UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

ToF studies with numu beam

(plots produced by Mathieu)

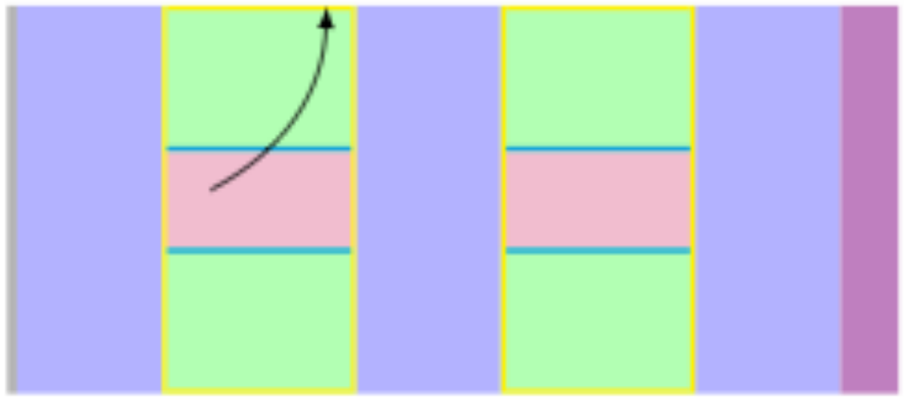
Davide Sgalaberna

Simulation studies of ToF PID

When we have a timing between the two detectors, we can compute $m_{ToF} = p \times \sqrt{\frac{c^2(\Delta t_{reco})^2}{L^2} - 1}$, L is the length[‡], Δt is the time of flight.

Goal

- We want to know if the resolution is sufficient enough to separate muons, electrons and protons, in particular for vertical tracks.
- Is it useful to add new ToF counters between the Target and the horizontal TPCs?



current ToF additional ToF

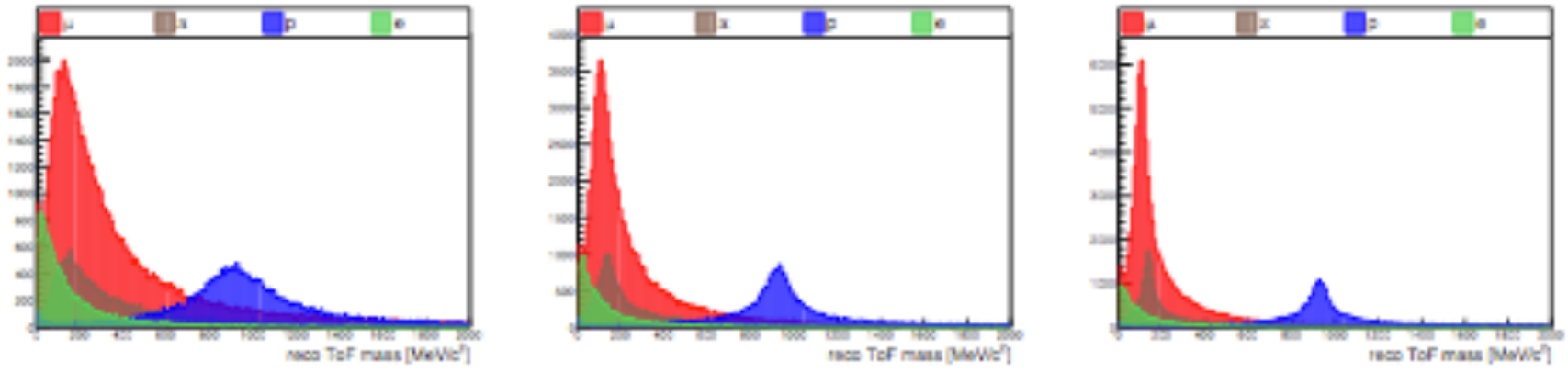
Analyze the sample of tracks going to ToF-Top >~80cm track length (~same as Vertical TPC length)

- p: we apply TPC resolution or 10% otherwise (for non-TPC tracks)
- time is smeared depending on the detector:
  - for Target/FGD: $\sigma_t = 3ns/\sqrt{N_{hits}} \oplus 0.6ns$, where $N_{hits} = L/2.5cm$
  - for ECal: $\sigma_t = 5ns$
  - for ToF counters: $\sigma_t = 0.6ns$ by default (but changed later)
- L is smeared with 1mm if we have a TPC segment, 1cm otherwise

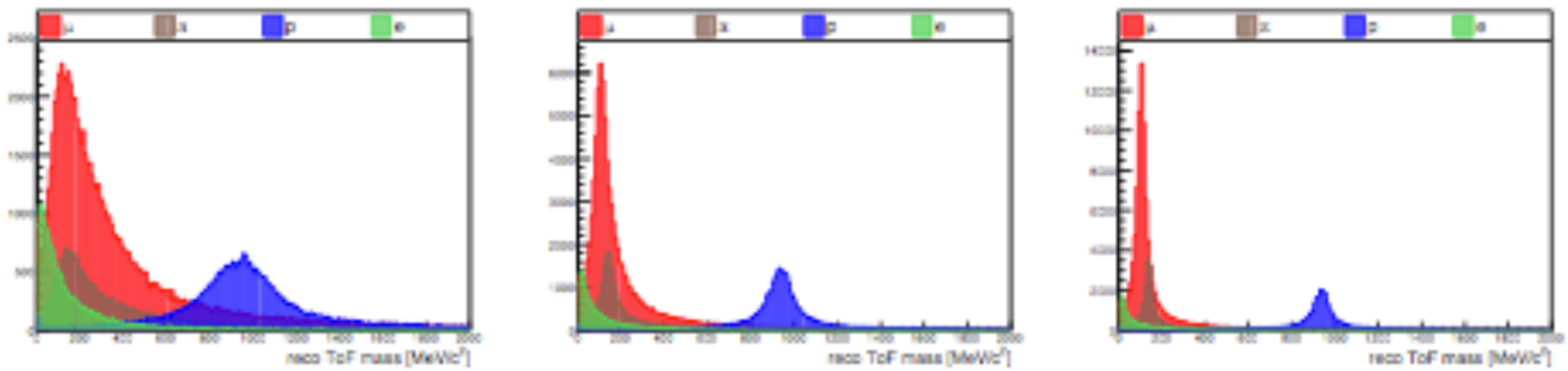
ToF mass

Sample of preselected ν_μ events
Look at all particles with ToF information (not only highest momentun

reference configuration



adding new ToF between Target and HTPC



$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

- Adding a ToF just around the target seems to help
- Target box made of scintillator bars presented by Franck Cadoux at the past ND280 upgrade workshops?)

Variable used for ToF PID

- Standard method used for the TPC PID cut using dEdx
- Used in all the T2K official analyses
- Build a likelihood for each true particle hypothesis

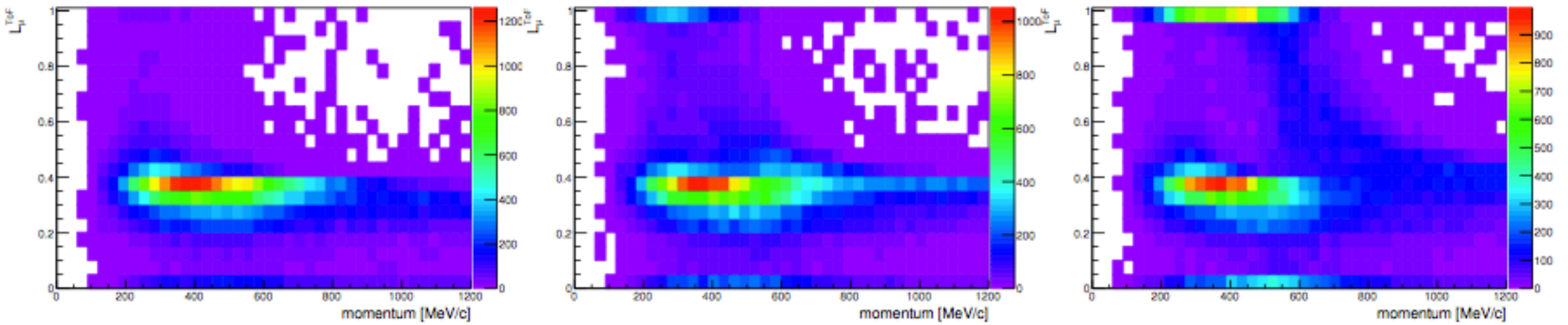
How to quantify separation?

- $m_{ToF} = p \times \sqrt{\frac{c^2(\Delta t_{reco})^2}{L^2} - 1}$
- $\text{pull}_e^{ToF} = \frac{m_{ToF} - m_e}{\sigma_m}$, pull_μ...
- $\mathcal{L}_e^{ToF} = \frac{e^{-(\text{pull}_e^{ToF})^2/2}}{\sum_{\text{hypo}} e^{-(\text{pull}_{\text{hypo}}^{ToF})^2/2}}$, $\mathcal{L}_\mu^{ToF}$...
- can be combined with TPC likelihood: $\mathcal{L}_{\text{hypo}} = \mathcal{L}_{\text{hypo}}^{ToF} \times \mathcal{L}_{\text{hypo}}^{TPC}$

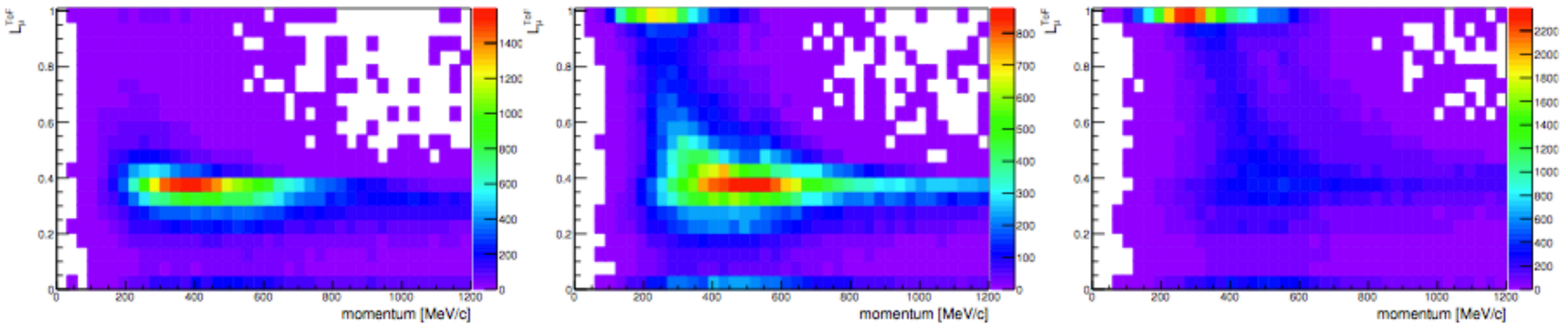
The selected electrons are only secondary electrons from ν_μ.
We will need to look how primary electrons from ν_e behave.

$\mathcal{L}_{\mu}^{ToF}$ vs momentum for true muons

reference configuration



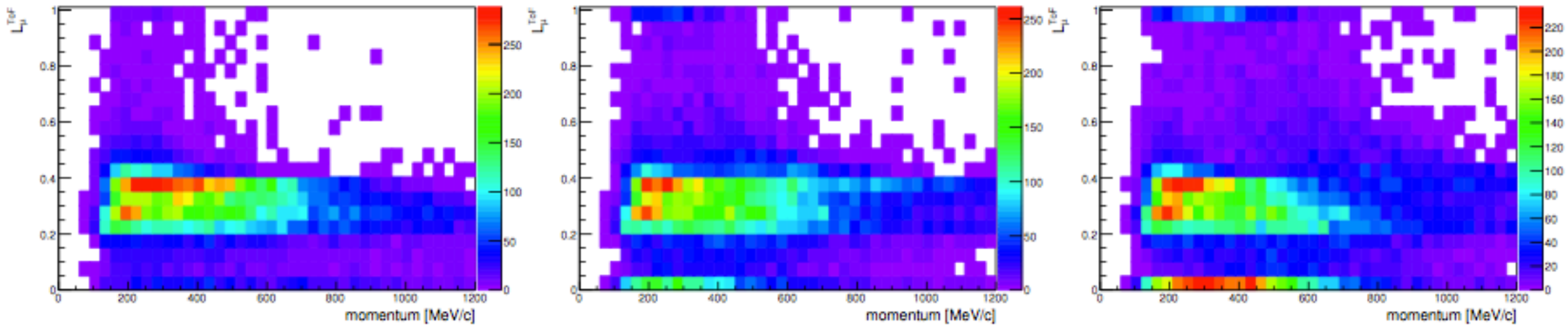
adding new ToF between Target and HTPC



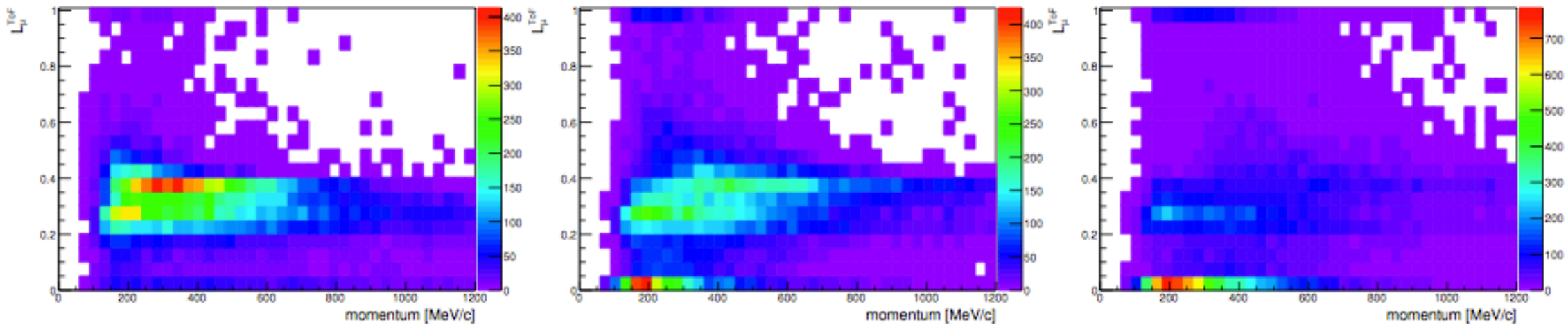
$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs momentum for true pions

reference configuration



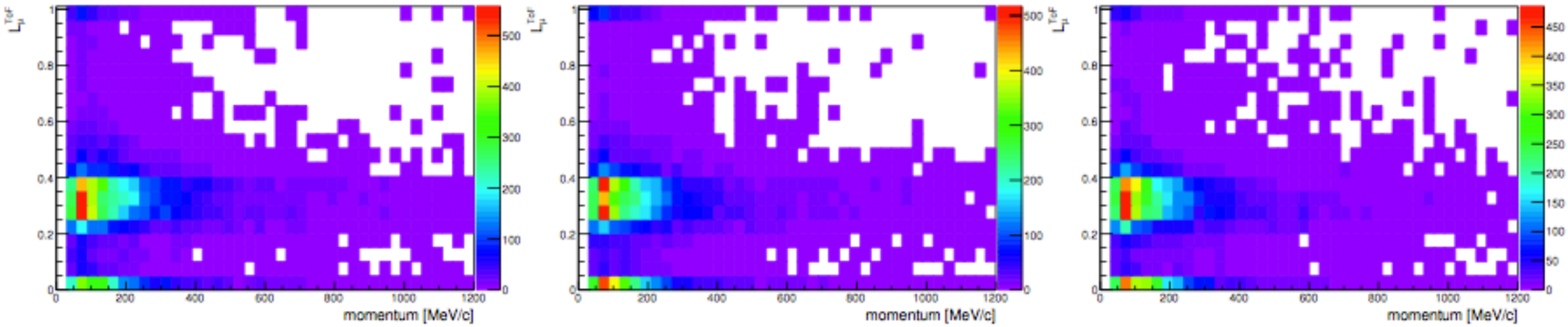
adding new ToF between Target and HTPC



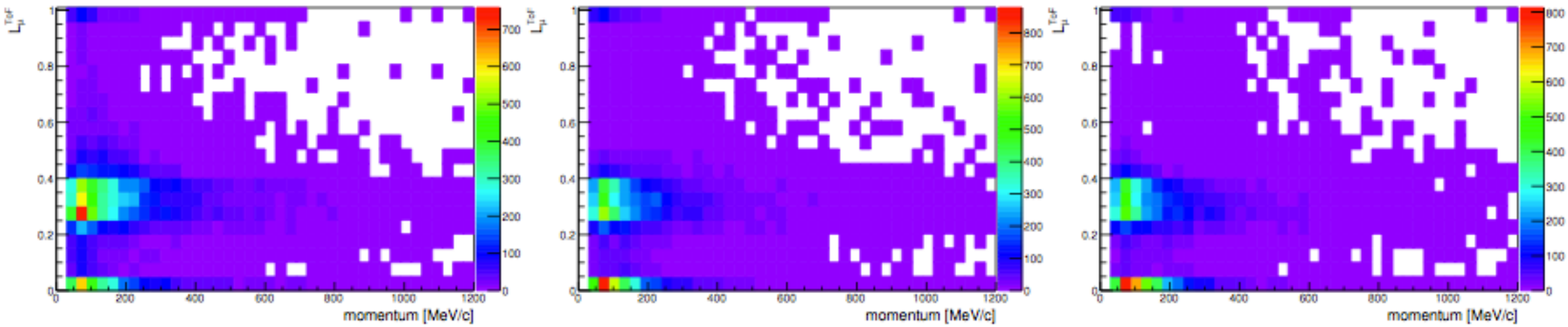
$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs momentum for true electrons

reference configuration



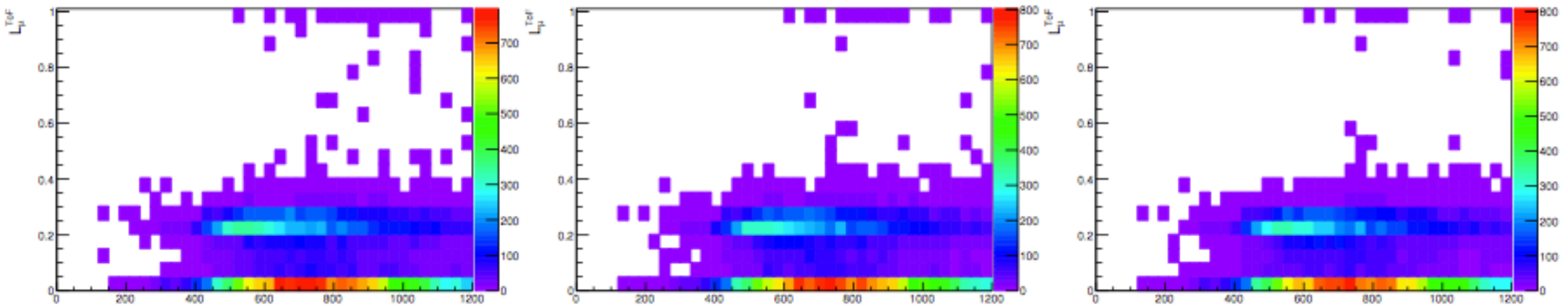
adding new ToF between Target and HTPC



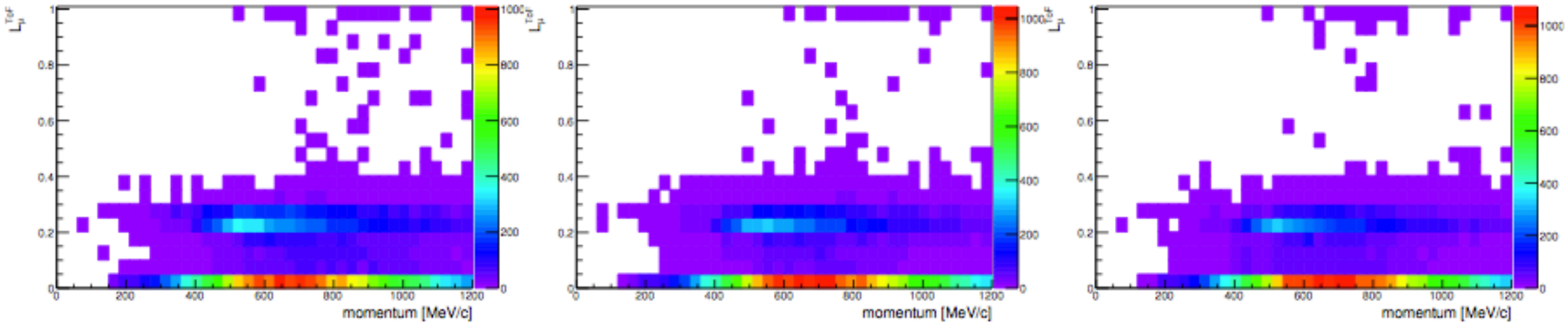
$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs momentum for true protons

reference configuration



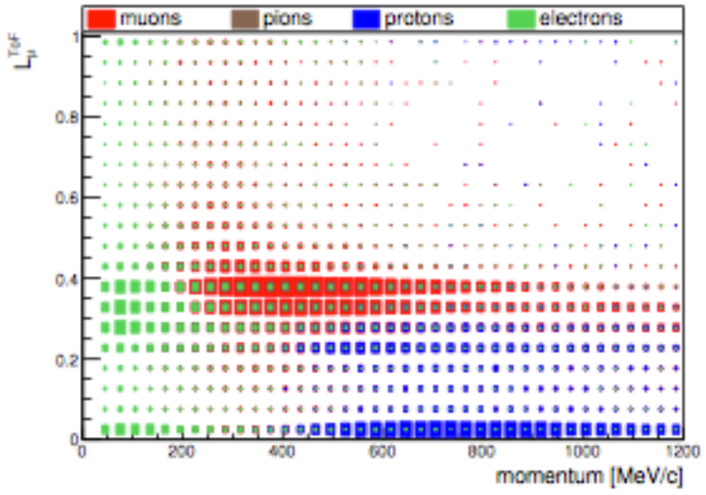
adding new ToF between Target and HTPC

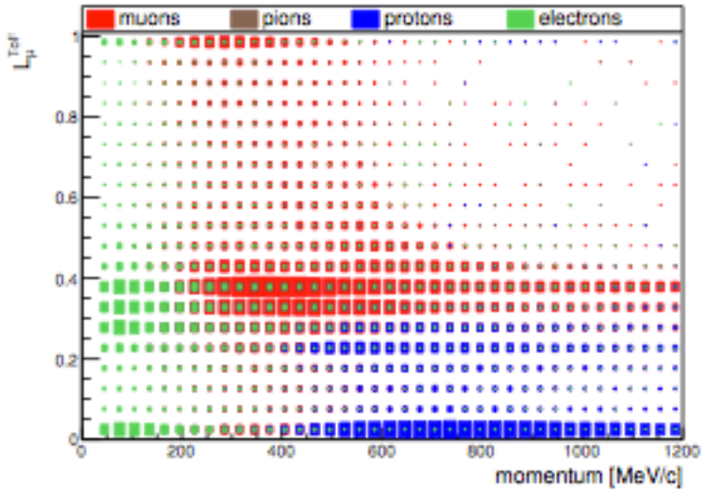


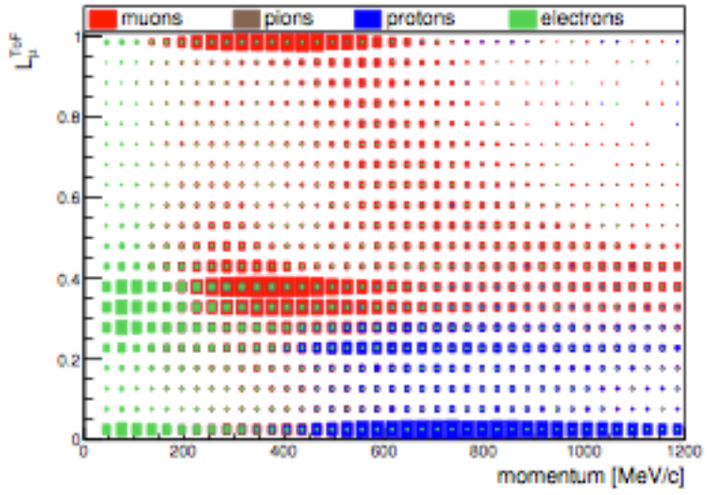
$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs momentum for different true particles

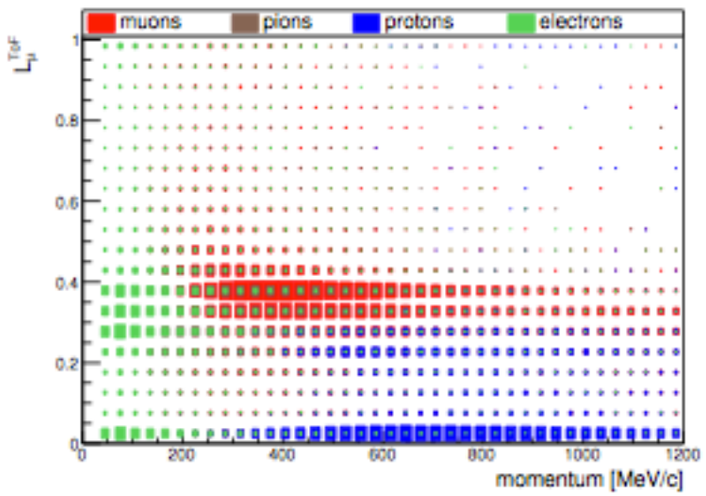
reference configuration

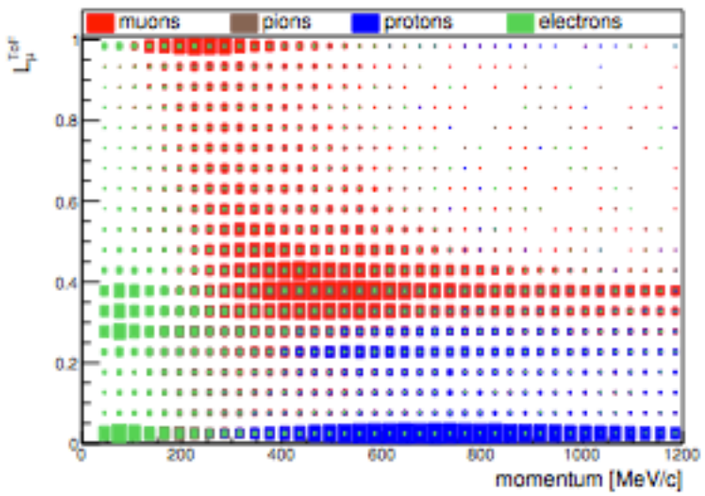


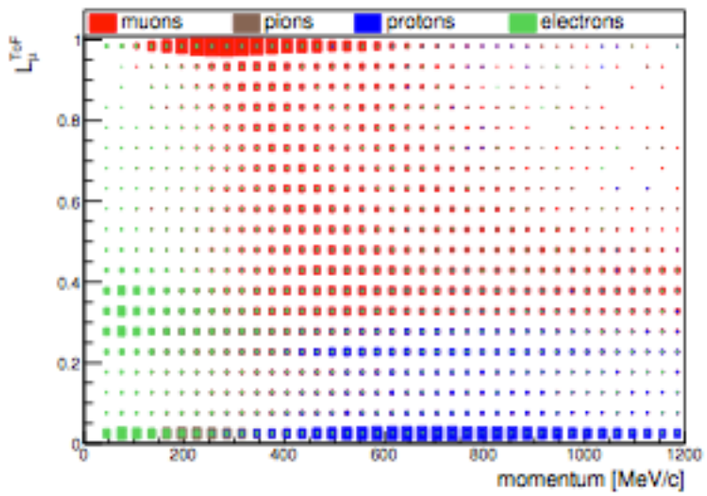




adding new ToF between Target and HTPC







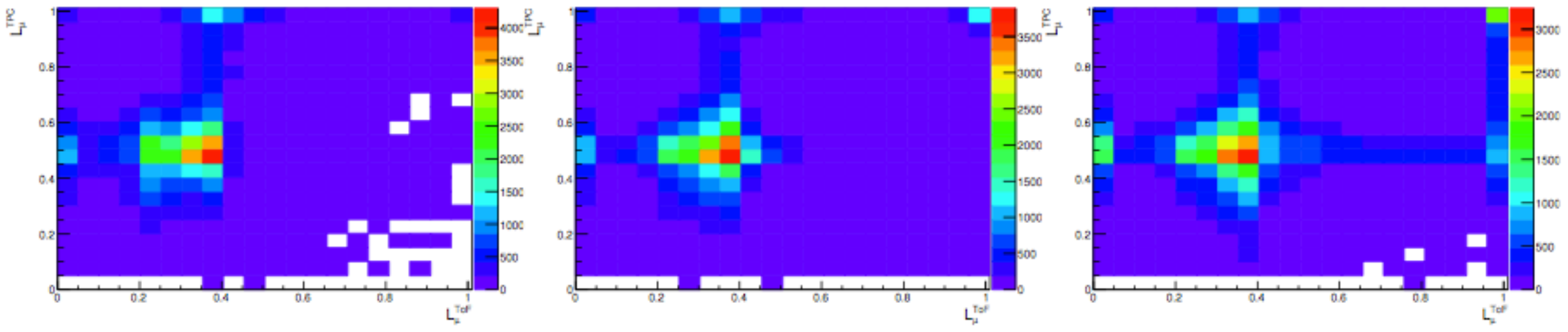
$\sigma_{ToF} = 600$ ps ↑

$\sigma_{ToF} = 150$ ps ↑

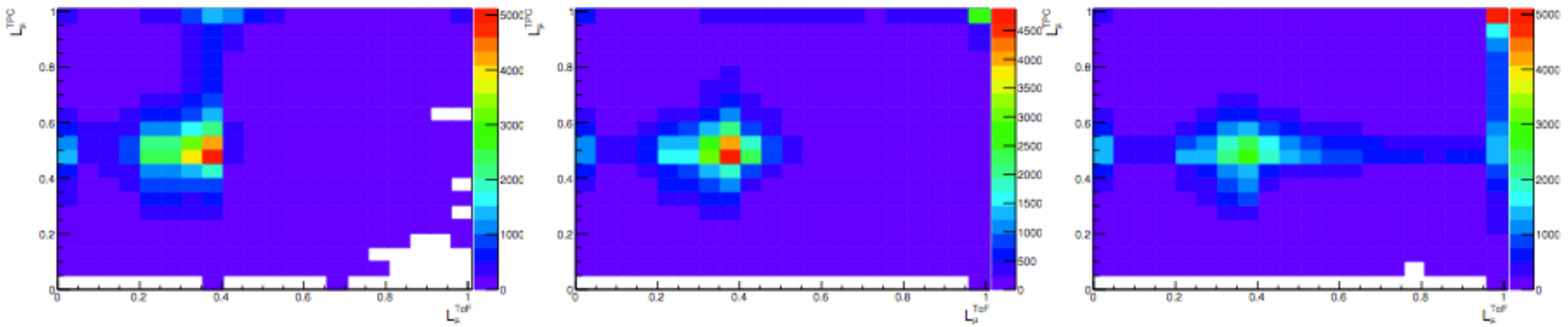
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs $\mathcal{L}_{\mu}^{TPC}$ for true muons

reference configuration



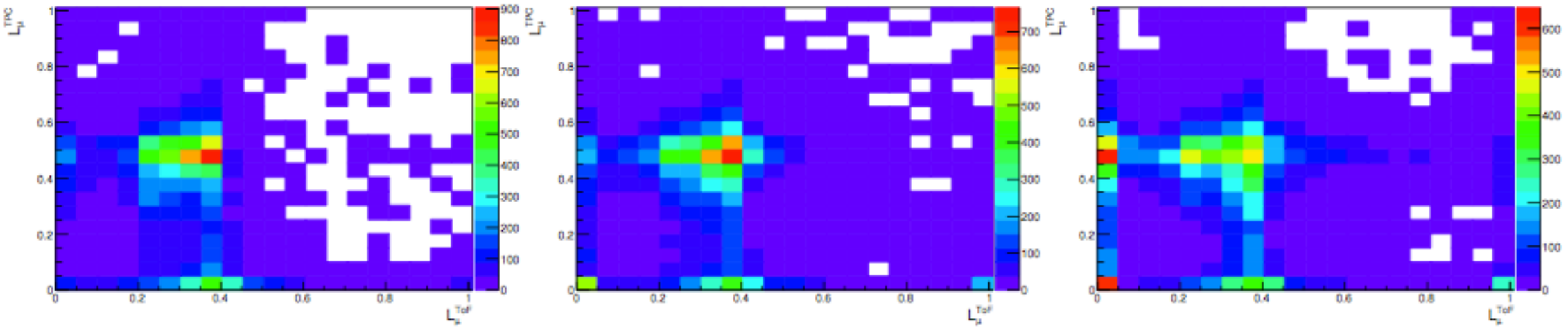
adding new ToF between Target and HTPC



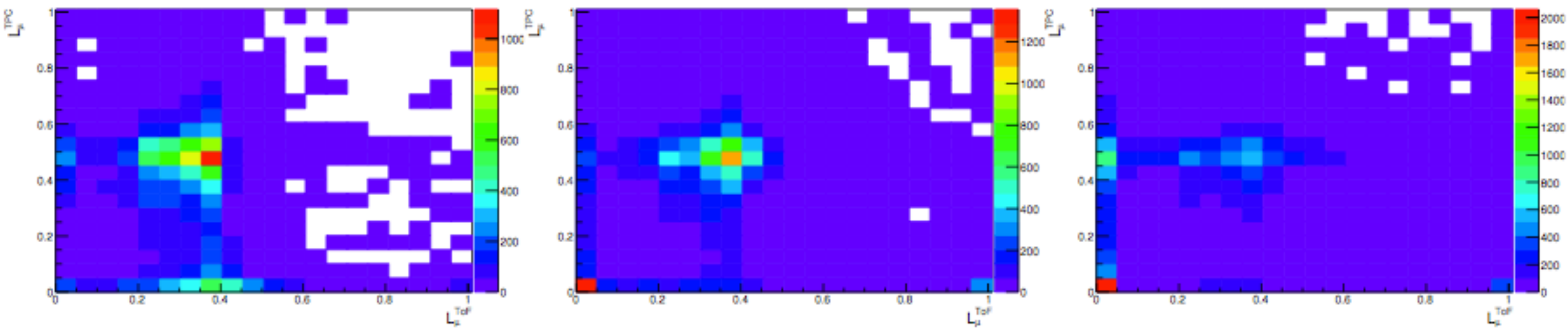
$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs $\mathcal{L}_{\mu}^{TPC}$ for true pions

reference configuration



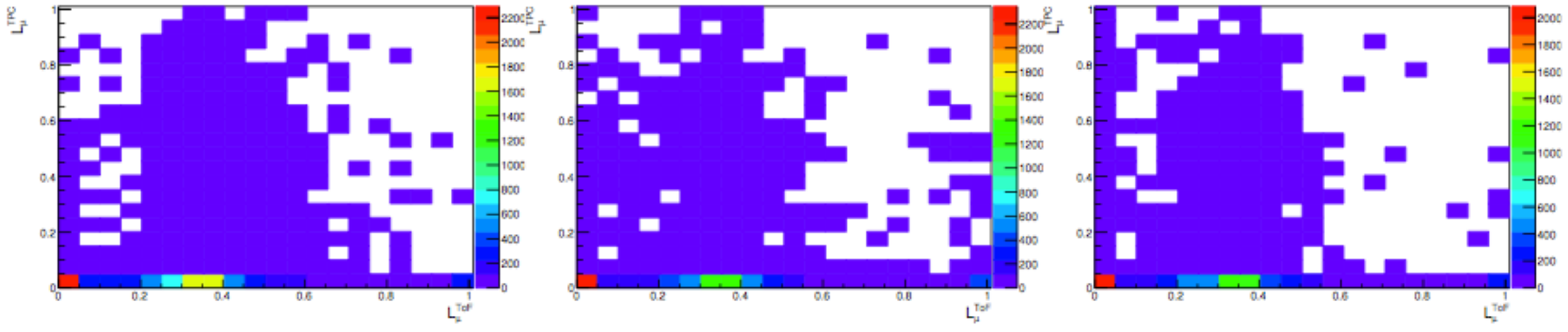
adding new ToF between Target and HTPC



$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs $\mathcal{L}_{\mu}^{TPC}$ for true electrons

reference configuration



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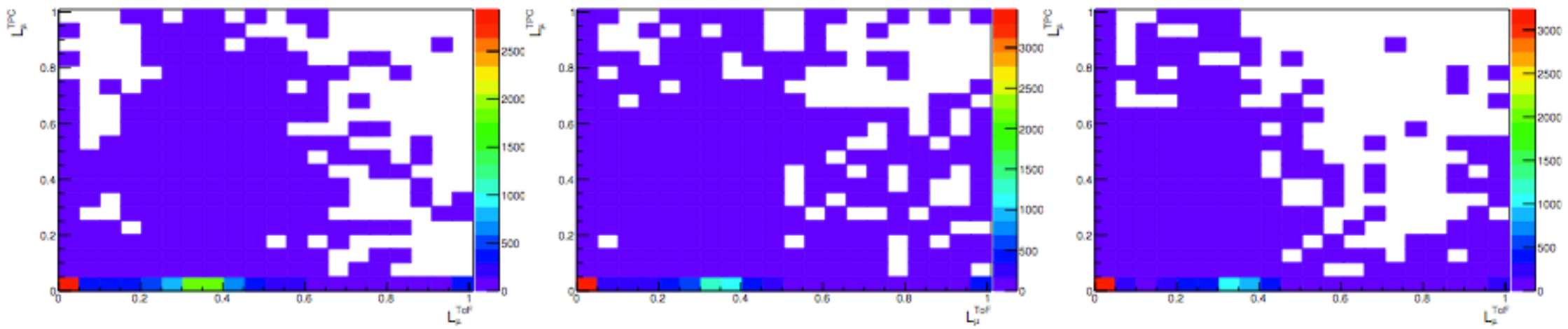
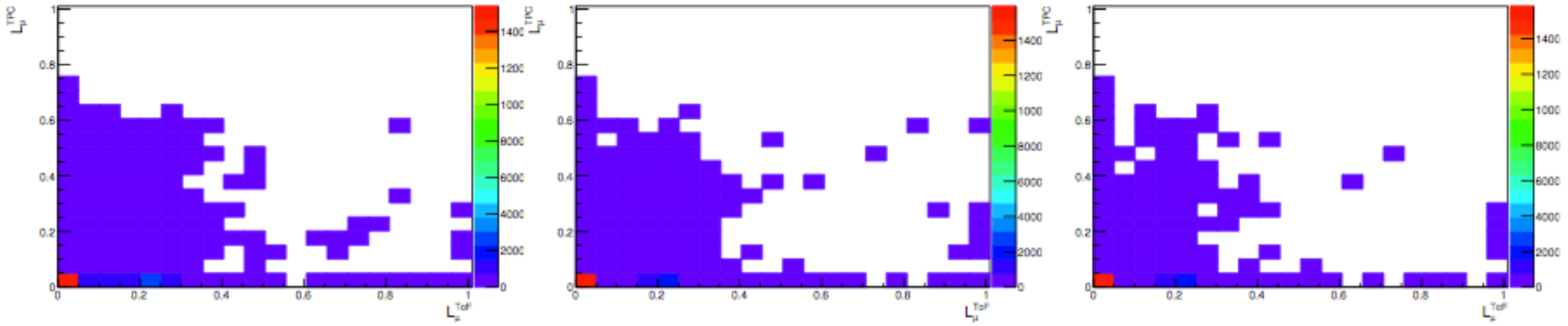


$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs $\mathcal{L}_{\mu}^{TPC}$ for true protons

reference configuration



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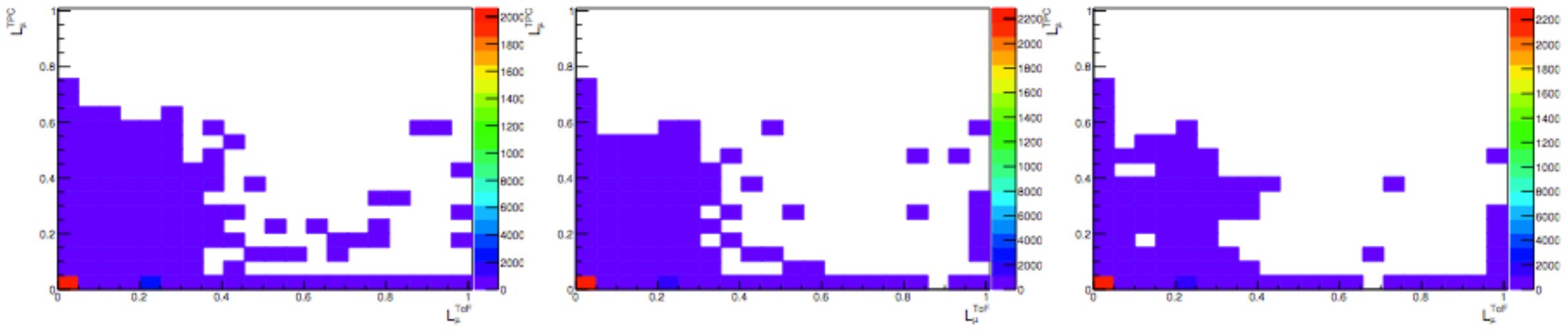


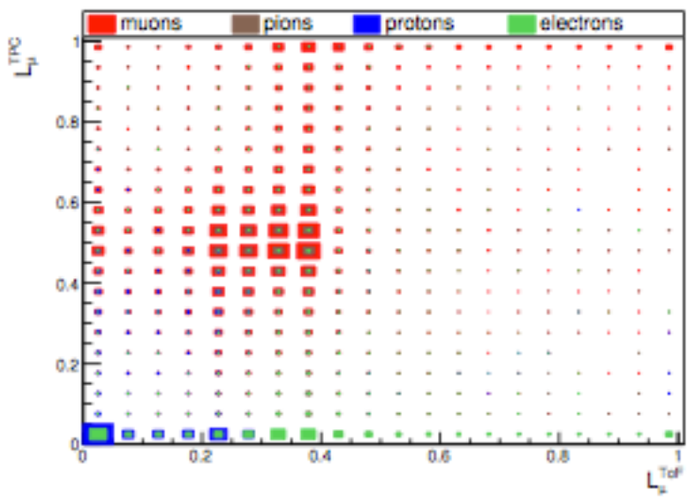
$\sigma_{ToF} = 600$ ps ↑

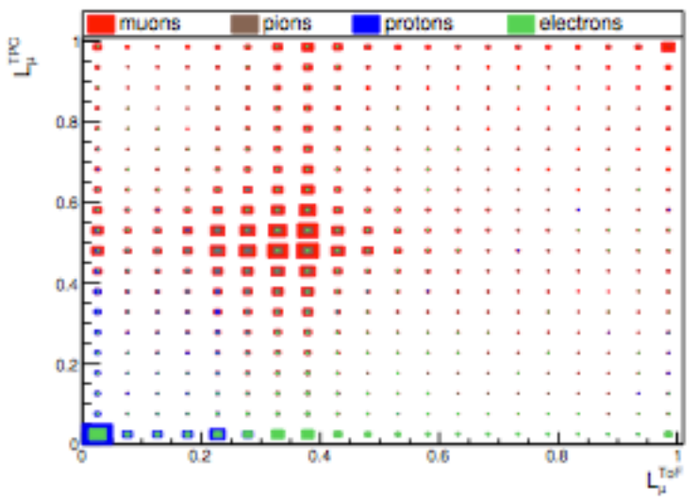
$\sigma_{ToF} = 150$ ps ↑

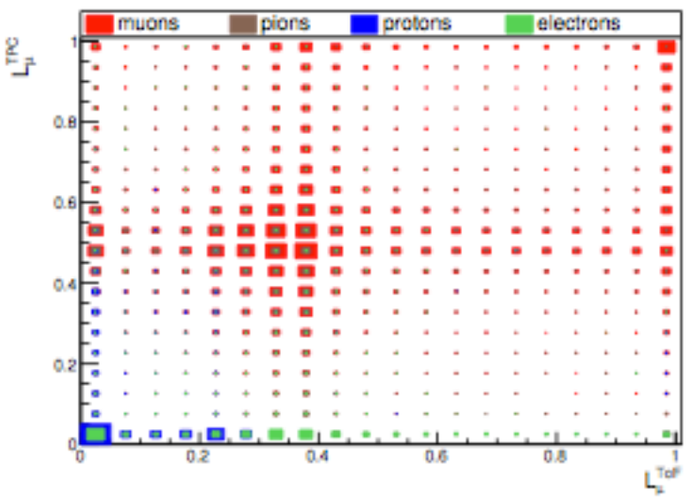
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}_{\mu}^{ToF}$ vs $\mathcal{L}_{\mu}^{TPC}$ for different true particles

reference configuration







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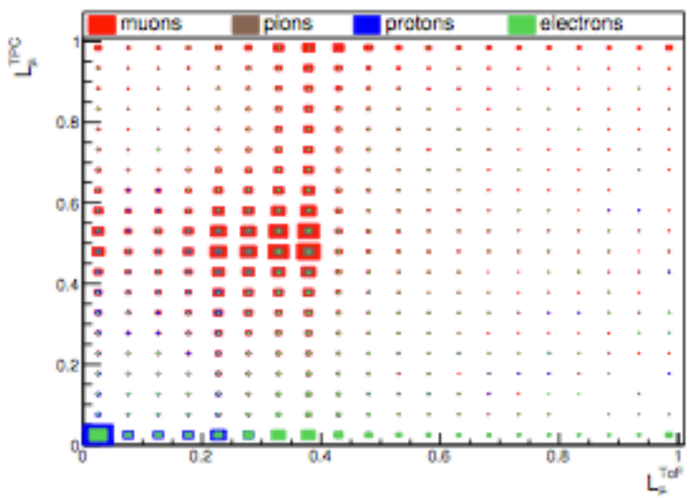
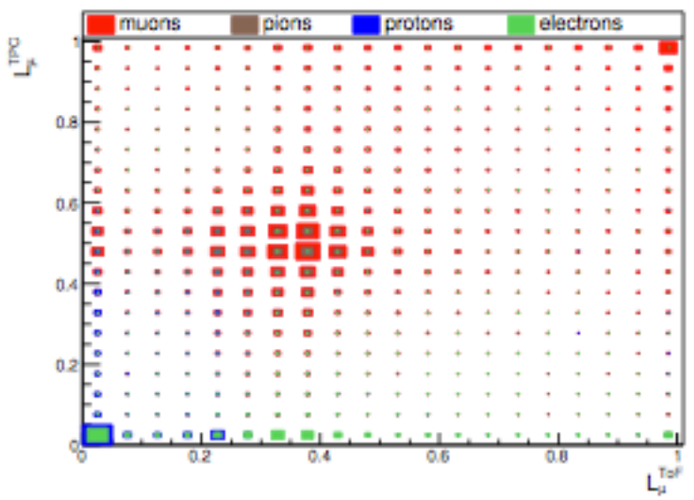
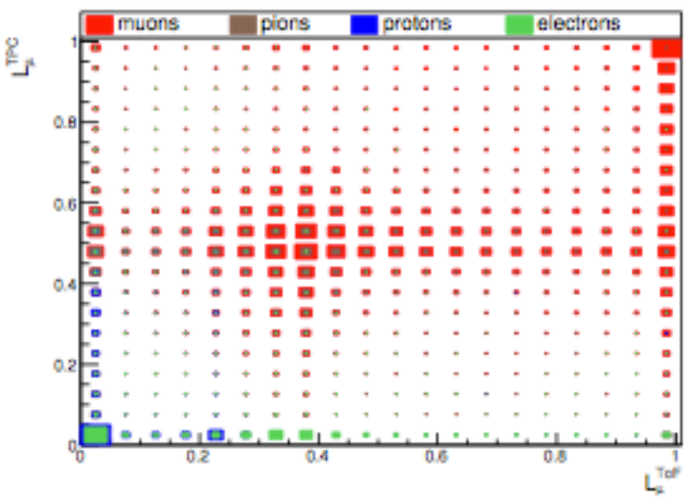






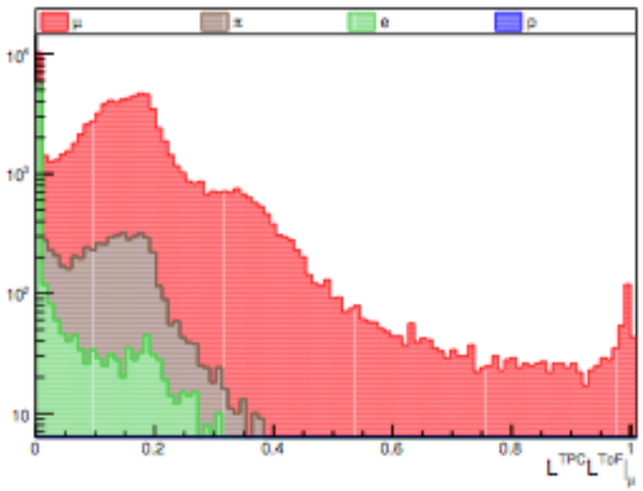
$\sigma_{ToF} = 600$ ps ↑

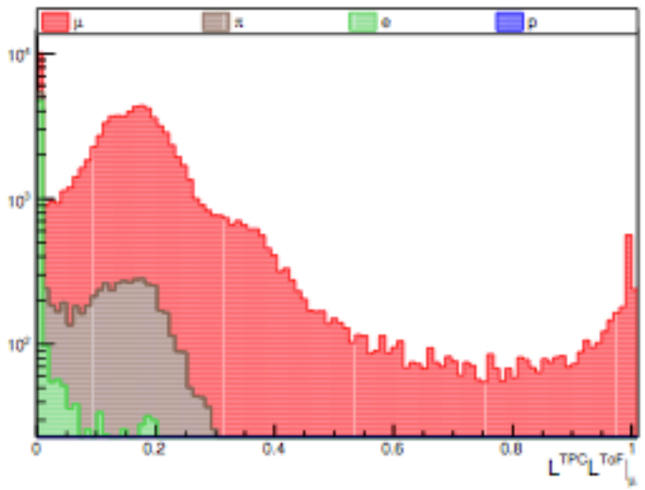
$\sigma_{ToF} = 150$ ps ↑

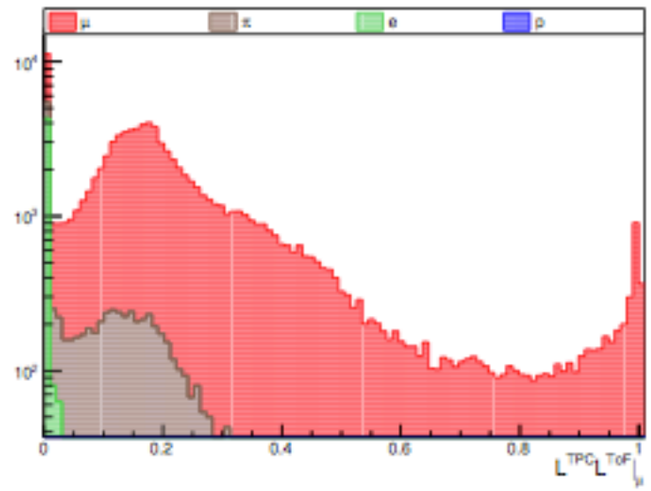
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}^{TPC} \times \mathcal{L}^{ToF}_{\mu}$ for different true negative particles

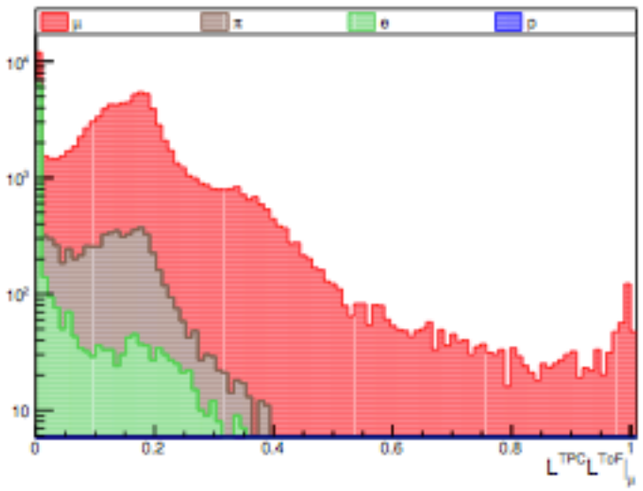
reference configuration

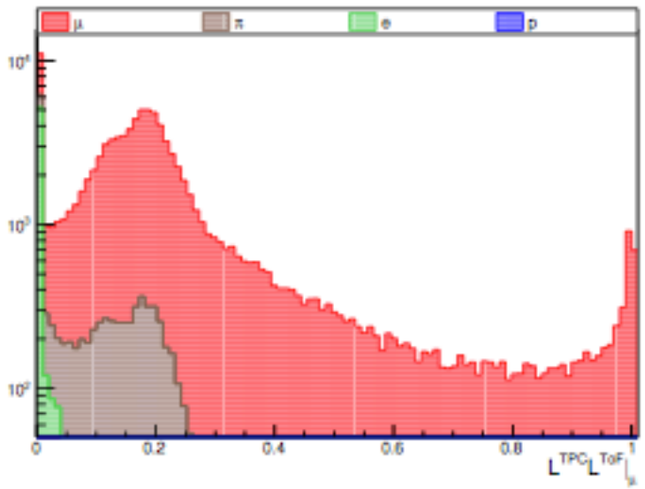


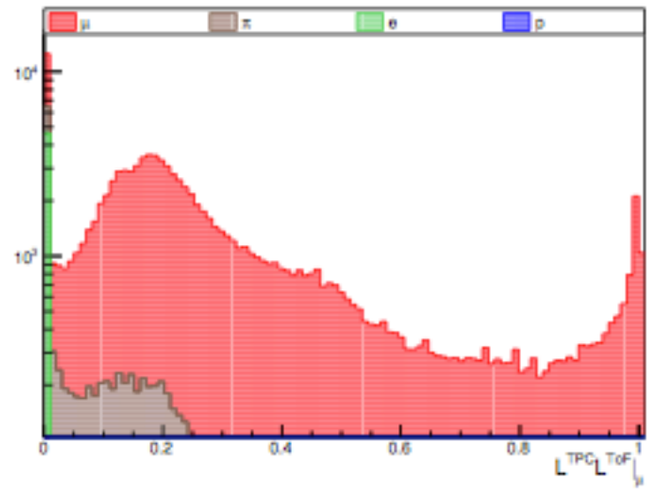




adding new ToF between Target and HTPC







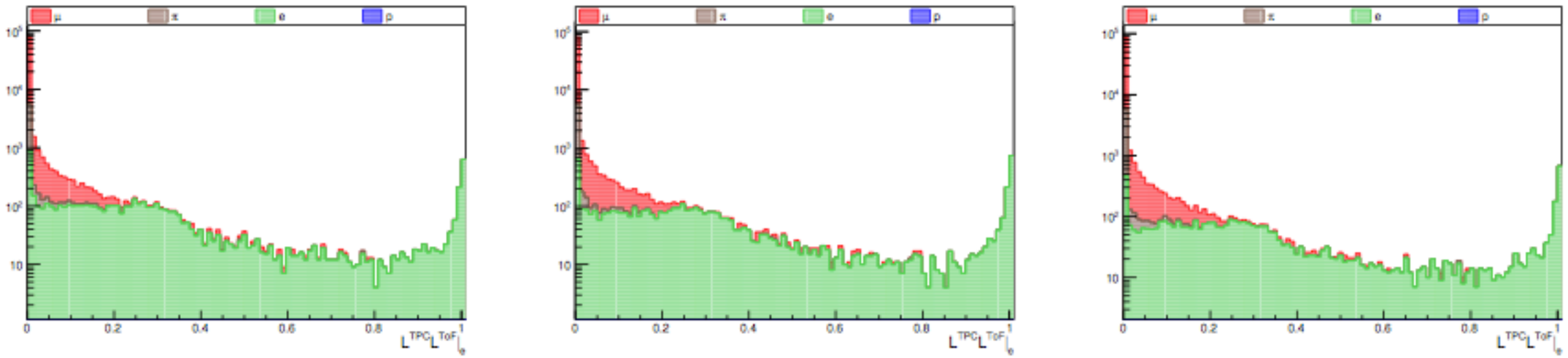
$\sigma_{ToF} = 600$ ps ↑

$\sigma_{ToF} = 150$ ps ↑

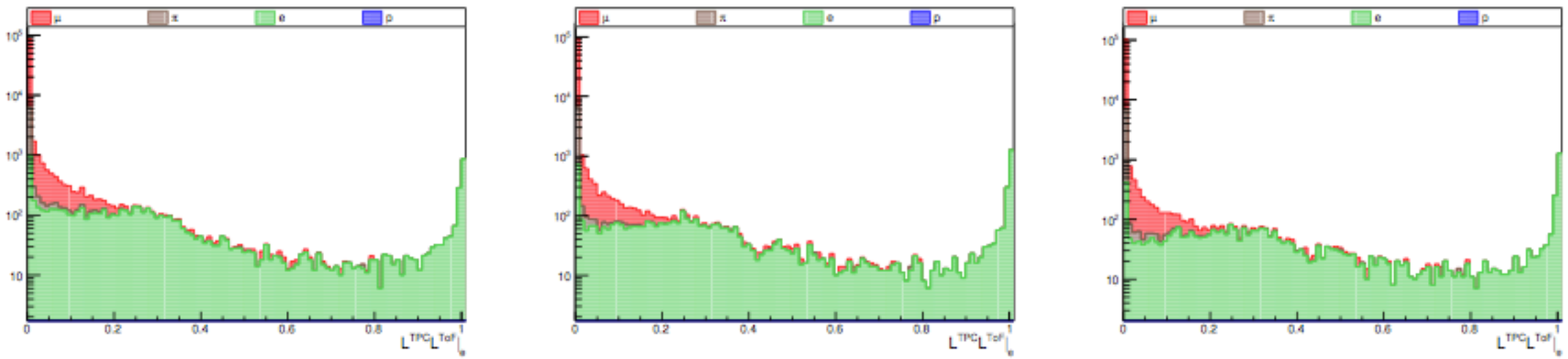
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}^{TPC} \times \mathcal{L}_e^{ToF}$ for different true negative particles

reference configuration



adding new ToF between Target and HTPC



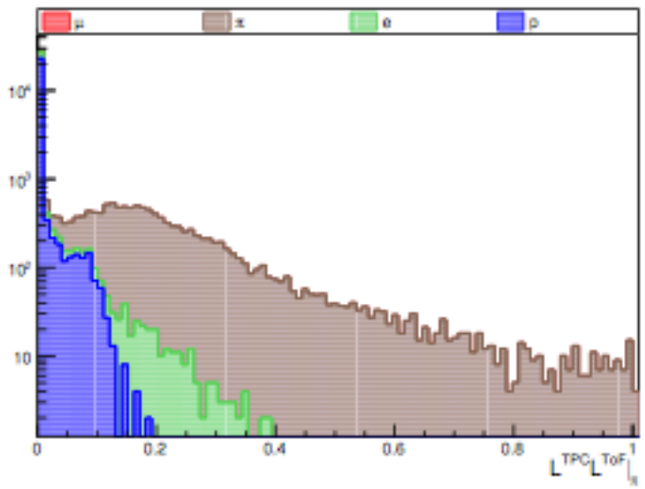
$\sigma_{ToF} = 600$ ps ↑

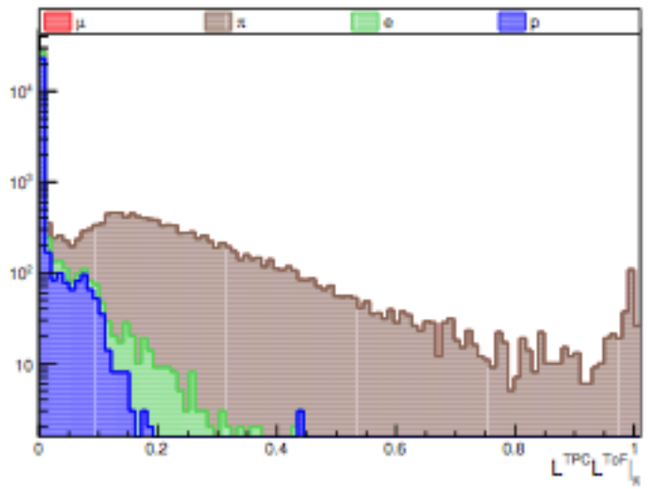
$\sigma_{ToF} = 150$ ps ↑

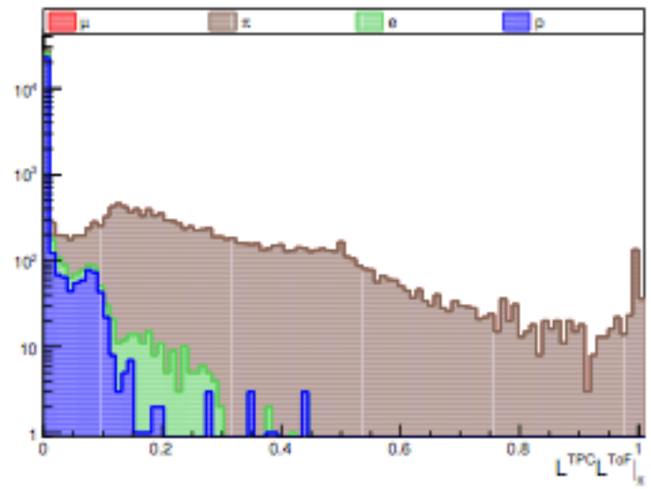
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}^{TPC} \times \mathcal{L}_{\pi}^{ToF}$ for different true positive particles

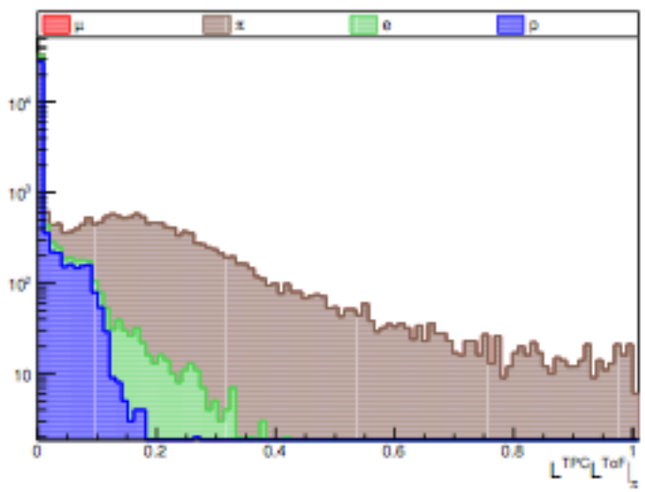
reference configuration

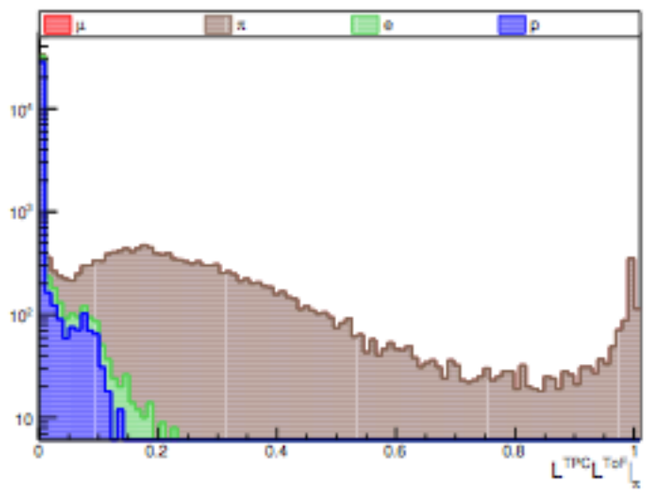


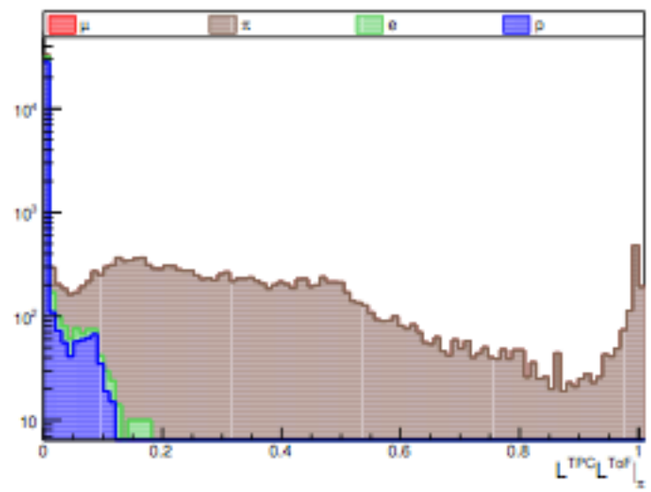




adding new ToF between Target and HTPC







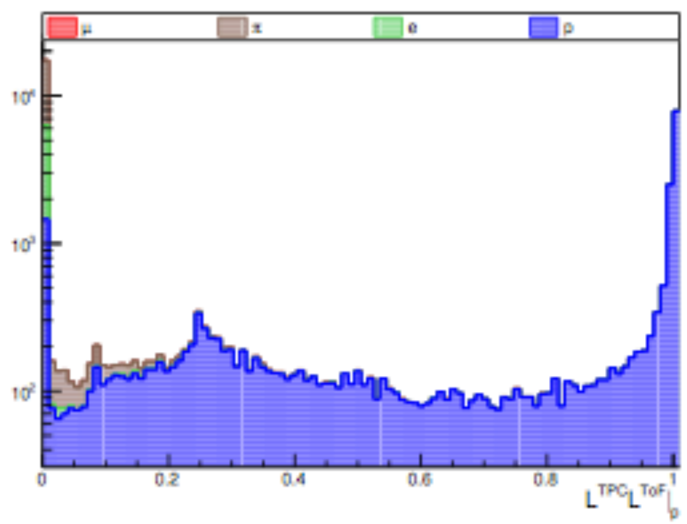
$\sigma_{ToF} = 600$ ps ↑

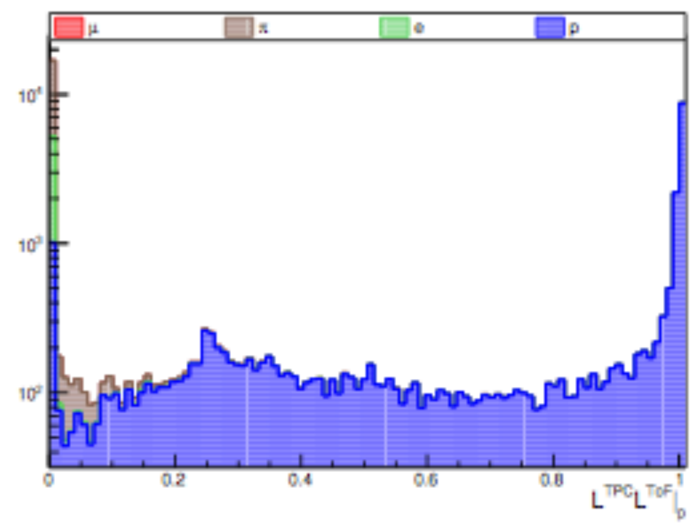
$\sigma_{ToF} = 150$ ps ↑

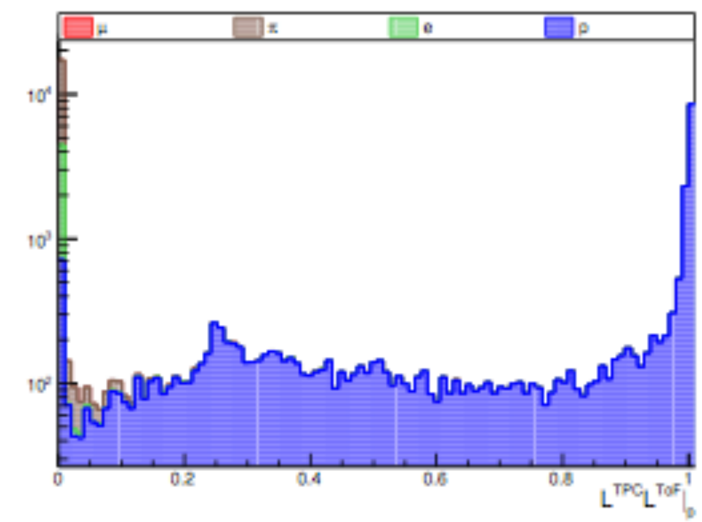
$\sigma_{ToF} = 50$ ps ↑

$\mathcal{L}^{TPC} \times \mathcal{L}_p^{ToF}$ for different true positive particles

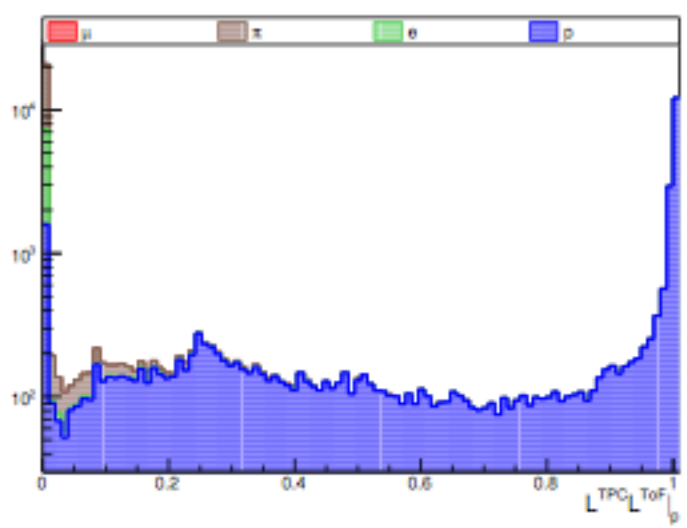
reference configuration



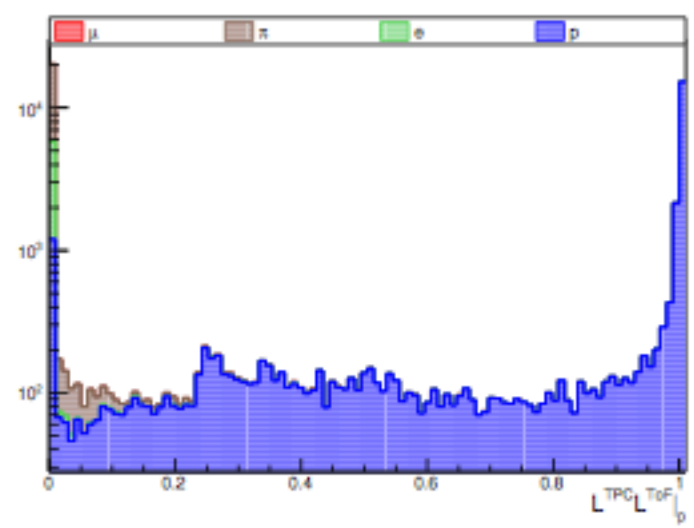




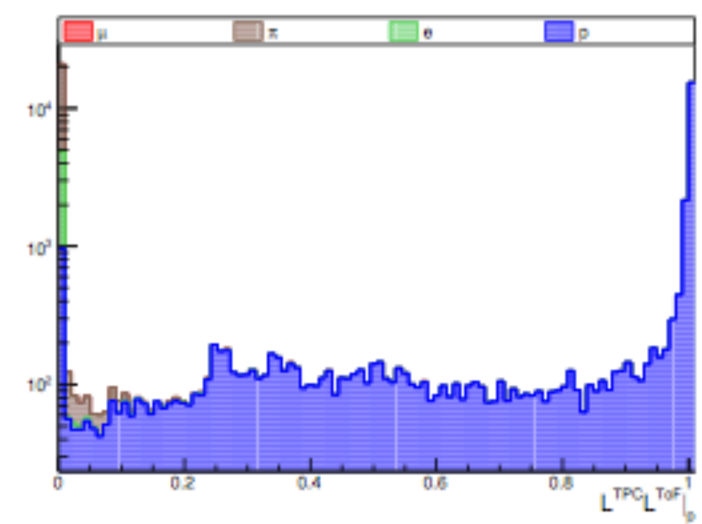
adding new ToF between Target and HTPC



$\sigma_{ToF} = 600$ ps ↑



$\sigma_{ToF} = 150$ ps ↑

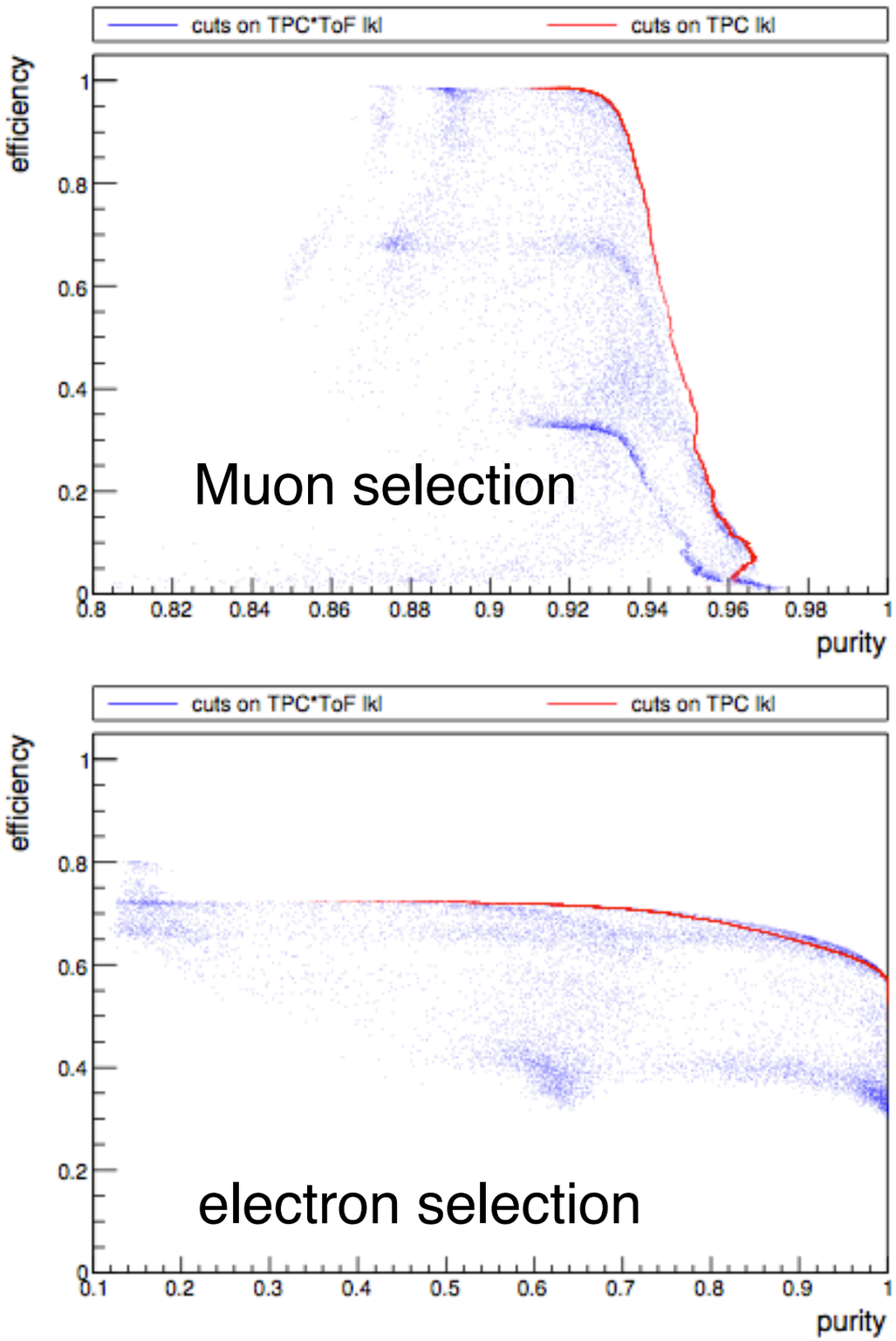


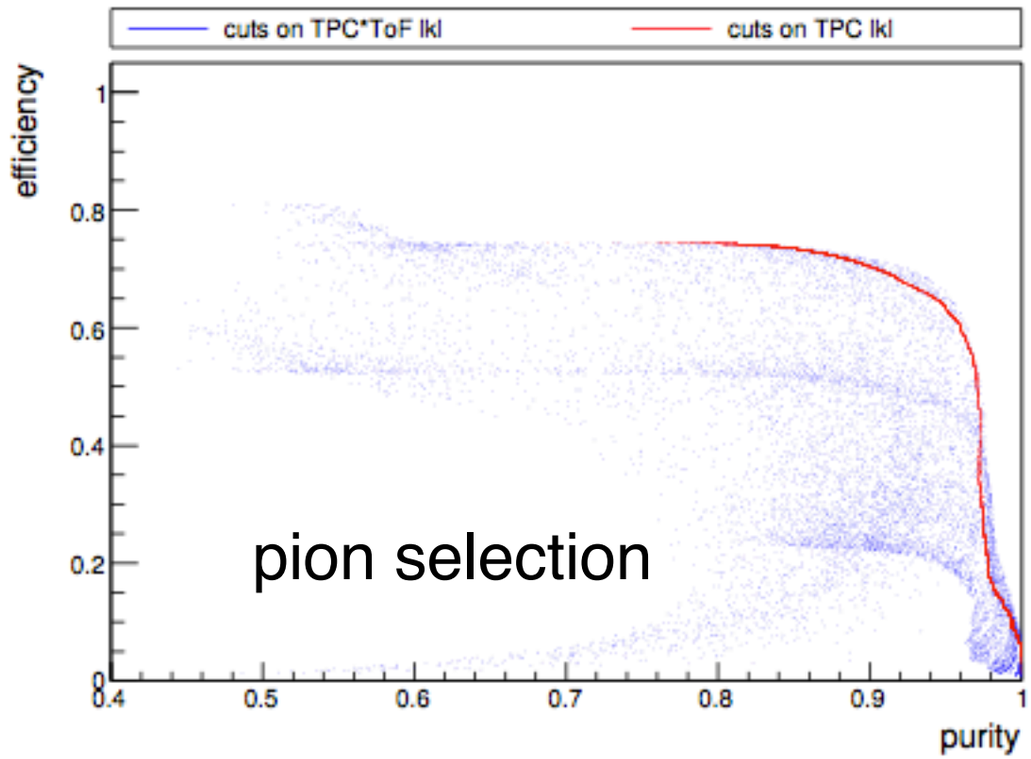
$\sigma_{ToF} = 50$ ps ↑

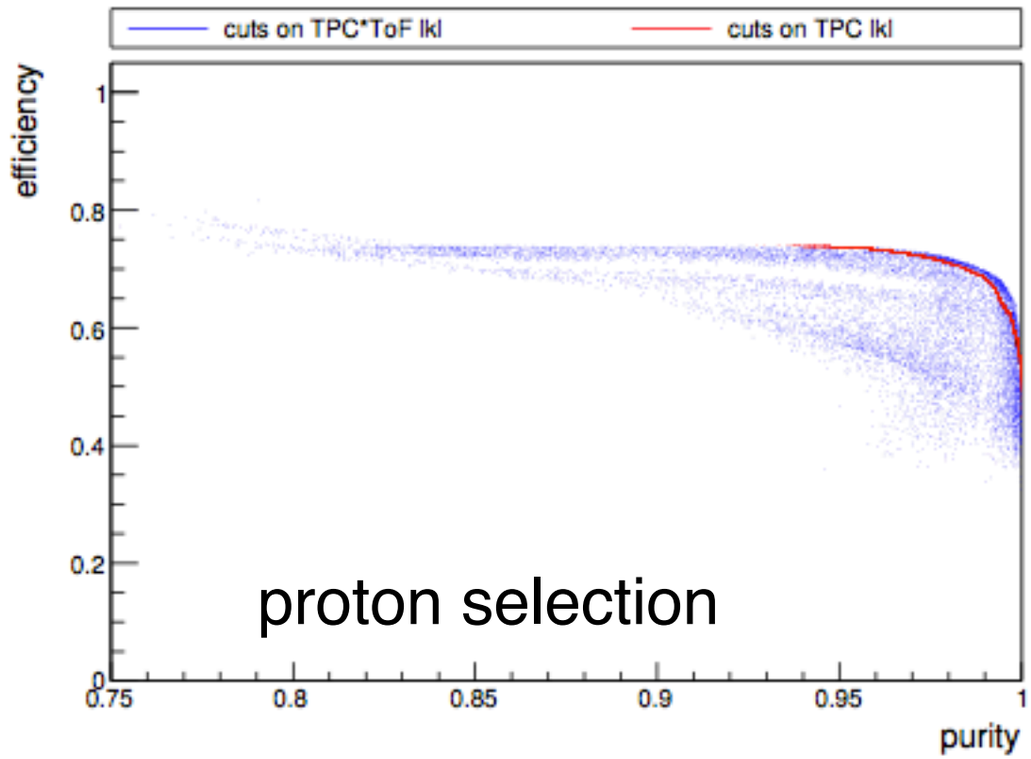
- We want to compare the performance of cutting on TPC likelihood only (method A), with the performance of cutting both on TPC likelihood and ToF likelihood (method B)
- For the selection of a given particle type i, the cuts are:
  - correct charge
  - method A: $\mathcal{L}_i^{TPC} > C$
  - method B: $f(\mathcal{L}_i^{TPC}, \mathcal{L}_i^{ToF}) > C$ if we have a ToF, $\mathcal{L}_i^{TPC} > C'$ otherwise

  Our estimators are:
  - efficiency = (selected true PID events)/(true PID events)
  - purity = (selected true PID events)/(selected events)
- For method A, we compute efficiency/purity for different values of C (thrown randomly between 0 and 1)
- For method B, we have chosen $f(x, y) = \alpha x + (1 - \alpha y)$ and we compute efficiency/purity for different values of C, C', α (thrown randomly and independently between 0 and 1)

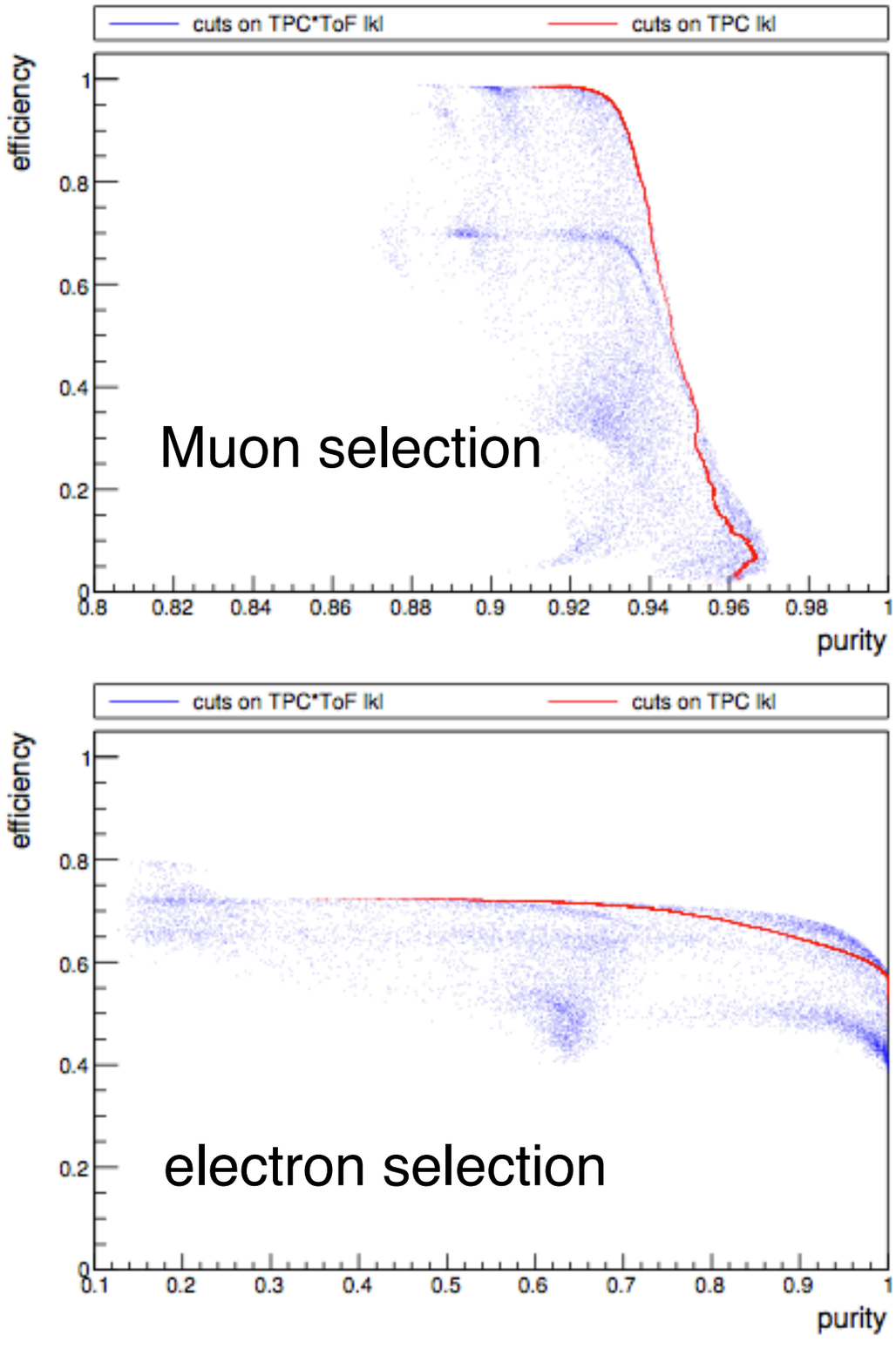
Efficiency vs purity ($\sigma = 600$ ps + new ToF)

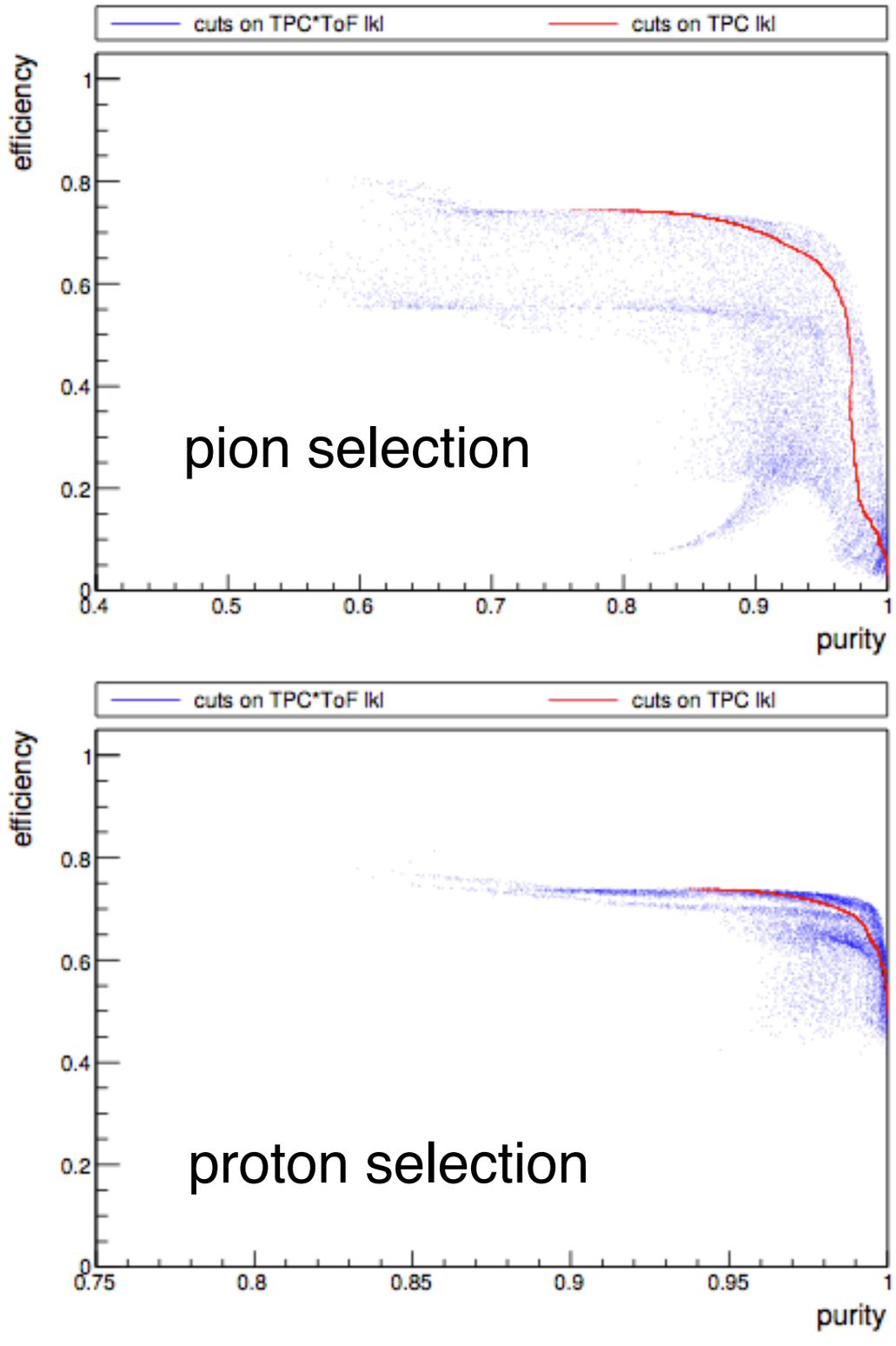




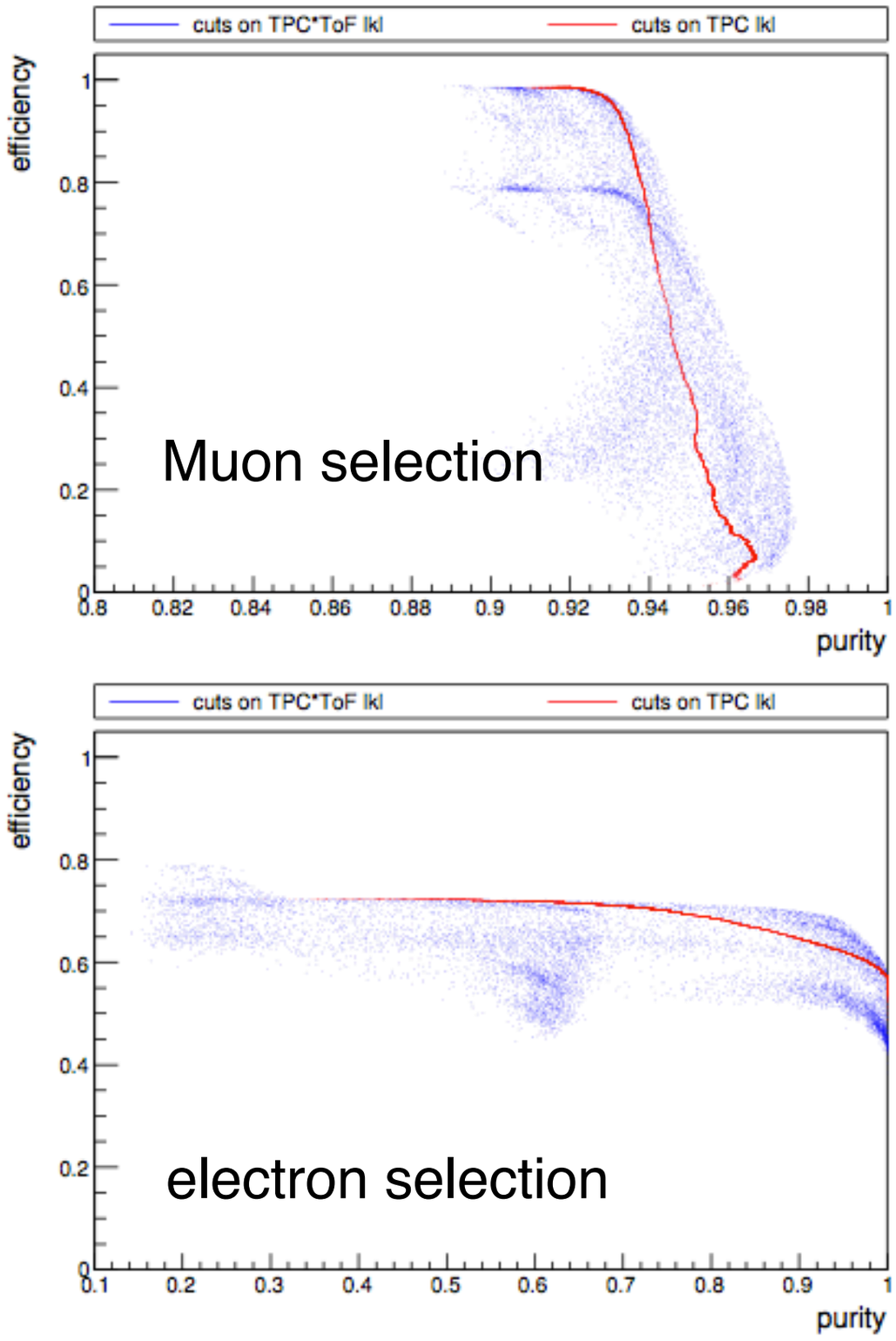


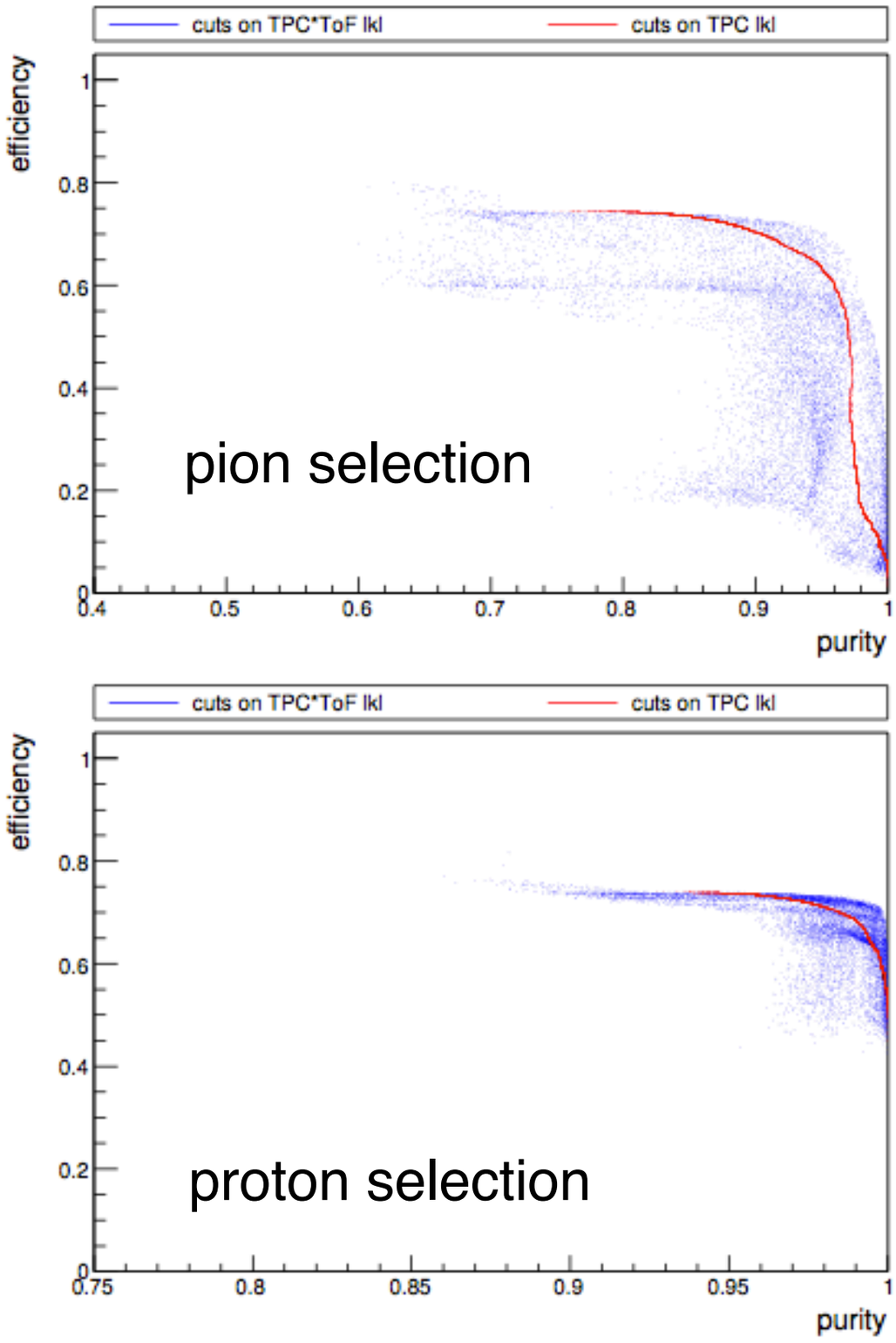
Efficiency vs purity ($\sigma = 150$ ps + new ToF)





Efficiency vs purity ($\sigma = 50$ ps + new ToF)





Conclusions

• It looks like ToF PID doesn't improve much the PID for the muon selection wrt only using TPC --> we can't do much muon/pion separation anyway

• Shown very new plots produced by Mathieu

• A more robust study will be presented at the workshop in Tokai

• The same study will be done with the nue beam to check whether the positron/proton separation can be improved with ToF and which resolution is required

• We probably need a ToF around the target. Can we get the same timing with the target detector? For the time being assuming 600ps systematic error due to time synchronization

• Assuming there is no space between the old tracker and ECal for the ToF --> need to verify it once in Tokai!!!

• However this study should be quite general for tracks crossing ~1m

BACKUP