

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

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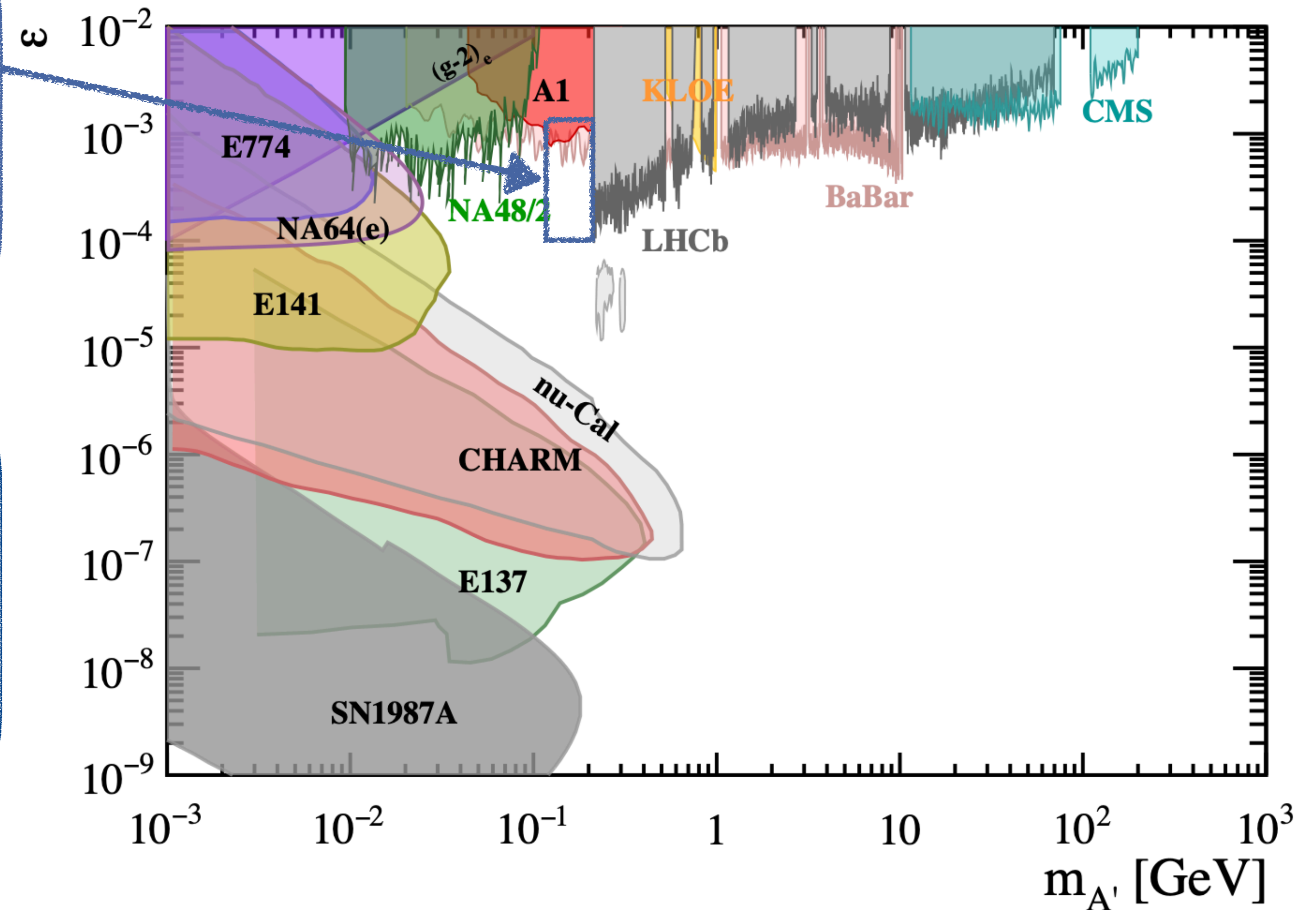
Search motivation

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
 - ➔ $105 \text{ m} < Z_{\text{vtx}} < 180 \text{ m}$
 - ➔ $|t_{\text{vtx}} - t_{\text{trig}}| < 2.5 \text{ ns}$
 - ➔ Track separation at Straw planes $> 15 \text{ mm}$
 - ➔ Track separation at LKr front plane $> 200 \text{ mm}$

Track selection

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

PID

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

Kinematic cuts

- ➔ Cut on the squared missing mass (to reduce
- ➔ Cut on the resonances mass

Normalisation

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

Few informations about the previous analysis

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

Experiment 865 at BNL (2002)

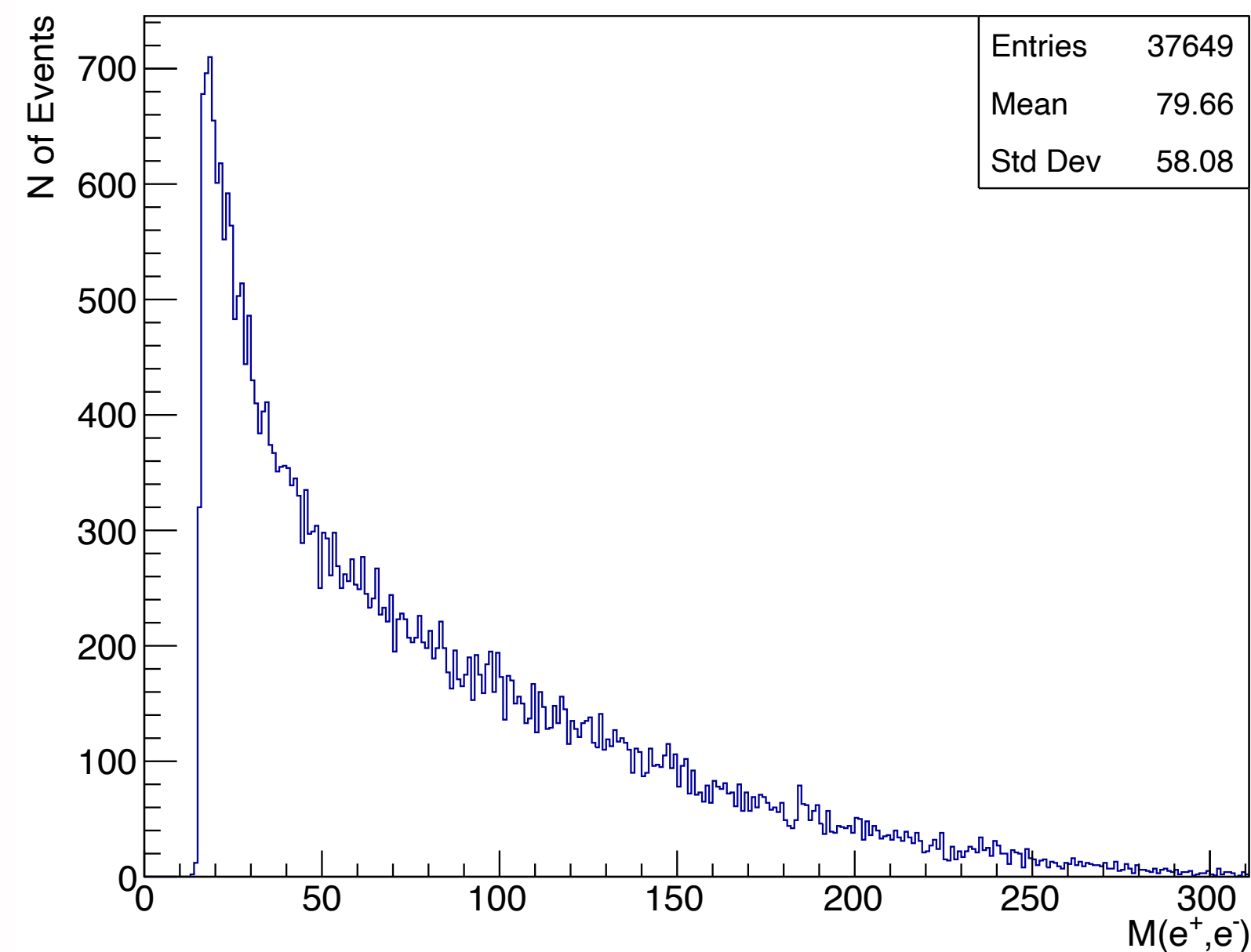
$$M_{e^+e^-} > 140 \text{ MeV} \rightarrow 2.2 \%$$

Signal acceptance

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

Events selected

$M_{e^+e^-}$ from $K^+ \rightarrow \mu^+ \nu e^+ e^-$ MC



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 $K^+ \rightarrow \mu^+ \nu e^+ e^-$ MC and fixing the N_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

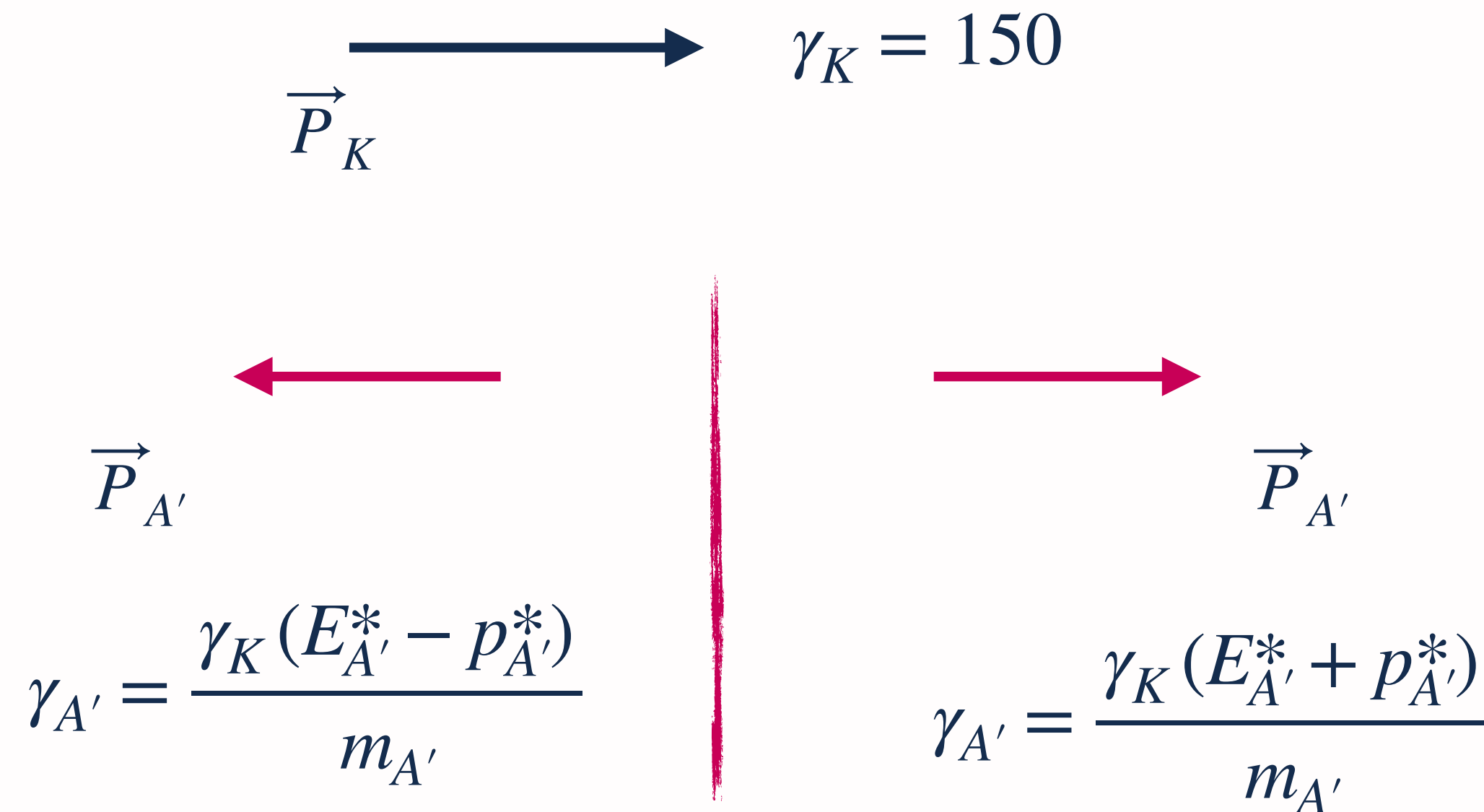
Spares



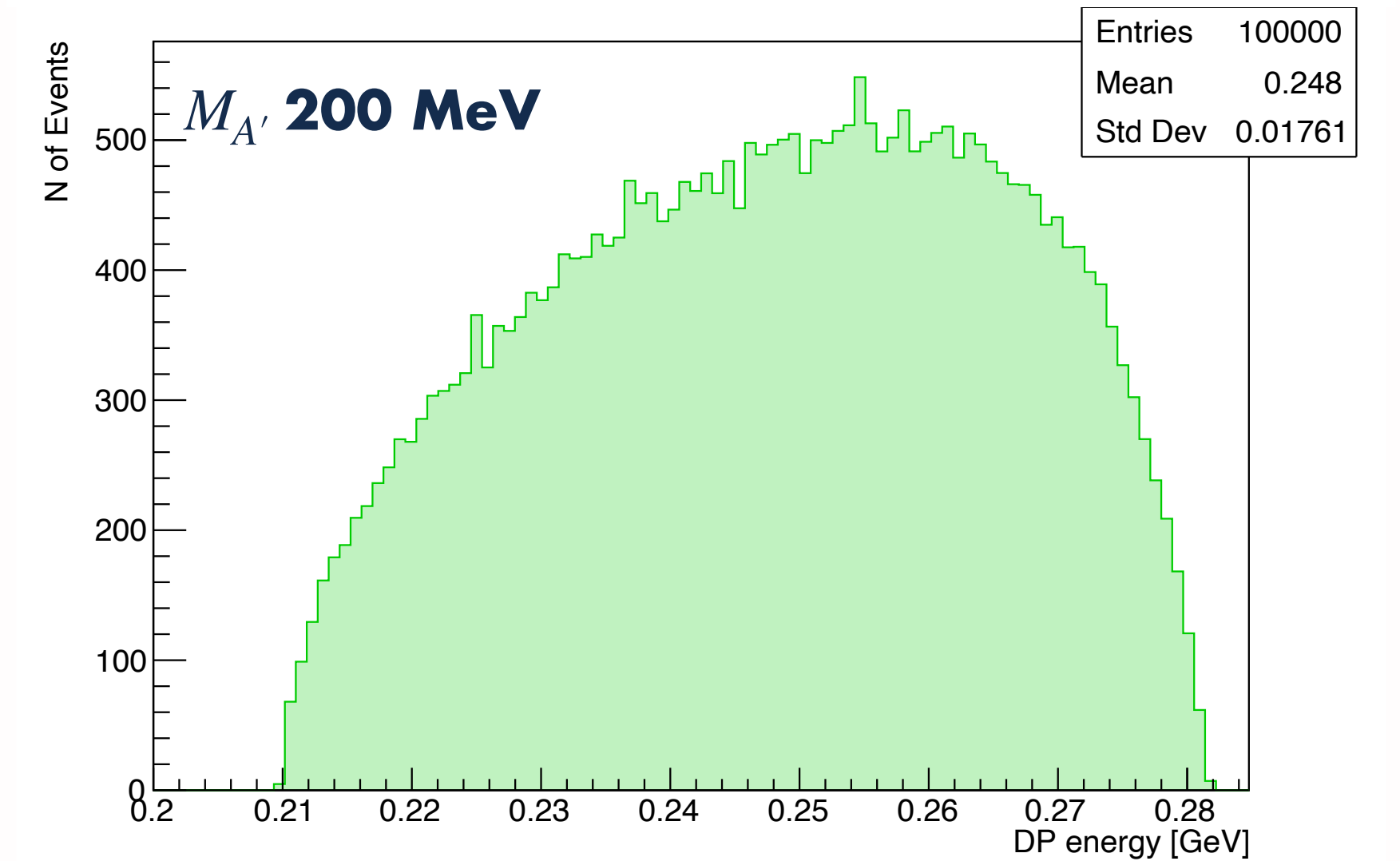
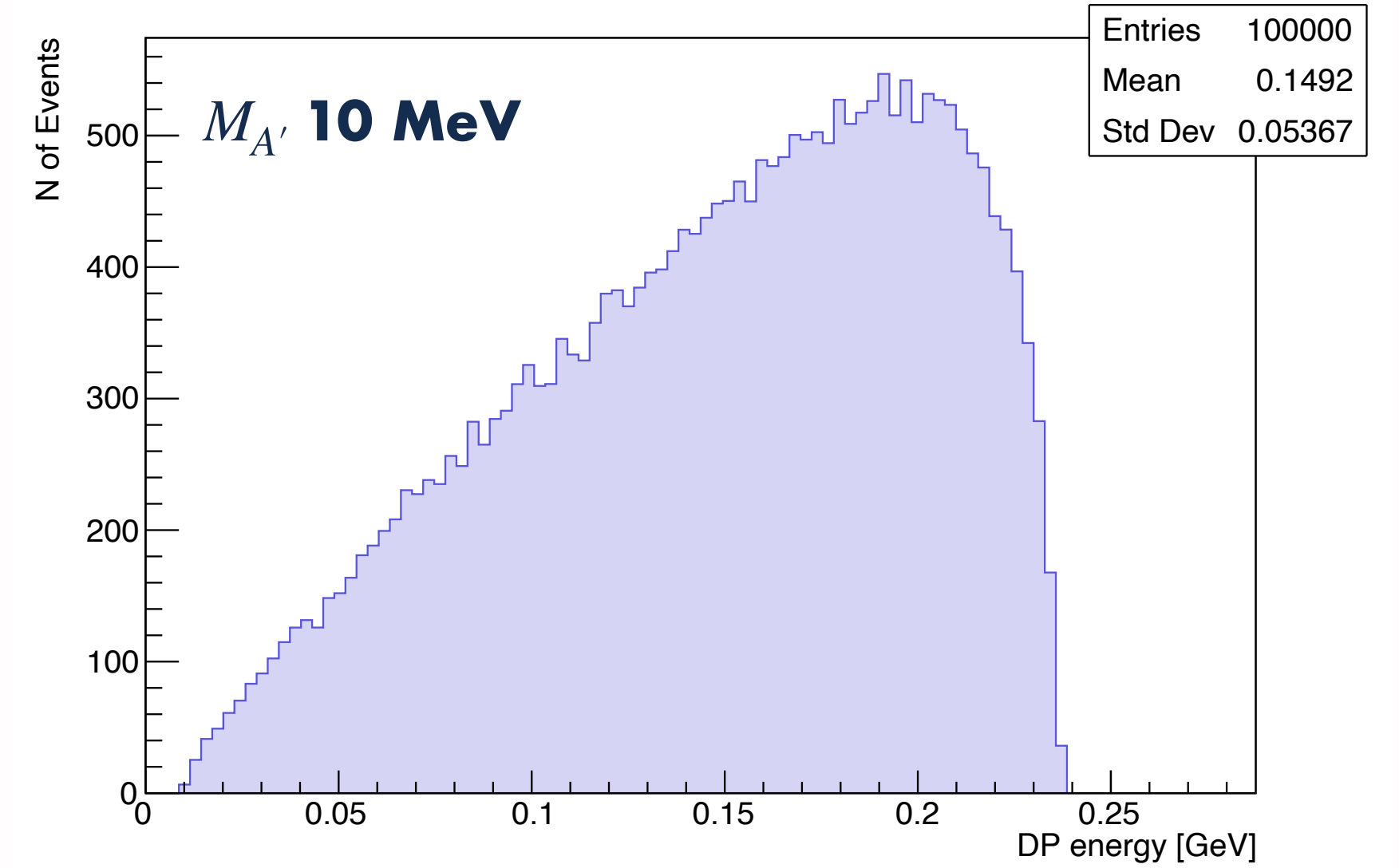
3-body decay

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

LAB frame



Dark Photon energy spectrum in K rest frame

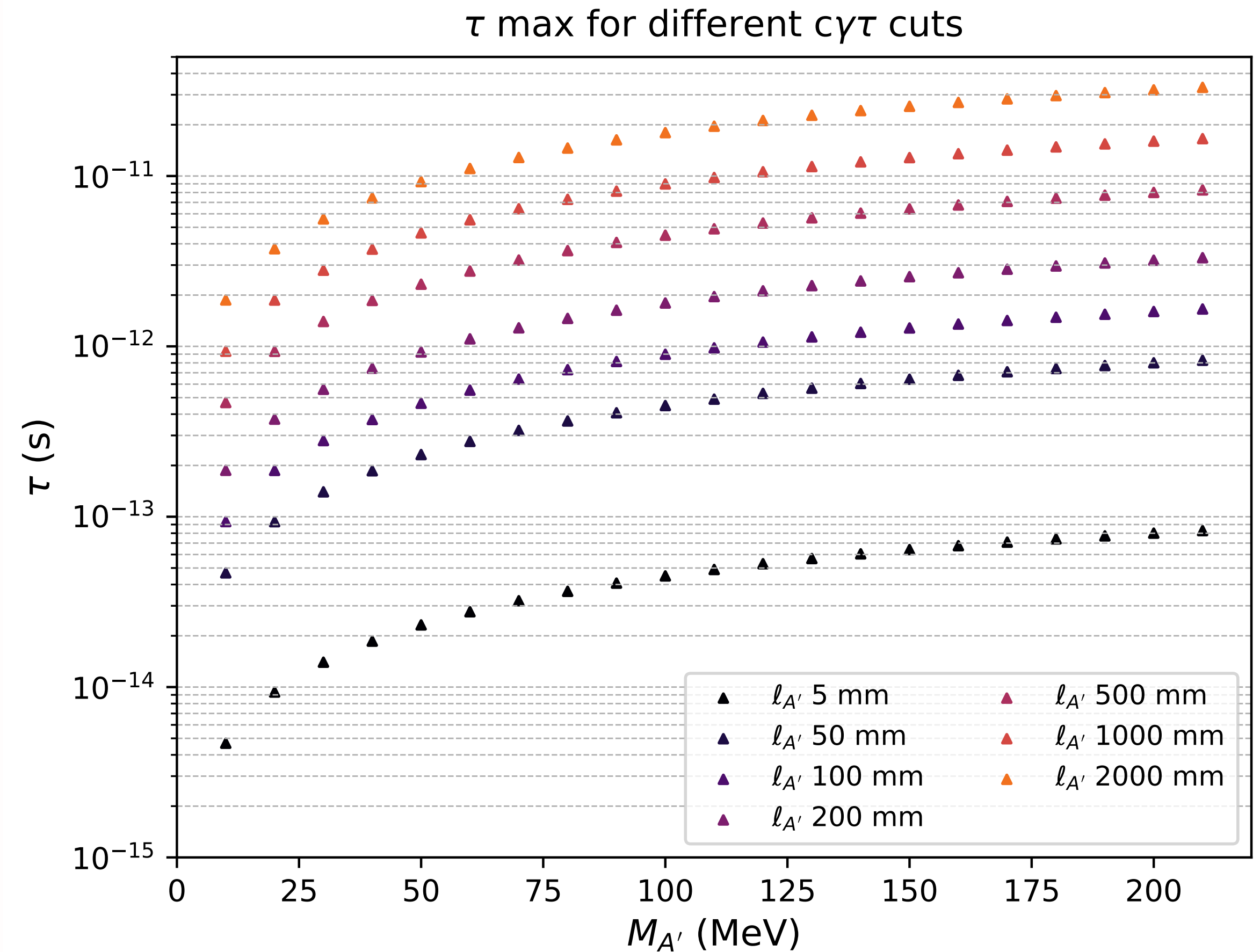


A quick look at the $\tau_{A'}$

LAB frame

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

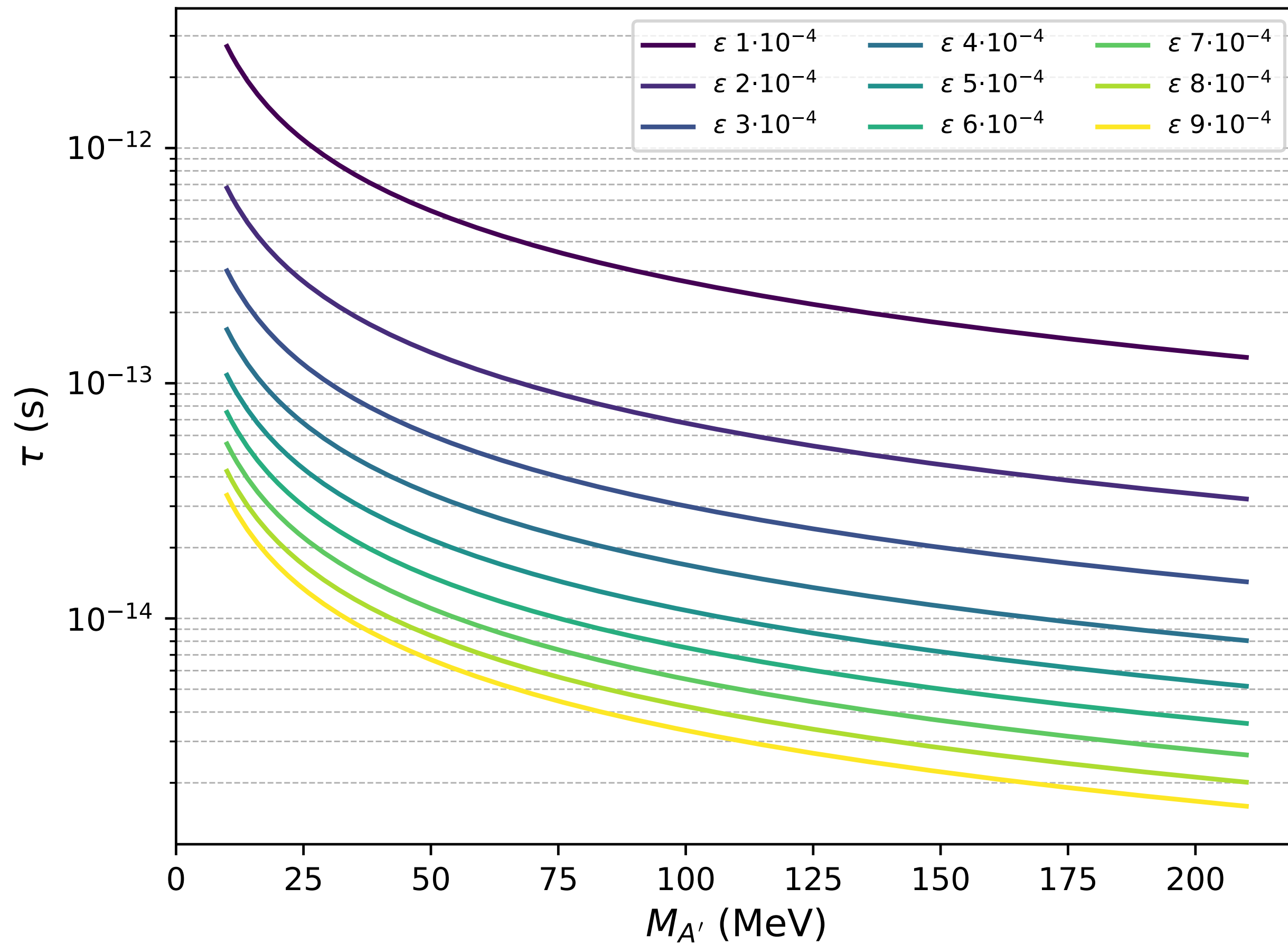
- If on average A' travels $\ell_{A'}$ in the lab frame, then its mean lifetime is $\tau_{A'}$.
- If the maximum distance between the vertex of A' and that of K^+ to which I am sensitive is d_{max} , this means that I can distinguish two regimes:
 - $\ell_{A'} > d_{max}$ **displaced**
 - $\ell_{A'} 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

τ for different coupling ϵ as a function of the DP mass



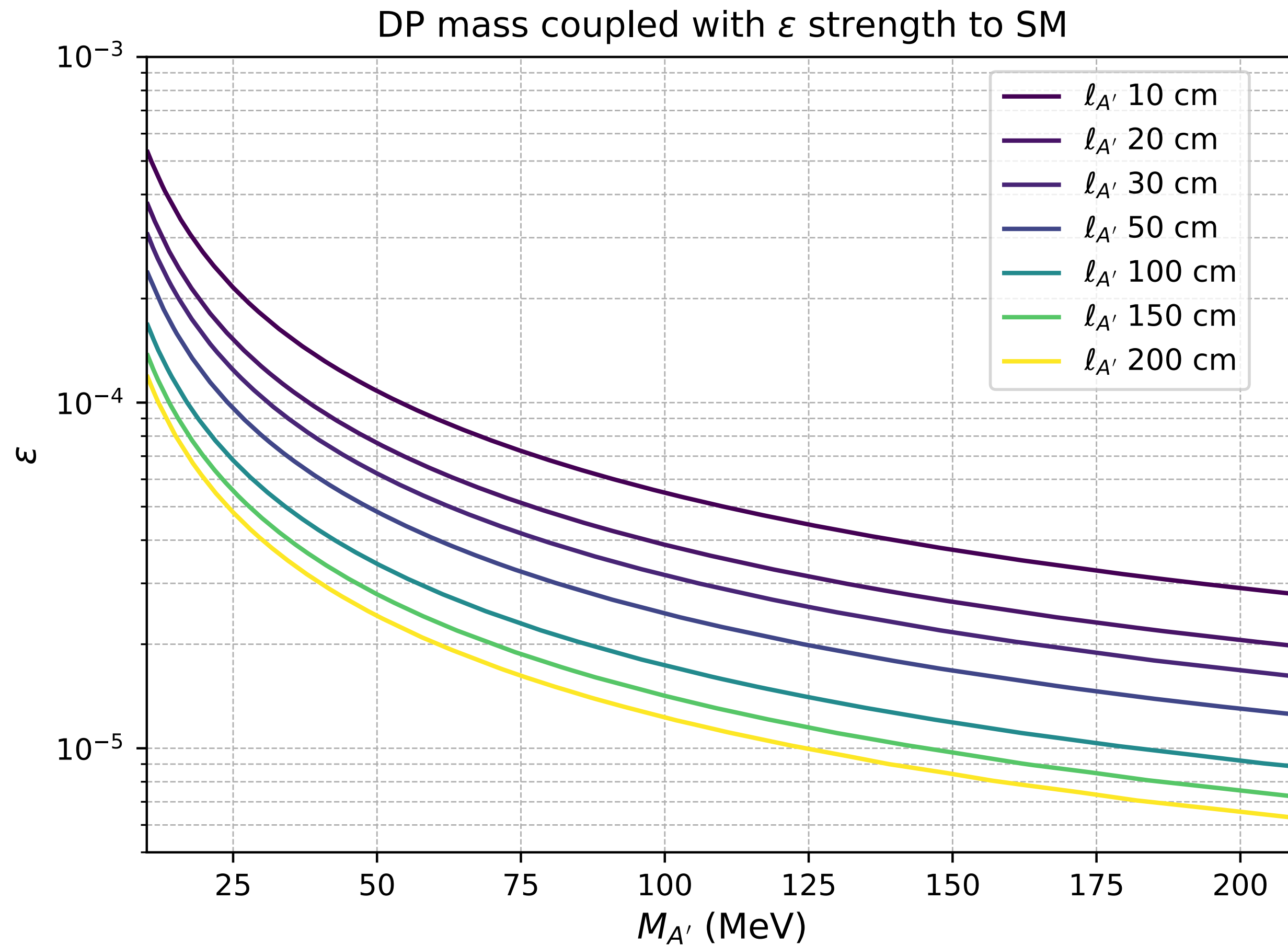
Assuming the only allowed decay mode is $A' \rightarrow e^+e^-$

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

Mean flight distance in the LAB frame

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

$\tau_{A'}$: level curves



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

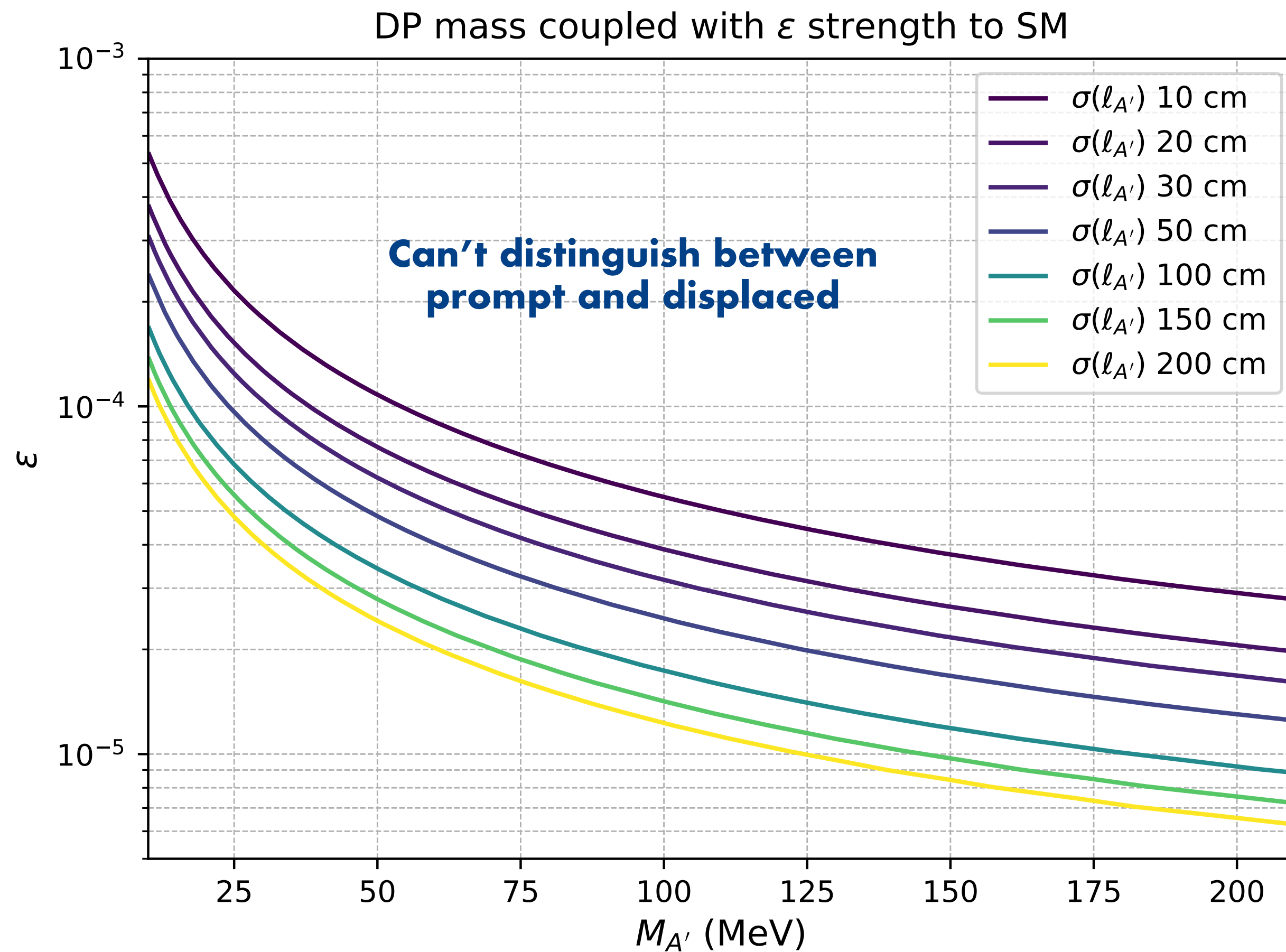
$$\tau_{A'} = \frac{\hbar}{\Gamma_{A'}}$$

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

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

- 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

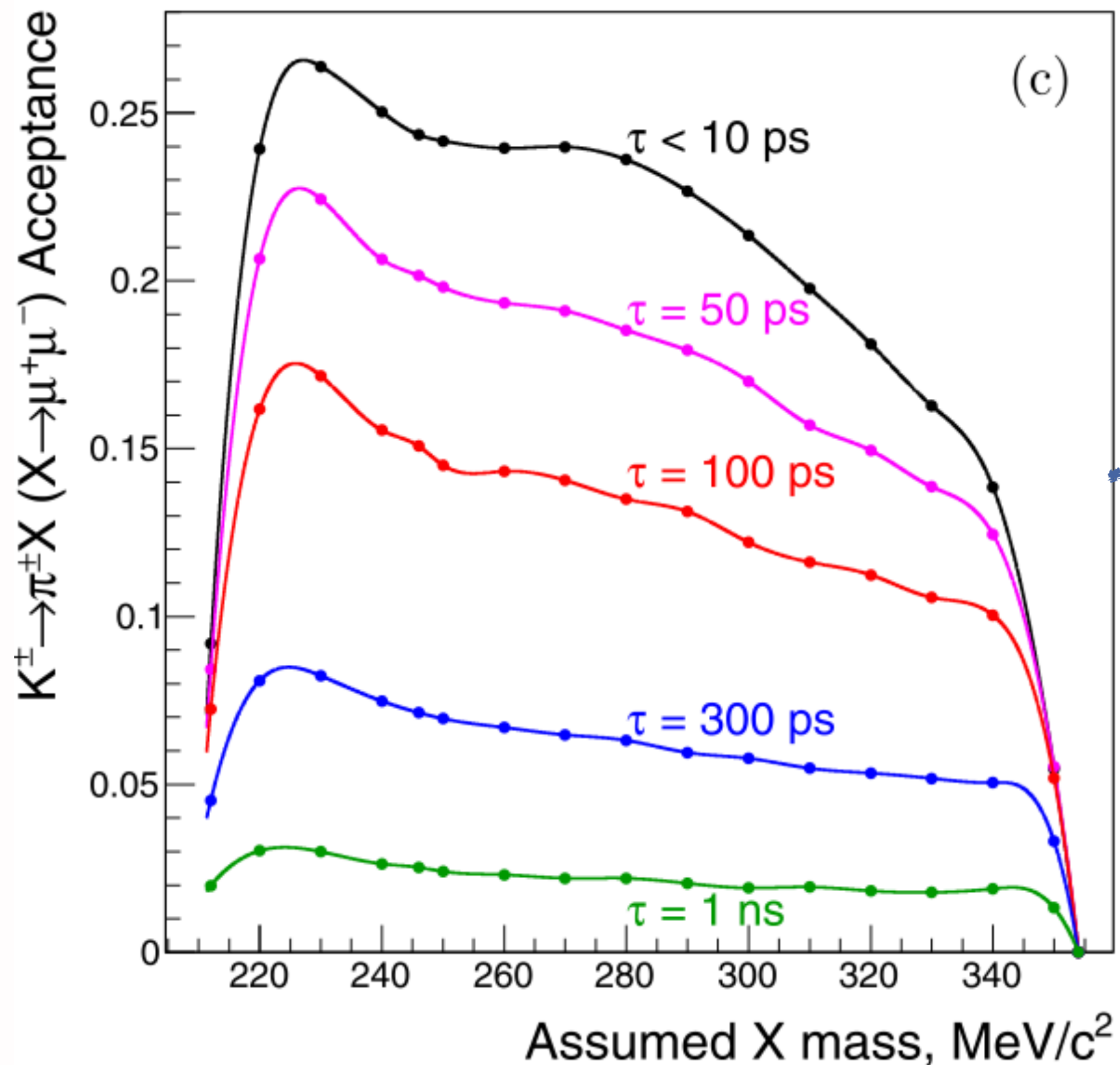


- If my resolution is $\sigma(\ell_{A'})$ the upper region of the phase space is the one in which I cannot distinguish between the prompt and the displaced decay
- Is important to understand which is my acceptance in the upper region as the lifetime varies

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

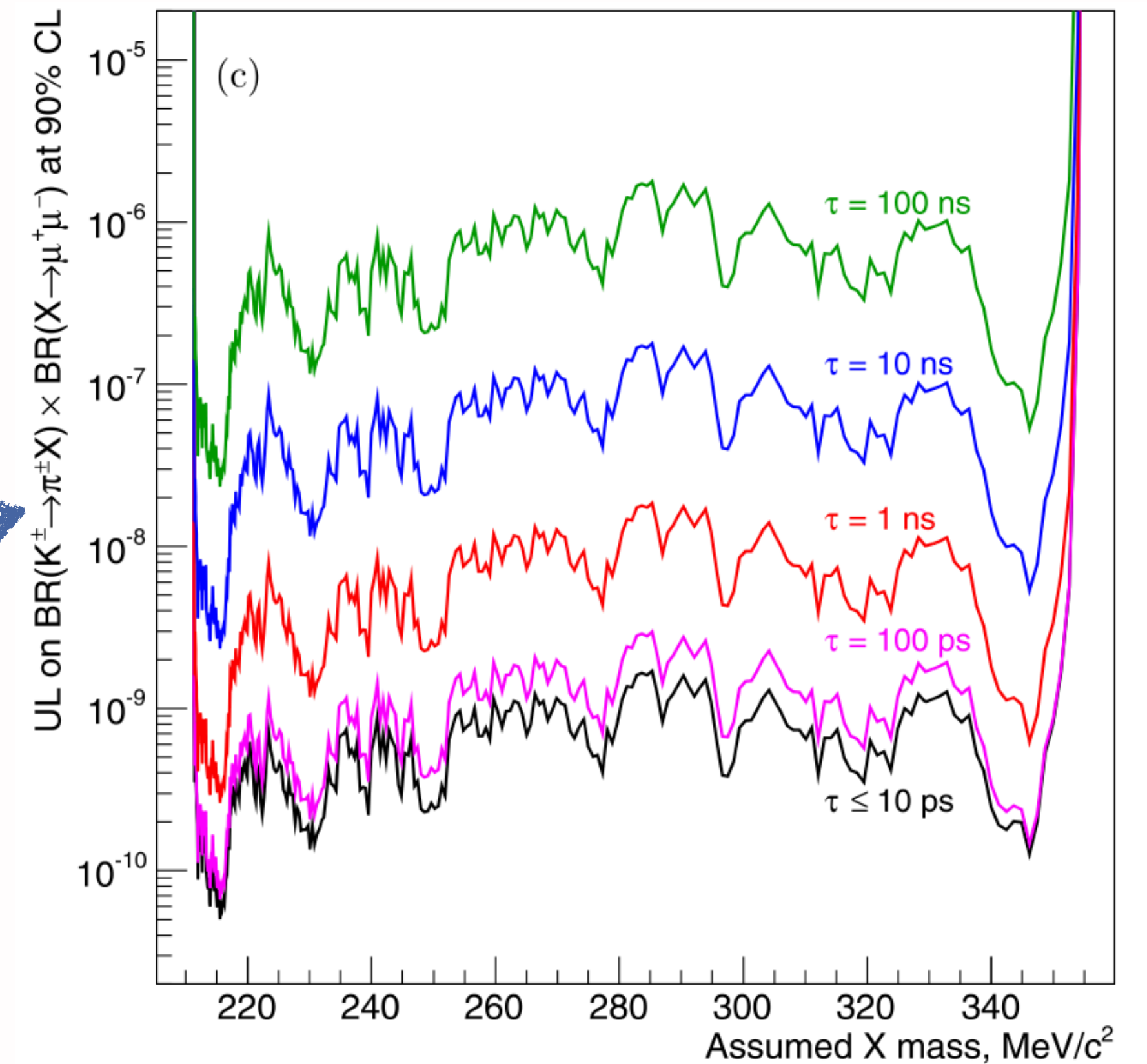
$K^+ \rightarrow \pi^+ \mu^+ \mu^-$ with NA48/2

Within the 50 cm resolution on the longitudinal vertex position, $K^\pm \rightarrow \pi^\mp \mu^\pm \mu^\pm$ and $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ decays (denoted $K_{\pi\mu\mu}^{\text{LNV}}$ and $K_{\pi\mu\mu}^{\text{LNC}}$ 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

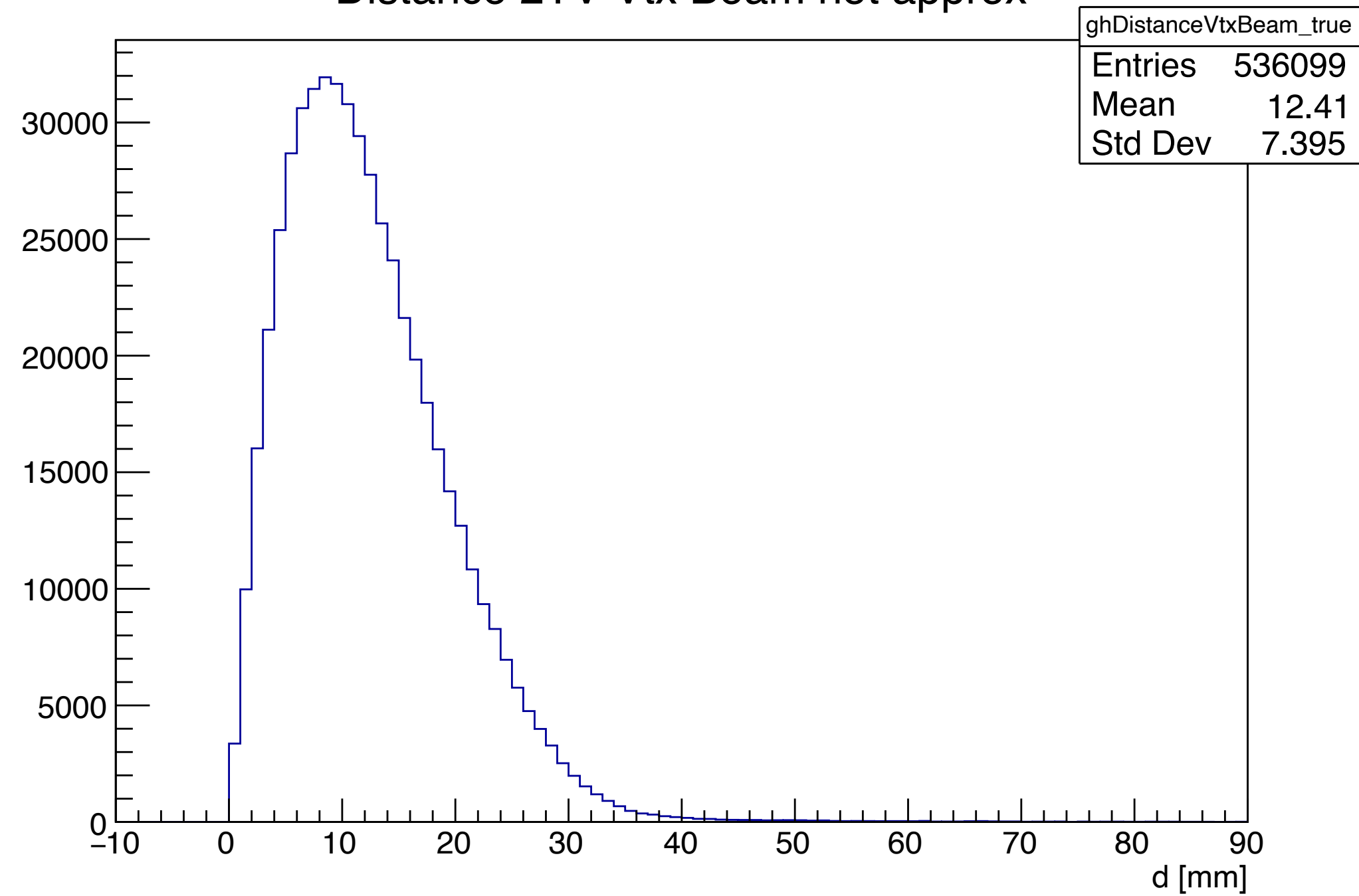
The better is the acceptance the more stringent is the U.L.



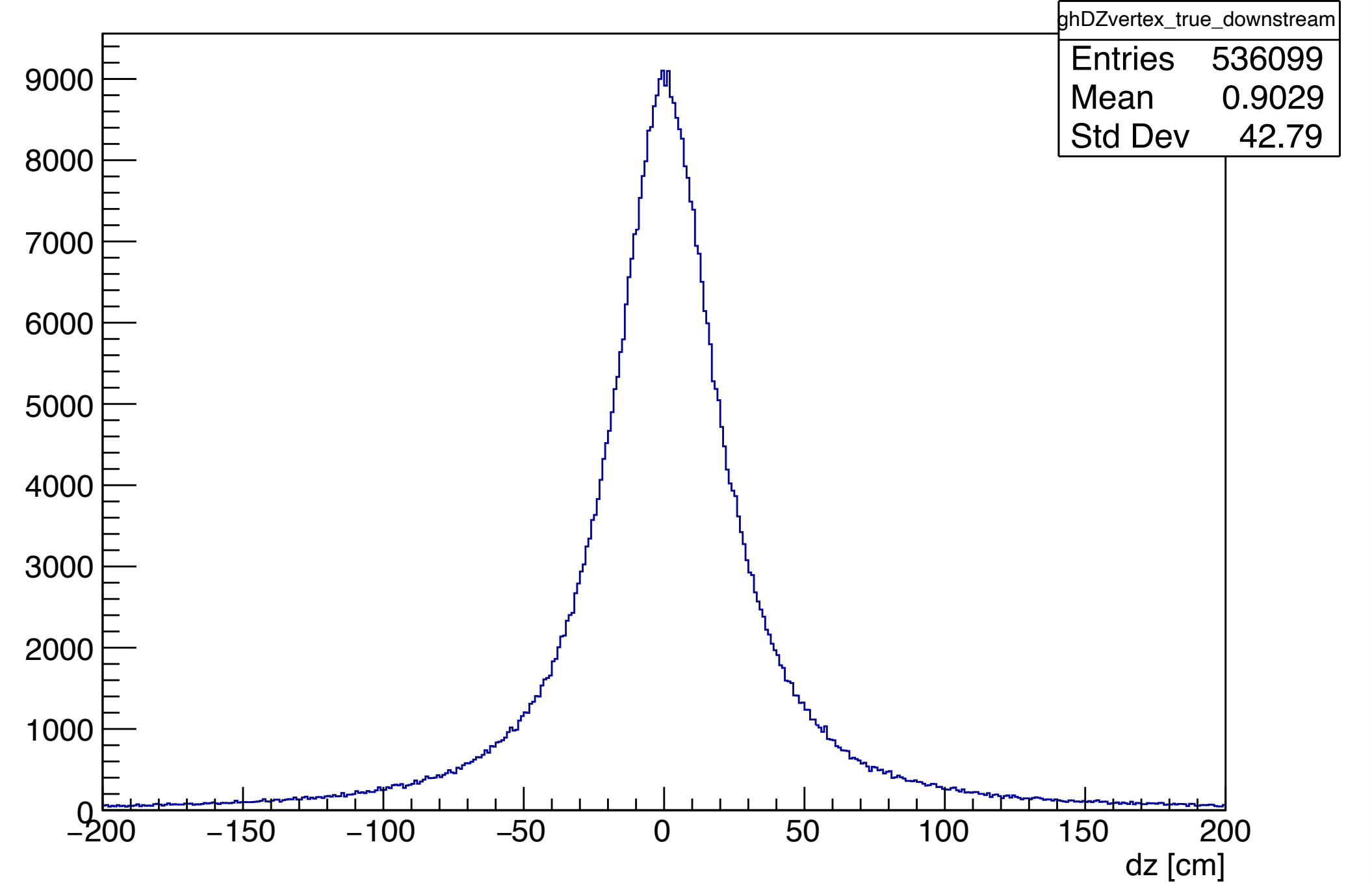
Vertex study

MC prompt: 2TV

Distance 2TV Vtx Beam not approx

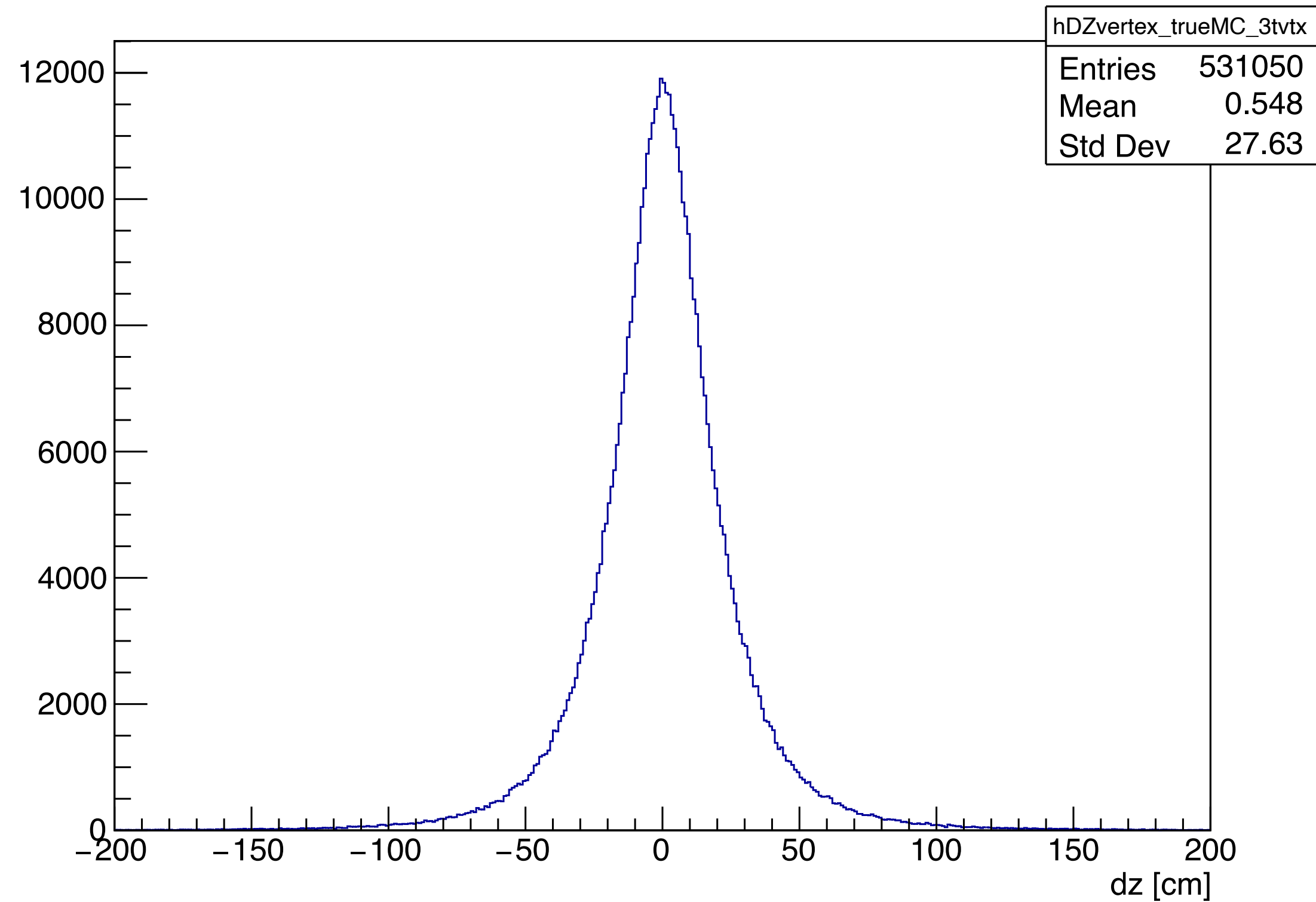


Delta Zvertex 2tvtx wrt true MC info



MC prompt: 2TV vs 3TV

Delta Zvertex 3tvtx wrt true MC info



DZ 3tv and 2tv

