

# On-site production of hyperpolarised helium-3

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# Overview

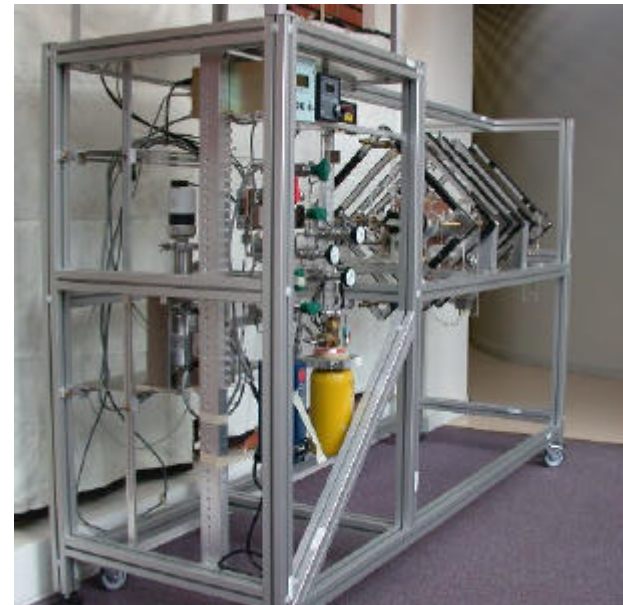
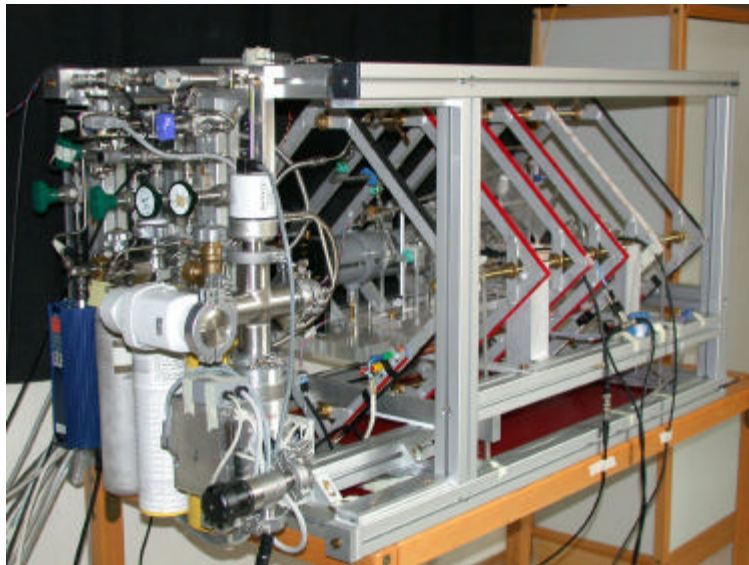
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Principle of operation

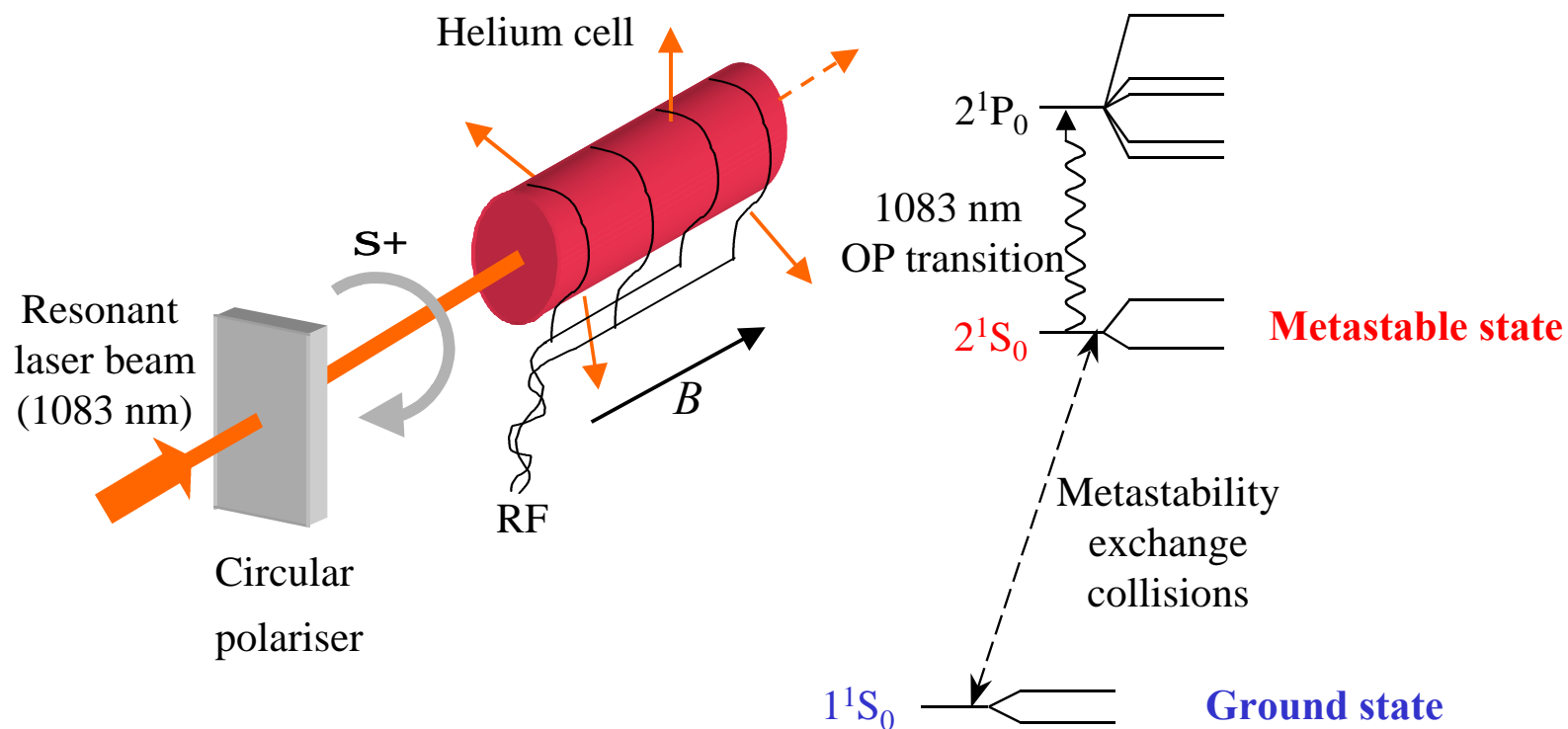
Polarised gas production devices

Current performance and prospects for improvement

Use and dissemination



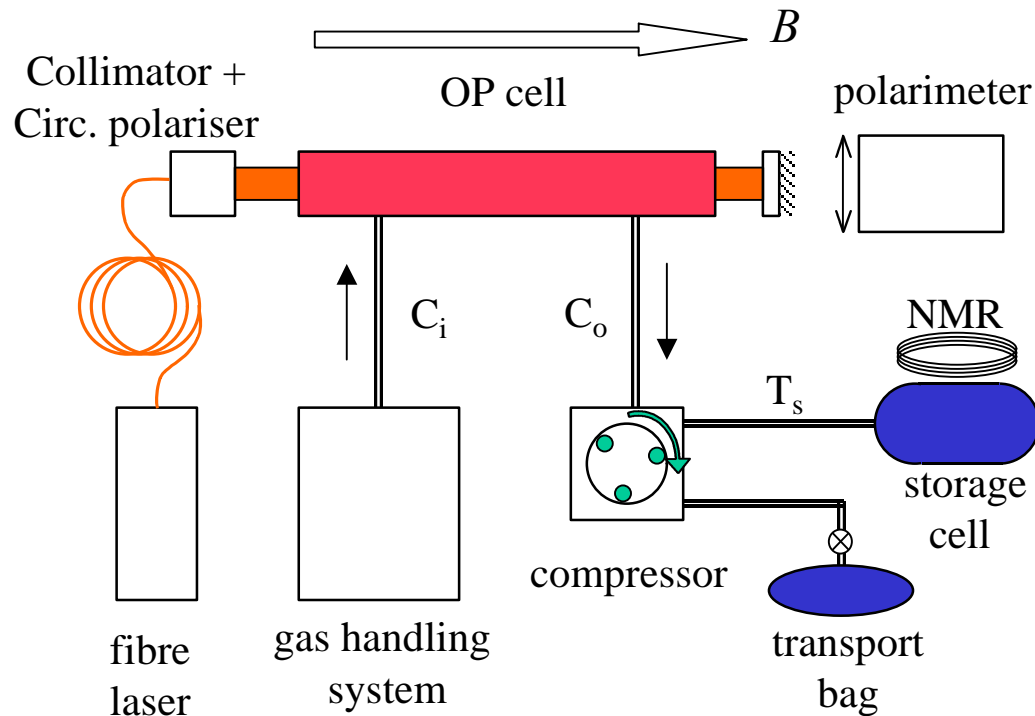
# Optical pumping : Principle



Metastability exchange optical pumping (ME OP):

- 1- **metastable state** populated by RF discharge, polarised by OP (1083 nm)
- 2 - collisions transfer nuclear polarisation into **ground state**

# Gas polarisation scheme



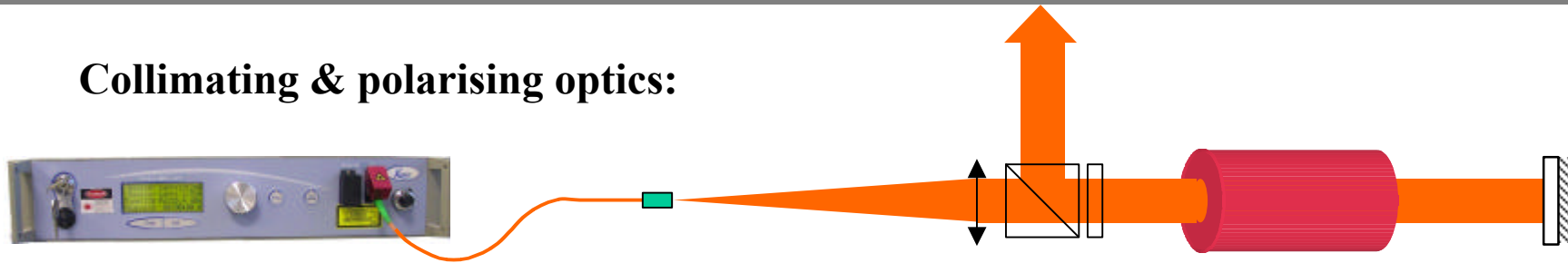
Connecting tubes :

- $C_i$  &  $C_o$ : narrow tubes (to prevent diffusion)
- $T_s$ : narrow tube (to prevent relaxation)

- ultra-pure  $^3\text{He}$  gas is flown through **OP cell** (acquires nuclear polarisation  $M_{\text{OP}}$ )
- polarised gas is extracted from OP cell and accumulated at increasing pressure  $P_{\text{sto}} \propto \text{time}$  ideally (i.e. with no relaxation losses) :  $M_{\text{sto}} = M_{\text{OP}}$
- when the required amount of  $^3\text{He}$  is obtained, it is:
  - 1- mixed with neutral gas if desired (e.g. 0.5 litre  $\text{N}_2$ )
  - 2- extracted into the bag (e.g. reversing compressor rotation)
  - 3- delivered to be inhaled from the bag

# Compact fibre lasers tailored for OP of helium

**Collimating & polarising optics:**



**All Yb doped fibre laser + amplifier**

**2W or 5W used in Paris**

Keopsys: up to 20W <http://www.keopsys.com/>

Features:

- 1083 nm wavelength tunable on He transitions
- **broadband emission** to match atomic Doppler profile
- several Watts for fast and efficient OP

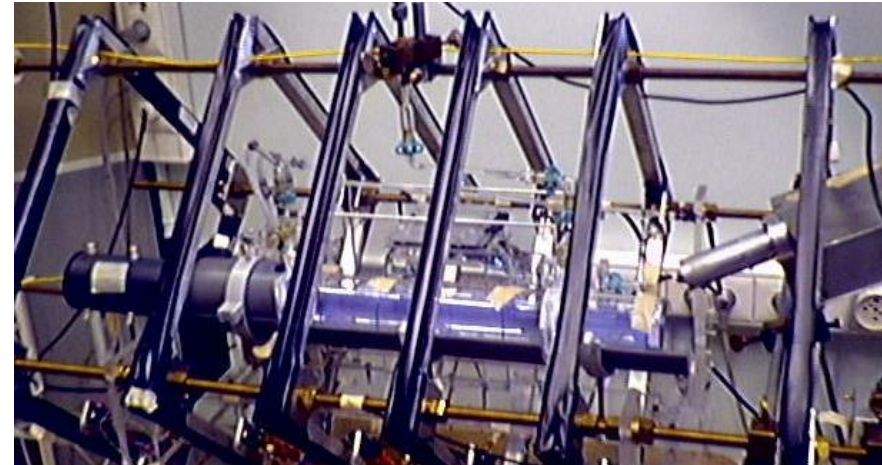
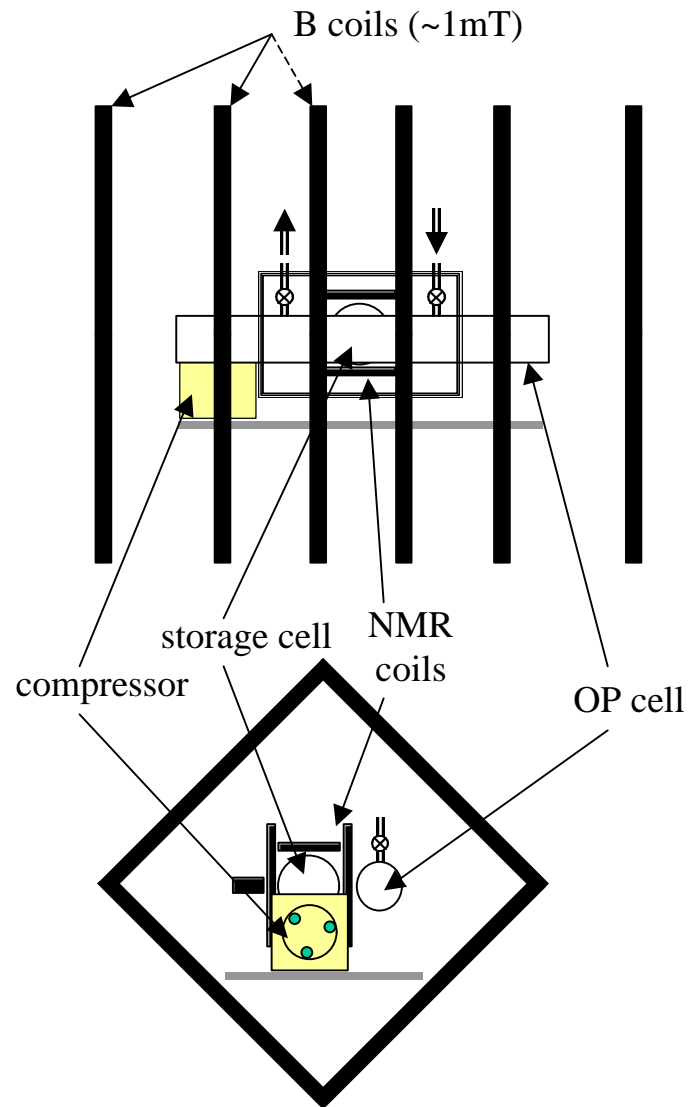
Also: laser diode + Yb doped fibre amplifier

**2×15W used in Mainz**

IPG: up to 40W <http://www.ipgphotonics.com/>

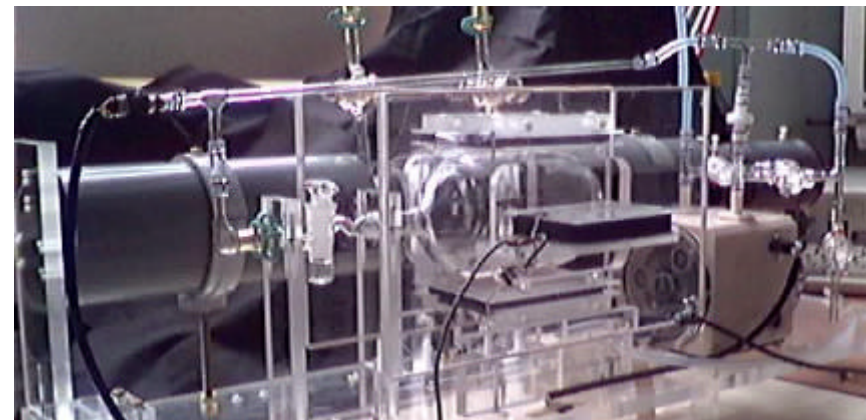
**Portable devices, easy to operate anywhere (e.g. hospital)**

# OP and storage cells – polarisation measurements



50 cm x 6 cm OP cell (1.4 litre)  
 $M_{OP}$ : Optical polarimetry on red He line

0.5 litre quartz storage cell  
NMR measurement of  $M_{sto}$



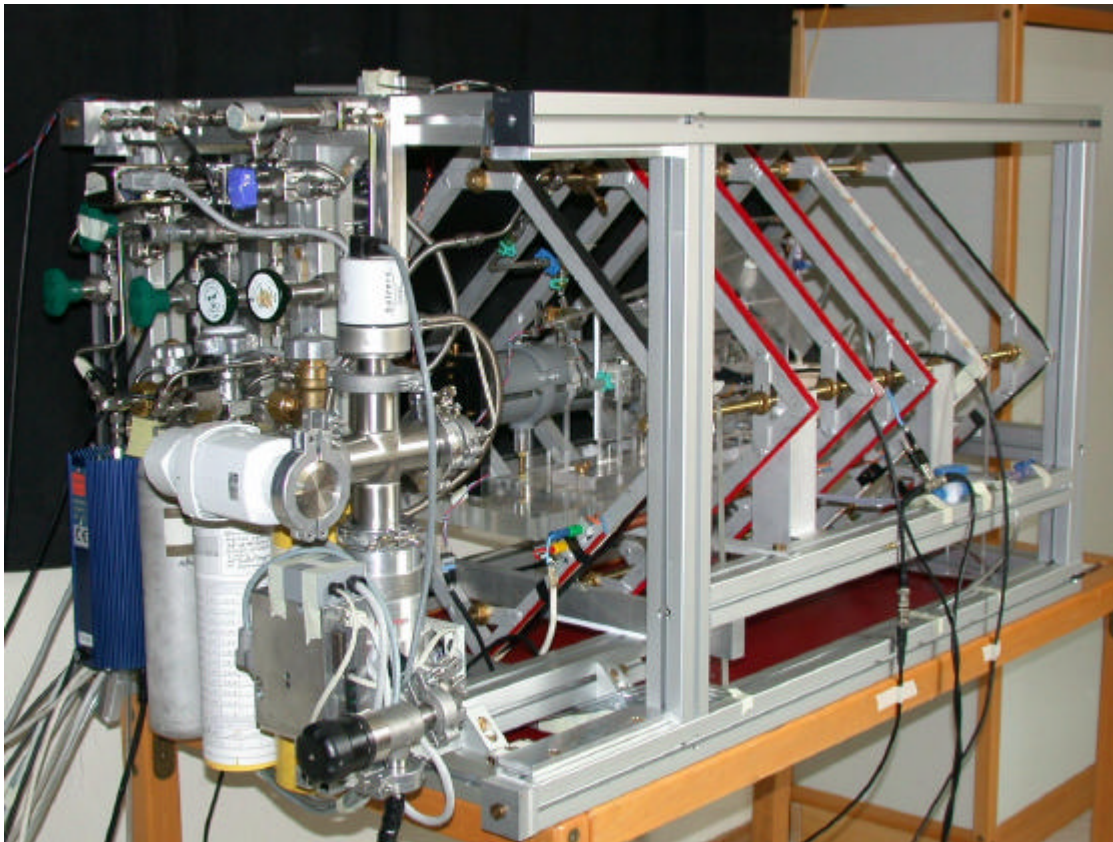
## Two systems for on-site gas polarisation

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### Hospital prototype PROTHOS

size : 1.1 x 0.64 x 0.64 m<sup>3</sup>

Routinely used for MRI since 2003



### Lab prototype PROTLAB

size : 2 x 0.64 x 1.3 m<sup>3</sup>

Fully equipped to monitor M.  
Used for tests and developments  
(and to produce polarised gas!)



# Gas production with PROTHOS

Initial basic system operating early 2001 (4-coil B, 15 cm cell)

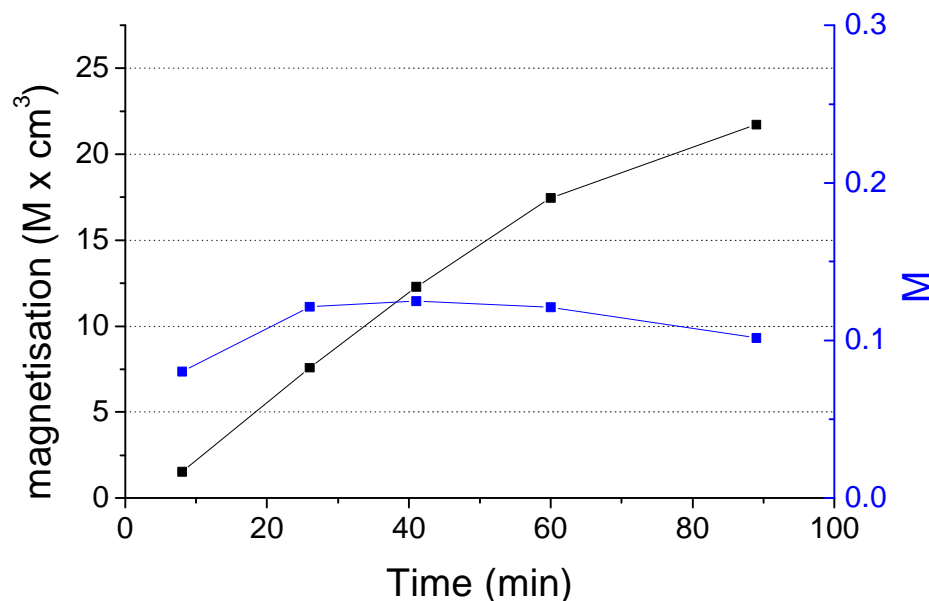
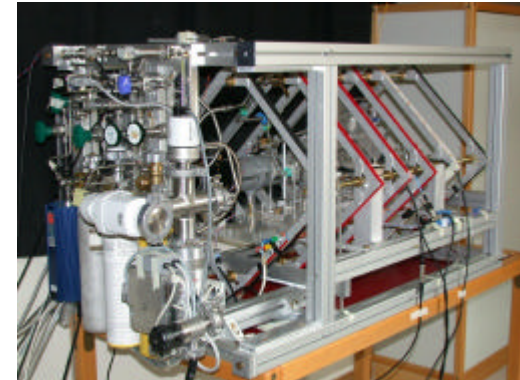
Upgraded system operating since early 2003

No quantitative measurement of M in system, only in MRI scanner

Last month of operation in KB hospital (Jan. 9 – Feb. 9, 2004)

**90 polarised gas doses, on average 125 cm<sup>3</sup> at M=13% in 50 min**

(longest day: 12hours, 11 doses, total 1.8 litre @ 13%)



Example of operation (NMR in storage cell):  
constant M and linear increase of magnetisation

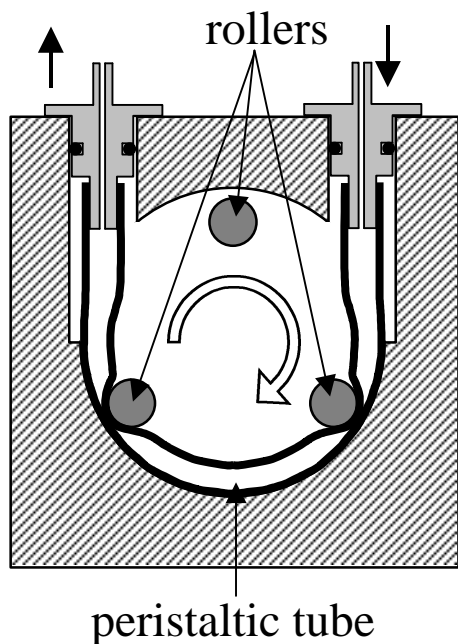
Loss of efficiency for  $t > 1$  hour (relaxation)

☺ reliable repeated operation

☹ limited performance

→ Systematic checks with PROTLAB

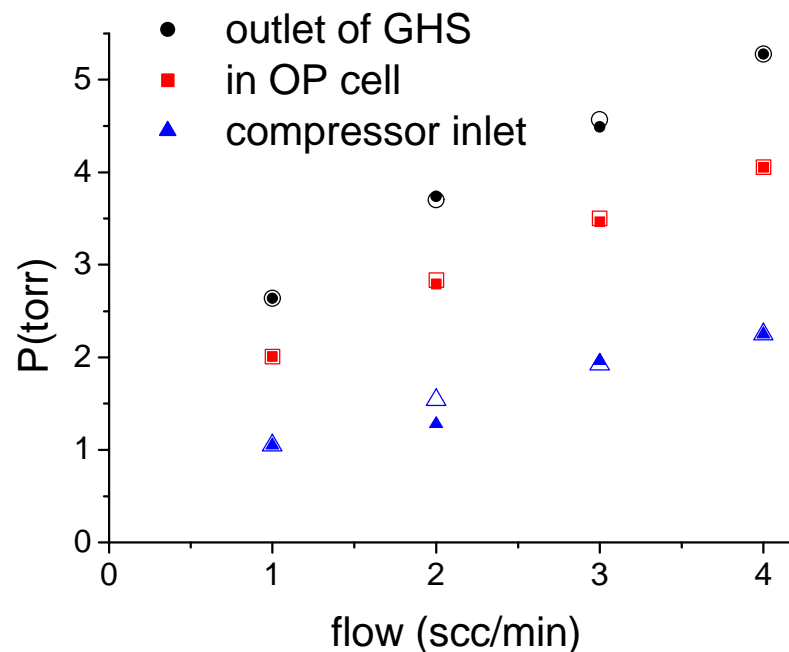
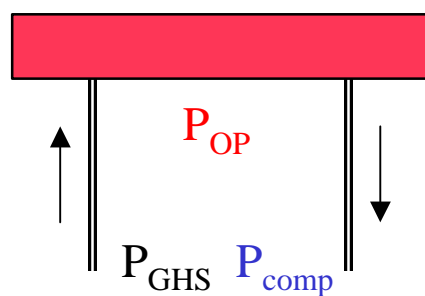
# Peristaltic compressor – flow rate



Nominal volume flow: 5 cm<sup>3</sup>/revolution  
 1 to 3 tubes in // } **up to 6 litres/min**  
 300-400 rpm

Actual volume flow from  
 pressure measurements  
 → 1.1 litre/min (1 tube)

☹ Rather high P in OP cell → limited M



# OP performance

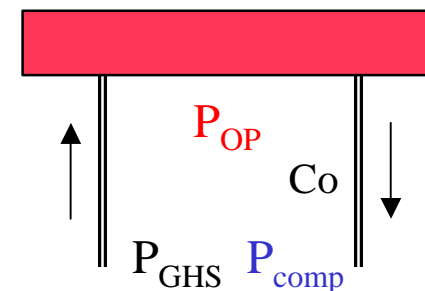
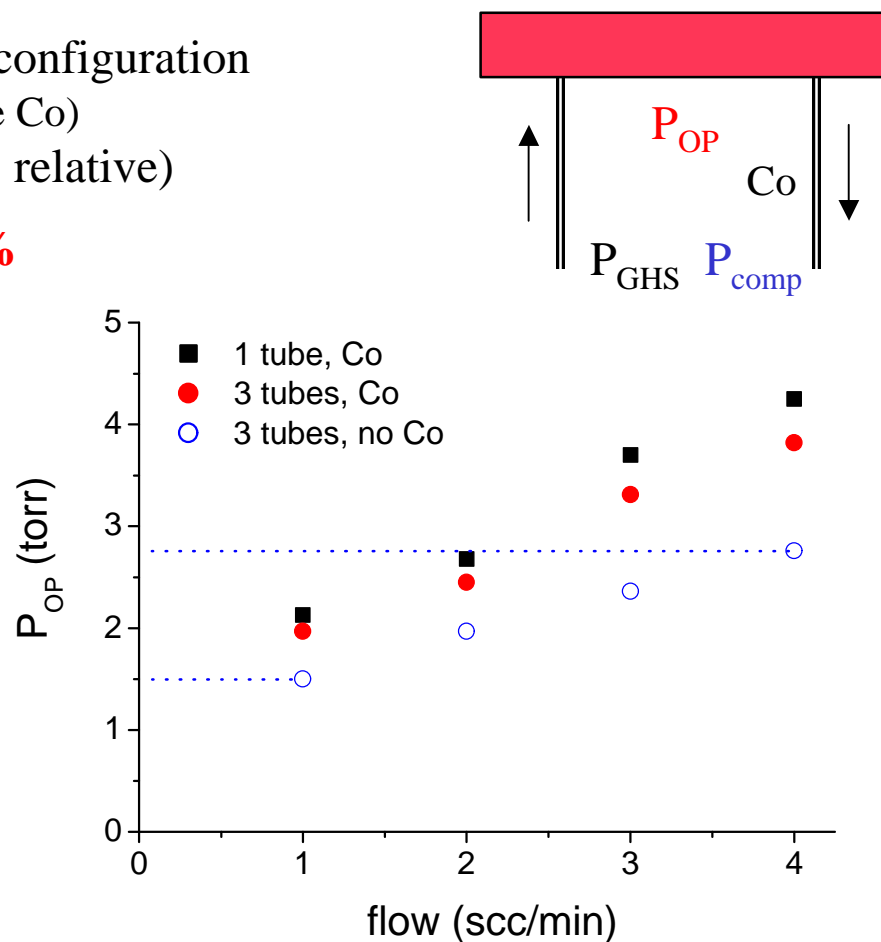
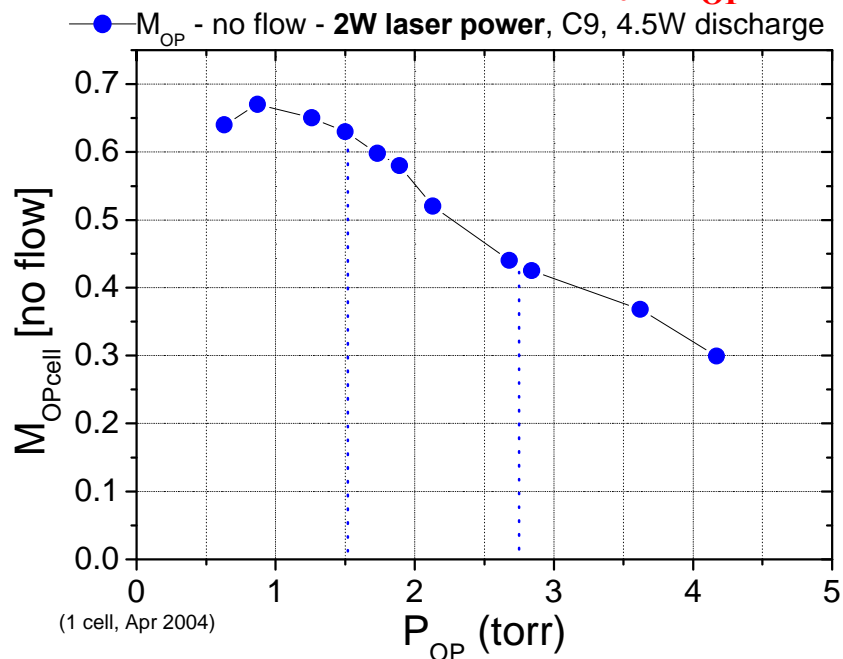
OP limitations:

- usual decrease of M at high pressure
- moderate B homogeneity (compact system) → decrease of M at low P
- imperfect cell windows → decrease of M at high laser power

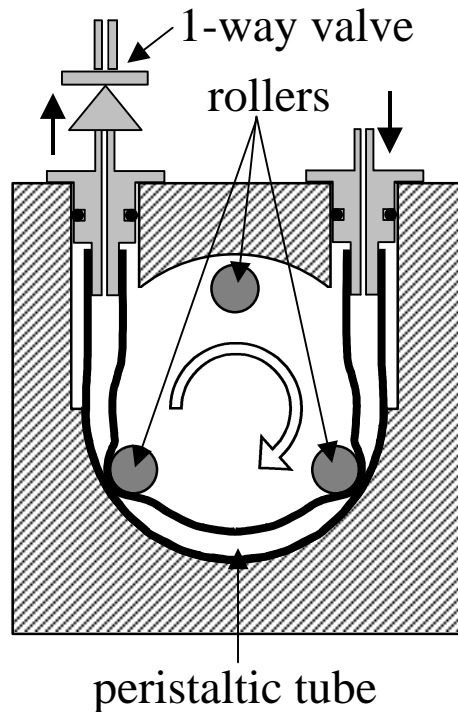
Effect of flow

- pressure increase depending on compressor configuration (1 to 3 tubes in //, presence of flow impedance Co)
- decrease of M due to incomplete OP (5-20% relative)

Currently  $M_{OP} \sim 60-40\%$



# Peristaltic compressor – relaxation losses

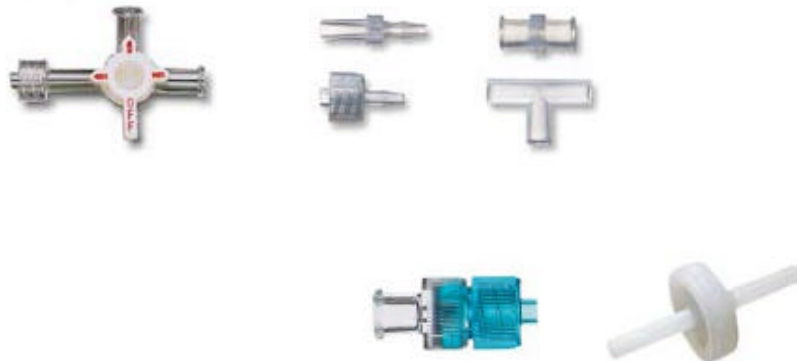


Wall relaxation losses in tubes:

$$T_1 = \theta_S V/A = \theta_S a/2 \quad a: \text{tube radius}$$

material	$\theta_S$ (s/m)
Pyrex glass	$10^6$
quartz	$3 \times 10^6$
peristaltic tube	$0.3 \times 10^6$
Teflon tube	$> 10^6$

Plastic Luer connections and valves



Loss for transit time  $\tau$ :

$$\tau/T_1 = 2\pi aLP/f\theta_S$$

( length L, pressure P, gas flow f )

**Highest loss for long, wide tubes, high P, slow flow and short  $q_S$ :**

- outlet of compressor
- connections to storage volume

**1-way valve to prevent backflow and reduce  $\langle P \rangle$  in peristaltic tube**

# Relaxation losses

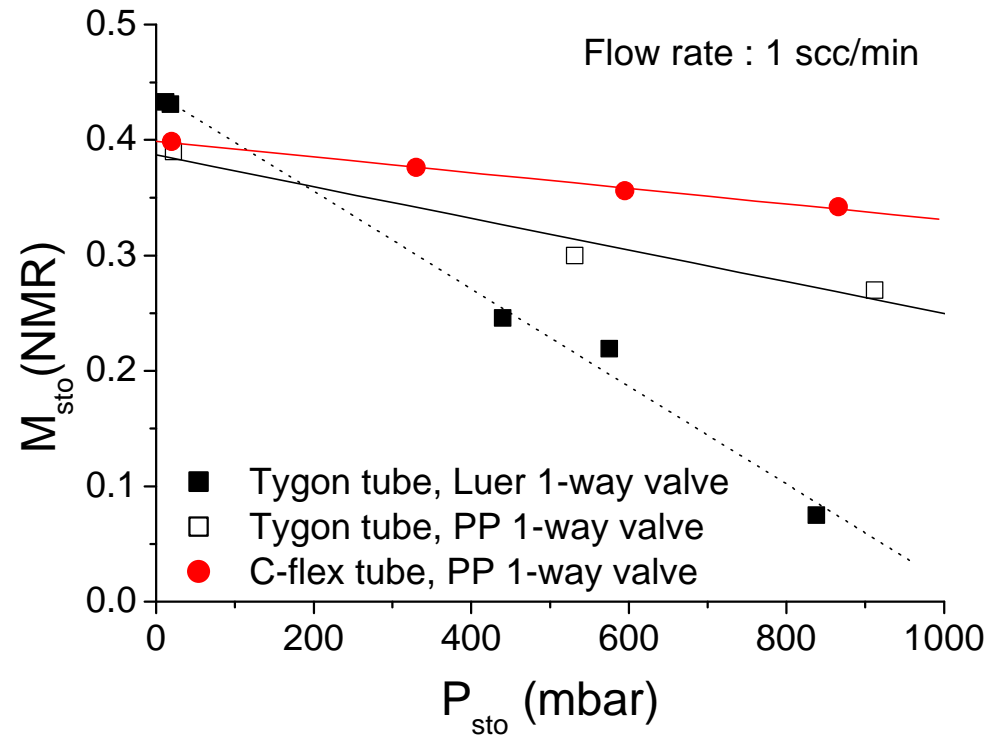
Loss for transit time  $\tau$ :

$$\tau/T_1 = 2\pi aLP/f\theta_S$$

( length L, pressure P, gas flow f )

Measurements made at small f  
(more sensitive to losses)

- loss  $\propto P \rightarrow M_{sto} \propto \exp(-\tau/T_1) \approx 1-kP$
- avoid Luer valves ■ (used in PROTHOS)
- different peristaltic tubes □ ●



**Systematic checks used to choose materials**

**For long accumulation periods,  $T_1$  in storage cell important as well**

## Gas production results

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**Current measurements** with 50 cm OP cell (2W laser):

$M_{OP}$  (no flow)  $\sim 70\%$  at 1.3 mbar

$M_{OP}$  (2scc/min flow)  $\sim 45\%$  at 3 mbar  $\rightarrow M_{acc} \sim 40\%$

$T_1 \sim 10$  h (fused silica storage cell)  $\rightarrow$  constant  $M_{acc}$  for  $\sim 1$  h

Reliability :  $>1.5$  year operation of 2 devices

$\sim 2$  h compressor servicing every  $\sim 50$  h of operation

**Short-term prospects** (end of 2004)

With 5W laser + higher compressor pumping speed

$M_{acc} > 50\%$  at 3scc/min -  $M_{acc} > 40\%$  at 5scc/min

Improved field homogeneity  $\rightarrow$  2OP cells in series

Improved reliability of modified compressor (less servicing)

## Use and dissemination

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### Two operating devices (Paris, Orsay/KB hospital)

Operation in hospital for > 1 year.

Numerous MRI tests, >100 lung images in patients and volunteers

Operation in lab during all of PHIL

Characterisation of systems, OP optimisation,  
diffusion in lungs and other porous media at 3mT (+ lung MRI)

### Three devices under completion (Madrid, Krakow, Vancouver)

Almost operational – testing stage

### Performance

Currently M ~ 40% at 2 scc/min

Targeted (end-2004) M > 50% at 3scc/min

M > 40% at 5scc/min

### Impact of PHIL

2-year funding for J.Choukeifé - construction of 2 systems, improved reliability of compressor

Collaboration with Cracow: 6 months stay of K.Suchanek (EC funding) - systematic measurements

Collaboration program with Orsay boosted by PHIL.

Dissemination to Madrid and Krakow for animals

Input from Lyon and Mainz on technical aspects