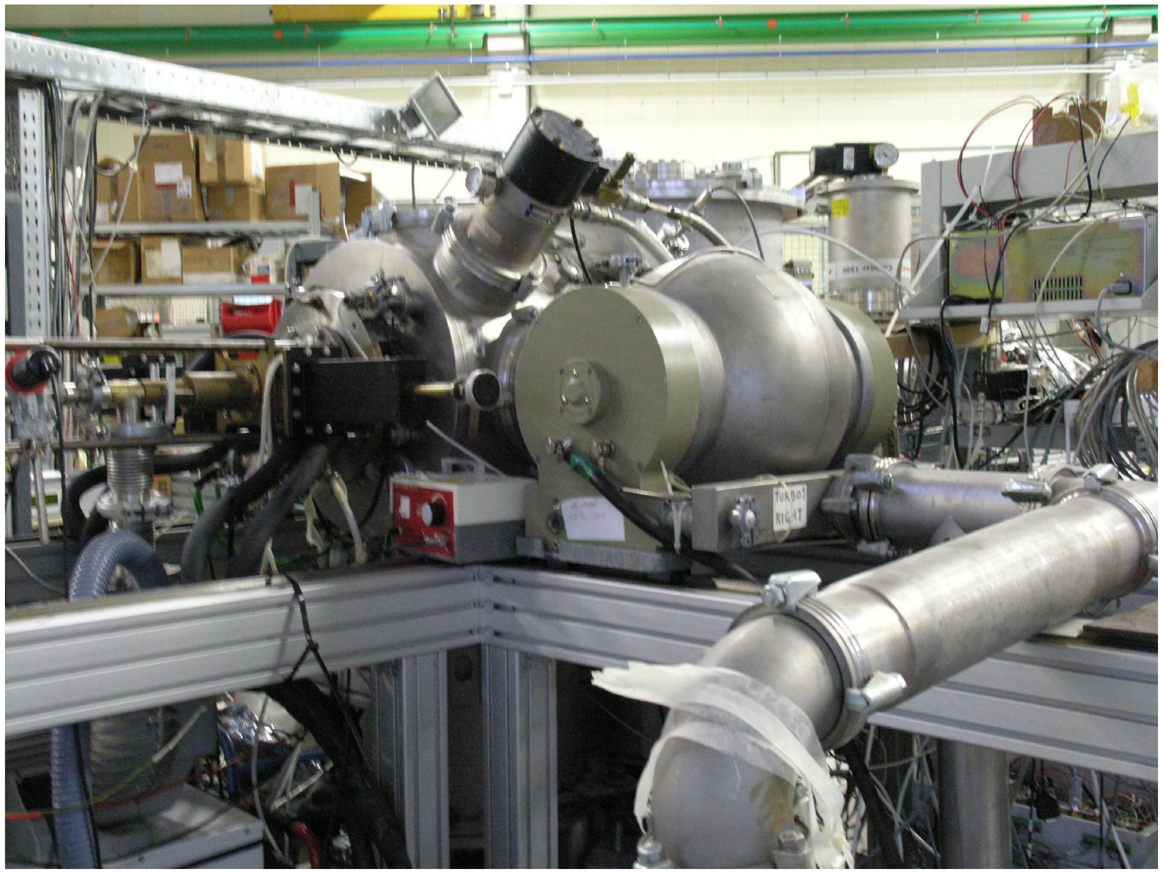
Rest Gas attenuation measurements

@SpinLab - Ferrara



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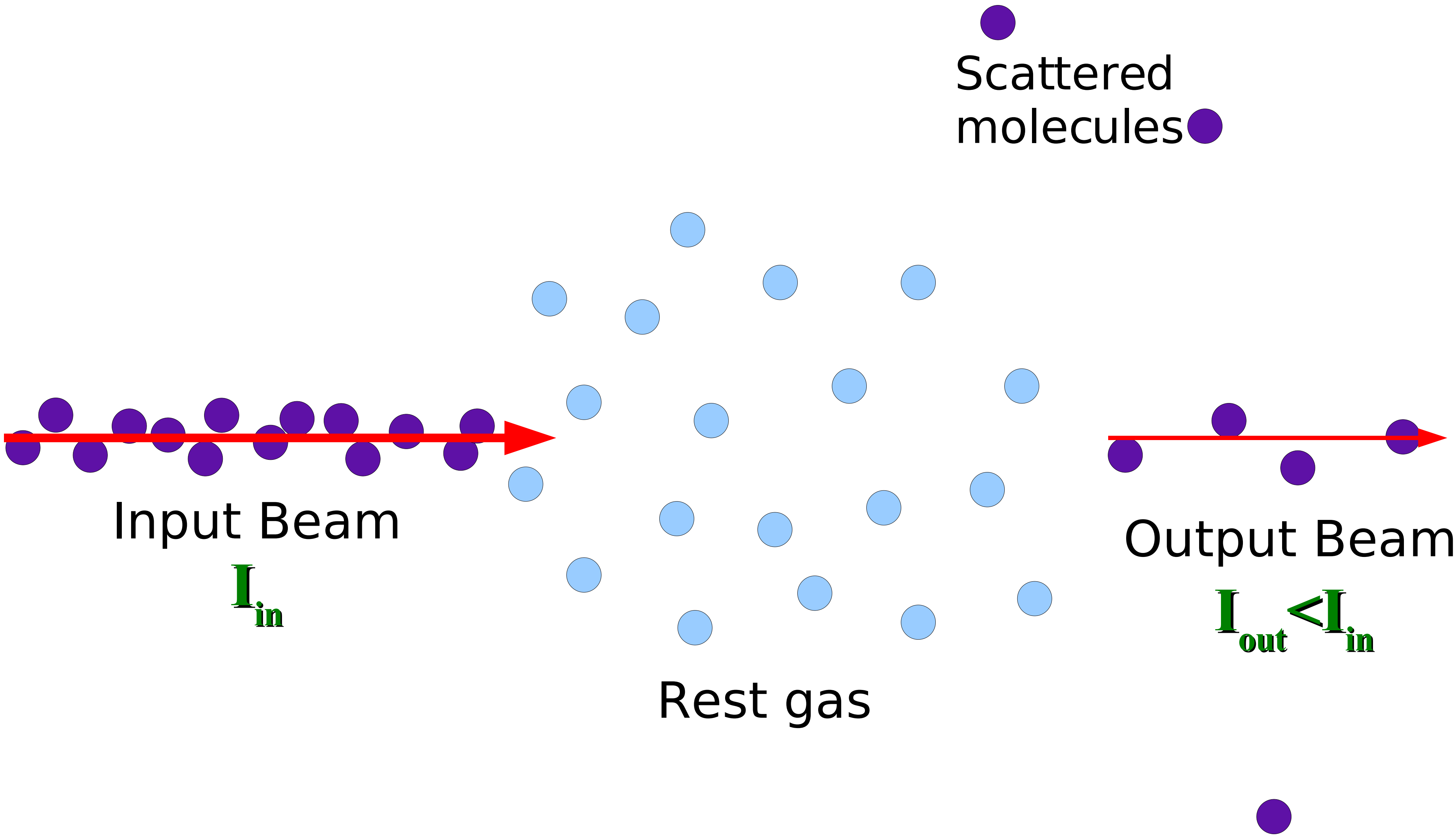
Interaction between beam and rest gas



$$\sigma_{eff} = \iiint f_b(v_b) \otimes f(v_g) \otimes \sigma(|\vec{v}_b - \vec{v}_g|) \otimes \sqrt{1 + \frac{V_g^2}{V_b^2}} \cdot dv_b dv_g$$

Legend

$V_b = Beam\,Velocity$
$V_d = Drift\,Velocity$
$V_{mp} = Most\,Probable\,Velocity\,(Maxwell-Boltzmann)$
$V_g = Rest\,Gas\,Velocity$
$\sigma_{hs} = Hard\,Sphere\,Cross\,section$
$T_b = Beam\,Temperature$
$g = |\vec{v}_b - \vec{v}_g|$
$uma = Atomic\,Mass\,Unit\,(1.6605 \cdot 10^{-27}\,Kg)$
$K_b = Boltzmann\,Constant\,(1.3806 \cdot 10^{-23}\,m^2\,kg\,s^{-2}\,K^{-1})$

$\boldsymbol{\sigma_{eff1}}$

$v_b \rightarrow \delta$
$v_g \rightarrow maxwellian$
$\sigma \rightarrow constant\,(\sigma_{hs})$

$$\sigma_{eff1} = \frac{2 \cdot i_1 \cdot \sigma_{hs}}{\sqrt{\pi} \cdot V_b^2 \cdot V_{mp}}$$

$$f_1(g) = g^2 \cdot e^{-\left(\frac{g^2 + V_b^2}{V_{mp}^2}\right)} \cdot \sinh\left(\frac{2 \cdot V_b \cdot g}{V_{mp}^2}\right)$$

$$i_1 = \int_a^b f_1(g) \cdot dg$$

$\boldsymbol{\sigma_{eff2}}$

$v_b \rightarrow mod.maxwellian$
$v_g \rightarrow maxwellian$
$\sigma_g \rightarrow constant\,(\sigma_{hs})$

$$\sigma_{eff2} = \frac{i_2}{i_{2b}}$$

$$f_2(v) = v^2 \cdot e^{-\beta(v - V_d)^2} \quad , \quad \beta = \frac{uma}{K_b \cdot T_b}$$

$$i_2 = \int_a^b f_2(v) \cdot \sigma_{eff1}(v) \cdot dv \quad , \quad i_{2b} = \int_a^b f_2(v) \cdot dv$$

$\boldsymbol{\sigma_{eff3}}$

$v_b \rightarrow delta$
$v_g \rightarrow delta$
$\sigma_g \rightarrow constant\,(\sigma_{hs})$

$$\sigma_{eff3} = \sigma_{hs} \cdot \sqrt{1 + \frac{V_g^2}{V_b^2}} \quad , \quad V_g = V_{mp}$$

Simulating cross sections

σ_{eff4}

$v_b \rightarrow mod.maxellian$

$v_g \rightarrow delta$

$\sigma_g \rightarrow constant(\sigma_{hs})$

$$\sigma_{eff4} = \sigma_{hs} \cdot \frac{i_4}{i_{4b}}$$

$$f_2(v) = v^2 \cdot e^{-\beta(v - V_d)^2} \quad , \quad \beta = \frac{uma}{K_b \cdot T_b}$$

$$i_4 = \int_a^b f_2(v) \cdot \sqrt{1 + \frac{V_g^2}{v^2}} \cdot dv \quad , \quad i_{4b} = \int_a^b f_2(v) \cdot dv$$

Legend

$V_b = Beam\, Velocity$

$V_d = Drift\, Velocity$

$V_{mp} = Most\, Probable\, Velocity\,(Maxwell - Boltzmann)$

$V_g = Rest\, Gas\, Velocity$

$\sigma_{hs} = Hard\, Sphere\, Cross\, section$

$T_b = Beam\, Temperature$

$g = |\vec{v}_b - \vec{v}_g|$

$uma = Atomic\, Mass\, Unit\,(1.6605 \cdot 10^{-27} Kg)$

$K_b = Boltzmann\, Constant\,(1.3806 \cdot 10^{-23} m^2 kg\, s^{-2} K^{-1})$

σ_{eff5}

$v_b \rightarrow mod.maxwellian$

$v_g \rightarrow maxwellian$

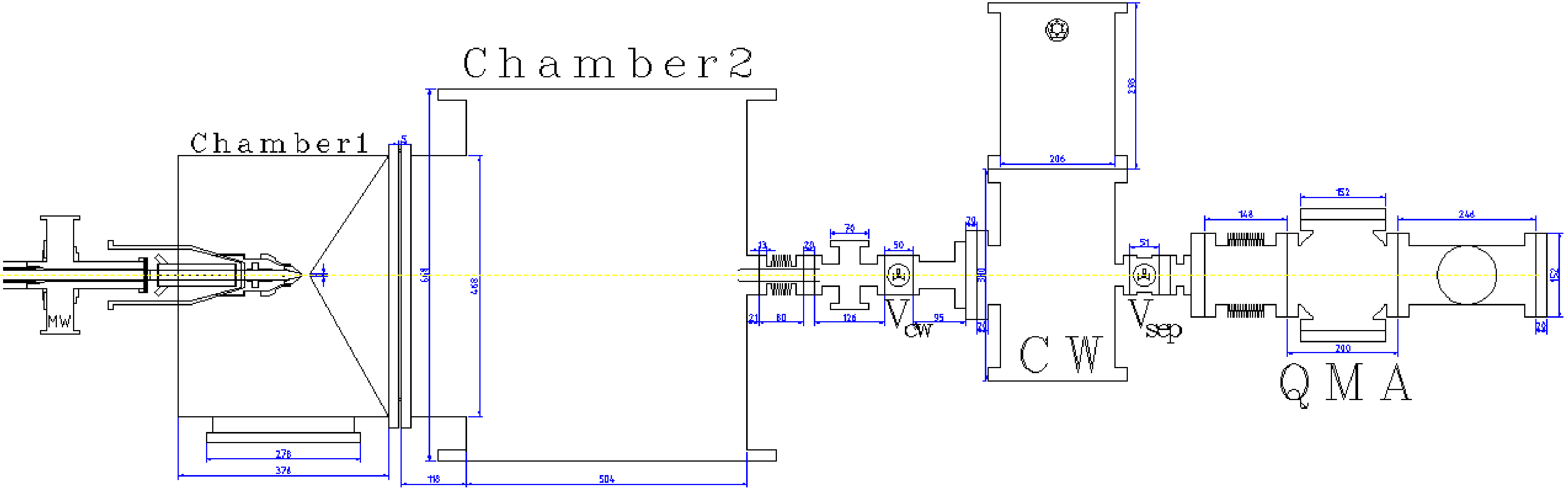
$\sigma_g \rightarrow \pi a^2 \left(\frac{b}{g}\right)^c$

$$\sigma_{eff5} = \frac{i_{5b}}{i_{2b}}$$

$$i_5 = \int_a^b f_1(g) \cdot \pi \cdot (\boldsymbol{a} \cdot 10^{-10} m)^2 \cdot \left(\frac{\boldsymbol{b}\, m/s}{g}\right)^{\boldsymbol{c}} dg$$

$$i_{5b} = \int_a^b f_2(v) \cdot \frac{2 i_5}{\sqrt{\pi} \cdot v^2 \cdot V_{mp}} dv$$

ABS1 layout



Procedure

Experimental

Measure Quadrupole Mass Analyzer (QMA) atomic/molecular signals(S_1,S_2) for different pressures in chamber 2 (HV2)

Plot and fit data: measured slope represents the effective cross section σ_{eff}

Repeat for different nozzle temperatures and plot result (σ_{eff} vs T_{noz})

Fit a,b,c

Compare results

Calculated

Calculate attenuation losses under different assumptions, at different T_{noz}

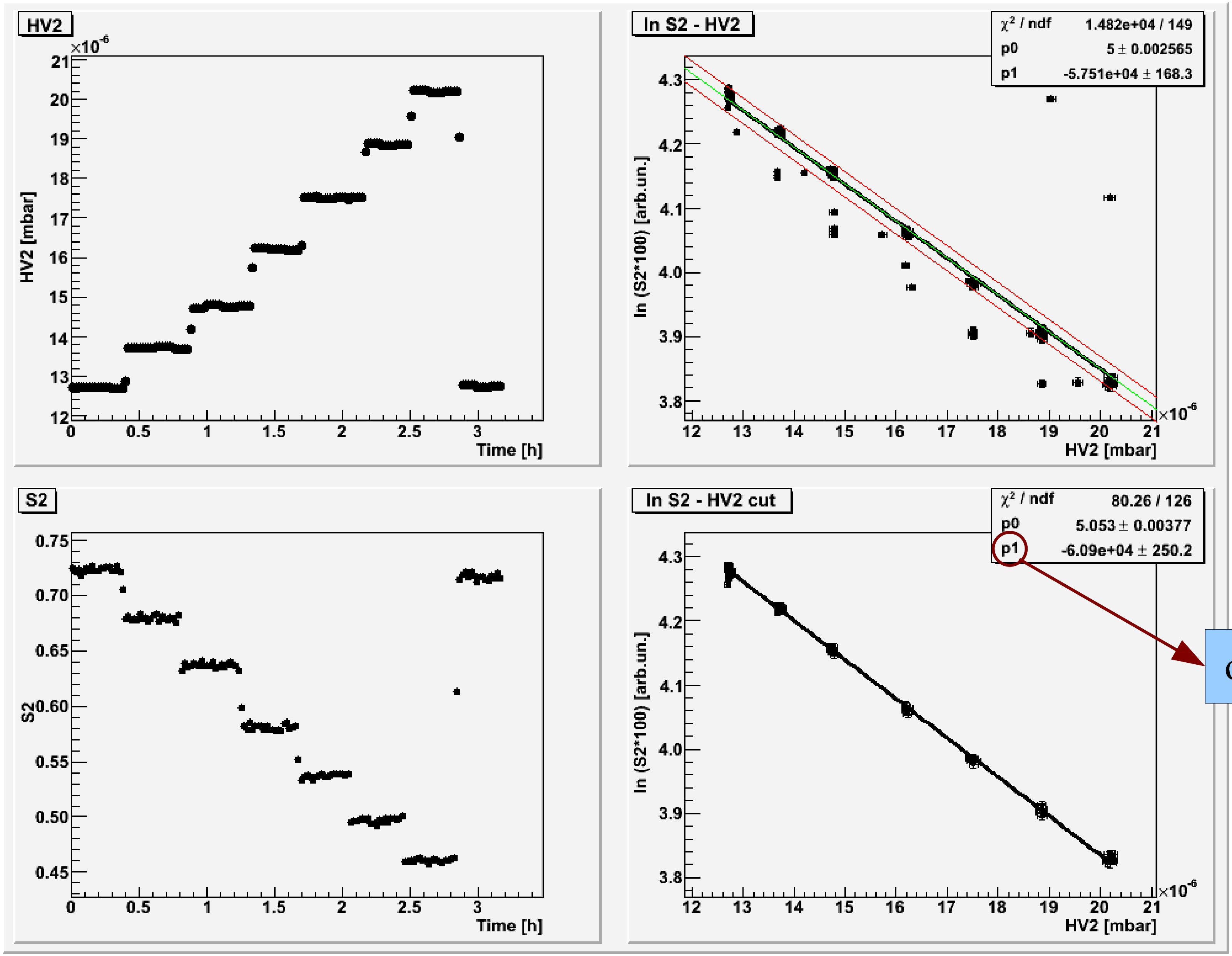
Experimental conditions

Discharge off			Discharge on	
Collar heater	-110 °C		Collar heater	-110 °C
H_2 dissociator flow	125 sccm (50% of 250 sccm)		H_2 dissociator flow	125 sccm (50% of 250 sccm)
O_2 dissociator flow	0 sccm (0% of 5 sccm)		O_2 dissociator flow	2.5 sccm (50% of 5 sccm)
Microwave power	0 W		Microwave power	600 W

Sample 1	Nozzle 2 mm, molecular beam, discharge off
Sample 2	Nozzle 2 mm, molecular beam, discharge on
Sample 3	Nozzle 2 mm, atomic beam, discharge on
Sample 4	Nozzle 4 mm, molecular beam, discharge off

Experimental data analysis

Sample 1
T_{noz} 55 uK



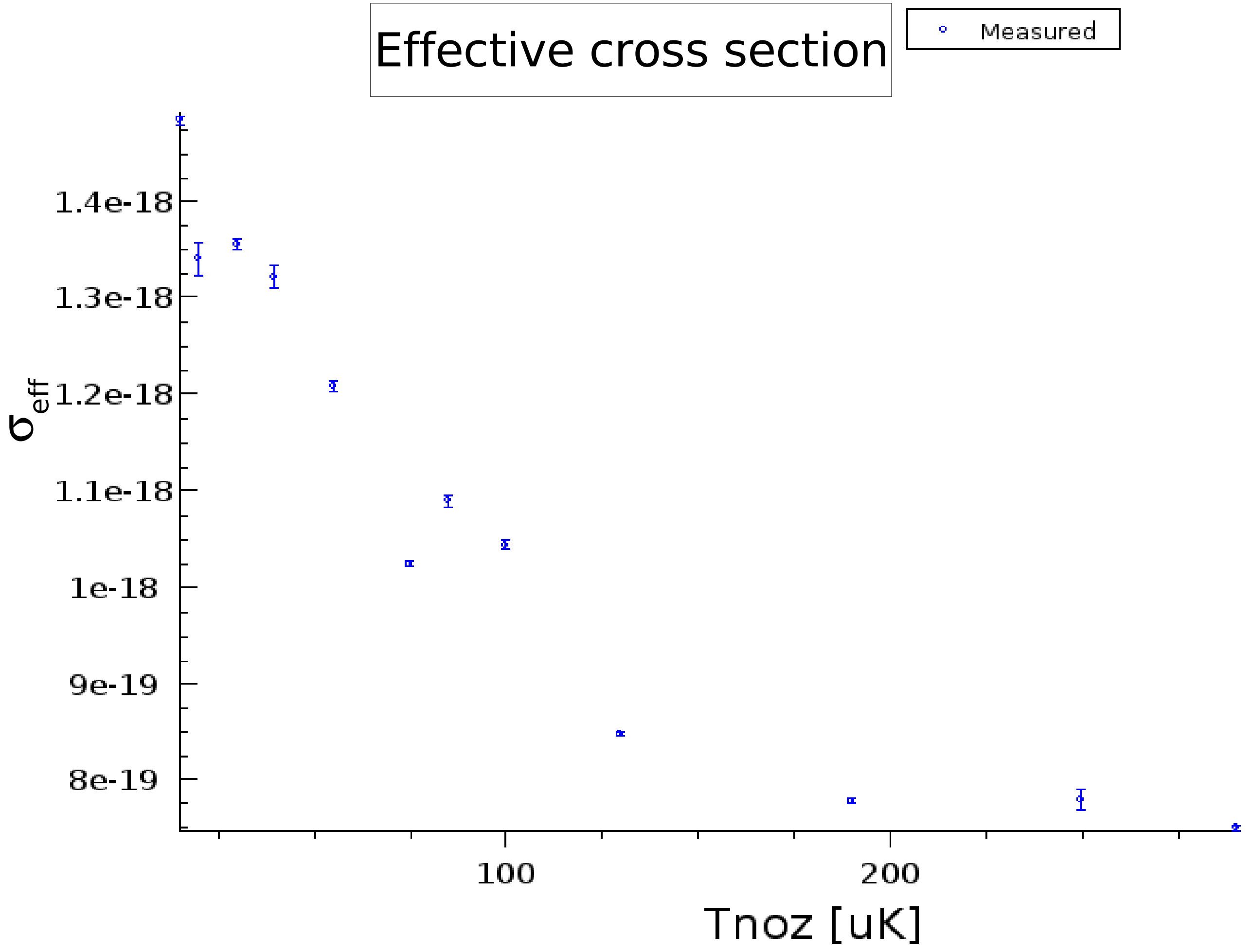
ϕ=slope

Sample 1

From attenuation measurements to σ_{eff}

$$\sigma_{eff}(T_{noz})=\phi\cdot K_b\cdot T_{rg}\cdot K_{gauge}/L$$

Effective cross section



Legend

$\phi = S_2\, vs\, HV2\, slope\,[pa^{-1}]$

$K_b = Boltzmann\, Constant$

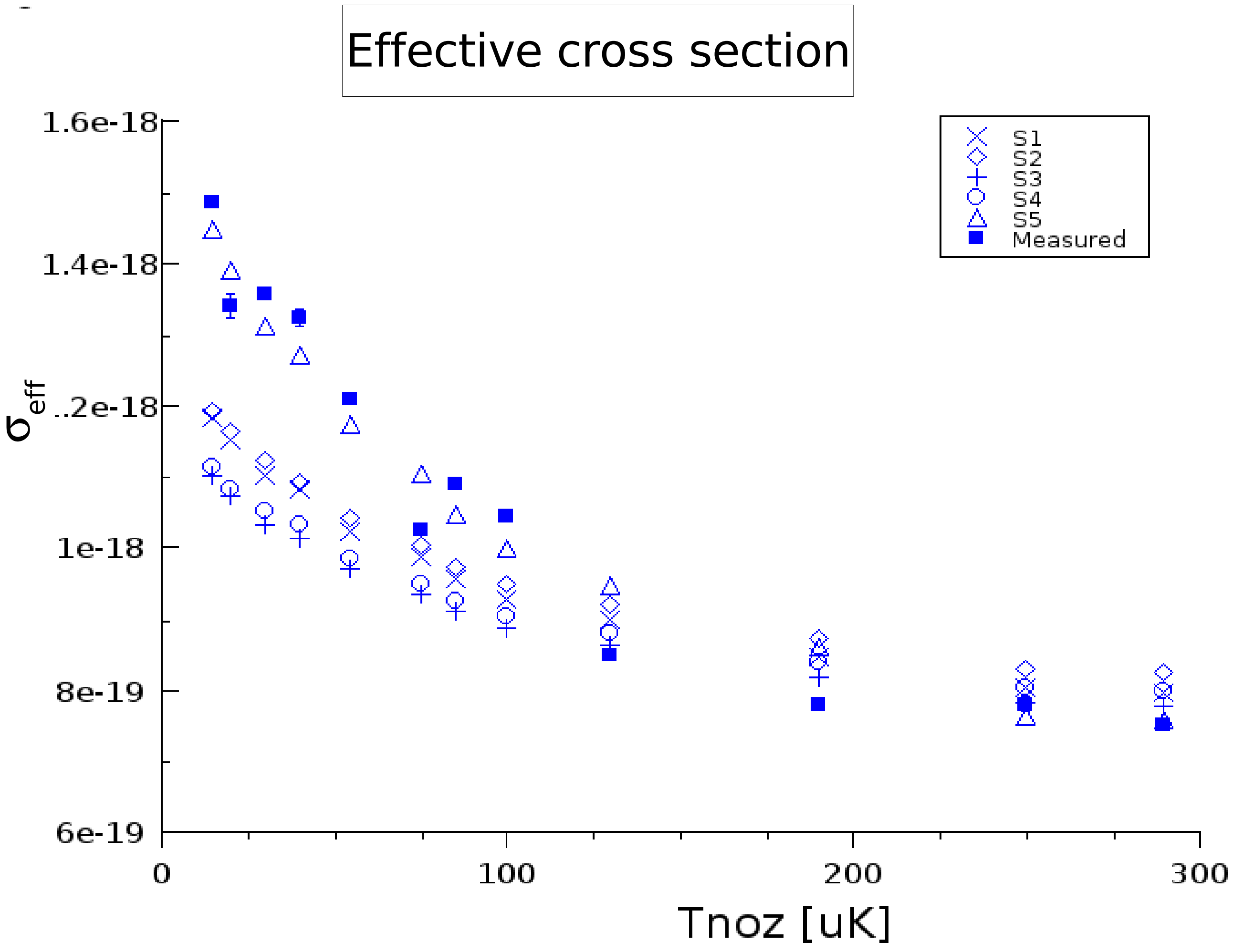
$T_{rg} = Rest\, Gas\, Temperature$

$k_{gauge} = gauge\, calibration$

$L = 0.84\, m\, (effective)$

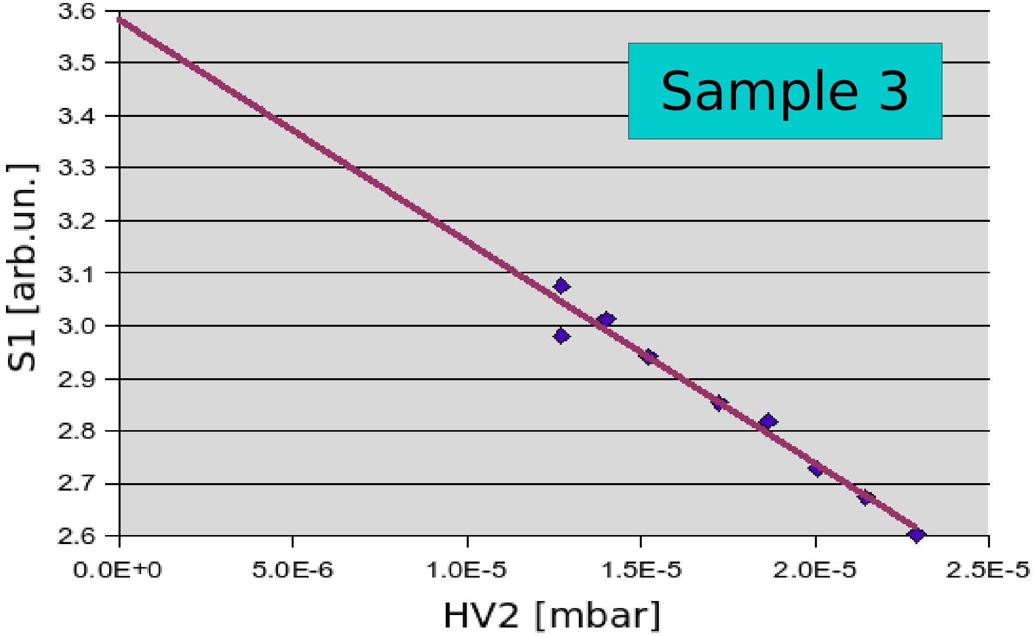
Comparison between experimental data and calculations

Sample 1

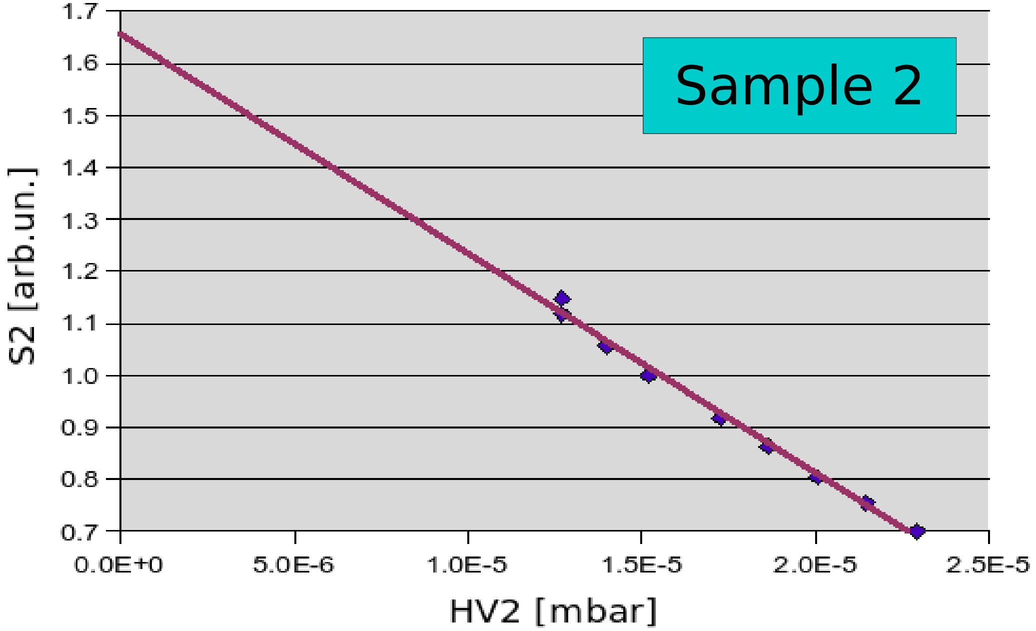


Beam attenuation by rest gas in Chamber 2

ln S1 vs rest gas pressure



ln S2 vs rest gas pressure



Beam attenuation by pressure in Chamber 2

Sample 2 + 3

Nozzle temperature [uK]	Survival fraction	
	Atomic	Molecular
44	60%	55%
50	61%	57%
60	62%	58%
85	63%	60%
90	63%	59%
100	64%	60%
130	67%	62%
190	68%	63%
250	70%	66%
290	71%	65%