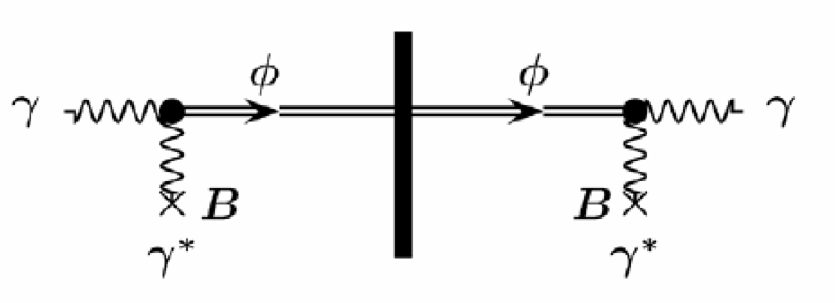
Extending the reach of ALPS II in mass by increasing the refractive index within the optical resonators.



ℓ is the length of the magnetic field B

The production probability for Axion like Particles (ALP) by the interaction of photons with a magnetic field is given by :

$$P_{\gamma\to\phi}(B,\ell,q) = \frac{1}{4}(g\,B\,\ell)^2\ F(q\ell)^2$$

q is the momentum transfer from photon to ALP

q depends on the **refractive index n**

$$q := n\cdot\omega - \sqrt{\omega^2 - m^2}$$

ω is the photon energy

m is the ALP mass

F(ql) is the so called **formfactor**:

For a single dipole of length l it is given by:

$$F(q\ell) = \left[\frac{\sin\left(\frac{1}{2}q\ell\right)}{\frac{1}{2}q\ell}\right]$$

$$q := \omega\cdot(n-1) + \frac{1}{2}\cdot\frac{m^2}{\omega}$$

For m << ω

For a string of N magnets (ALPS II) the probability is more complicated:

from DESY 10-147; ArXiv 1009.4875

[Paola Arias, Joerg Jaeckel, Javier Redondo, Andreas Ringwald]

$$P_{\gamma\Phi} = \frac{1}{4}\cdot(g\cdot N\cdot l\cdot B)^2\cdot\frac{\omega}{\sqrt{\omega^2 - m^2}}\cdot\underbrace{\left(\frac{\sin\left(\frac{q\cdot l}{2}\right)}{\frac{1}{2}\cdot q\cdot N\cdot l}\right)^2\cdot\left[\frac{\sin\left[\frac{1}{2}q\cdot N\cdot(l+\Delta)\right]}{\sin\left[\frac{1}{2}q\cdot(l+\Delta)\right]}\right]^2}_{F^2}$$

F^2 (form factor)^2

$$q := \omega\cdot(n - 1) + \frac{1}{2}\cdot\frac{m^2}{\omega}$$

l is the length of an individual dipole: **8.826 m**

N is the number of dipoles in the string **12**

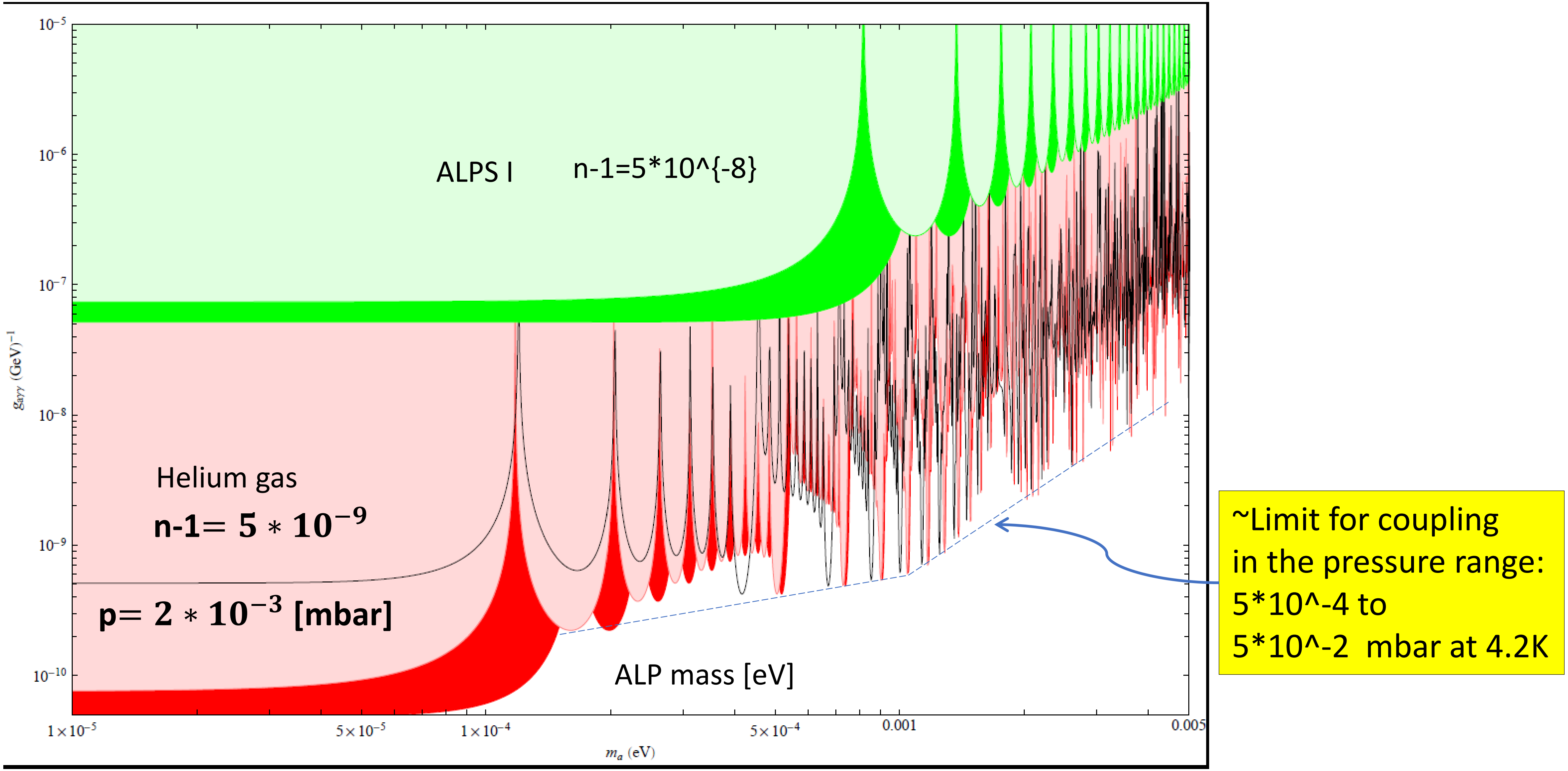
Δ is the distance between individual dipoles **0.9 m**

For the single dipole of **ALPS I** with a beam tube at **room temperature, Argon** gas was used to increase the refractive index.

For **ALPS II,** gases injected into the **cold vacuum pipe** will condense on the surface, with vapor pressures too low for an increase of the refractive index useful for the experiment.

Only the insertion of **Helium** can lead to a pressure increase in the cold pipe yielding a usable change of the refractive index at **ALPS II**.

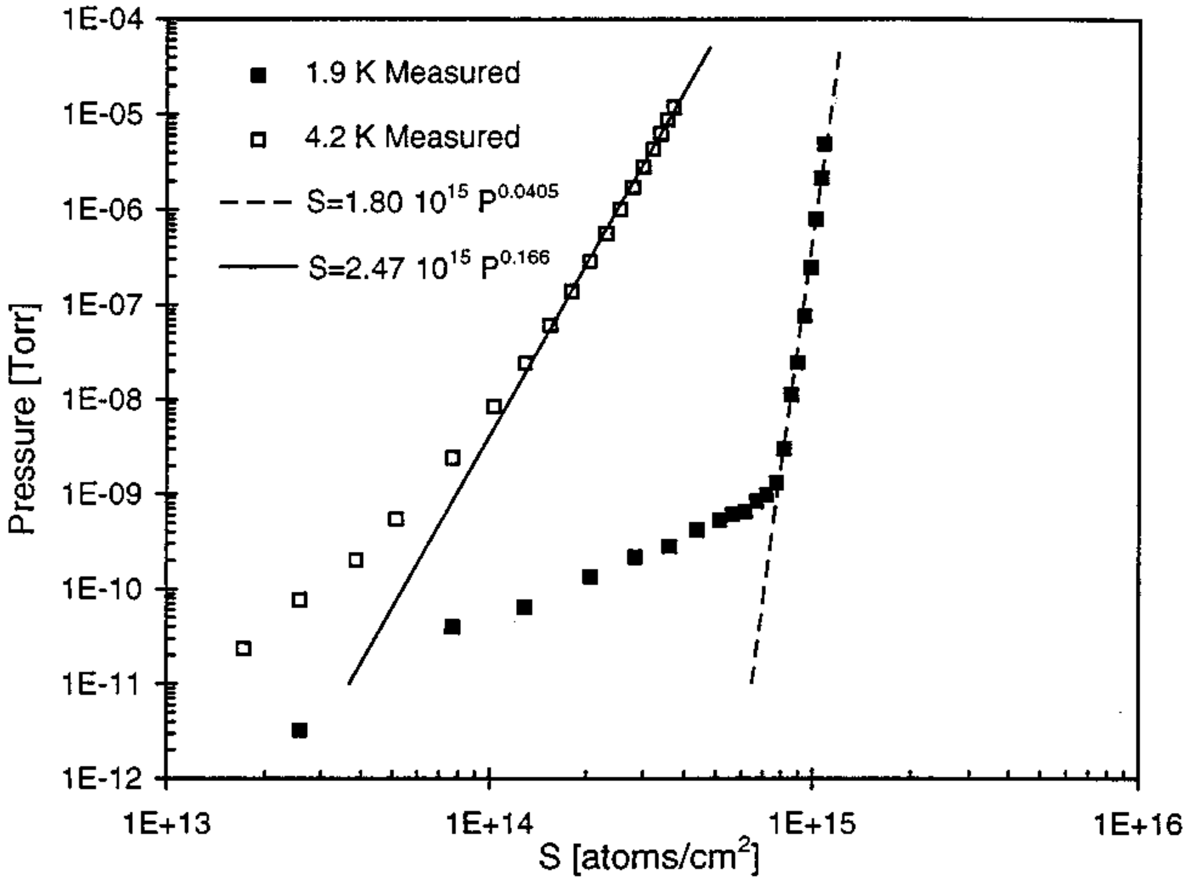
Paola Arias has calculated the photon-ALP coupling strength for n> 1 in the ALPS IIc setup with **10 dipoles**! Here an example:



Calculation by Paola Arias

Dieter Trines

Helium atoms will also condense on the cold wall of the pipe. But when the coverage of molecules approaches a so called ‘mono layer’ (~ 10^15 molecules/cm^2) the gas pressure in the pipe will reach values useful for the ALPS II experiment.



Experimental test of the propagation of a He pressure front in a long, cryogenically cooled tube

E. Walle´n
CERN, CH-1211 Geneva 23, Switzerland

J. Vac. Sci. Technol. A 15(6), 2949-2958 ,Nov/Dec 1997

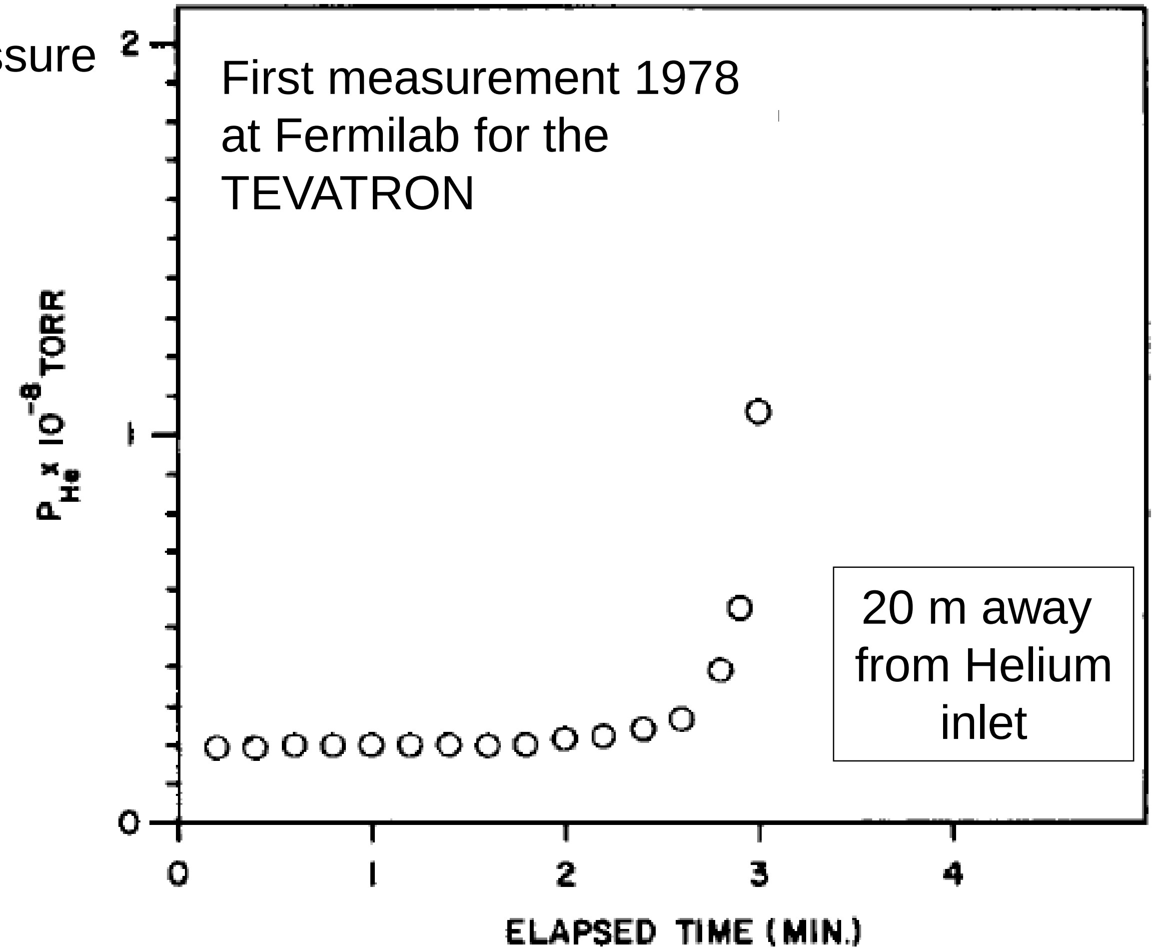
For the pressure range between
5*10^-4 and 5*10^-2 mbar
we need higher surface coverage.

When one inserts Helium into an evacuated pipe at 4.2K
it takes some time for the Helium to spread along the pipe.

Helium gas injected into the cold beam pipe will condense on the cold wall of the pipe. The coverage will propagate along the pipe until an equilibrium between the pressure in the gas and the coverage on the wall has been established in the whole tube.

One has to wait until an equilibrium has been established.

pressure

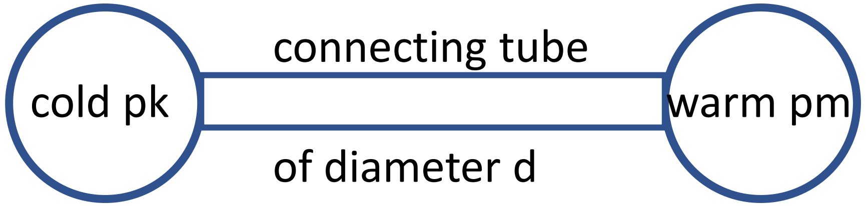


Helium gas was inserted into the beam pipe of the TEVATRON at Fermilab and the pressure was measured 20 m away from gas inlet.

FIG. 3. A record in time of the helium pressure at the sniffer location after establishing a helium pressure of ~2.5×10^{-4} Torr 20m away.

D. Edwards jr., P. Limon J.Vac.Sci.Technology 15(3)1978,p.1186

To determine the ‘cold’ pressure pk f.i. in a beam pipe from the pressure pm measured at room temperature, the Knudsen equation, relating the pressures within vessels at different temperatures connected by a tube, is used in the literature.

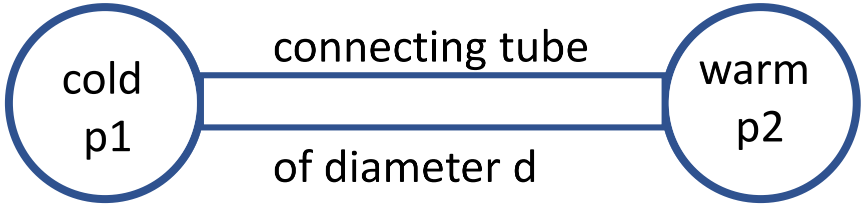


$$p_k := p_m \cdot \sqrt{\frac{T_k}{T_m}}$$

For mean free path
λ >> tube diameter

However, this simple Knudsen relation starts to break down for Helium in the pressure range above 10^-5 mbar at 4.2 K for the size of the ALPS II beam pipe (5.3 cm).
(mean free path λ ≈ 4 cm at ~10^-5 mbar and 4.2 K).

The so called **'thermal transpiration ratio R (=p_1/p_2)'** for connected vessels at different temperatures has been **measured** for Helium and **empirical formulas** have been established to describe the behavior **between molecular and viscous regime.**



Some Measurements of Thermal Transpiration

S. Chu Liang
National Research Council, Ottawa, Canada
(Received July 7, 1950)

for instance

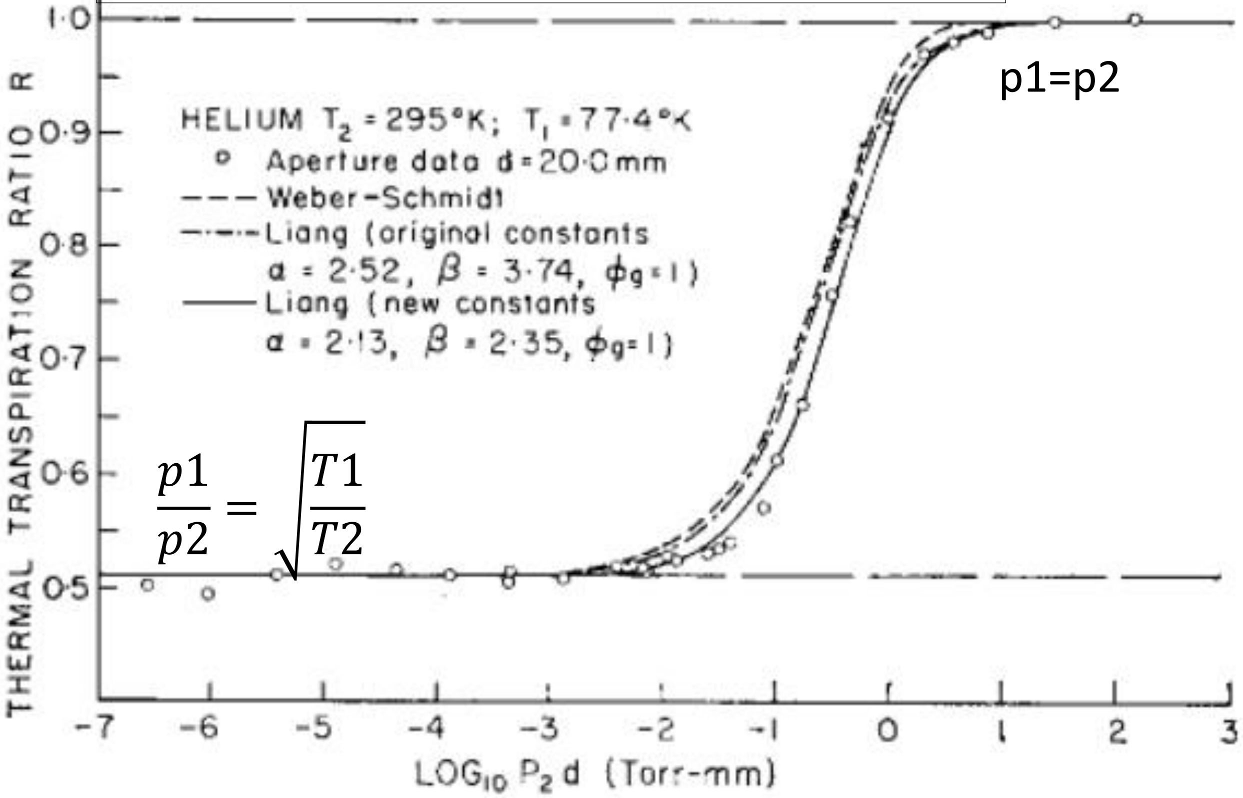
$$R = \frac{\alpha_{He}(\phi_g X)^2 + \beta_{He}(\phi_g X) + R_m}{\alpha_{He}(\phi_g X)^2 + \beta_{He}(\phi_g X) + 1},$$

where $X = P_2 d$,

ϕ=0 for Helium $\quad R_m = (T_1/T_2)^{1/2}$,

The figure shows measurements of the thermal transpiration ratio for Helium at 77,4 K as a function of the 'warm' pressure p2 times the tube diameter by Edmonds and Hobson

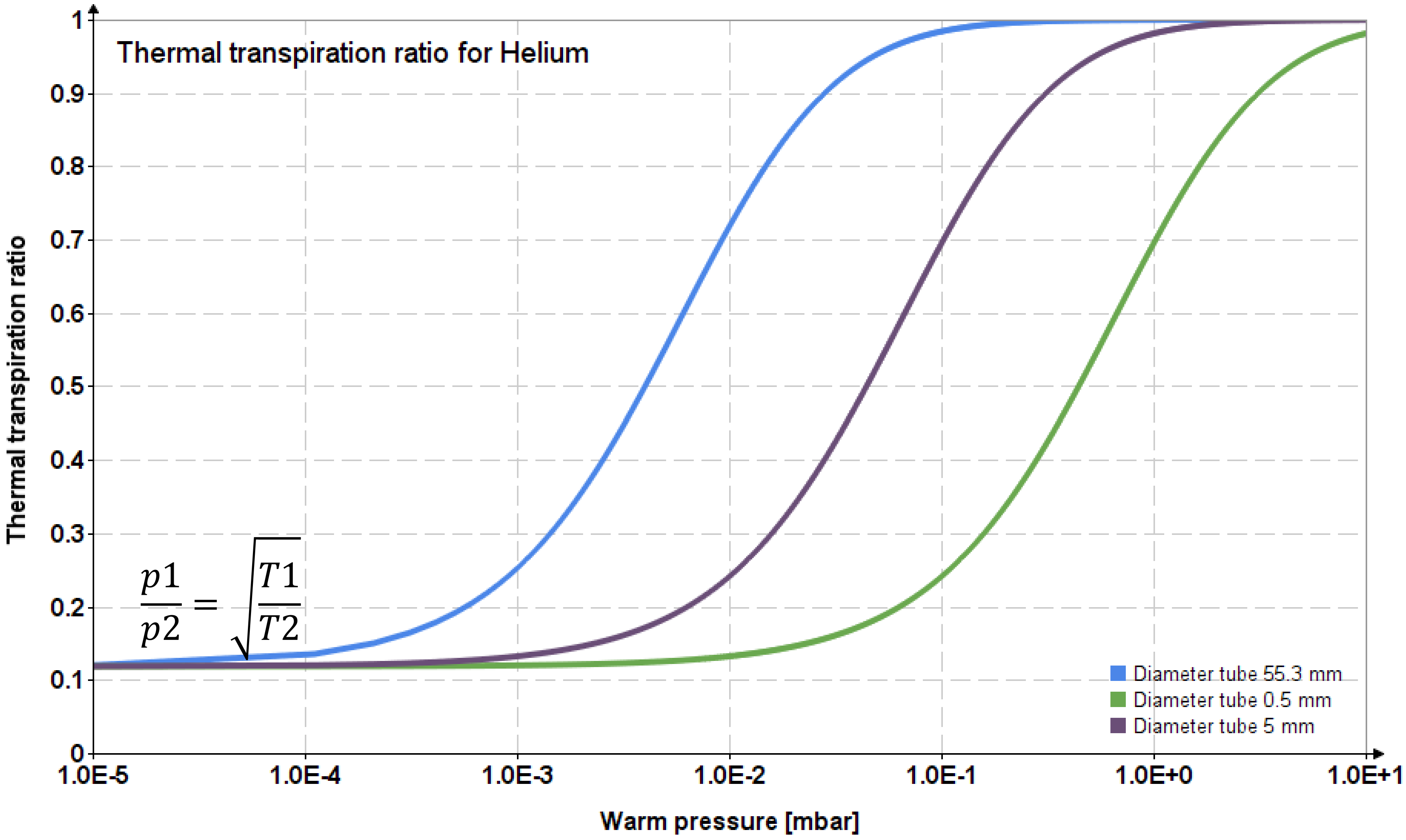
empirical formula fits the data very well



A Study of Thermal Transpiration Using Ultrahigh-Vacuum Techniques
Edmonds and Hobson
Journal of Vacuum Science and Technology **2**, 182 (1965); https://doi.org/10.1116/1.1492423

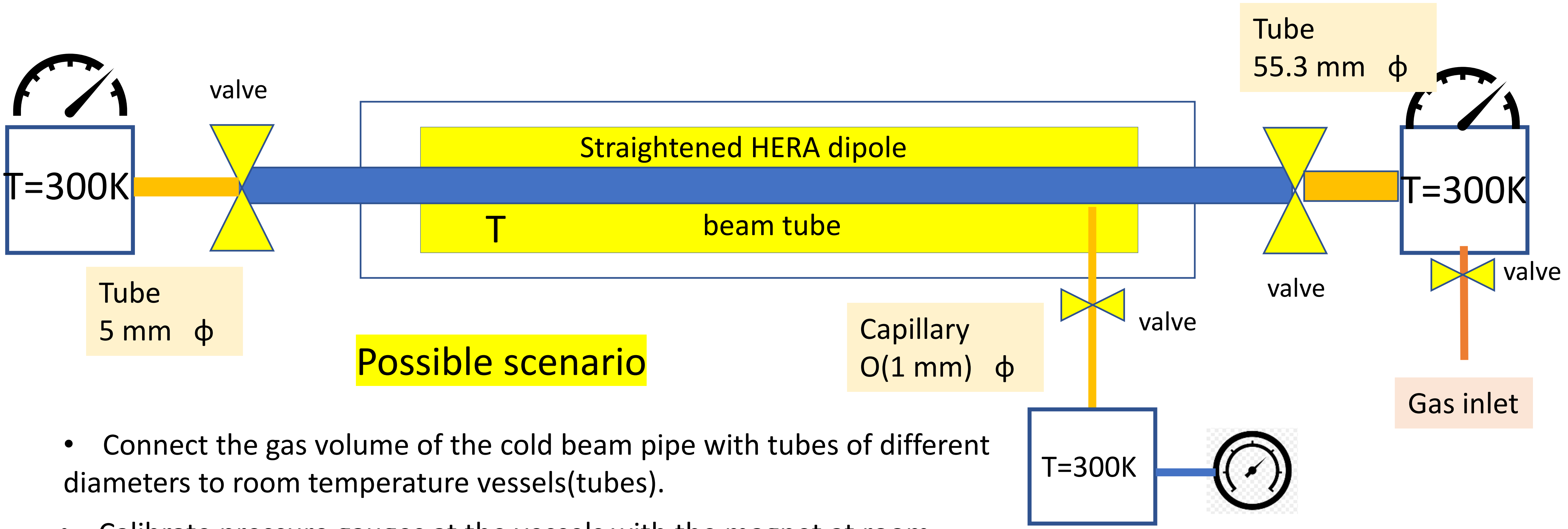
The transpiration ratio R=p1/p2 for Helium, using the Liang formula (with the constants modified by Edmonds and Hobson), is shown for a temperature of 4.2 K and tubes with different diameters connecting cold and warm volume.

It should be verified, that the relation is applicable in temperature range below ~10K.



I am considering to perform an experiment at the HERA dipole remaining on the test bench. Experimental program and details have to be worked out with the colleagues from the vacuum group MVS and the cryogenics group MKS. Christoph Reinhardt wants to join.

Goal: establish best method to determine Helium pressure in cold pipe

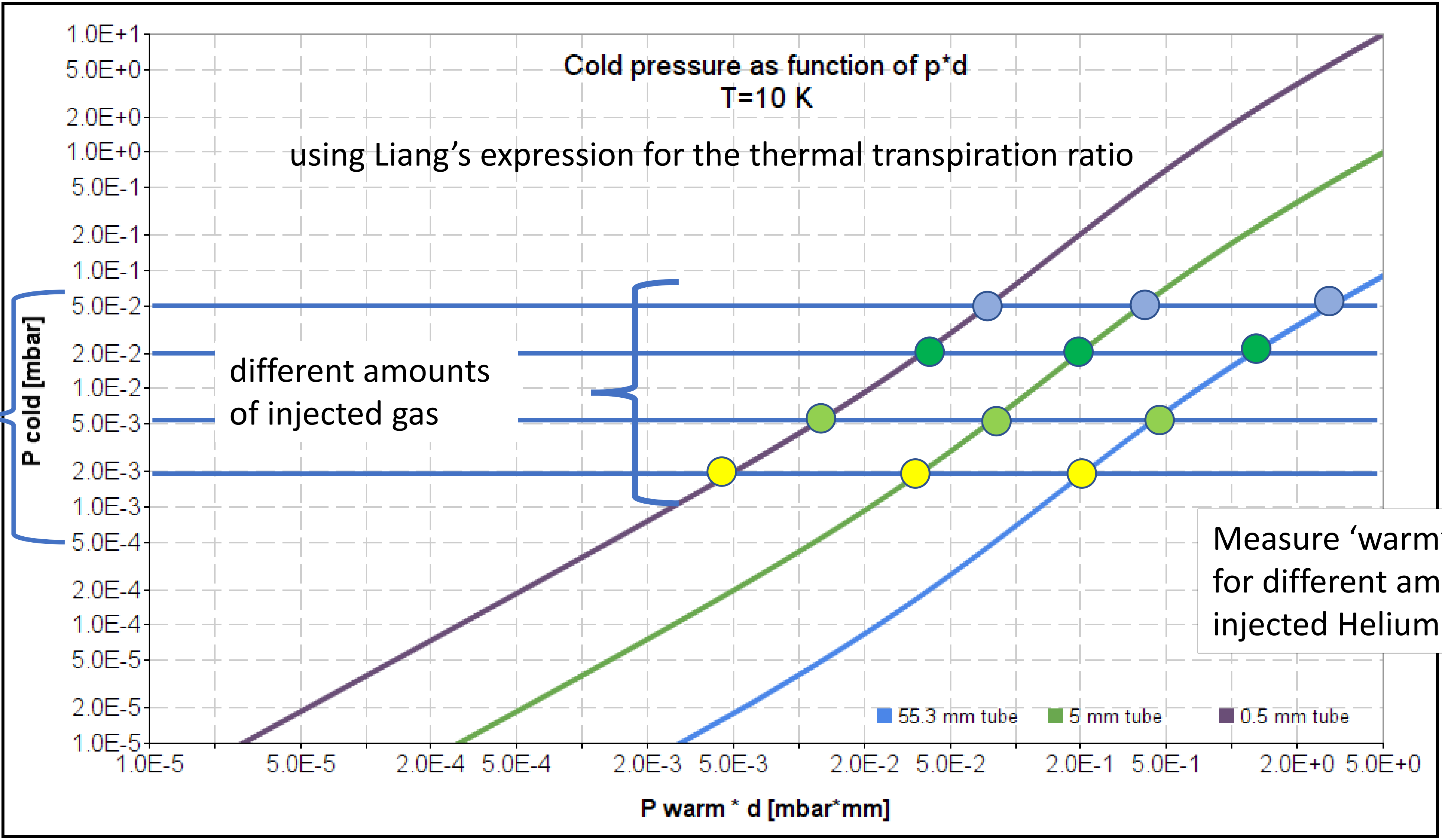


Possible scenario

- Connect the gas volume of the cold beam pipe with tubes of different diameters to room temperature vessels(tubes).
- Calibrate pressure gauges at the vessels with the magnet at room temperature by establishing several Helium pressures in the pipe.
- Cool down dipole to ~ T~10 K
- When cold, let several fixed amounts of Helium gas into the system starting from low pressure. Wait for stabilization of pressures.
- The pressure in the cold magnet tube is given by the amount of inserted gas. It can be related to the pressures measured at room temperature.

Possible experiment at the HERA dipole on the test bench.

relevant pressure range: 5*10^-4 to 5*10^-2 mbar at 4.2K



Measure 'warm' pressures for different amounts of injected Helium gas.

Once validity of relation is established use relation to determine pressure in beam pipe at 4.2 K from pressure measurement at room temperature.

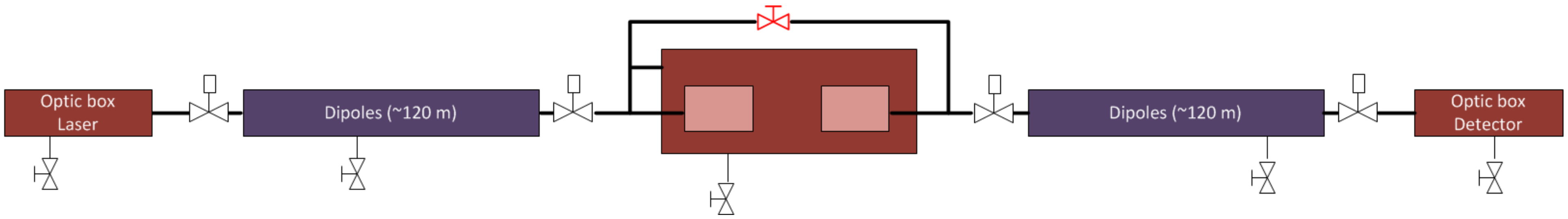
How do we measure the Helium pressure at room temperature?
Range 5*10^-4 to 5*10^-2 mbar.

Capacitive manometers are adequate, provided gas is mainly Helium.

With Non-Evaporable-Getter (NEG) pumps other gases can be pumped away without effecting the Helium pressure.

Other way: After pressure stabilization, close valve between tube and vessel, pump on vessel (through a needle valve) and measure Helium rate at the pump station with a **calibrated leak detector**; integrate rate to get Helium pressure**. Clumsy but possible**.

Scenario for ALPS IIc.
Many details remain to be worked out
with the colleagues from MVS and MKS.



System at room temperature

(Install Non-Evaporable-Getter (NEG) pumps at optical vessels.)?

Pump down whole system with turbo pumps

Valve off ion sputter pumps.

Inject defined quantities of Helium into the system for the calibration of pressure gauges

Pump out Helium gas from pipe

Cool down magnet strings

System at 4.2 K

(Activate NEG pumps)?
Inject defined quantities of Helium into the system at one side.
Measure Helium pressure and evolution.
Wait for stabilization.
Measure ALPs rate.

END

Dependence of the refractive index n on the pressure p of Helium in the cold beam pipe

The refractive index of Helium at 300K, 1000mbar and
a wavelength of 1064 nm is 1,00003475
and for green light of 532 nm 1,00003503

from Michael Polyansky 'refractive index Info'; Source: Handbook of Optical Materials
Marvin J. Weber

The relation between the gas density ρ and the refractive index is given by the Lorentz-Lorenz law

$$\text{konst}\cdot\rho := \frac{n^2 - 1}{n^2 + 2}$$

As the deviation of n from 1 is very small in our case the relation simplifies to:

$$\text{konst}\cdot\rho := \frac{2}{3}\cdot(n - 1)$$

$$n_c - 1 = (n_w - 1)\frac{T_w}{T_c}\frac{p_c}{p_w}$$

With pw=1000 mbar
Tw =300K

END