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On preparation and analysis of gravitational quantum states in a flow-through mode

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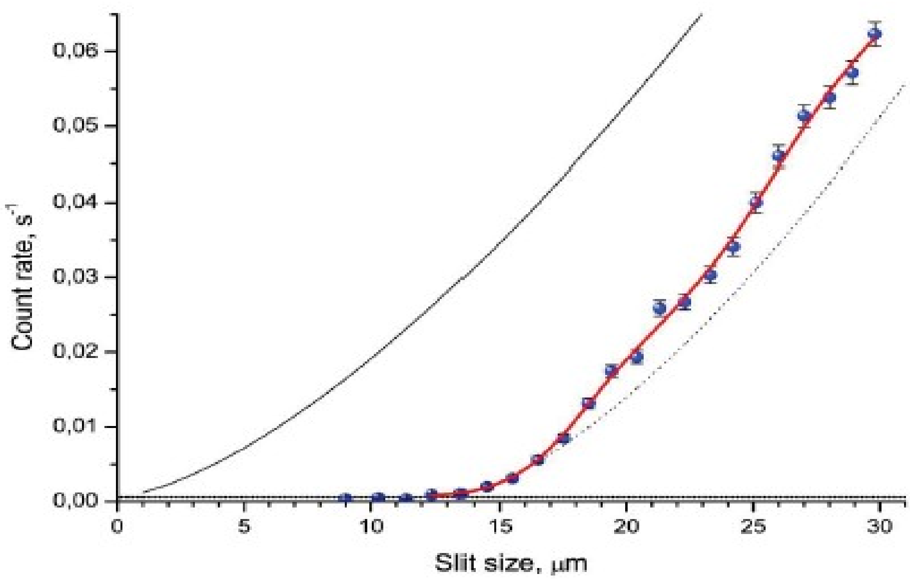
1. Problematic and the system

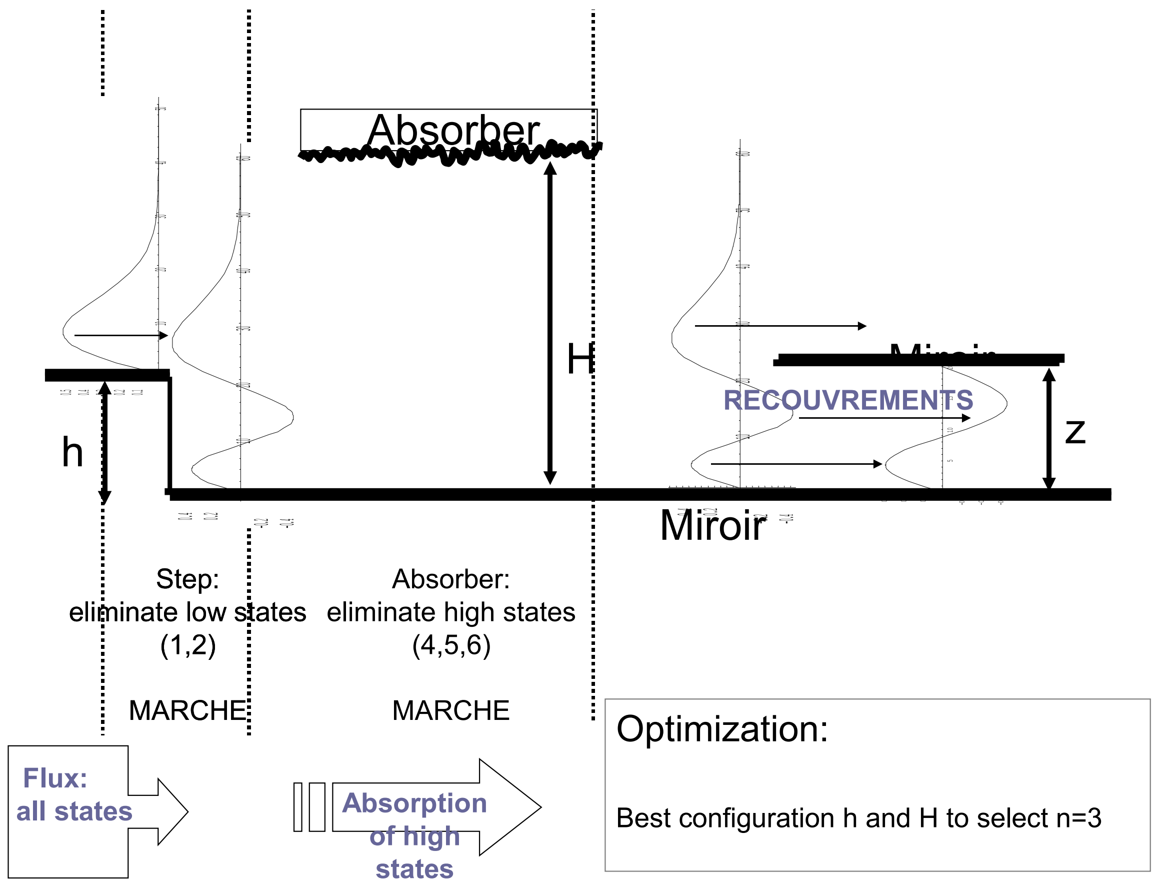
Aim 1: Improve resolution for each quantum states

Aim 2: We need to have only one quantum state to study transition: $3 \rightarrow 1$ or $2 \rightarrow 1 \Rightarrow$ optimisation of step and absorber heights.

Integral method to see quantum states (mirror + absorber $\rightarrow$ detector)



New method :


Absorber
H
h
Miroir
RECOUVREMENTS
z
Step:
eliminate low states
(1,2)
Absorber:
eliminate high states
(4,5,6)
MARCHE
MARCHE
Flux:
all states
Absorption
of high
states
Optimization:
Best configuration h and H to select n=3

2. Preparation of quantum states

- **Quantum states of Neutrons in gravitational field:**

Hamiltonian : $H = \frac{-\hbar^2}{2m}\frac{d^2}{dz^2} + mgz$

Schrodinger equation : $H\psi(z) = E\psi(z),\ \psi(0) = 0$

Eigenfunctions : $\psi_n(z) = a_n Airy(\frac{z-z_n}{z_0}),\ z_0 = (\frac{\hbar^2}{2m^2 g})^{1/3}$

Eigenvalues : $E_n = mgz_n,\ Airy(-z_n/z_0) = 0$

Semiclassical : $E_n \simeq (\frac{9}{8}m\pi^2\hbar^2 g^2 (n - \frac{1}{4})^2)^{1/3}$

- **Step:**

- Initial population : $\beta_i = 1, \; i \neq 0, \; \beta_i = 0.5, \; i = 0$

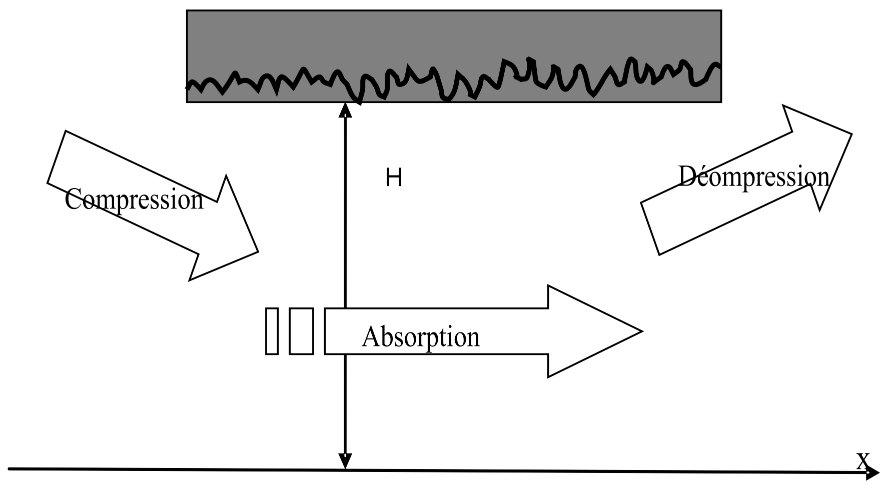
- each quantum states $n \mapsto 1, 2, .., n, ..$ quantum states

- Probability : $P^S_{i \to j} = \int_h^\infty \psi_i(z)\psi_j(z+h)dz$

- Population: $\beta_j^{(S)} = \sum_{i=1}^\infty \beta_i^{(0)} P_{i \to j}$

- **Absorber:**

Description : one smooth mirror + one rough mirror



Three part :

(i) Compression: $\psi_i \mapsto \{\phi_j\}_j$

(ii) Absorption: decreasing of population inside the absorber

(iii) Decompression: $\phi_i \mapsto \{\psi_j\}_j$

Quantum states between two mirrors:

Hamiltonian : $H = \frac{-\hbar^2}{2m}\frac{d^2}{dz^2} + mgz$

Schrodinger equation : $H\phi(z) = E\phi(z),\ \phi(0) = 0,\ \phi(H) = 0$

Eigenfunctions : $\phi_n(z) = c_n \mathrm{AiryAi}(\frac{z-z_n^A}{z_0}) + b_n \mathrm{AiryBi}(\frac{z-z_n^A}{z_0})$

Eigenvalues :

$E_n^A = mgz_n^A,\ c_n \mathrm{AiryAi}(-z_n^A/z_0) + b_n \mathrm{AiryBi}(-z_n^A/z_0) = 0$

(i) Compression:

- Probability : $P_{i \to j}^{(in,A)} = \int_0^H \psi_i(z)\phi_j(z)dz$

- Population : $\beta_j^{(in,A)} = \sum_{i=1}^{\infty} \beta_j^{(S)} P_{i \to j}^{(in,A)}$

(ii) Absorbtion:

Heuristically :

For a quantum state ψ_n: $H < z_n \Rightarrow$ absorption

For a quantum state ψ_n: $H > z_n \Rightarrow$ ok

Model [R.Adhikari, Y.Cheng, and A.E.Meyerovich, V.V.Nesvizhevsky, PHYSICAL REVIEW A 75, 063613 (2007)] :

Absorber = miroir with perturbation (rugosity)

Life time of a j-quantum state : $\tau_j^{(0)}$

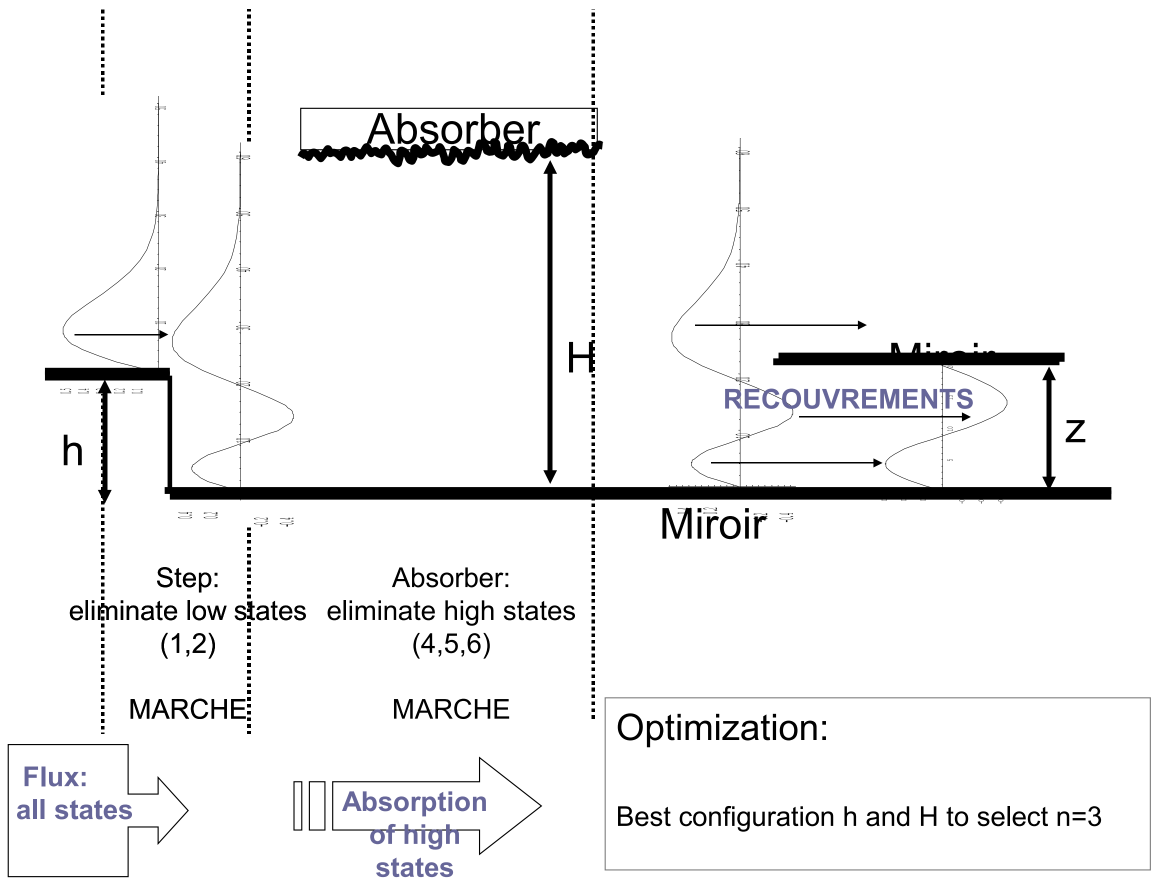
Absorption : $\beta_j^{(A)} = \beta_j^{(in,A)} e^{-t/\tau_j^{(0)}}$

(iii) Decompression:

- Probability : $P_{i \to j}^{(out,A)} = \int_0^H \phi_i(z)\psi_j(z)dz$

- Population : $\beta_j^{(out,A)} = \sum_{i=1}^{\infty} \beta_j^{(A)} P_{i \to j}^{(out,A)}$

Our system:



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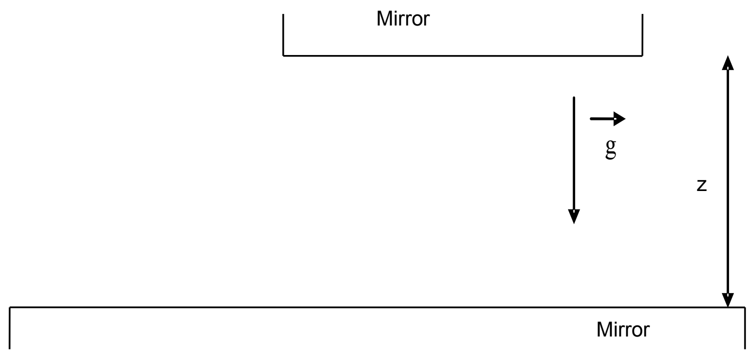
2. Analysis of quantum state: a simple method



Probability for each states : $P_i(z) = \int_0^z ds \psi_i(s)^2$

Populations for each states : $\beta_i^{(end)}(z) = \beta_i^{(out,A)} P_i(z)$

Flux (for total population) : $F(z) = \sum_i \beta_i^{(end)}(z)$

$\Rightarrow$ Optimization of h (step) and H (absorber) to have:

$F(z) \simeq \beta_n^{(end)}(z) + ...$

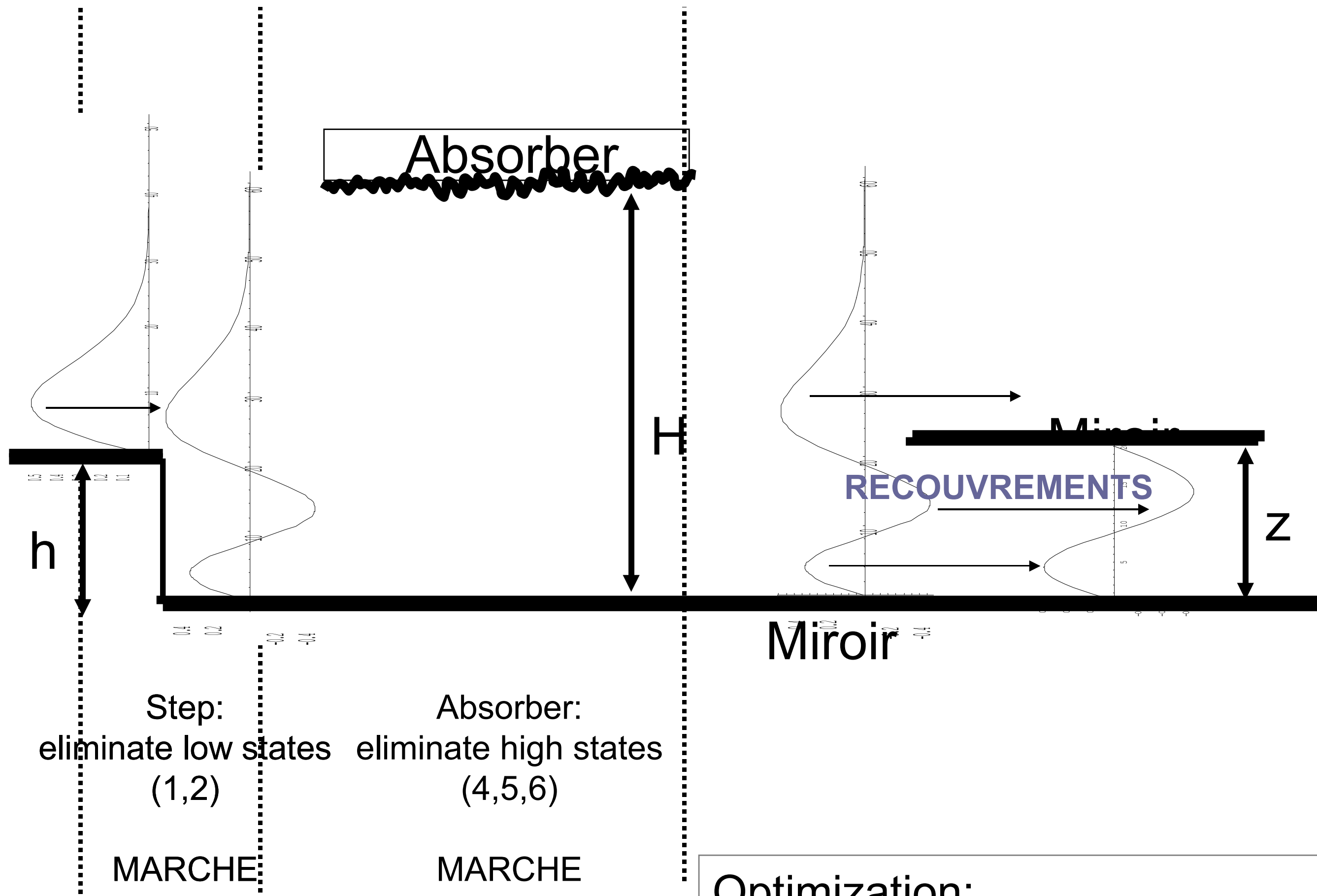
3. Numerical simulations

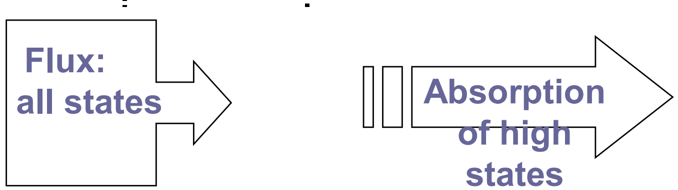
- We want to analyze third state $n = 3$

- Number of quantum states in simulation: $N = 30$

- Heights : $h = 29\mu m$, $H = 29\mu m$, $z_3 = 32.47\mu m$

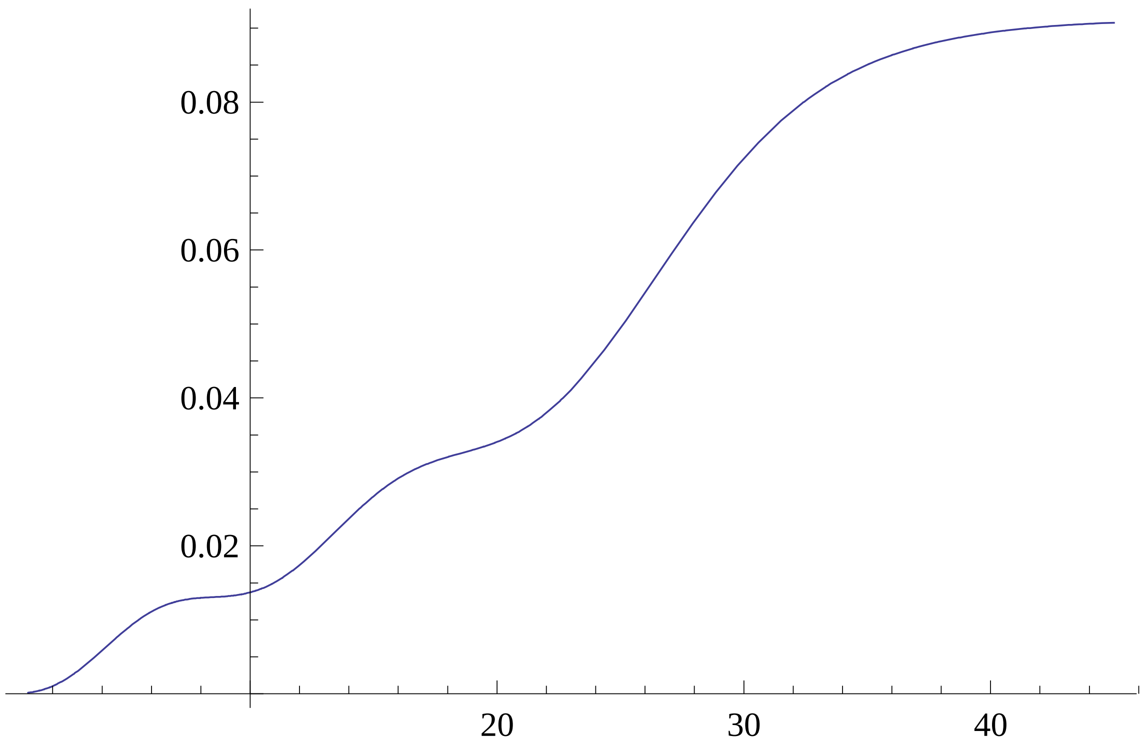
- Parameters : $e = 500$, $t = 0.02$, $r = 0.01$, $\eta = 0.1$





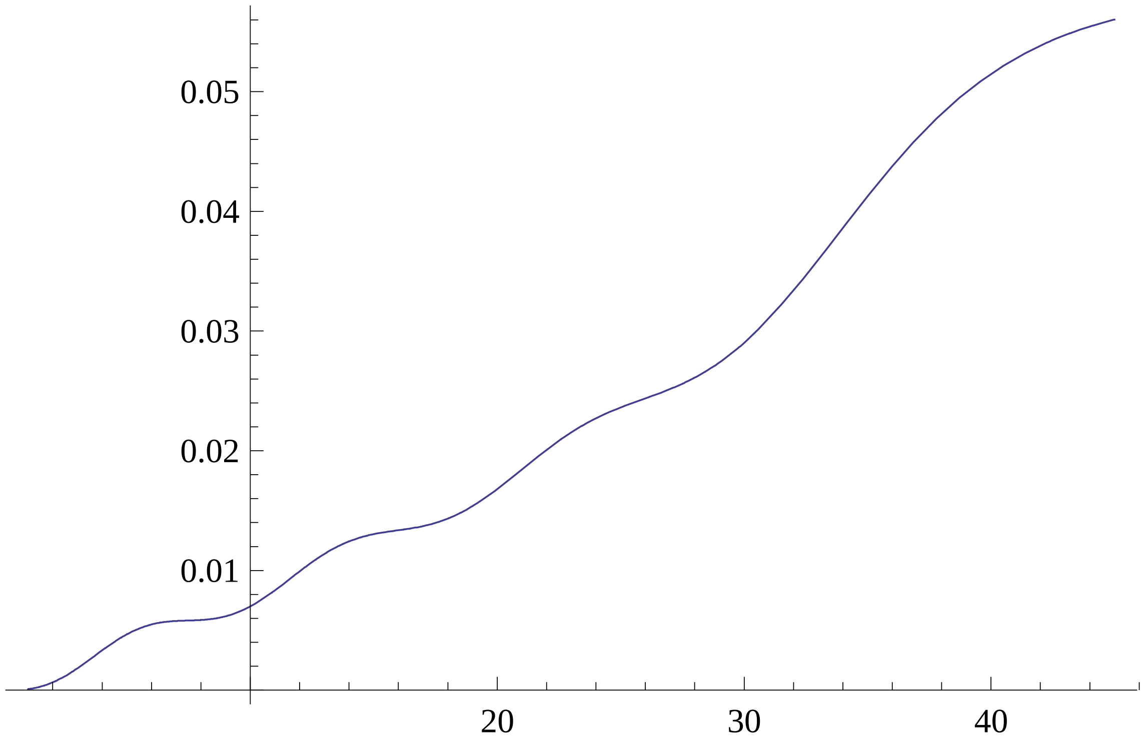
Optimization:

Best configuration h and H to select n=3


0.08
0.06
0.04
0.02
20
30
40

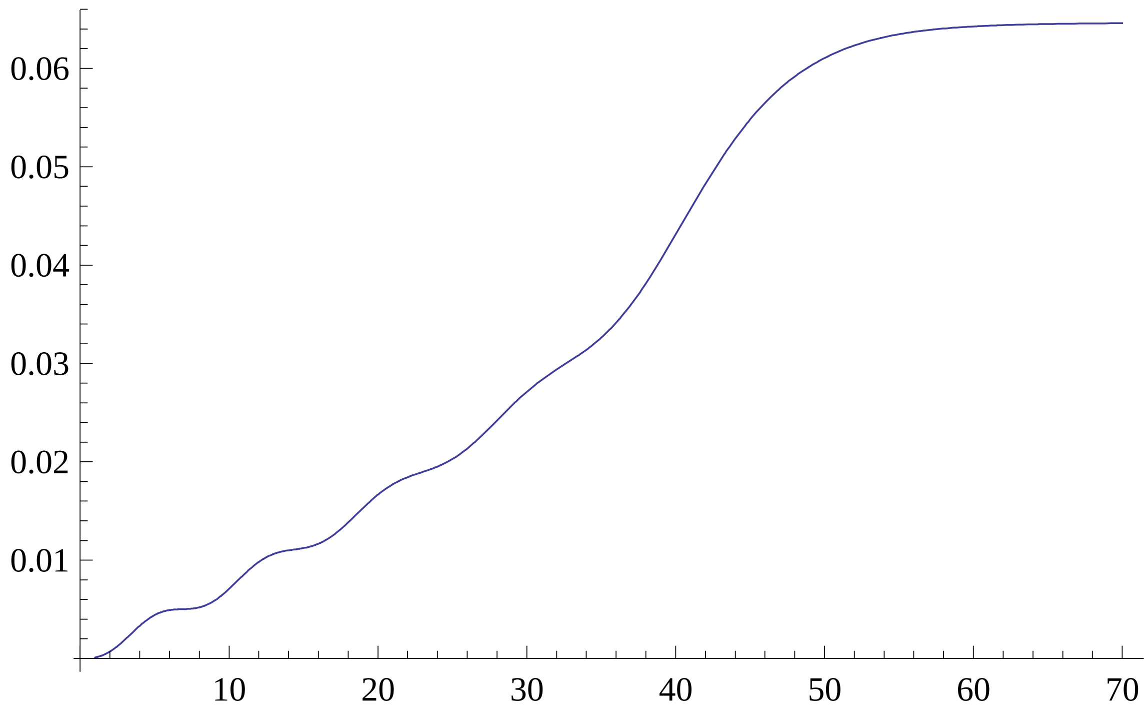
- We want to analyze state $n = 4$

- Heights : $h = 37\mu m$, $H = 45\mu m$, $z_4 = 39.92\mu m$



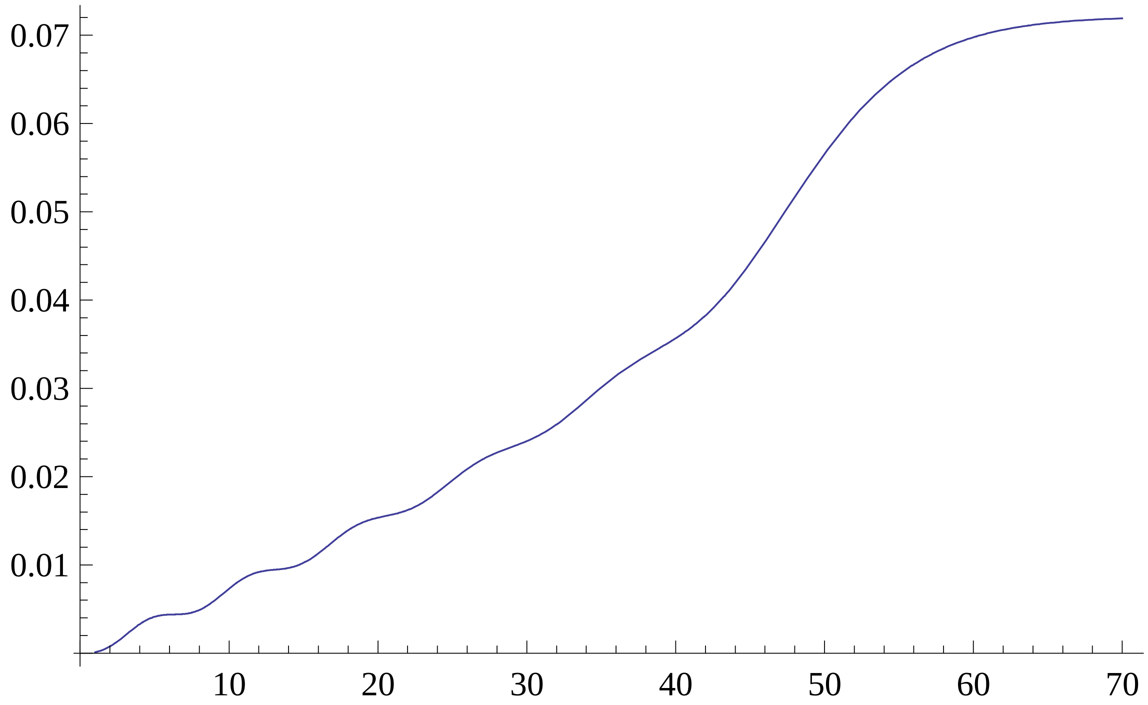
- We want to analyze state $n = 5$

- Heights : $h = 43\mu m$, $H = 5\mu m$, $z_5 = 46.73\mu m$



- We want to analyze state $n = 6$

- Heights : $h = 50\mu m$, $H = 58\mu m$, $z_6 = 53.08\mu m$



4. Conclusions and perspectives

Conclusions:

- We can analyze low quantum states (n=3,4,5) and see local maximum

- We can select one quantum state with good resolution (a priori)

Perspectives:

- Improve numerical simulation (choice of parameters, optimization ...)

- Implementation to GRANIT project

Thank you for your attention