cm at 3 mTorr

nEDM at a room temperature

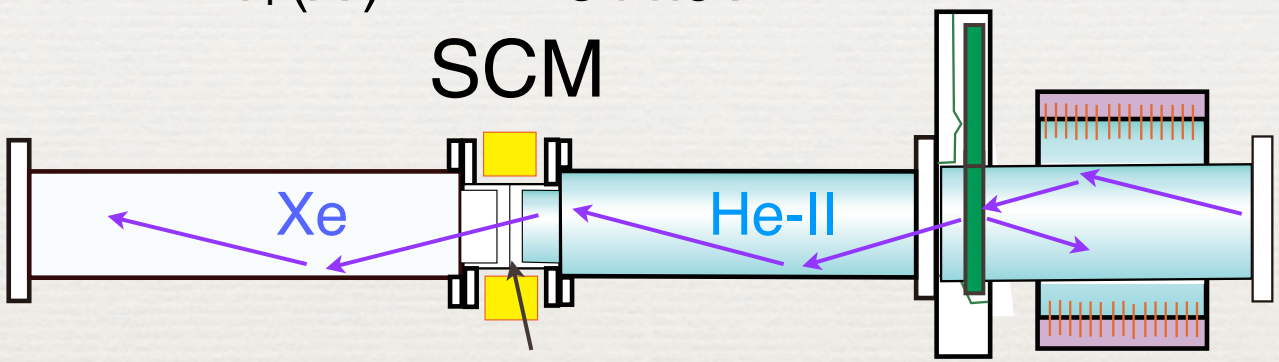


Improving UCN transport for higher ρ_{UCN} in the cell

Extracting polarized UCN

$\mu B(>3.5T) > 210$ neV
$V_F(\text{guide}) = 210$ neV
$V_F(\text{Al}) = 54$ neV

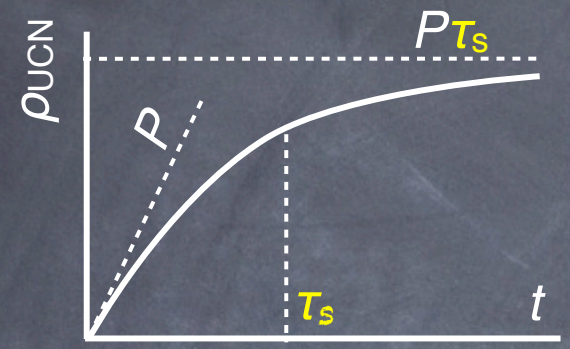
opened at EDM cell filling



V_F(Al) is compensated with μB, and UCN transmission is enhanced
UCN loss, hydrogen effect, at the Al foils is expected to be small

	absorption	up-scattering	reflection
^{1}H	$\sigma_\gamma = 0.33$ b	$\sigma_{inc} = 20$ b	$b_{coh} = -3.74$ fm
^{27}Al	$= 0.23$ b	$= 9.8$ mb	$= 3.45$ fm
Fe	$= 2.56$ b	$= 0.38$ b	$= 9.55$ fm

Increasing ρ_{UCN} in the source



P (production rate) $\propto I_p \times E_p$

$(\iint dE_{in} dE_{UCN}\, N\, \sigma(E_{in} \rightarrow E_{UCN})\, d\Phi_n(E_{in})/dE_{in})$

τ_s (UCN lifetime)

$= 1/\{1/\tau_{ph} + 1/\tau_w + 1/\tau_\beta\}$

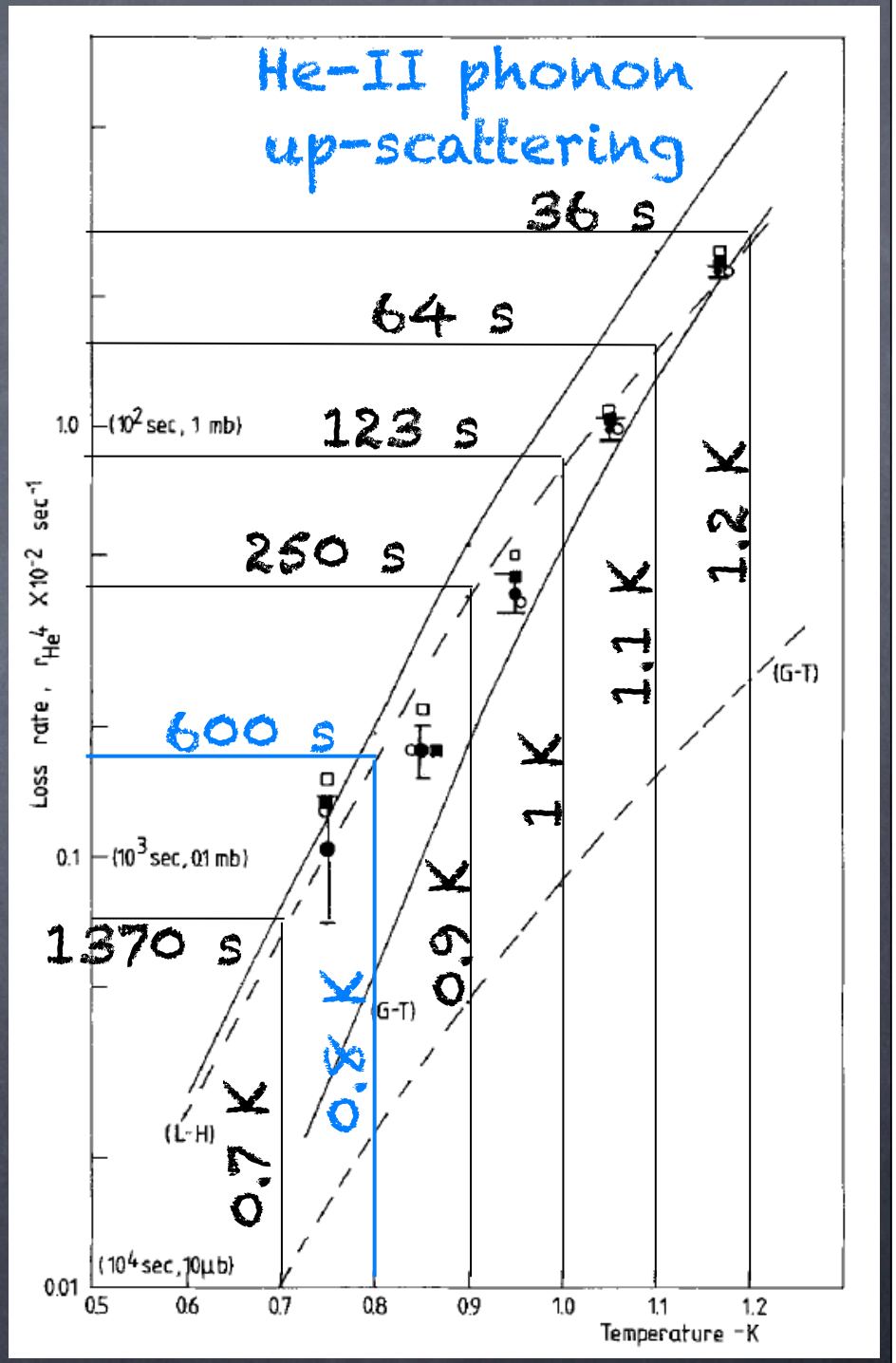
τ_{ph} = 600 s at 0.8 K

τ_w = 246 s (wall loss)

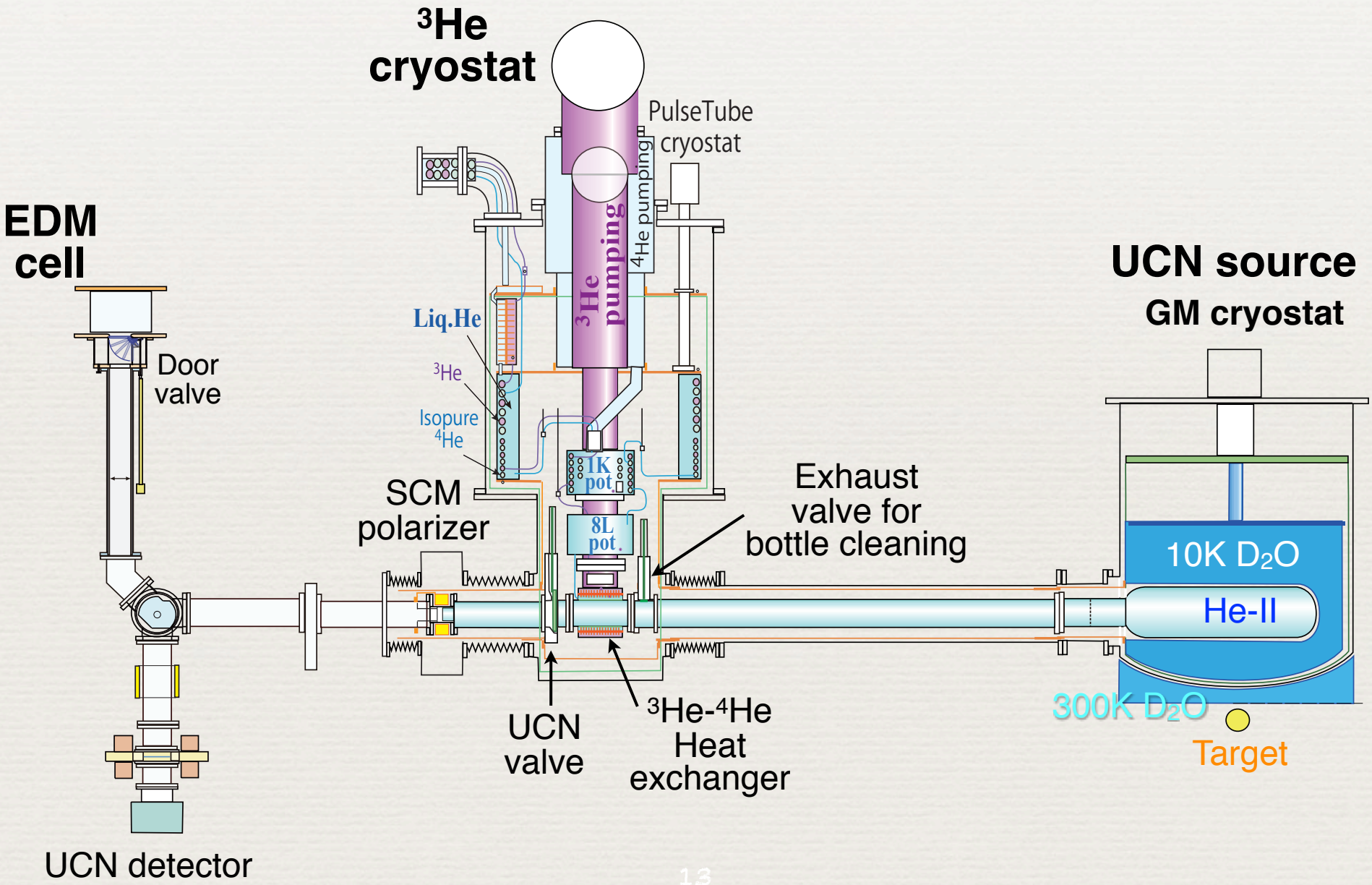
Z. Phys. B59(1985)261

τ_β = 886 s (β decay)

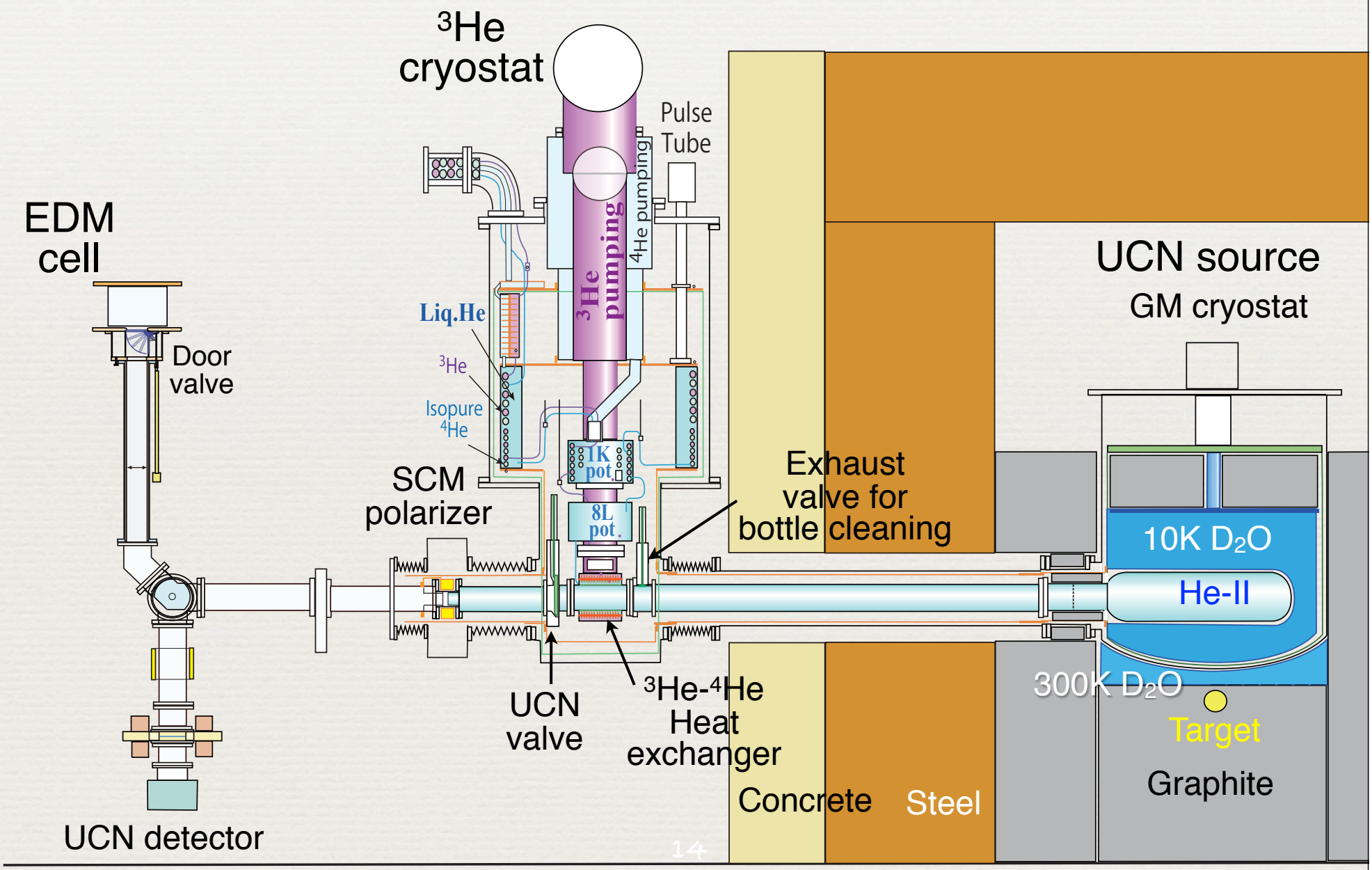
= 174 s



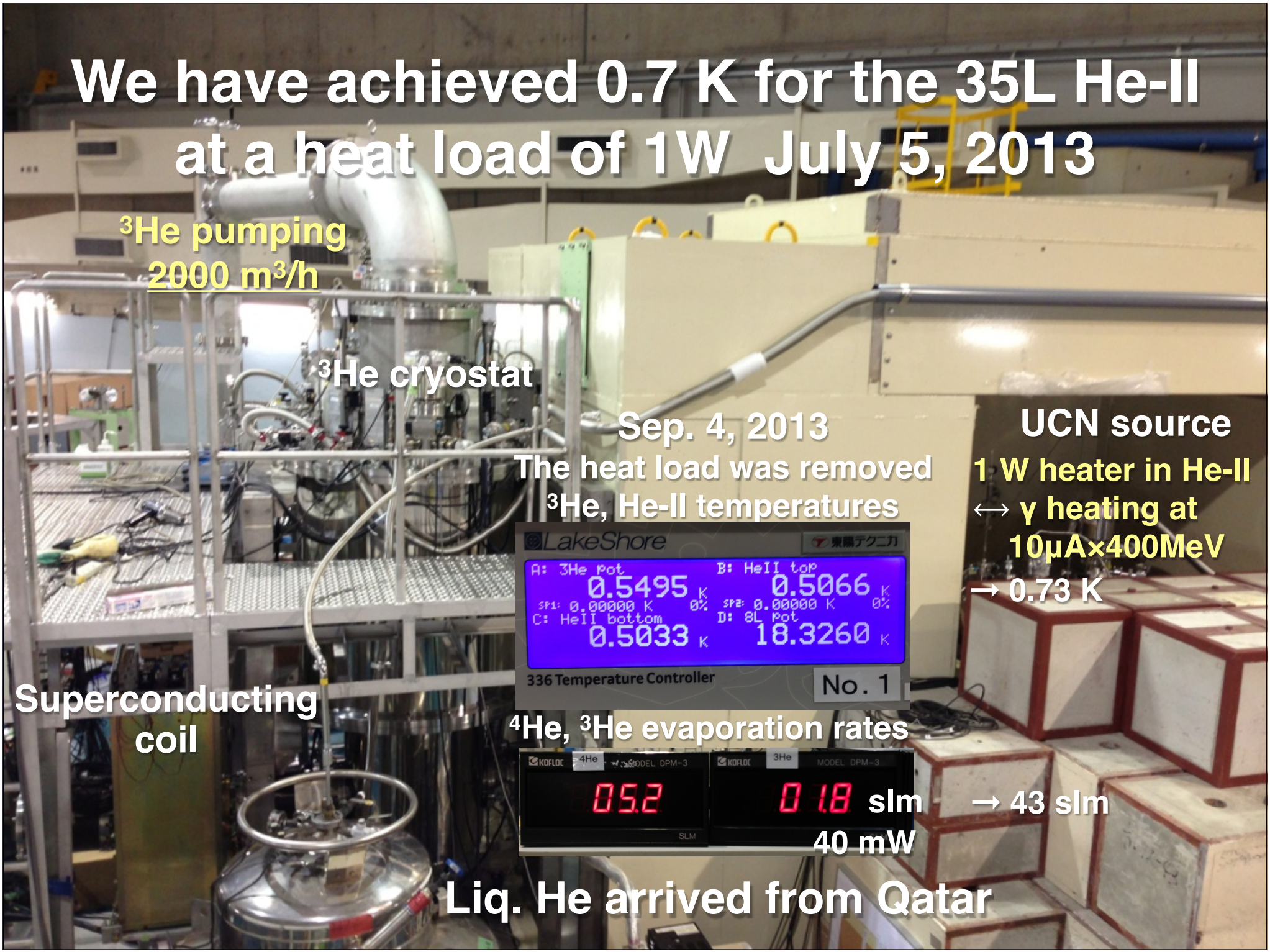
0.8 K He-II production



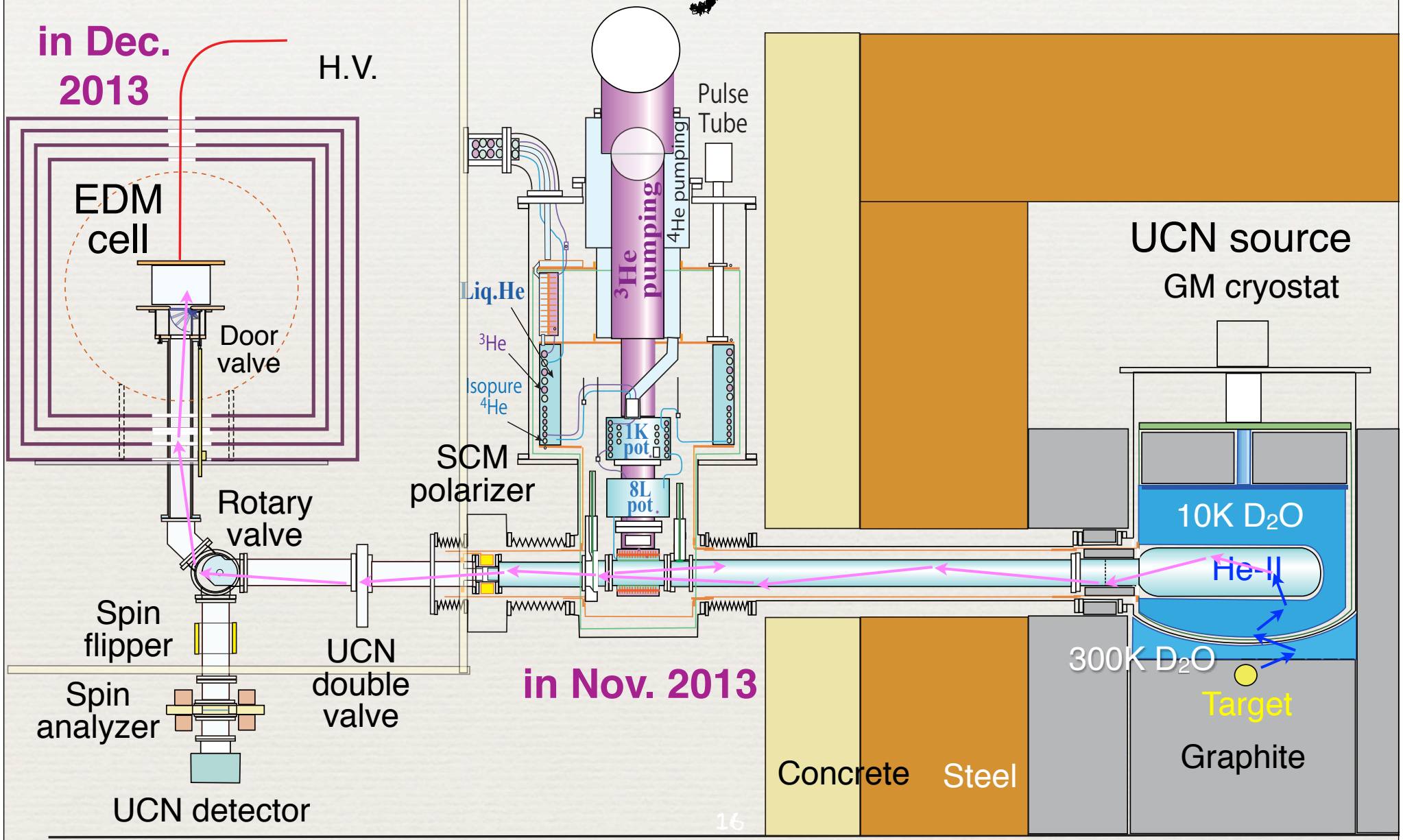
Reflector and shielding



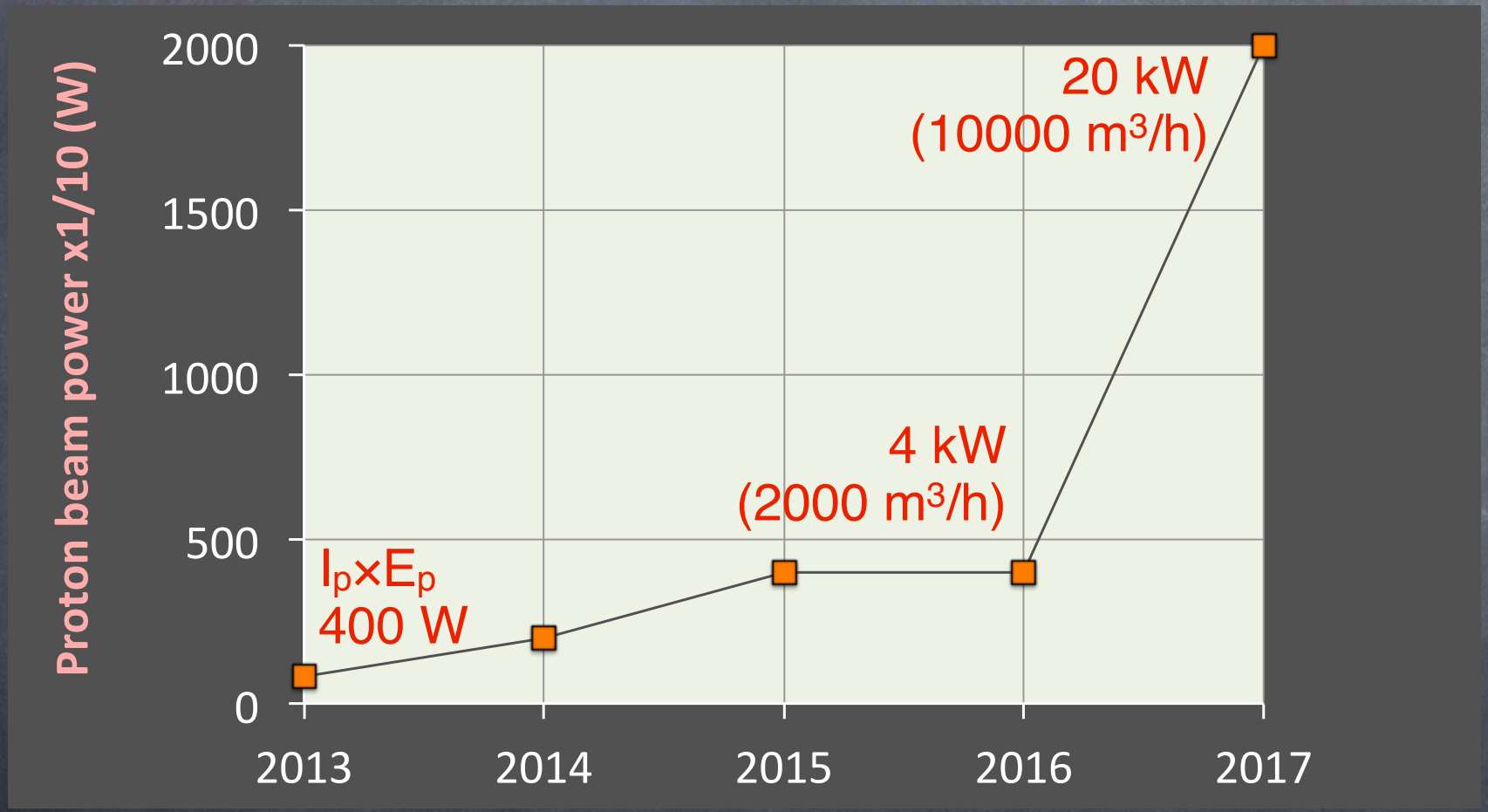
We have achieved 0.7 K for the 35L He-II at a heat load of 1W July 5, 2013



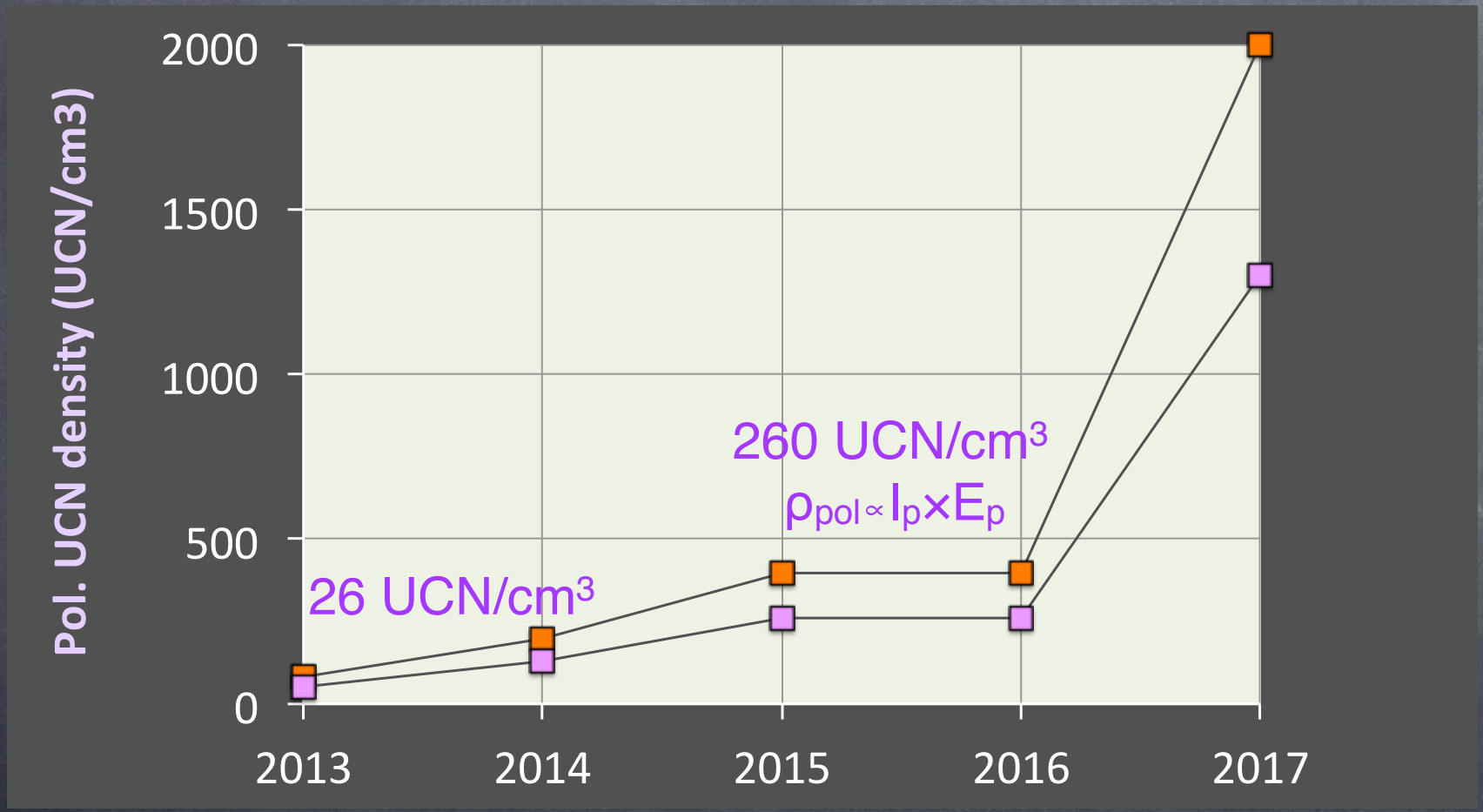
We will restart UCN production and Ramsey resonance



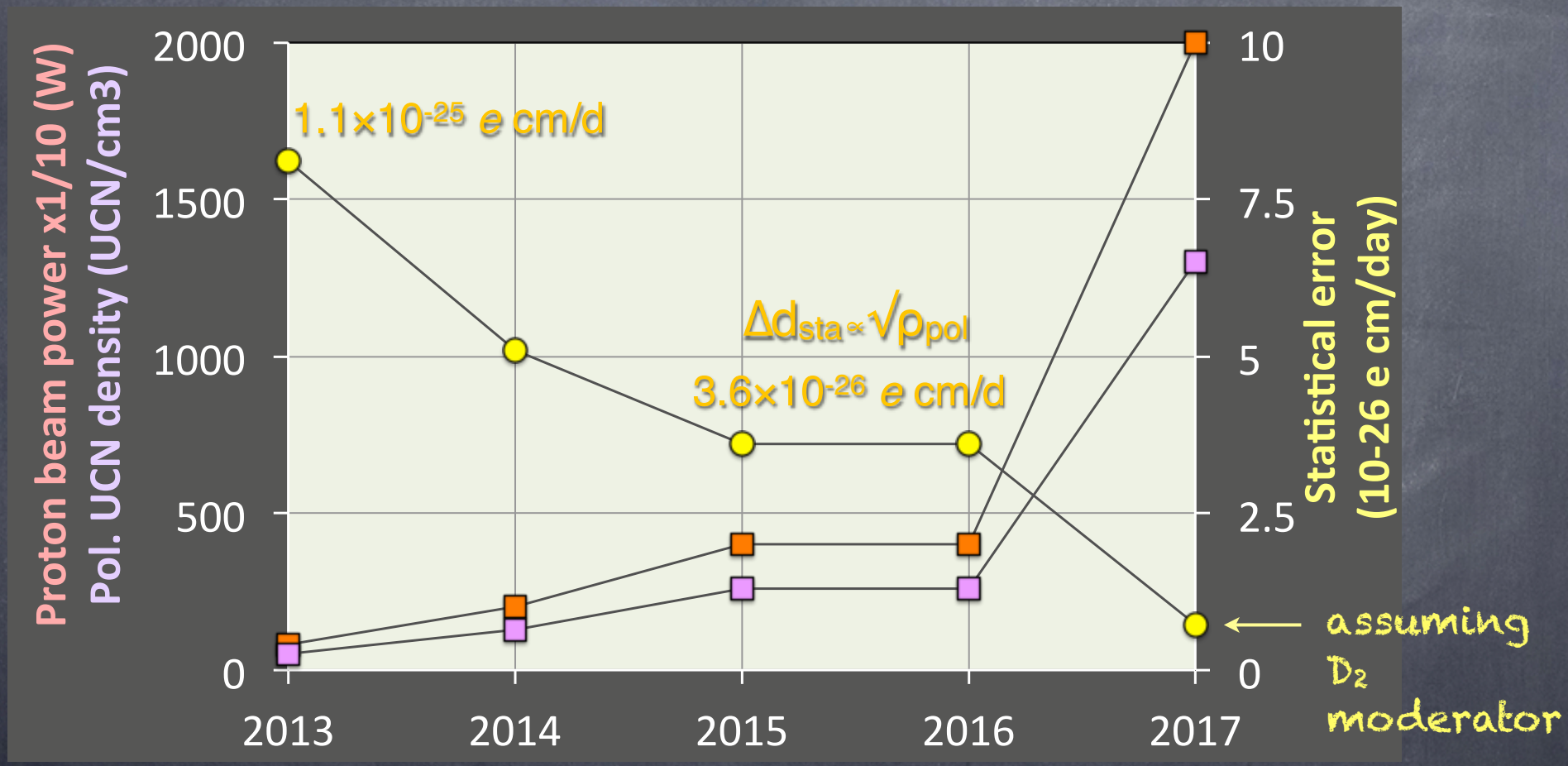
nEDM Timeline



nEDM Timeline



nEDM Timeline



RCNP, Osaka → ← TRIUMF

E_c = 90 neV
V_{cell} = 3 L

E_c = 90 neV
V_{cell} = 3 L
R. Picker's poster

Thanks

T. Adachi, Y. Makita, H. Takahashi, K. Tanaka, (KEK), D. Nishimura (Osaka),
I. Tanihata (Beihang, RCNP)
R. Picker, E. Pierre, Yunchang Shin, D. Ramsay (TRIUMF), S. Page (Manitoba), Momose (UBC),
E. Korkmaz (UNBC), M. Barnes (CERN), R. Golub, E. Korobkina (North Carolina)