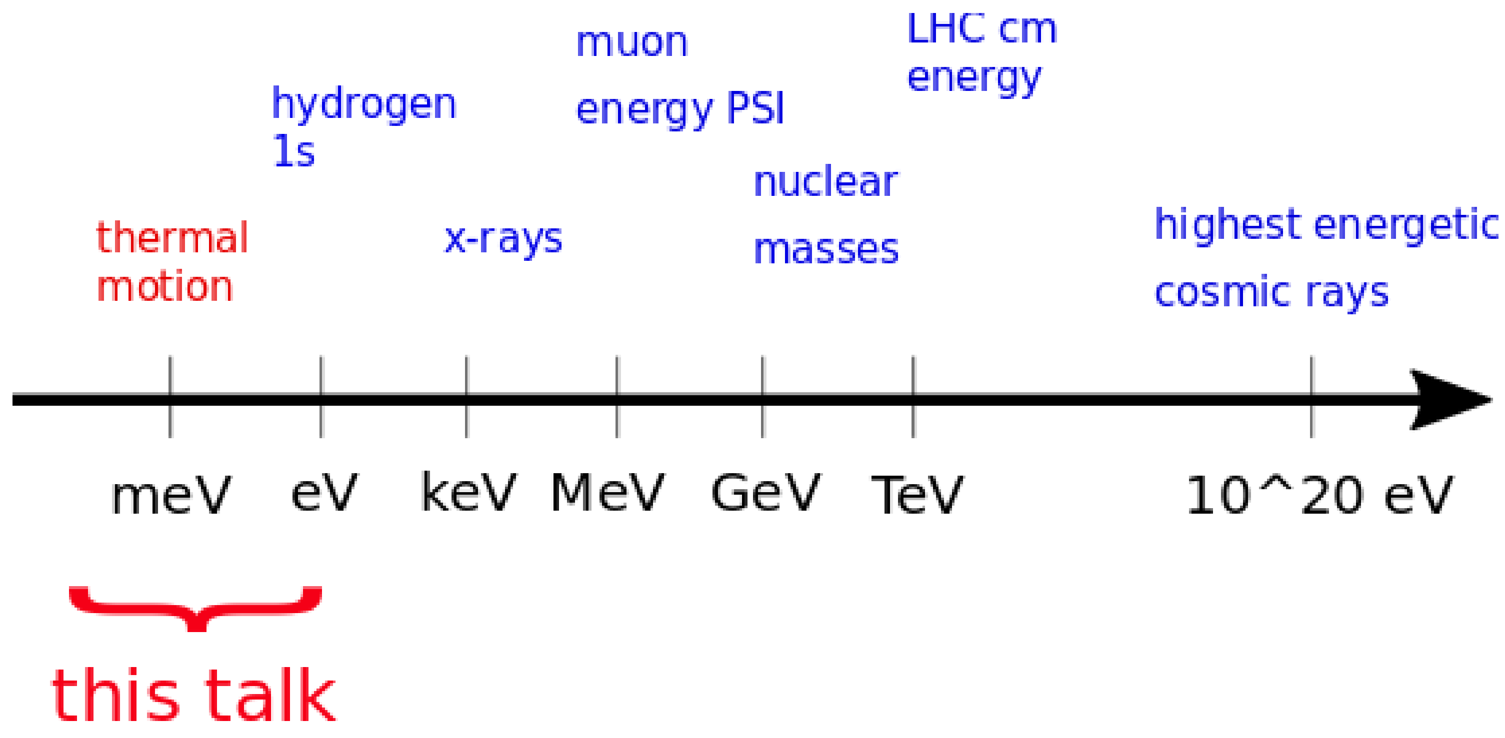

muon
energy PSI
LHC cm
energy
hydrogen
1s
nuclear
masses
thermal
motion
x-rays
highest energetic
cosmic rays
meV
eV
keV
MeV
GeV
TeV
10^20 eV
this talk

Simulation of muonic atom diffusion in HyperMu targets

Muon Group Seminar 8.5.2018

Talk by Jonas Nuber

Outline

The new HFS experiment: How it works

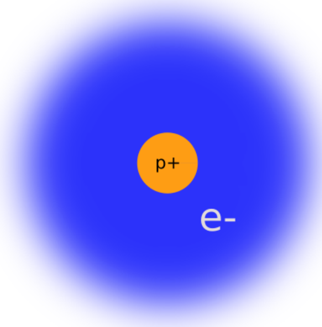
Setup of target simulations for HyperMu

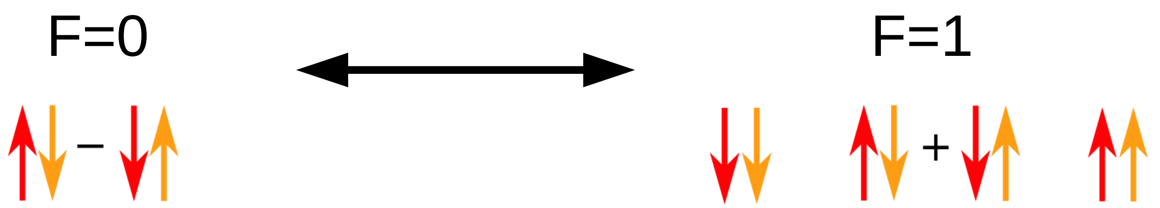
Preliminary optimization results

The new HFS experiment

- Large wavefunction overlap in groundstate of muonic atoms
  → study proton structure by muP spectroscopy

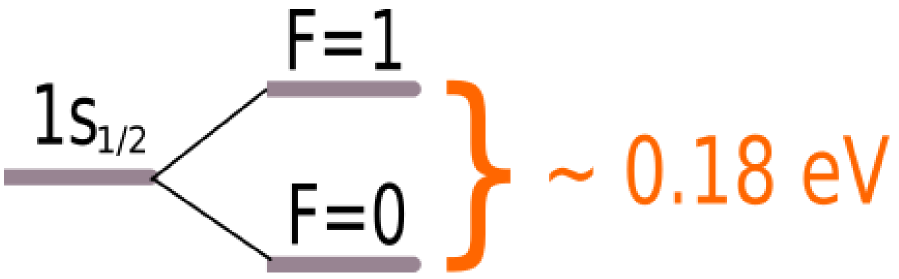
- Aim: Learn about magnetic distribution
  by measuring 1s hyperfine splitting





- Useful: mean kinetic energy of molecules << E (HFS)

$$\bar{E}_{\mathrm{kin}}\,(50K) \approx 0.006eV$$



Schematic target setup of HyperMu

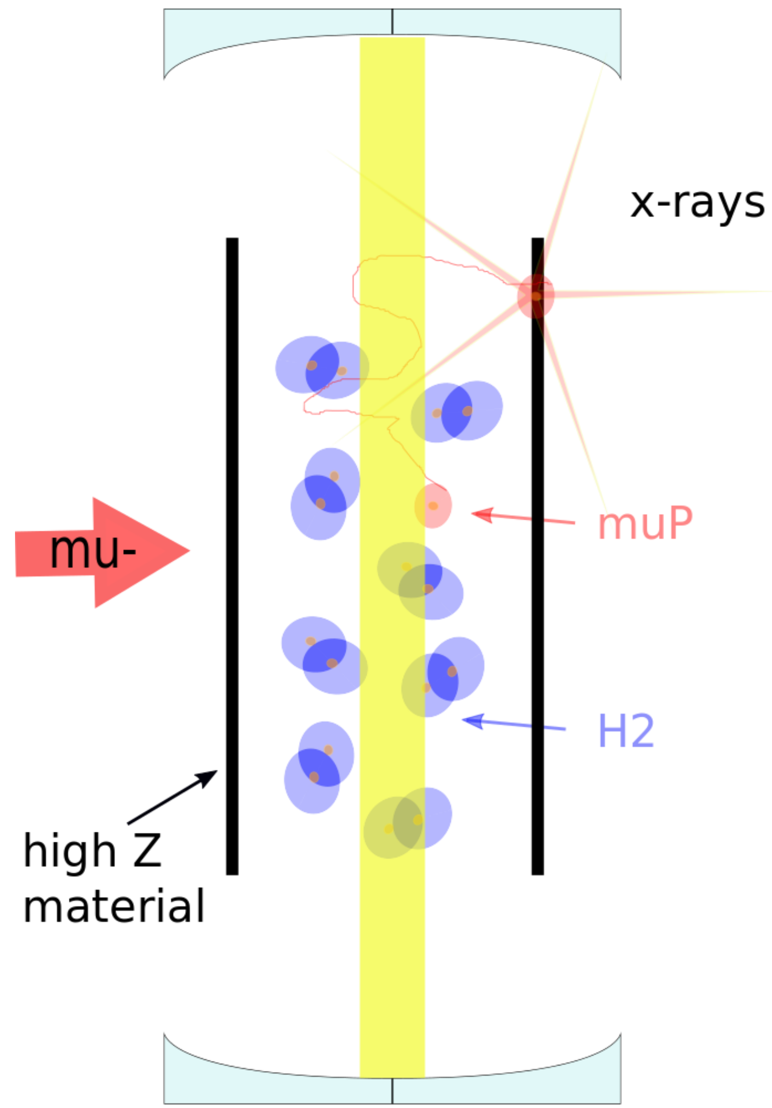
- H2 target: p≈1bar, T=50K (or less?)

- After stopping: µP formation with accelerating x-ray cascade:
  - $E_0\ (\mu P) \approx O(\text{eV})$
  - most μP in F=1 state

- <u>0-1µs:</u> thermalization and "quenching" (F=1→F=0)

- <u>1µs:</u> Laser shot,
  In resonance: F=0→F=1

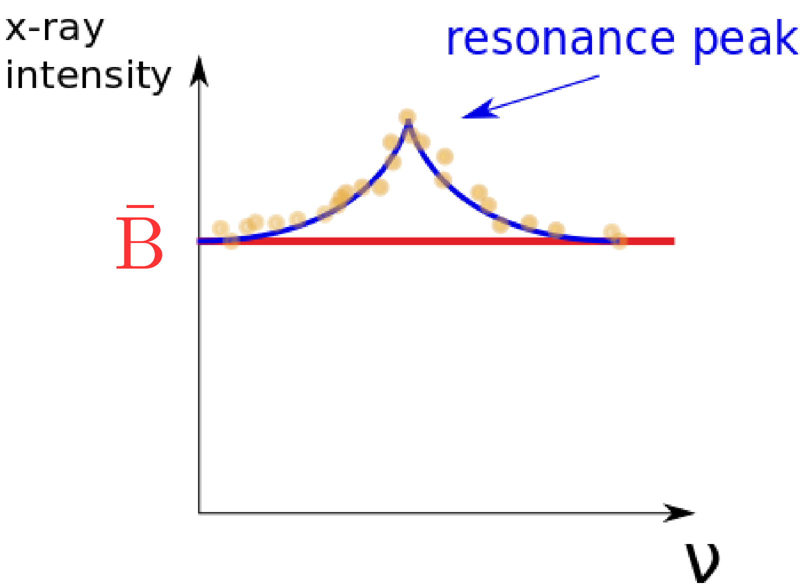
- Collisional deexcitation with energy kick leads to higher probability to hit the wall

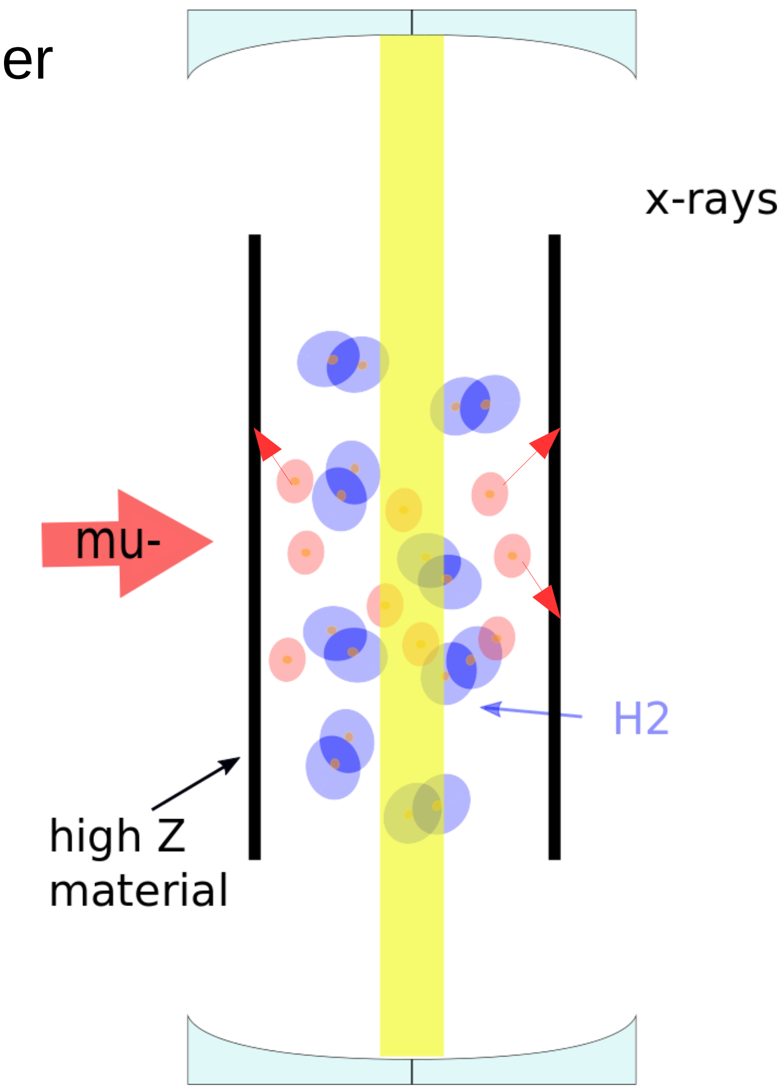


Background and resonance

- Lots of µP atoms hit the wall without laser excitation
  → Background

- Approaching the HFS frequency, the number of wall hits increases
  → Resonance

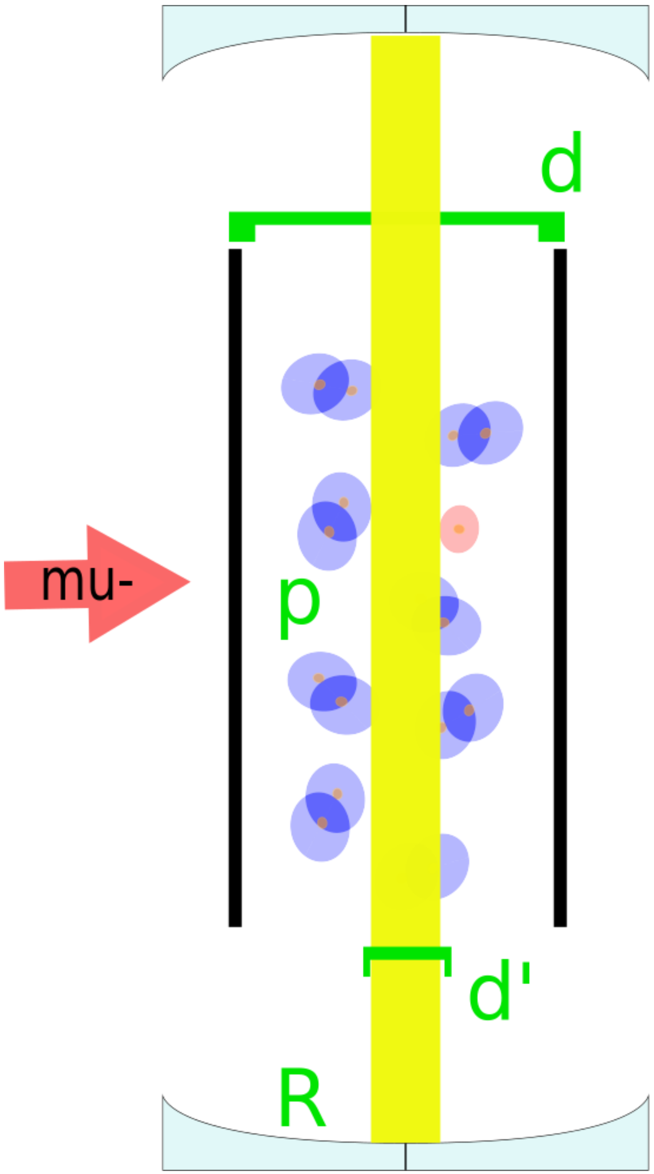




Optimization of target parameters

- Interesting parameters for this optimization:
    - pressure p
    - target length d
    - width of laser region d'
    - mirror reflectivity R

- Aim: Find realizable target configuration with
    1) optimal signal-background ratio
    2) high signal rate



Low energy scattering processes

- Main diffusion processes for HyperMu conditions:

$\mu P(F=1) + H2 \rightarrow \mu P(F=0) + H2$
$\mu P(F=0) + H2 \rightarrow \mu P(F=1) + H2$
} inelastic/spinflip processes

$\mu P(F=0) + H2 \rightarrow \mu P(F=0) + H2$
$\mu P(F=1) + H2 \rightarrow \mu P(F=1) + H2$
} "elastic" processes

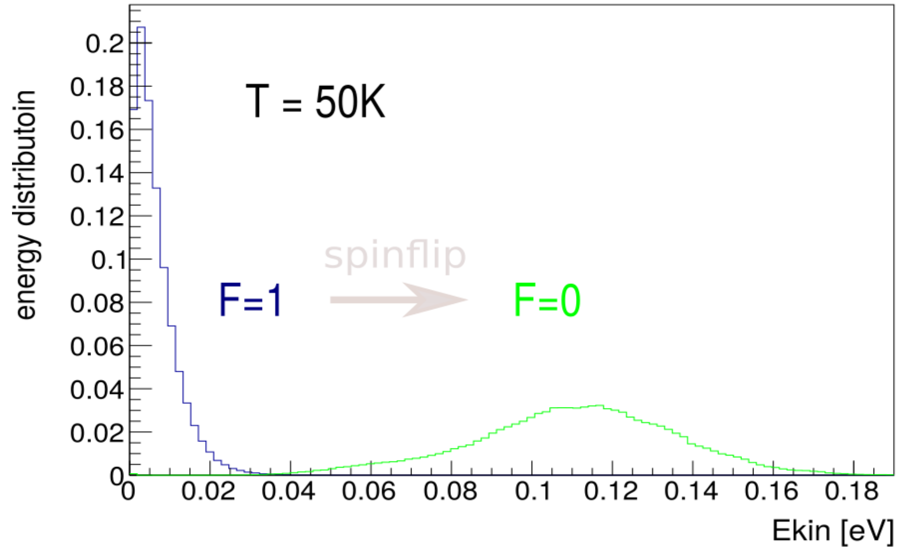
- Differential cross sections calculated by A. Adamczak
[Phys.Rev. A74 (2006) 042718]

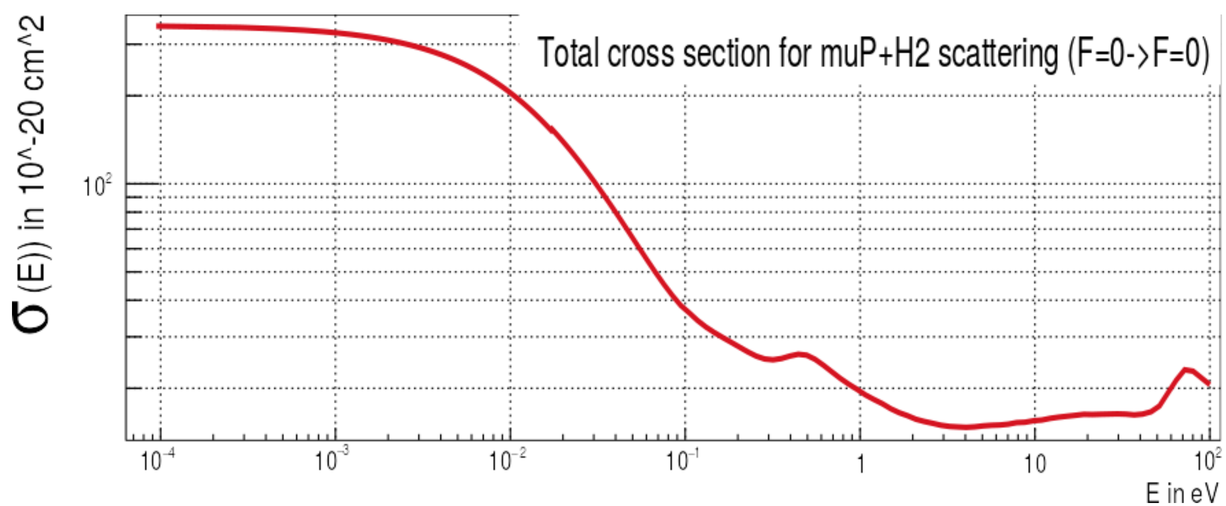
- Target simulations:
  - Implementation of muonic atoms and processes in Geant4
  - Application to specific target setup

Bugs !?

Spinflip with energy kick

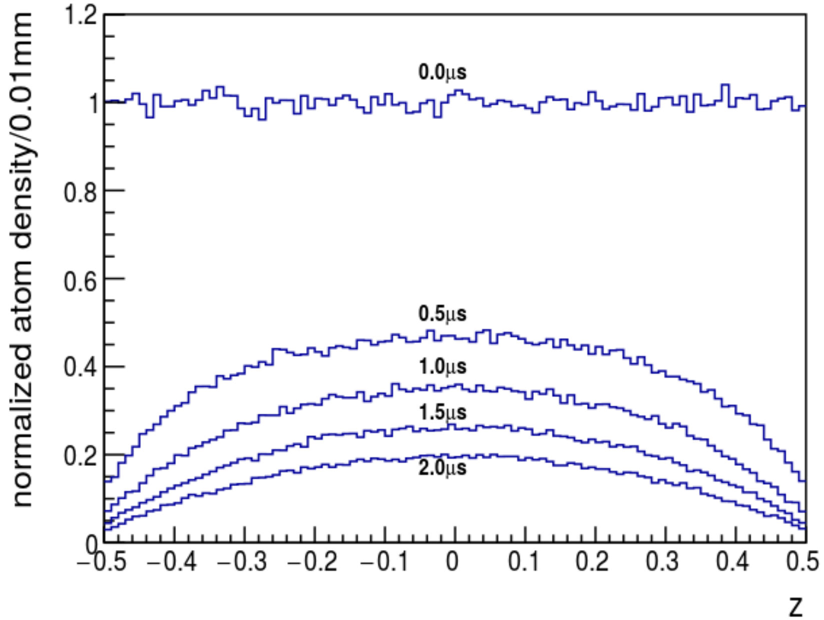
- Thermalized µP with F=1 in H2 gas
- Collisional deexcitation of µP:
  µP(F=1) + H2 → µP(F=0) + H2
- Spinflip leads to energy kick
  → E ≈ 0.1eV
- Smaller cross section allows further travel of µP atom





HyperMu diffusion simulations

- Split simulation into different independent runs
- Use normalization factors for signal-to-background analysis



µP loss by wall hit or decay, p=1bar

1) muon loss before excitation

thermal diffusion 0 to 1µs

2) background run

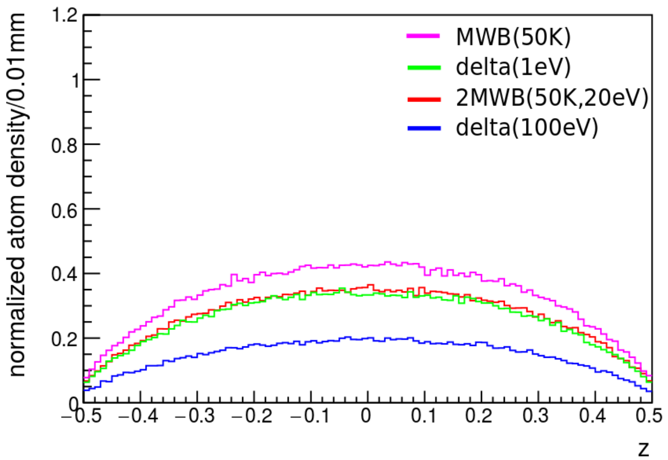
thermal diffusion starting from 1µs

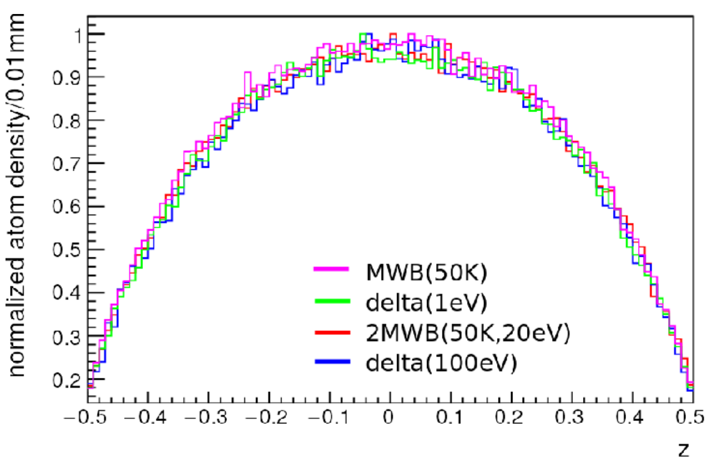
3) "pure" signal run

laser accelerated diffusion starting from t > 1µs

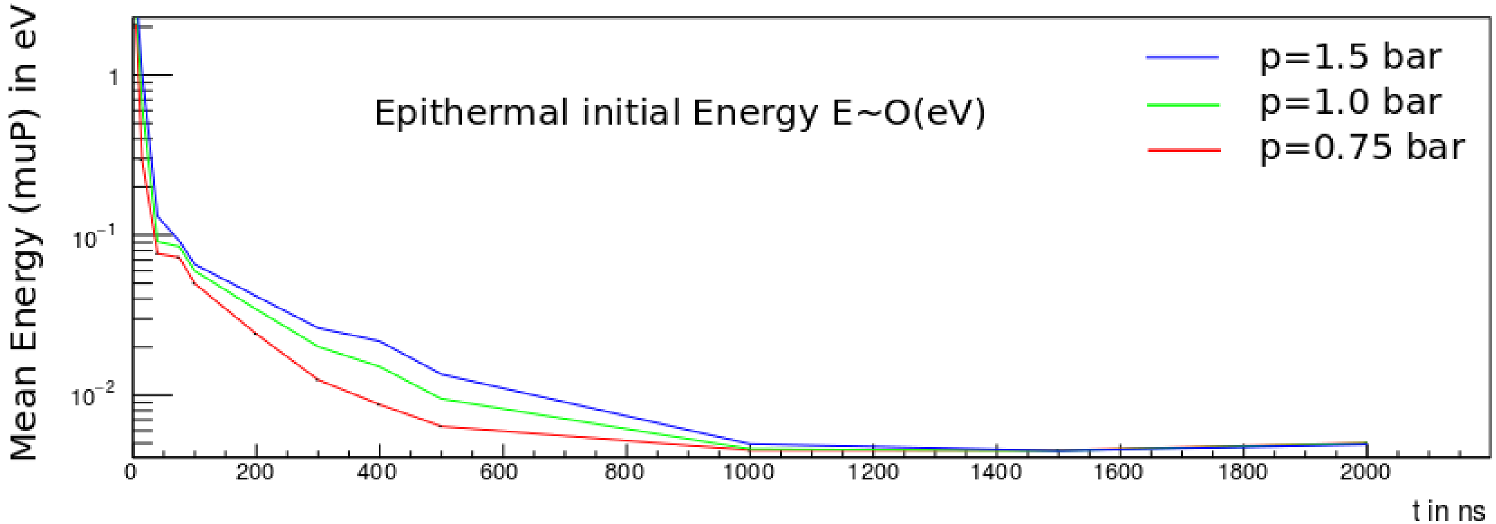
Thermalization and loss between 0-1µs

Initial energy distribution of µP after stopping not completely known





Complete thermalization during first 1µs



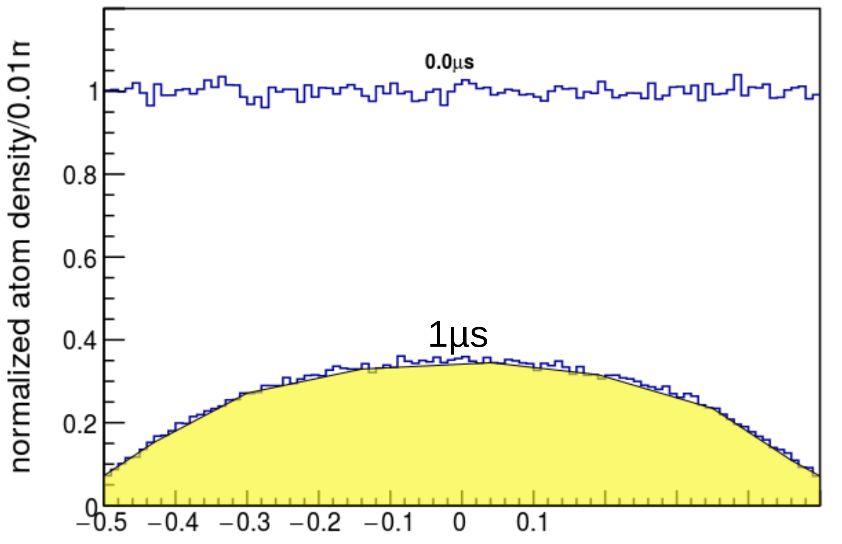
Signal and background normalization

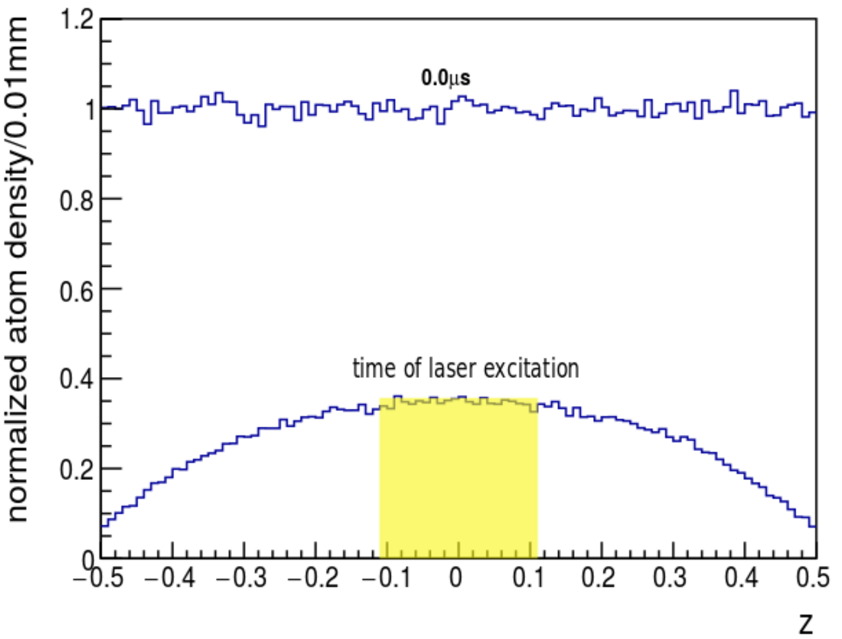
- Background: thermal diffusion starting from result of loss run at t=1µs

- Signal: start in F=1 state within laser band

- Normalization factors:
  - stopping factor ~ pd
  - relative integral in loss graph
  - decay

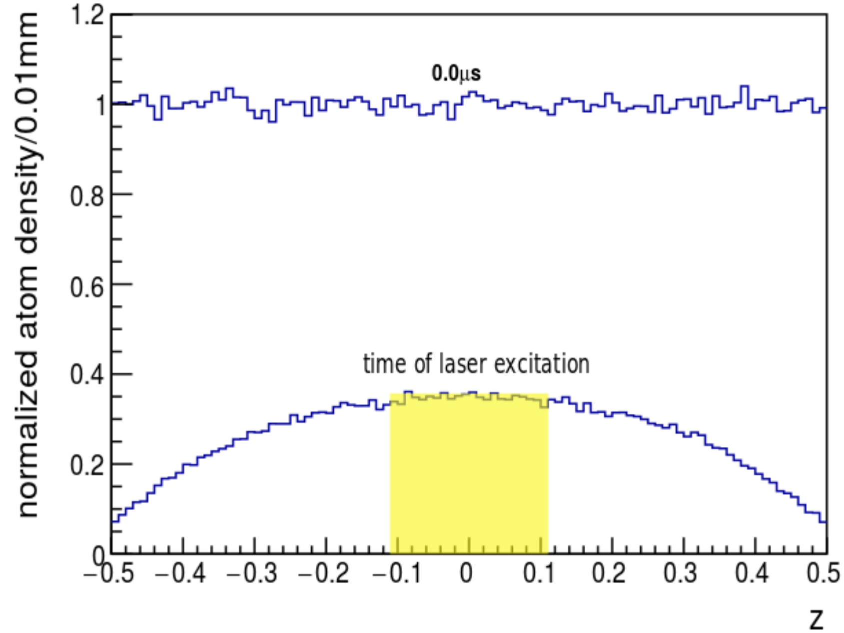
- Additional signal normalization:
  - excitation probability ~ F / d'
  - TODO: subtract double-counted signal-background pairs

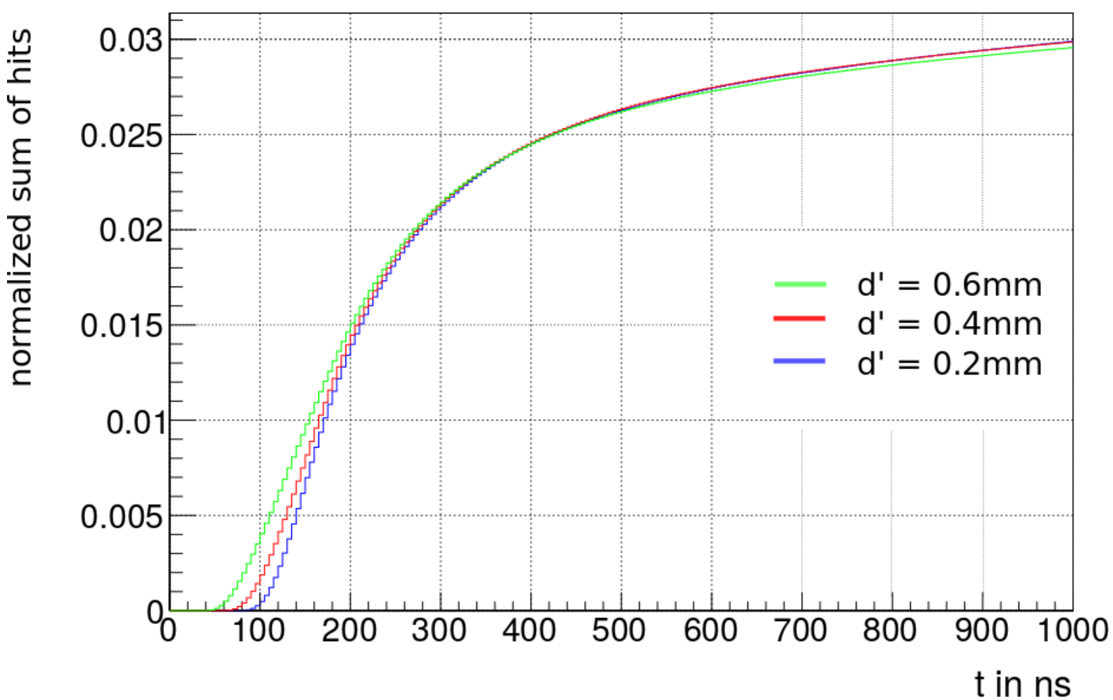




Sensitivity to lasing volume

- Fluence decreases with increasing lasing volume (nearly linearly)
- Neglecting saturation effects: Choose d' as small as possible



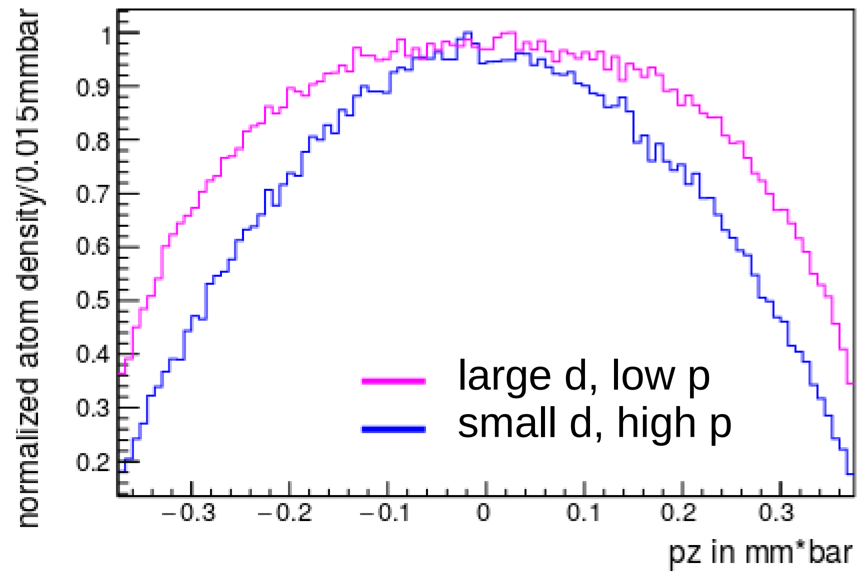


$$F = \int_0^\infty \mathrm{I}(t)\ \mathrm{d}t$$

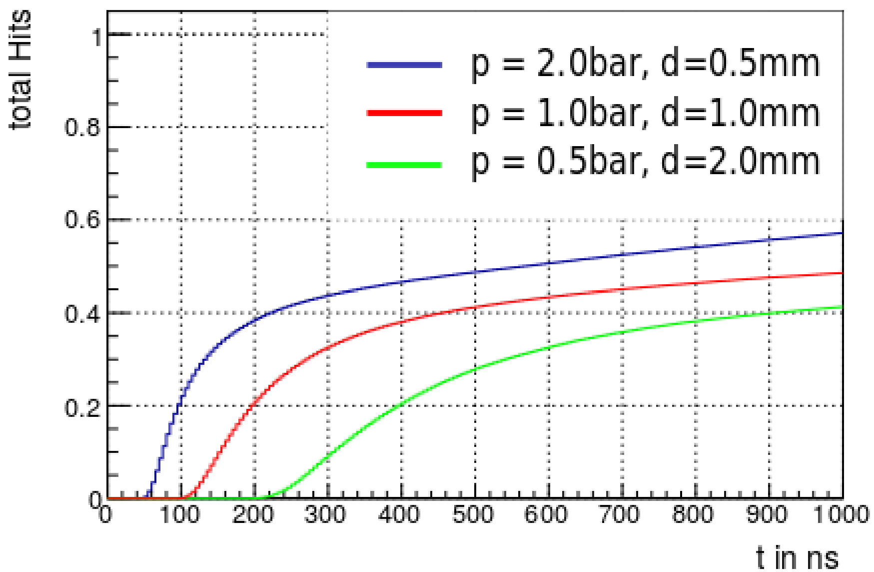
$$p_{ex} = 1 - exp\left(\frac{F}{F_s}\right) \approx \frac{F}{F_s}$$

In search of optimal p-d setting

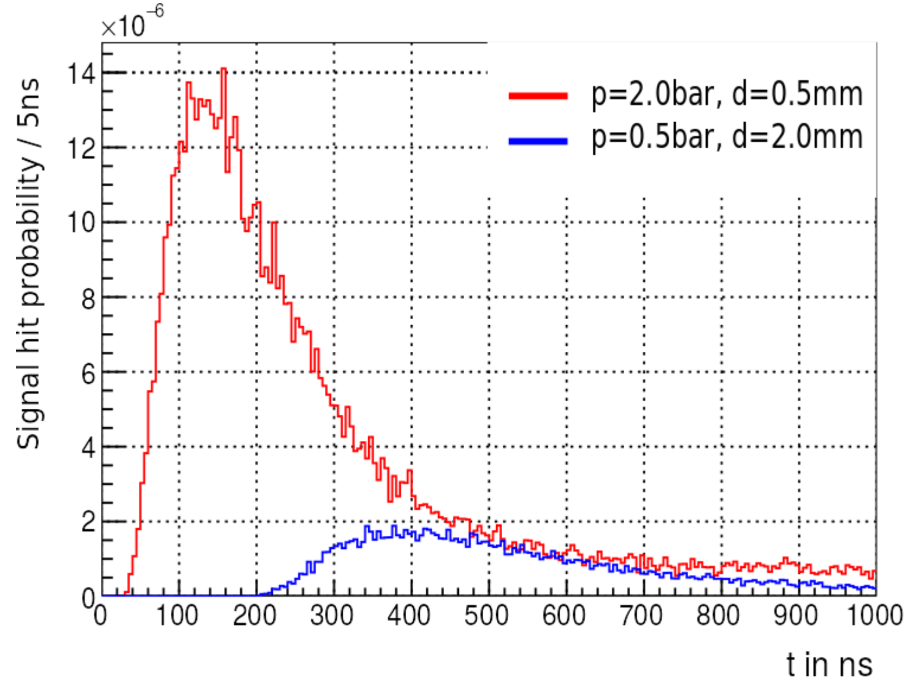
Small targets with high pressure have higher fraction of μP in center
→ good for signal/background



Small time window with high signal rate for small targets (background minimalization)



How to measure the resonance

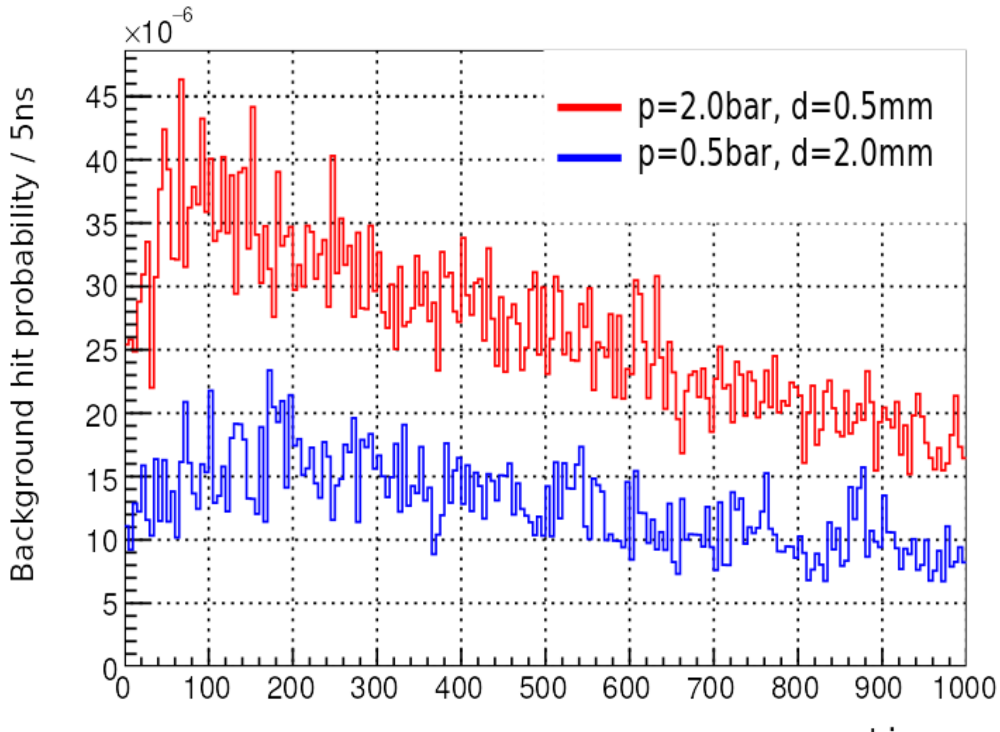


Advantages small target:

- Higher signal-to-background
- Higher signal rate

Problem:

- Hard to realize



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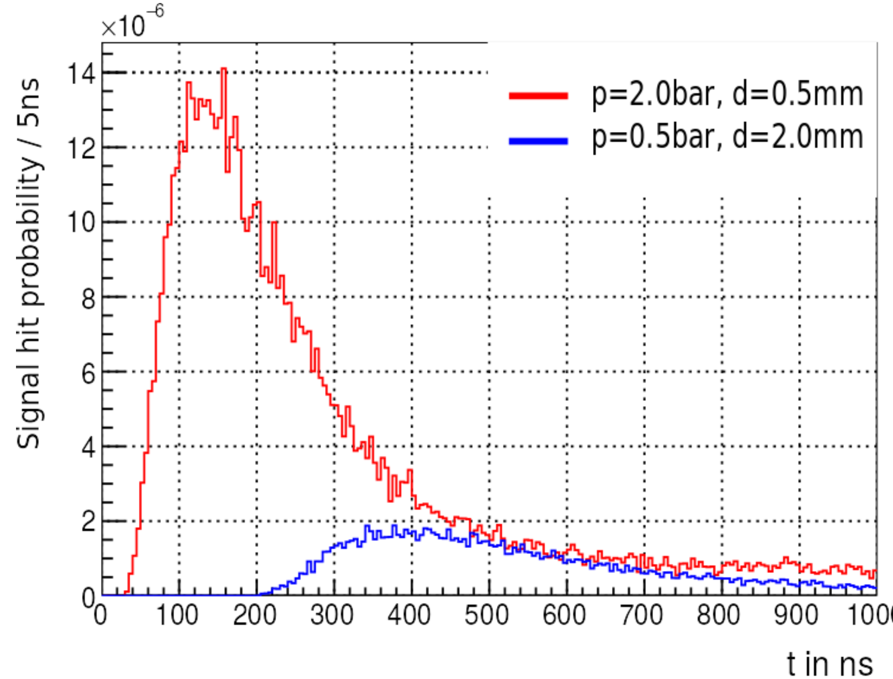
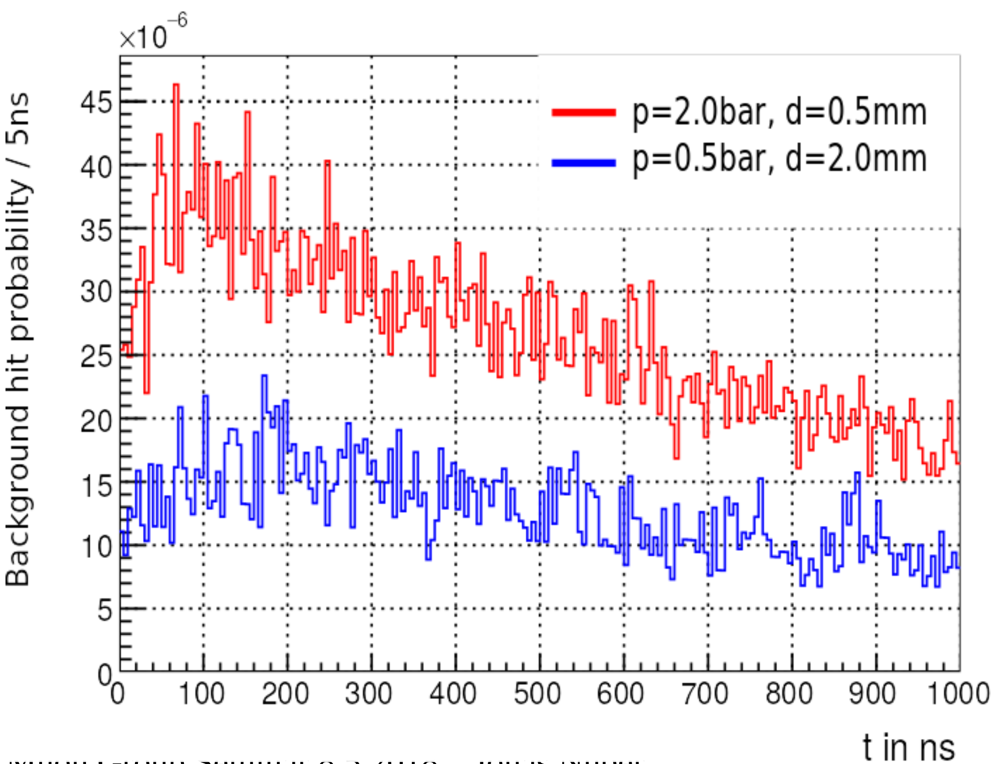
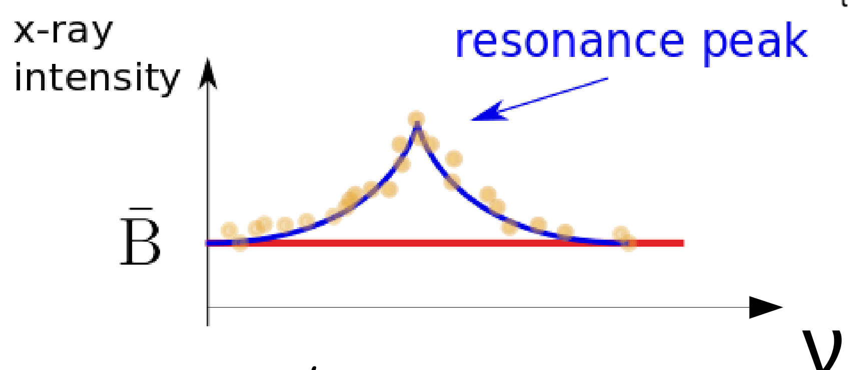
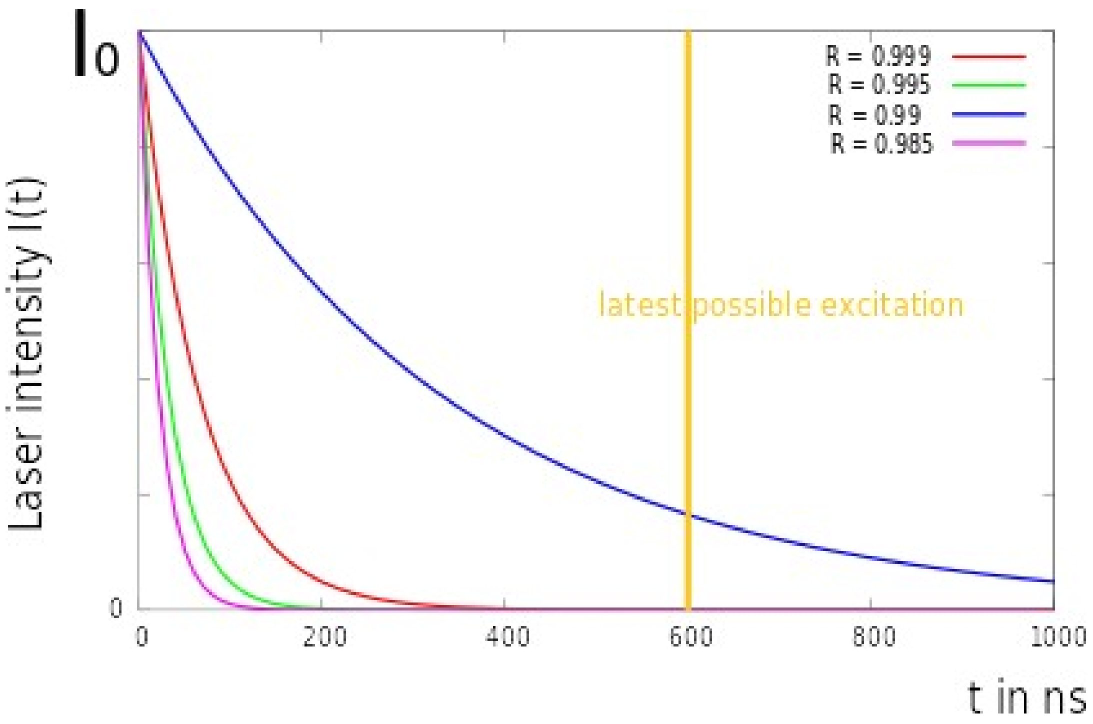






$$\frac{\int_{t_1}^{t_2} \text{Signal d}t}{\sqrt{\int_{t_1}^{t_2} \text{Signal} + \text{BG d}t}}$$

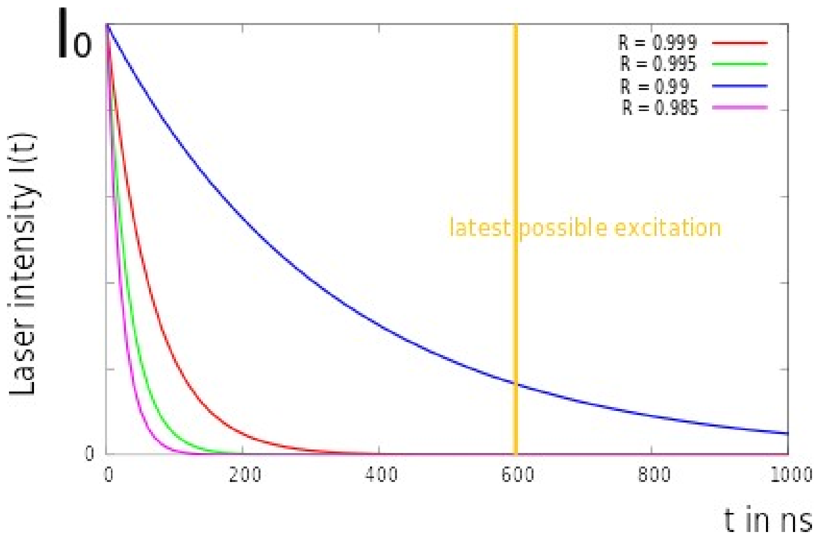
Sensitivity towards mirror reflectivity



$$p_{\text{excitation}} \sim F = \int_0^\infty \mathrm{I}(t)\ \mathrm{d}t$$

F = 62 J/cm2
F = 12.5 J/cm2
F = 6.25 J/cm2
F = 4.1 J/cm2

Sensitivity towards mirror reflectivity



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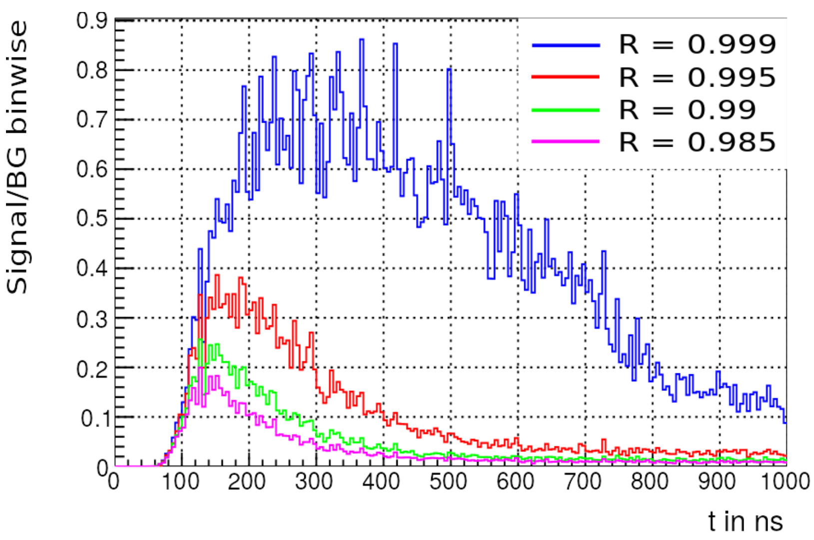
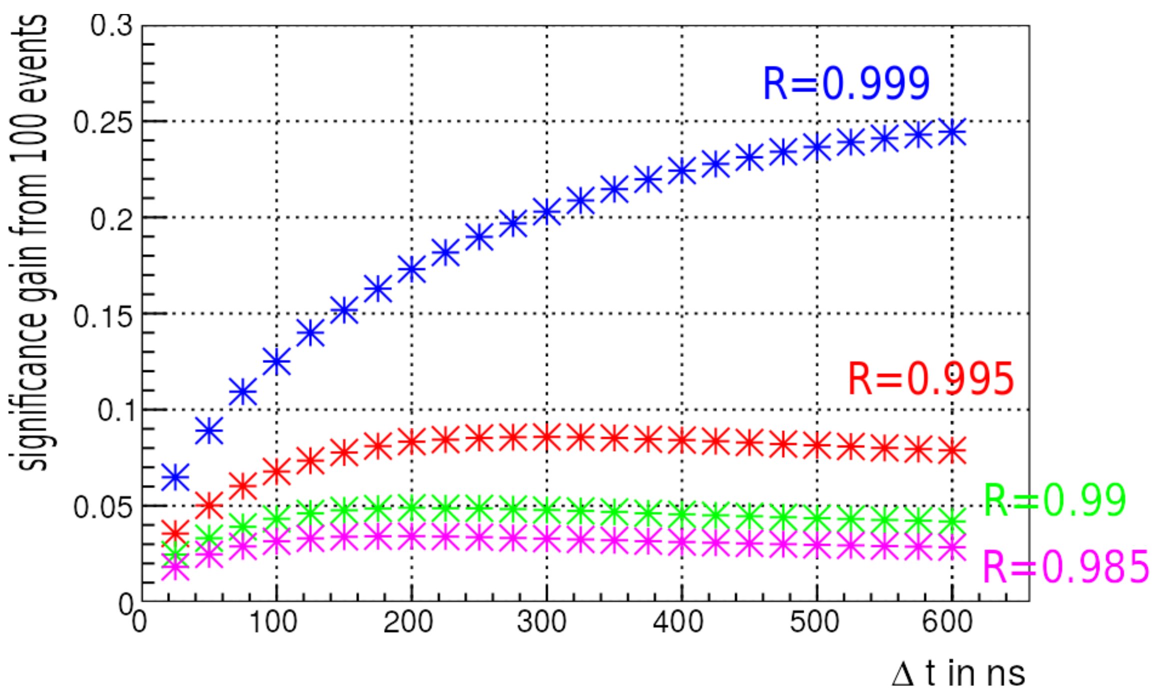
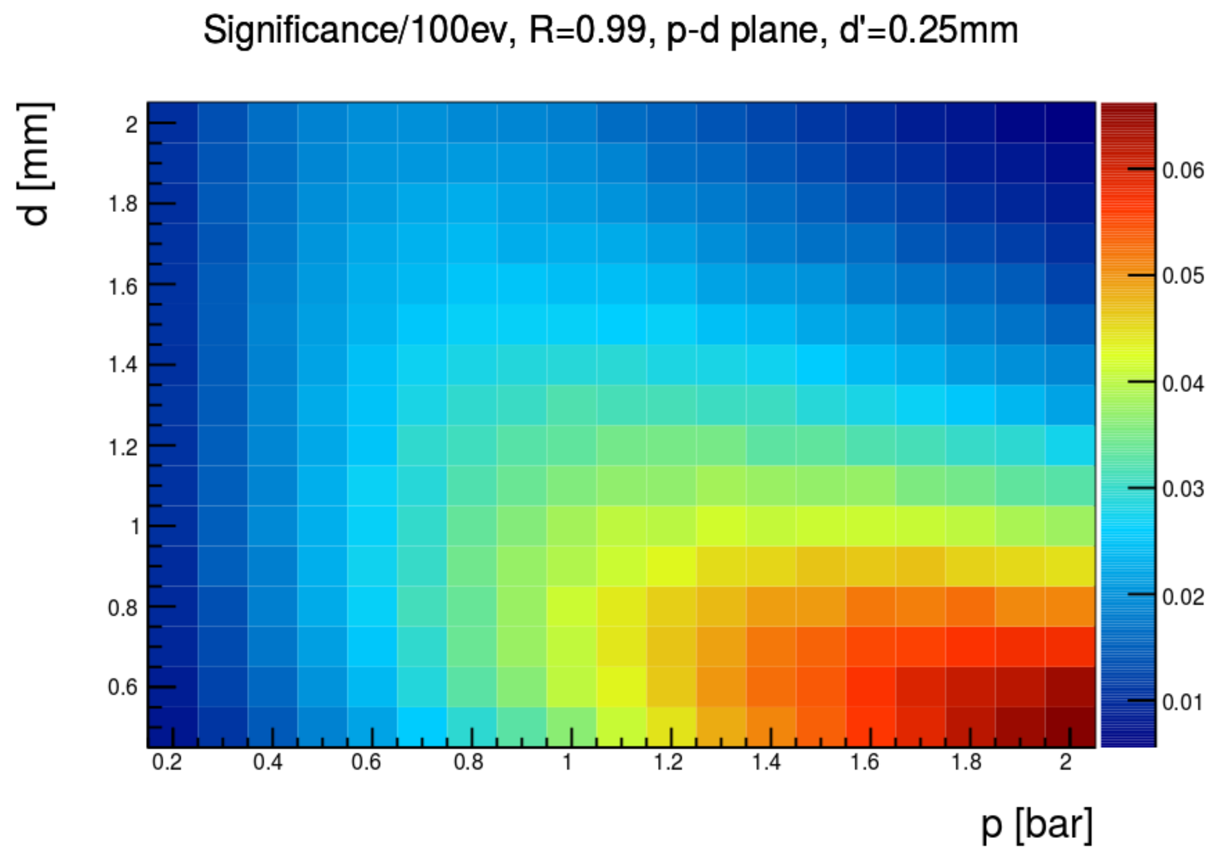




Results of target optimization

- Optimal parameters (preliminary):
  - Small lasing regions (d')
  - Small targets with high pressure
- Main challenge is laser system
- Aim for: d≈0.8mm, p≈1.7bar
- But: Subtraction of double-counting will change low d region



Conclusion

- My master project:
  - Implementation of low energy muonic atom scattering in Geant4
  - Target simulations for HyperMu
  - Next: Evaluate possible modifications of MuX target

- Idea of the HFS measurement
  - Exploit energy kick by $F=1 \rightarrow F=0$ transition
  - Measure resonance

- HyperMu simulations
  - Separate runs for signal and background
  - Best: d’ small, d small, p high