Study of the $K^+ \to \mu\nu A'$ with $A' \to e^+e^-$

Ilaria Rosa

NA62 Italia Meeting

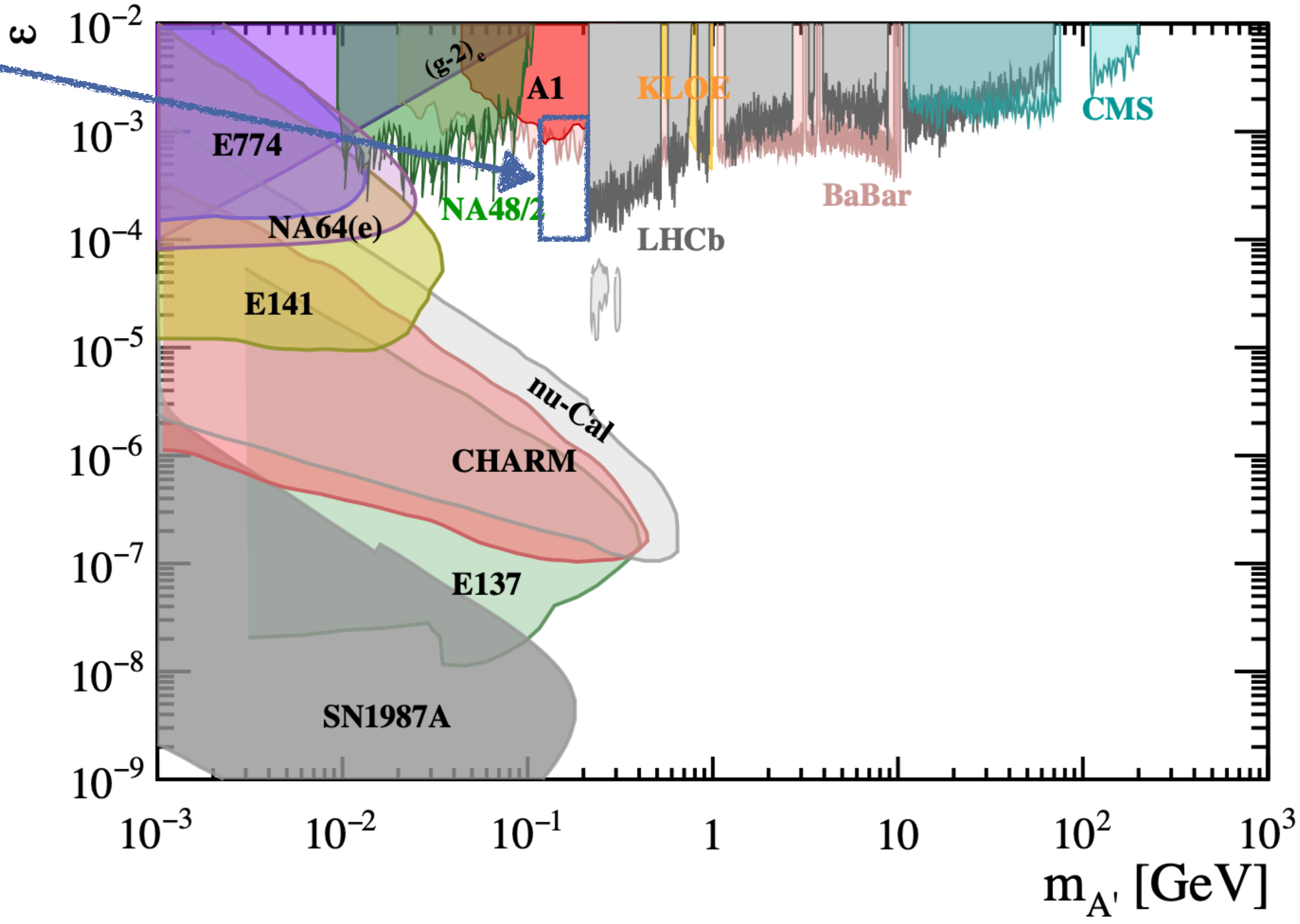
November 7th, 2024

Scuola Superiore Meridionale

Search motivation

Are we truly sensitive in this portion of the phase space (?)

Can we assume that the decay $A' \rightarrow e^+e^-$ is prompt without losing in acceptance (?)



2 competing effects

- For large values of ϵ, the momentum of the DP is higher to compensate for a shorter lifetime
- At smaller values of ϵ, the rest lifetime of the DP is longer

Selection criteria

Selection criteria

Vertex selection

- Exactly one good vertex
  - ➡Q=+1
  - ➡Vertex $\chi^2 < 25$
  - ➡Maximum Vtx-Beam distance 40 mm
  - ➡105 m < Z_{vtx} < 180 m
  - ➡$|t_{vtx} - t_{trig}| < 2.5$ ns
  - ➡Track separation at Straw planes > 15 mm
  - ➡Track separation at LKr front plane > 200 mm

Track selection

- Track momenta in the range 6-65 GeV/c
- Geometrical acceptance with STRAW1-4 LKr NewCHOD

PID

- E/p (<0.2 μ^+, between 0.9 and 1.1 for $e^{\pm}$)
- Associated outer MUV3 candidate within 5 ns

Kinematic cuts

- ➡ Cut on the squared missing mass
- ➡ Cut on the resonances mass

Normalisation

- The plan is to use the $K^+ \to \pi^+ e^+ e^-$ decay or maybe the SM channel $K^+ \to \mu^+ \nu e^+ e^-$

Few informations about the previous analysis

$Br(K_{\mu 2ee} \,|\, M_{e^+e^-} > 140\, MeV/c^2) = (793 \pm 18\,|_{stat} \pm 28\,|_{syst} \pm 0.5\,|_{model}) \cdot 10^{-10}$

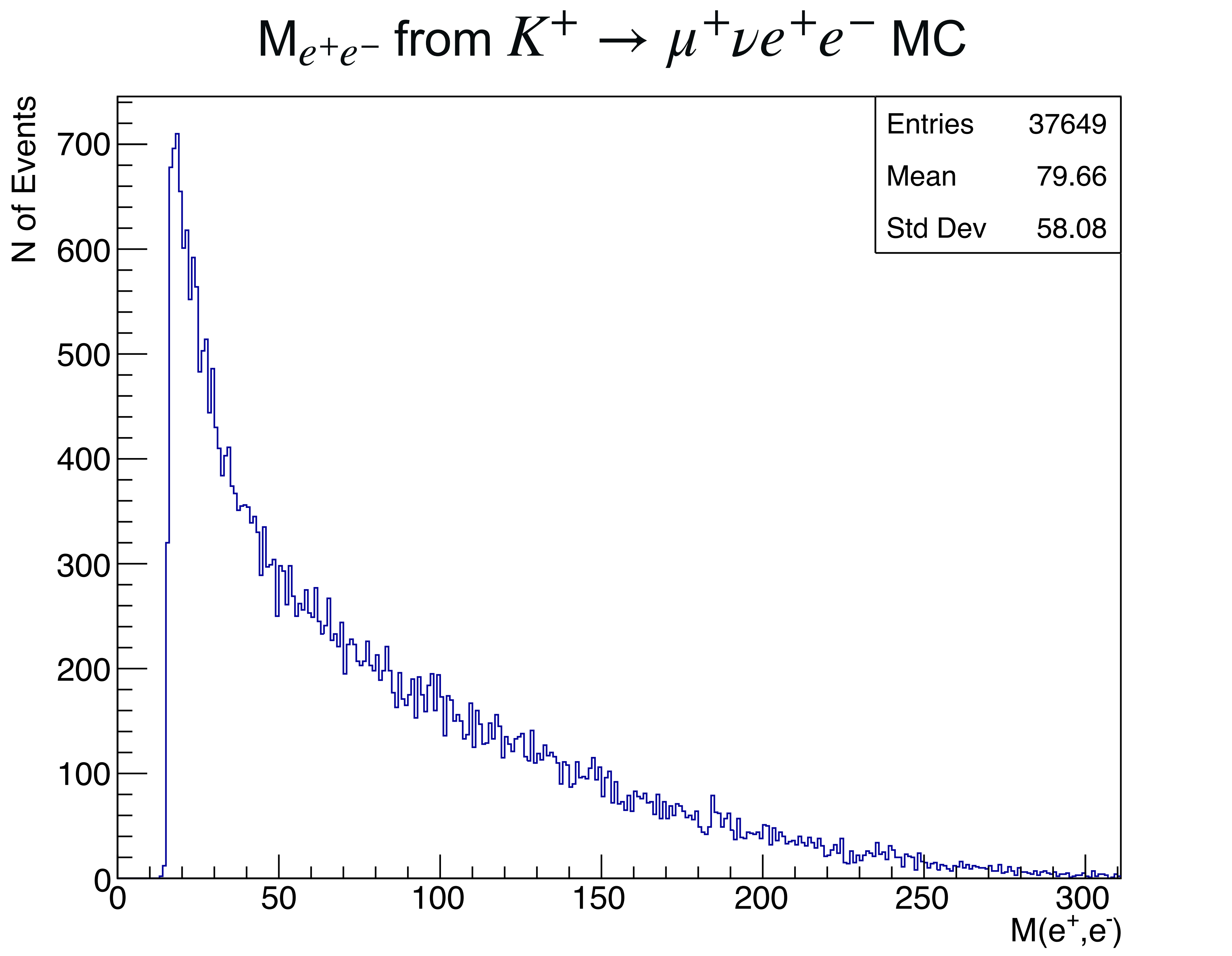
Experiment 865 at BNL (2002)

$M_{e^+e^-} > 140\, MeV \rightarrow 2.2\,\%$

Signal acceptance

$M_{e^+e^-} > 140\, MeV \rightarrow 2570$

Events selected



Things to be refined/determined

- Mass resolution on $M_{e^+e^-}$
- Signal acceptance
- Mass step (depends on the acceptance)
- Normalisation channel
- Background estimation

Next steps

- A first **rough estimation** of the sensitivity can be done using only the $K^+ \to \mu^+ \nu e^+ e^-$ MC and fixing theN_K and $\sigma(m_{e^+e^-})$ (taking it from other analysis)
- Probably the approach to follow should be the **data driven** background estimation (fit the data around $M_{A'}$ with a polynomial function)
- The selection needs to be refined to maximise the **acceptance**
- We really need to understand if we are **competitive** with other experiments (APEX for example)
- Lots of work to do in the last 2 years of my PhD

Spares

$K^+ \to \mu^+ \nu A'$

3-body decay

$$E_{A'} = \frac{M_K^2 + m_{A'}^2 - m_{\mu\nu}^2}{2M_K}$$

LAB frame

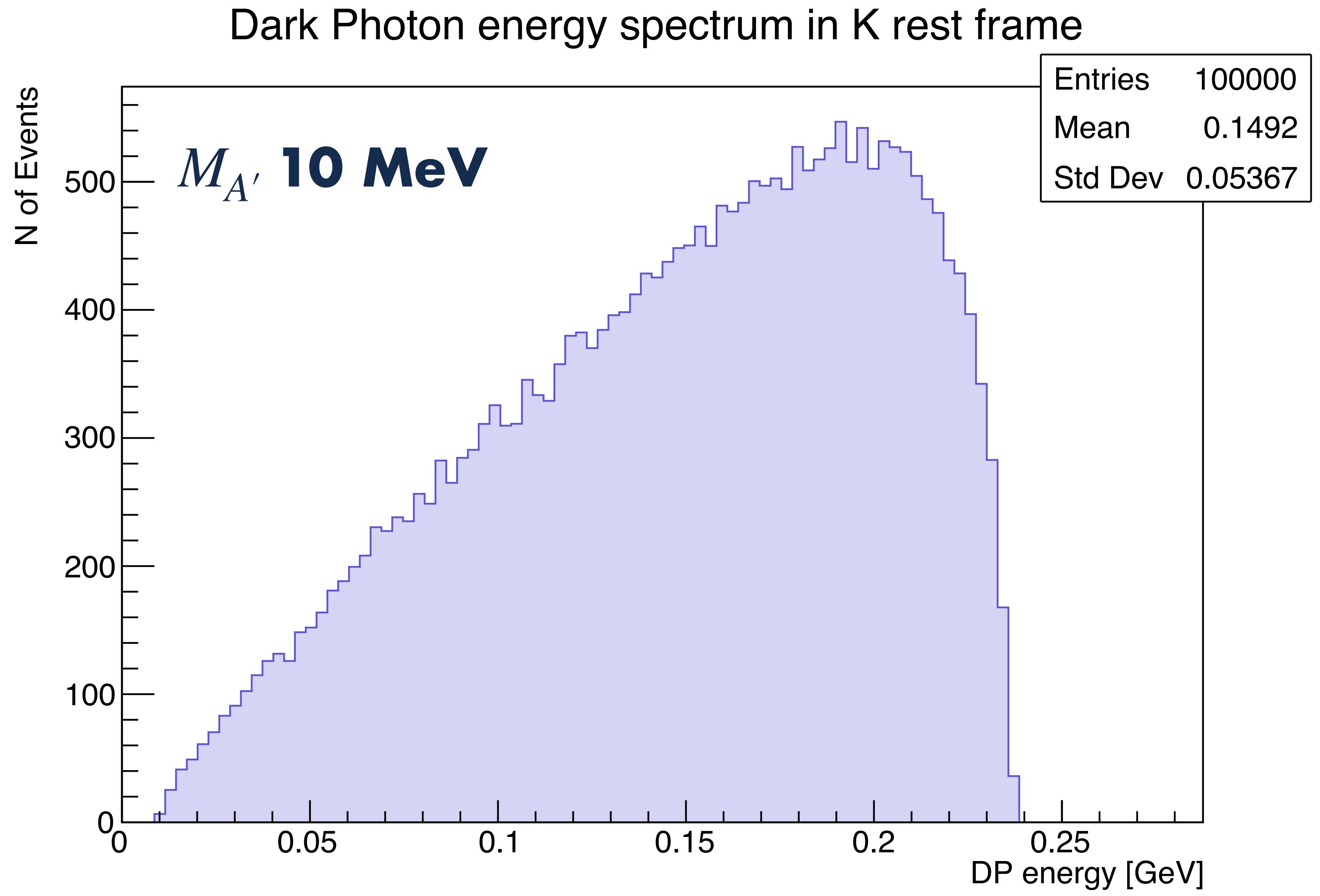
$\vec{P}_K$ $\gamma_K = 150$

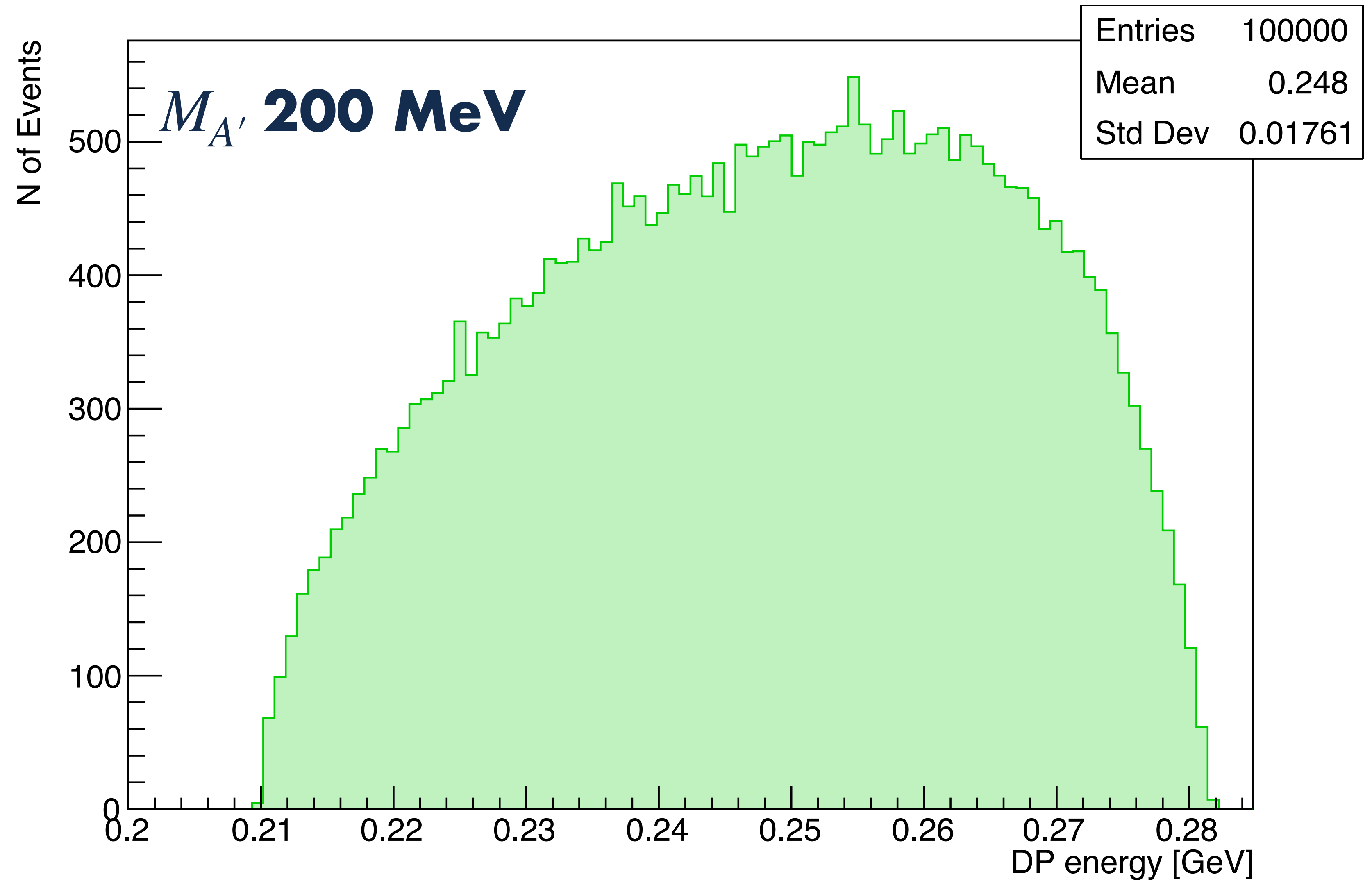
$\vec{P}_{A'}$

$$\gamma_{A'} = \frac{\gamma_K (E_{A'}^* - p_{A'}^*)}{m_{A'}}$$

$\vec{P}_{A'}$

$$\gamma_{A'} = \frac{\gamma_K (E_{A'}^* + p_{A'}^*)}{m_{A'}}$$



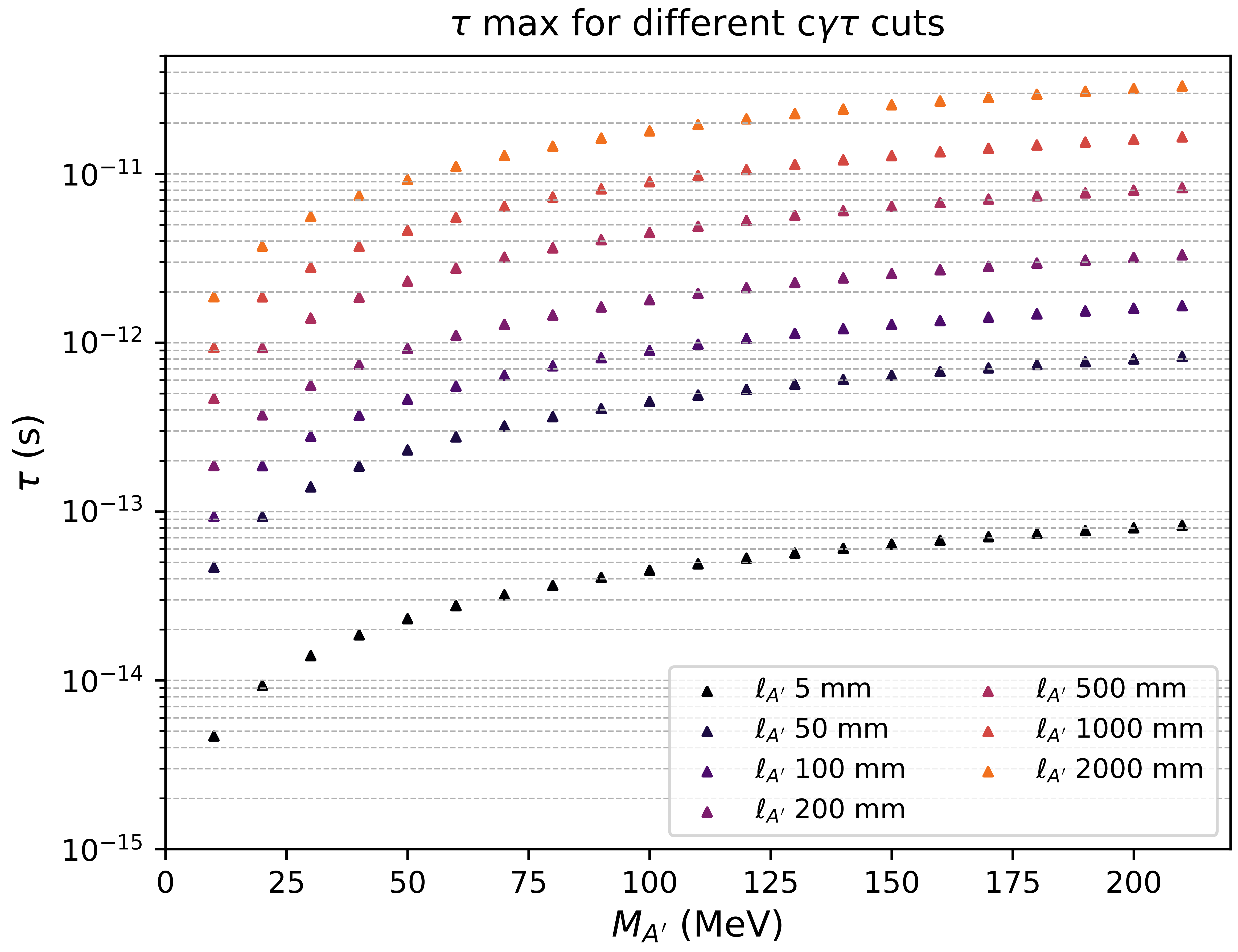


A quick look at the $\tau_{A'}$

LAB frame

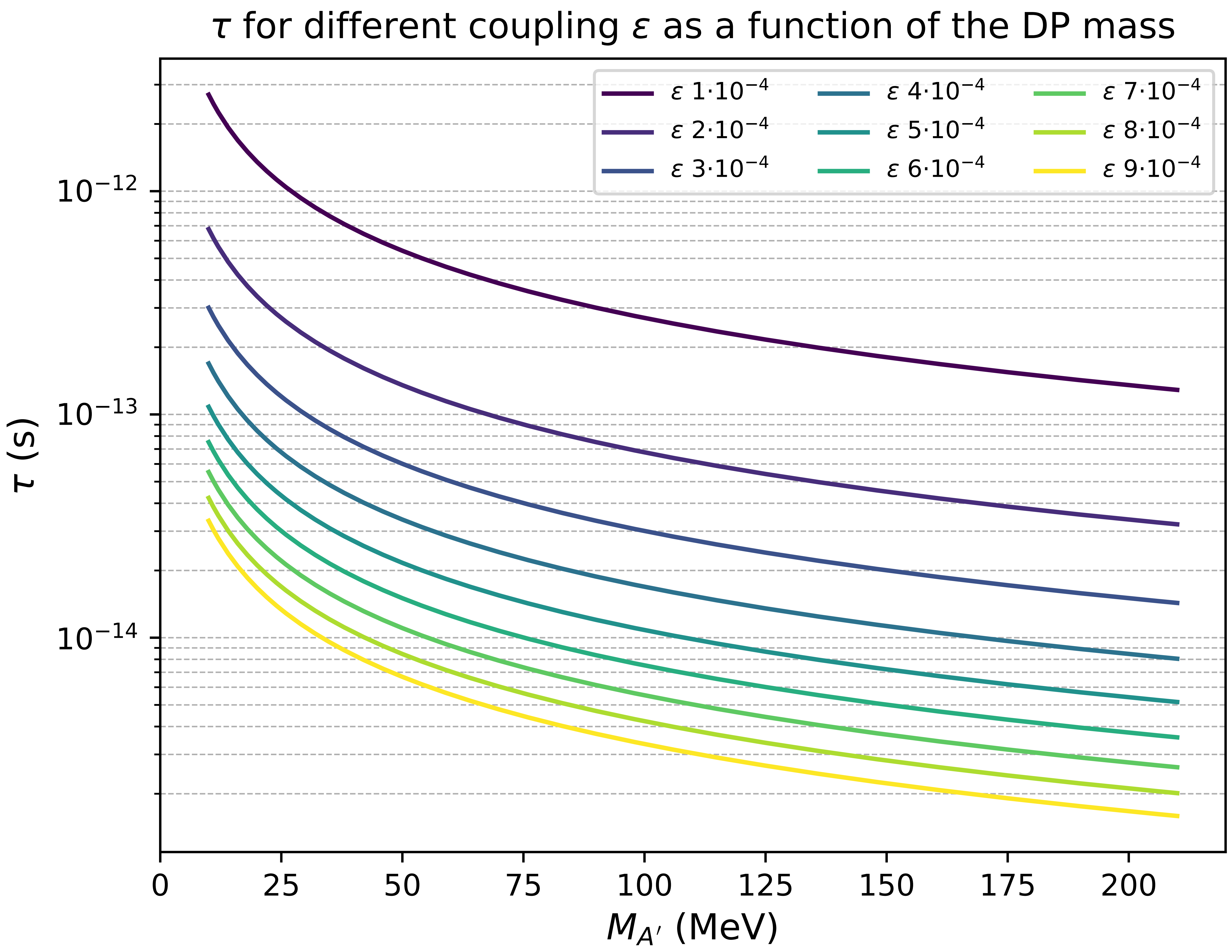
$$c\,\gamma_{A'}\,\tau_{A'} = \ell_{A'}$$

- If on average A' travels $\ell_{A'}$ in the lab frame, then its mean lifetime is $\tau_{A'}$.
- If the maximum distance between the vertex of A' and that of K^+ to which I am sensitive is d_{max}, this means that I can distinguish two regimes:
  - $\ell_{A'} > d_{max}$ **displaced**
  - $\ell_{A'} < d_{max}$ **prompt**
- The regimes can be translated in terms of lifetime:
  - $\tau_{A'} < \tau_{max}$ **prompt**
  - $\tau_{A'} > \tau_{max}$ **displaced**



Introduciamo l'accoppiamento

A quick look at the $\tau_{A'}$



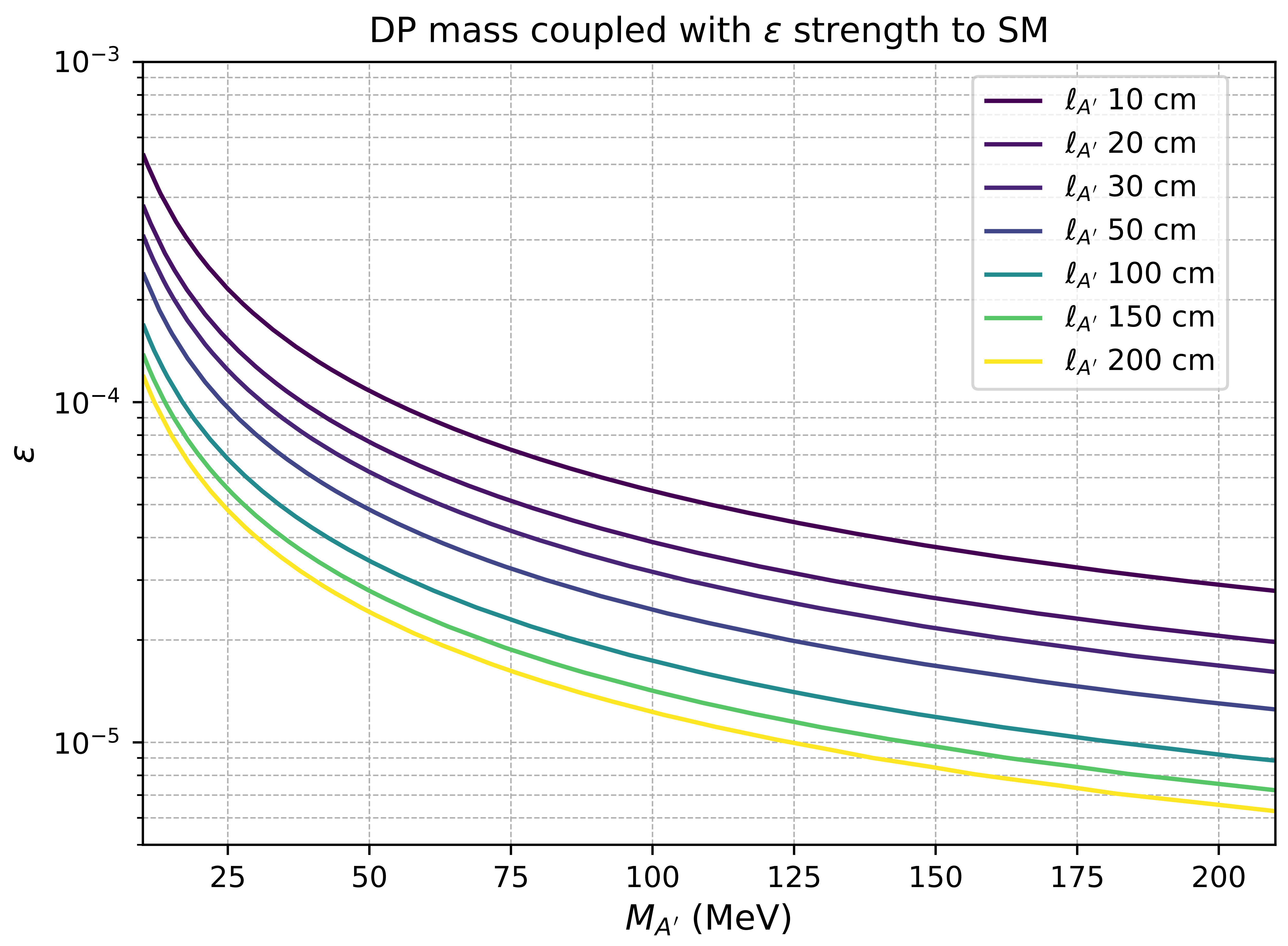
Assuming the only allowed decay mode is A′ → e+e−

$$\Gamma(A' \to \ell^+\ell^-) = \frac{1}{3}\alpha\epsilon^2 m_{A'}\sqrt{1-\frac{4m_\ell^2}{m_{A'}^2}}\left(1+\frac{2m_\ell^2}{m_{A'}^2}\right)$$

Mean flight distance in the LAB frame

$$\ell_{A'} \simeq 16\,mm\left(\frac{\gamma_{boost}}{10^2}\right)\left(\frac{10^{-8}}{\epsilon^2}\right)\left(\frac{50\,MeV}{M_{A'}}\right)$$

$\tau_{A'}$: level curves



$$\Gamma(A' \to \ell^+\ell^-) = \frac{1}{3}\alpha\epsilon^2 m_{A'}\sqrt{1 - \frac{4m_\ell^2}{m_{A'}^2}}\left(1 + \frac{2m_\ell^2}{m_{A'}^2}\right)$$

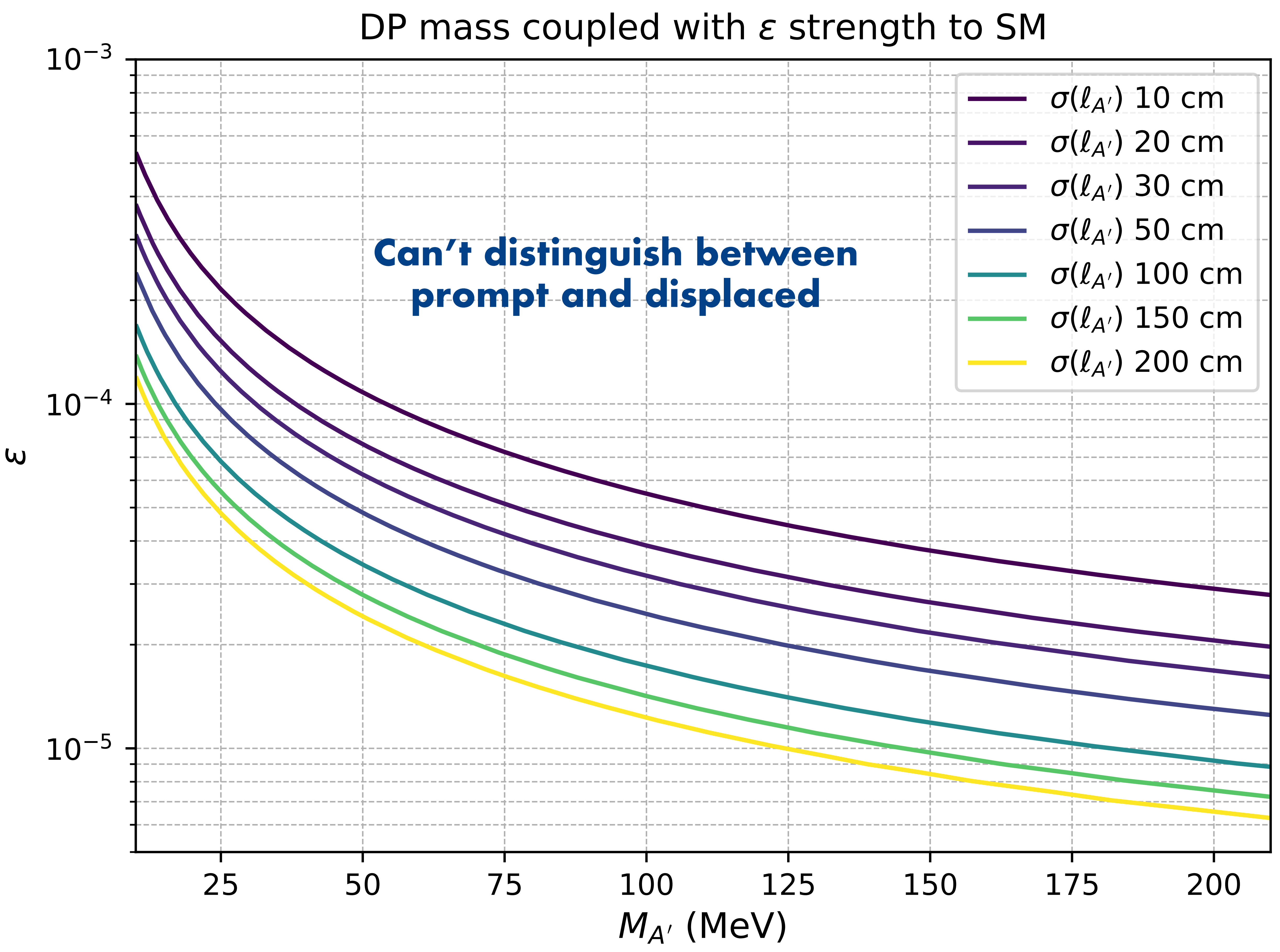
$$\tau_{A'} = \frac{\hbar}{\Gamma_{A'}}$$

$$c\,\gamma_{A'}\,\tau_{A'} = d_{lab}$$

$$d_{lab} = f(\epsilon, M_{A'})$$

- Construct a grid in the $\epsilon, M_{A'}$ phase space
- Construct the contour lines at fixed values of d_{lab}
- $\gamma_{A'}$ is a function of the DP mass

$\tau_{A'}$: level curves



- If my resolution is $\sigma(\ell_{A'})$ the upper region of the phase space is the one in which I cannot distinguish between the prompt and the displaced decay

- Is important to understand which is my acceptance in the upper region as the lifetime varies

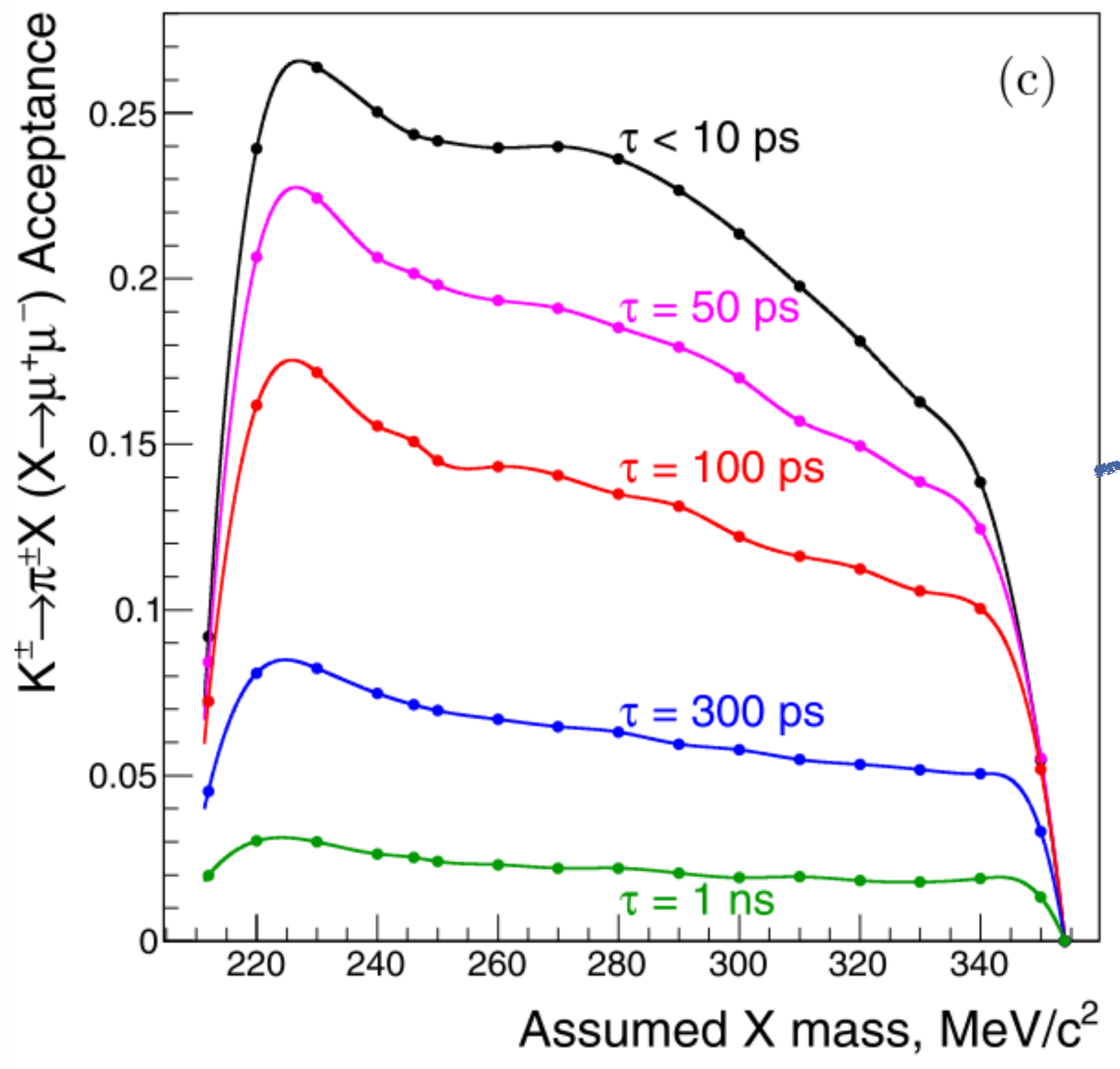
A study on the acceptance for different lifetime hypothesis and in the mass range should be performed

$K^+ \to \pi^+\mu^+\mu^-$ with NA48/2

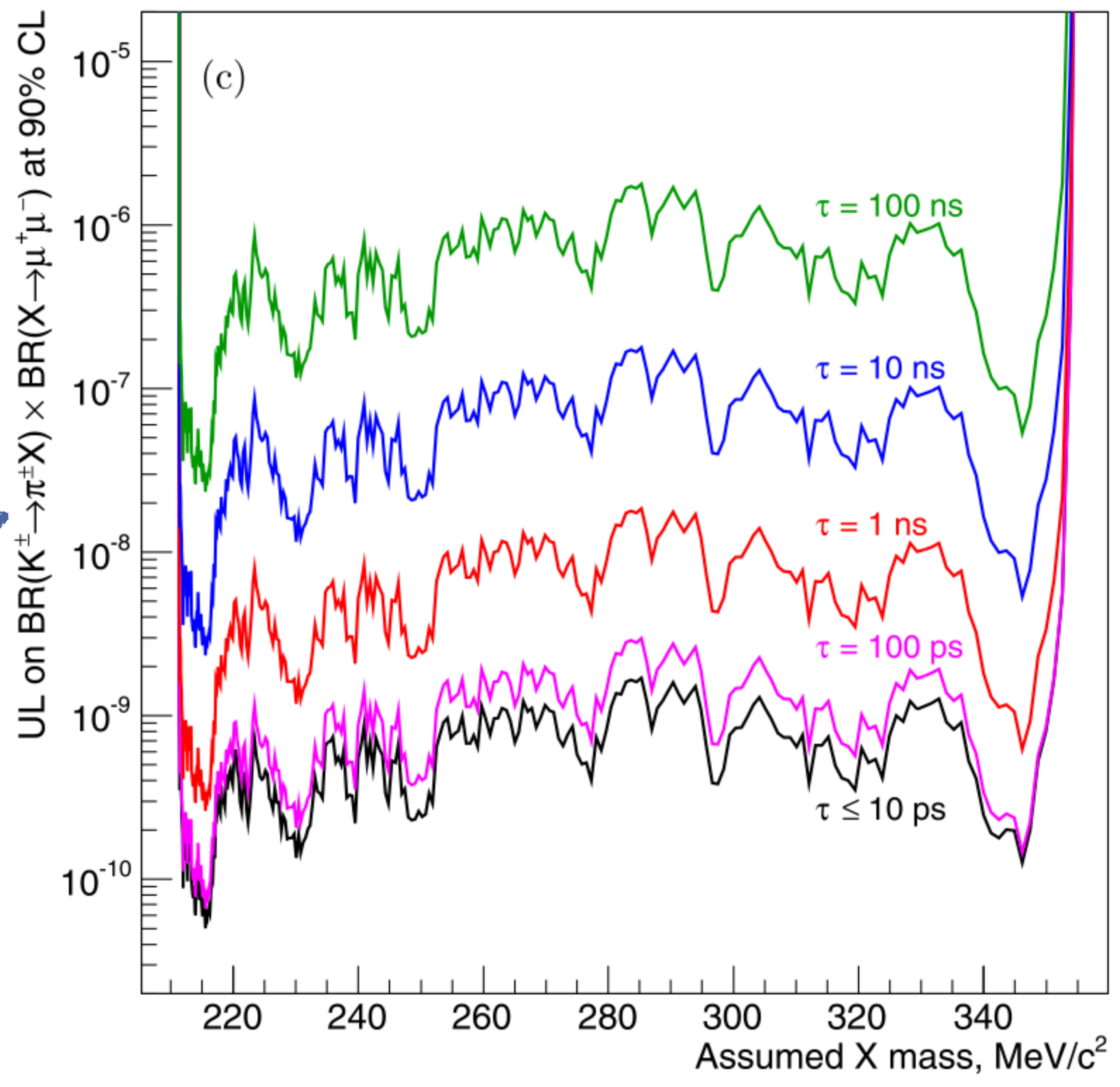
Within the 50 cm resolution on the longitudinal vertex position, $K^\pm \to \pi^\mp\mu^\pm\mu^\pm$ and $K^\pm \to \pi^\pm\mu^+\mu^-$ decays (denoted $K^{LNV}_{\pi\mu\mu}$ and $K^{LNC}_{\pi\mu\mu}$ below) mediated by short-lived (lifetime $\tau \lesssim 10$ ps) particles are indistinguishable from three-track decays.

N.B. K+ 60 GeV/c

DCH different resolution

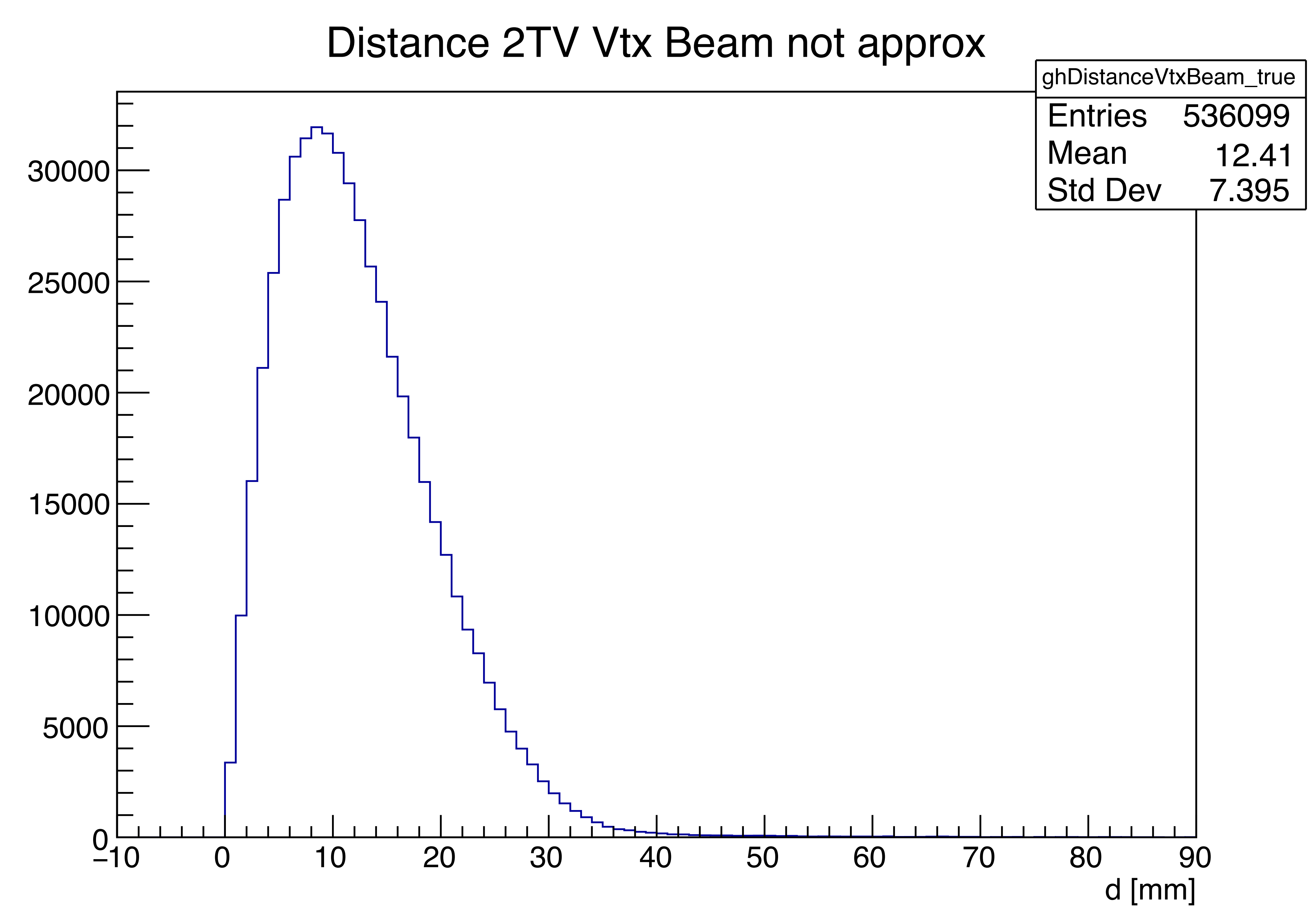


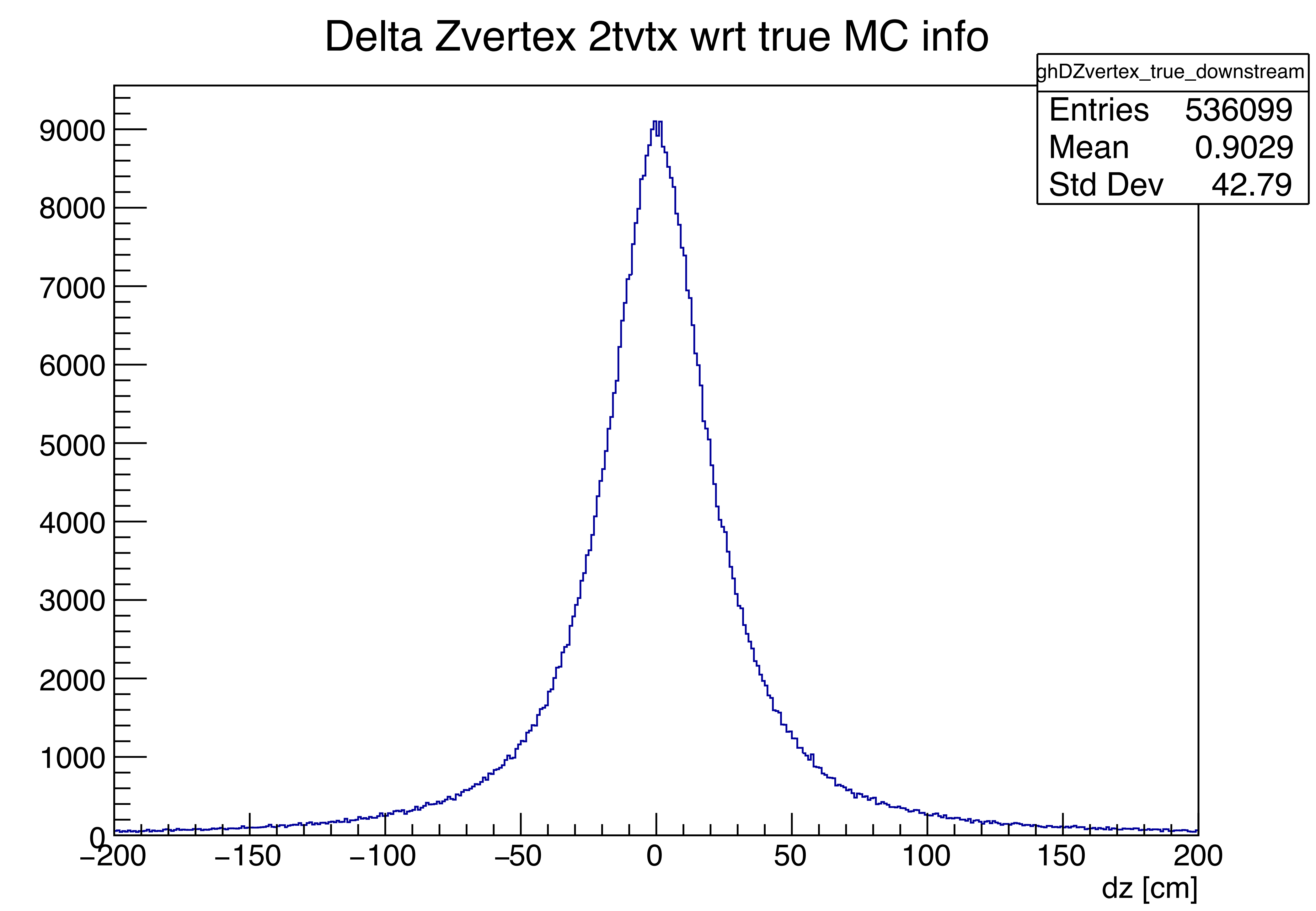
The better is the acceptance the more stringent is the U.L.



Vertex study

MC prompt: 2TV





MC prompt: 2TV vs 3TV