A new UCN source at TRIUMF

for EDM, β decay, gravity etc.

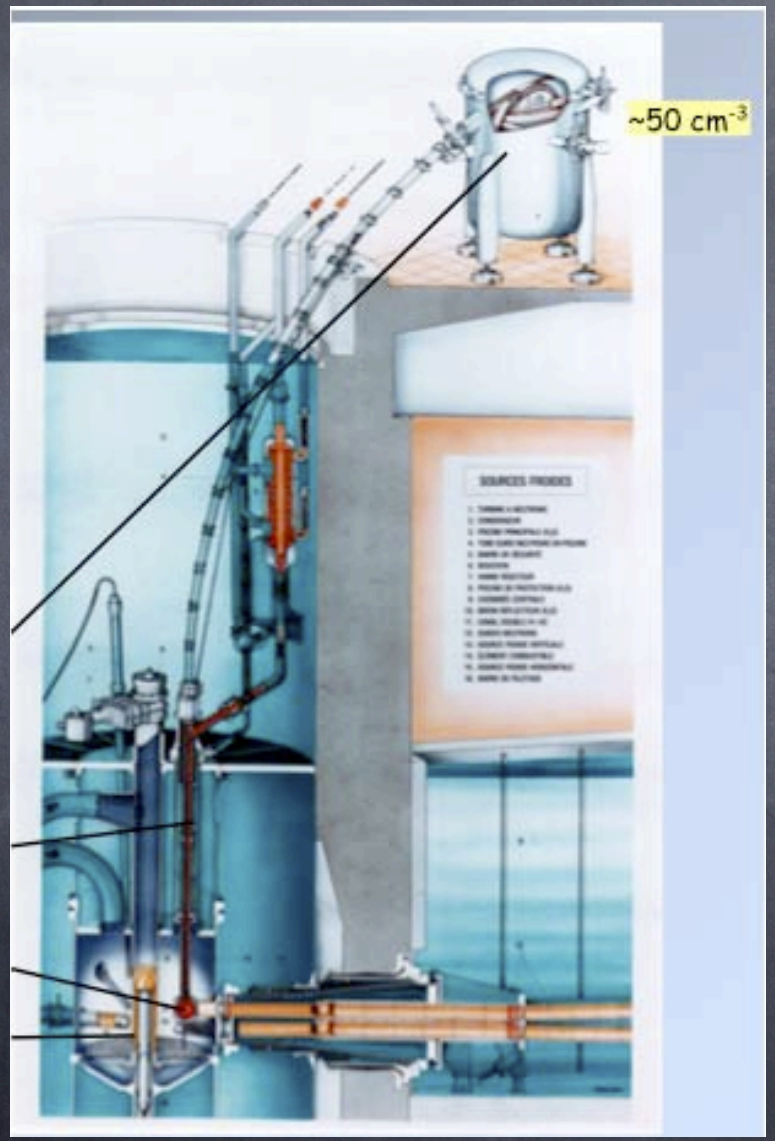
For these experiments,
Phase space density is crucial.

Momentum space is limited by
Fermi potential (E_c = 100~200 neV) and
magnetic potential (60 neV/T),

real space
by bottle size

$$V_F = (2\pi\hbar^2/m)a\,N$$

Present UCN source at ILL



Turbine

Vertical guide

Cold source

60 MW Reactor

50 UCN/cm^3
in source E_c = 335 neV

2 to 3 UCN/cm^3
in an experimental
bottle of E_c = 100 neV
0.7 UCN/cm^3
in EDM cell

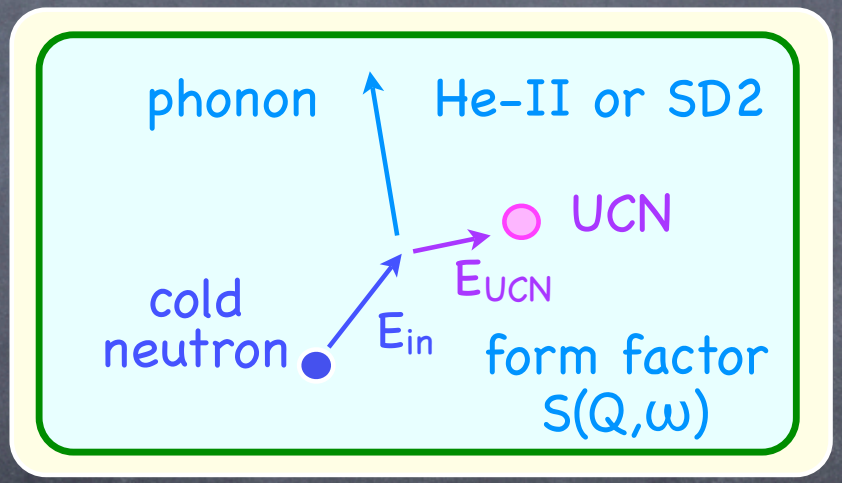
UCN density is limited
by Liouville's theorem
for the deceleration
by gravity and
Doppler effect

New UCN sources

LANL, PSI, NCSU, Munich, ILL, SNS and Ours

use neutron cooling by phonon

no limitation of Liouville's theorem, we can use phonon phase space



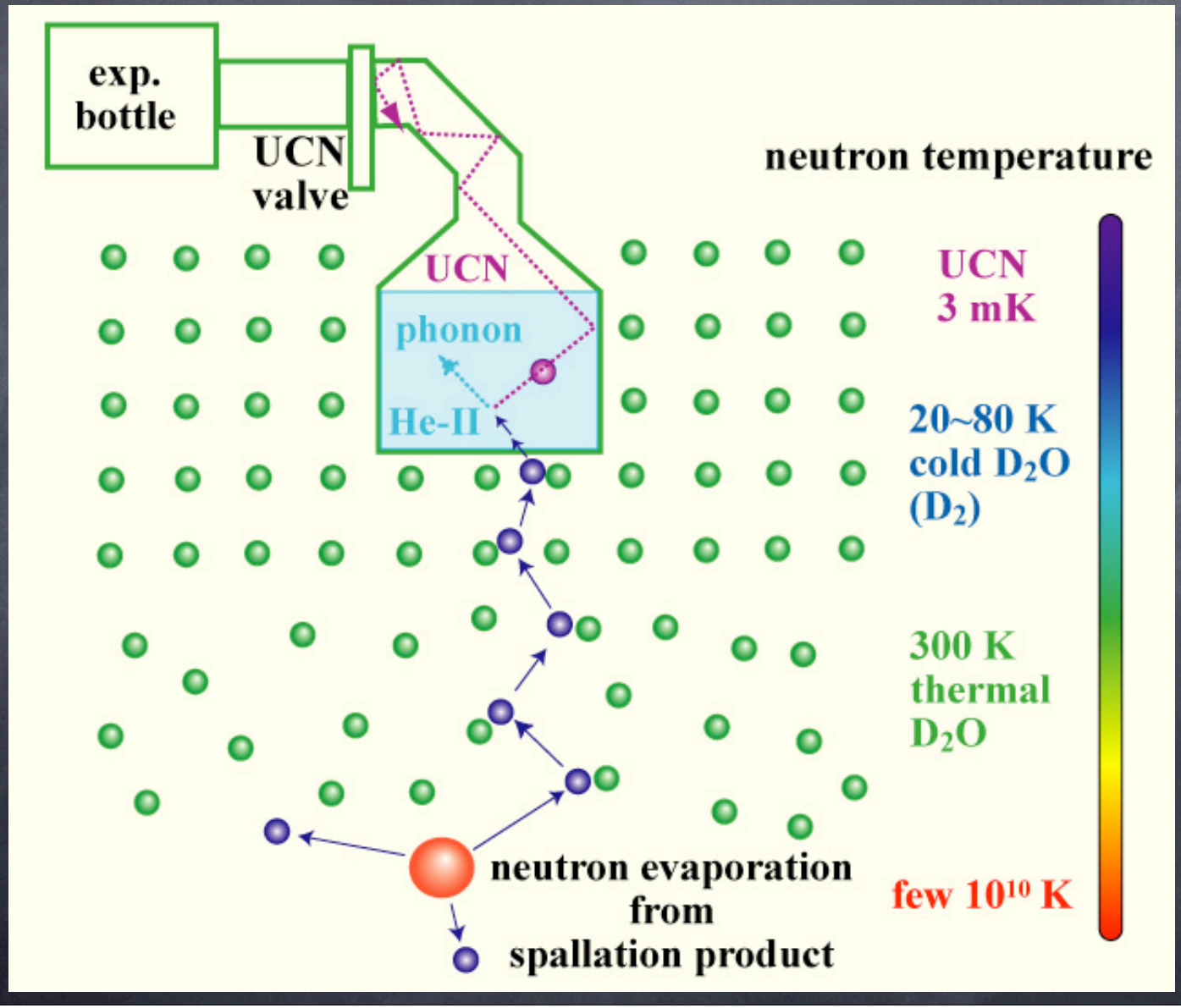
Production rate, P_{UCN}

$$P_{UCN} = \int \int \sigma_{coh}(E_{in} \rightarrow E_{UCN})\ \Phi_n(E_{in})\ N\ dE_{in}\ dE_{UCN}$$

$$d^2\sigma/dQd\omega = k_f/k_i\ \sigma_{coh}/4\pi\ S(Q,\omega)$$

$$\rho_{UCN} = P_{UCN} \times \tau_s \text{ (storage lifetime)}$$

A new UCN production



Cold neutron flux Φ_n

in cold neutron moderator

Ours 20kW: $\Phi_n = 2\times10^{12}$ n/cm^2/s

PSI 1.2MW: $\Phi_n = 2.6\times10^{13}$ n/cm^2/s

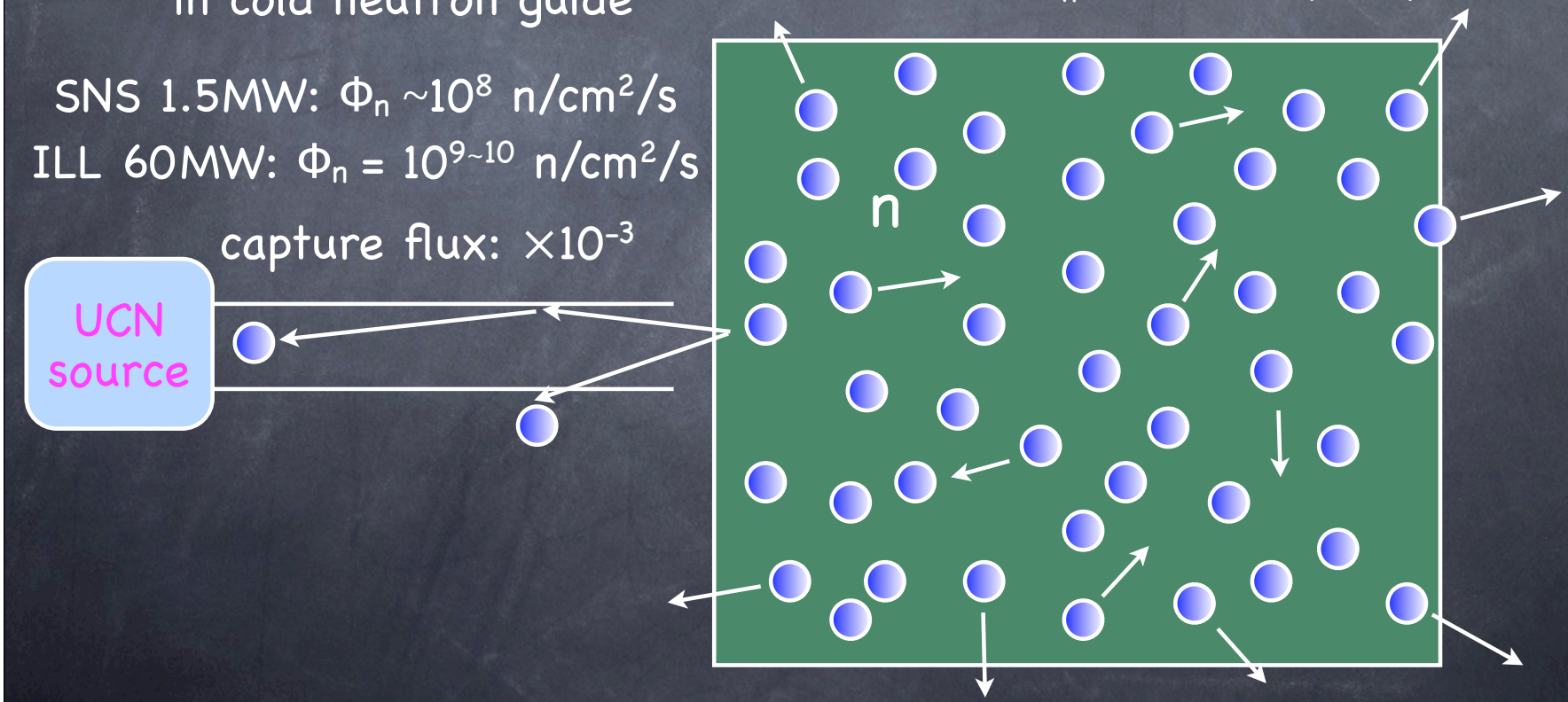
NCSU 1MW: $\Phi_n = 1\times10^{12}$ n/cm^2/s

in cold neutron guide

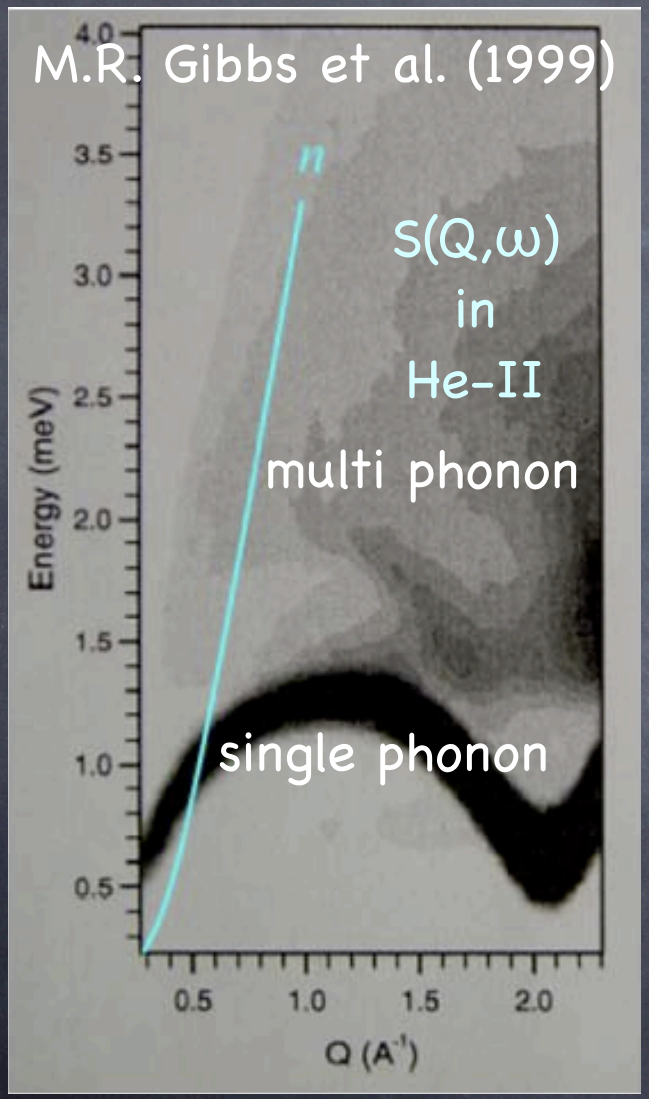
SNS 1.5MW: $\Phi_n \sim10^{8}$ n/cm^2/s

ILL 60MW: $\Phi_n = 10^{9\sim10}$ n/cm^2/s

capture flux: $\times10^{-3}$



UCN production rate P_{UCN}



In our He-II

$P_{UCN} = (2\sim4)\times10^{-9}\ \Phi_n/cm^3/s$,

Phys.Lett A301(2002)462

$= 0.37\sim0.73\times10^4$ UCN/cm^3/s

20 kW

In Los Alamos SD2

$P_{UCN} = 4.4\times10^4$ UCN/cm^3/s,

Phys.Lett B593(2004)55

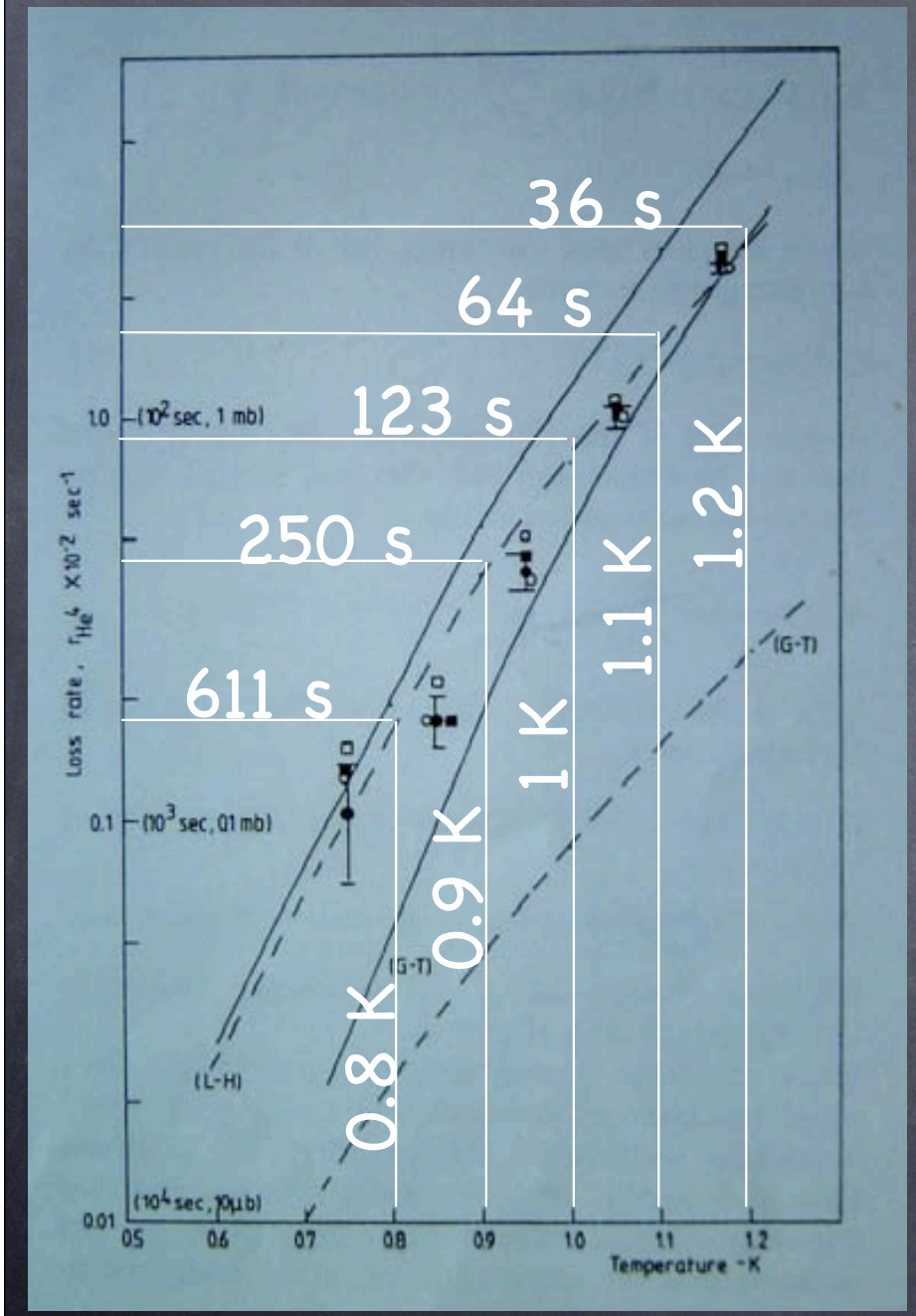
76 kW

In PSI SD2

$P_{UCN} = 2.9\times10^5$ UCN/cm^3/s,

Phys.Rev C71(2005)054601

1.2 MW



Storage time τ_s

He-II [Golub et al. (1983)]

phonon up-scattering, $1/\tau_{ph} \propto T^7$

τ_{ph} = 600 s at $T_{He\text{-}II}$ = 0.8 K

β decay lifetime, τ_β = 886 s

wall loss, τ_{wall} = 300 s

τ_s = 150 s

SD2 [Phys.Rev.C71(2005)054601]

τ_{ph} = 40 ms at T_{SD2} = 8 K

$\tau_{ortho\text{-}para}$ = 100 ms

τ_a = 150 ms

τ_s = 24 ms

diluted in vacuum

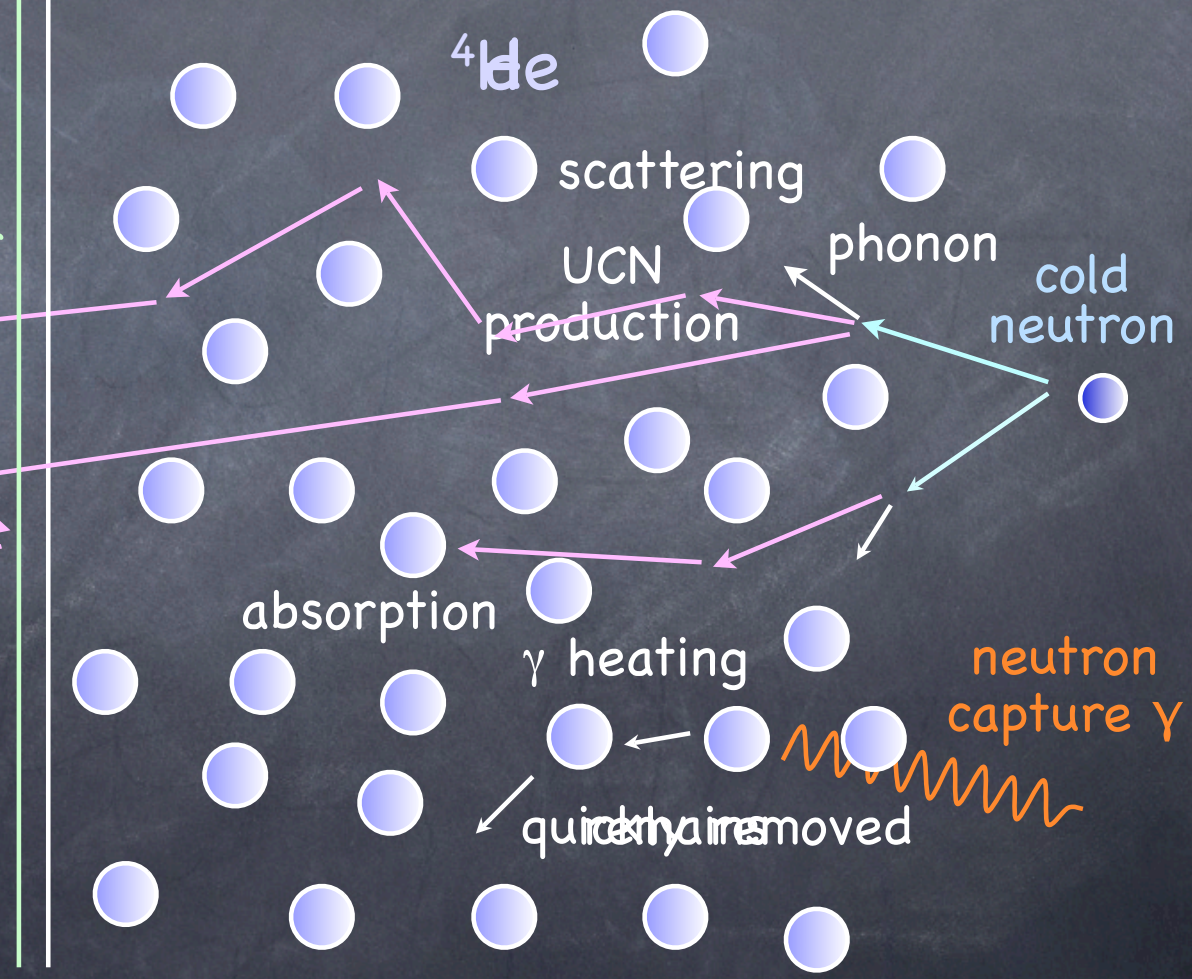
τ_s = 1.6 s, 0.24→9.6L Los Alamos

τ_s = 6 s, 27L→2 m^3 PSI

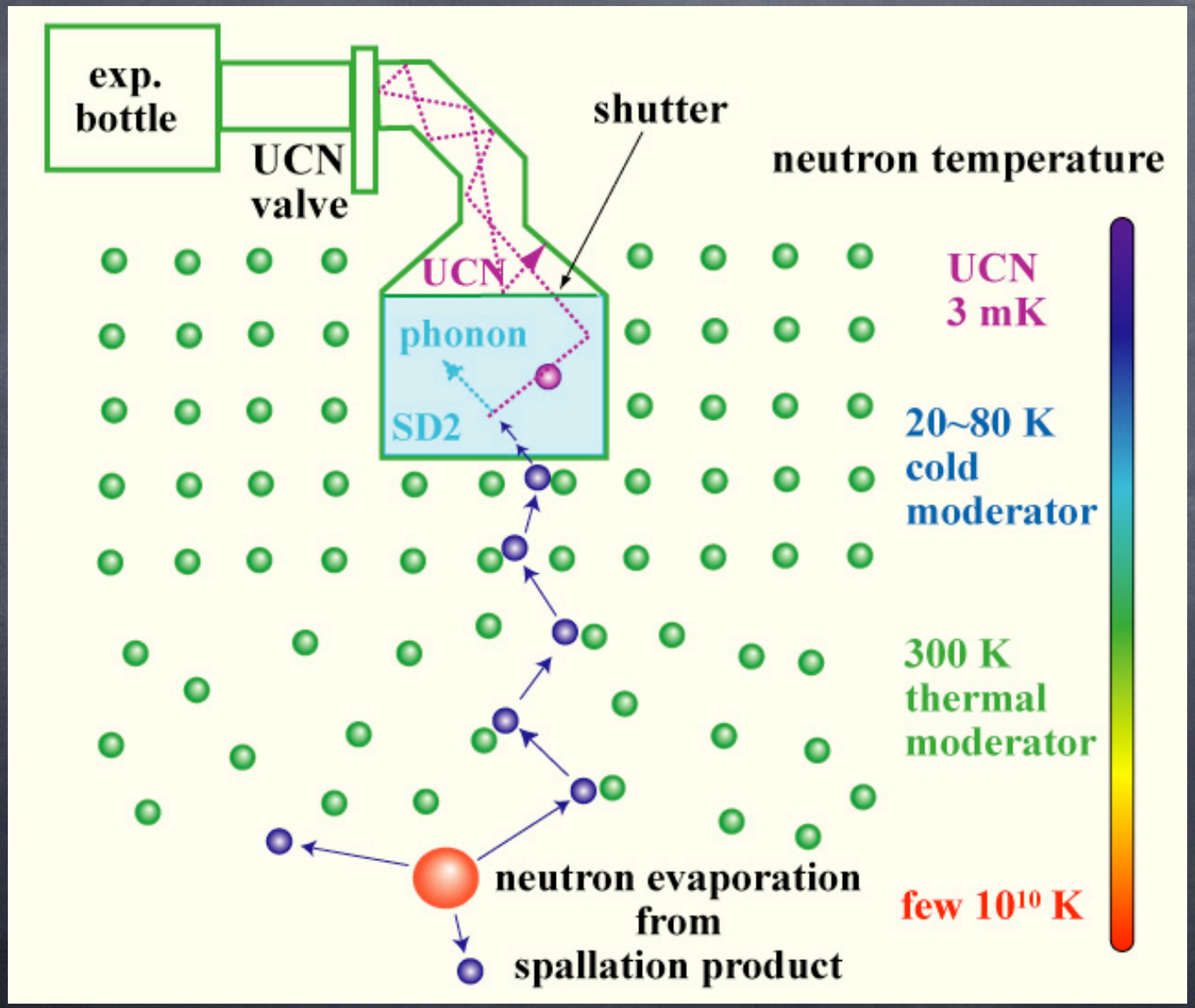
Extraction from source

Superfluid He, ε~100%

SD2, ε~10% [Phys.Rev.C71(2005)054601]



Shuttered UCN source



World's UCN projects, $\rho_{UCN} = P_{UCN} \times \tau_s \times \varepsilon_{ext} \times$(dilution factor)

	source type	E_c neV	P_{UCN} /cm^3/s	τ_s s	ε_{ext}	ρ_{UCN} /cm^3 source/exp.
TRIUMF	spallation He-II	210	0.4×10^4 (10L)	150	~1	3×10^5 (20L) /5×10^4
ILL	n beam He-II	250	10	150	~1	**/1000
SNS	n beam He-II	134	0.3 (7L)	500	1	**/150
LANL	spallation SD2	250	4.4×10^4 (240cm^3)	1.6	1.3×10^3/ 4.4×10^4*	145 (3.6L) /120
PSI	spallation SD2	250	2.9×10^5 (27L*)	6	0.1	2000 (2m^3) /1000
NCSU	reactor SD2	335	2.7×10^4 (1L)	**	**	1300/**
Munich	reactor SD2	250	**	**	**	1×10^4/**

Present status

Los Alamos 76 kW:

ρ_{UCN} = 145 UCN/cm^3 in a 3.6 liter bottle at E_c = 200 neV

0.8 UCN/cm^3 at experiment

PSI 1.2 MW : will start in 2009

Munich 100 kW Trigger reactor at Mainz:

8 UCN/cm^3 in a 10 liter bottle at E_c = 250 neV

Sussex-RAL 60MW:

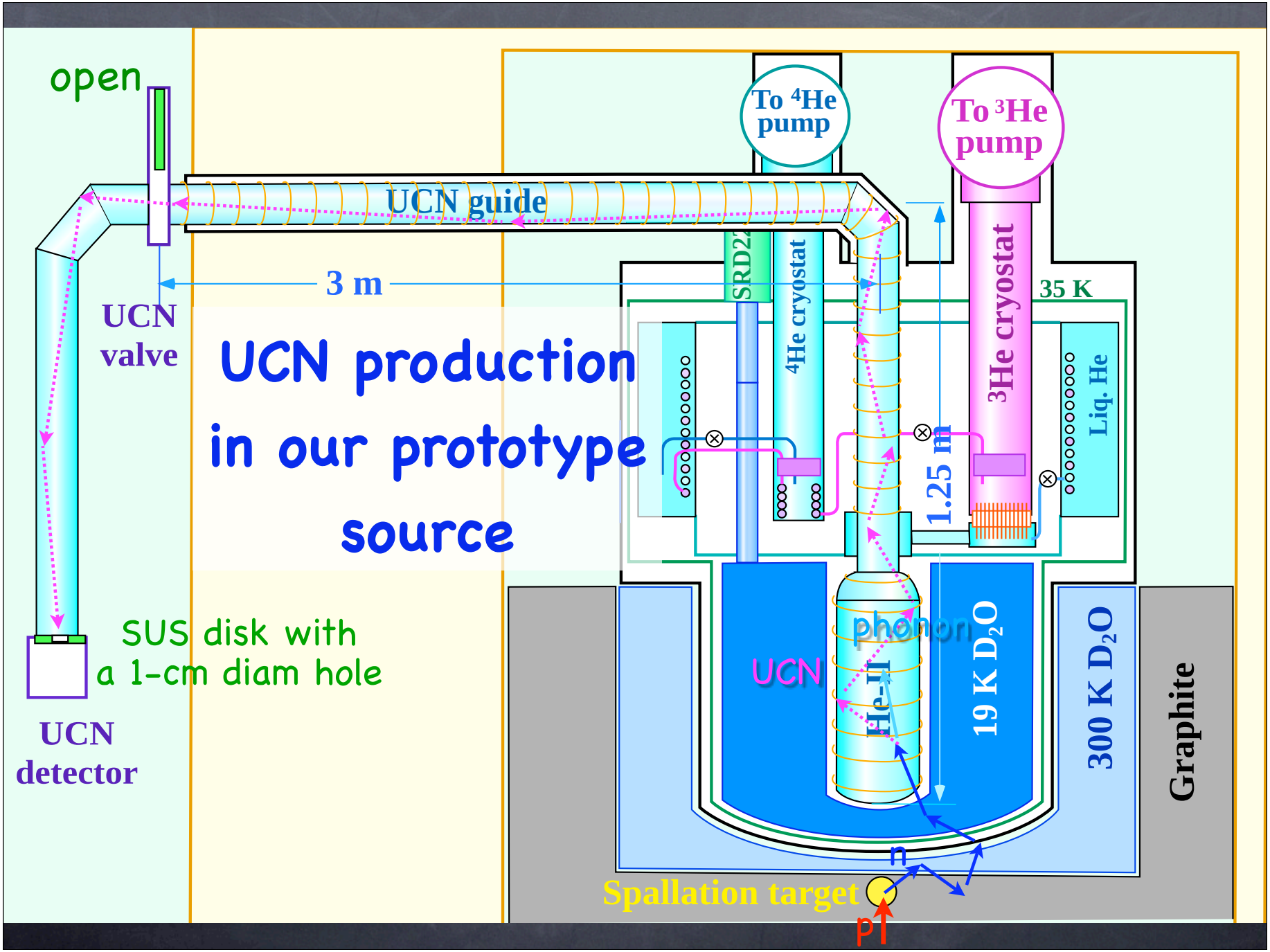
P_{UCN} = 1 UCN/cm^3/s at E_c = 250 neV

Ours 390 W:

P_{UCN} = 4 UCN/cm^3/s in a 10-liter He-II at E_c = 210 neV

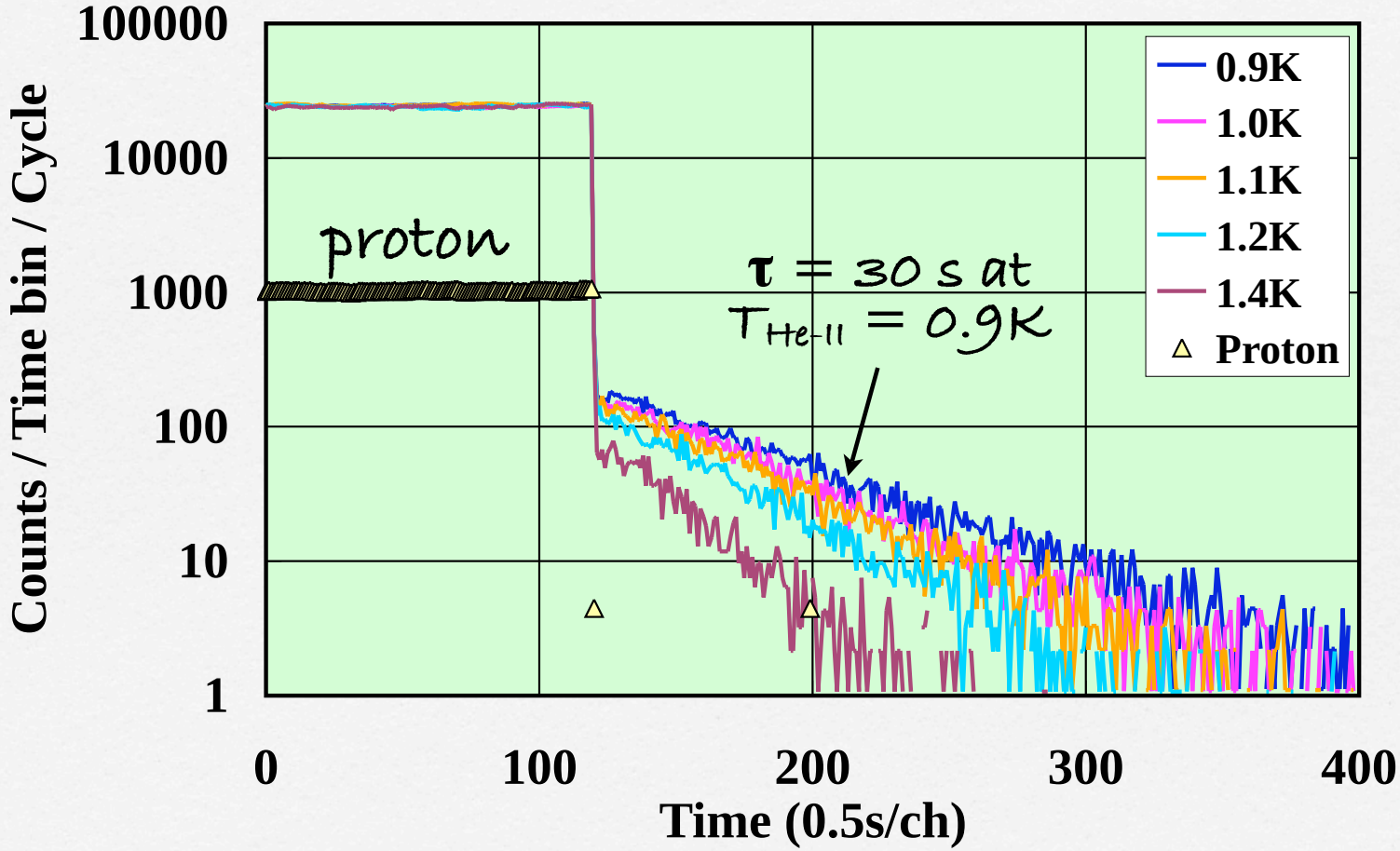
(ρ_{UCN} = 160 UCN/cm^3 at τ_s = 40 s)

ρ_{UCN} = 10 UCN/cm^3 at experimental port of E_c = 90 neV

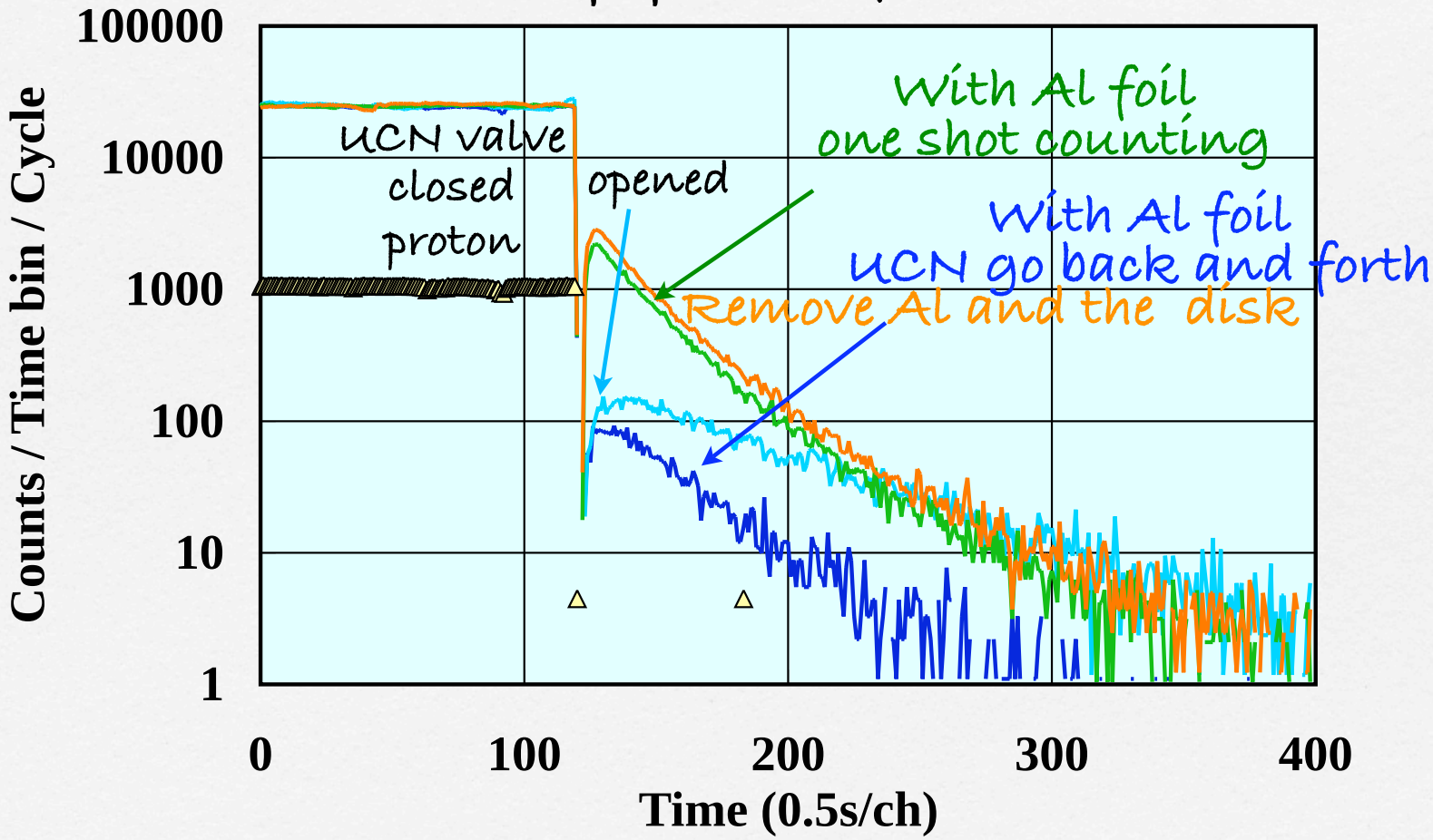

open
UCN guide
To ^{4}He pump
To ^{3}He pump
3 m
UCN valve
UCN production in our prototype source
SRD22
^{4}He cryostat
^{3}He cryostat
35 K
Liq. He
1.25 m
SUS disk with a 1-cm diam hole
UCN detector
phonon
UCN
He-II
19 K D_2O
300 K D_2O
Graphite
n
Spallation target
p

Result of Nov. 2006

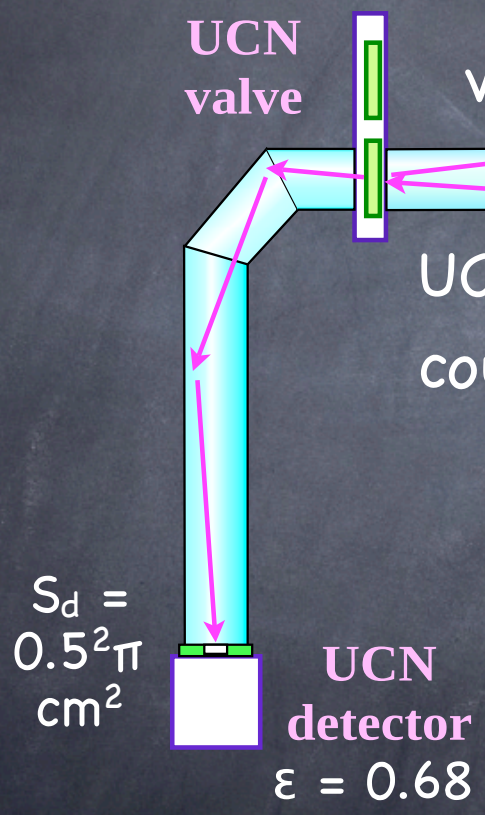
UCN production with a proton-pulse of 1 μA



With/without the annular SUS disk, with a p-pulse of 1μA



UCN density by 390W p beam



v_{av} = 3.1 m/s at E_c = 90 neV

$S = 4.2^2\pi\ cm^2$

UCN flow rate = $1/4 \cdot \rho v_{av} S$

count rate = $1/4 \cdot \rho v_{av} S_d \cdot \varepsilon$ = 409 counts/s

ρ = 10 UCN/cm^3

assuming statistical distribution

1.2×10^6 UCN / 36 liter

1.2×10^6 UCN/30 s for 10 liter He-II

production rate = 4 UCN/cm^3/s

Comparison with the theoretical prediction

Present exp. : production rate = 4 UCN/cm^3/s

5.2 UCN/cm^3/s (E_c:210→250 neV)

↔ 0.9 UCN/cm^3/s at ILL 250neV [Phys.Lett. A308(2003)67]

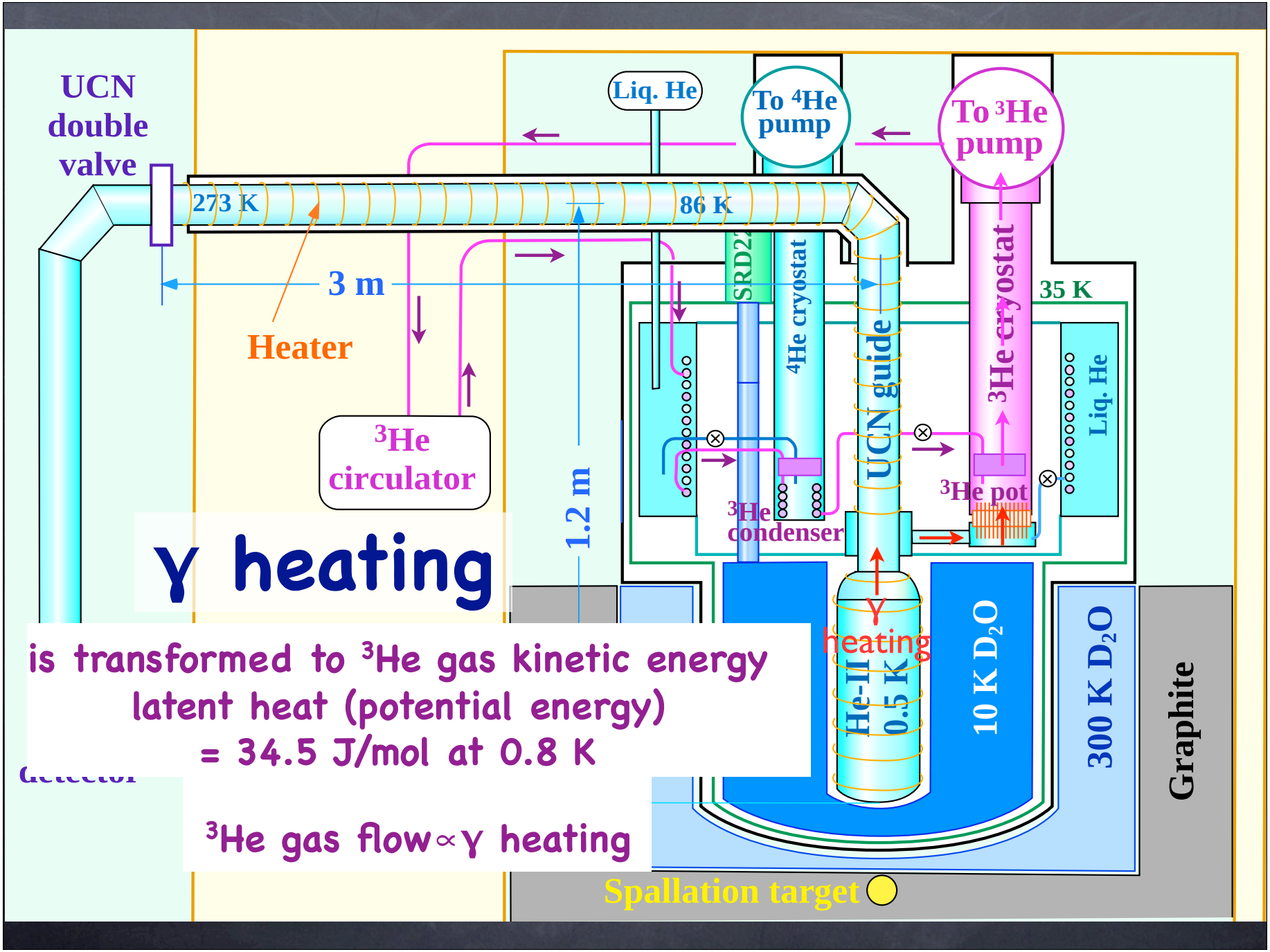
4 ~ 8 UCN/cm^3/s at 400W, 250neV

Predicted production rate

$(1/8)\times(2\sim4)\times10^{-9}\ \Phi_n$ /cm^3/s, $\Phi_n(T_n = 80\ K)$

$\Phi_n = 1.5\times10^{10}$ (n/cm^2/s) by Monte Carlo

[$(2\sim4)\times10^{-9}\ \Phi_n$ /cm^3/s, $\Phi_n(T_n = 20\ K)$]



γ heating

is transformed to ^{3}He gas kinetic energy
latent heat (potential energy)
= 34.5 J/mol at 0.8 K

^{3}He gas flow ∝ γ heating

γ heating in He-II

at a 390W of proton beam

^{3}He gas flow increased by 0.8 slm

γ heating = 20 mW

He-temperature increased by 0.01 K

↕

75 mW

by Monte Carlo assuming D_2O is an ideal gas

Neutron temperature expected to be higher, 20 K → 80 K

neutron capture rate may be smaller at higher temperature

or Bragg cut off ?

Cooling power for He-II

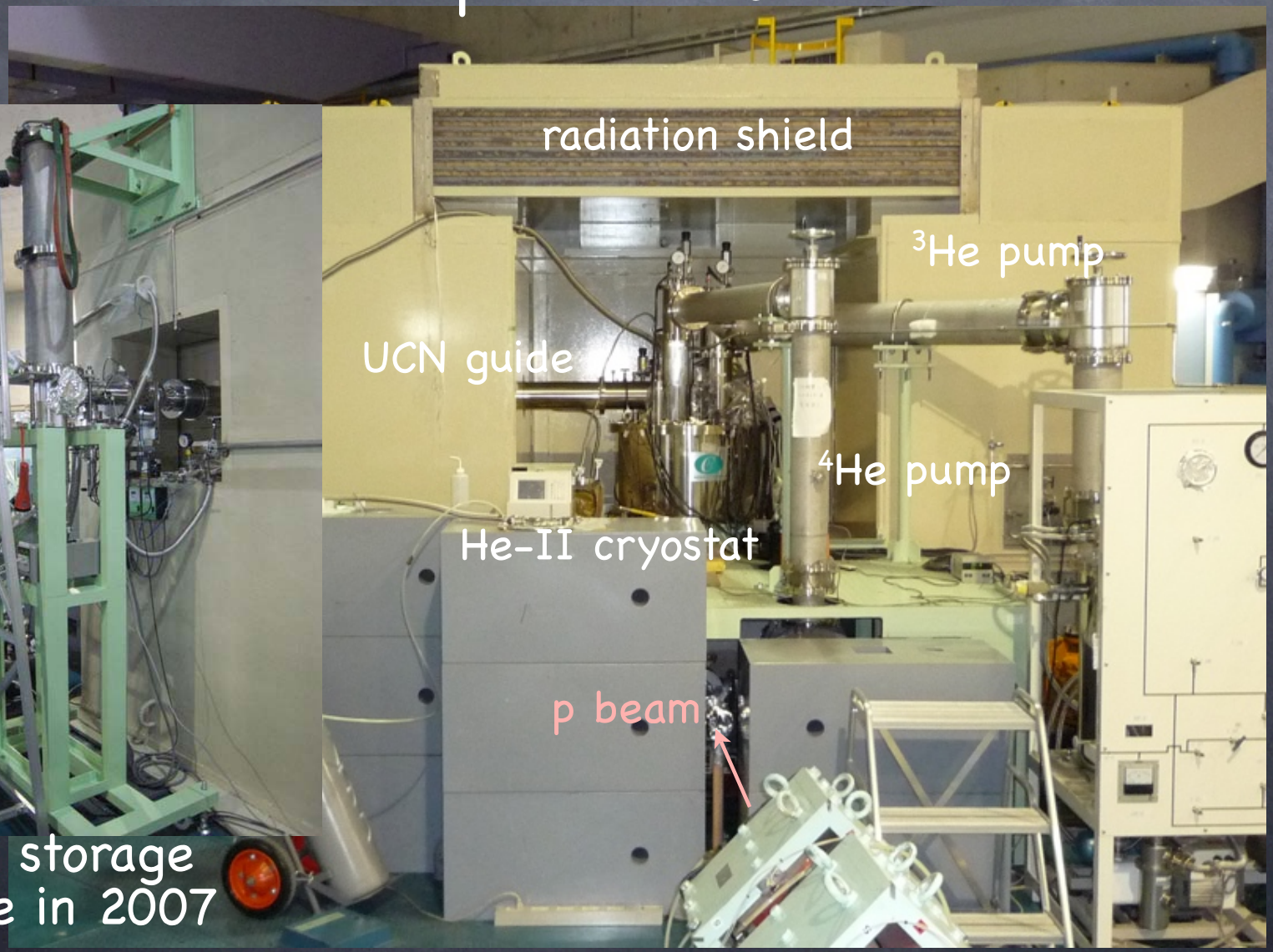
latent heat of vaporization (34.5 J/mol)
× P_{He} (vapor pressure 3 Torr at 0.8 K)
× dV/dt (pumping power 1×10^4 m^3/h)
/ R (gas constant)

17 W

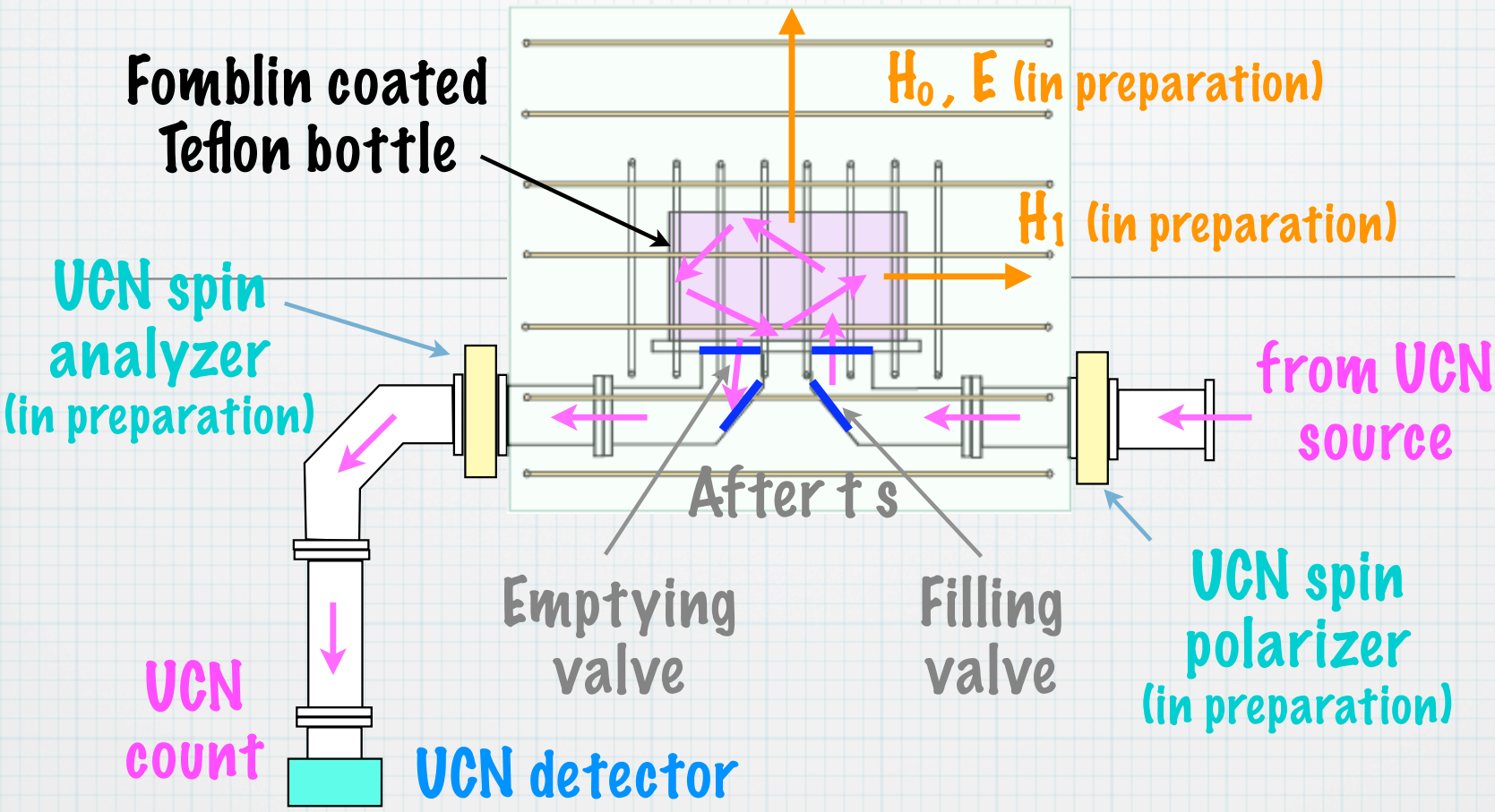
γ heating is 8 W at 20 kW of p beam
by Monte Carlo
(^{3}He flow rate showed much smaller heating)

Preparation for Ramsey resonance with the present source

UCN storage bottle in 2007

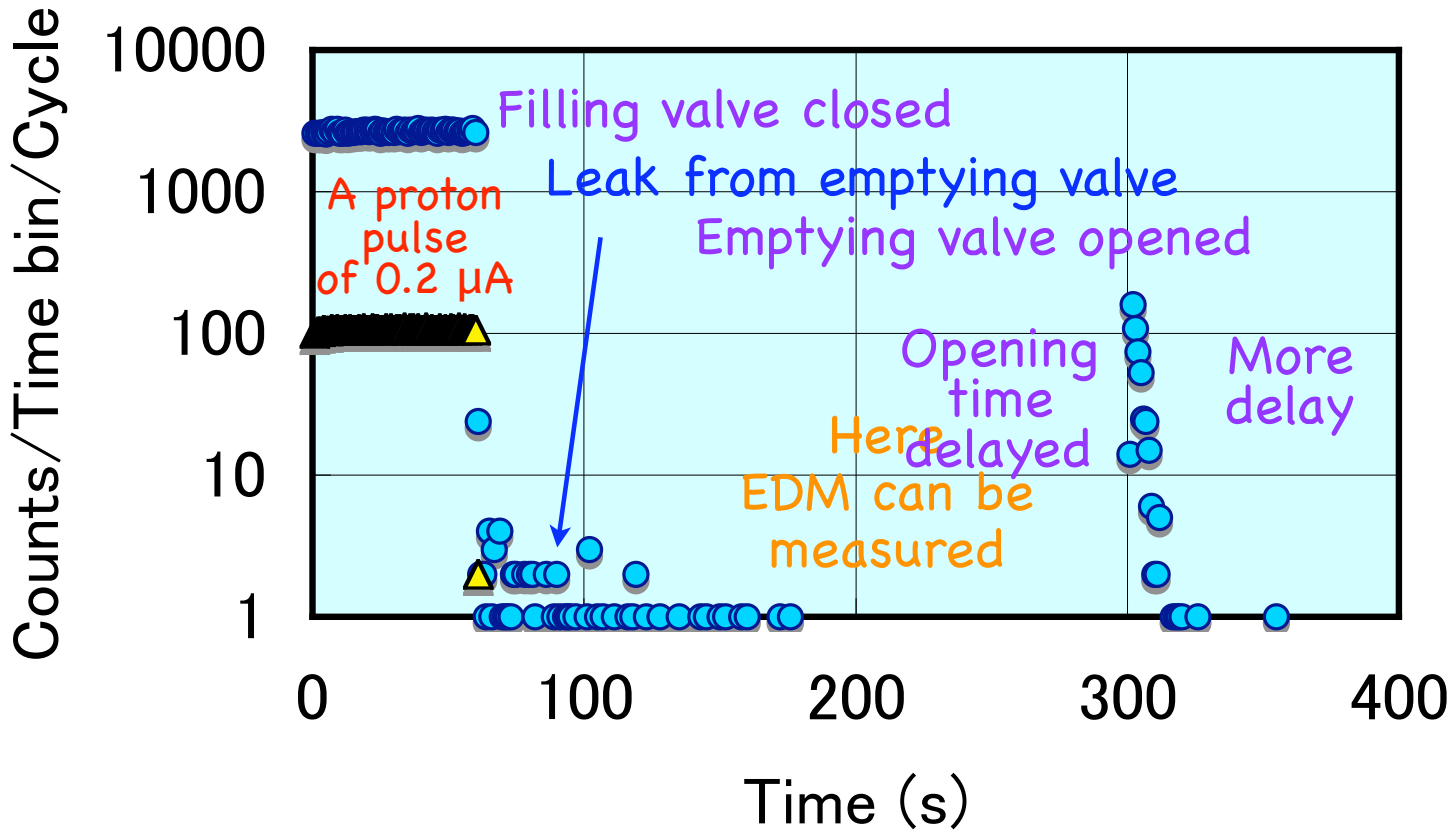


Study of EDM cell

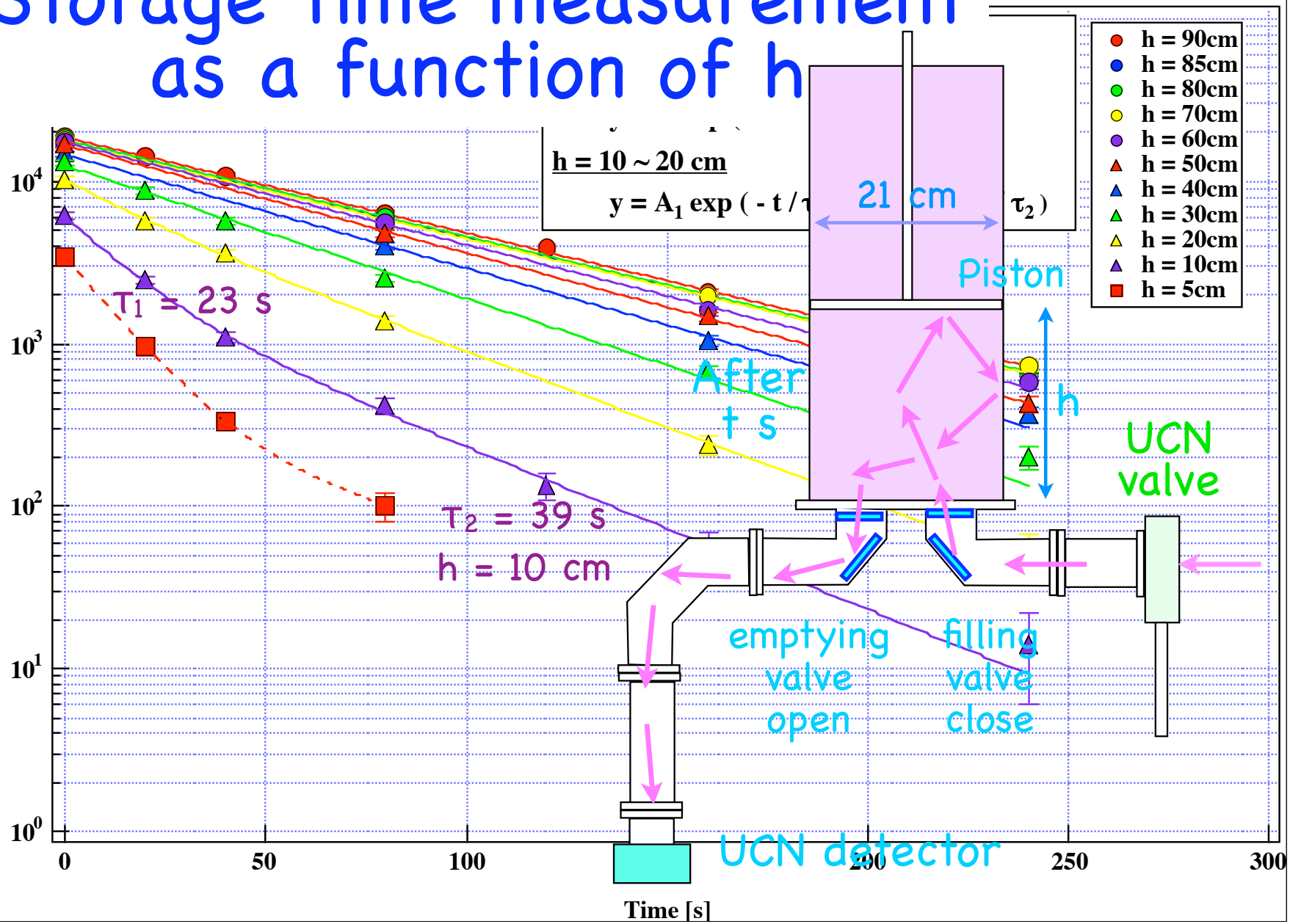


Results of Nov. 2007

storage time in the Teflon bottle: τ_s = 210 s



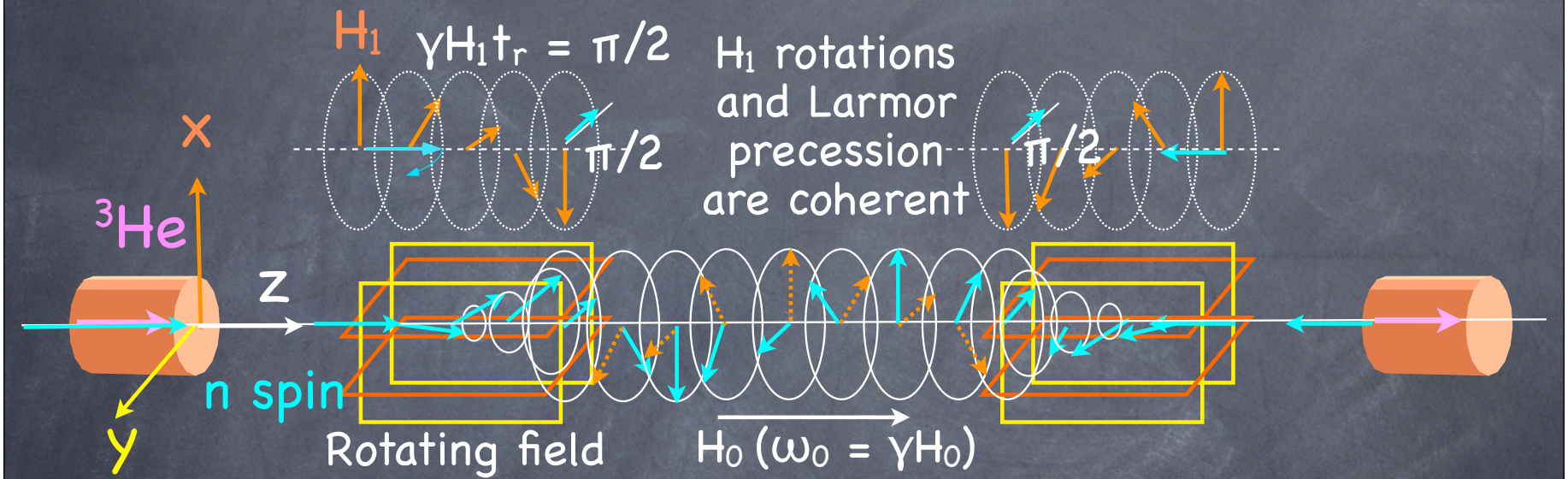
Storage time measurement as a function of h



Ramsey resonance

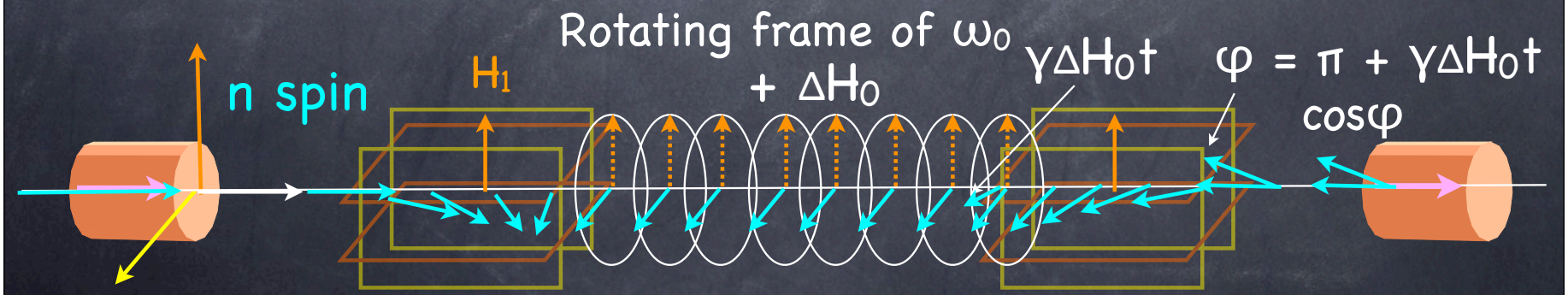
Y. Mauda et al.,Phys. Lett. A364 (2007)87_92

Appl. Phys. Lett. 87, 053506(2005)

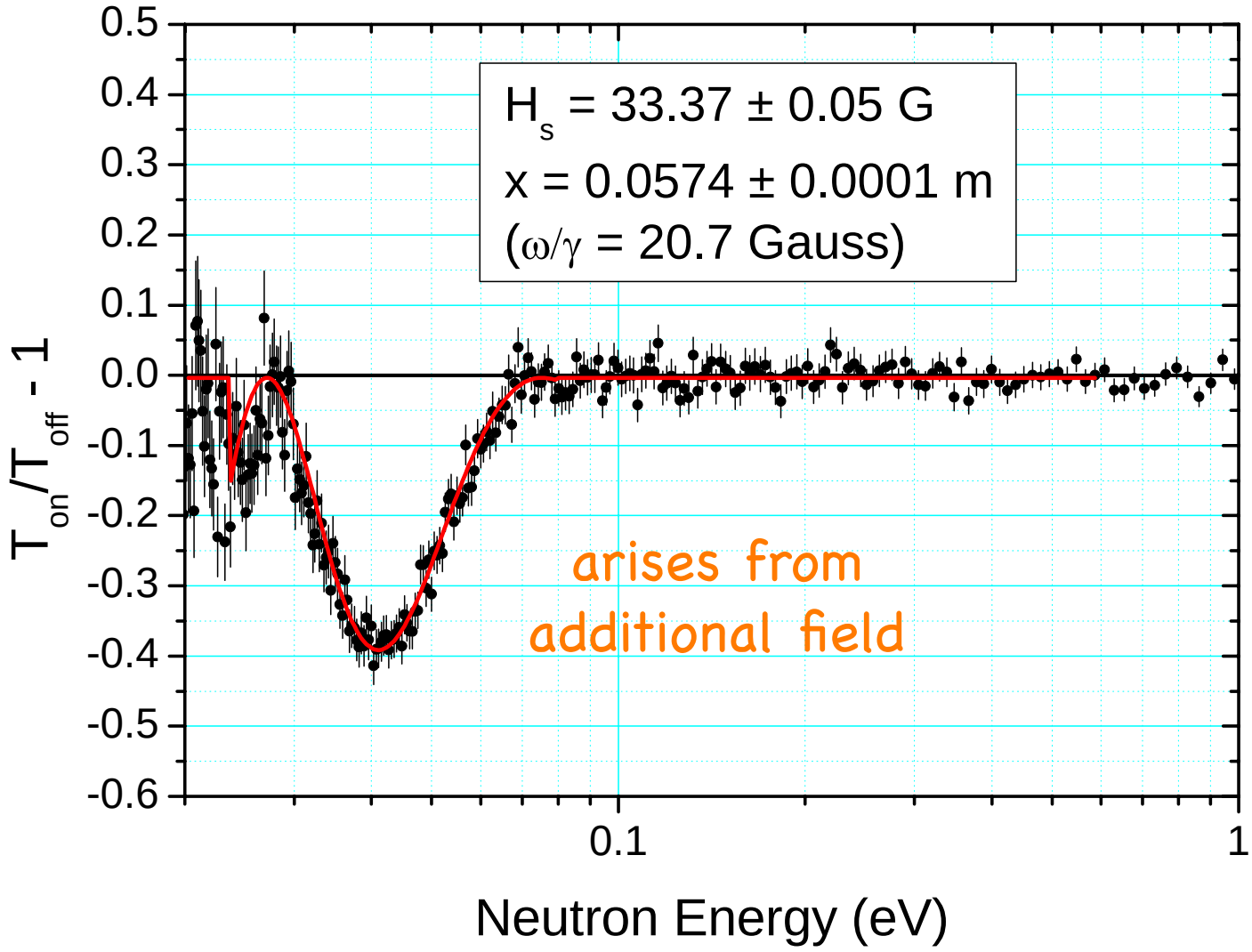


$H_1 \cdot x \cdot \cos\omega t_r + H_1 \cdot y \cdot \sin\omega t_r$

$\omega = \omega_0$



$\varphi = \pi + \gamma \Delta H_0 t$



Experiment with prototype source

1. UCN density is consistent with the prediction.
2. We can remove the γ heating, which is not so serious.
3. Storage time τ_s = 30 s (improved to 40 s in Nov. 2007) is limited by the wall loss, but much longer in He-II bottle.
4. We are preparing Ramsey resonance with the present source

At TRIUMF

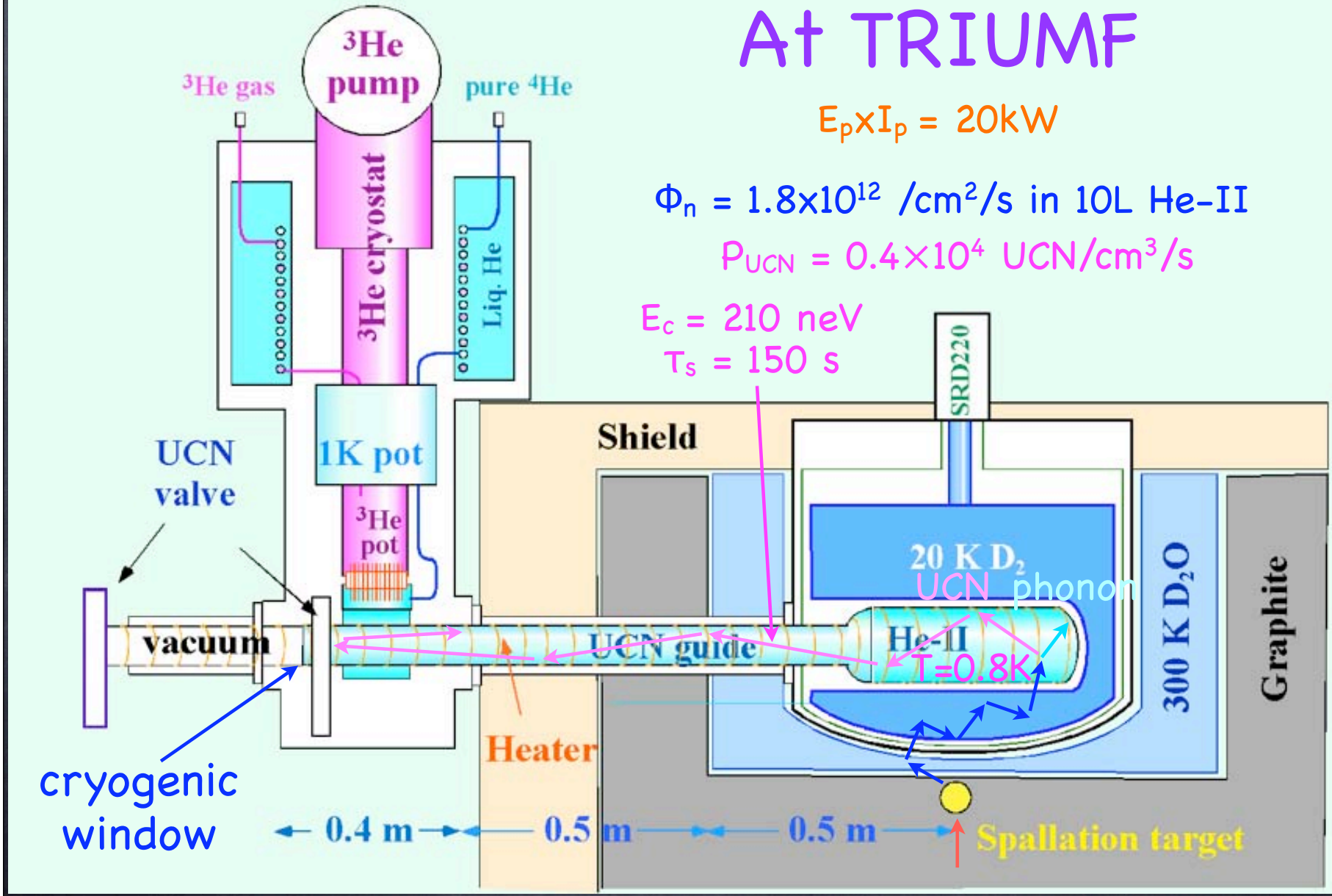
$E_p x I_p$ = 20kW

Φ_n = 1.8x10^{12} /cm^2/s in 10L He-II

P_{UCN} = 0.4×10^4 UCN/cm^3/s

E_c = 210 neV

τ_s = 150 s



$$\rho_{UCN} = P_{UCN} \times \tau_s \times \varepsilon_{ext} \times (\text{dilution factor})$$

	source type	E_c neV	P_{UCN} /cm^3/s	τ_s s	ε_{ext}	ρ_{UCN} /cm^3 source/exp.
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Munich	reactor SD2	250	**	**	**	1×10^4/**