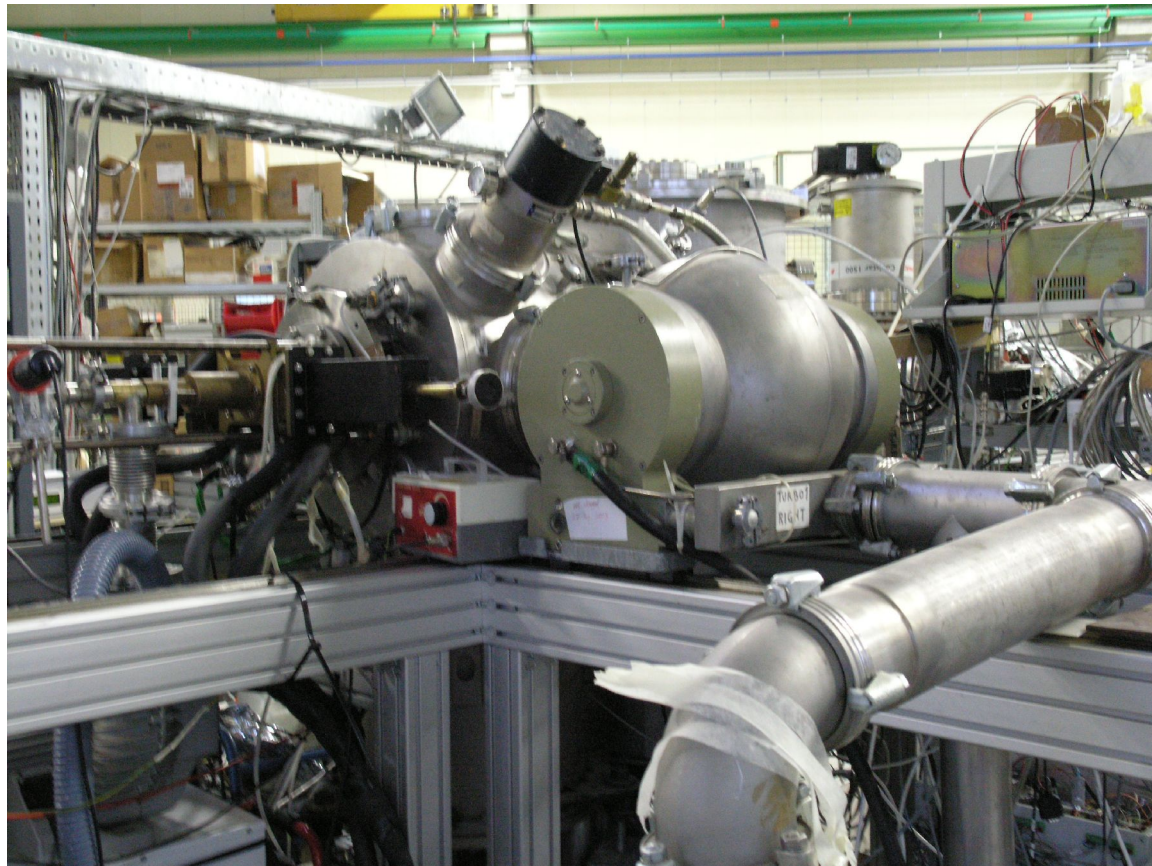


Rest Gas attenuation measurements

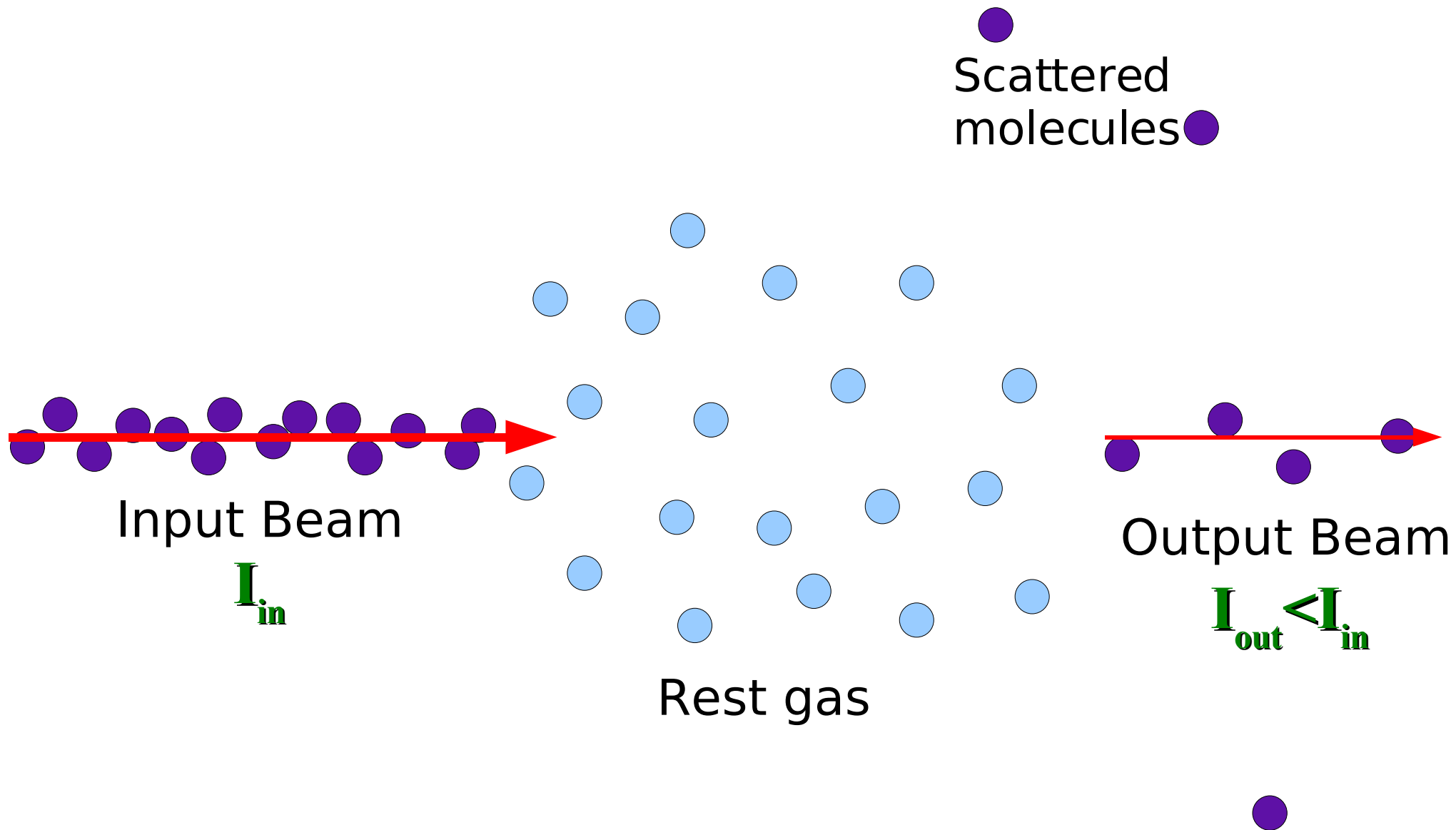
@SpinLab - Ferrara



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Interaction between beam and rest gas



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

σ_{eff1}

$V_b \rightarrow \delta$

$V_g \rightarrow \text{maxwellian}$

$\sigma \rightarrow \text{constant} (\sigma_{hs})$

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

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

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

σ_{eff2}

$V_b \rightarrow \text{mod.maxwellian}$

$V_g \rightarrow \text{maxwellian}$

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

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

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

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

σ_{eff3}

$V_b \rightarrow \text{delta}$

$V_g \rightarrow \text{delta}$

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

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

Legend

$V_b = \text{Beam Velocity}$

$V_d = \text{Drift Velocity}$

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

$V_g = \text{Rest Gas Velocity}$

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

$T_b = \text{Beam Temperature}$

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

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

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

Simulating cross sections

σ_{eff4}

$v_b \rightarrow \text{mod.maxellian}$

$v_g \rightarrow \text{delta}$

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

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

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

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

Legend

$V_b = \text{Beam Velocity}$

$V_d = \text{Drift Velocity}$

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

$V_g = \text{Rest Gas Velocity}$

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

$T_b = \text{Beam Temperature}$

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

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

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

σ_{eff5}

$v_b \rightarrow \text{mod.maxwellian}$

$v_g \rightarrow \text{maxwellian}$

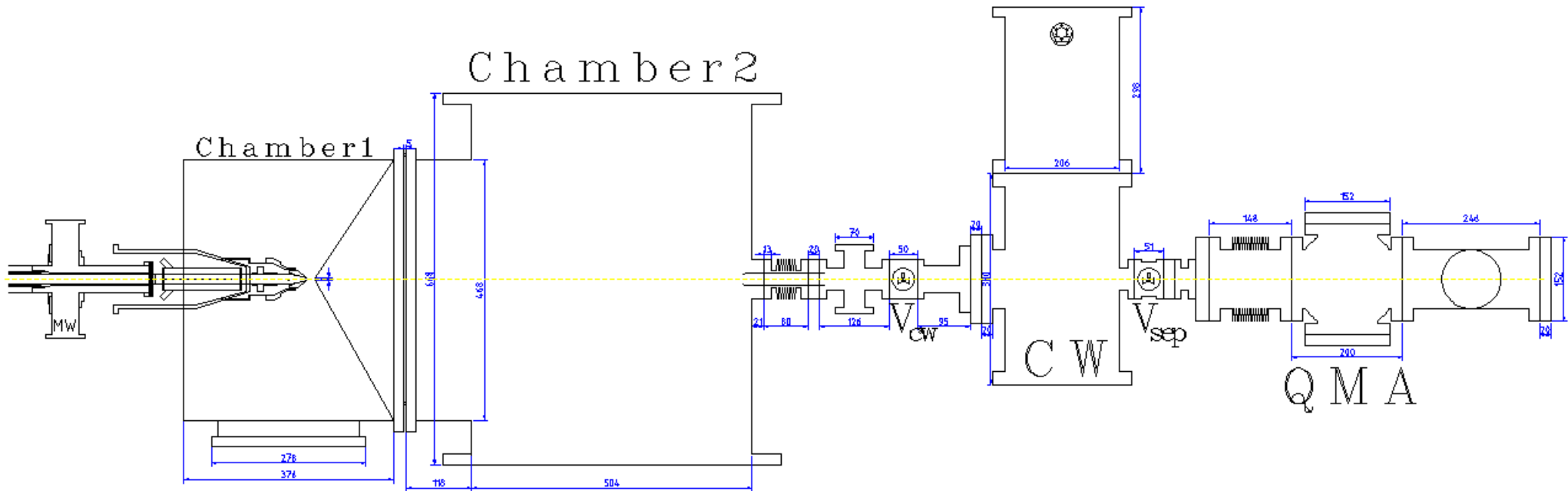
$\sigma_g \rightarrow \pi a^2 \left(\frac{b}{g}\right)^c$

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

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

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

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

Simulation

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

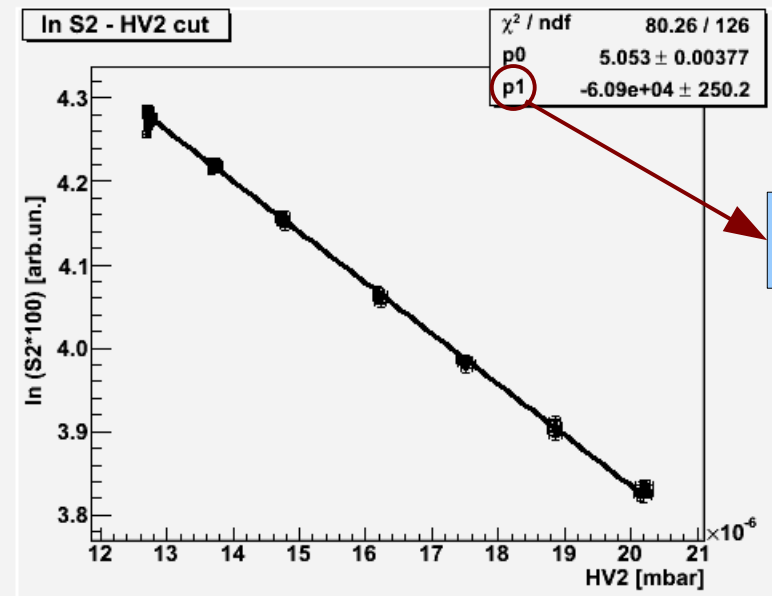
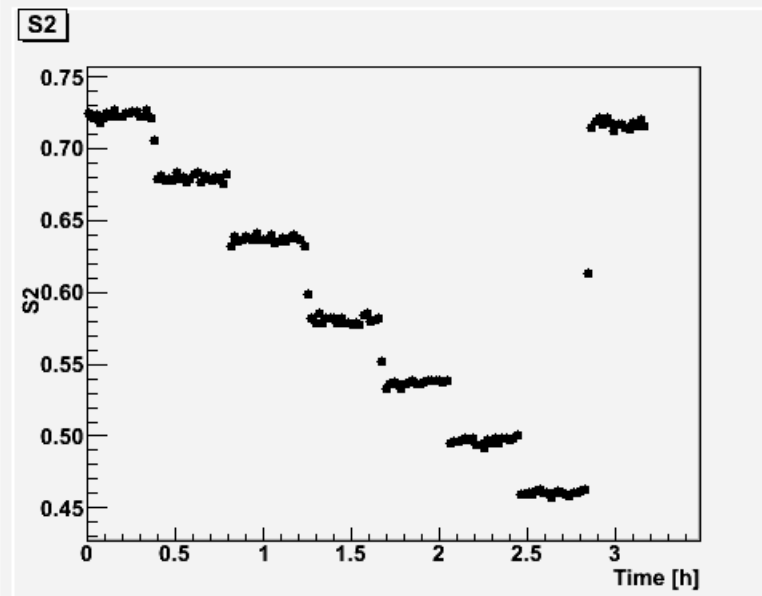
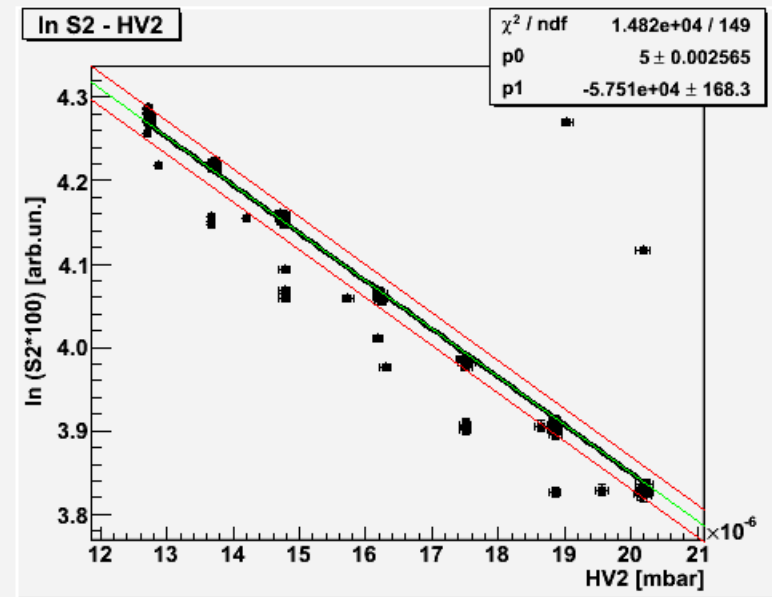
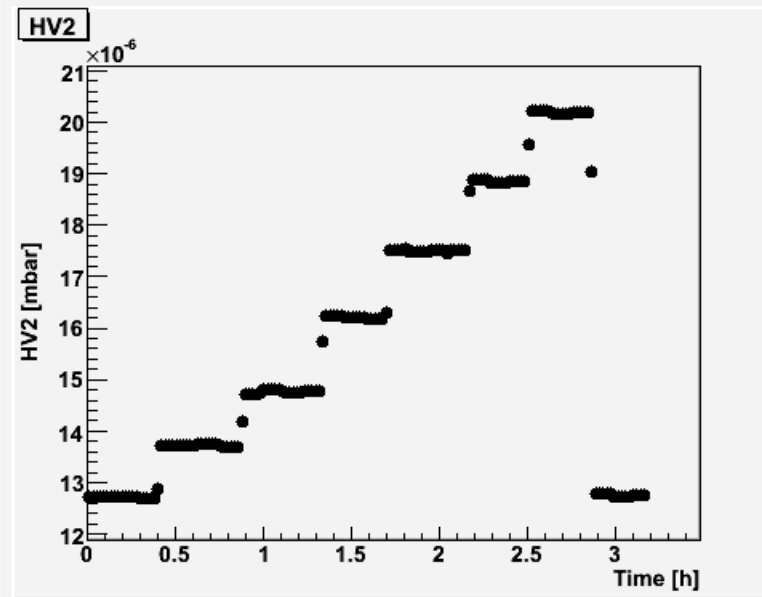
Experimental conditions

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 μ K

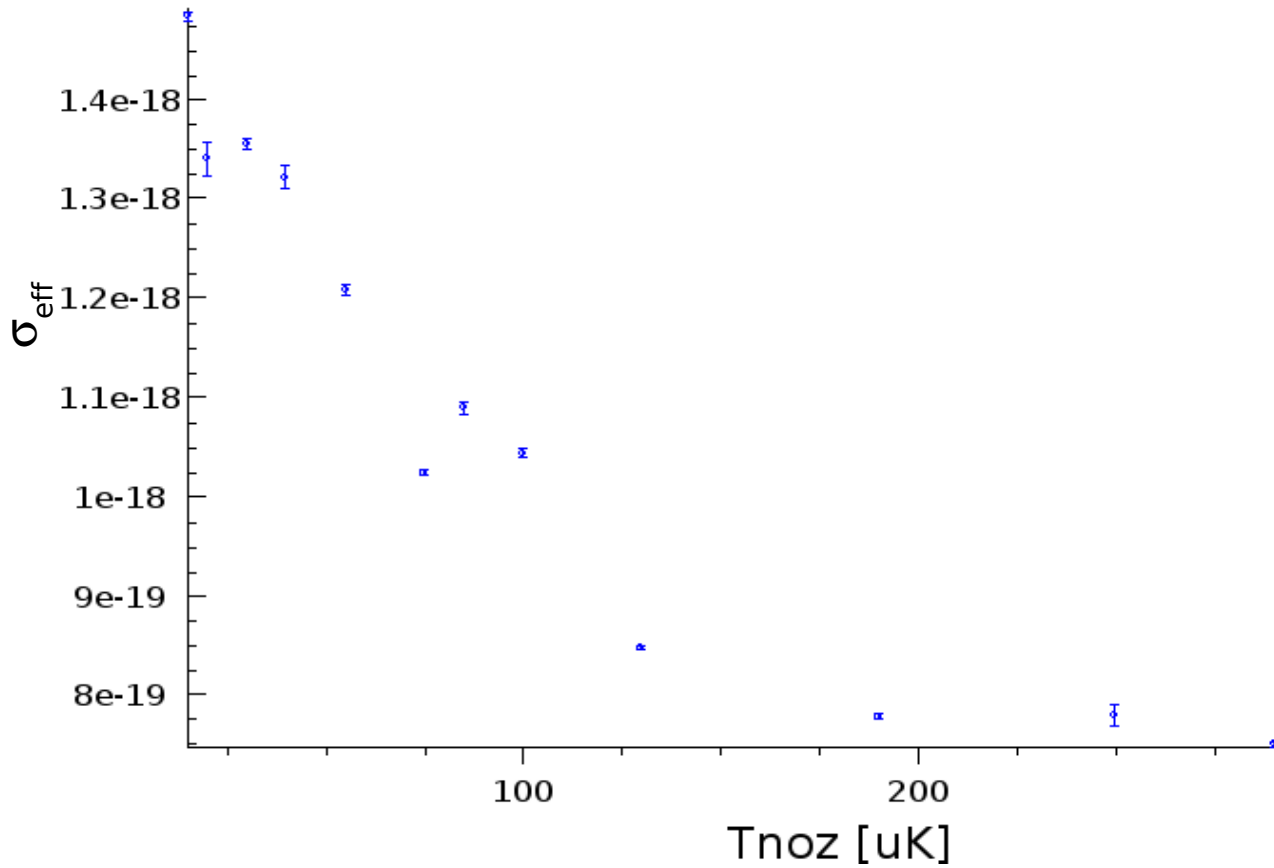


RestGas attenuation measurements

From attenuation measurements to σ_{eff}

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

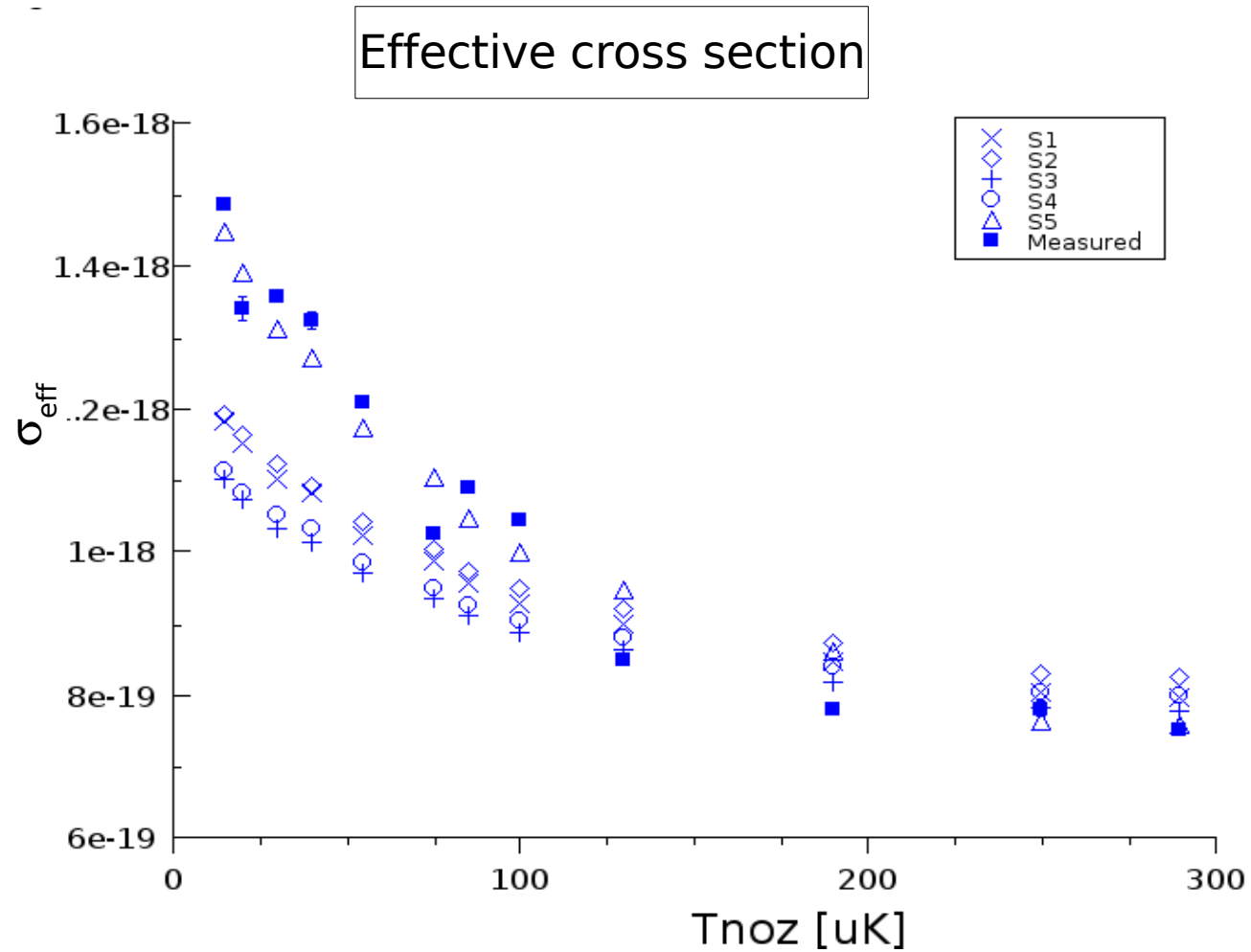
Effective cross section ◦ Measured



Legend

- $\phi = S_2$ vs HV2 slope [pa^{-1}]
- $K_b = \text{Boltzmann Constant}$
- $T_{\text{rg}} = \text{Rest Gas Temperature}$
- $k_{\text{gauge}} = \text{gauge calibration}$
- $L = 0.84 \text{ m (effective)}$

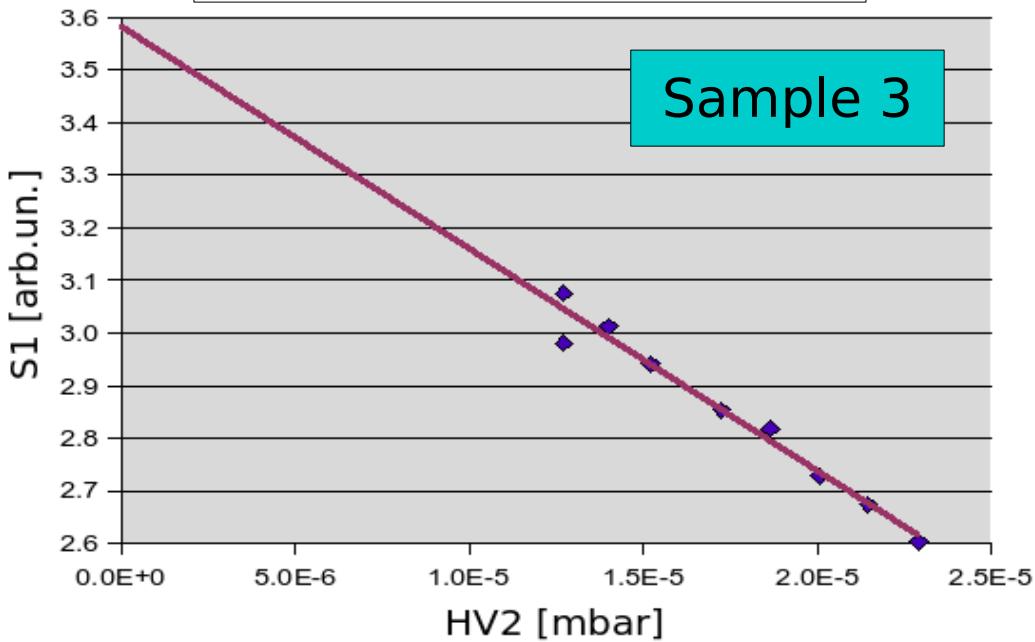
Comparison between experimental data and simulations



Beam attenuation by rest gas in Chamber 2

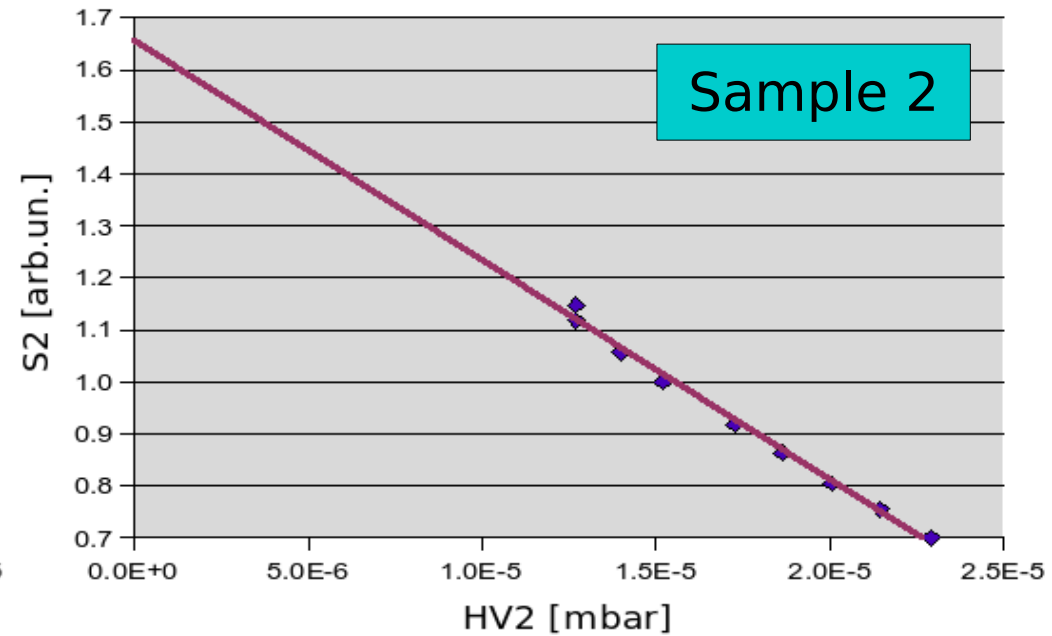
In S1 vs rest gas pressure

Sample 3



In S2 vs rest gas pressure

Sample 2



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%

Beam survival fractions

