L5 Practical Aspects of MuSR

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Note Title 04/08/2011

What is the technical goal of a μSR experiment?

Simple Answer:

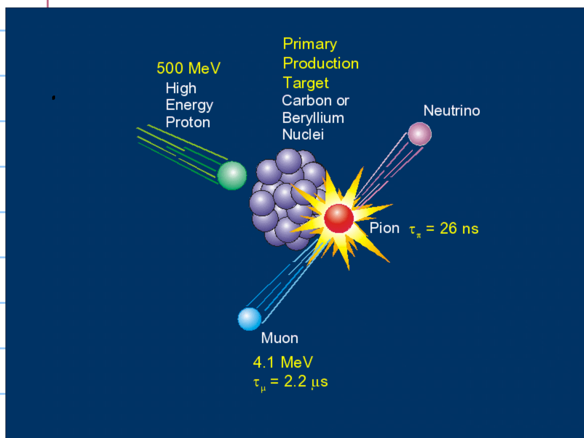
To measure the polarization of the muons in your sample under known conditions.

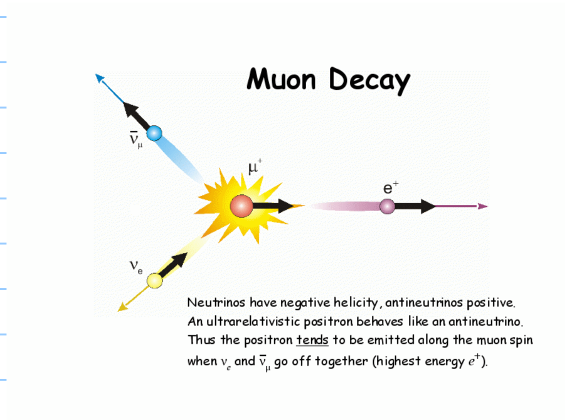
But what do the terms.

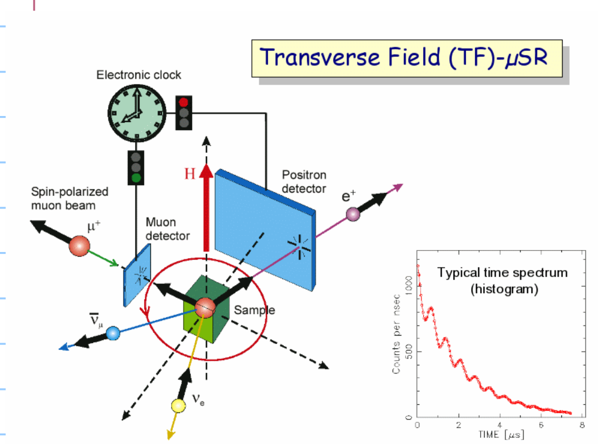
i) measure the polarization
ii) your sample
iii) known conditions

require, and does doing any one or two of these tasks very well affect the quality of the others. Lets keep this question in the back of our mind as we look at how to accomplish i) → iii)

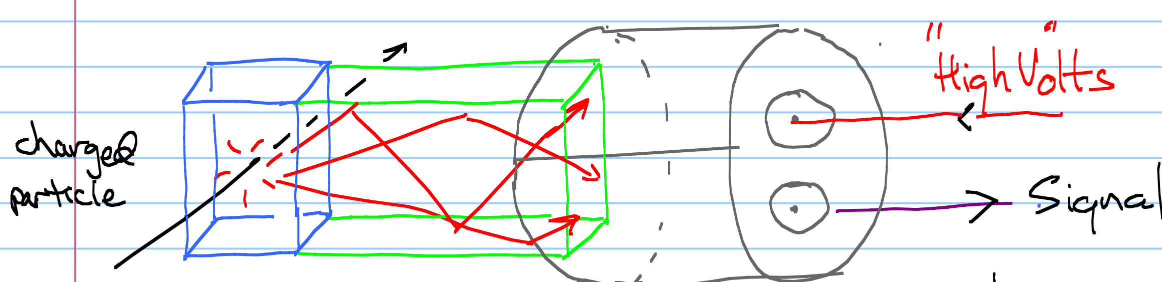
Detection of μ^+ & e^+







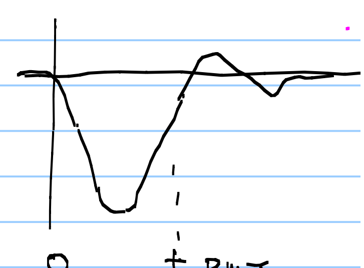
& creation of the electronic pulse which represents the particle & its timing



Scintillator

LIGHT GUIDE

Photo multiplier tube or solid state detector



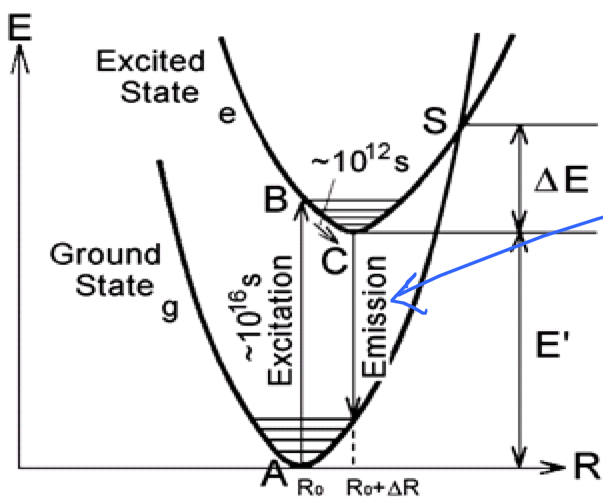
2. Scintillation mechanism

Basic processes:

excitation

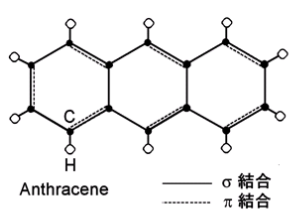
→thermal relaxation to the bottom of excited state

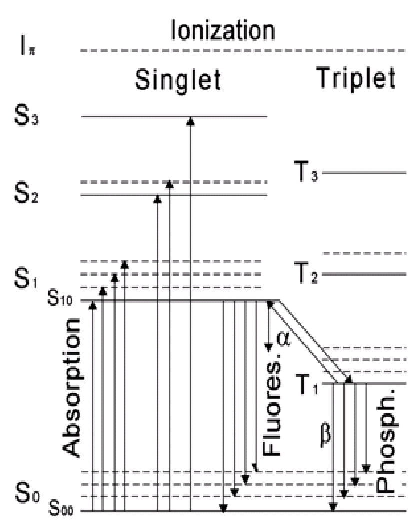
→emission



This step occurs on the ns timescale.

Fig.
luminescence in the configurational coordinate diagram.
R=inter-atomic distance between ground state of ligand atom and the





The standard light emitting scintillation calibration material.

L5

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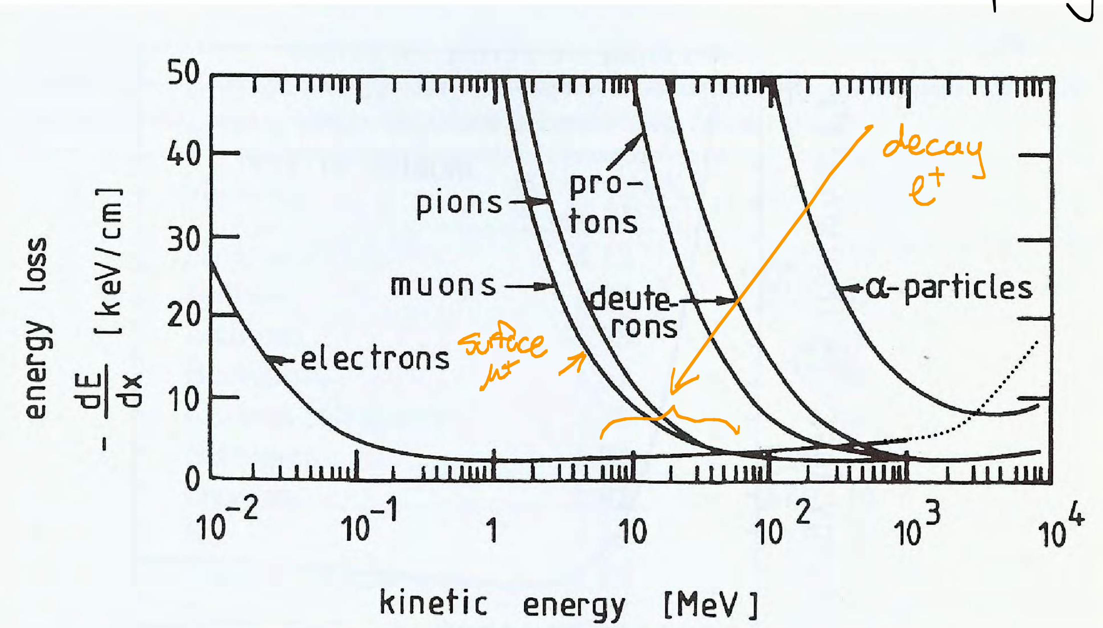


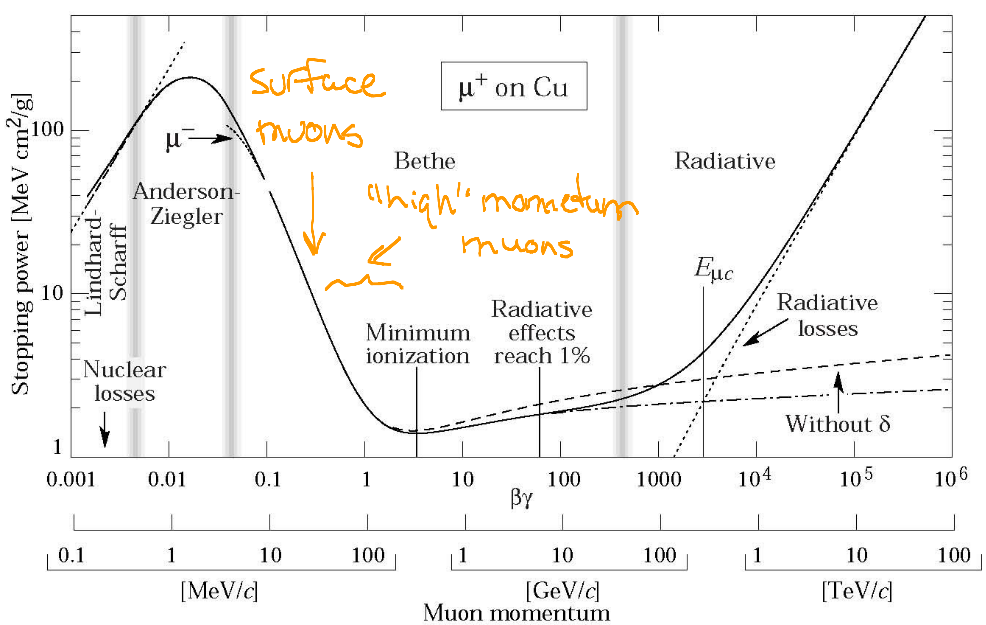


Fig. 27.1: Stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta\gamma \approx 0.1$ are taken from ICRU 49 [4], and data at higher energies are from Ref. 5. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled "μ^-" illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies [6].

Relevent Properties:

	Surface μ^+	Decay Positron
Energy	4.1 MeV	10 - 50 MeV
Momentum	29.8 MeV/c	10 - 50 MeV/c
Speed	~ .2β	~ 1β
Range	180 mg/cm^2	~ 4 - 16 g/cm^2
in Scint	.18 cm	4-16 cm
in Al	.06 cm	1.5-6 cm
in SS.	.02 cm	.5 - 2 cm
$\partial E/\partial x$ (plastic)	13 MeV/cm	2 - 3 MeV/cm
Scintillator thickness	.025 cm	1.25 cm
Photon production rate	10^4/MeV	10^4/MeV
# of Photons	~ 3,500	~ 25,000

Muon Precession

$$\frac{d\vec{m}_\mu}{dt} = \gamma_\mu \, \vec{m}_\mu \times \vec{B}_{ext}$$

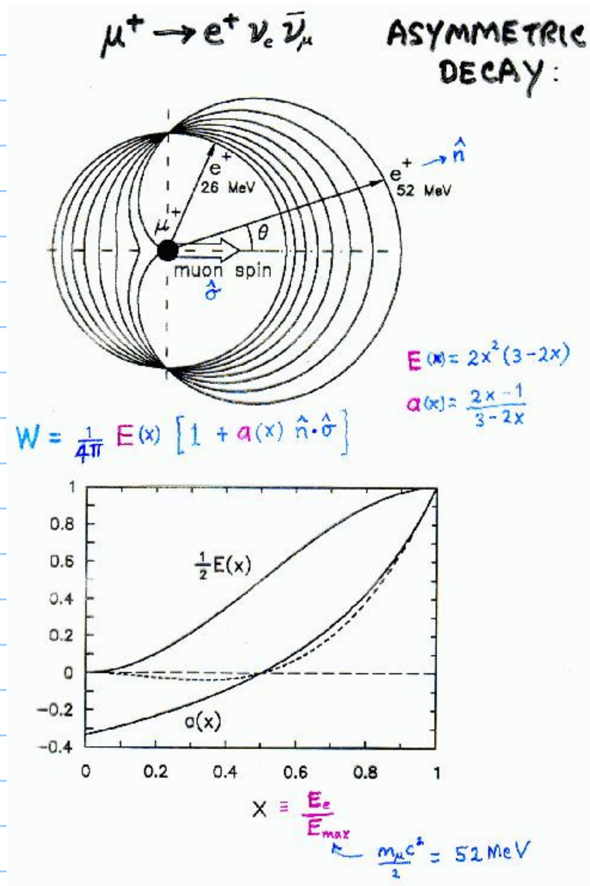
gyromagnetic ratio

magnetic moment

$\gamma_\mu = 2\pi \times 1.35\ \mathrm{GHz/T}$, the μ^+ frequency is ~950 MHz in 7 T

⇒ sub nanosecond timing

MEASURING THE POLARIZATION (t)



Courtesy JHB

Probability of emission of a e^+ at an angle θ wrt spin direction $\vec{S}_\mu$ is

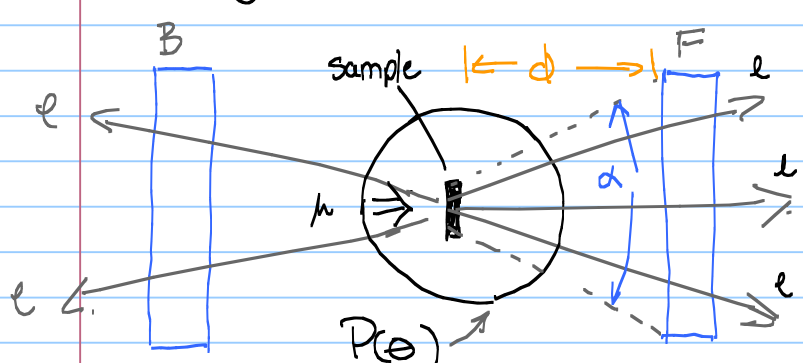
$$P^{e^+}(\theta) = \int_0^1 W(x)\,dx$$

$$= \frac{1}{4\pi}\left(1 + \frac{1}{3}\cos\theta\right)$$

or in reality

$$= \frac{1}{4\pi}\left(1 + a\cos\theta\right), \quad a < 1/3$$

How does one chose the geometry of a detector?



i.e what should α be for the scintillator?

Assuming cylindrical geometry, the rate of e^+ into the scintillator is

$$R_{F/B} \propto \frac{1}{4\pi}\int_0^{\theta_0} d\phi \sin\theta\,(1 \pm a\cos\theta)\,d\theta$$

$$= \frac{1}{2}\left(1-\cos\theta_0 \pm \frac{1}{2}a\sin^2\theta_0\right)$$

The signal is proportional to the number of "asymmetric" counts

$$R_A = R_F - R_B \propto \frac{1}{2}a\sin^2\theta_0$$

The counting noise is proportional to $\sqrt{R_T}$, the square root of the total count rate

$$\sqrt{R_T} = \sqrt{R_F + R_B} \propto \sqrt{(1-\cos\theta_0)}$$

Maximizing the S/N ratio

$$\Rightarrow \frac{d}{d\theta_0}\frac{\sin^2\theta_0}{\sqrt{1-\cos\theta_0}} = 0$$

$$\Rightarrow \cos\theta_0 = 1/3$$

$$\Rightarrow \theta_0 = 70^\circ \;!!$$

How does one choose d?

Moun's & positrons are charged particles & experience the Lorentz force

$$\vec{F} = q\vec{E} + \frac{\vec{v}}{c} \times \vec{B}.$$

In a magnetic field the component of their velocity $\perp$ to the field will cause them to spiral (or bend) $\perp$ to the field direction.

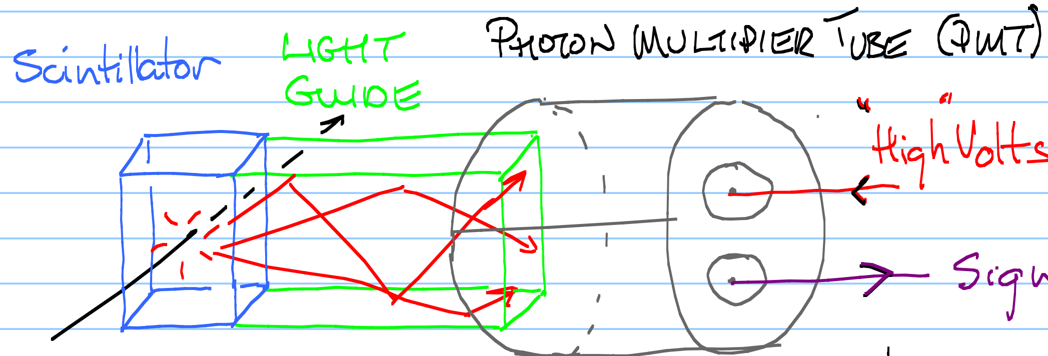
$$r = \frac{\gamma m v}{qB}, \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

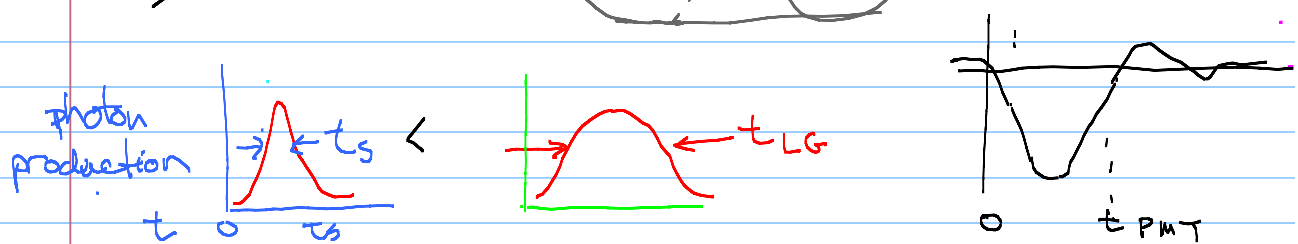
$r_{electron}$ (mm)

Field (T)	Electron Energy (MeV) 50	30	10
10	24	10	3.5
5	48	20	7.0
2	96	40	14

$\Rightarrow$ at high fields e^+ counters must be close to sample!!

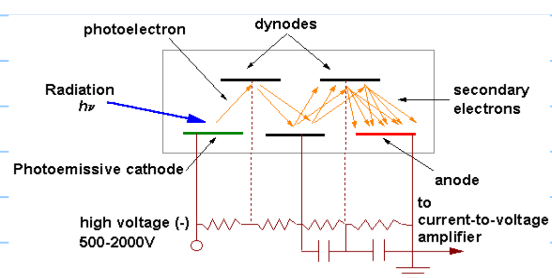
Choosing the Light Guide Geometry

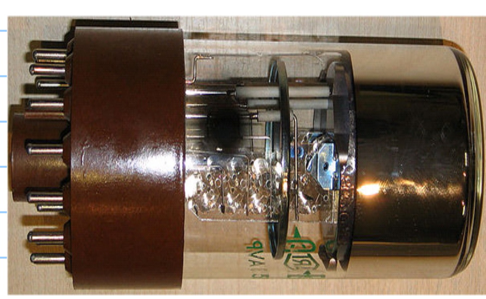




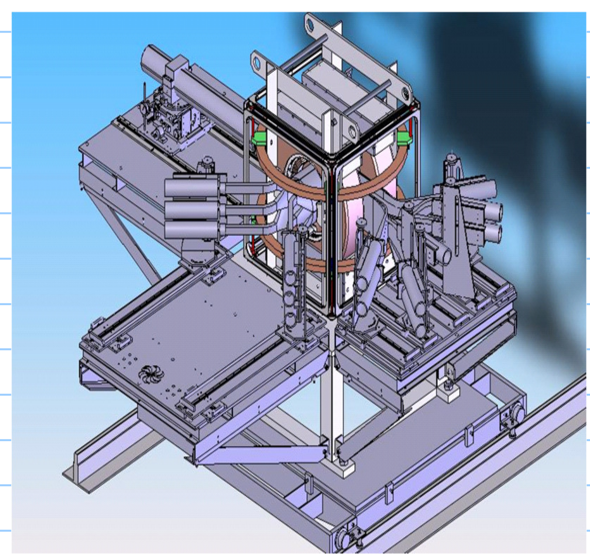
typically ~3ns ~5-7ns ~5-10ns

But first, why does one even need a light guide?



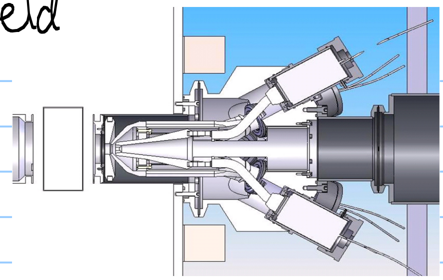


Standard PMT



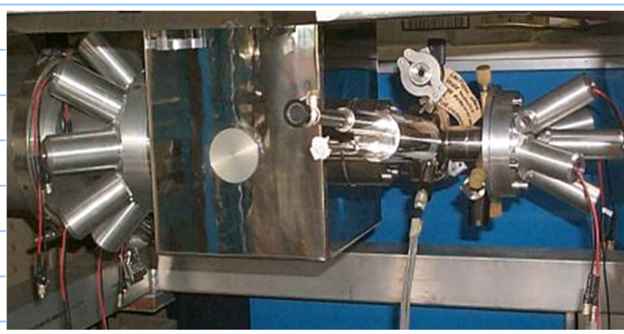
Omni' (in M9A)

High Field "mesh dynode" PMTs



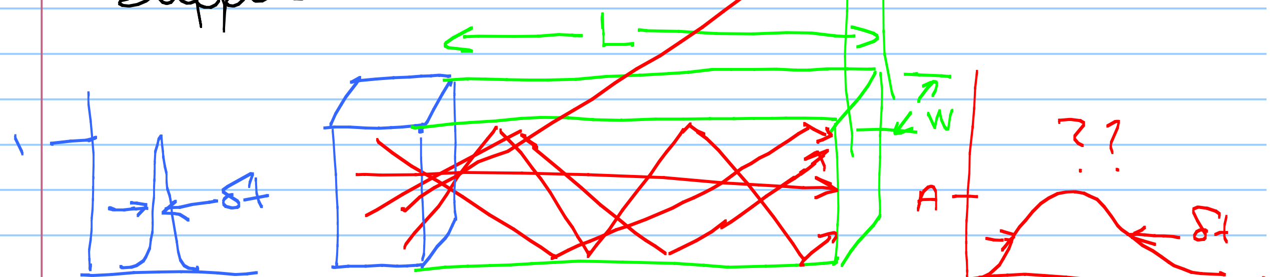
DR "Front End"

HiTime



DR

Suppose



~.2 ns

Specular reflection + total internal reflection $\theta < 45°$.

what does this look like?

Time of arrival of light propagating at an angle θ is $vL\cos\theta$. Assuming θ varies isotropically from 0 to ~45° the distribution of arrival times at the end of the light guide is

$$D(\tau) \approx \int_0^{\pi/4} \delta\left(\tau - vL/\cos\theta\right) \sin\theta \, d\theta$$

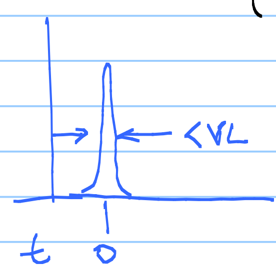
, $v \equiv$ velocity of light in guide

let $x = vL/\cos\theta$, $dx = (vL/\cos^2\theta)\sin\theta \, d\theta$

$$\Rightarrow D(\tau) \propto \int_{vL}^{\sqrt{2}vL} \delta(\tau - x) \, x^2/vL \, dx$$

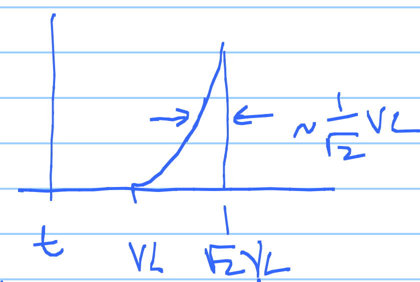
$$= \frac{(\tau - vL)^2}{(vL)^3} \, \frac{3}{2\sqrt{2}} \qquad vL < \tau < \sqrt{2}vL$$

$\Rightarrow$



in the scintillator

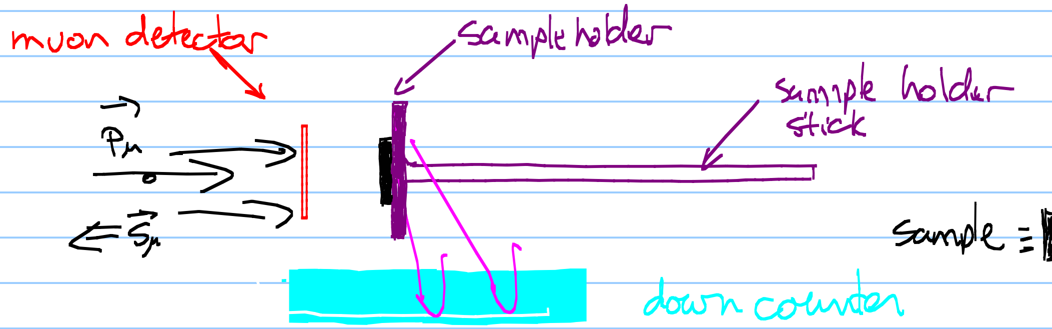
$\Rightarrow$



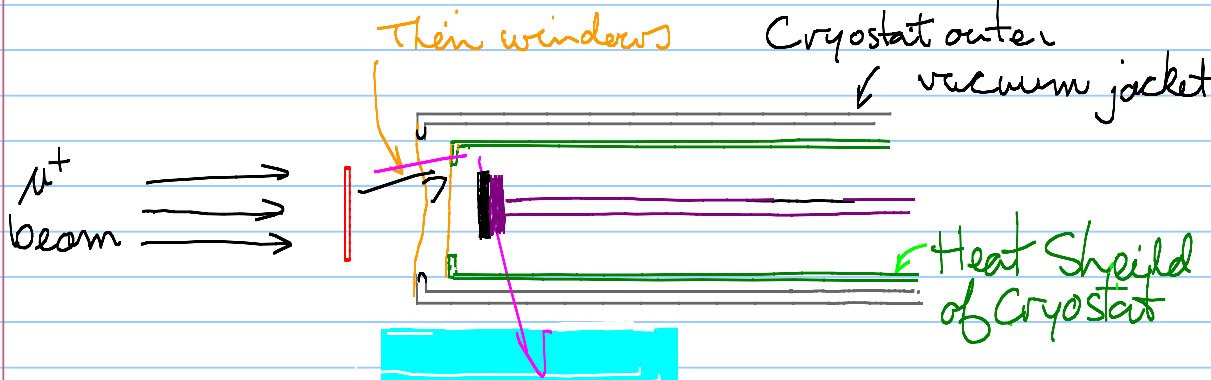
at the end of the guide

Conclusion: If $\frac{1}{\sqrt{2}}vL >$ than the intrinsic rise time of the scintillator pulse you are doing worse. If $\frac{1}{\sqrt{2}}vL \gg$ required time resolution you cannot do your experiment!

CHOOSING YOUR SAMPLE!



What is wrong with this picture??



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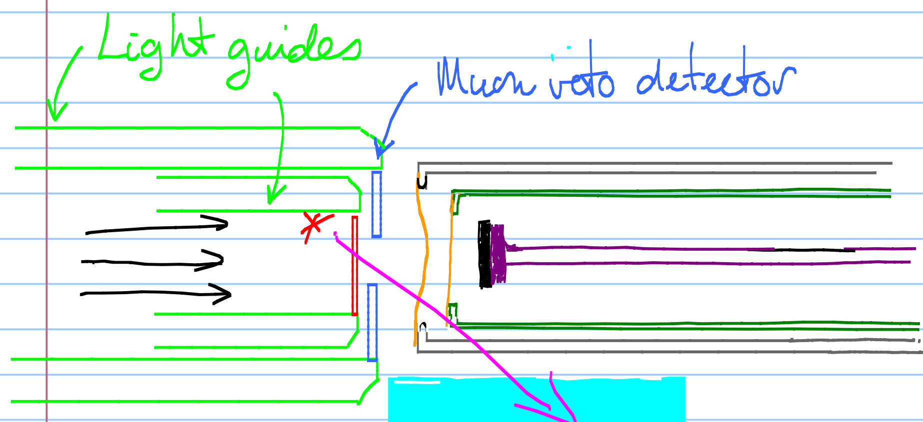
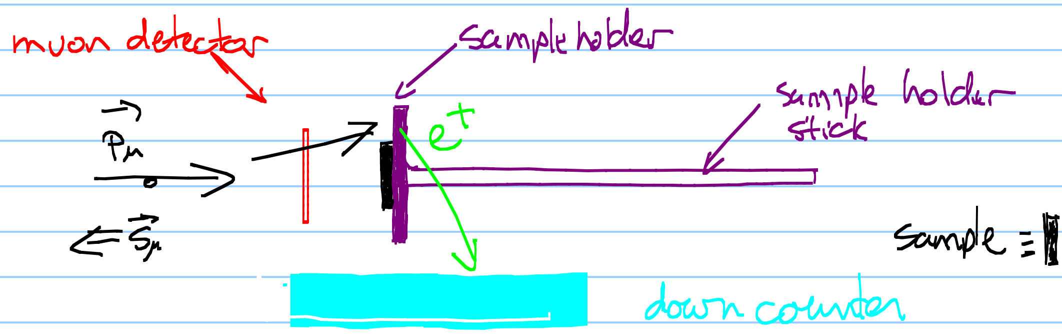


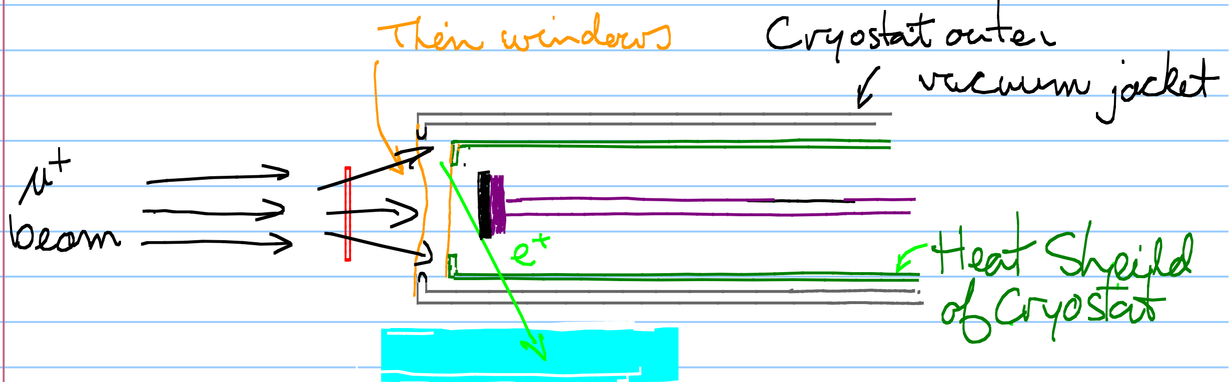
What is wrong with this picture?

Have you chosen your sample yet?

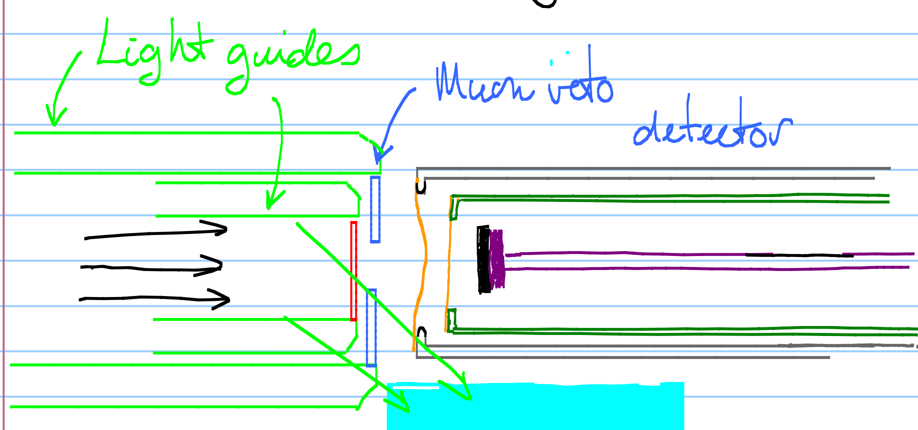
CHOOSING YOUR SAMPLE!



Muons land in your sample holder → contaminat^n signal

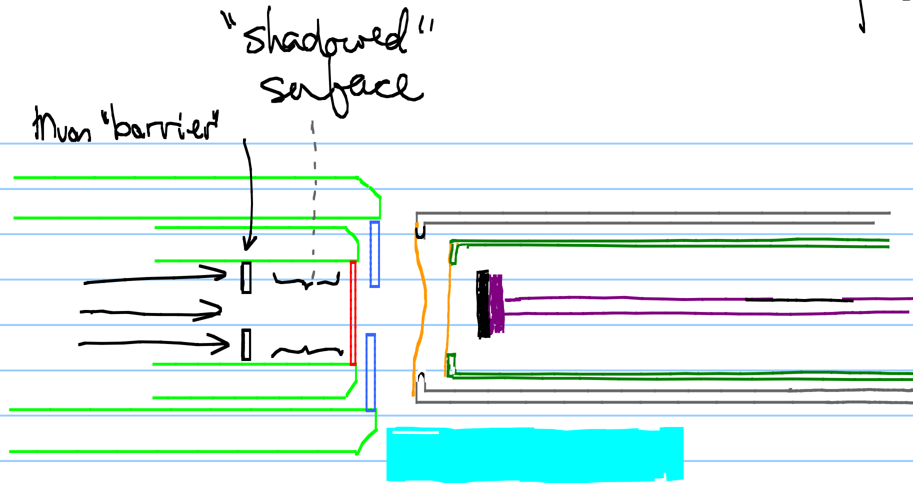


Muons land in the cryostat walls → contaminat^n signal

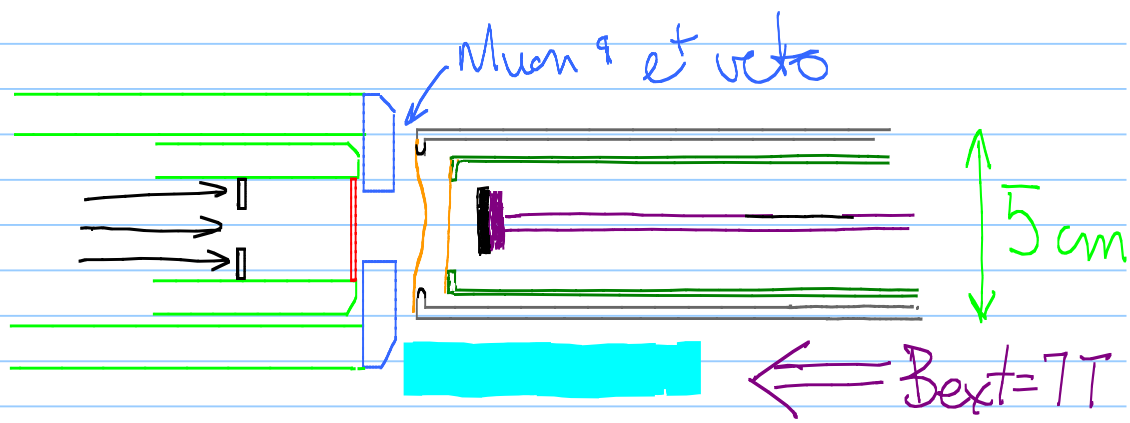


Muons land in the light guide → "uncorrelated" electrons & give background

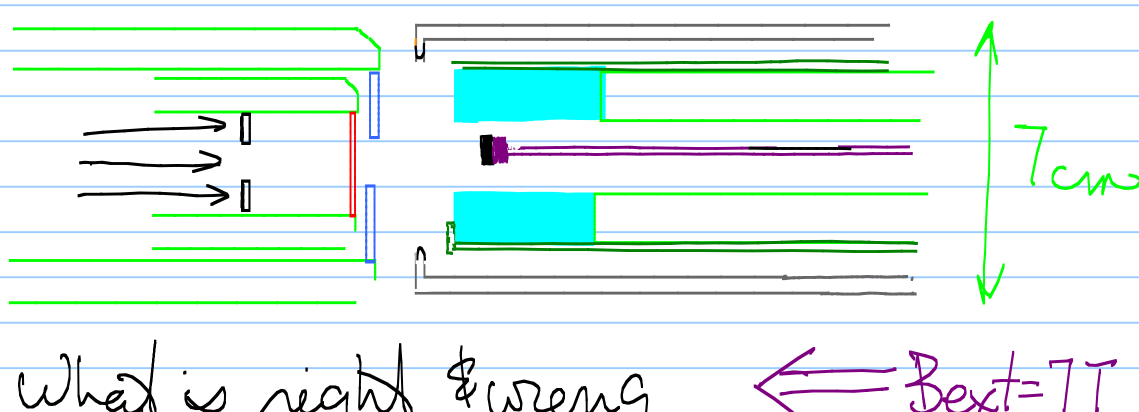
Have you chosen your sample yet?



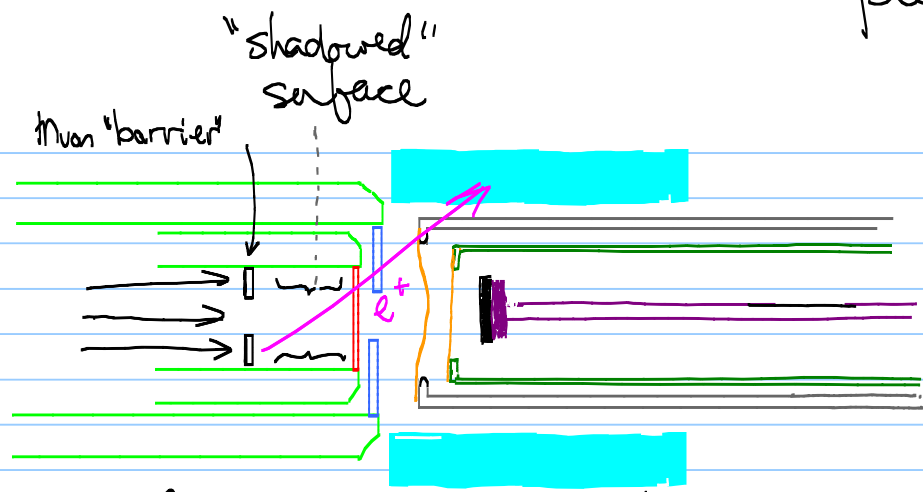
Are there "uncorrelated" e^{+} background events to limit S/N?



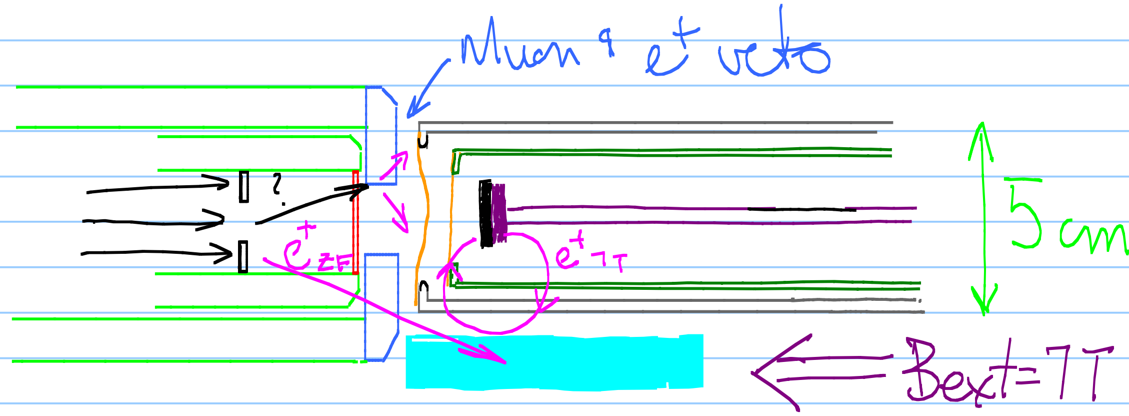
What is wrong with this picture?



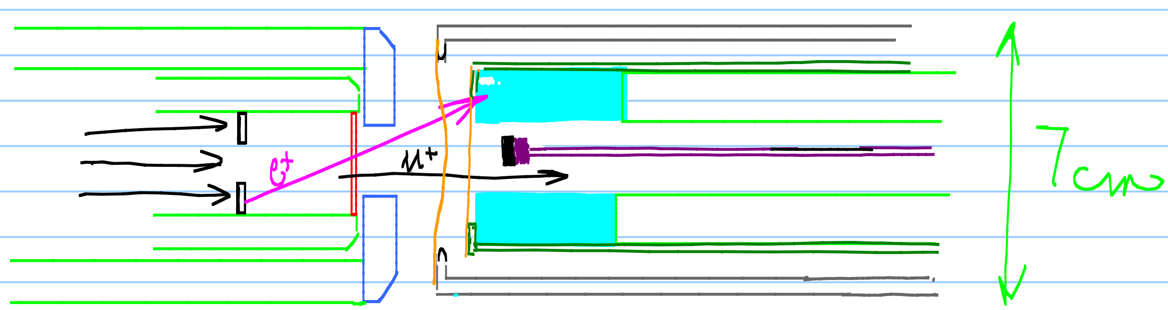
What is right & wrong with this picture?



Are there "uncorrelated" e^+ background events to limit S/N? Still YES!!



Large fraction of e^+ do not reach the detector + a few μ^+ on veto surface.

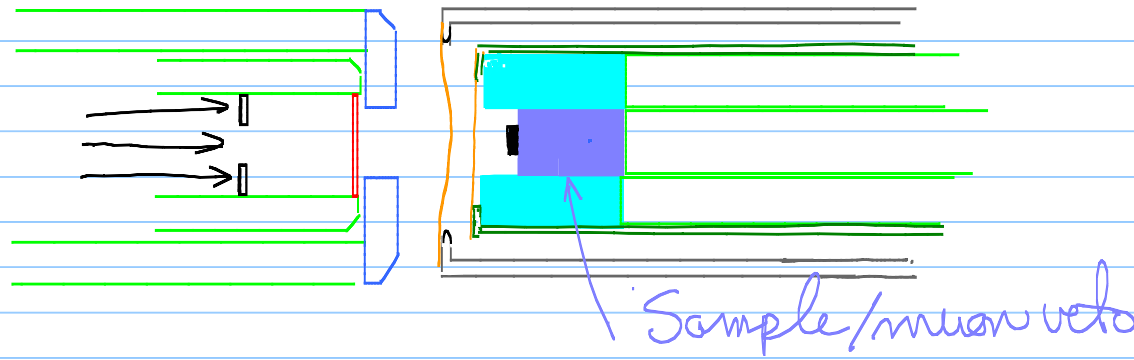


- Some muons miss sample
- Background e^+ still exists

⟸ Bext=7T

→ Comprimize "Solution"

The "High Time" Spectrometer



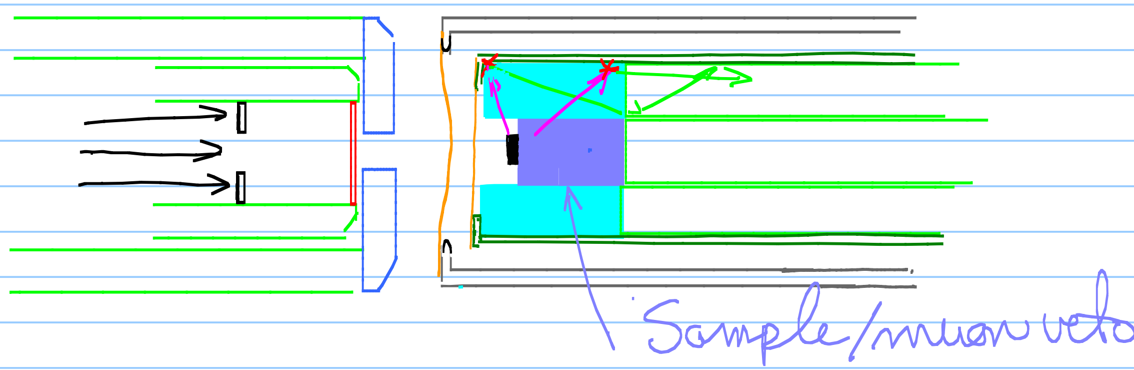
What are the problems with achieving the "ultimate" time resolution with this arrangement?

Where do you put your

i) thermometer
ii) magnetic field measurement device
iii) How does one "in fact" measure the magnetic field?

... or can one make better use of the sample/muon veto detector?

The "High Time" Spectrometer



Finite dimensions of detection scintillator contribute "systematic" errors in the timing.

Where do you put your

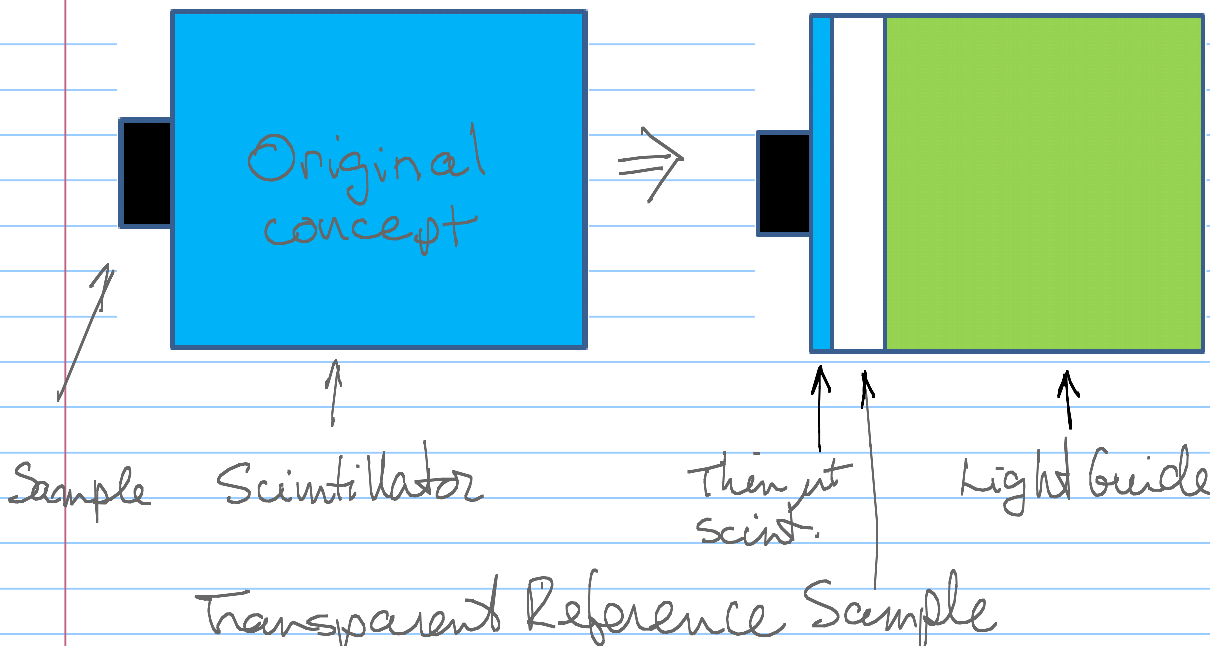
i) thermometer

ii) magnetic field measurement device

iii) How does one "in fact" measure the magnetic field?

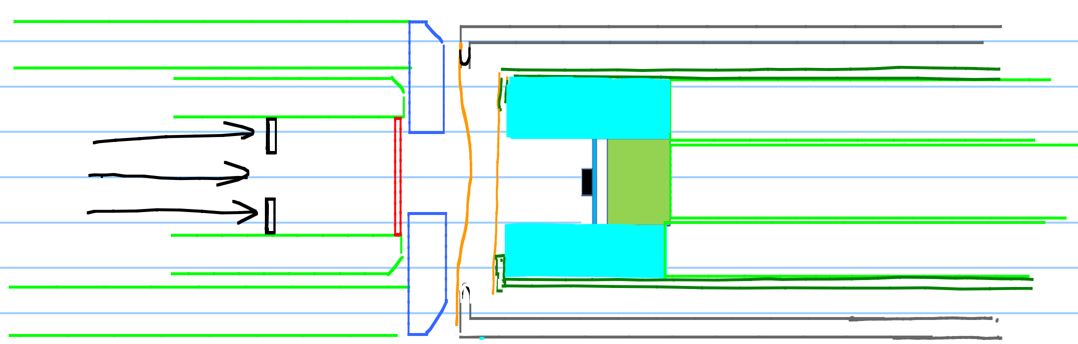
... or can one make better use of the sample/muon veto detector?

'Designing' the muon/sample veto



i.e. $CaCO_3$ - 80% μ^+ formation & all nuceli spin 0

What happens when the μ^+ misses the sample ?



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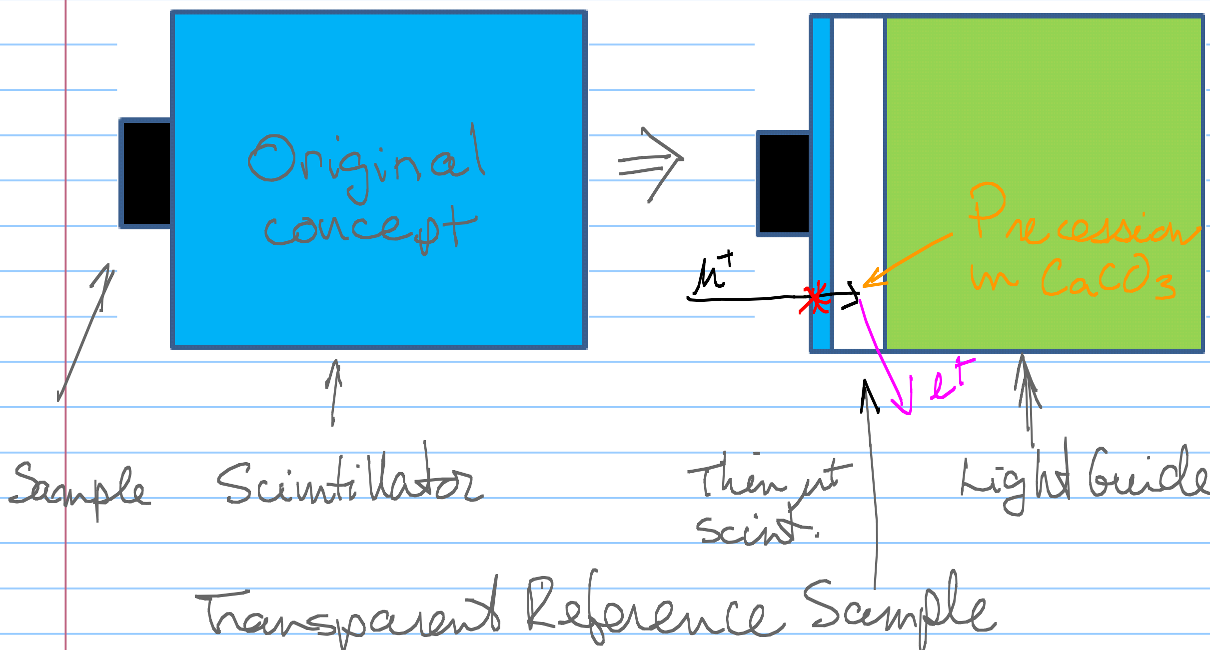

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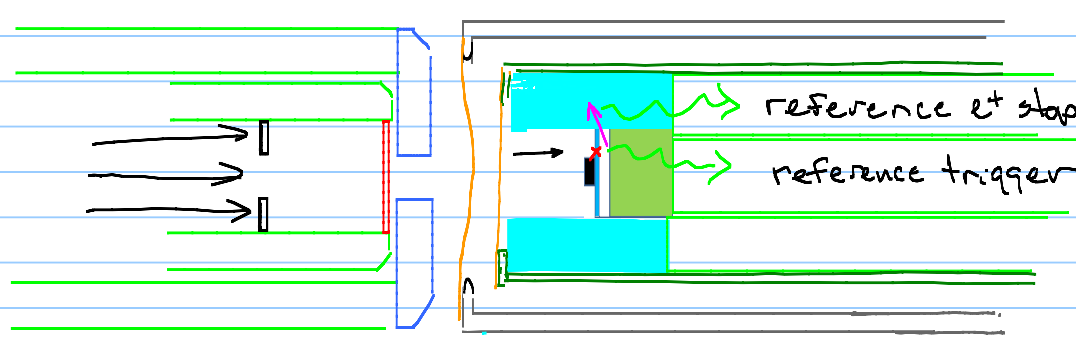


Sample/reference mode of operatitech.

Back to the questions about measuring accurately the temperature & magnetic field of the sample, not the measuring device

i.e. The location of the measuring device is not at your sample location, otherwise "it" would be the sample!

What do you do about this?

CALIBRATE!!

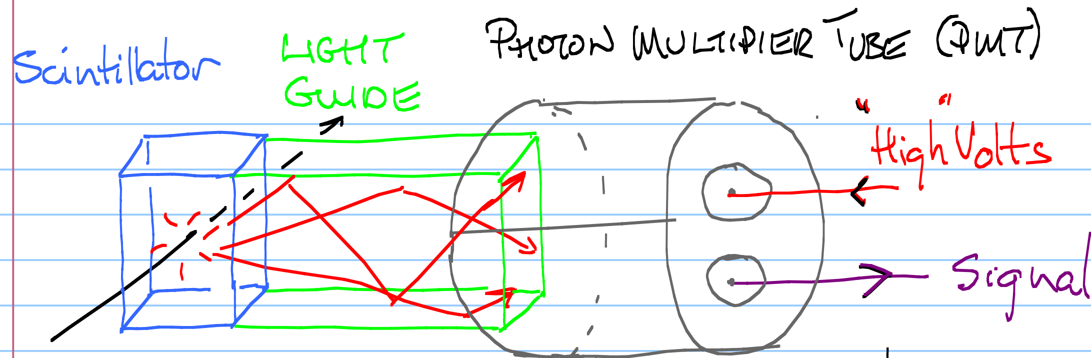
i) Put a known reference (i.e. pure Ag) in as your sample & compare with the reference signal

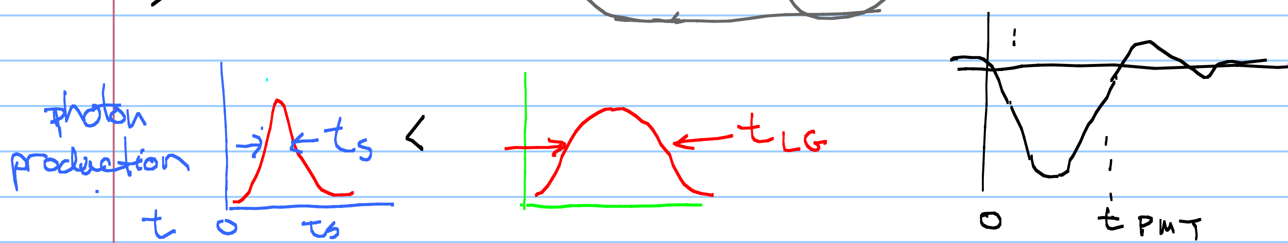
ii) Put in two thermometers, "before & after" to measure the T gradient.

Well, these are enough questions and ideas for today. It is up to your generation to find better answers!

But have fun doing so.

THE END

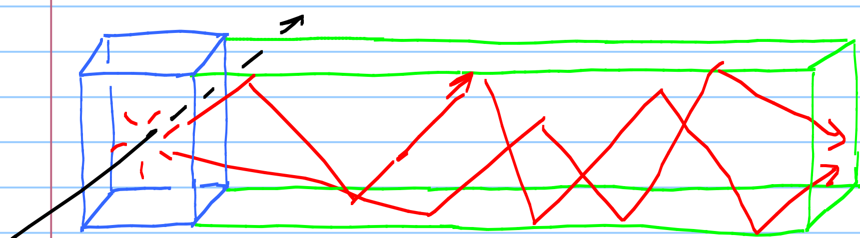


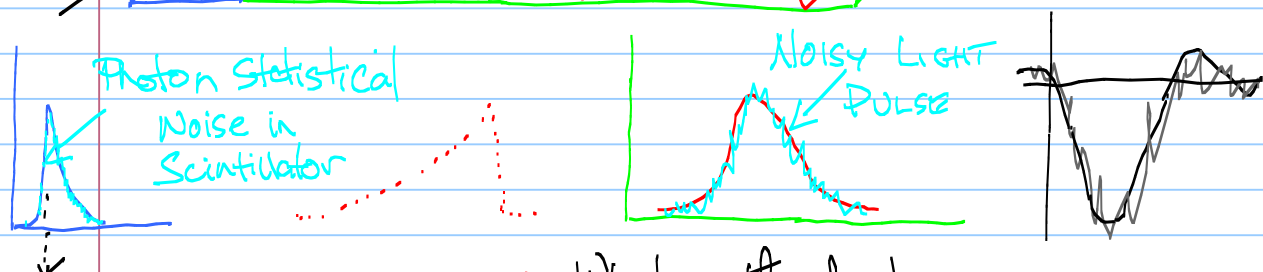


typically ~ 3ns

5 - 7ns

~ 5-10ns





Best place to detect "t" in scintillator

Convolut^n Funct^n

What is the best place to characterize "t" in the broadened peak?

Noisy PMT peak

Max Rate of Change/Noise should be used

⇒ inflection pt on rise time of pulse

⇒ CFD i.e. CONSTANT FRACTION DETECTION