

PAUL SCHERRER INSTITUT

PSI

ETH zürich

Design of the detection system for
the measurement of the hyperfine
splitting in muonic hydrogen



Laura Šinkūnaitė

27-08-19 @ SPS Zürich

FNSNF

Introduction

Muonic
hydrogen

Hyperfine
splitting

Introduction

Muonic
hydrogen



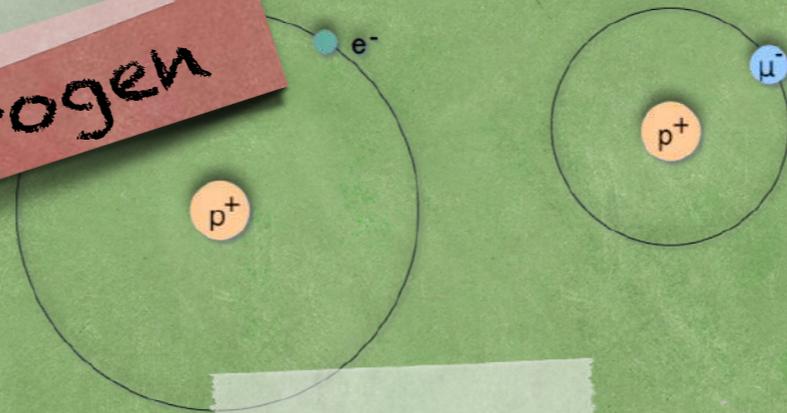
$$|\Psi(r=0)|^2 \propto m_r^3$$

Hyperfine
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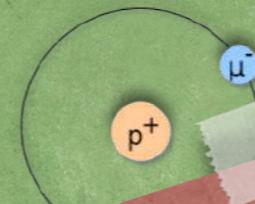
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Muonic hydrogen



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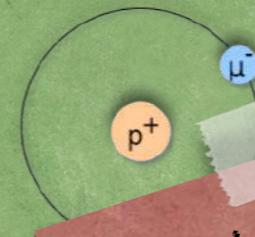
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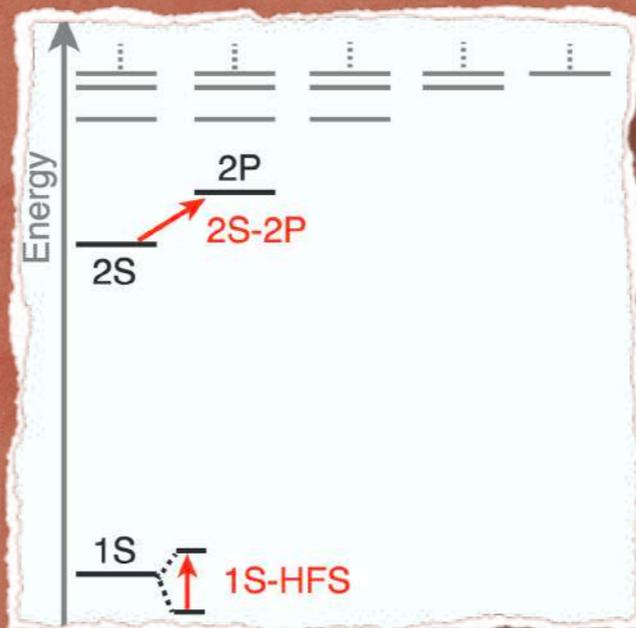


Muonic hydrogen



$$|\Psi(r=0)|^2 \propto m_r^3$$

Hyperfine splitting



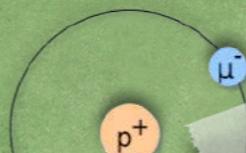
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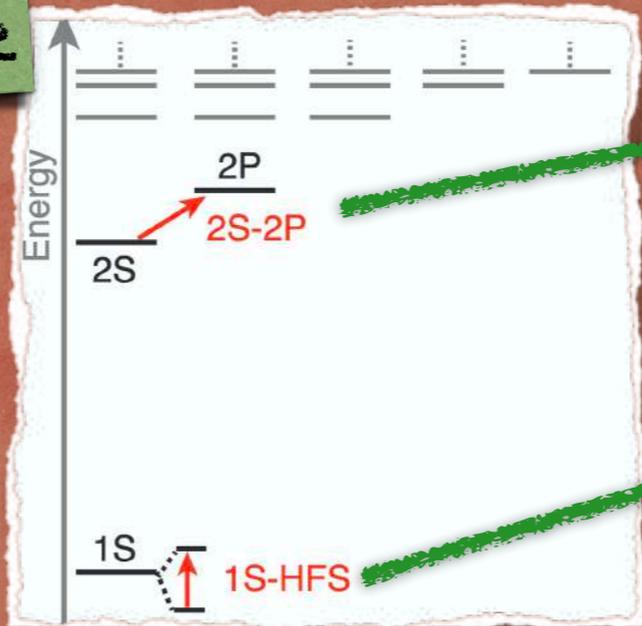
Muonic hydrogen



$$|\Psi(r=0)|^2 \propto m_r^3$$

Proton radius puzzle

Hyperfine splitting



Charge radius

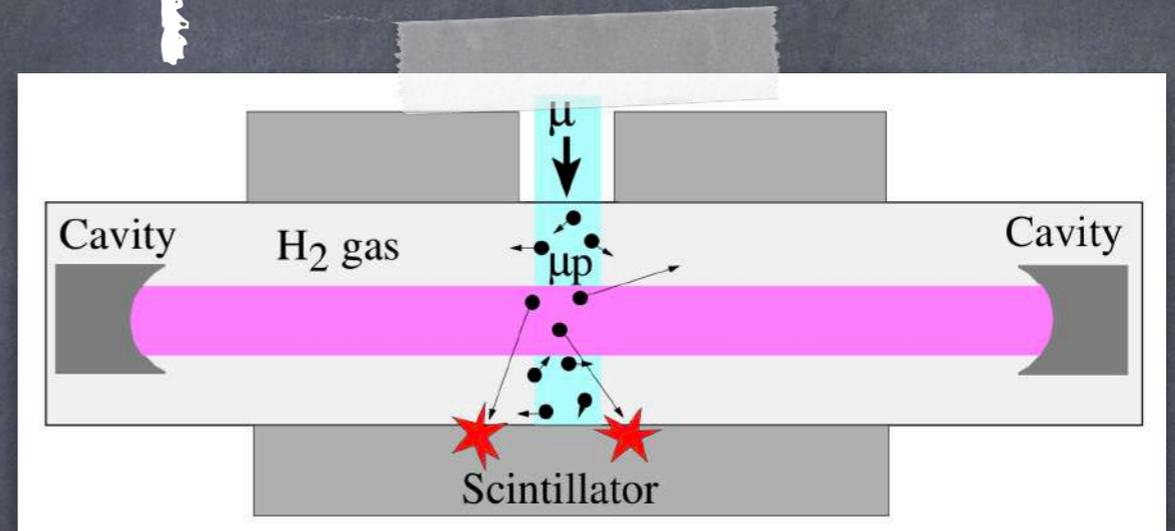
$$\langle r_p^2 \rangle = -6\hbar^2 \frac{dG_E(Q^2)}{dQ^2} \Big|_{Q^2=0}$$

Zemach radius
(in progress)

$$r_z = -\frac{4}{\pi} \int_0^\infty \frac{dQ}{Q^2} \left[G_E(Q^2) \frac{G_M(Q^2)}{1 + \kappa_p} - 1 \right]$$

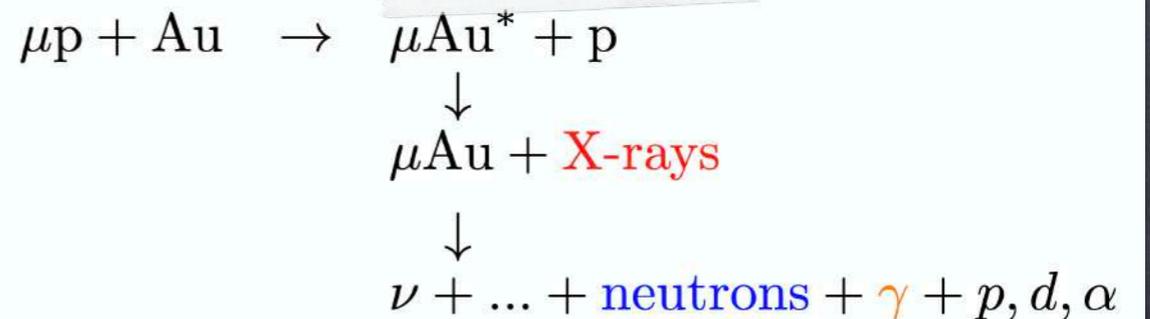
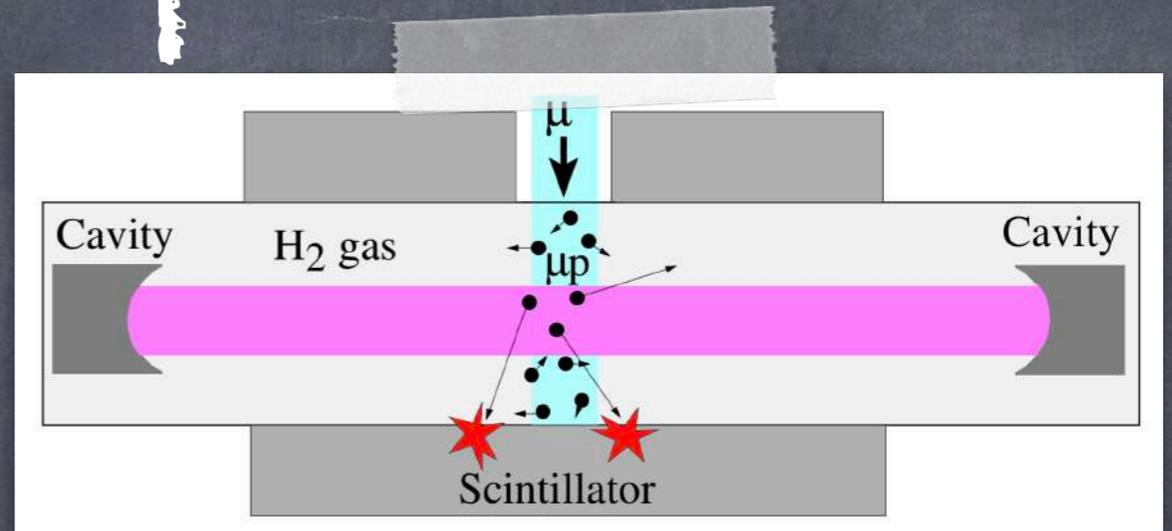
Principle

1. Formation
2. De-excitation
3. Laser excitation
4. Collisional de-excitation
5. Diffusion
6. At the wall
7. Detection



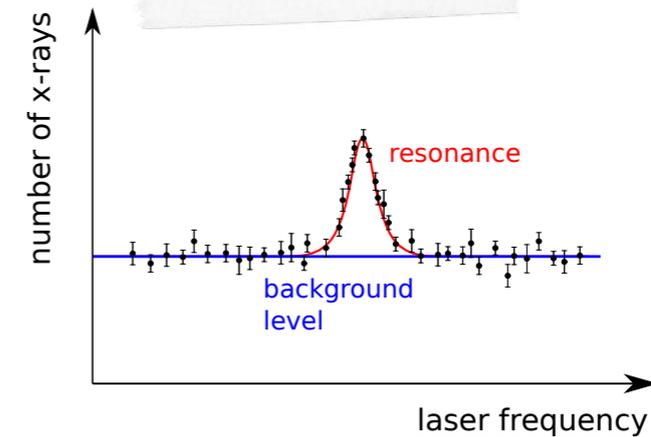
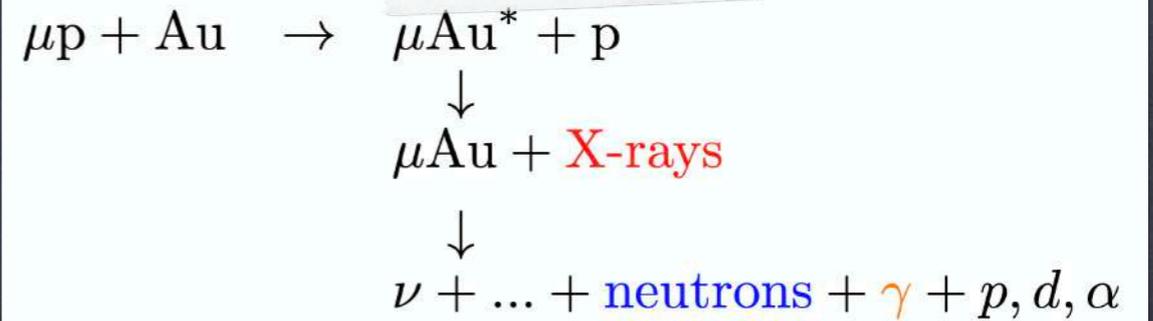
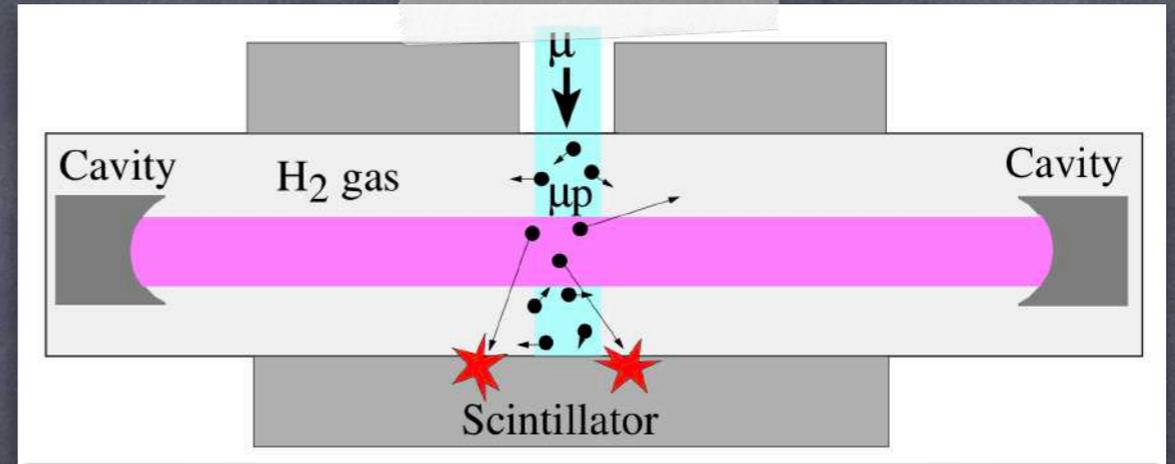
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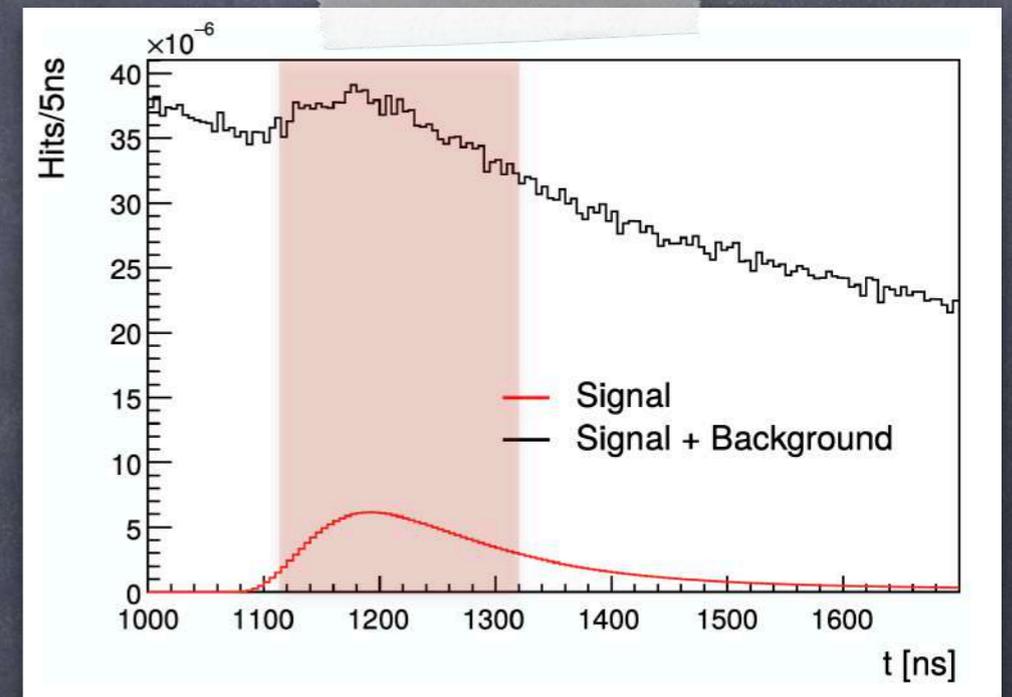


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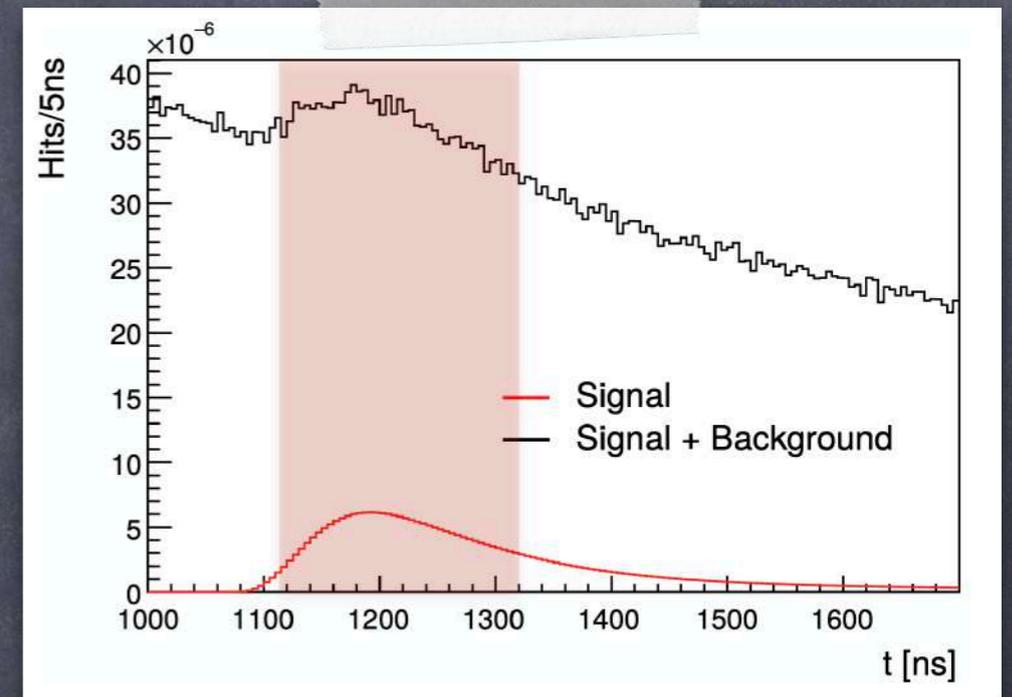


Signal and background



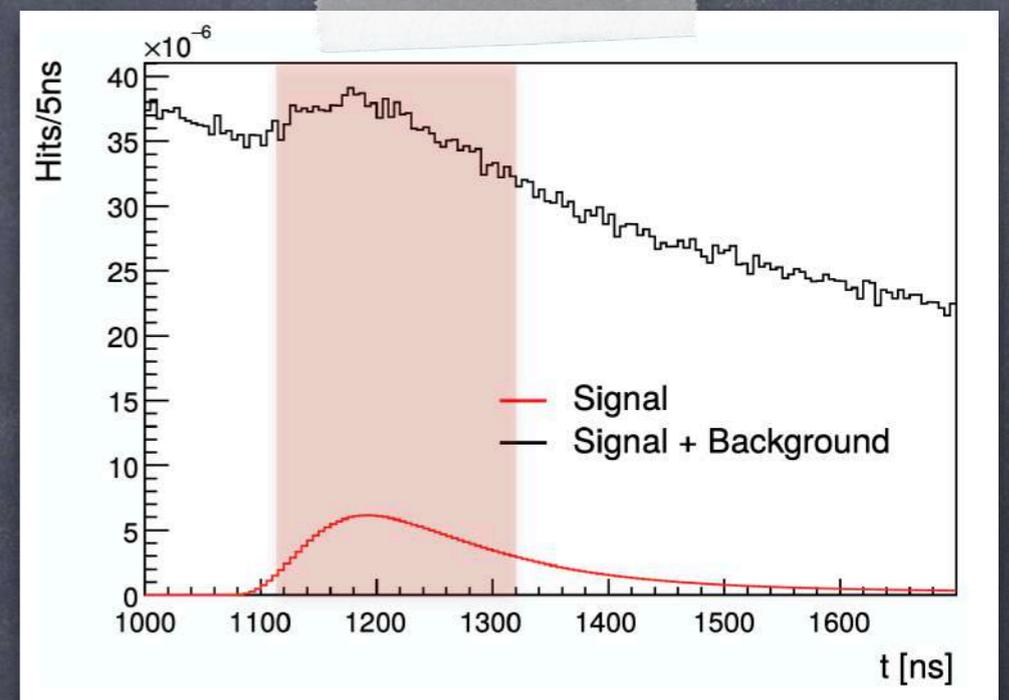
Signal and background

Signal: MeV X-rays detected within a time window Δt .



Signal and background

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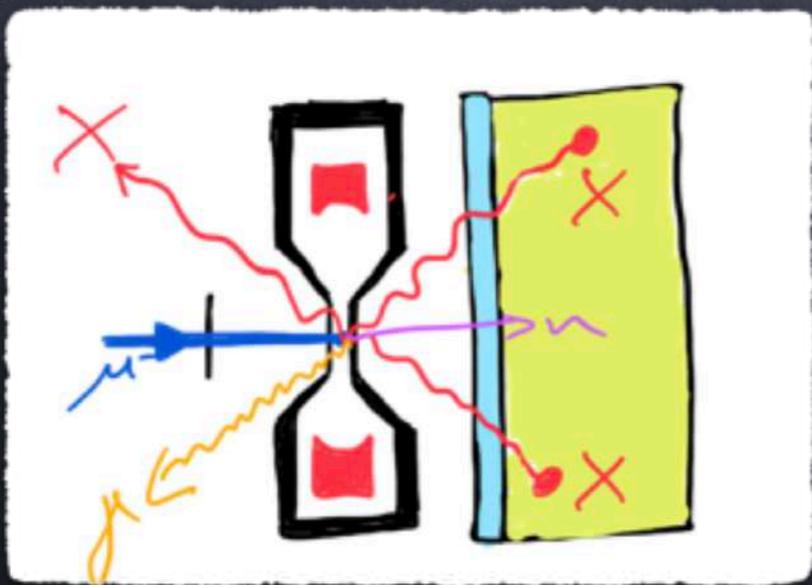
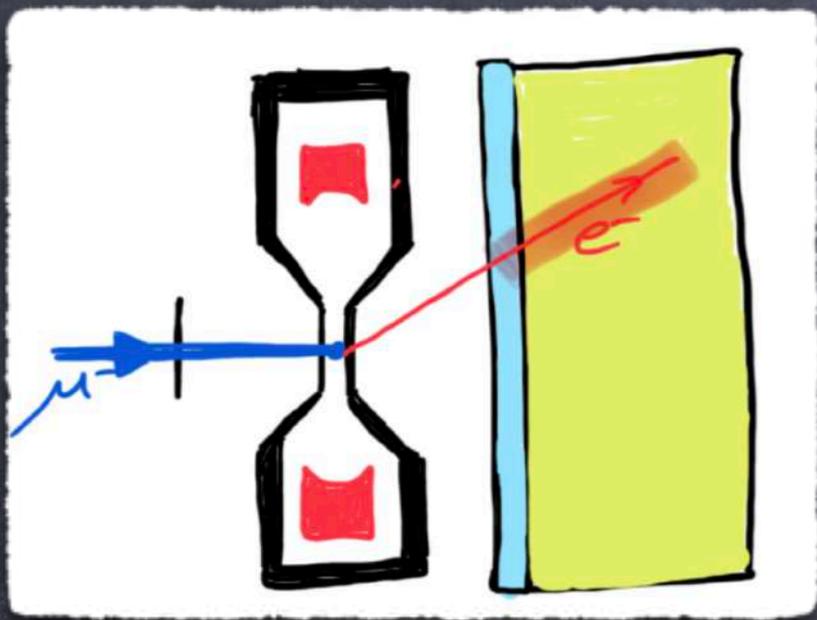


Intrinsic background: non-laser excited μp atoms that diffuse to the target walls within Δt .

Erroneous background: electrons produced when the muon decays.

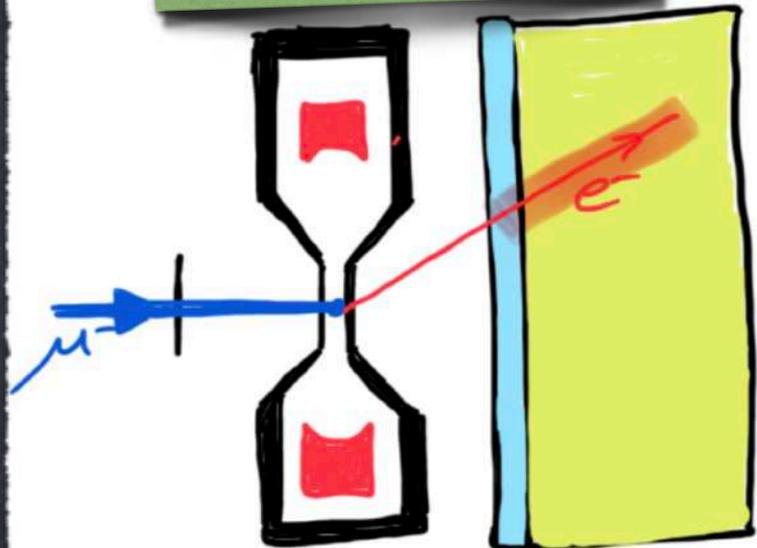


What is it all about?

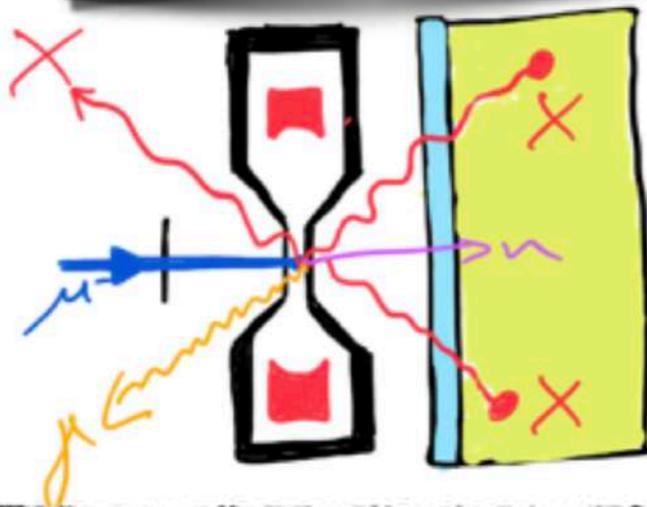


What is it all about?

Muon decay

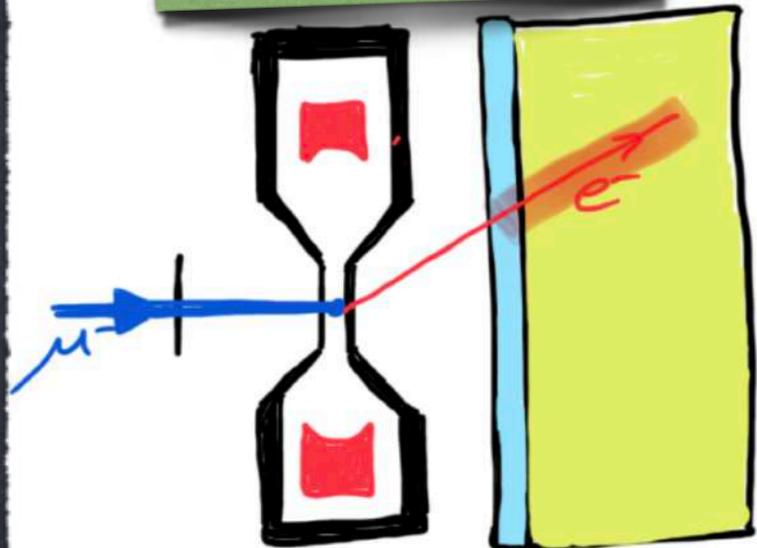


μ Au X-ray cascade



What is it all about?

Muon decay

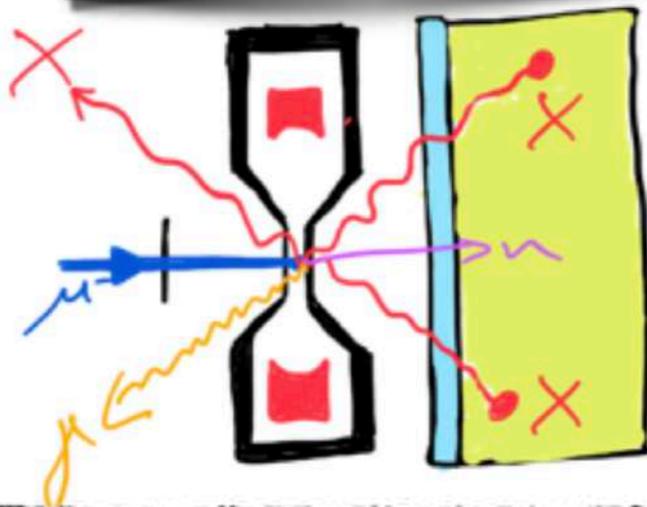


Muonic gold
(μAu) X-ray
cascade

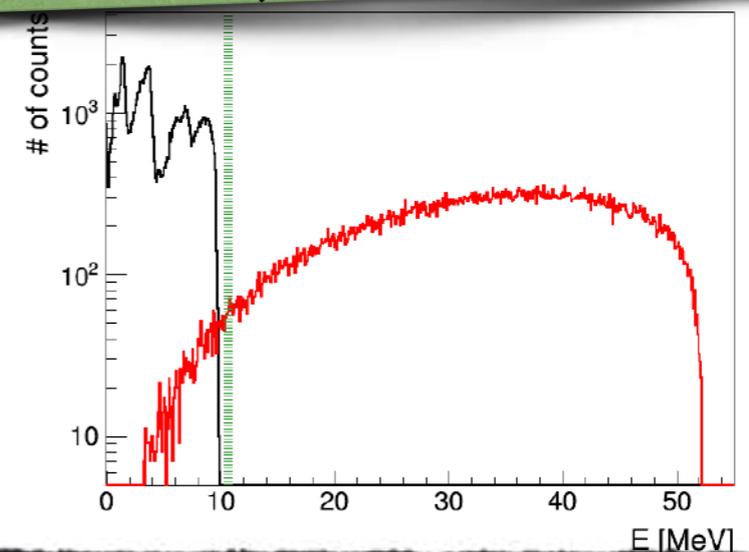
Muon decay
 $\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$

Theoretical
energy
threshold

μAu X-ray cascade

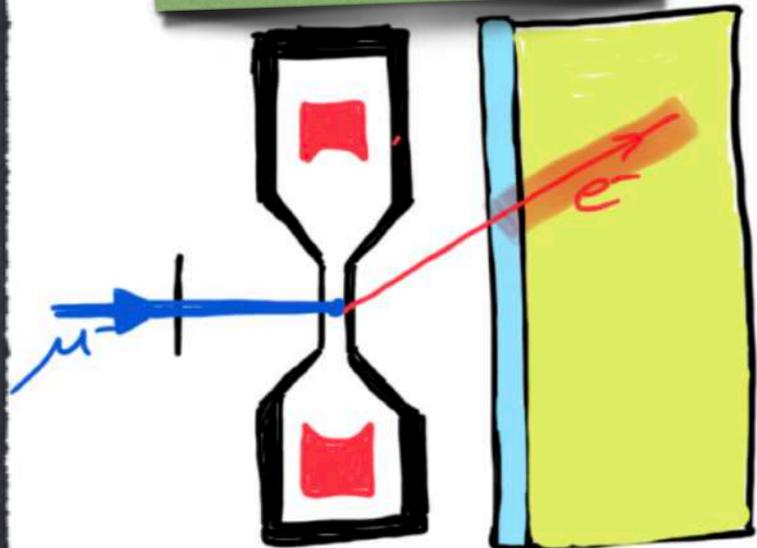


250-mm plastic scintillator

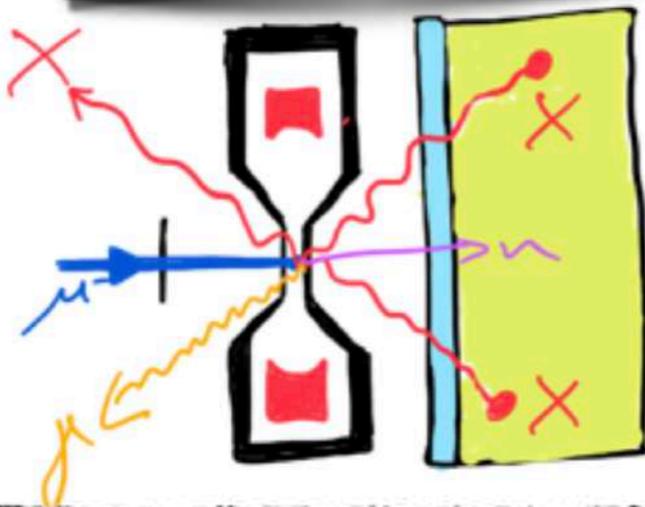


What is it all about?

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μAu X-ray cascade

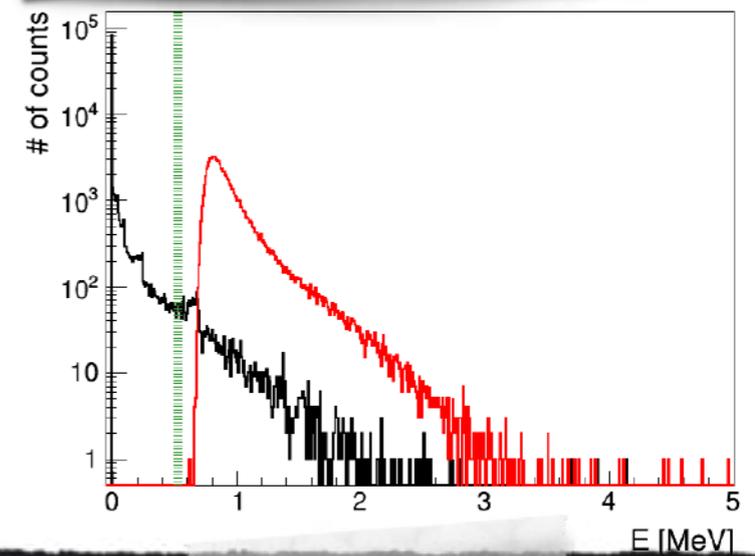


Muonic gold
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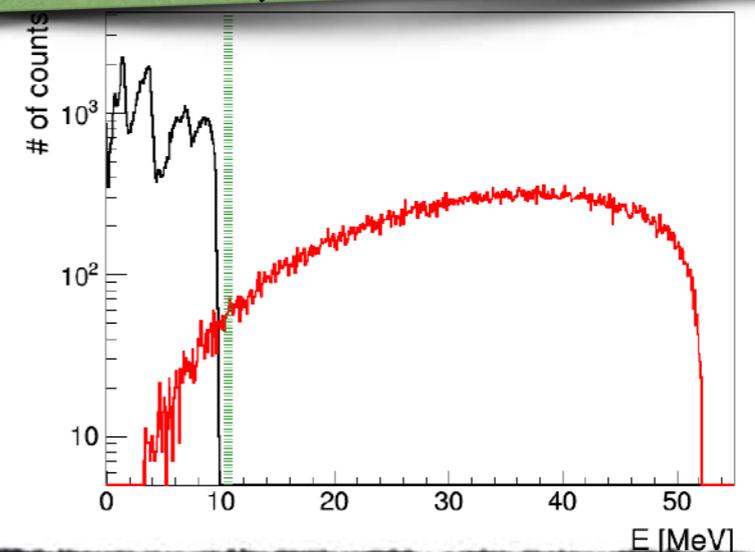
Muon decay
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Theoretical
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5-mm plastic scintillator



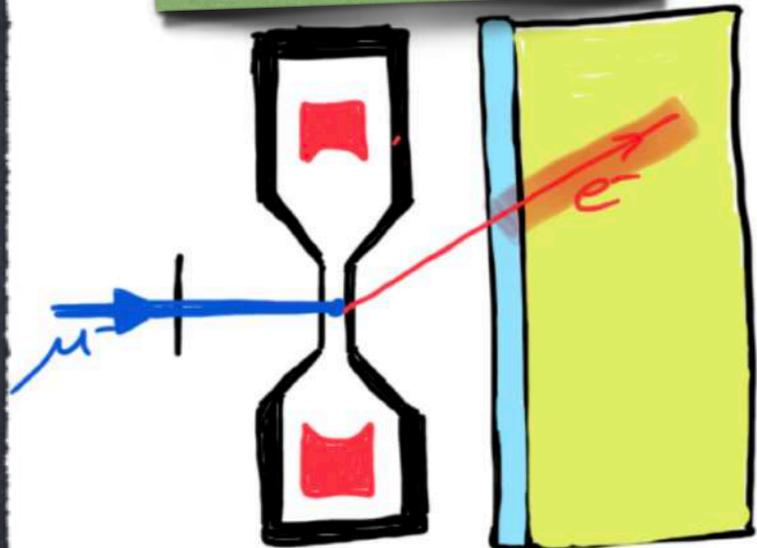
250-mm plastic scintillator



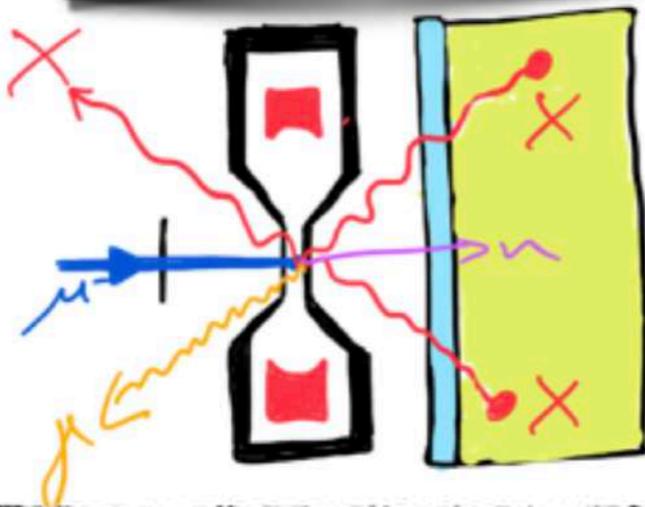
What is it all about?

30 x more electrons than cascade events

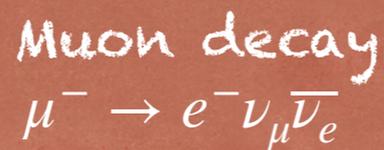
Muon decay



μ Au X-ray cascade

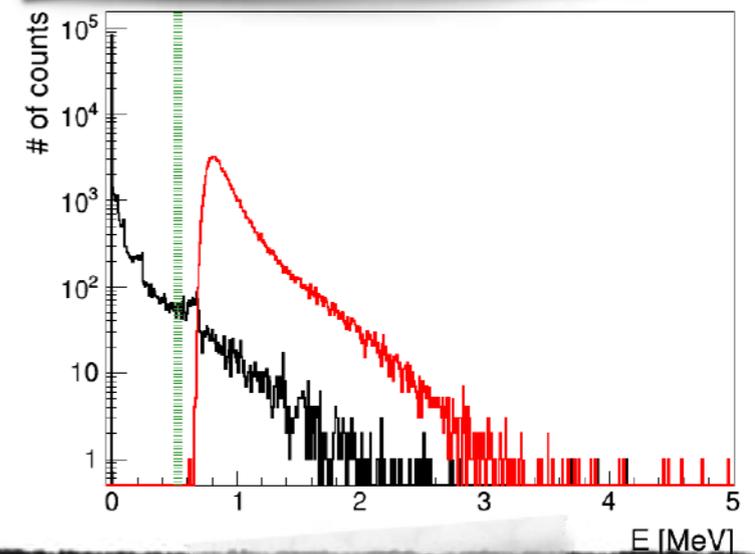


Muonic gold (μ Au) X-ray cascade

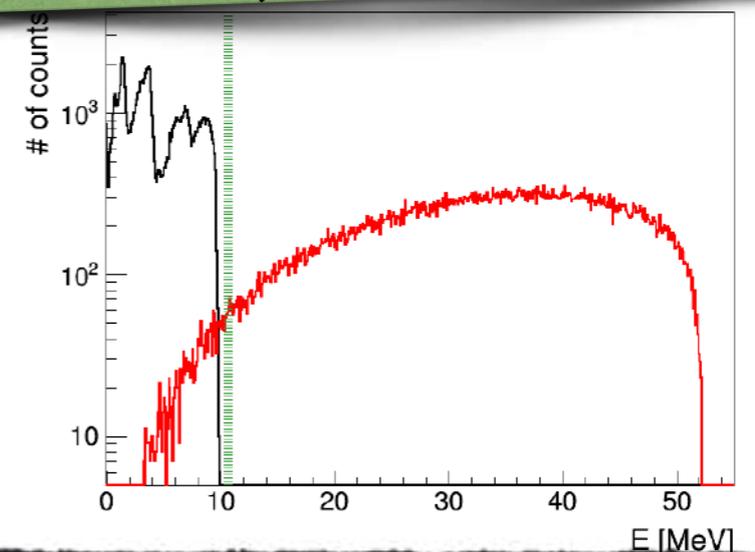


Theoretical energy threshold

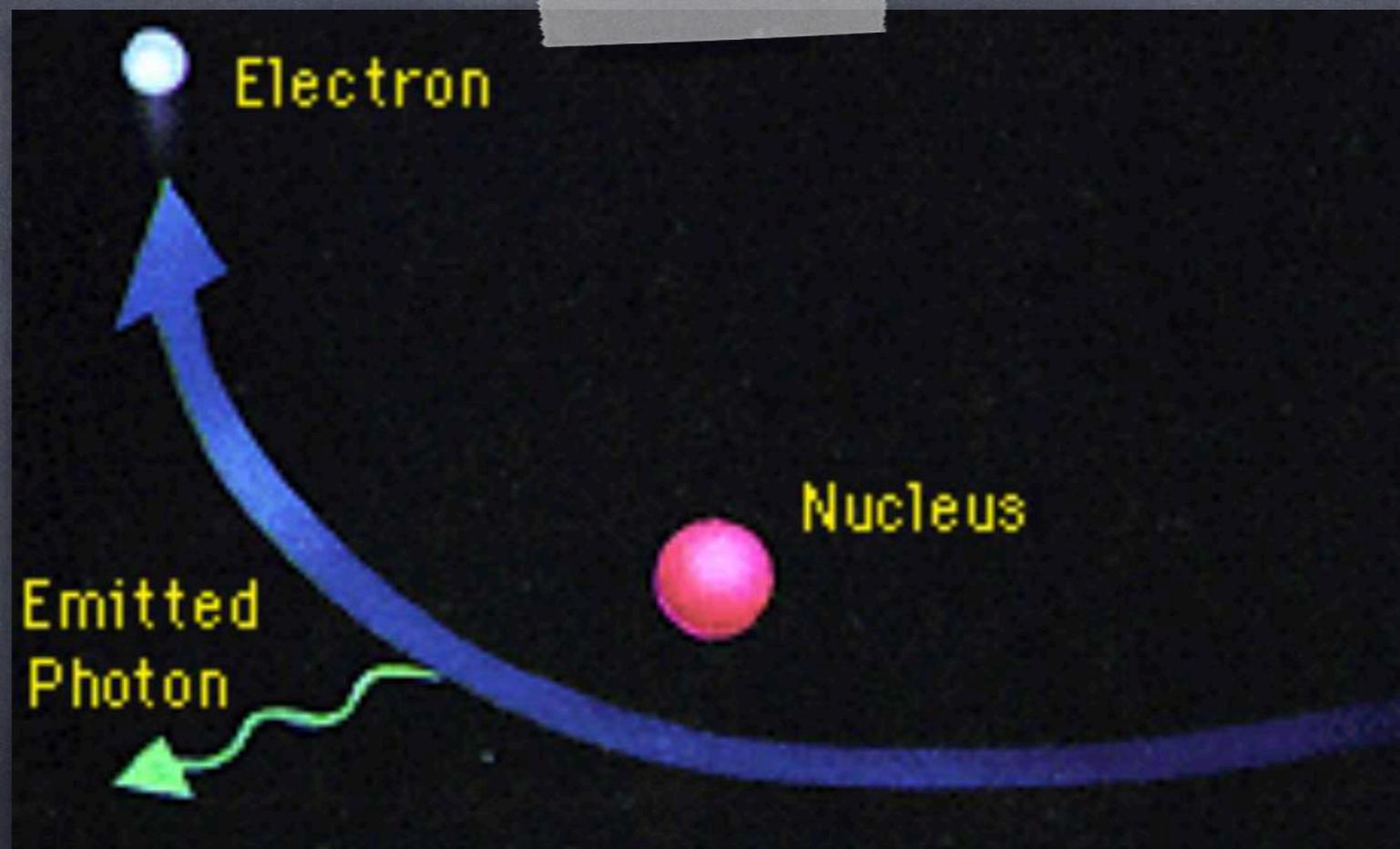
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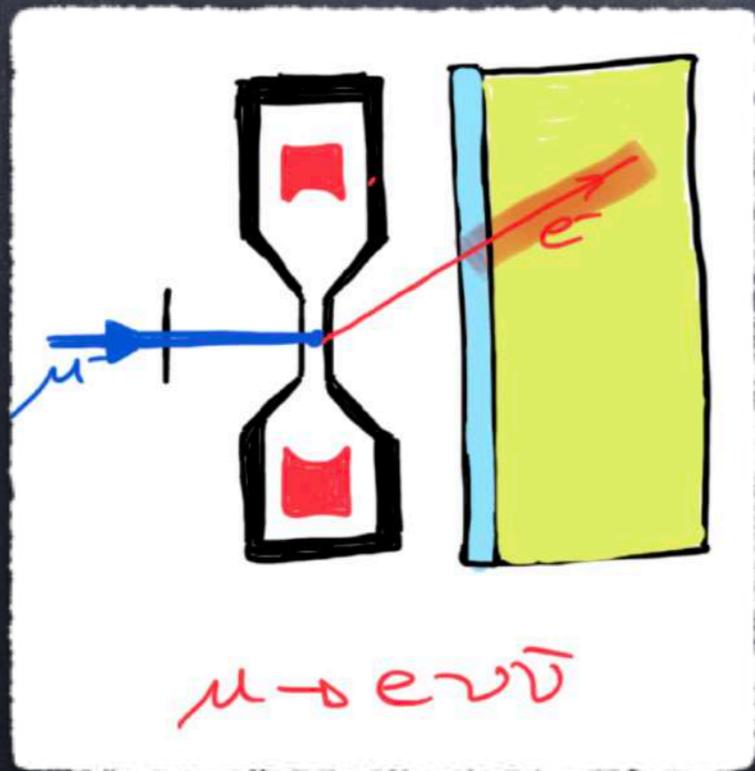
250-mm plastic scintillator



Bremsstrahlung

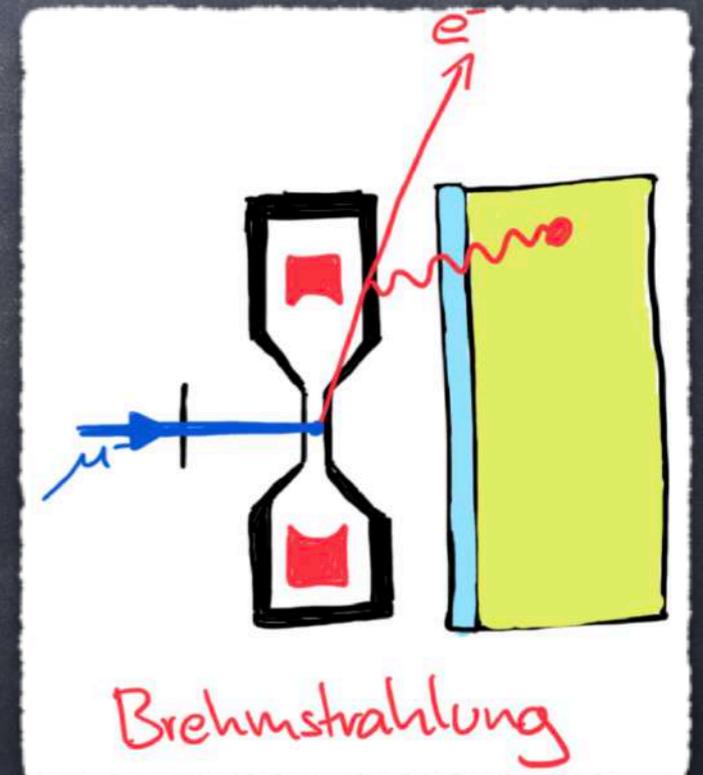
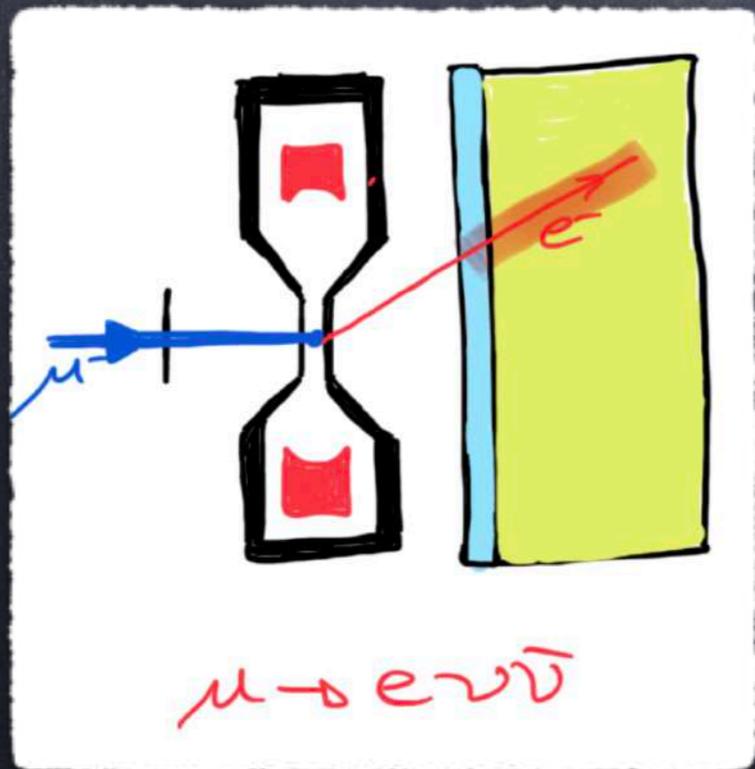


Bremsstrahlung

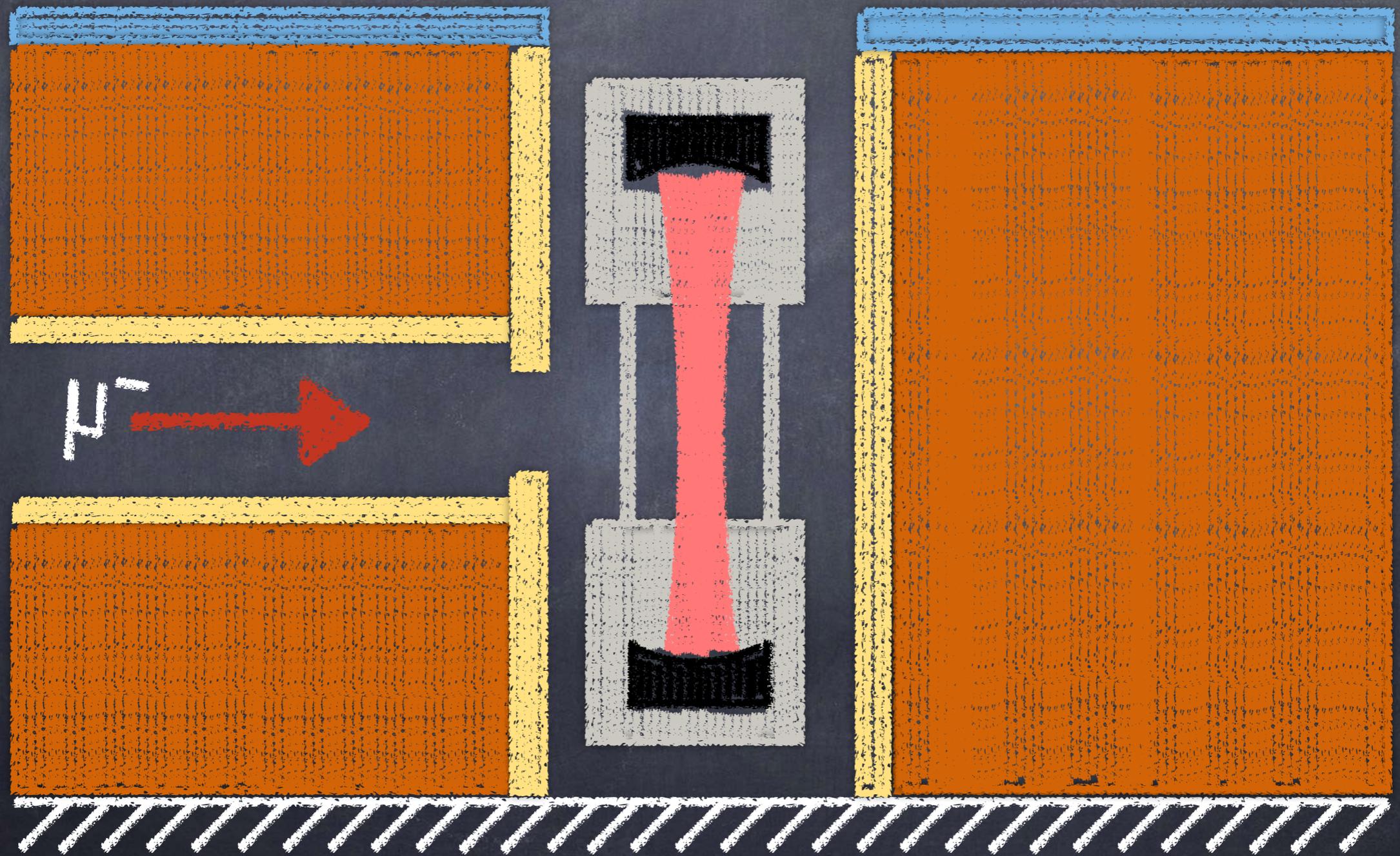


Bremsstrahlung

False identification of e^- as a cascade event

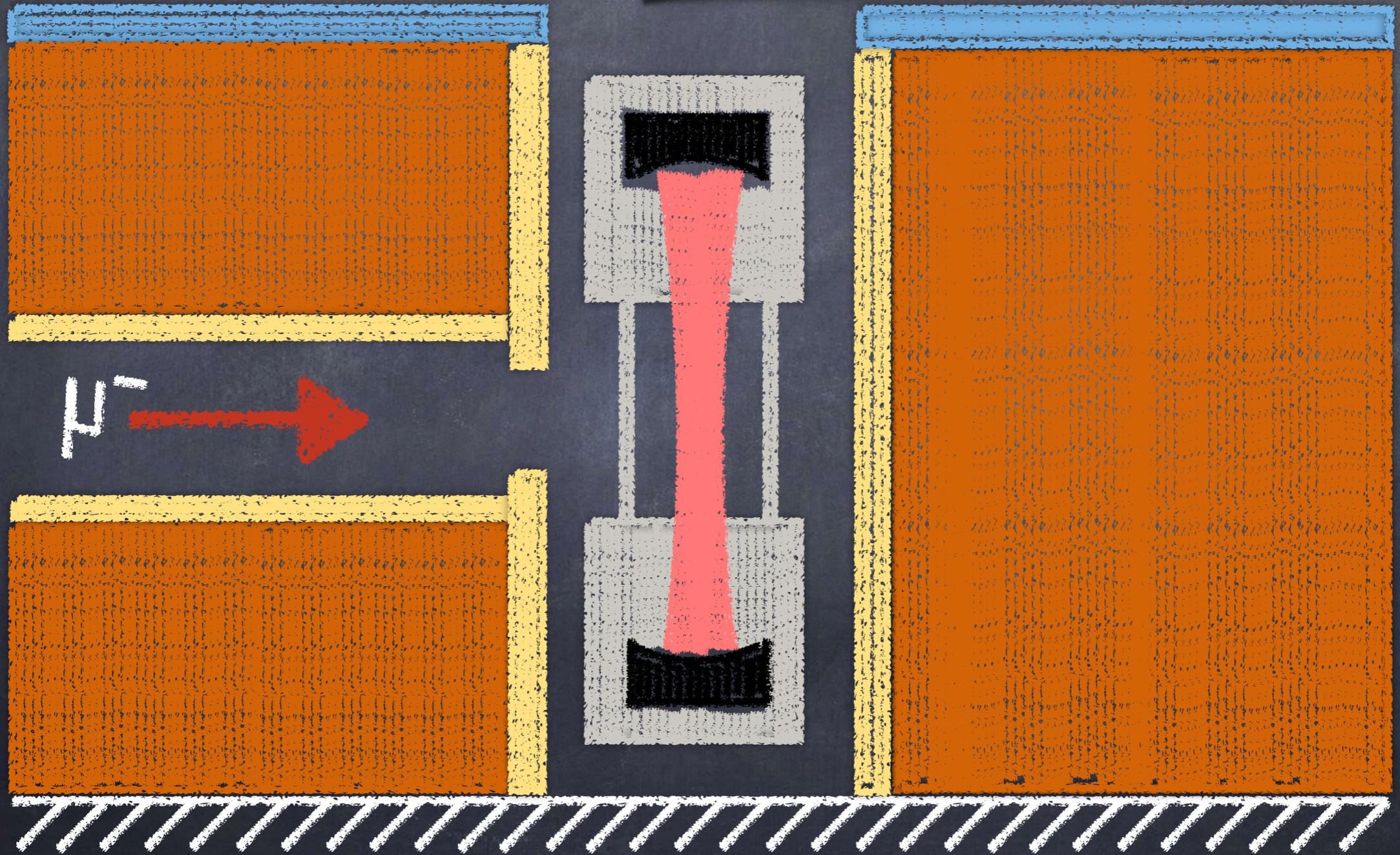


Detection system

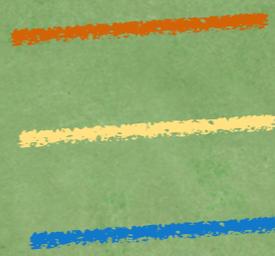


Detectio

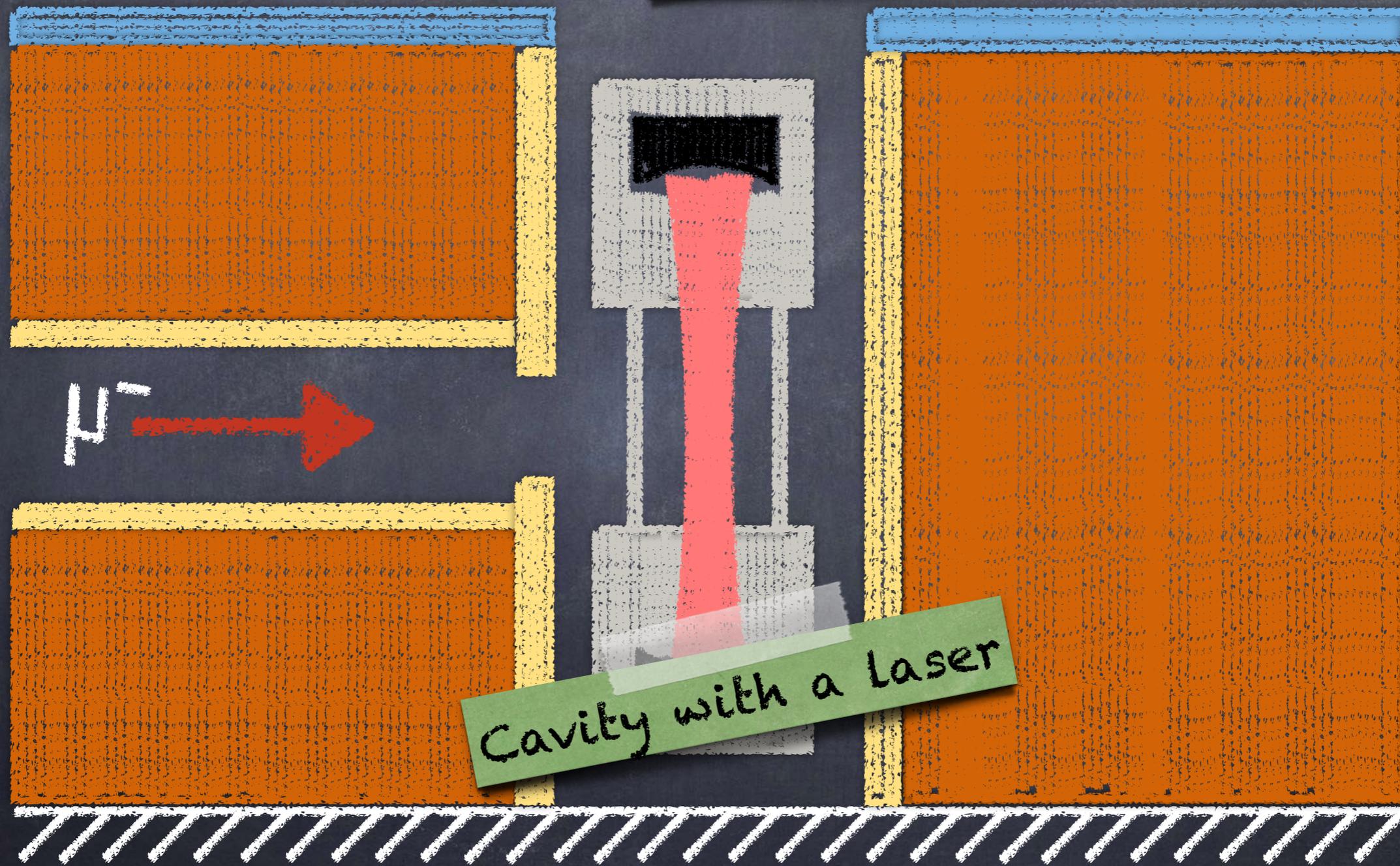
Thick scintillator
Thin scintillator
Veto detector



Detection



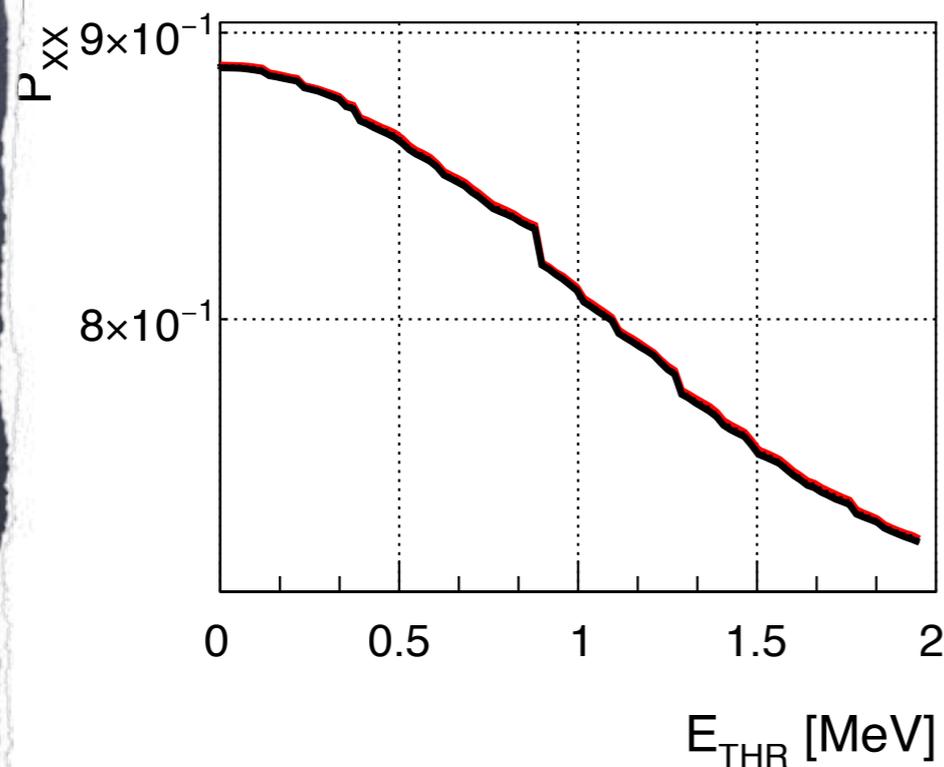
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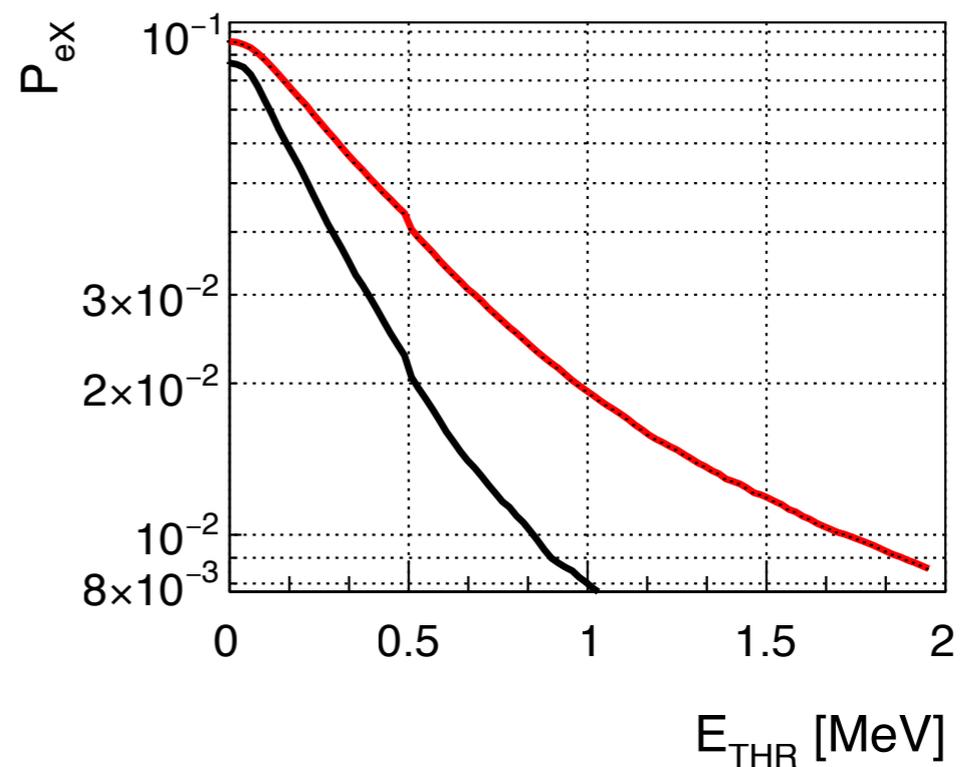
Cavity with a Laser

Simulations

P_{XX} - μ Au cascade
detection efficiency



P_{ex} - probability to
misidentify e^- as X-ray



~~Target cavity is made of glass~~

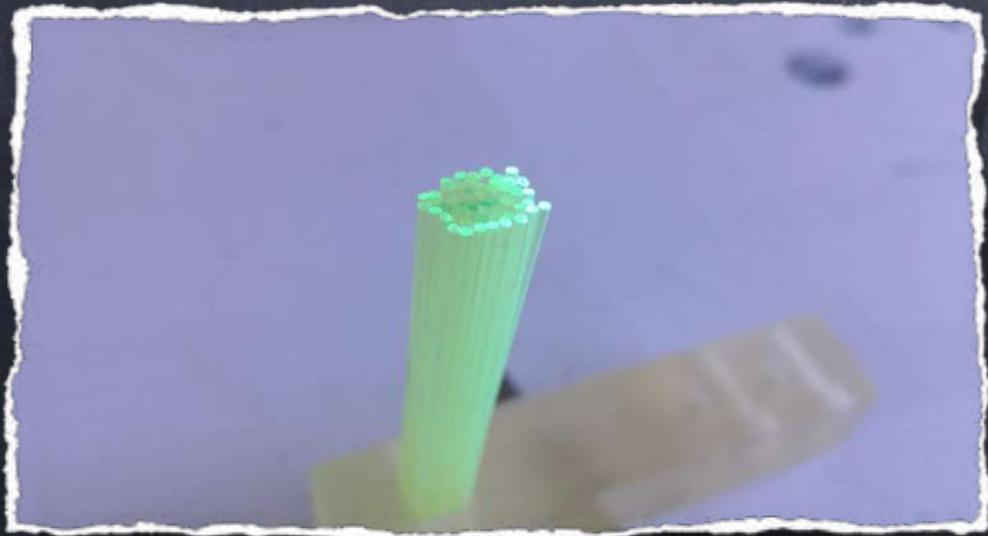
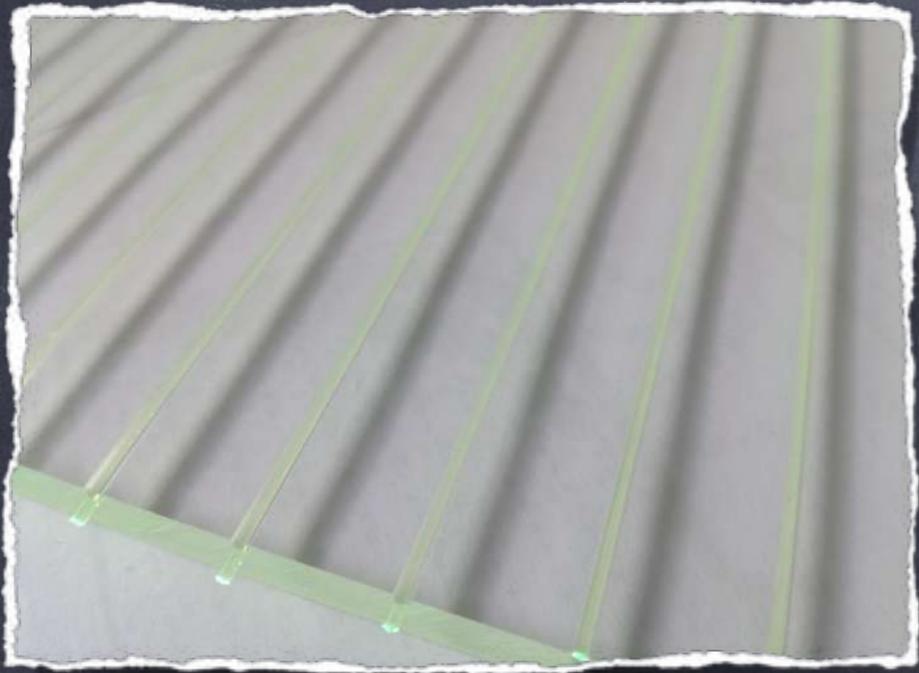
Target cavity is made of glass

~~Target cavity is made of copper~~

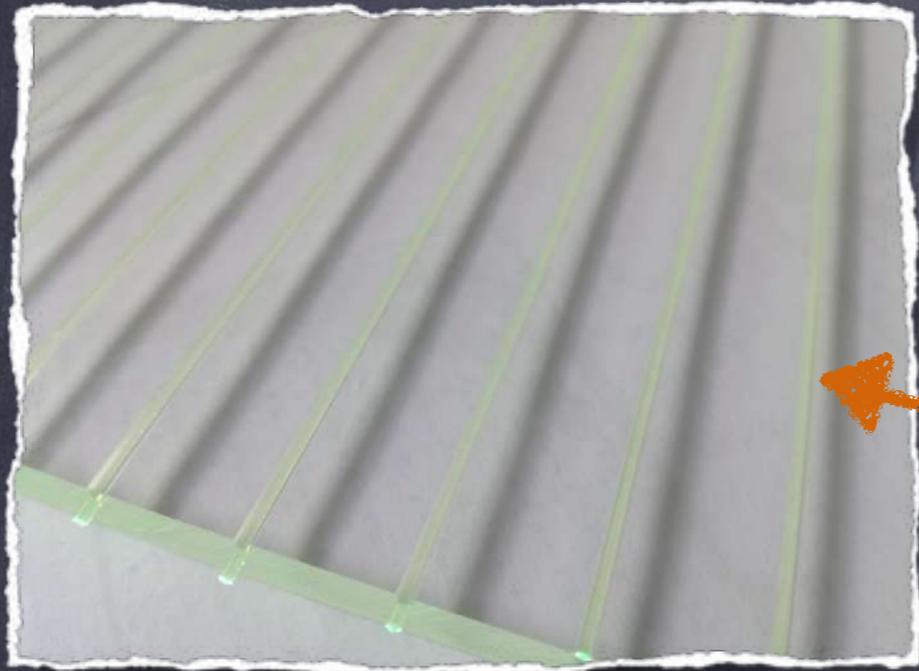
Target cavity is made of copper

Thin plastic scintillators

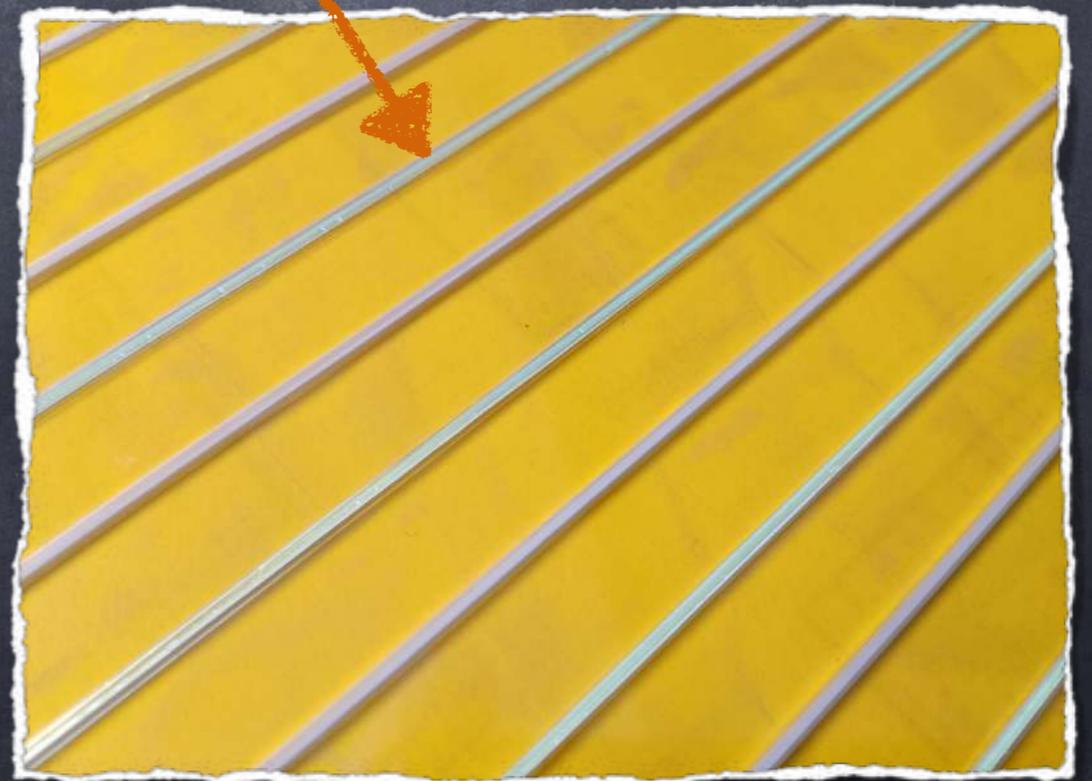
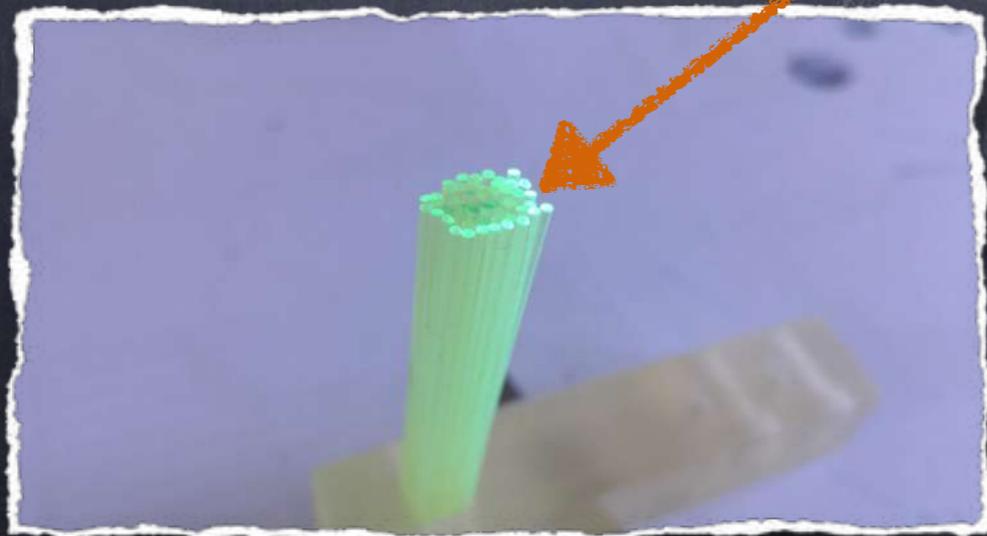
Thin plastic scintillators



Thin plastic scintillators



Wavelength-shifting fibers

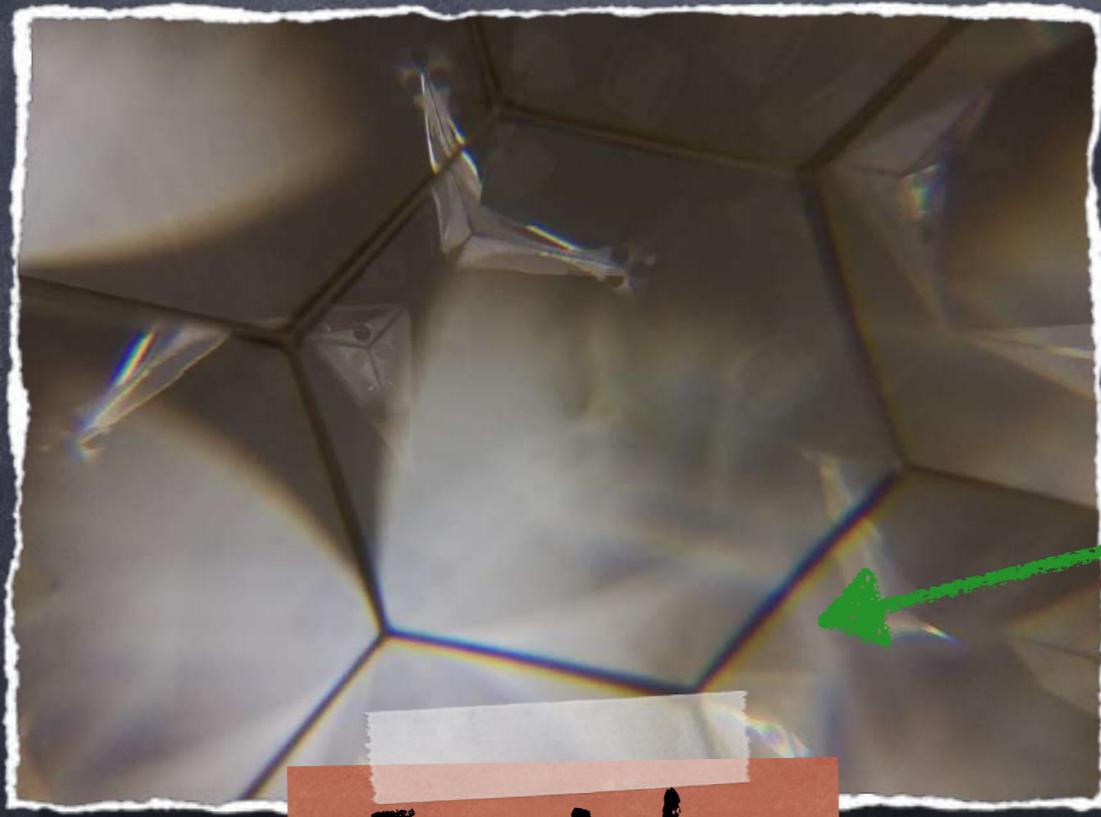


Thick plastic scintillators

Thick plastic scintillators



Thick plastic scintillators



Inside



Crystals

PMTs

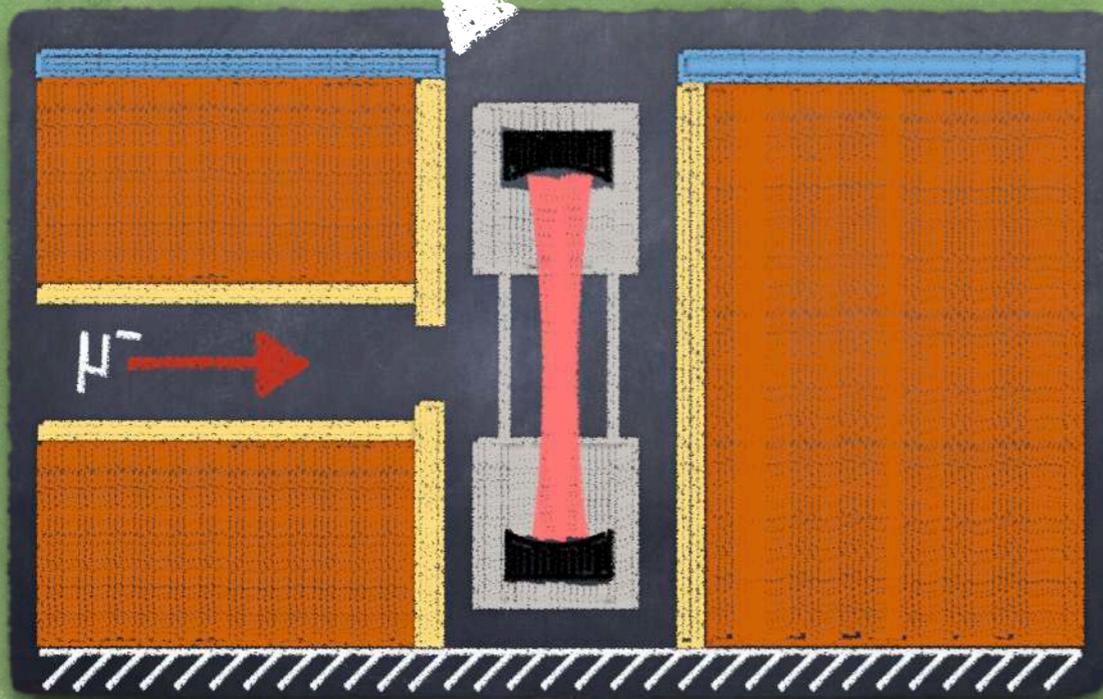
Conclusions

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- Detection system will be tested during the coming beam-time at PSI in November 2019.

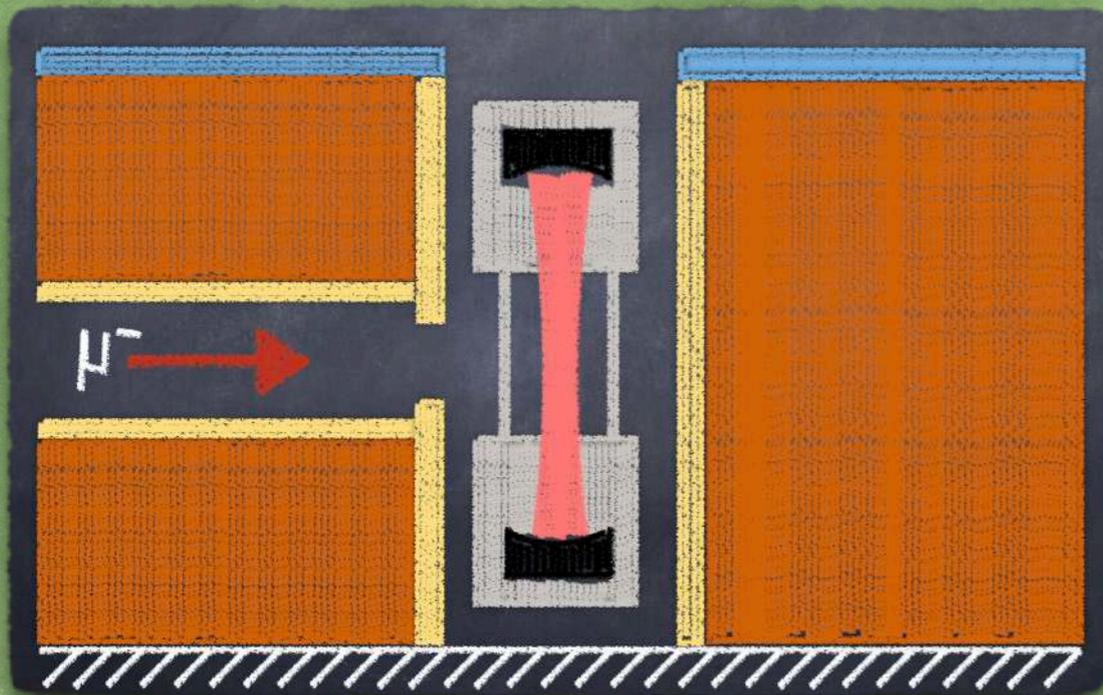
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