Superfluid-helium UCN sources: concepts for the ESS?

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LPSC, 26 March 2013

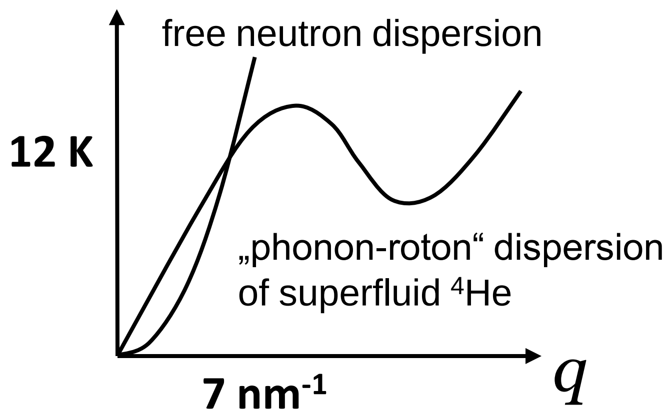
Golub & Pendlebury, PL 53A (1975) 133

$\sigma_{capture}(^4He) = 0$

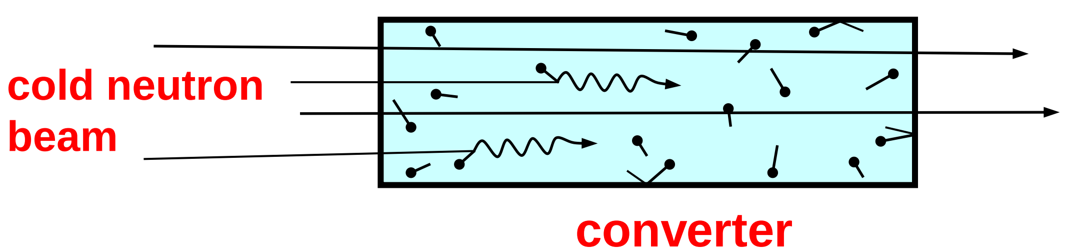
$$\rho_{UCN} = P\tau$$

$$\tau^{-1} = \tau^{-1}_{\beta} + \tau^{-1}_{up} + \tau^{-1}_{He3} + \tau^{-1}_{wall}$$

$$\tau^{-1}_{up} \approx (T[K])^7/100s$$



T [K]	τ_{max} [s]
1	100
0.8	310
0.7	510
0.5	820



SNQ UCN source study
(Golub/Böning/Weber 1980)

Premise: cooling power @ 0.8 K

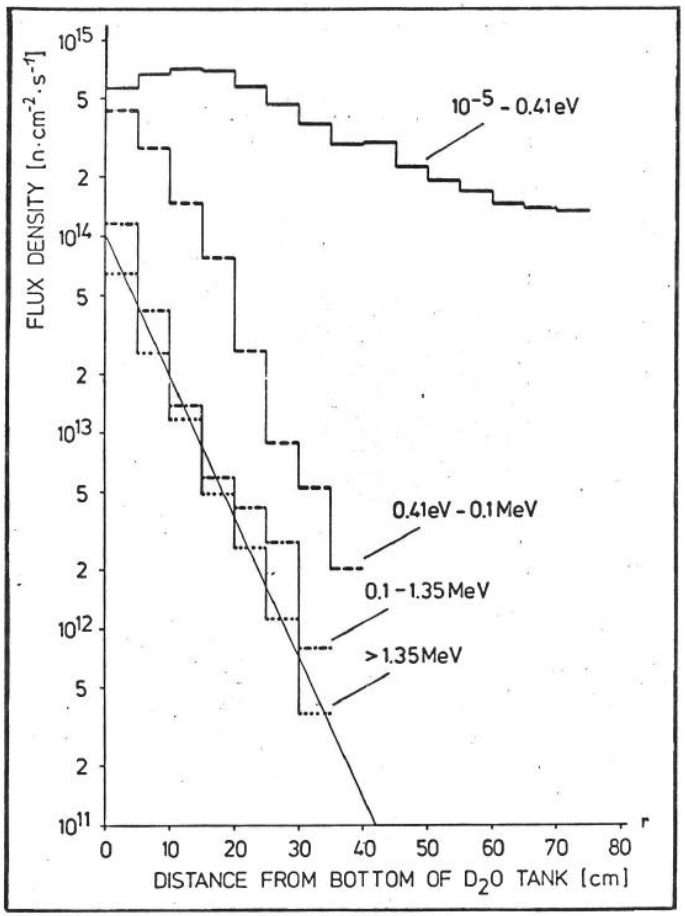


Fig.5 Calculated flux distribution normal to rotating target in D_2O-tank of hybrid moderator system (Armstrong et al)

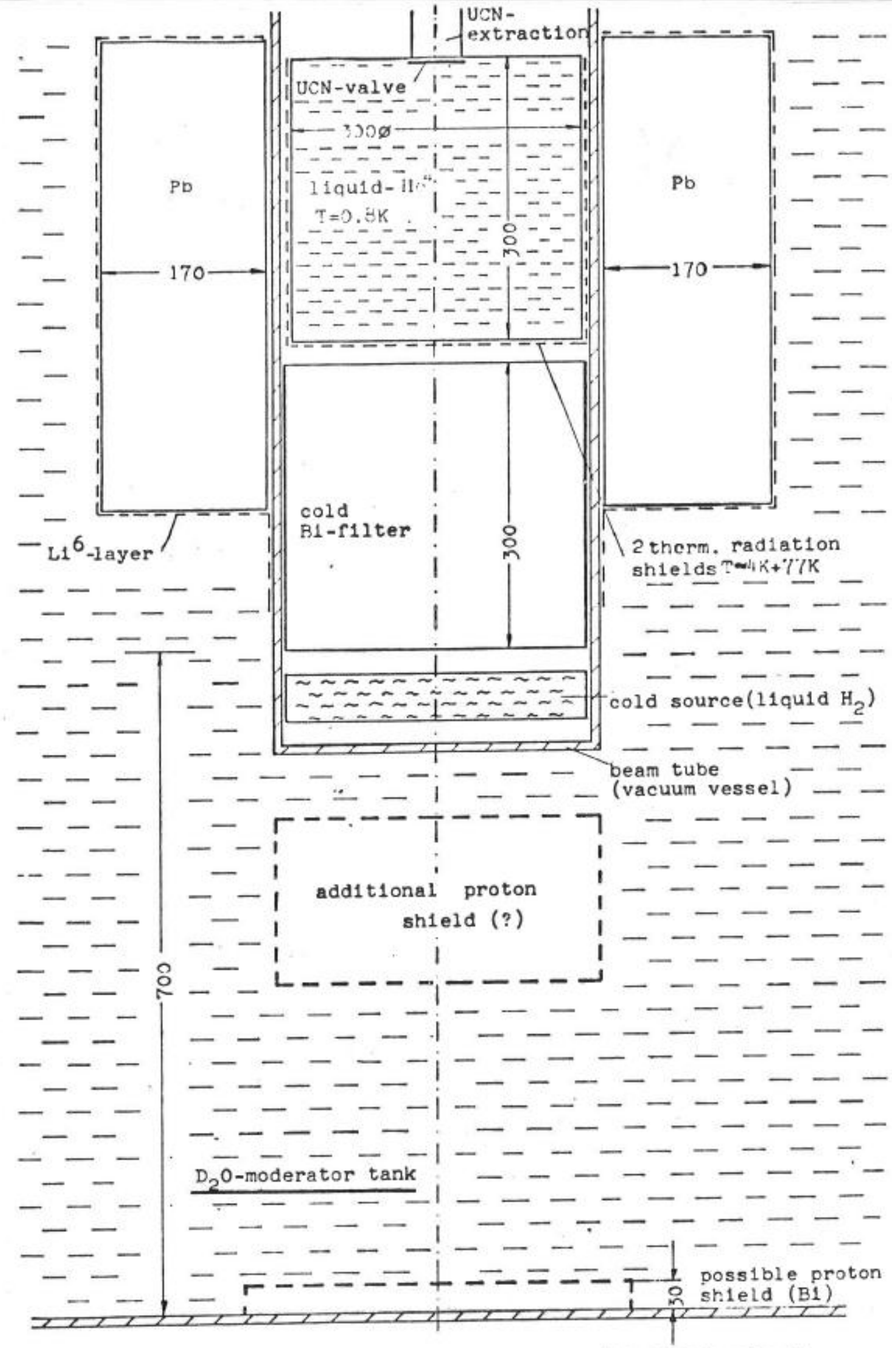


Fig.6 Superthermal UCN-source (concept)

iv) <u>Reaction rates in the curved portion of the cylindrical shell</u>

The volume element is $d^3V = 2\cdot\pi\cdot R\cdot t\cdot dz$

where t is the thickness of the shell.

The reaction rate is

$$\sum\int \phi(\vec{d})\, d^3V = \sum t\, 2\pi R \int_{z_1}^{z_2} dz\, \frac{S_A}{4} \log \frac{1}{2}\left[\sqrt{\alpha^4 + 2(1-\rho^2)\alpha^2 + (1+\rho^2)^2} + \alpha^2 + 1 - \rho^2\right] \tag{22}$$

from equ. (10) where $\alpha = R/Z$. We wish to evaluate (22) for $\rho = R/z = \alpha$, thus (22) becomes

$$= \sum t \frac{\pi S_A}{2} R^2 \int_{z_1}^{z_2} \frac{dz}{R} \log \frac{1}{2}\left[\sqrt{\alpha^4 + 2(1-\alpha^2)\alpha^2 + (1+\alpha^2)^2} + 1\right]$$

$$= \sum t \frac{\pi S_A}{2} R^2 \int_{z_1}^{z_2} \frac{dz}{R} \log \frac{1}{2}\left[\sqrt{4\alpha^2 + 1} + 1\right] \tag{23}$$

iv) Summary of Heat Inputs .

The various contributions to the heating of the liquid Helium vessel discussed above are:

Fast neutrons	1.4 mW	
neutron capture in Be	1.7 mW	*
neutron capture in Bi filter	3.5 mW	* ✓ only γ's near filter output escape
neutron capture in D_2O (with 17 cm Pb shield on sides)	9.0 mW	(* ?)
Fast protons	100.0 mW	
total	116.0 mW	

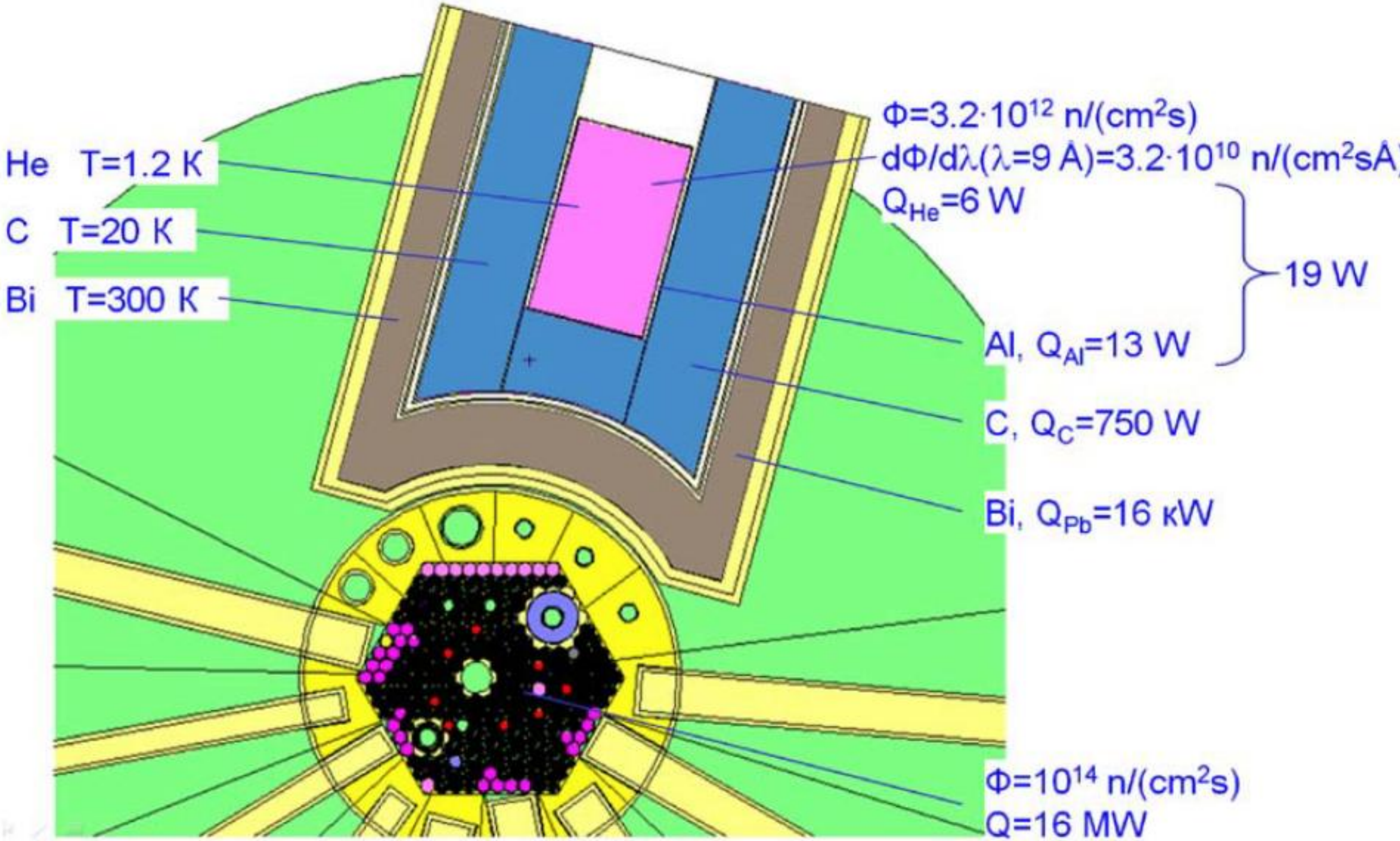
* these contributions are proportional to the thermal flux coming through the Bismuth filter and are hence proportional to the UCN production rate.

+ many mW thermal radiation along UCN extraction guide
(studied in our present “ex-pile” project)

PNPI source project

(Serebrov et al.)

Premise: cooling power @ 1.2 K



SNQ in-pile UCN source study (Golub/Böning/Weber)

190 mW on He-II bath + tank (21 l)

$T = 0.8$ K $\rightarrow \tau = 300$ s

$P = 1340$ cm^{-3}s^{-1}, $\rho_{UCN} = 4\times10^5$ cm^{-3} (with cold source)

PNPI in-pile source project (Serebrov et al.)

19 W on He-II bath + tank (35 l)

$T = 1.2$ K $\rightarrow \tau = 20$ s

$P = 2900$ cm^{-3}s^{-1} (10^8 s^{-1} in total), $\rho_{UCN} = 5.8\times10^4$ cm^{-3}

Ex-pile, state-of-the-art cold neutron beam transport (*m*=2):

$T < 0.7$ K $\rightarrow \tau =$ "many 100 s"

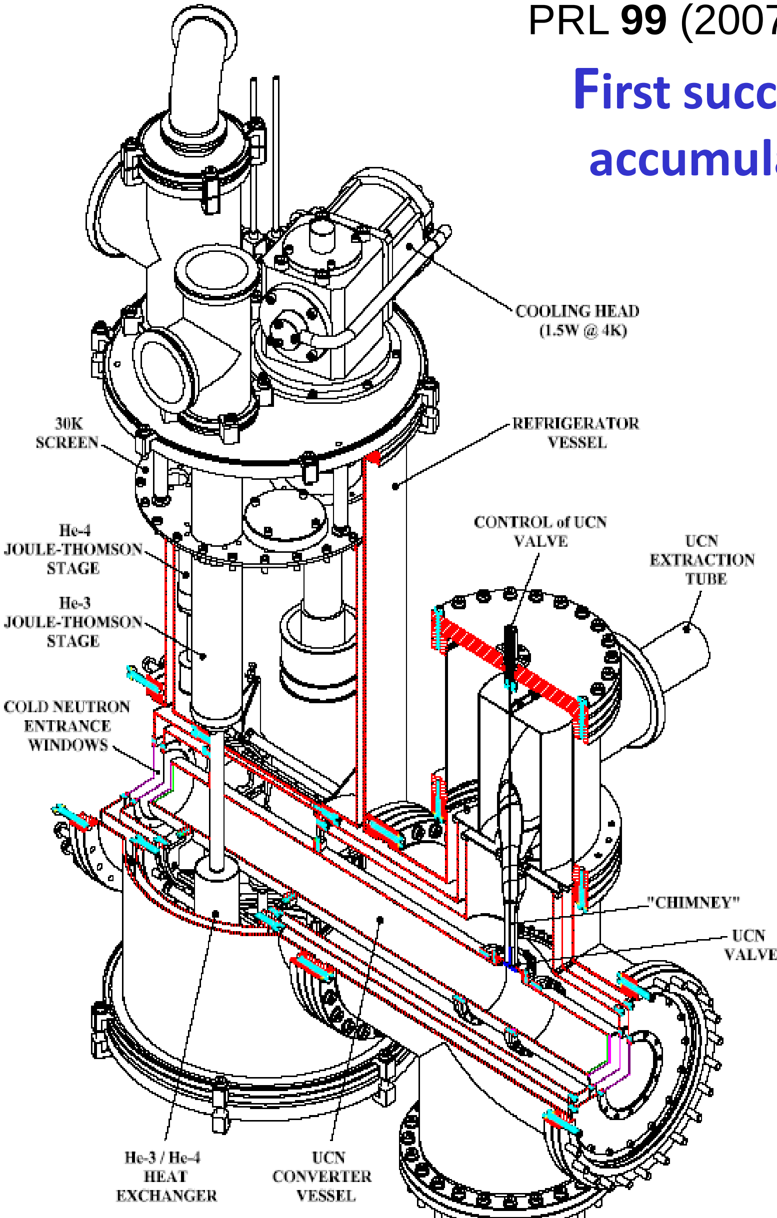
$P < 30$ cm^{-3}s^{-1}, $\rho_{UCN} \rightarrow 10^4$ cm^{-3}

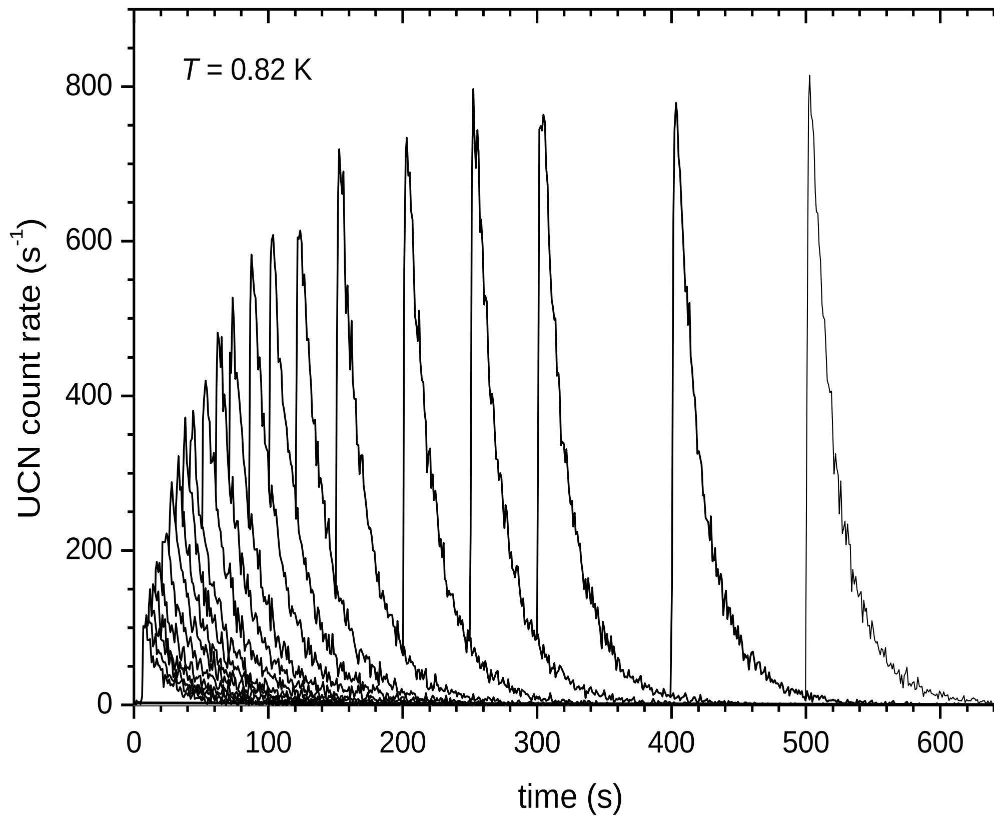
Short history of our “ex-pile” helium UCN source development

Prototype converter (TU Munich >2003)

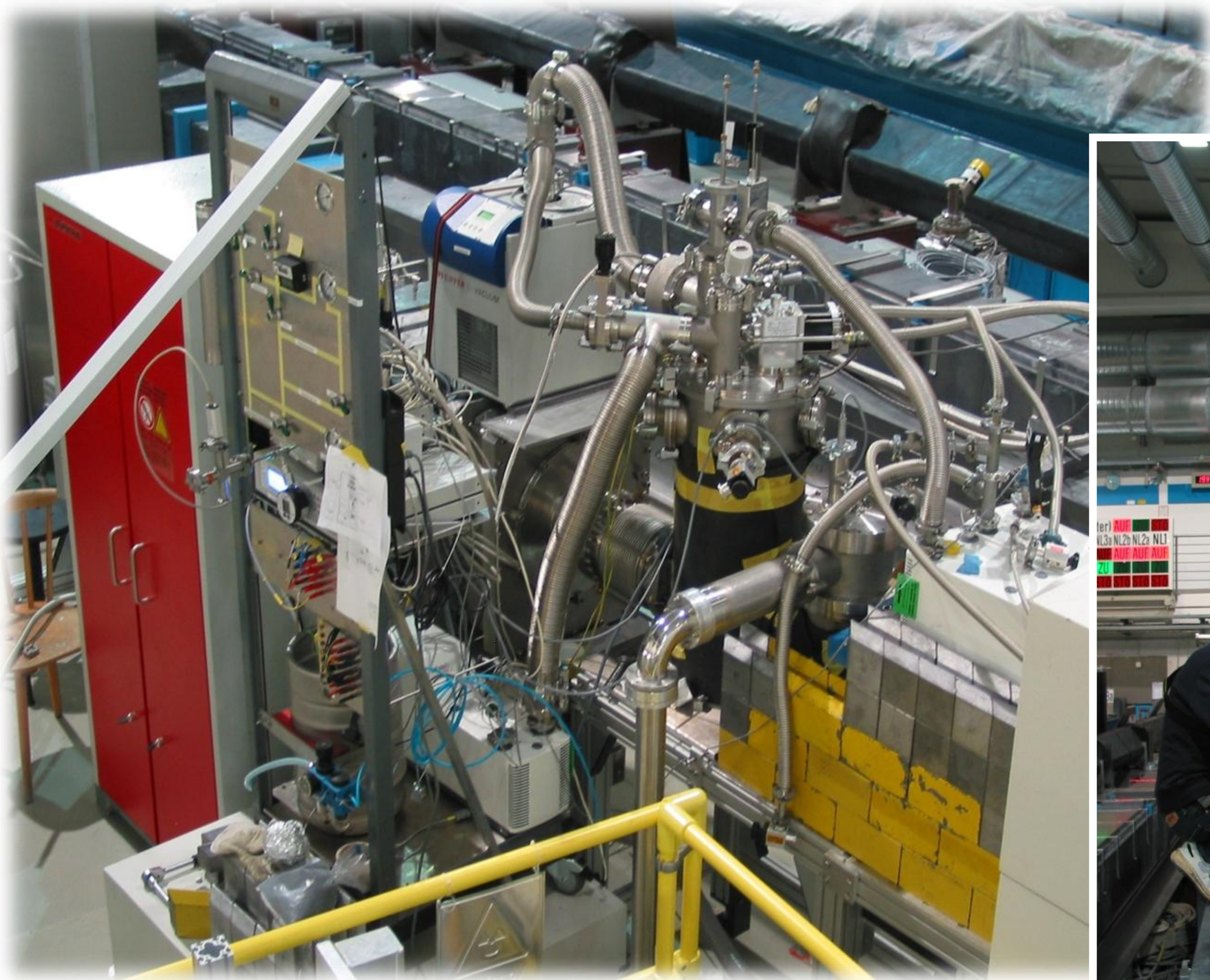
PRL **99** (2007) 104801, EPJ C **67** (2010) 589

First successfull extraction of UCN accumulated in superfluid helium

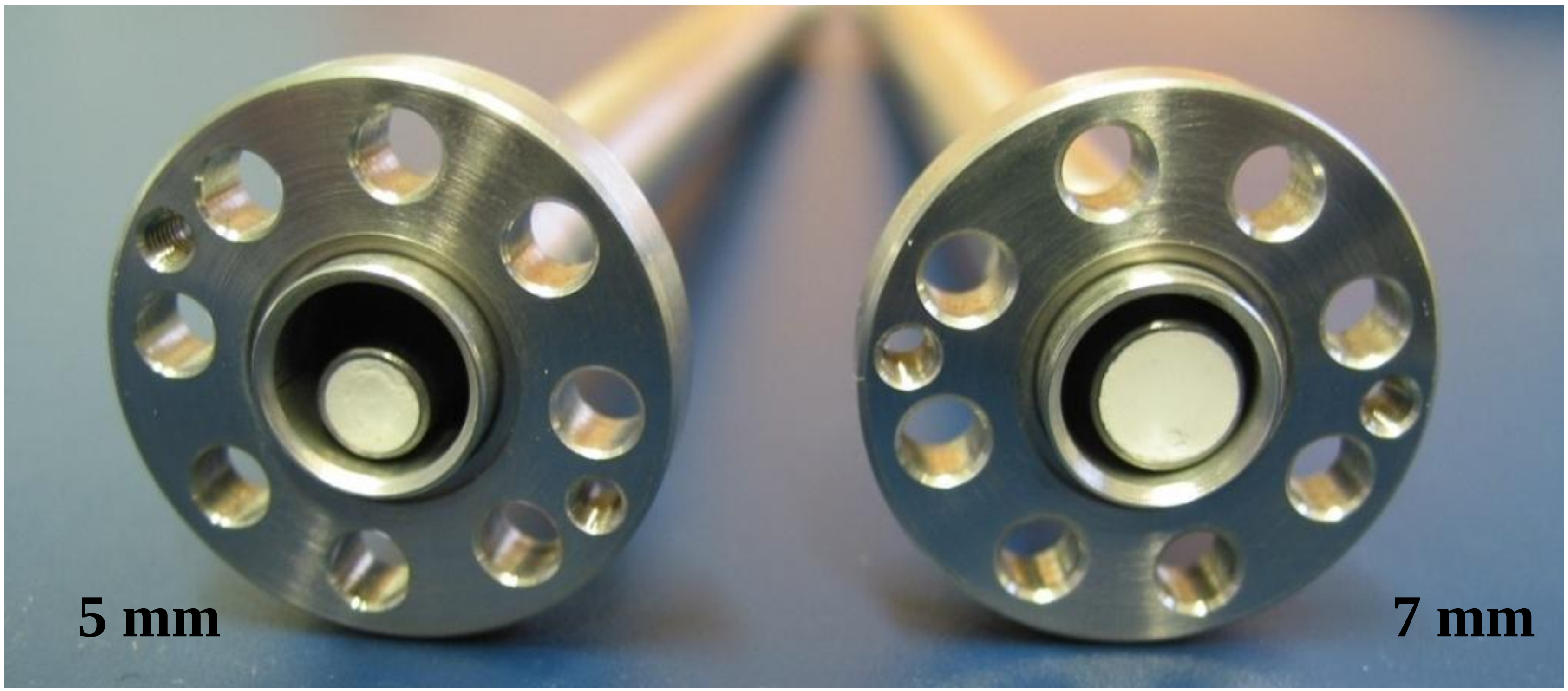




...installed at the research reactor FRM II in Munich (2006)

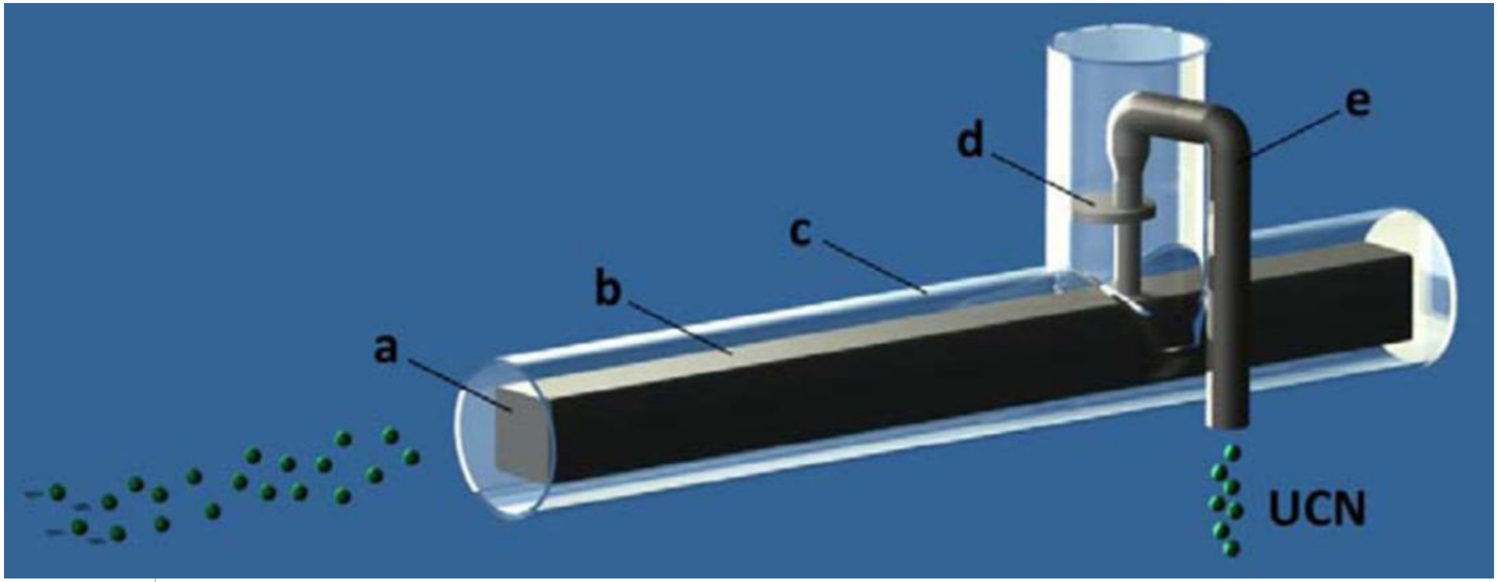


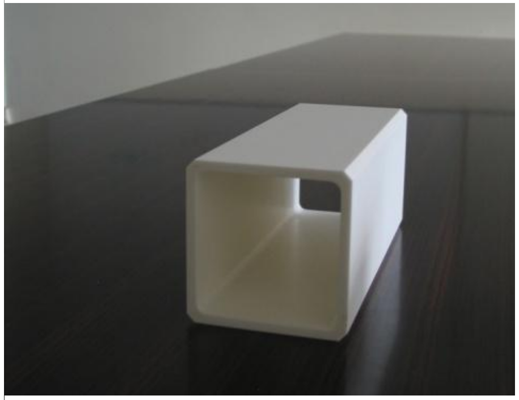
technical detail... **superleak to filter ^{3}He**



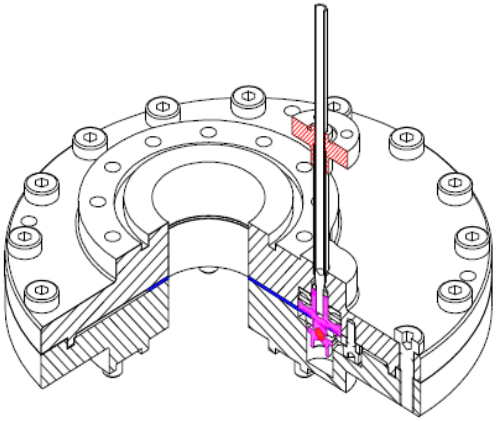
compressed Al_2O_3 powder (50 nm)

...move to Grenoble and upgrade (→ SUN-1)

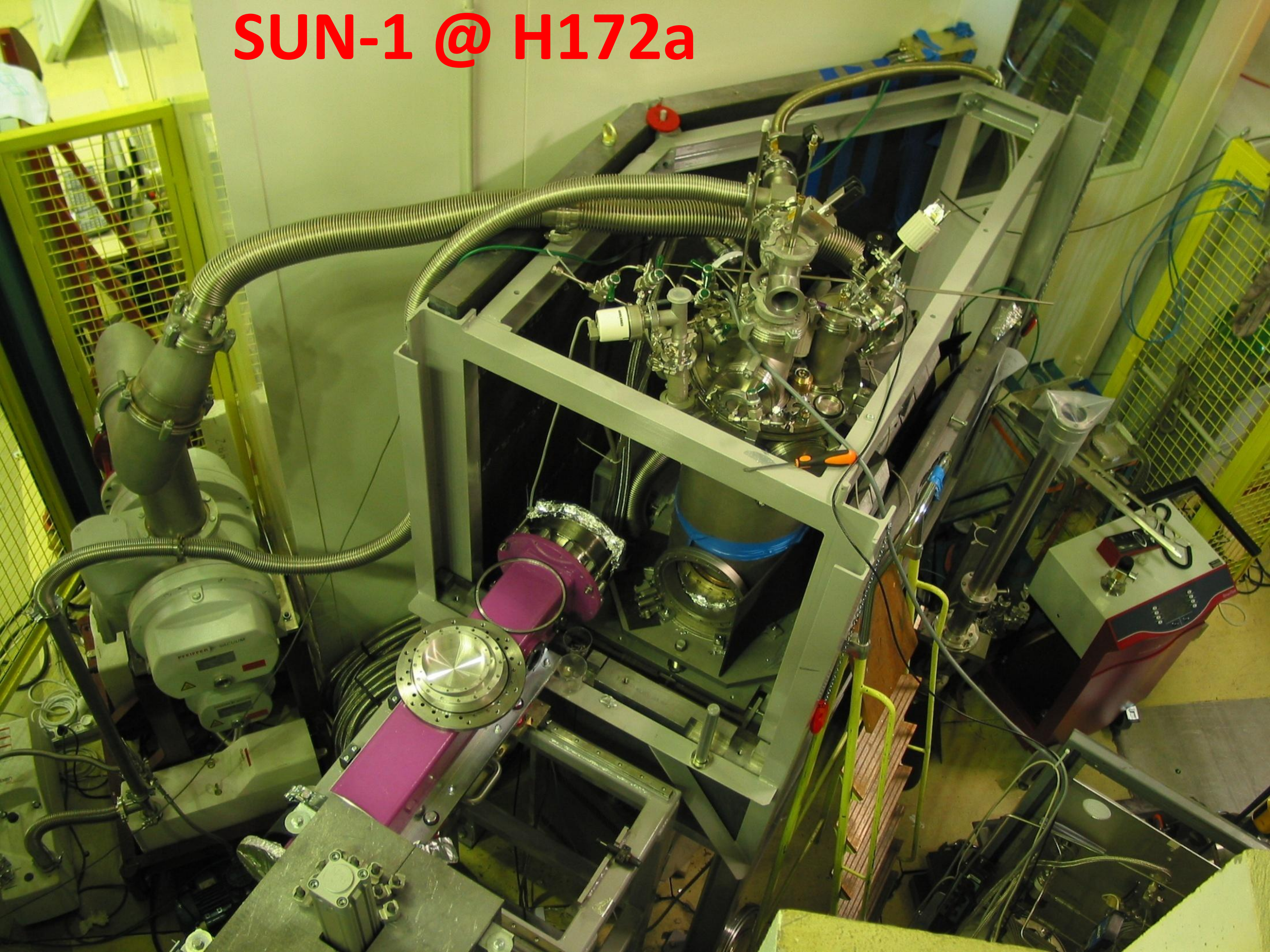




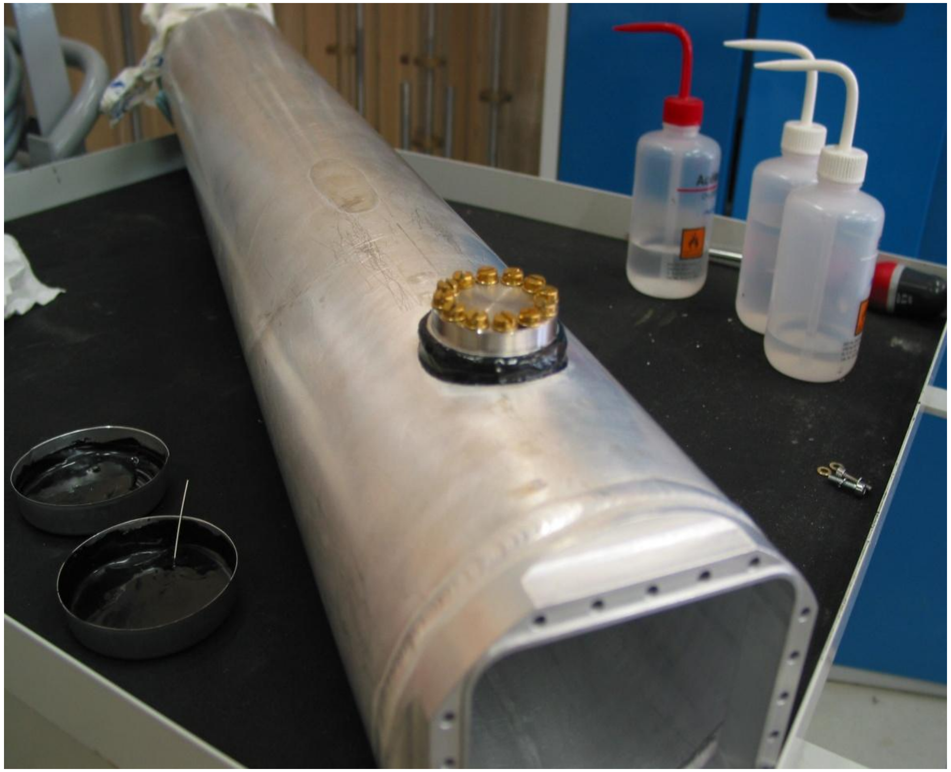
BeO ceramics (260 neV)

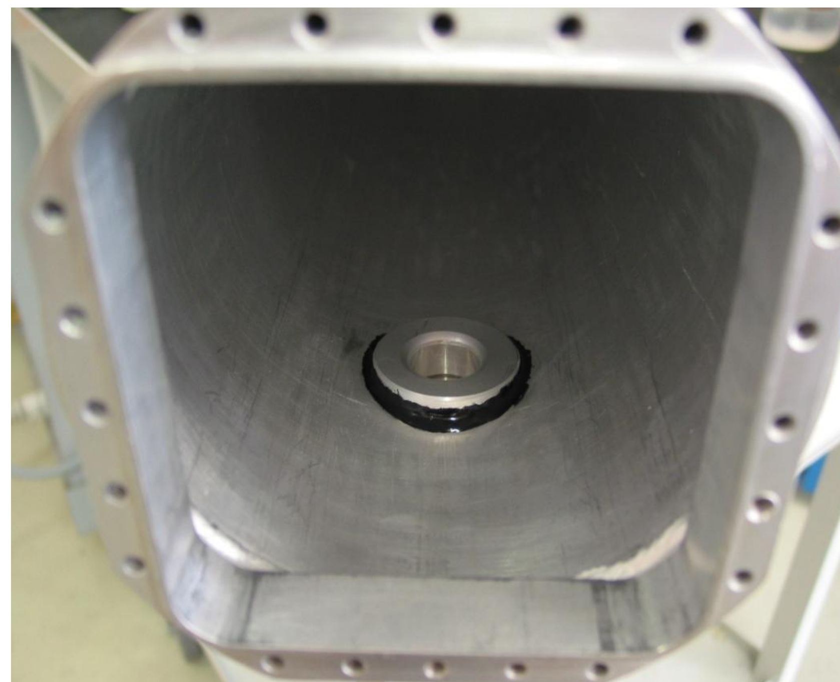


SUN-1 @ H172a

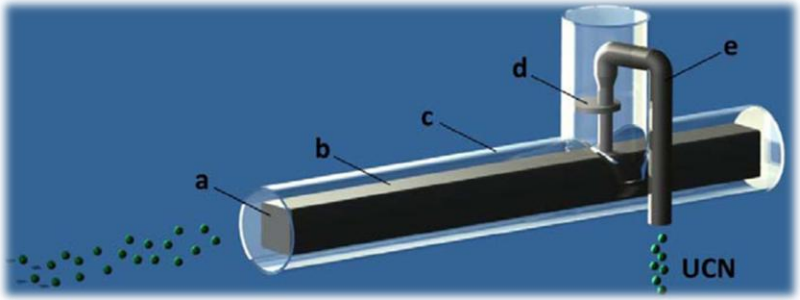


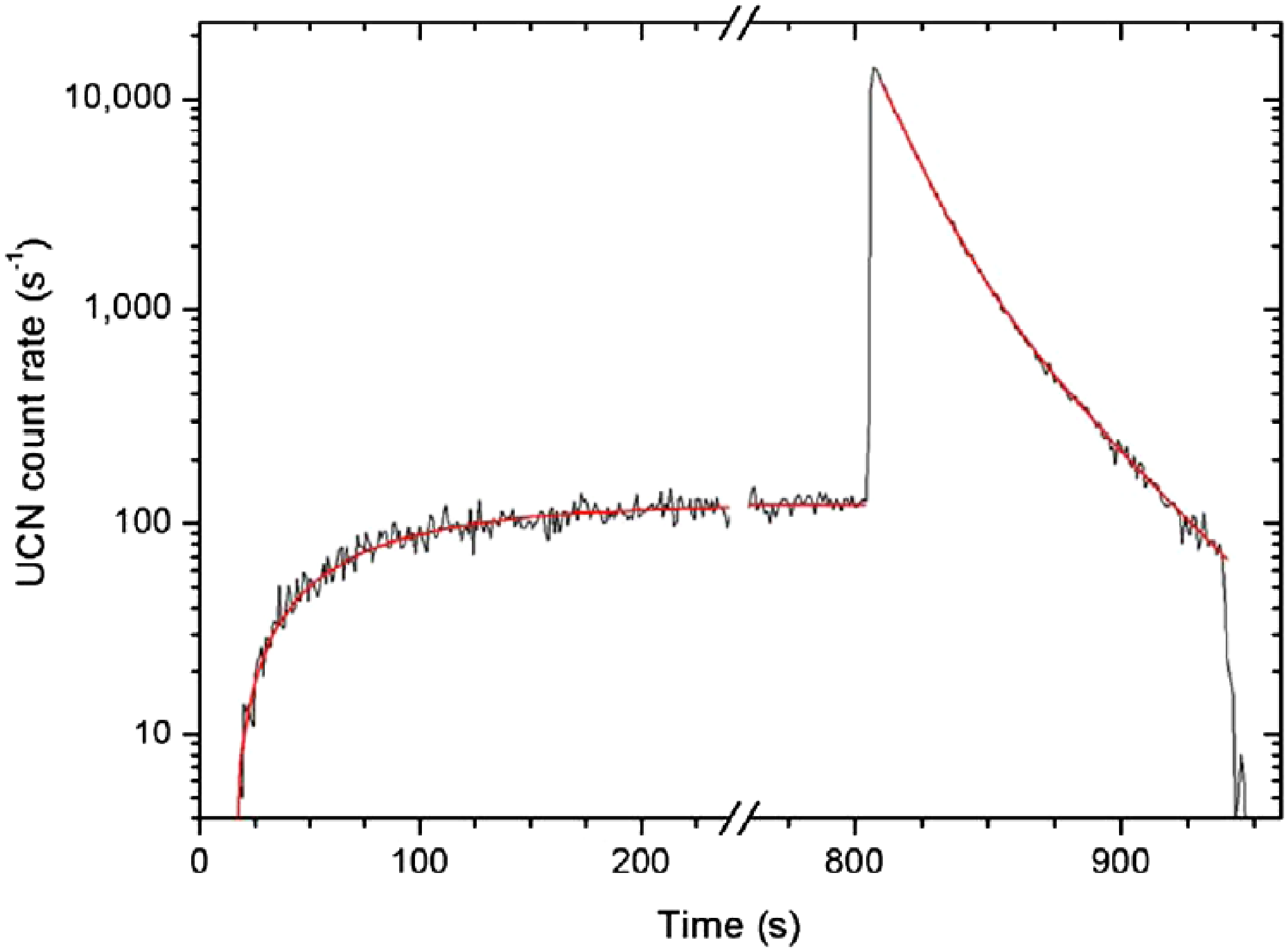
...several months of fighting against leaks...





... but finally:



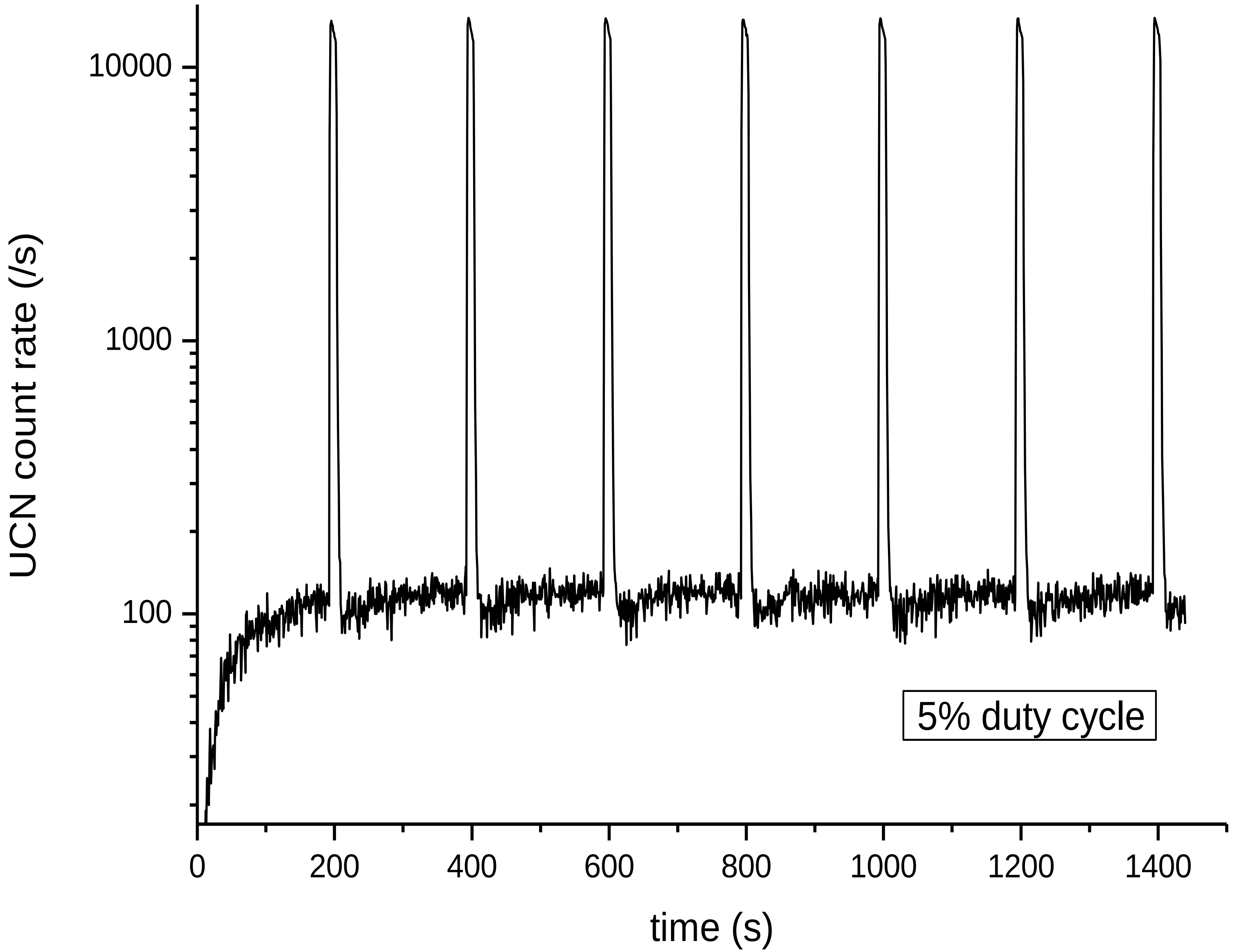


274,000 counts

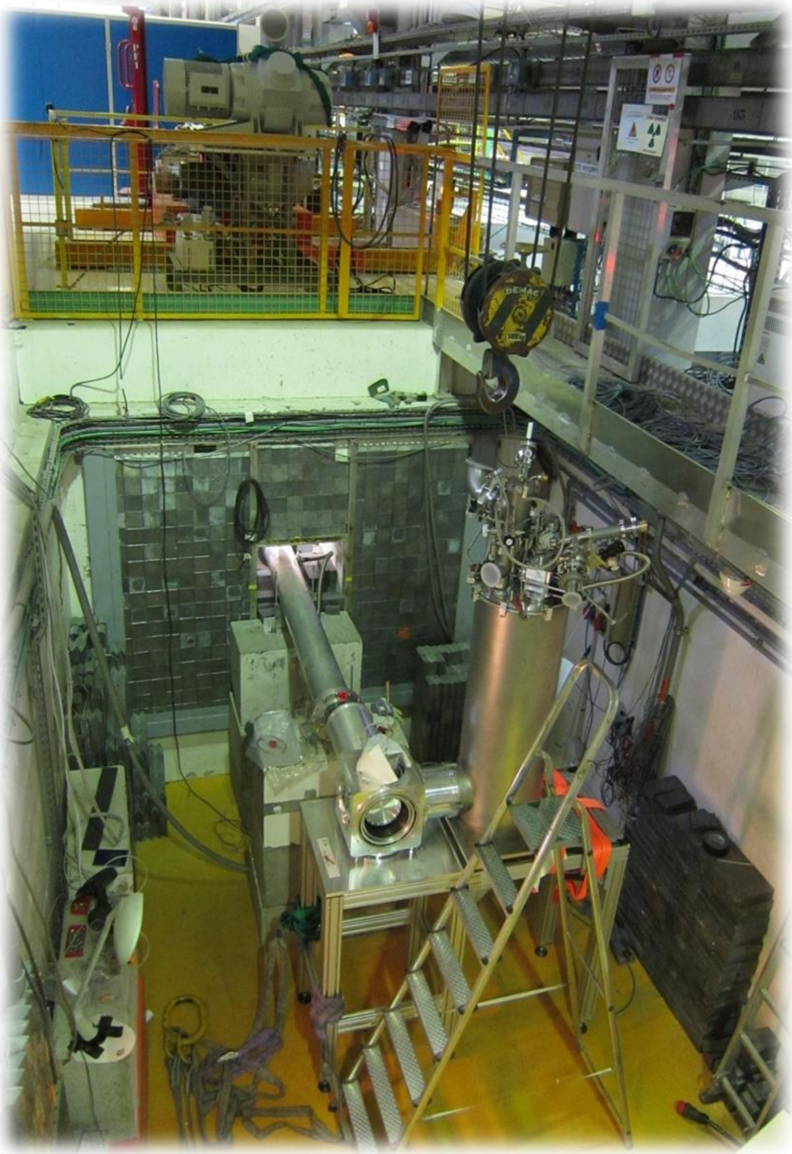
55 per ccm

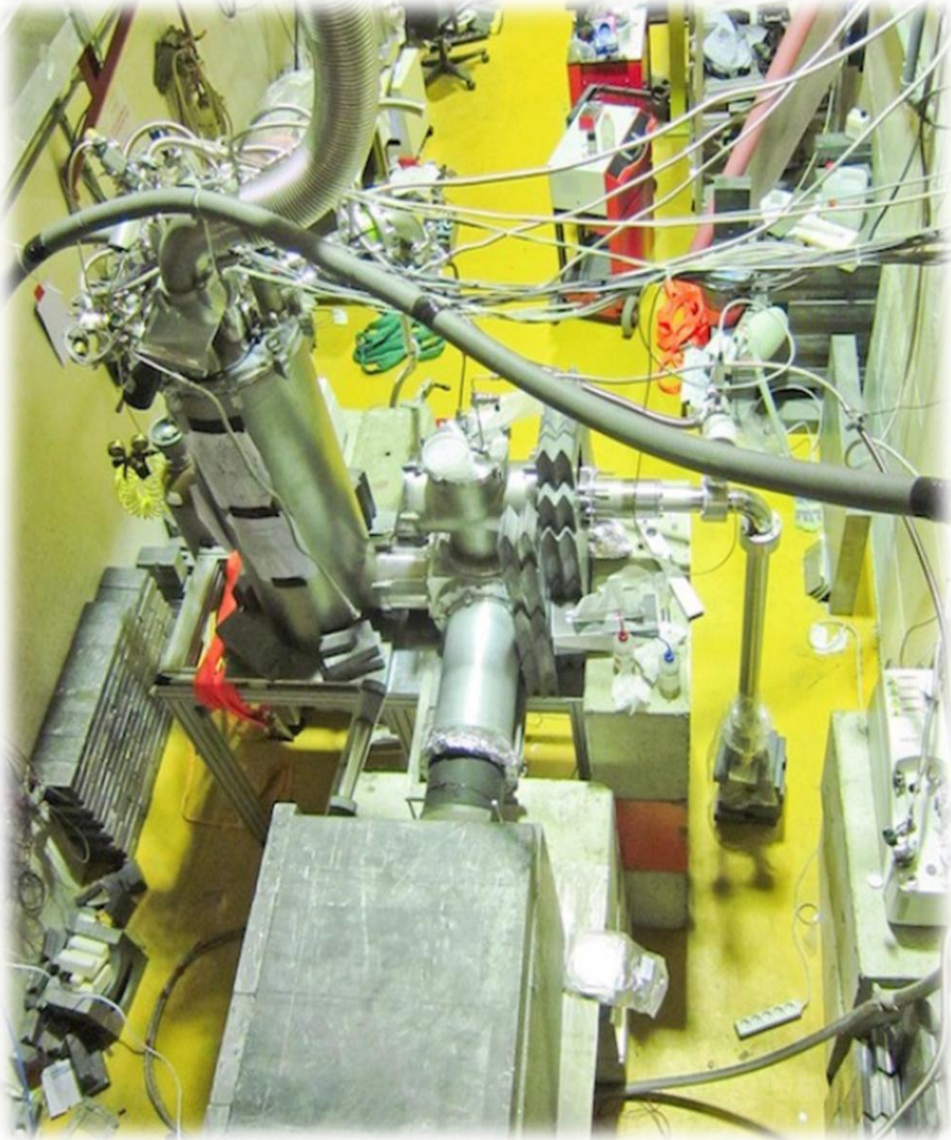
O. Z., F.M. Piegsa, S.N. Ivanov, PRL **107** (2011) 134801

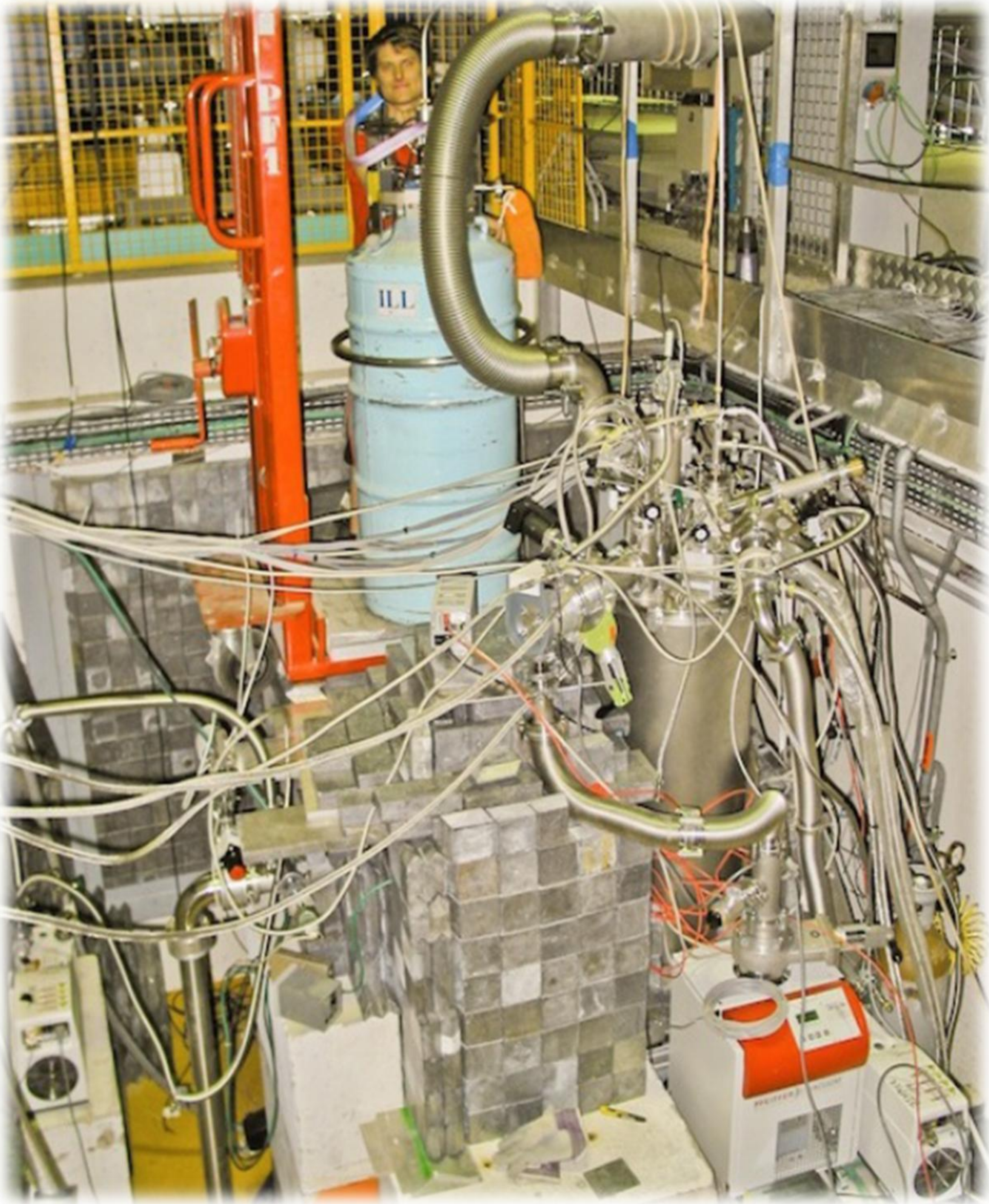
Cyclic operation of the source



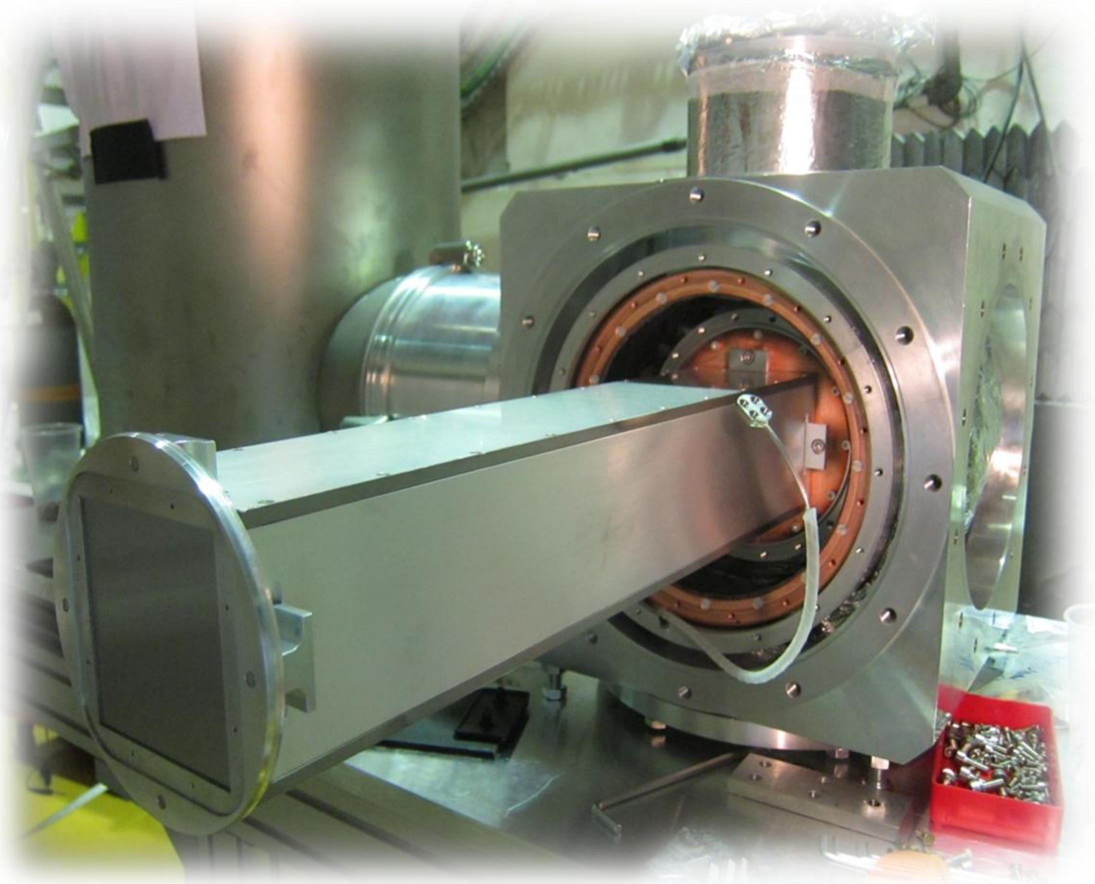
SUN-2 modular, high cooling power cryostat, ...first test @ white cold beam PF1b (2011)





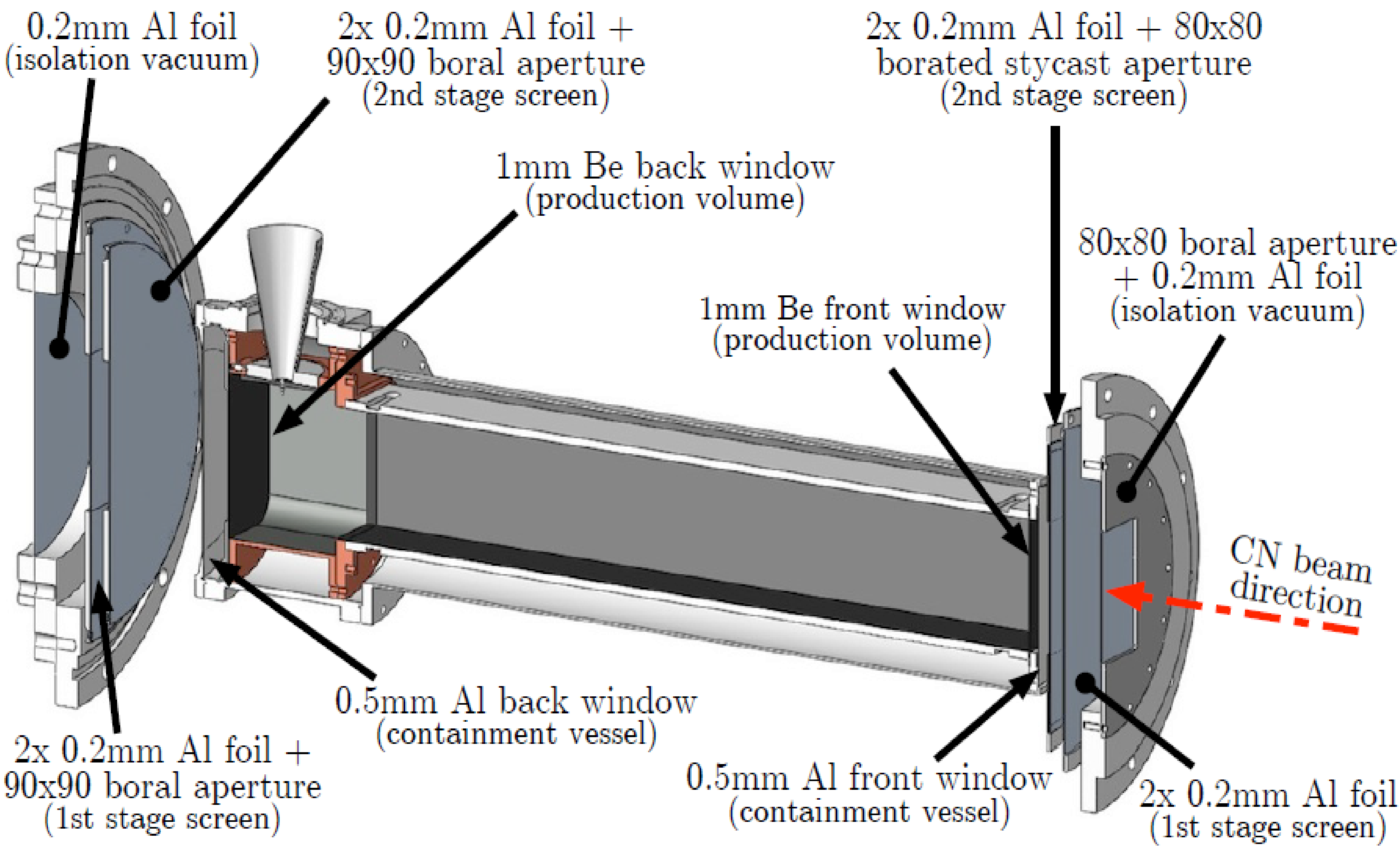

PF1
ILL

Preparation of converter vessel

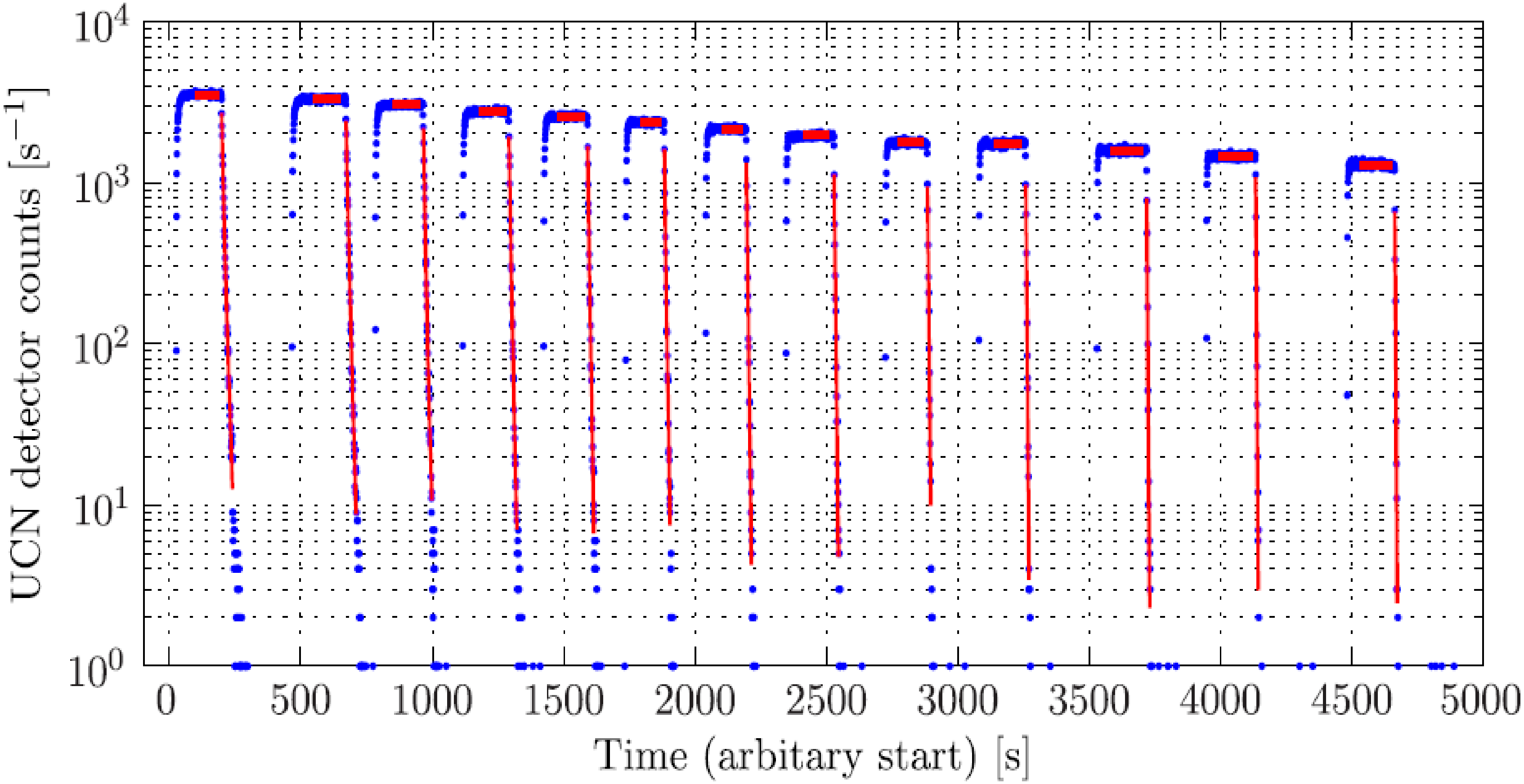


- Be-coated UCN vessel
- volume: 4 l (upgradable)
- Be entrance/exit windows
- choosable UCN extraction hole size

Schematics of converter vessel



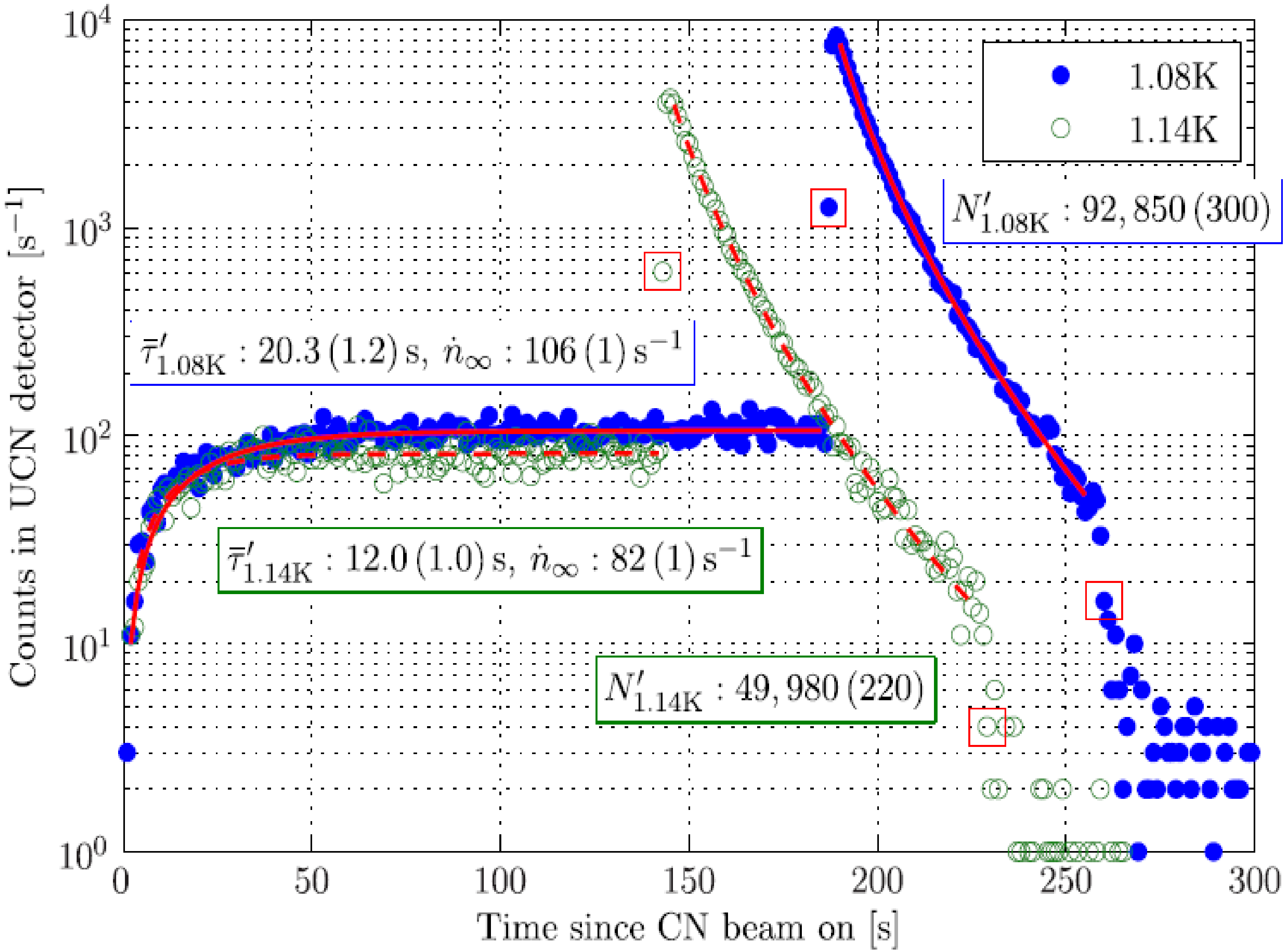
UCN extraction from open converter



Highest UCN output with open converter:

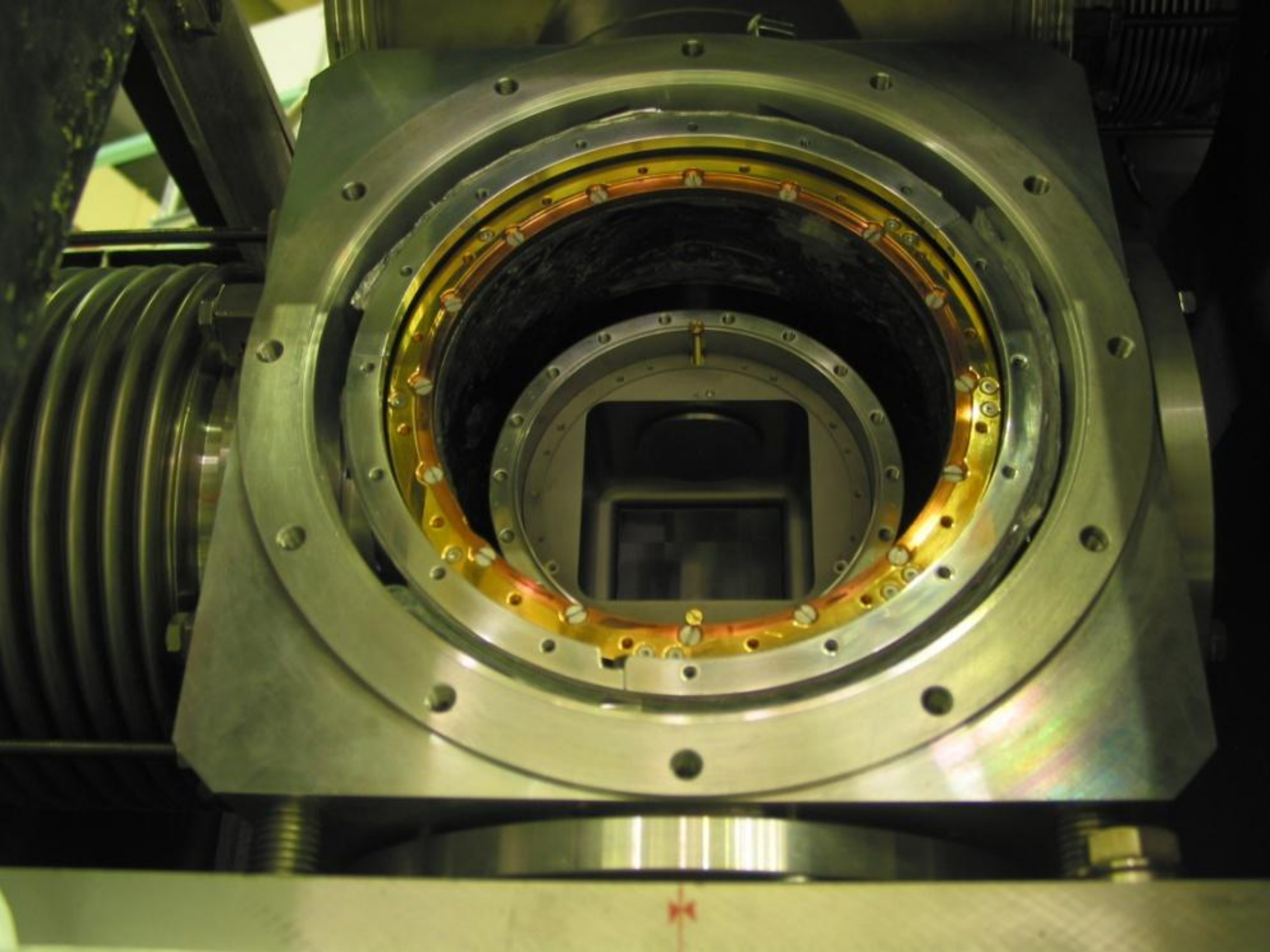
6000 UCN/s through 2cm² hole @ 1.08K

UCN accumulation experiments

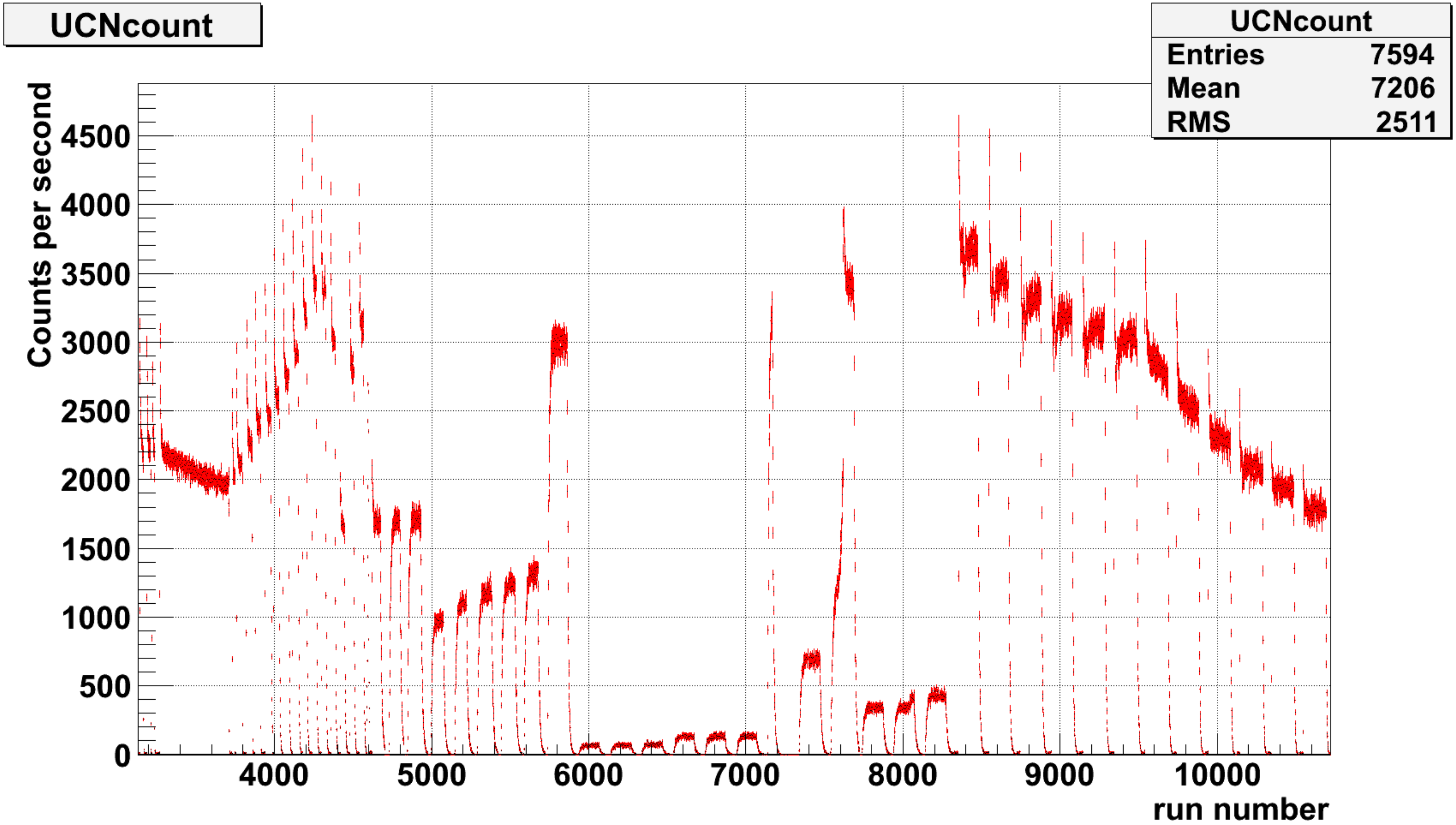



November 2012
SUN-2 assembly

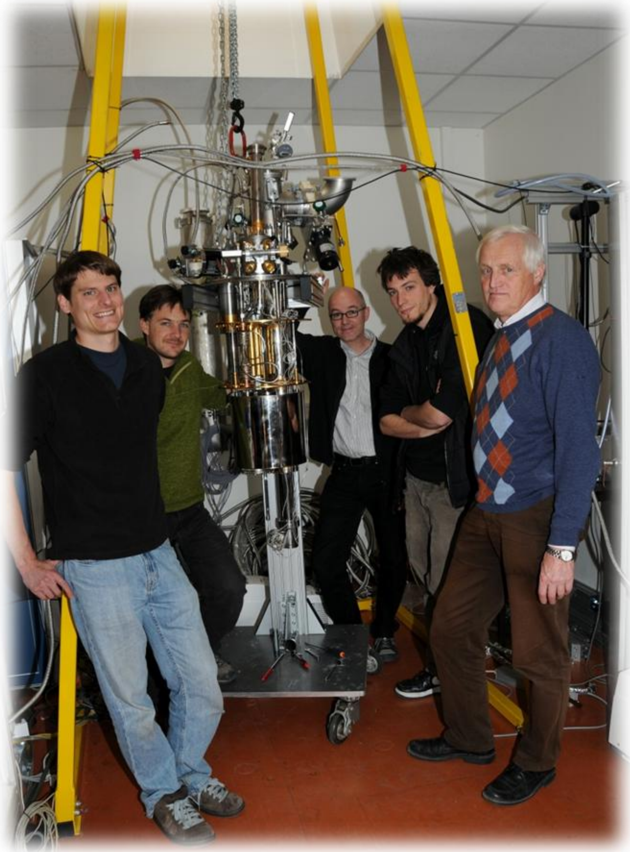

30 November 2012
250 KG
TUBESCA

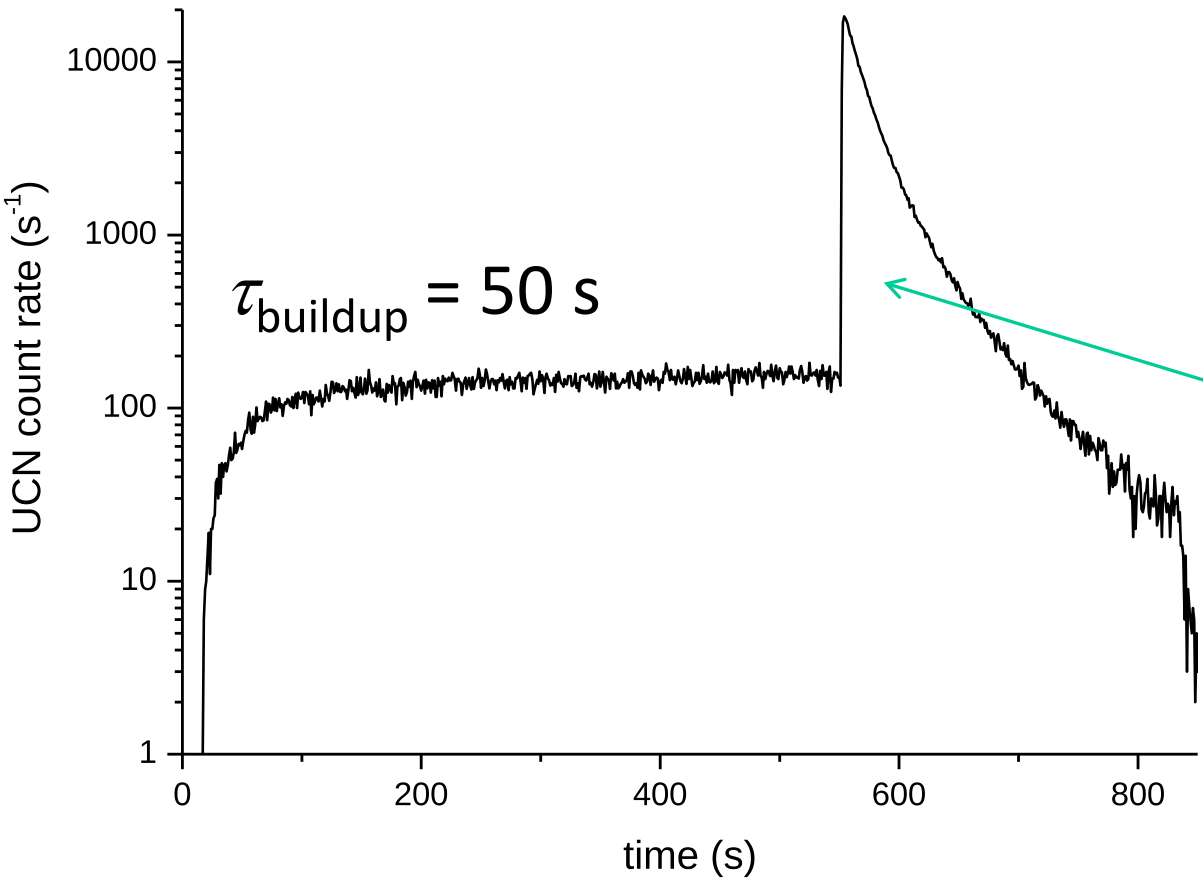


...last night before the reactor shutdown (8/12/2012):



New result on UCN production
(March 2013)

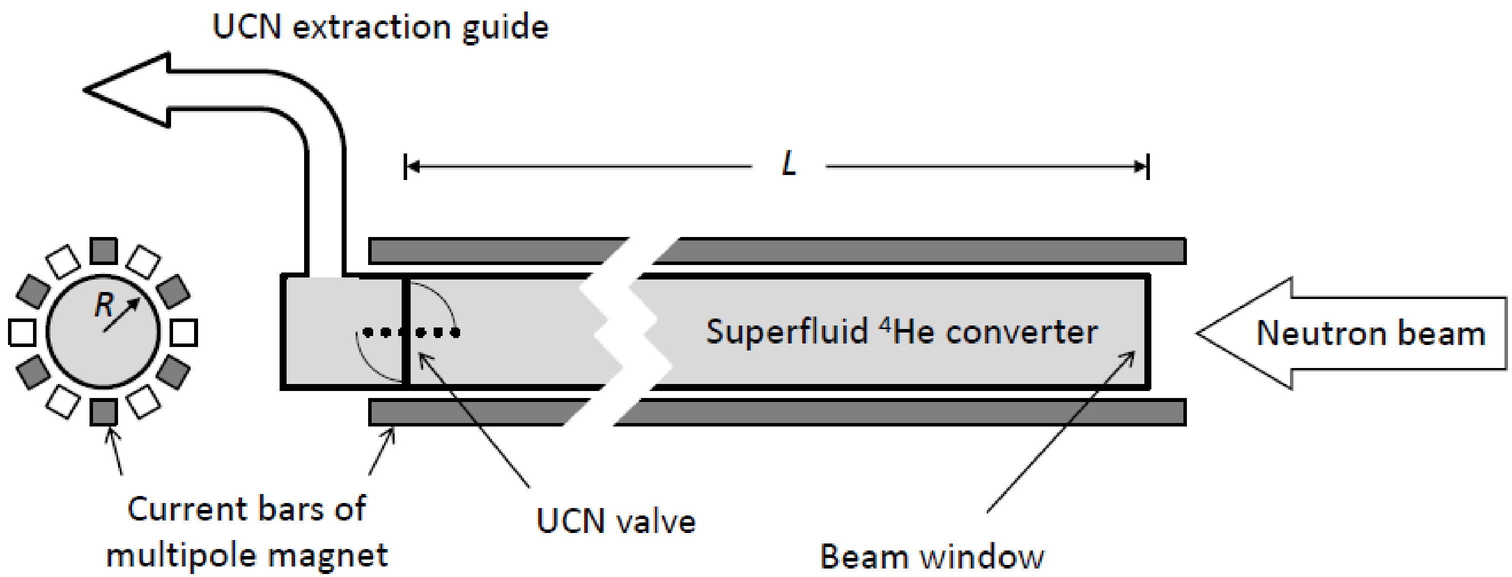


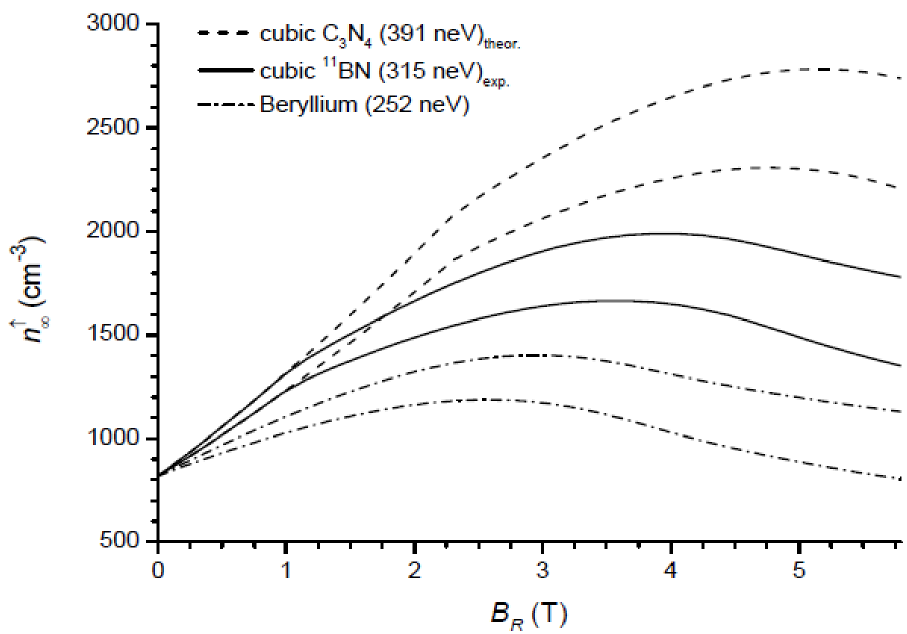


440,000 UCN
extracted from 4 l
converter

110/cm^{-3}

Ex-pile opportunity: magnetic UCN reflector





- weak dependence of ρ_{UCN} on wall quality
- in-situ UCN polarizer
- Enhancement of UCN spectrum possible

Zimmer & Golub, arXiv:1303.1944

→ ILL Endurance project
SuperSUN

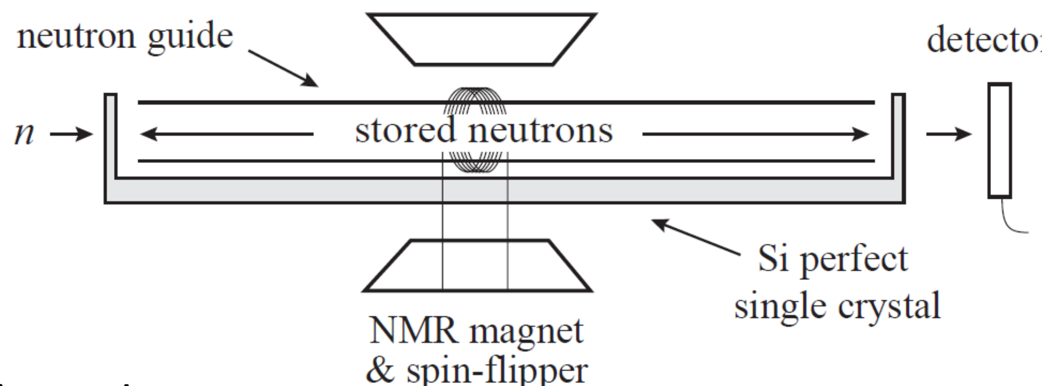
Use of pulse structure of beam?

...maybe possible ex-pile:

- mean free path of 0.89 nm neutrons in He-II (1.25 K): l = 17 m
- pulse plateau length: t = 2.2 ms, neutron velocity: v = 450 ms^{-1}

  → vt = 1 m → one pulse fits in a 0.5 m long 0.89 nm resonator
- time between pulses: T = 0.07 s
- time for 1/e decrease of 0.89 nm neutrons in He-II: $T < l/v$ = 0.037 s

  → every pulse can be used



...but:

need it for 1.0283 – 1.0543 meV

→ magnetic resonance filling doesn't work

→ suitable crystal to be found
(lattice spacing gradient, switchable)

VESTA:
Storage apparatus for 0.627 nm
(Jericha, Rauch et al.)

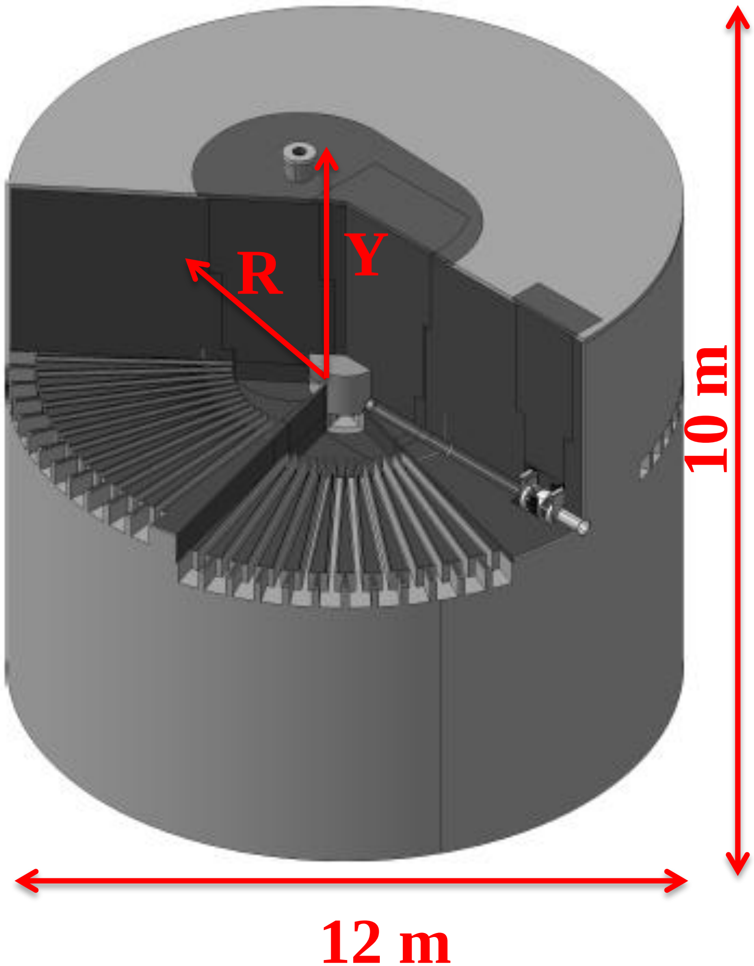
Ex-pile UCN source:

+ no need for far transport of UCN
+ needs less powerful cryogenics
+ easy access to source for
  - study of converters and UCN extraction schemes
  - trouble shooting
+ space for bulky reflectors (magnetic or diffusive)
+ progress in guide technology → more UCN
– cold neutron flux by a factor 100 lower than in-pile
  → UCN current lower by same factor
  → UCN density lower by factor 10 – 50

→ ex-pile source is at least a good precursor of an in-pile source
→ in-pile source might be best choice for high UCN flux experiments

Potential opportunities for ESS:

- huge feeding guide for ex-pile UCN source
- optimization of cold beam spectrum with colder pre-moderator
- design of optimized in-pile UCN source



Heat deposition in the target monolith

Luca Zanini