UCN production in He-II for NNbar oscillation experiment

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Berkeley
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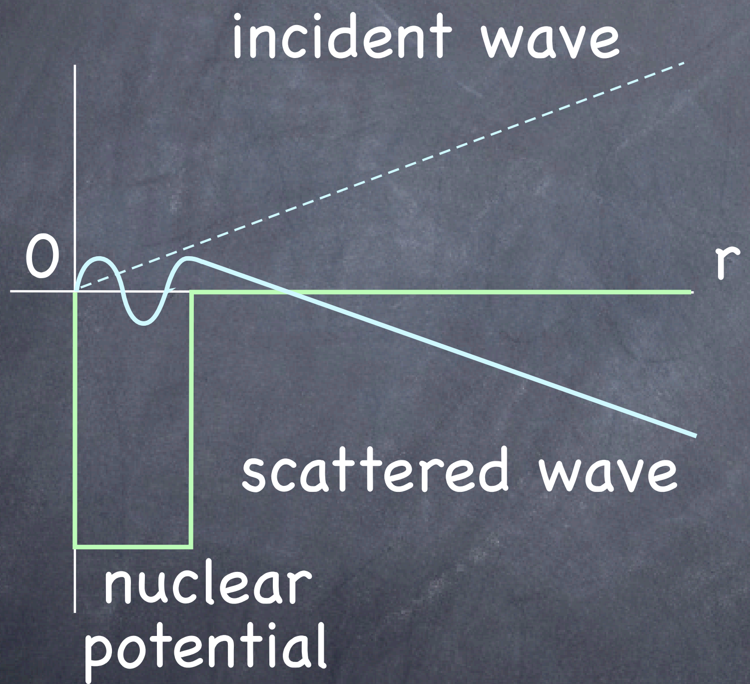
We are developing a UCN source for n EDM, because it has high UCN density.

UCN ?

very low energy neutrons



Fermi potential

$(2\pi h^2/m)\ a_{coh}\ \delta(r)$

$\downarrow$ average

$V_F = (2\pi\hbar^2/m)\ a_{coh}\ N$

335 neV for ^{58}Ni

210 neV for iron

$E_n < E_c = V_F$

complete reflection

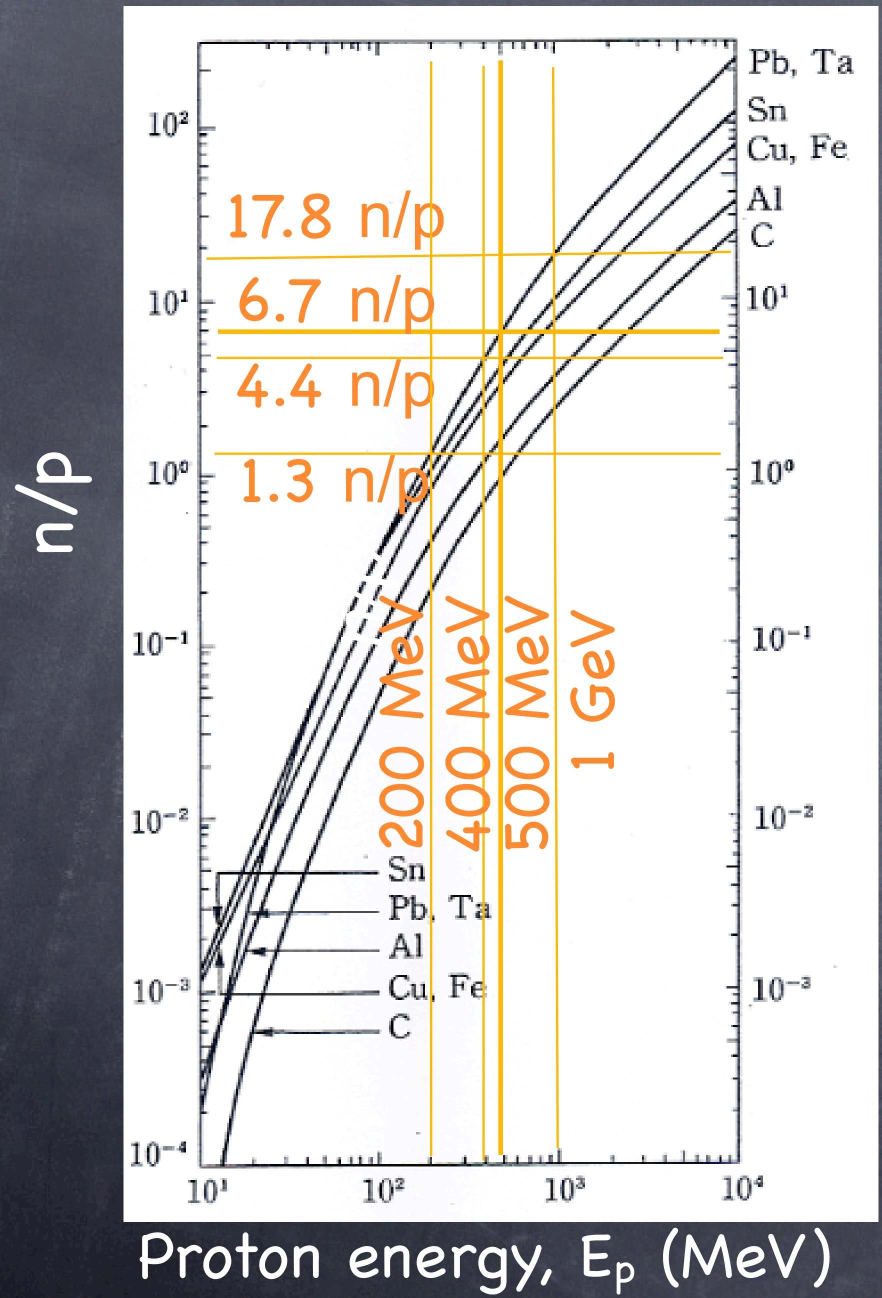
from material surface

NNbar workshop 2002

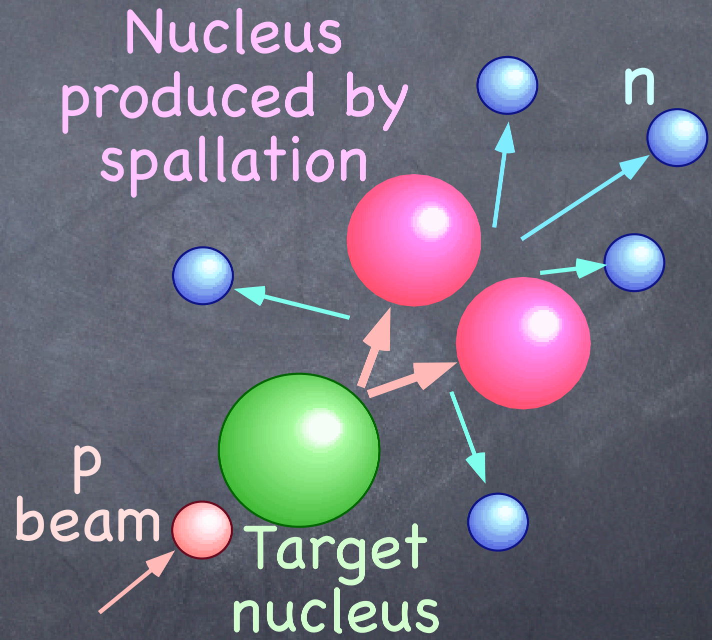
For the measurement of
oscillation time of 3×10^{9} s
we need 1.2×10^{7} UCN/s

Possibility of He-II
for high production rate

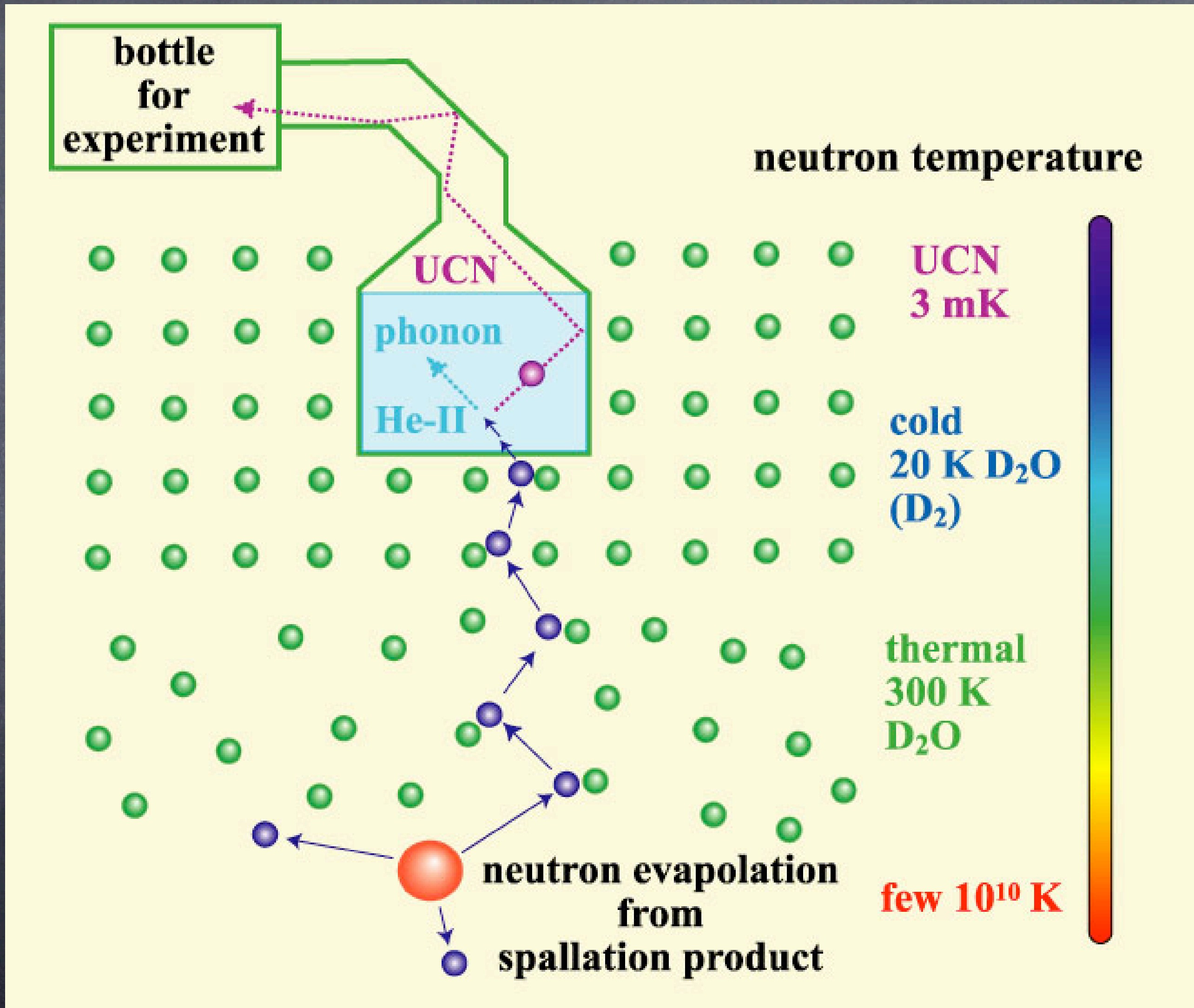
Neutron production



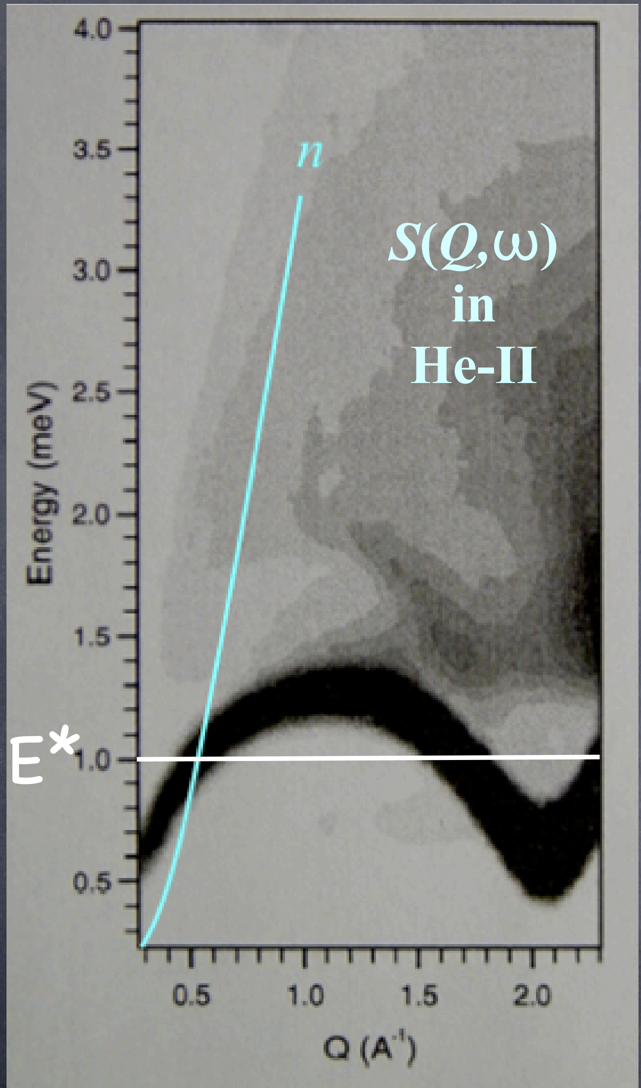
K. Tesch (1985)



Our UCN production

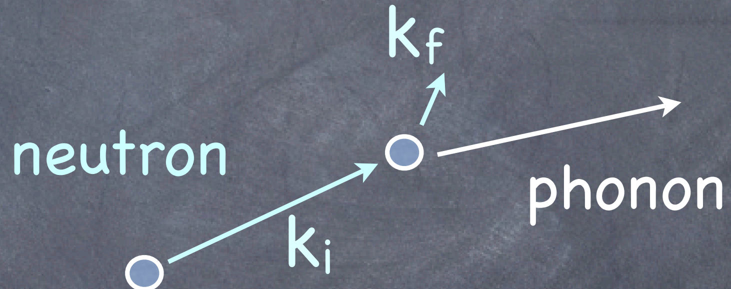


UCN production in He-II



M.R. Gibbs et al. (1999)

Coherent inelastic neutron scattering in He-II



Born approximation

$$d^2\sigma/dQd\omega$$
$$= k_f/k_i\, a^2\, S(Q,\omega)$$

a: **coherent scattering length**

Golub and Pendlebury

UCN production rate

$$P = \int_0^{E_c} \sigma_{coh}(E^* \rightarrow E)\, dE\, N_{He}\, \Phi_n(E^*)$$

$$\int_0^{E_c} \sigma_{coh}(E^* \rightarrow E)\, dE \propto E_c^{3/2}$$

E_c: maximum UCN energy (limited by Fermi potential)

$\Phi_n(E^*)$: n flux at E^* $\propto$ proton beam power

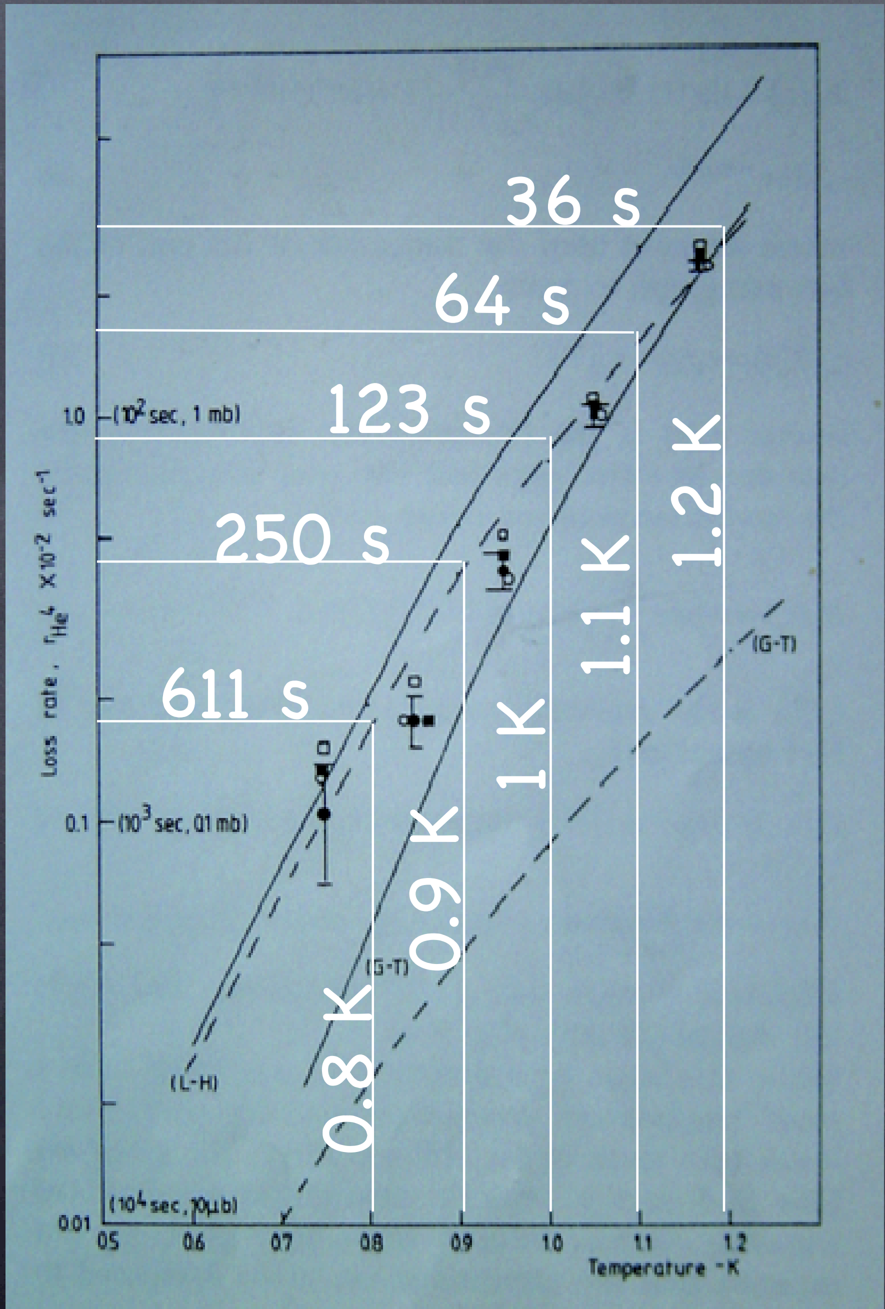
beam power limited by γ heating

UCN loss depends on temperature

$P \sim 2\times10^{-9}\ \Phi_n/\mathrm{cm}^3/\mathrm{s} \times V(\text{He-II})\mathrm{cm}^3$ (Golub)

Cold n flux $\Phi_n = 1.7\times10^{13}\ \mathrm{n/cm^2/s}$ for 200kW p (Monte Carlo)

$\rightarrow 3.3 \times 10^8$ UCN/s



UCN loss rate $1/\tau_s$

$\tau_s \propto (1/T_{He\text{-}II})^7$

Golub

τ_s = 4.8 s at 1.6 K

1 s at 2 K

γ heating in H-II

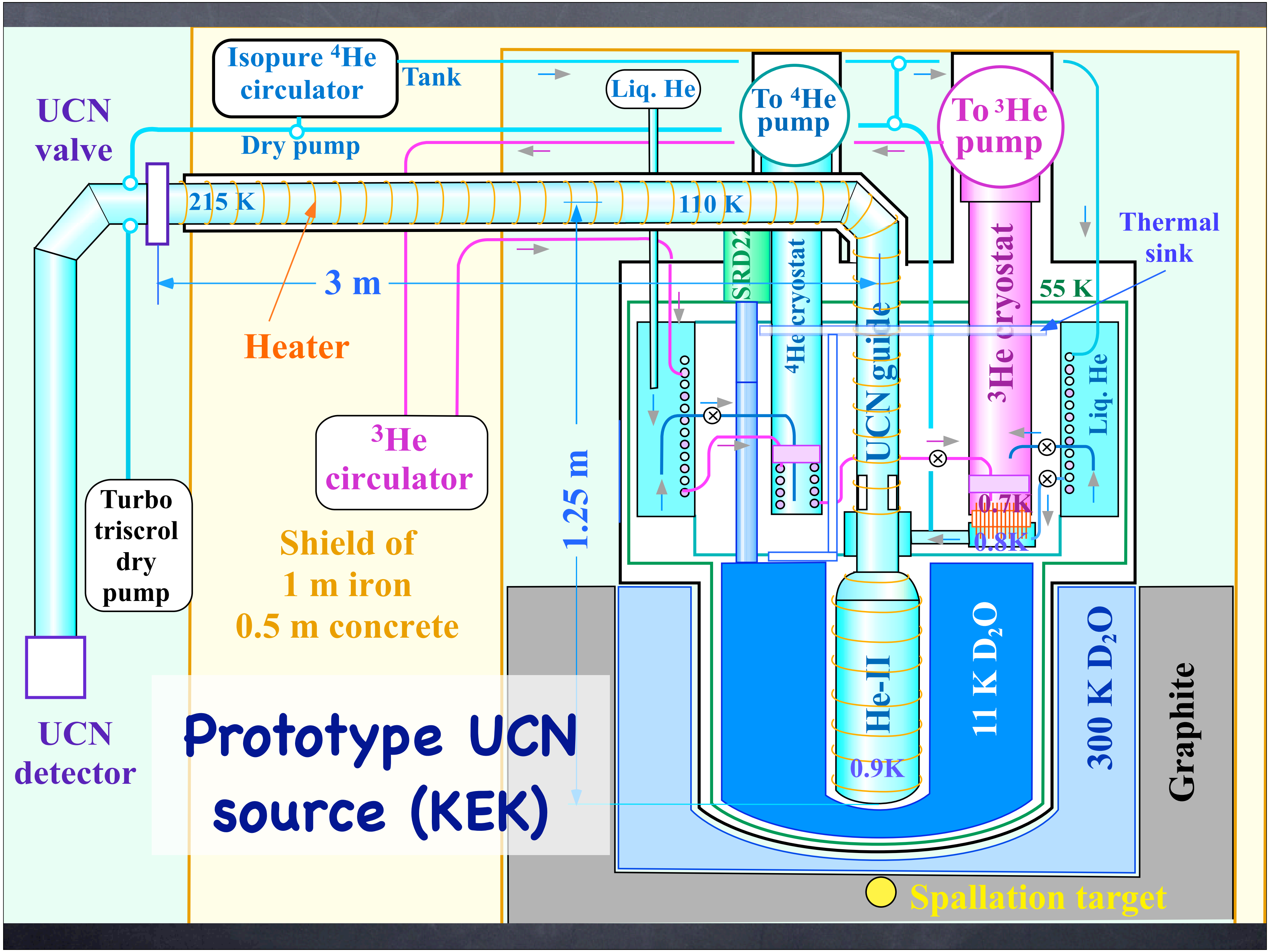
100 W at a 200 kW of p beam power (horizontal)

1.2×10^4 m^3/h ^4He pumping at 1.6 K
helium liquefier has few 100 W

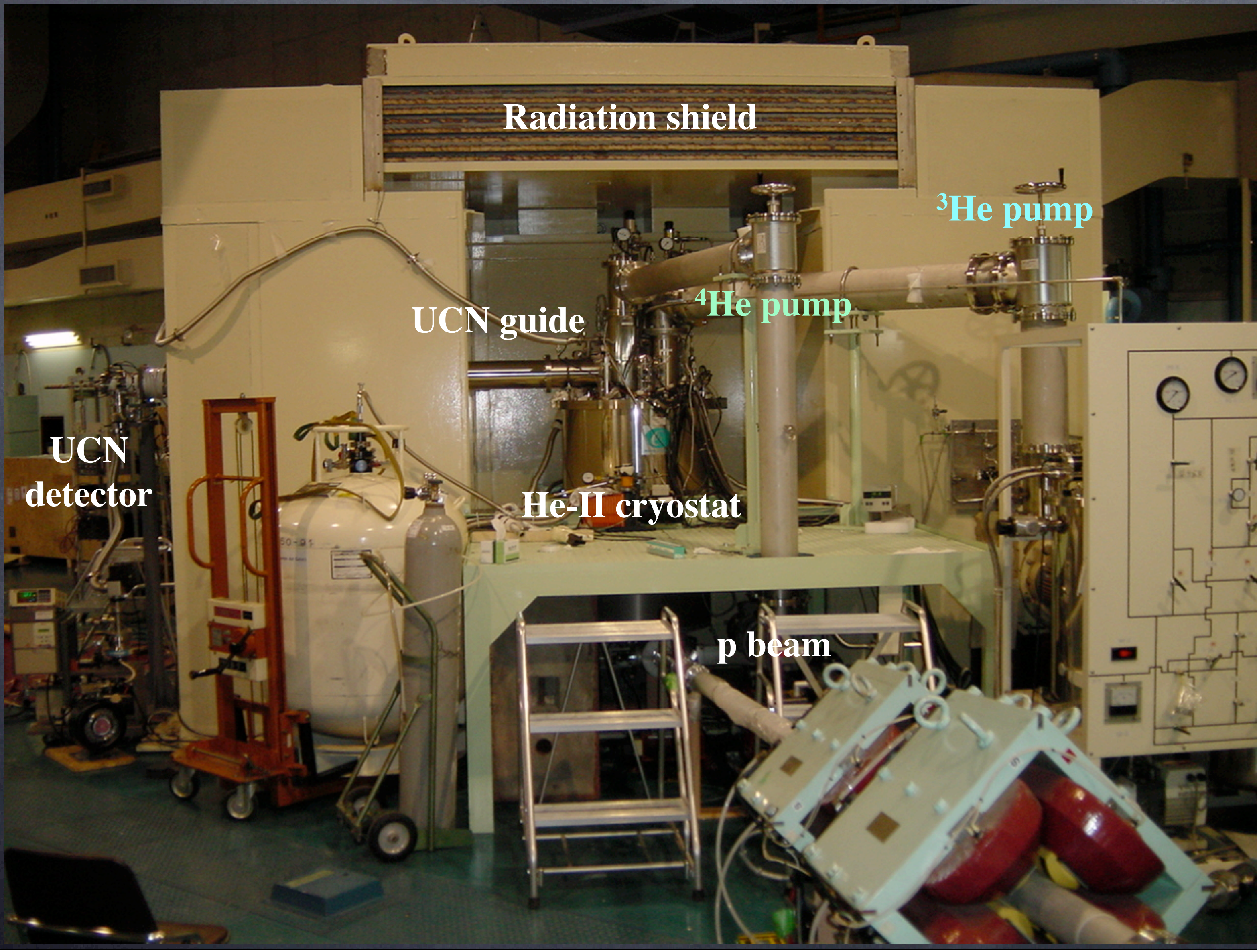
Cooling power $\propto$ latent heat of vaporization
$\cdot P_{He}$ (vapor pressure) $\cdot$ dV/dt (pumping power)
n (mol) = PV/RT

	latent heat, P_{4He}	latent heat, P_{3He}
0.8 K		34.5 J/mol, 3 Torr
1.6 K	90 J/mol, 6 Torr	
2 K	90 J/mol, 25 Torr	

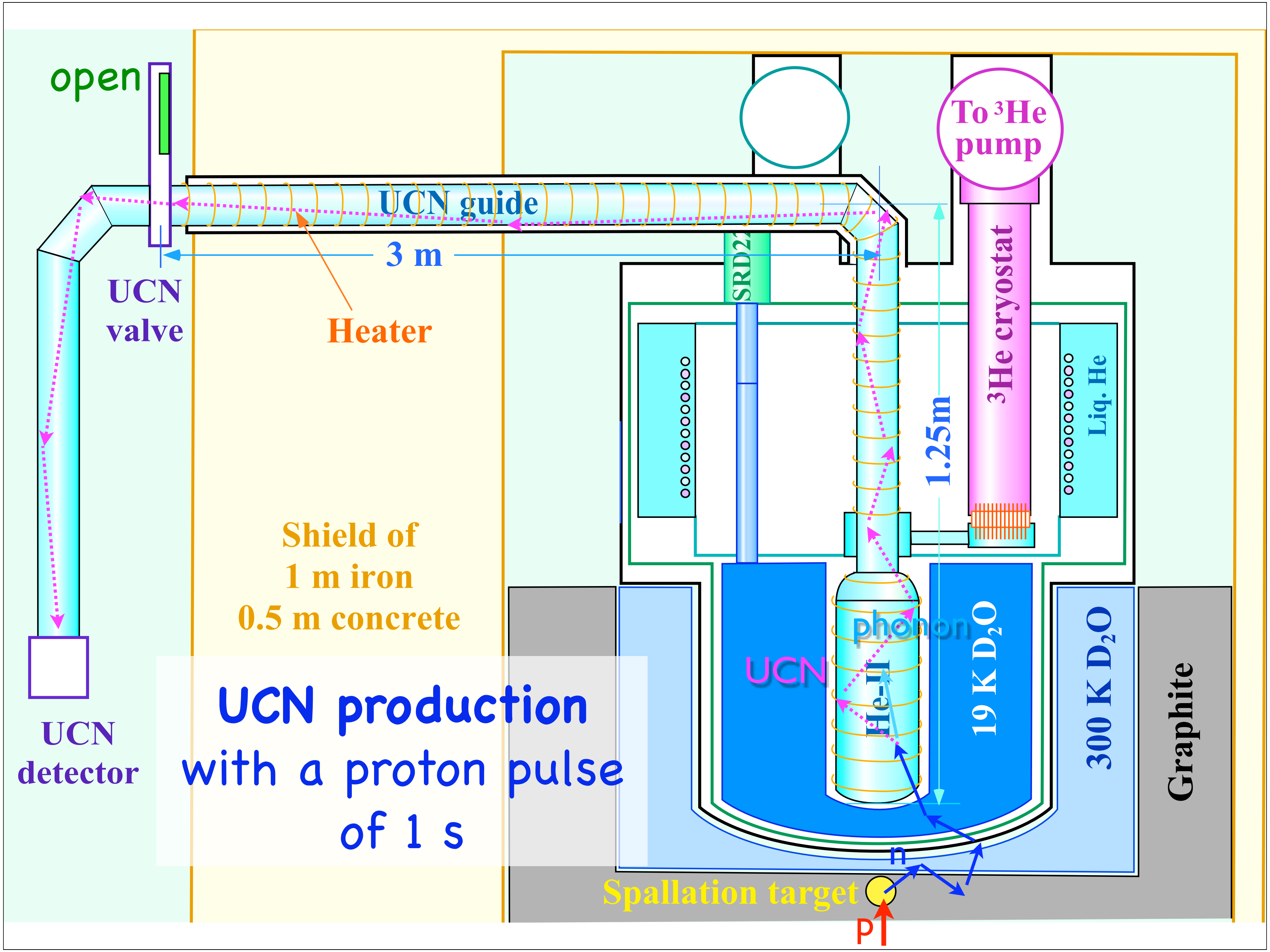
Prototype UCN source (KEK)



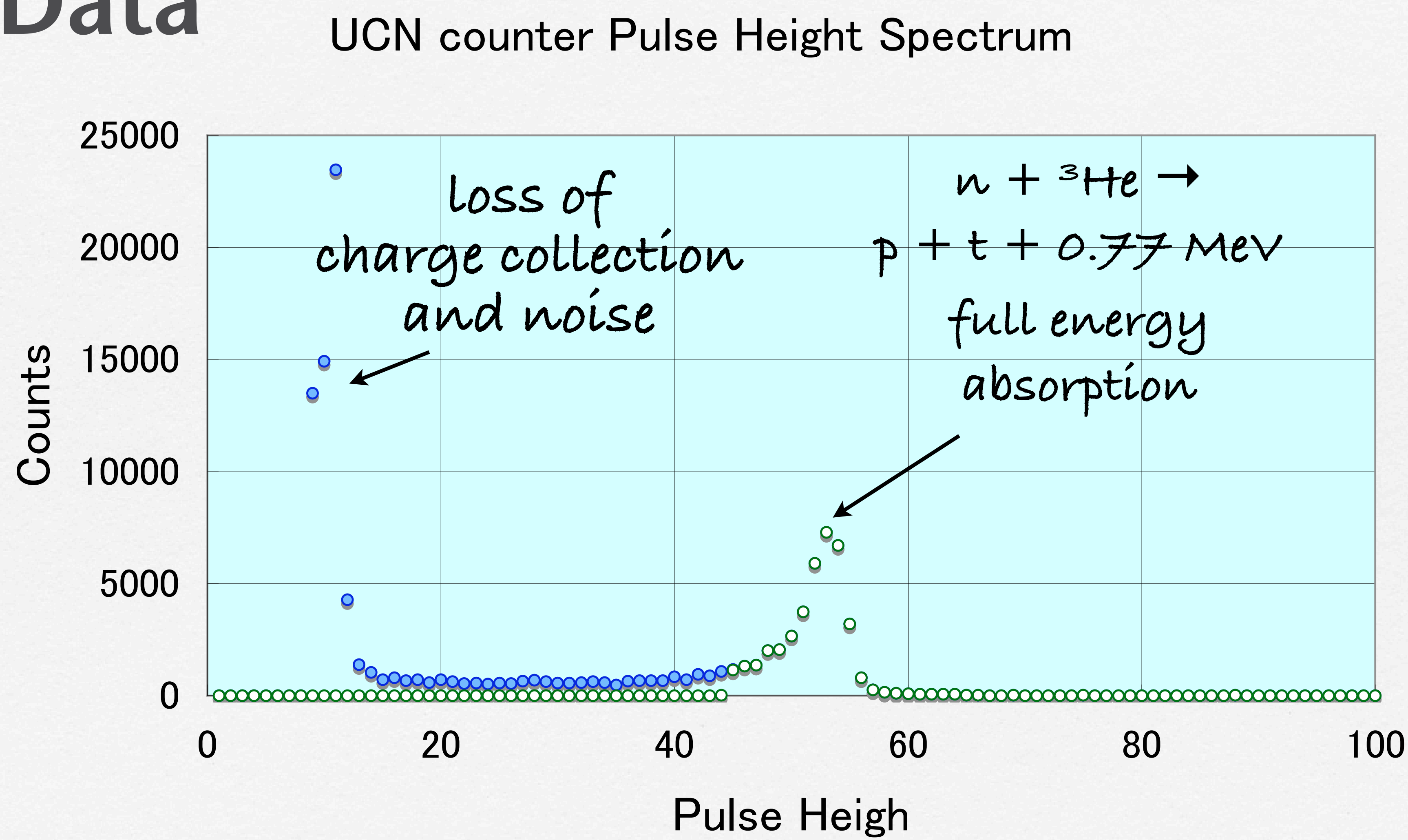
Our UCN source 2007



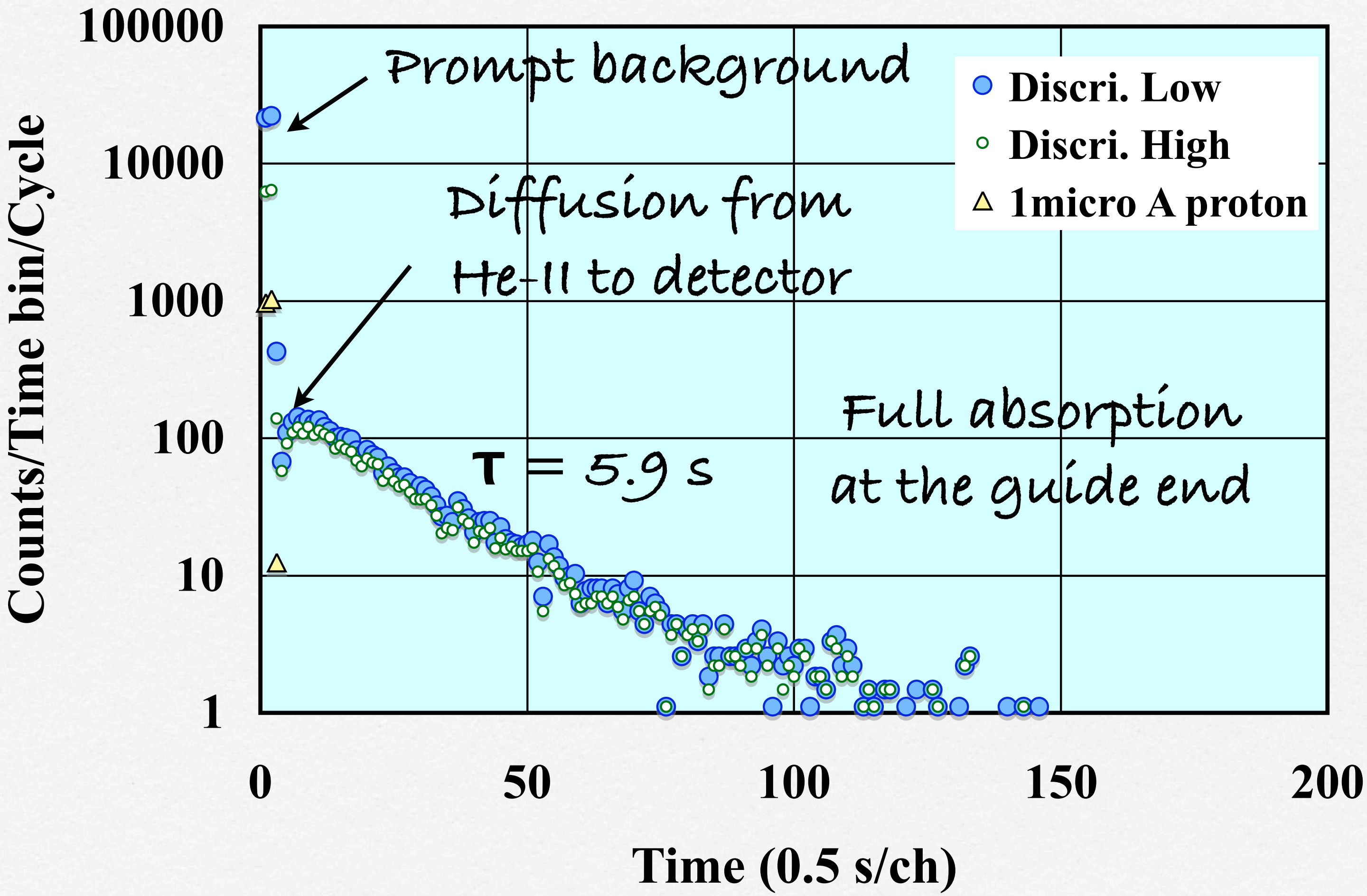
UCN production with a proton pulse of 1 s

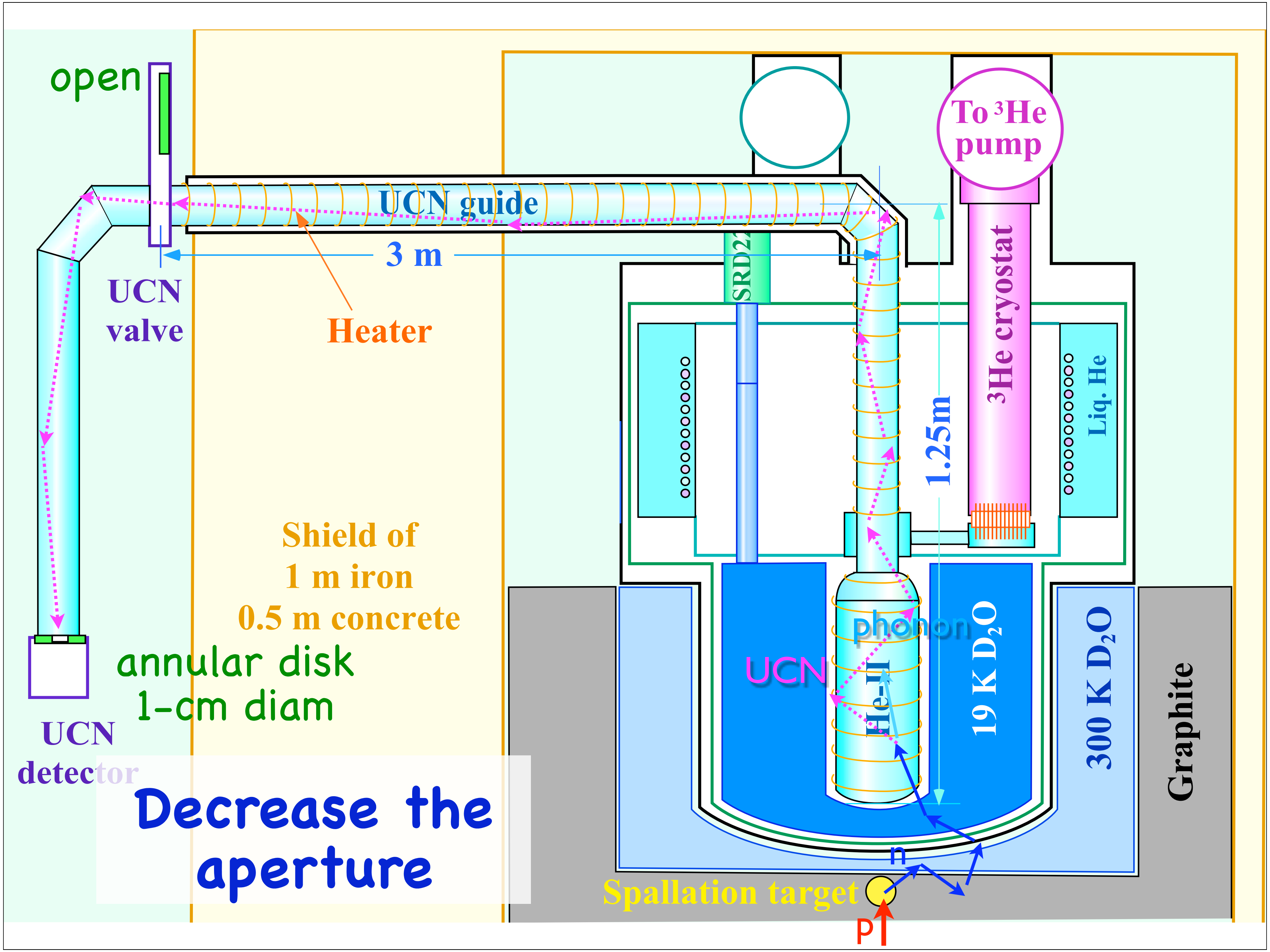


Data


UCN counter Pulse Height Spectrum
25000
20000
15000
10000
5000
0
Counts
0
20
40
60
80
100
Pulse Heigh
loss of
charge collection
and noise
n + ³He →
p + t + 0.77 MeV
full energy
absorption

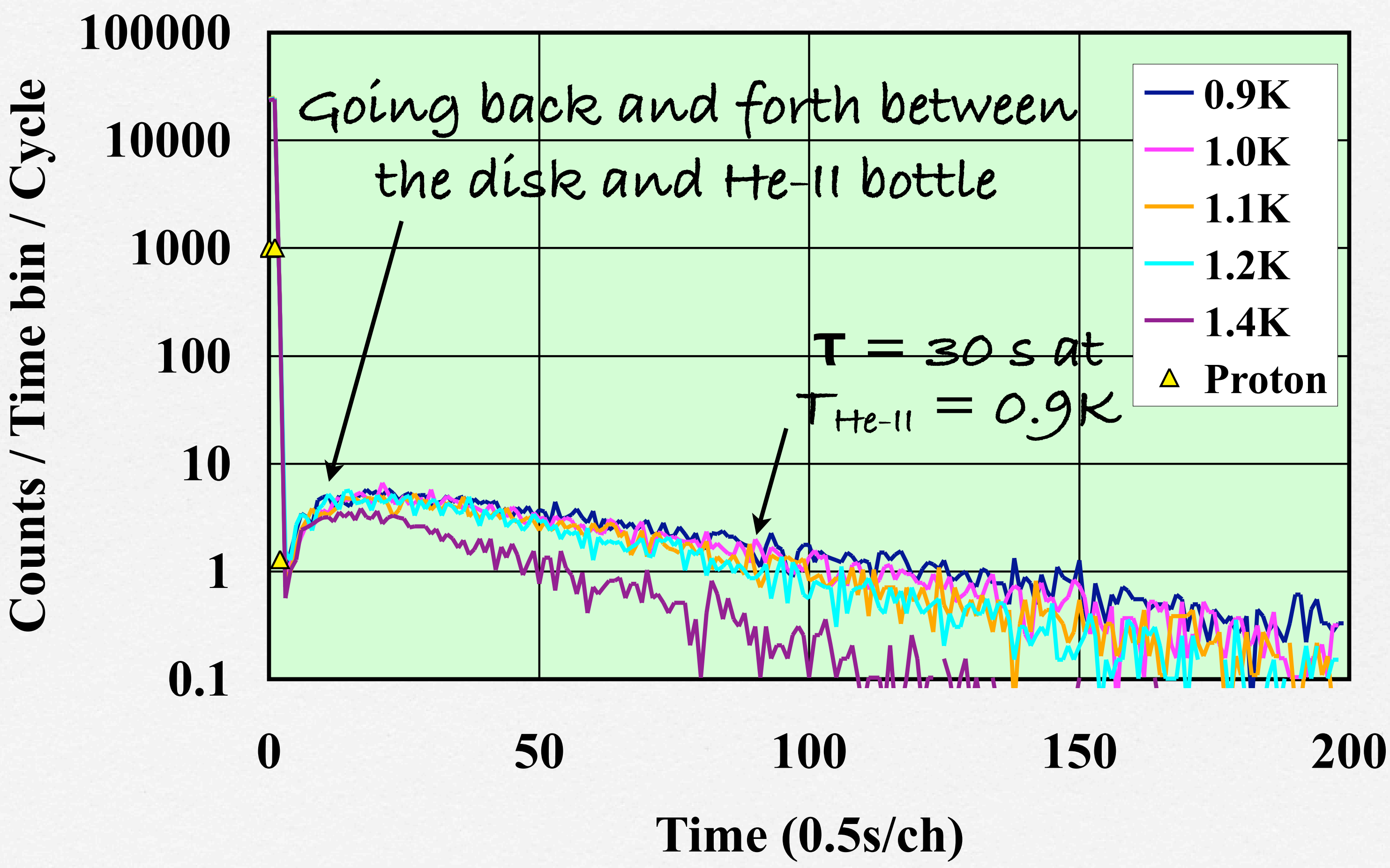
UCN production with a proton pulse of 1s



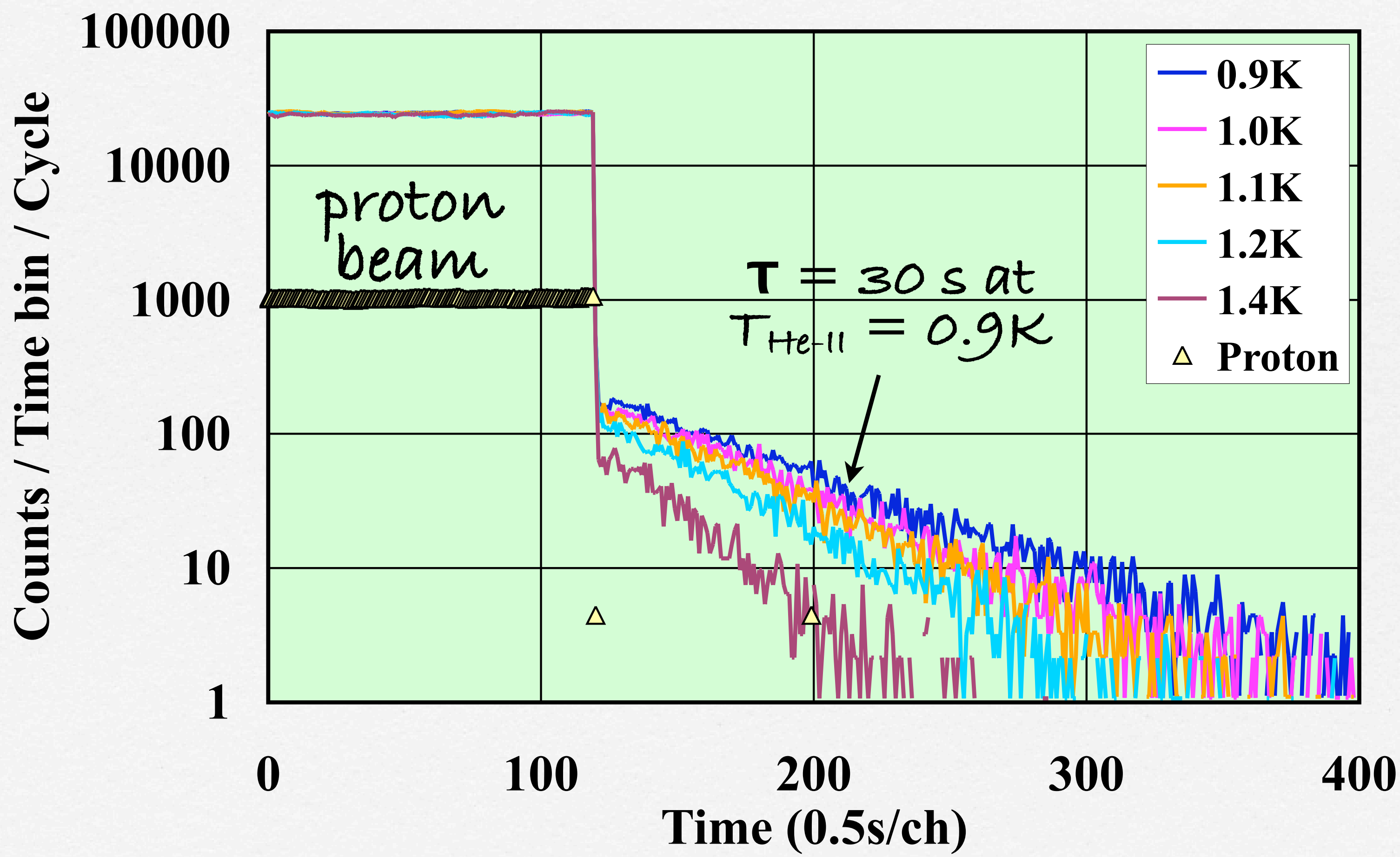


Decrease the aperture

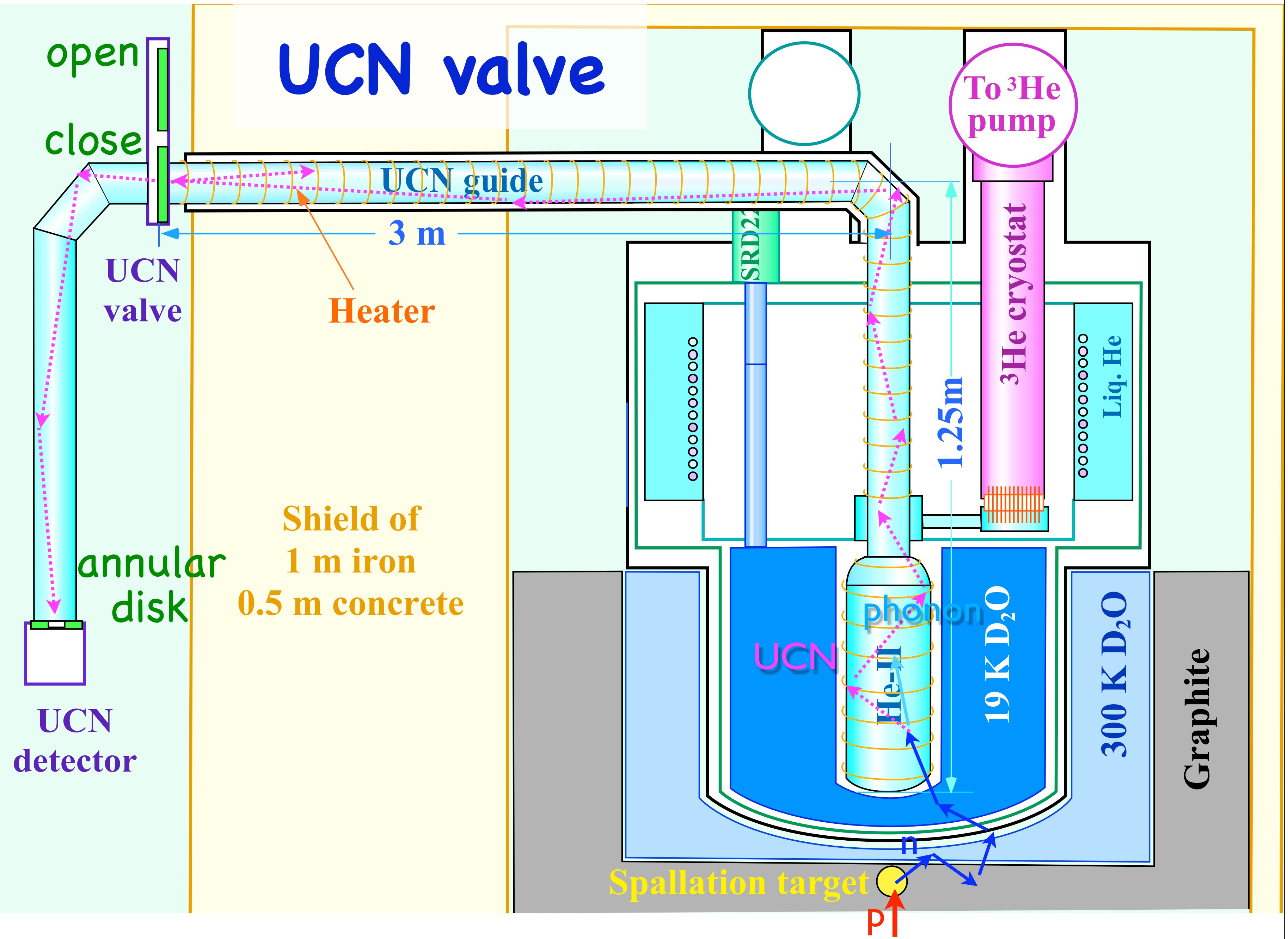
With the annular disk



UCN production with a proton pulse of 60 s

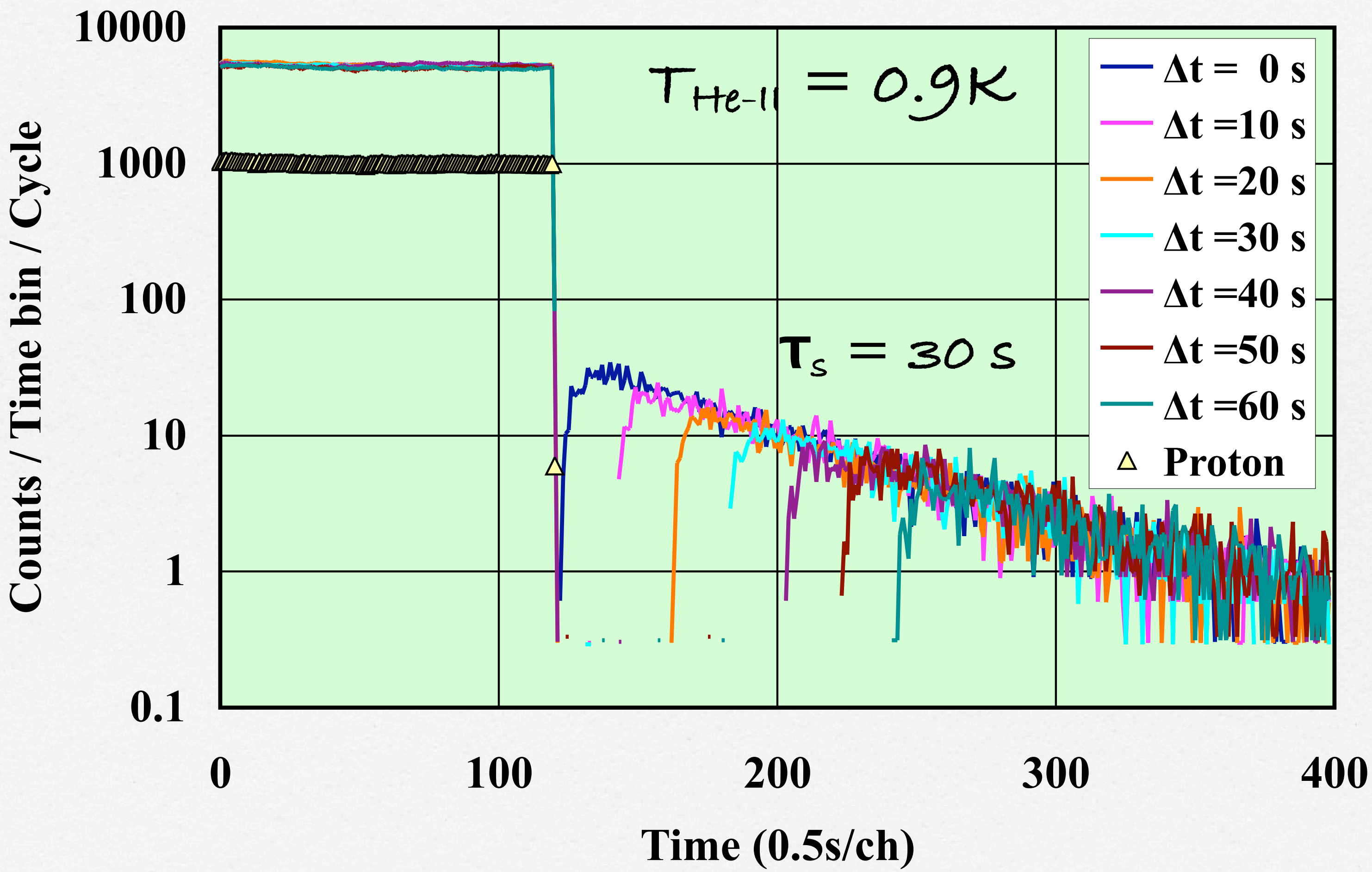


UCN valve

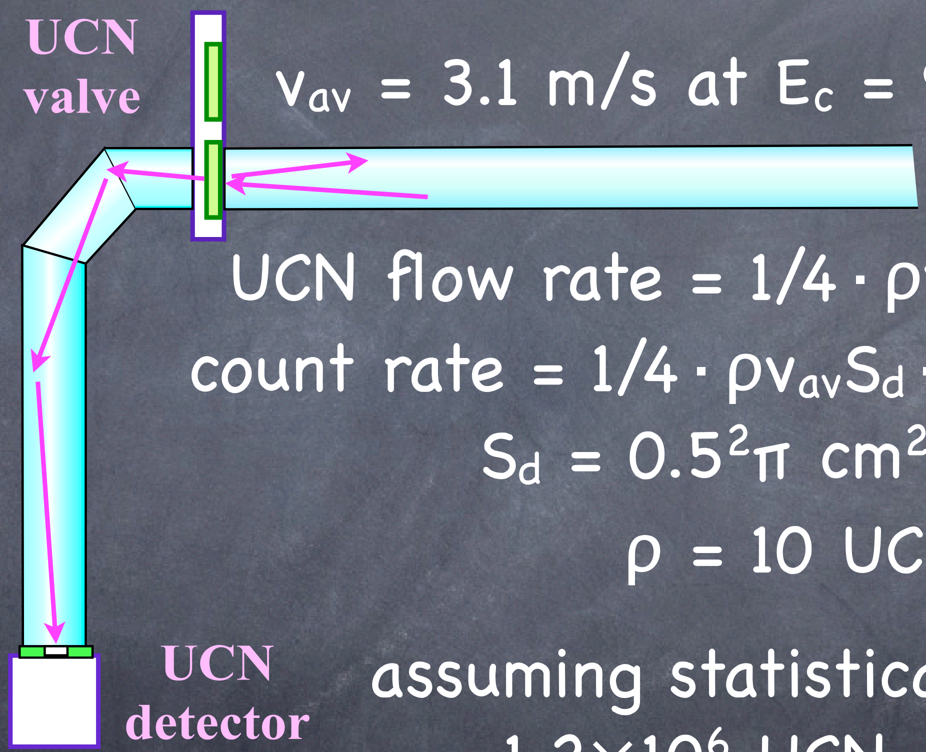


open
close
UCN valve
UCN guide
3 m
Heater
To ^{3}He pump
SRD22
3He cryostat
Liq. He
1.25m
Shield of
1 m iron
0.5 m concrete
annular
disk
UCN
detector
phonon
UCN
He-II
19 K D_2O
300 K D_2O
Graphite
n
Spallation target
P

T_s measurement by UCN valve



UCN density by 390W p beam



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

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

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

$S_d = 0.5^2\pi$ cm^2, $\epsilon = 0.68$

ρ = 10 UCN/cm^3

assuming statistical distribution

1.2×10^6 UCN / 36 liter

E_c = 90 neV

New cryostat

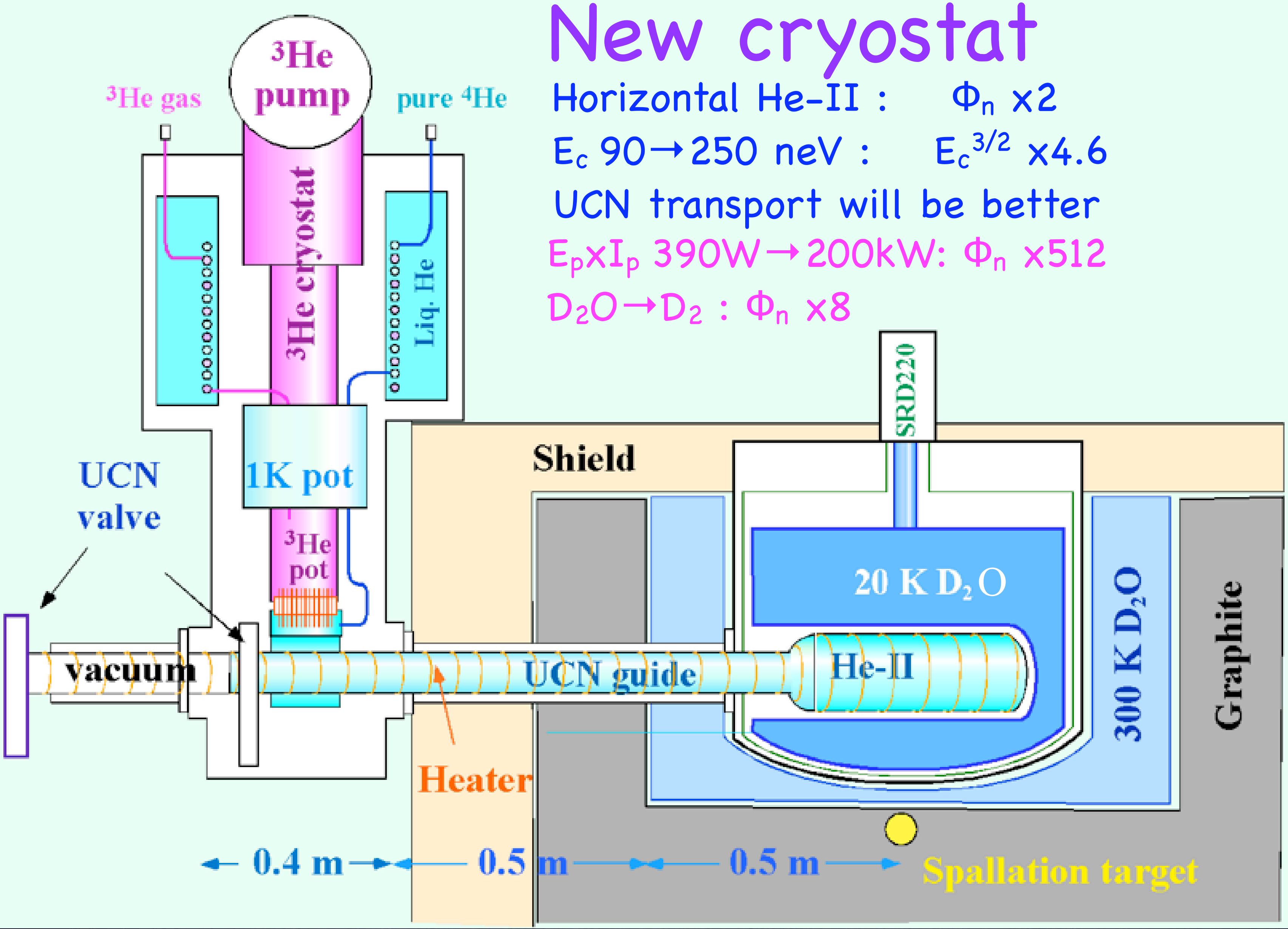
Horizontal He-II : Φ_n x2

E_c 90→250 neV : $E_c^{3/2}$ x4.6

UCN transport will be better

E_pxI_p 390W→200kW: Φ_n x512

D_2O→D_2 : Φ_n x8



UCN production rate in He-II for NNbar

1.2×10^6 UCN/30 s (present exp)

× 512 × 2 × 8 × 1.3
(200kW) (horizontal) (D_2) (E_c 250neV)

= 4.2×10^8 UCN/s >> 1.2×10^7 UCN/s for τ_{NNbar} 3×10^9 s ?

Production rate predicted

3.3×10^8 UCN/s

2×10^{-9} Φ_n /cm^3/s x V cm^3 (V: He-II volume) by Golub

$\Phi_n = 1.7 \times 10^{13}$ (n/cm^2/s) for V = 10^4 (cm^3) by Monte Carlo

Thanks