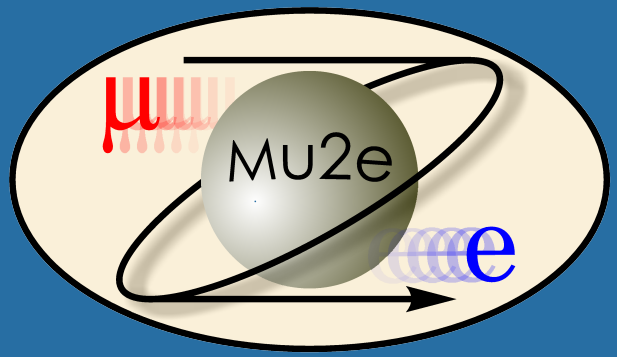

A Toy Monte Carlo to estimate the Radiative Muon Capture background for μ^--e^+ conversion

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Istituto Nazionale di Fisica Nucleare

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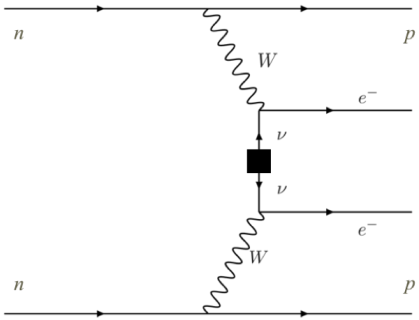
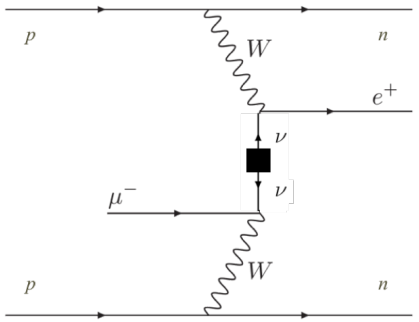
Lepton Number Violation

• As well as for CLFV, an observation of LNV will represent a clear sign of New Physics

• Processes with the change of Lepton Number by 2 ($\Delta L = 2$) have been mostly explored through the 0νββ decay, which correspond to an investigation on the *ee sector*.



0νββ decay



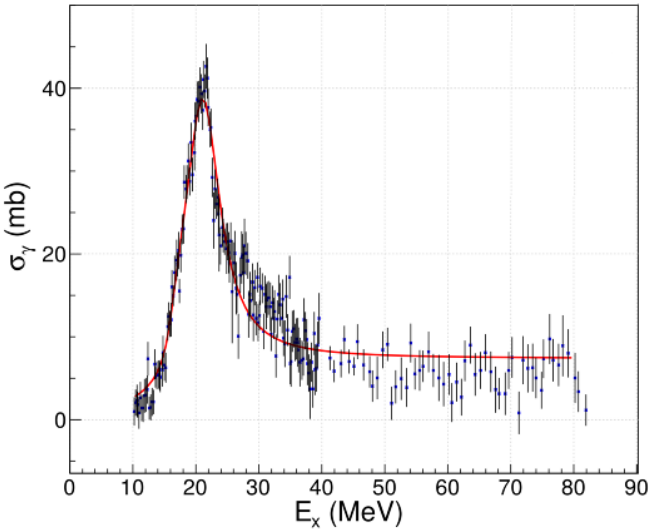
$\mu^- - e^+$ conversion

•Even if the sensitivity of 0νββ to LNV is prominent with respect to the one of muon conversion, flavour effect can strongly reduce the rate of 0νββ (diagonal sector) favouring processes occurring in off-diagonal sector, like the $\mu^- - e^+$ conversion.

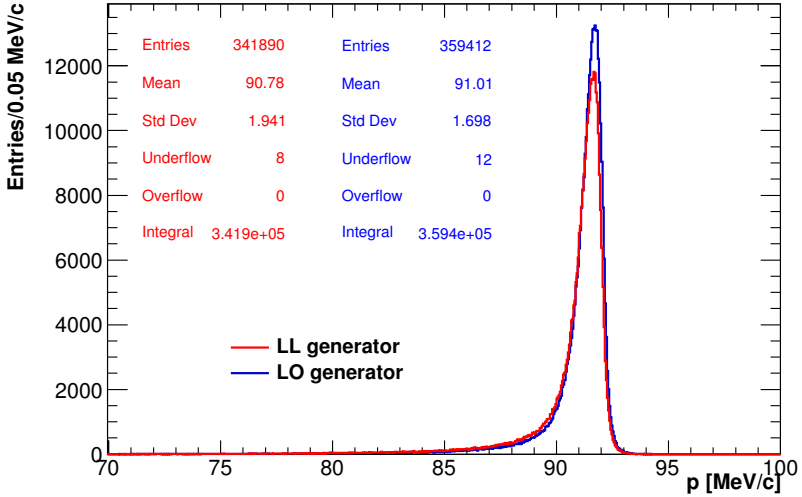
$\mu^- - e^+$ conversion

- Mu2e will search for the **$\mu^- + {}^{27}Al \rightarrow e^+ + {}^{27}Na$**
- Conversion can undergo through:
  - Giant Dipole Resonance: modelled with a Breit-Wigner distribution with 21.1 MeV mean and a width of 6.7 MeV→ Ee^+ = 83.9 MeV. Strongly suffer from RMC background
  - Ground State Transition: **Ee^+ = 92.32 MeV**

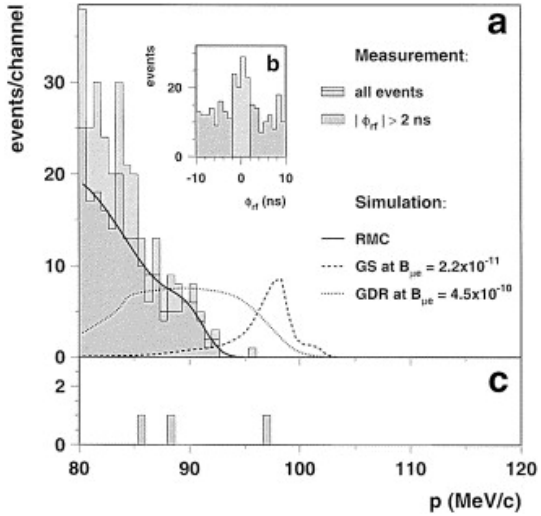
Giant Dipole Resonance



Ground State



Sindrum-II results



In the following we consider only the ground state transition.
We will look for signal requiring 1 e+ track only satisfying a set of Quality Track to reduce the high tails.

$$B^{GS}_{\mu^- e^+} < 1.7 \cdot 10^{-12} \quad (90\%\,CL)$$

$$B^{GDR}_{\mu^- e^+} < 3.6 \cdot 10^{-11} \quad (90\%\,CL)$$

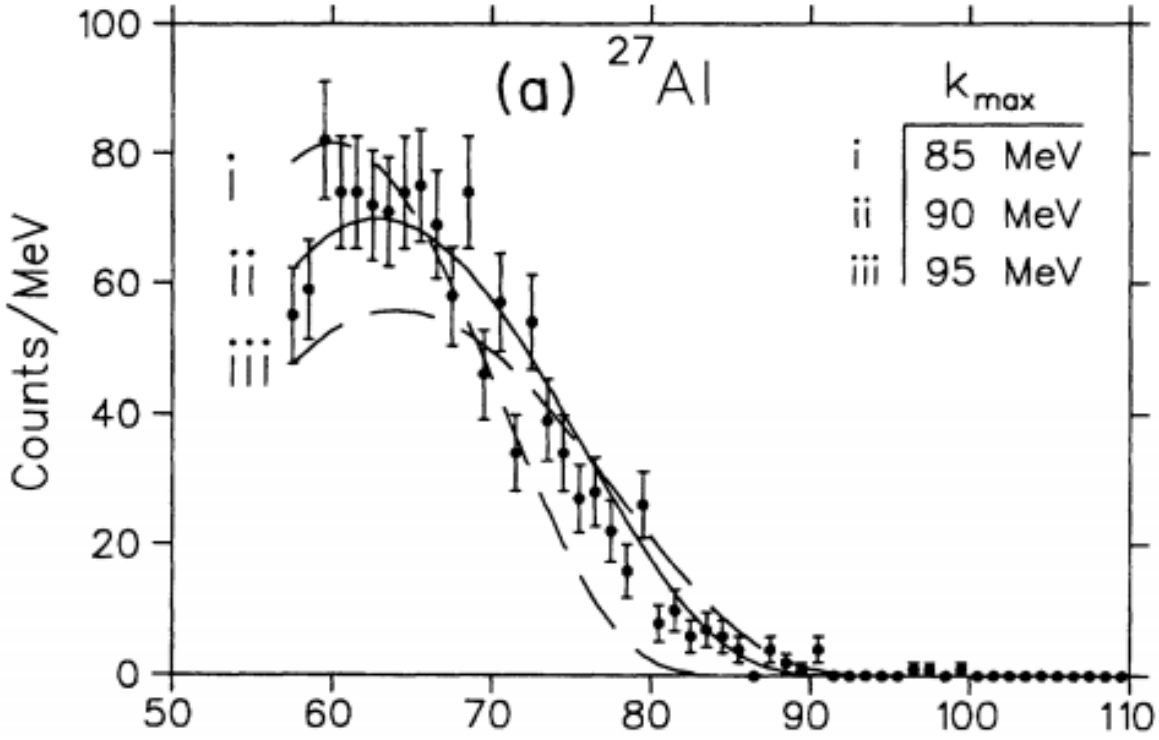
J. Kaulard et al., *Improved limit on the branching ratio of* $\mu^- \rightarrow e^+$ *conversion on titanium*. Phys. Lett. B 422, 334 (1998).

Background

- Prominent background:
  - **Radiative Muon Capture:** detailed description in this presentation
  - **Cosmic Rays :** they should be smaller than 0.4 events as in the case of CE since the e^+,e^- observed in CR generated sample is similar. A large production of CR is under way.
  - **Antiprotons:** when not decaying in the TS they can interact in ST and produce delayed secondaries.
  - **Radiative Pion Capture**: Pions that survive to arrive at the aluminum stopping target during the delayed live gate can potentially give rise to a large background from the $\boldsymbol{\pi^- + Al \rightarrow \gamma^{(*)} + X}$ process. Only the one produced late could represent a real background

Radiative Muon Capture

- From previous considerations, we expect that the prominent background for the $\mu^- - e^+$ search will be positron produced in the $\mu^- + {}^{27}Al \rightarrow \gamma + \nu_\mu + {}^{27}Mg$
- The photon in the final state can convert internally or externally, potentially yielding a positron with an energy consistent with that of a conversion positron.
- Last reported measures from TRIUMF experiment on Al stated an endpoint of the E_γ distribution at **k_{max} ~ 90 MeV** depending on the years of the publication



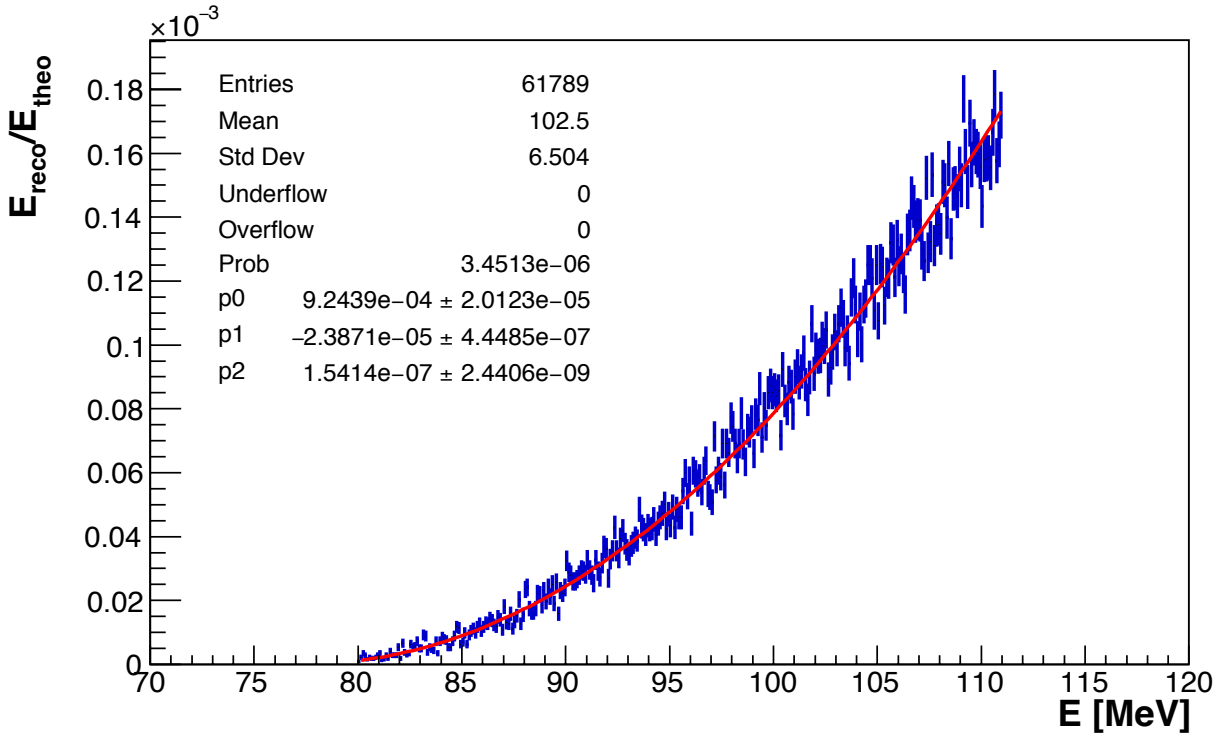
TOY MC: Procedure

- Since the production of photons with the right RMC spectrum and the tracker acceptance are small numbers, a full simulation of this background will take months. We therefore evaluated the number of background expected at the end of the analysis cut with a Toy MC based on:
  - A fast parametrisation of the tracker acceptance as a function of E_γ
  - An application of the RMC spectrum
  - an e^+ momentum extraction from a 2D plot between P_{e+} -E_γ
  - a convolution with two different curve of momentum resolution

In the following 3 different k_{max} will be investigated.
k_{max} = 90.1 MeV, 91.6 MeV (σ= 0.5 MeV), 91.9 MeV (σ= 1.8 MeV)
These value have been selected following the results of the TRIUMF experiment and Mu2e collaboration calculation supposing a σ =0.5 MeV on k_{max}

Obtaining the Fitting function

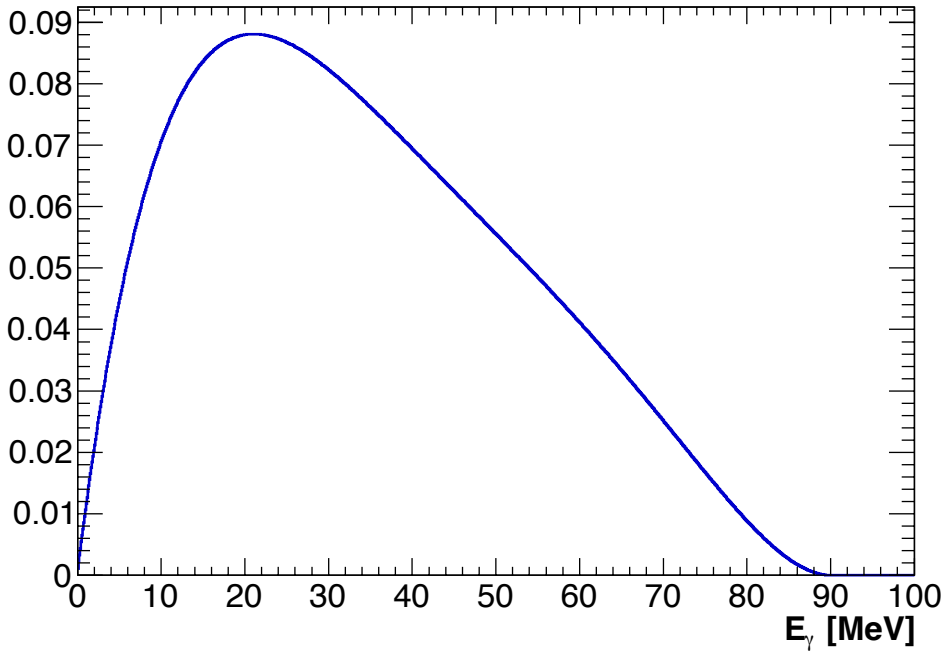
- Even if the photons are generated flat from 80-111 MeV.
- For each photon in the flat gamma spectrum, we saved only the events that have particles detected in the trackerKnowing the total number of generated photon and the reconstructed one, the tracker acceptance can be evaluated in each bin as: $\alpha_i = \frac{E_i^{reco}}{E_i^{theo}}$



Consider only RMC

- The RMC can be modelled using the Closure approximation:

$$\frac{d\Lambda_\gamma\left(E_\gamma\right)}{dE_\gamma} = N\left(1-2x+2x^2\right)x(1-x)^2 \qquad x = \frac{E_\gamma}{k_{max}}$$



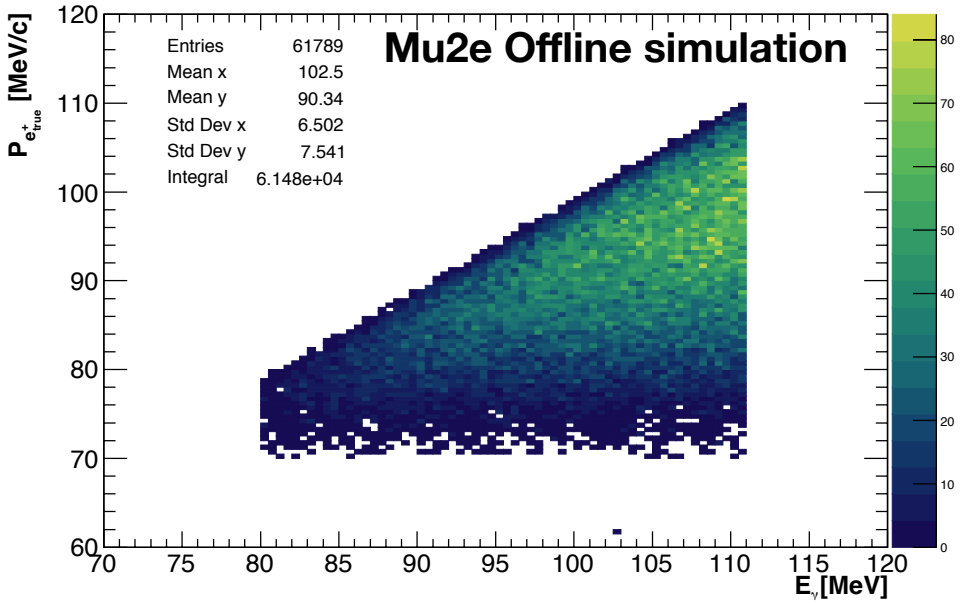
- Each Toy MC photon energy is weighted following the Closure Approximation to account only for the RMC process

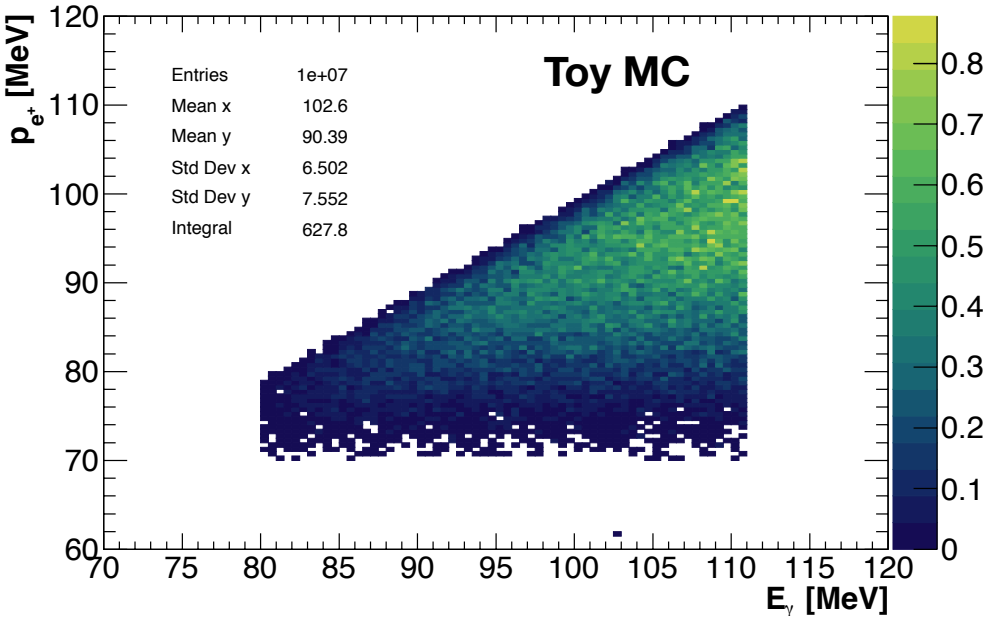
Obtaining the fitting function

- From the Official Simulation the 2D histogram p_{true} vs E_γ is divided is 0.1 MeV slices and the projection on the p_{true} axis is saved.

- Extract from a flat distribution and apply the acceptance correction and then extract from the relative ptrue slice a momentum

- Good agreement shown:
  - Offline: 9.8 x 10^8 events simulated correspond to 6.148 x 10^4 reconstructed events —> 627.34 expected reconstructed events considering 10^7 events
  - MC toy: 627.8 event produced





E_γ distribution

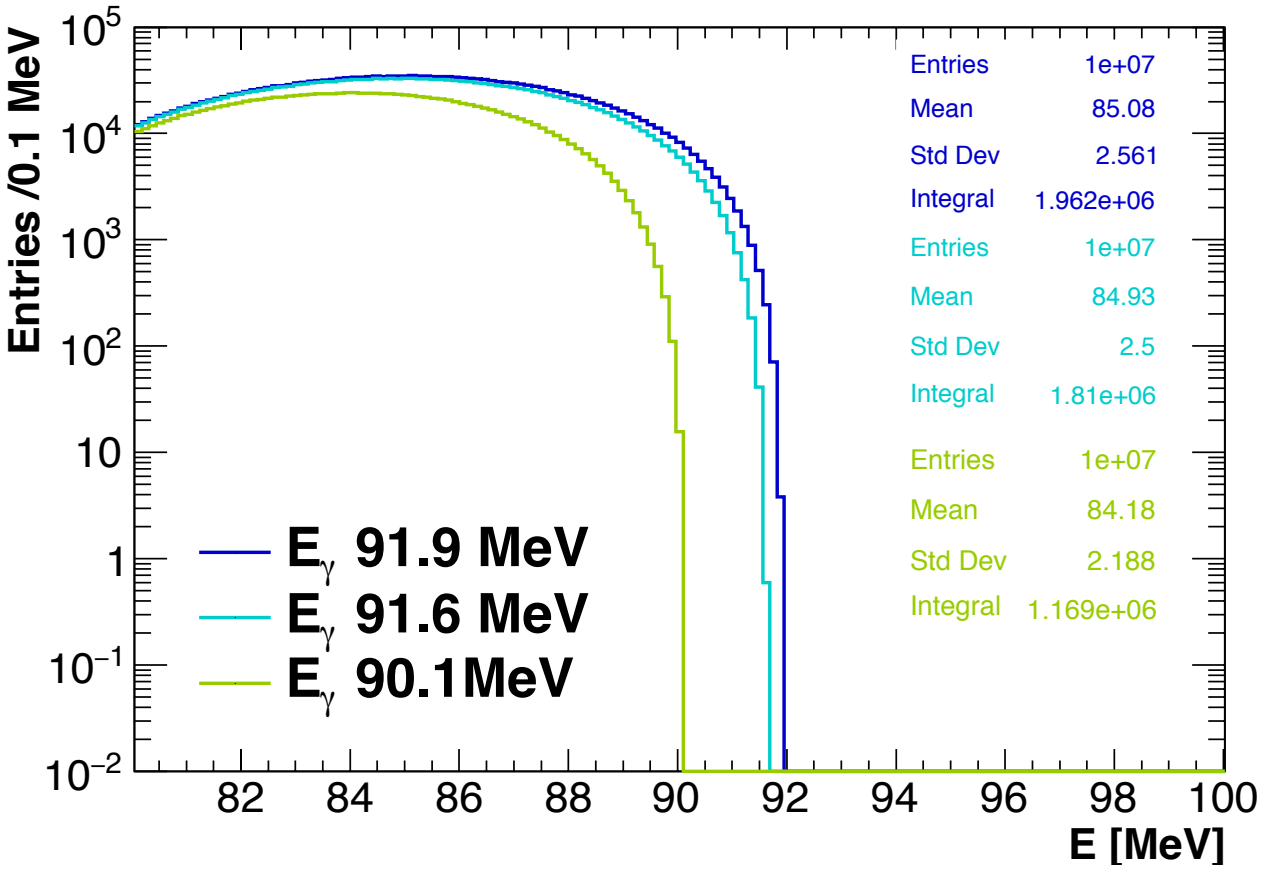
- It is necessary to scale to entire Mu2e Life time using :

$$SF = N_{pot} \times \mathscr{P}_{stop} \times P_{\mu capt} \times \mathscr{P}_{clos} \times \frac{\mathscr{R}(E > 80)}{\mathscr{R}(E > 57)}$$

$$\frac{\mathscr{R}(E > 80)}{\mathscr{R}(E > 57)} = \frac{\int_{E>80} (1 - 2x + 2x^2)x(1-x)^2 dx}{\int_{E>57} (1 - 2x + 2x^2)x(1-x)^2 dx}$$

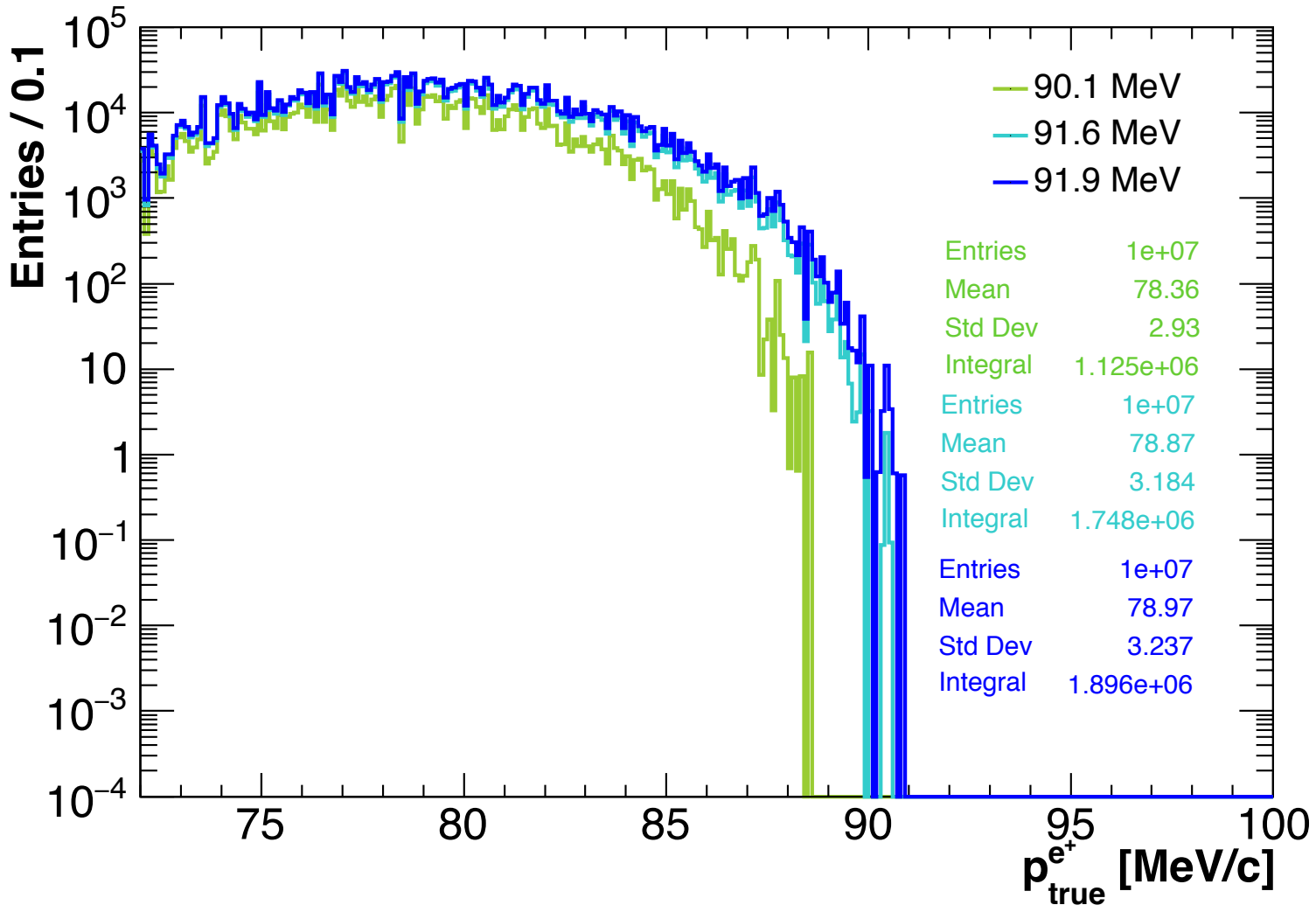
$N_{POT} = 3.6 \times 10^{20}$
$P_{stop}=0.015$
$P_{\mu capt} = 0.61$
$P_{clos} = 1.43 \times 10^{-5}$

- As a control we produce the Eg spectrum scaled for acceptance in the tracker and RMC weights



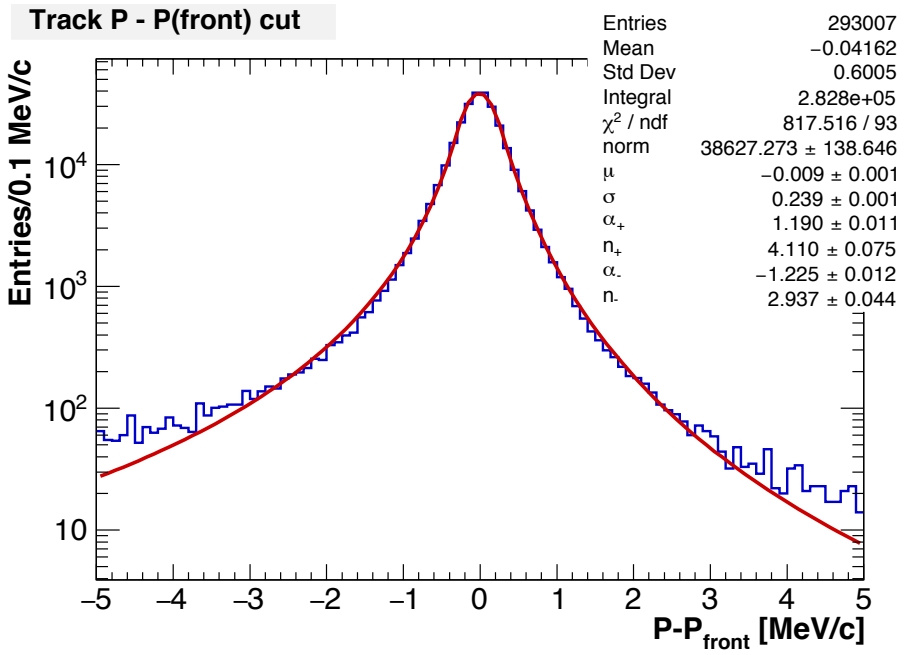
e^+ momentum extraction

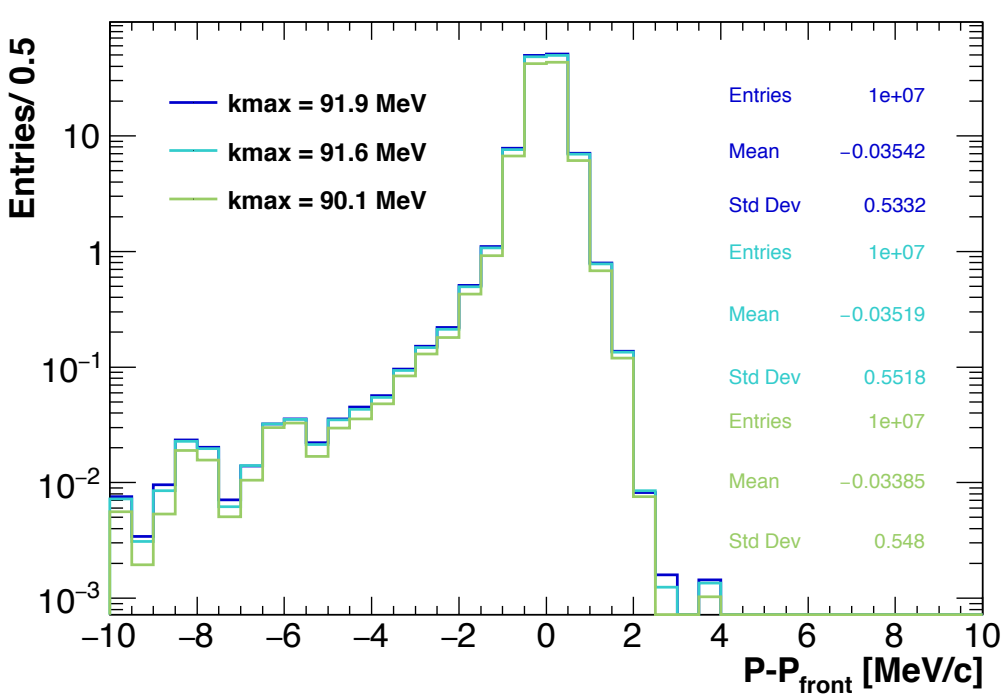
- The positron momentum is directly extracted from the 2D plot be per each photon energy already scaled



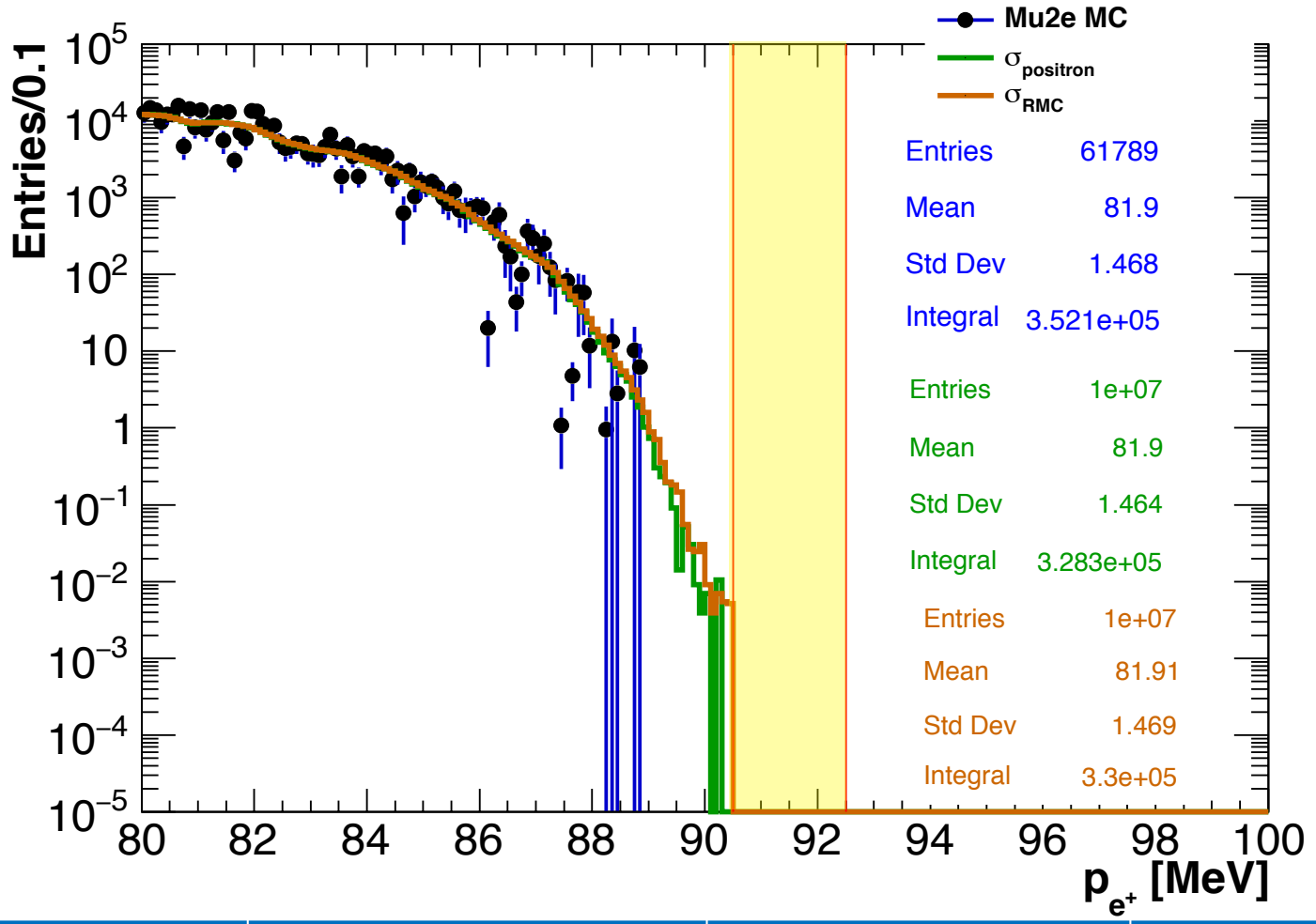
Add the resolution effect

- Add the tracking resolution effect following two different strategies:
  - extract the resolution from the Conversion positron dataset
  - extract the resolution from the RMC dataset



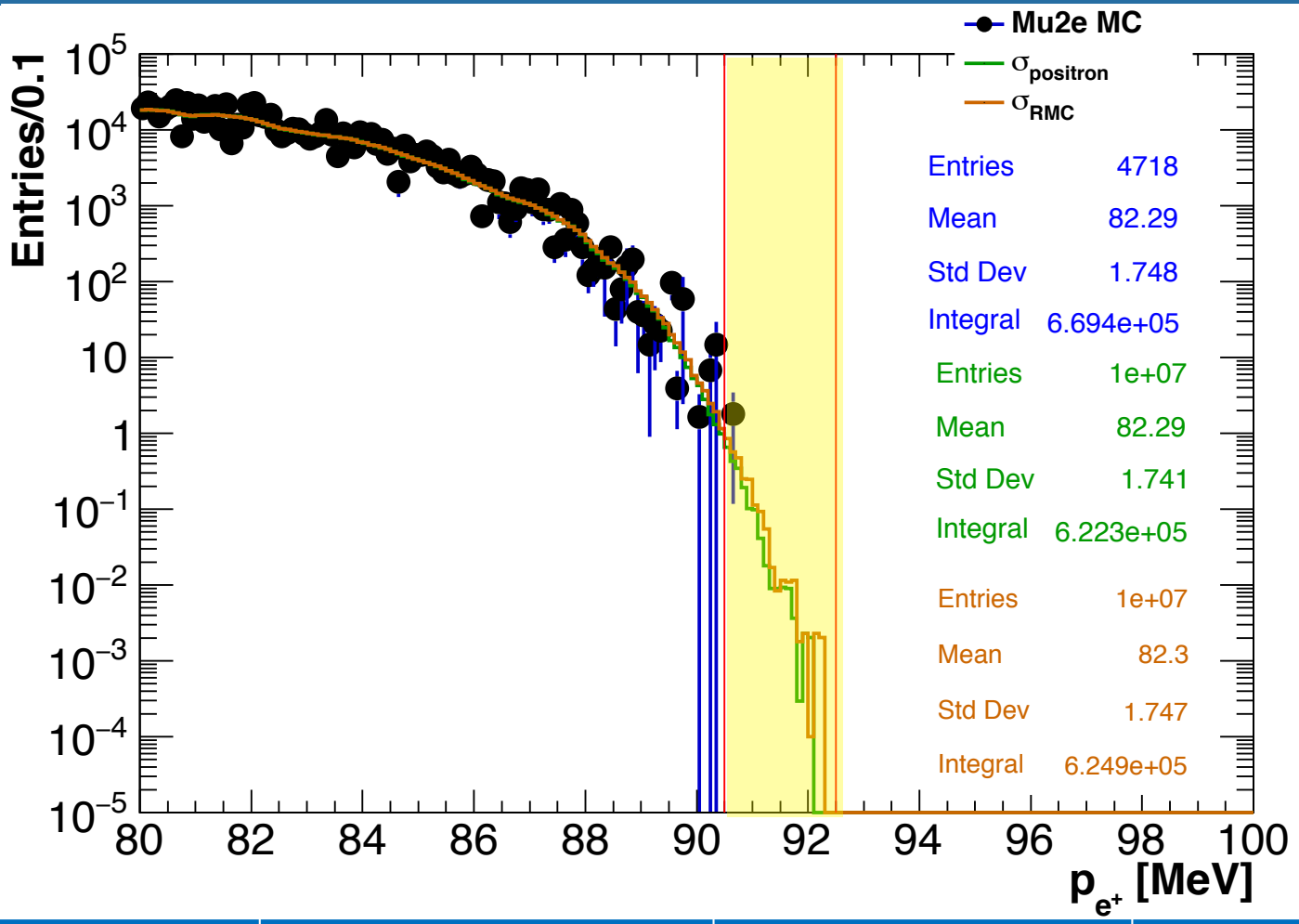


Momentum distribution (k_{max} = 90.1 MeV)



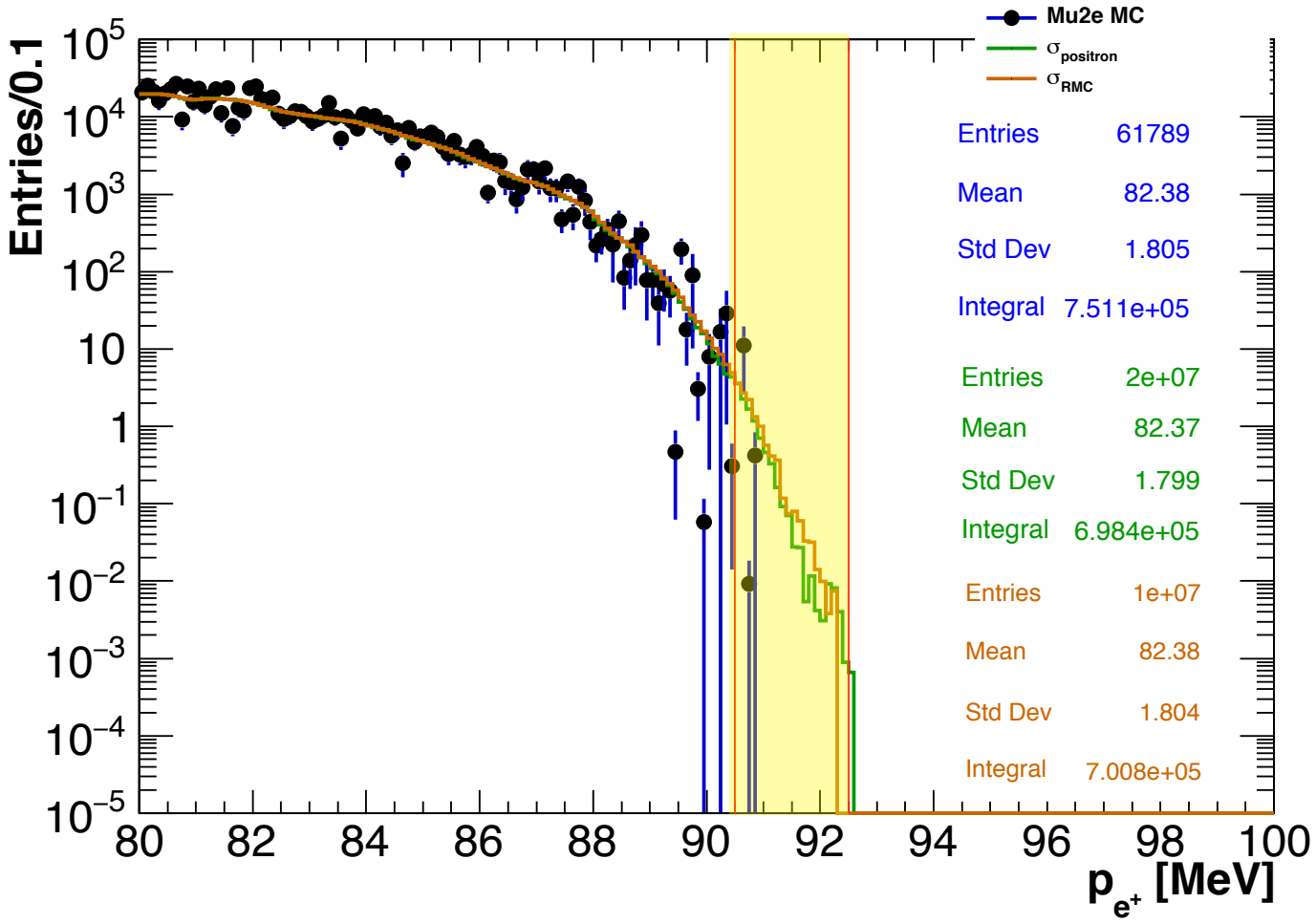
Simulation type	Integral(72,kmax)	Integral (80,88)	Integral
Mu2e MC	1.281 x 10^6	3.521 x 10^5	0
Toy (Ceplus reso)	1.124 x 10^6	3.281 x 10^5	0
Toy (RMC reso)	1.125 x 10^6	3.299 x 10^5	0

Momentum distribution (kmax = 91.6 MeV)



Simulation type	Integral(72,kmax)	Integral (80,88)	Integral
Mu2e MC	1.963x 10^6	6.677x 10^5	1.801±1.27
Toy (Ceplus reso)	1.747x 10^6	6.203x 10^5	1.926
Toy (RMC reso)	1.747x 10^6	6.227x 10^5	2.728

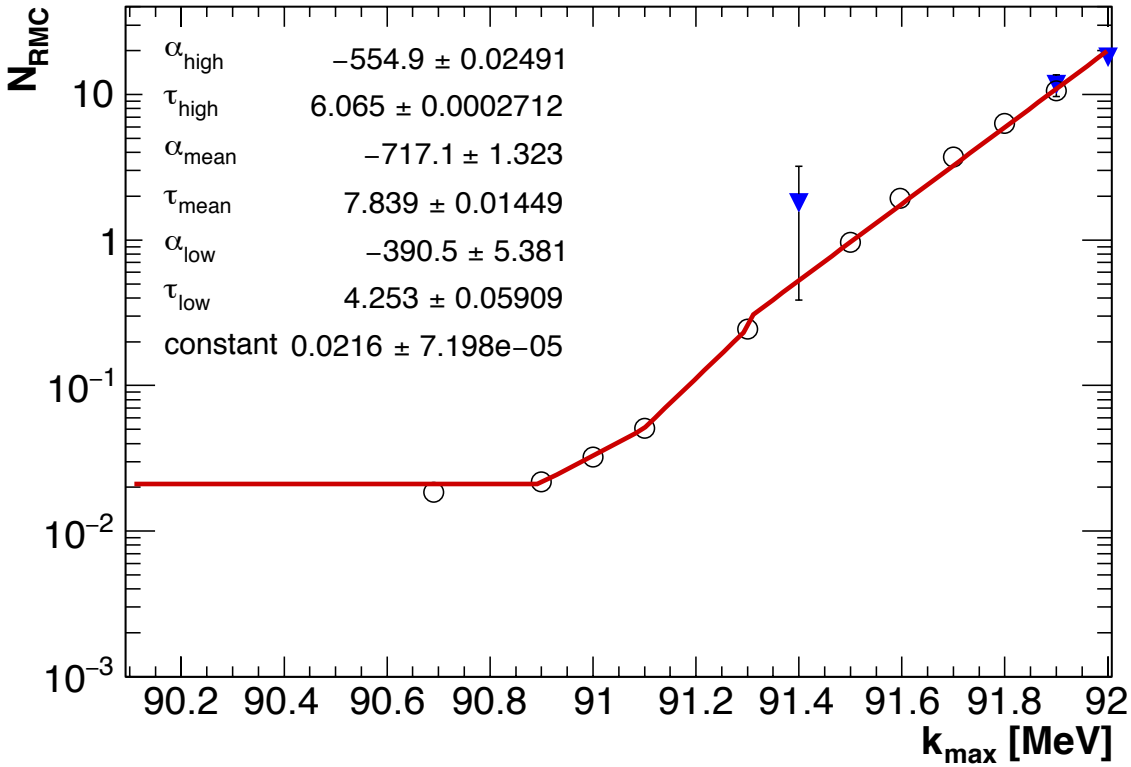
Momentum distribution (kmax = 91.9 MeV)



Simulation type	Integral(72,kmax)	Integral (80,88)	Integral
Mu2e MC	2.123x 10^6	7.481x 10^5	11.66±5.83
Toy (Ceplus reso)	1.895x 10^6	6.951x 10^5	10.568
Toy (RMC reso)	1.894 x 10^6	6.973x 10^5	12.608

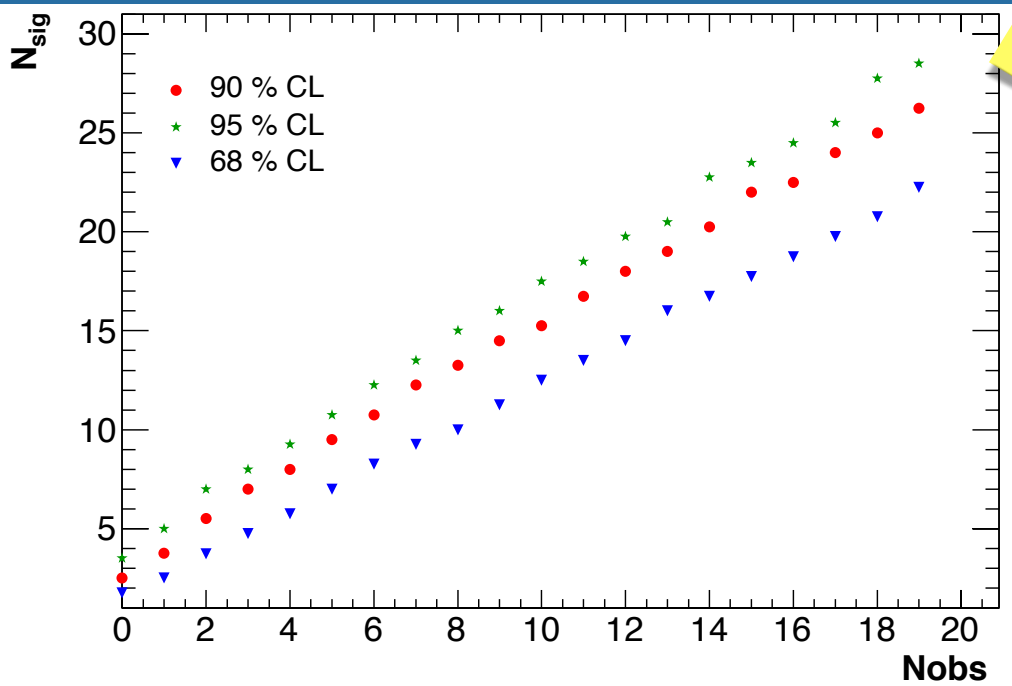
Towards the upper limits…

- Varying the k_{max} of the RMC spectrum in a 2 MeV range correspond to a variation of ~10 backgrounds events



- Uniformly extract the background from the function fitting the data
- Uniformly extract the signal between 0-40

Upper limit



Results obtained using the CLs technique

- The sensitivity can be obtained assuming (Ne+ = 8.26 x 10^{15})
  - N_{POT} = 3.6 x10^{20};
  - Acceptance loss 10%
  - Reconstruction reduction 17%
- $$\mathscr{R}_{\mu e^+} = \frac{N_{sig}}{N_{e^+} \cdot \mathscr{A} \cdot \epsilon}$$
- If No event will be observed: $\mathscr{R}_{\mu e^+} \leq 3 \times 10^{-16}$ @ 90% CL

Conclusion

- First attempt to evaluate the Mu2e sensitivity to the $\mu^- - e^+$ conversion almost completed
- $\mathscr{R}_{\mu e^+} \leq 3 \times 10^{-16}$ @ 90% CL obtained
- Repeat the sensitivity evaluation changing the background modelling (gaussian around 90.1 MeV with σ= 0.5 MeV and σ=1.8 MeV)