Rare muon decays

Robert Szafron*

UNIVERSITY OF ALBERTA

Matter To The Deepest
Ustroń

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*Email: szafron@ualberta.ca
Dept of Physics, University of Alberta, Edmonton, Alberta, Canada.

Outline

Motivation

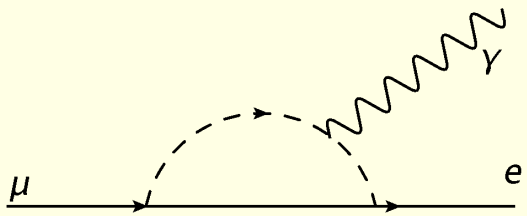
$\mu \to e\gamma$

$\mu - e$ conversion

Outlook and conclusions

Search for charged lepton flavour violation

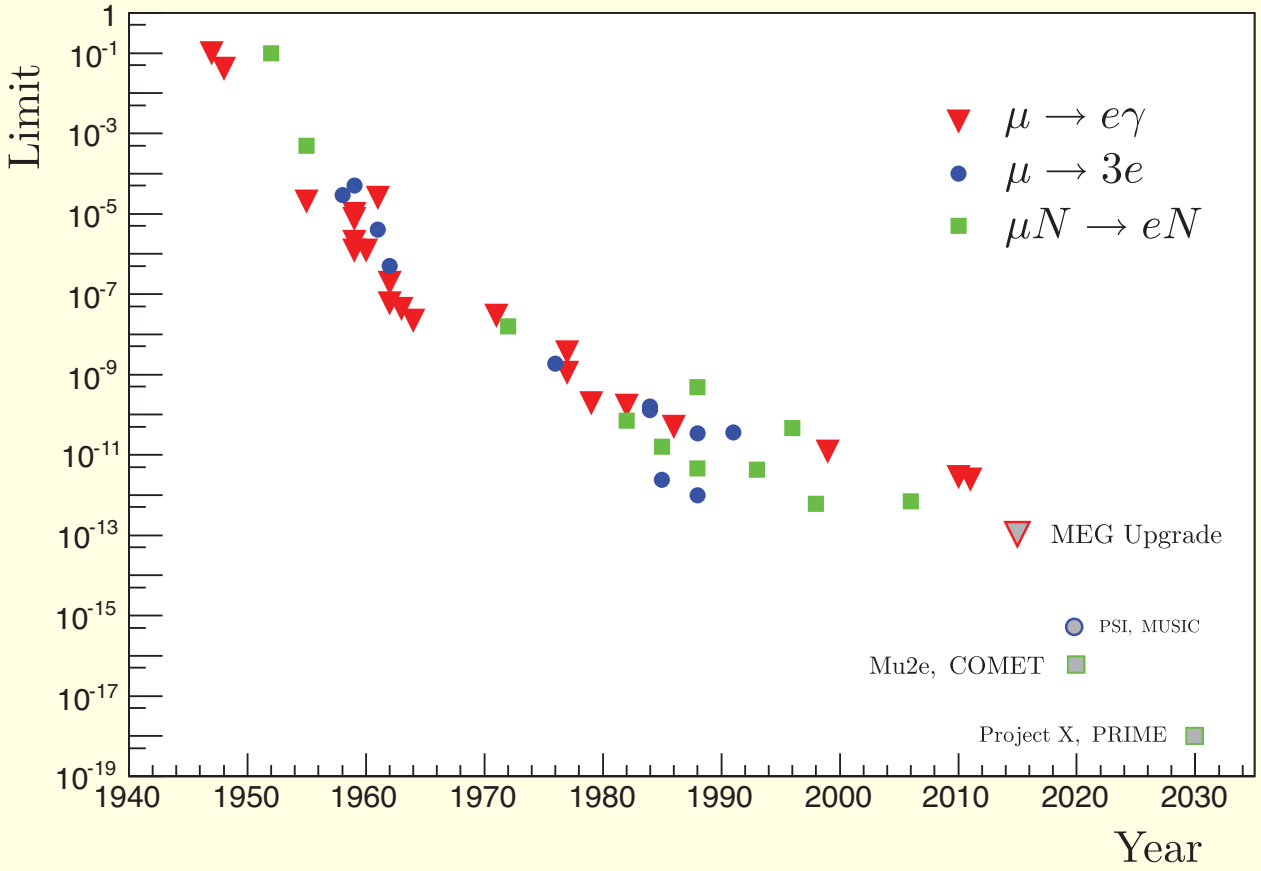
- many New Physics models predicts lepton flavour violation process to occur with much higher probability than SM



- SM branching ratios are unobservable
  Typically SM (BR$< 10^{-40}$), SUSY (BR$\sim 10^{-11} - 10^{-15}$)
- In many models there is a relation between LFV and dipole moments.
- Any signal observed may help to understand flavour structure of SM

- Flavour transitions in neutral sector is observed
- Ongoing effort in measuring possible Charged Lepton Flavour Violation (CLFV)

History of $\mu \to e\gamma$, $\mu N \to eN$, and $\mu \to 3e$



[R. Bernstein, P. Cooper arXiv:1307.5787]

MEG experiment at Paul Scherrer Institute is looking for $\mu \to e\gamma$

Upgrade in progress (Construction 2015, Data taking 2016 - 2018)

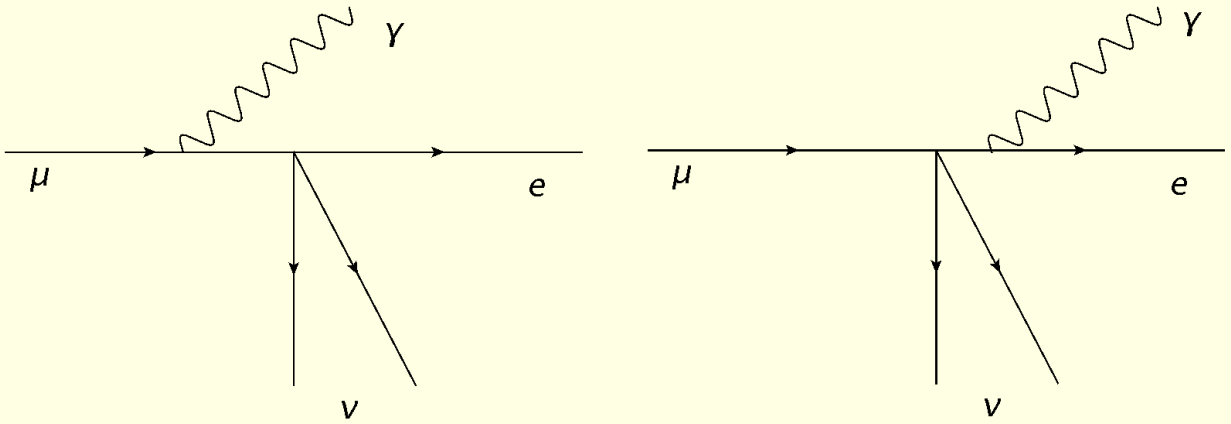
- present limit 5.7×10^{-13} [MEG Collaboration, Phys. Rev. Lett. 110, 201801 (2013)]
- expected limit 6×10^{-14}

Signal and background:

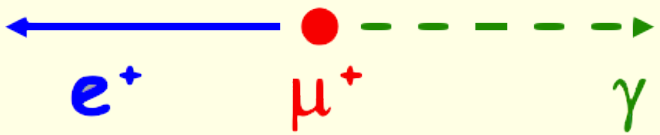
- Signal – two body decay: back to back monoenergetic $e\gamma$,

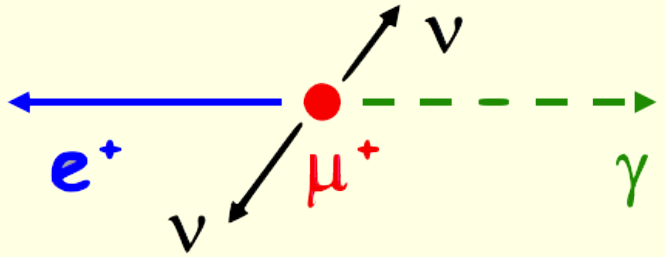
$$E_e = E_\gamma = \frac{m_\mu}{2}$$

- Background
  - Accidental background - dominant, determined by detector resolution
  - Radiative muon decay (RMD)

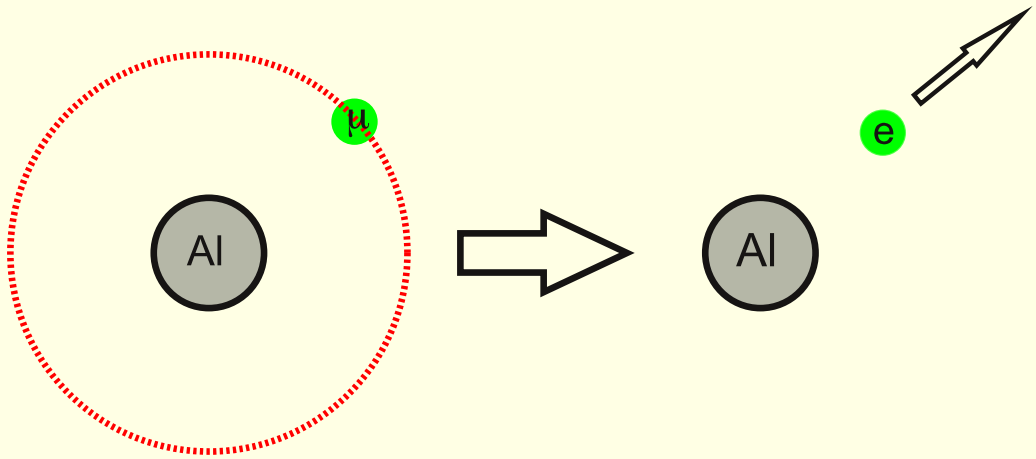


Ongoing work – improvment in evaluation of the background – electron and photon distribution in RMD with A. Czarnecki, Y. Liang, K. Melnikov

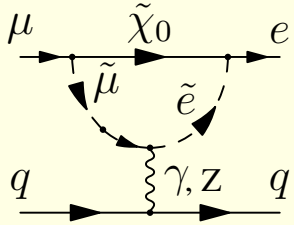


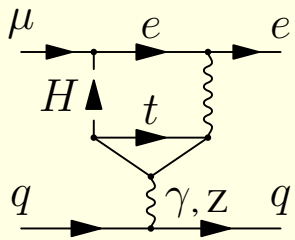


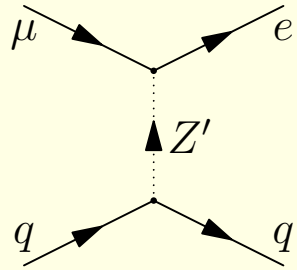
$\mu - e$ conversion



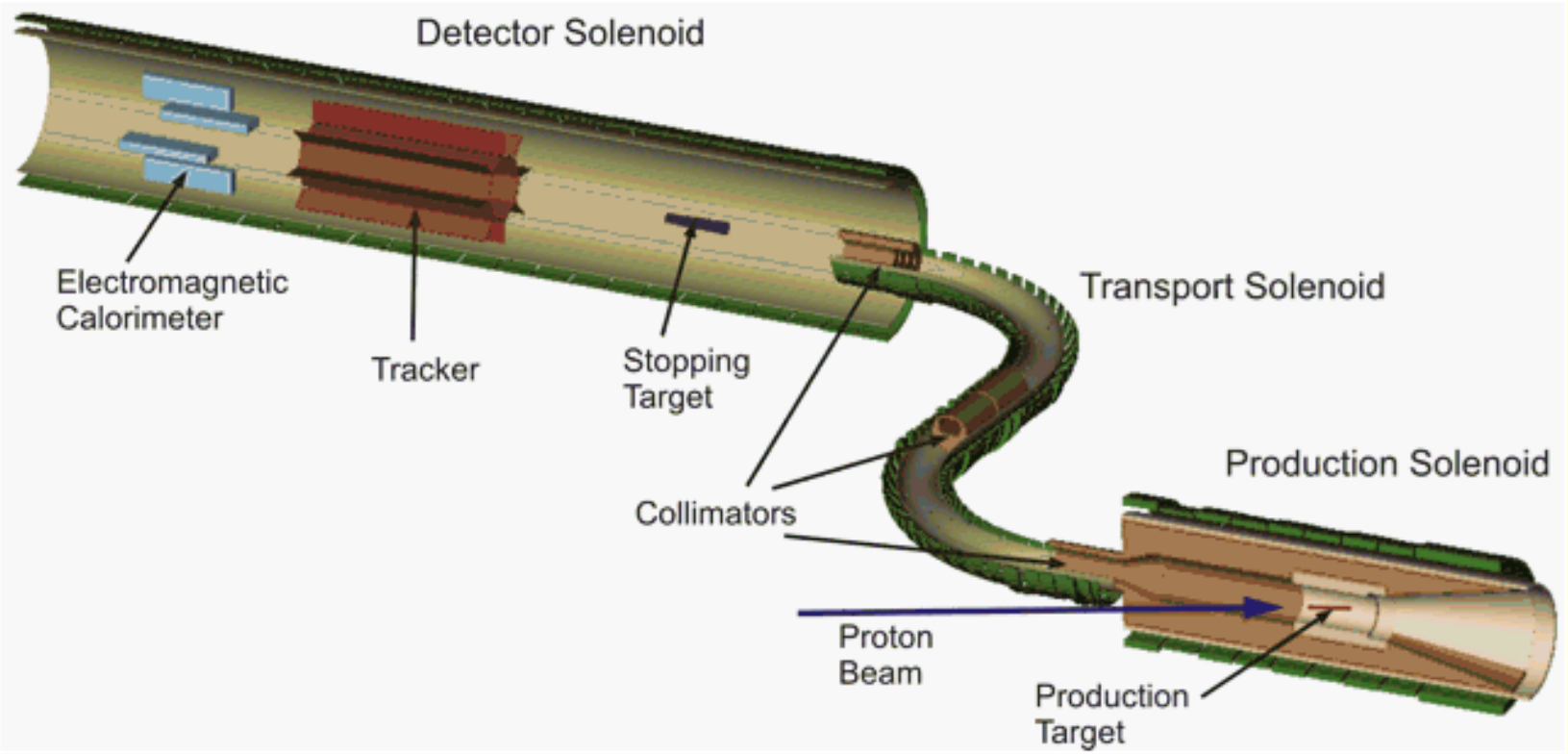
This process can occur in many models: SUSY, 2HDM, Z', ...
Contributions can be both photonic and non-photonic.







Experiment **Mu2e** at Fermilab: Construction may begin in 2015, commissioning in 2019 and initial preliminary results may be ready about 2020.



Experiment measures rate of coherent muon to electron conversion on nucleus normalized to all nuclear captures

$$R_{\mu e} = \frac{\Gamma[\mu+(A,Z)\to e+(A,Z)]}{\Gamma[\mu+(A,Z)\to \nu_\mu+(A,Z-1)]}$$

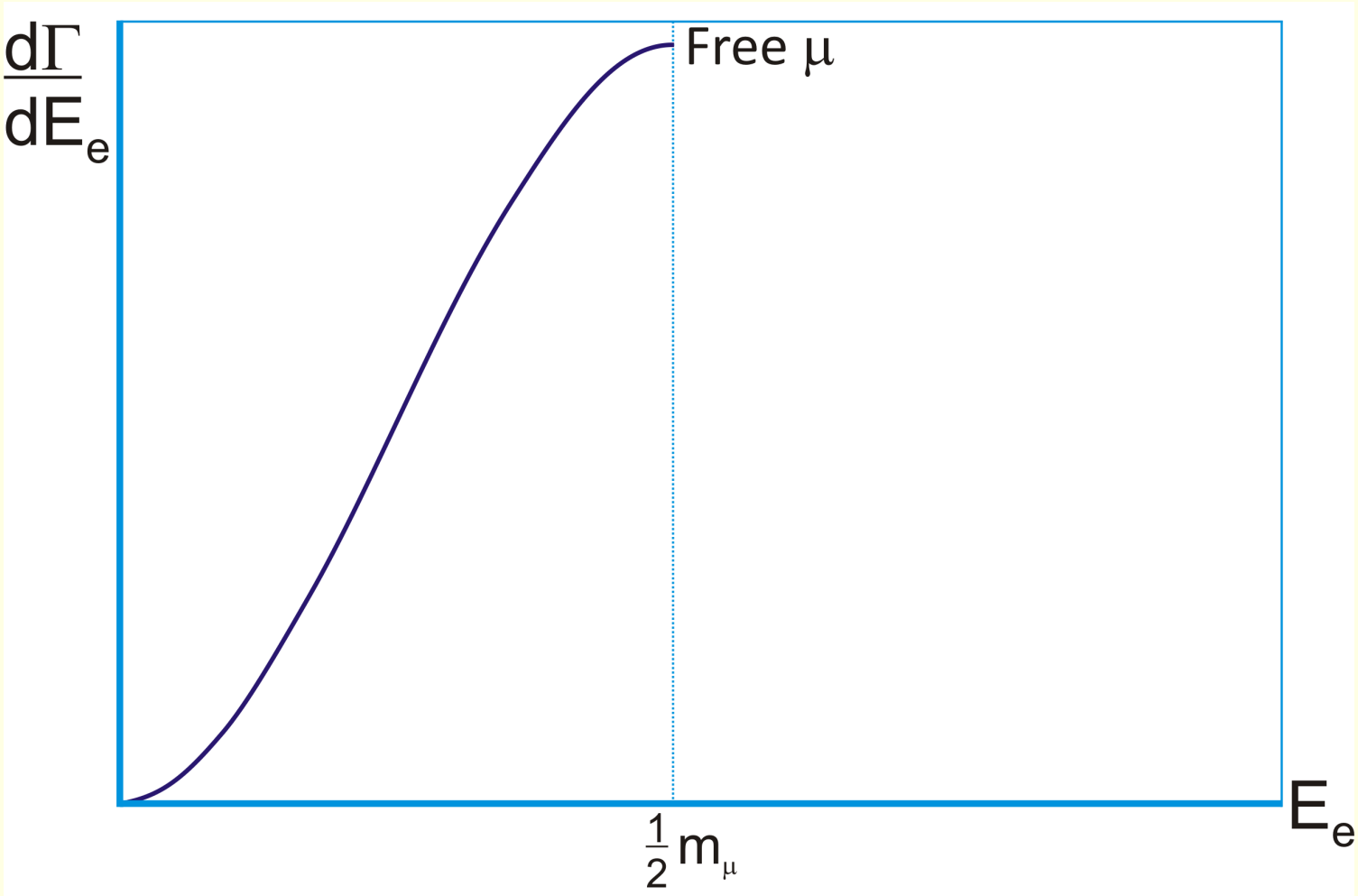
Present limit: $R_{\mu e} < 7 \cdot 10^{-13}$

Expected sensitivity $R_{\mu e} \sim 10^{-17}$

$\Downarrow$

This study are complementary to the LHC and can probe New Physics scale up to **10,000** TeV
If New Physics is found CLFV can help discriminate models

Signal and background



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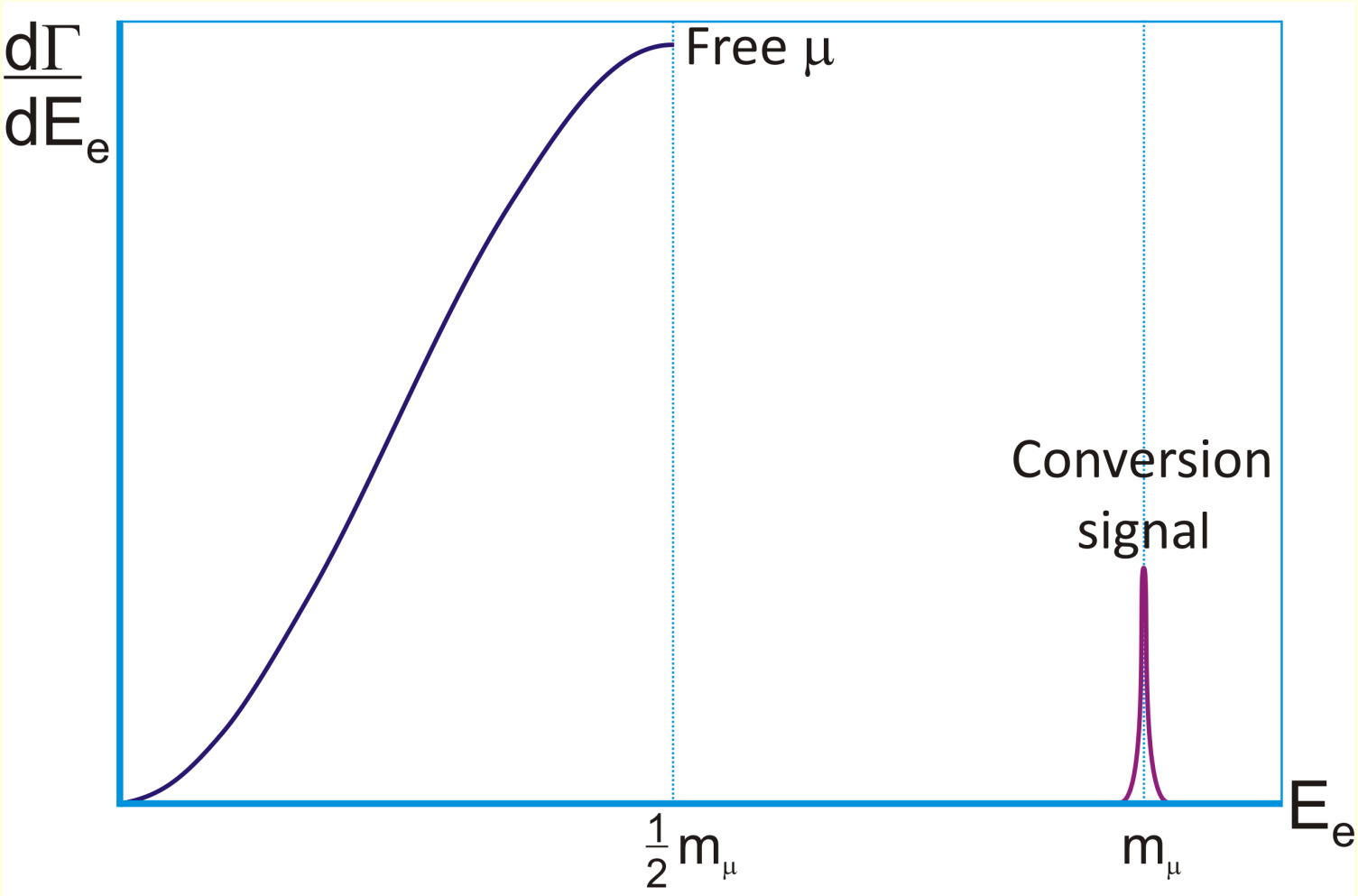

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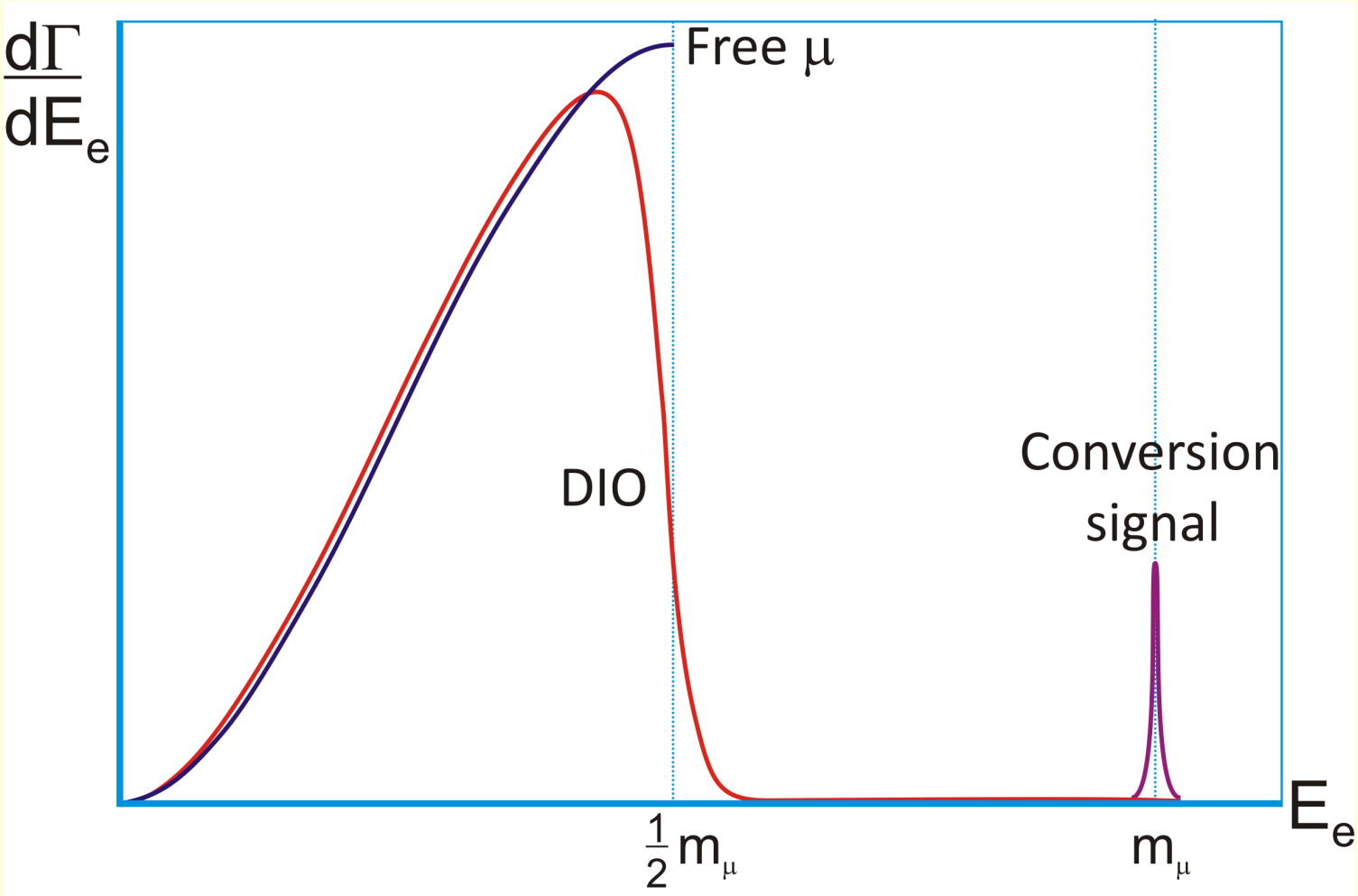
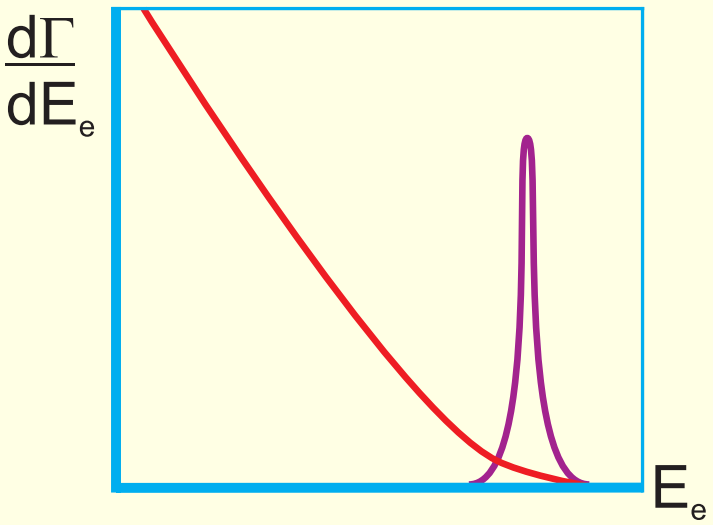


Experimental signature – monoenergetic electron

$$E_{conv} = m_\mu - E_{bin} - E_{rec}$$

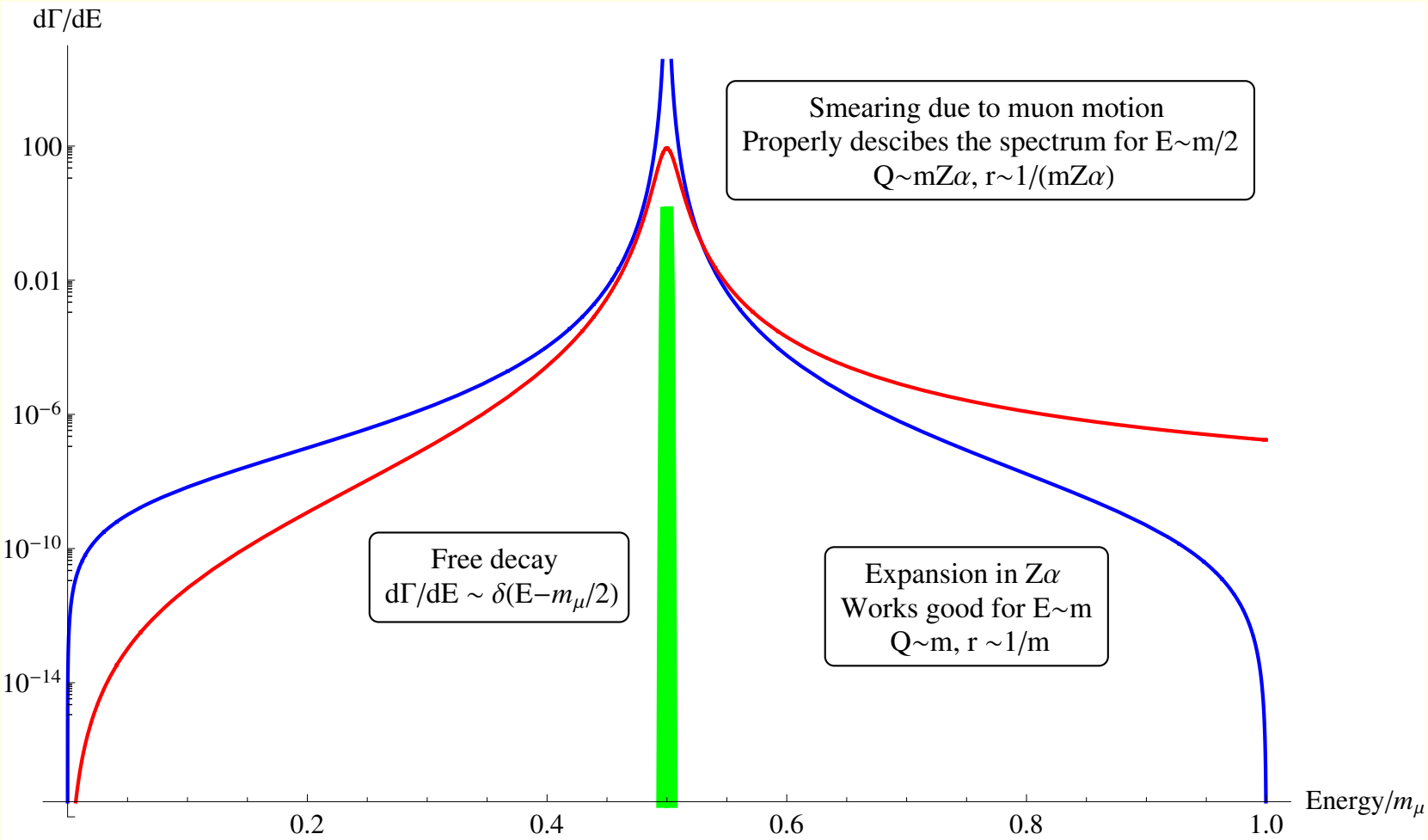
Background – muon decay in orbit (DIO), tail of the spectrum



Most recent evaluation:
A. Czarnecki X. Garcia i Tormo, W. Marciano (2011)

- numerical solution of Dirac equation
- includes recoil and finite nucleus size effects
- no radiative corrections

Toy example: $\mu \to eJ$



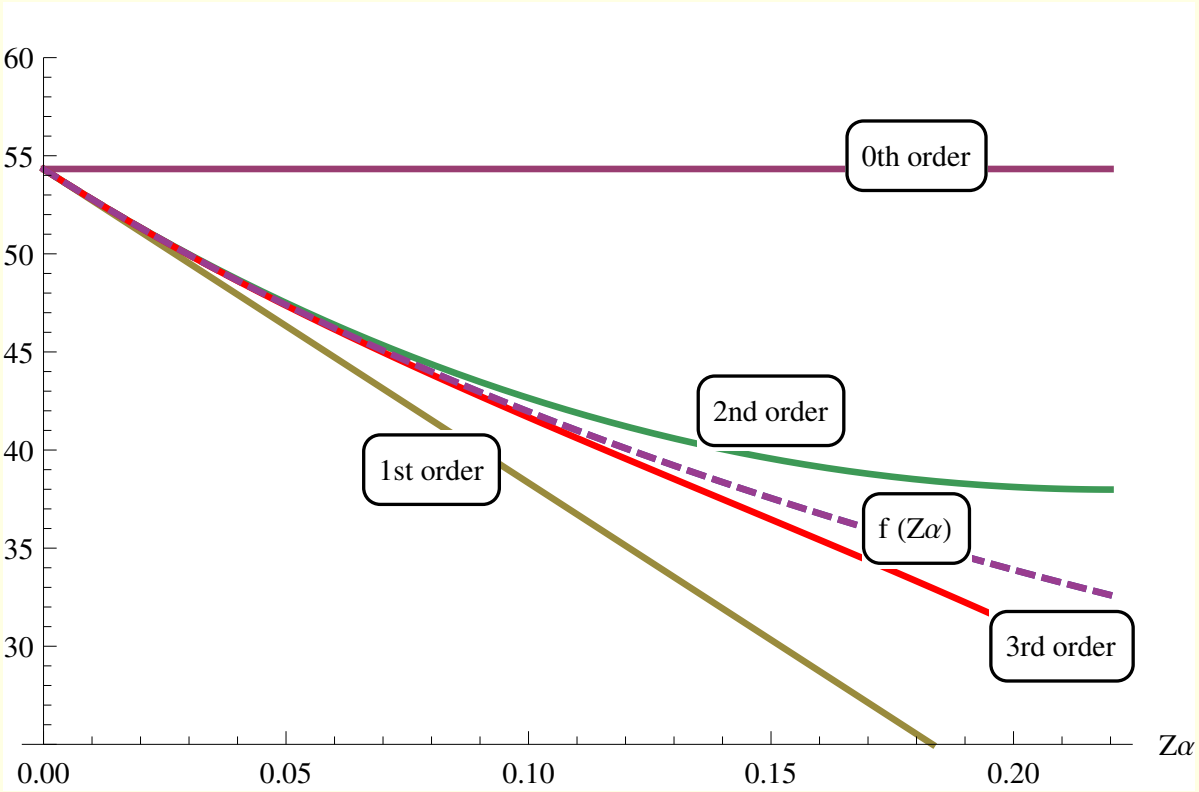
Muon wave function $\psi(q) \sim \frac{1}{(q^2+(m_\mu Z\alpha)^2)^2}$

Expansion close to $E_e \sim m_\mu$.

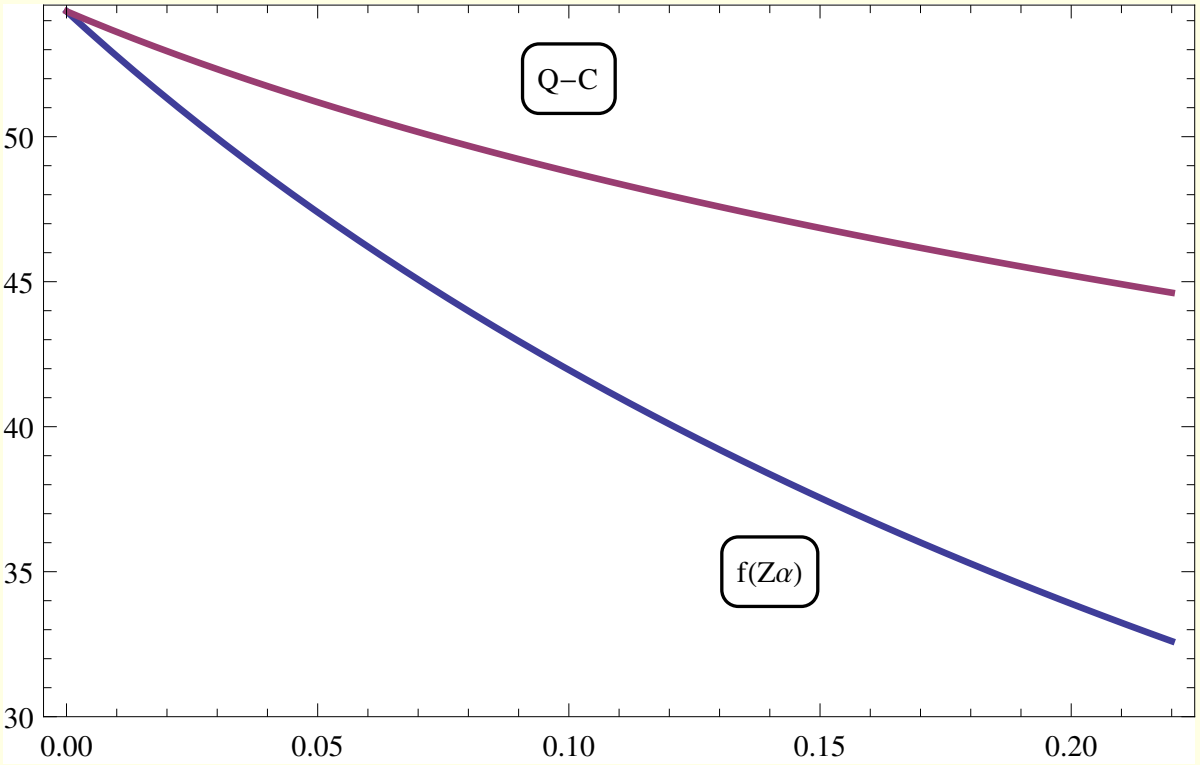
$$\frac{m_\mu}{\Gamma_0}\frac{d\Gamma}{dE_e} \approx (Z\alpha)^5 (E_e - E_{max})^3 f(Z\alpha)$$

Function $f(Z\alpha)$ can be expanded but corrections are large

$$f(Z\alpha) \approx \frac{512}{3\pi} - 160\, Z\alpha + \frac{6064 + 473\pi^2 - 2944\log(2) - 1536\log(Z\alpha)}{9\pi}(Z\alpha)^2$$



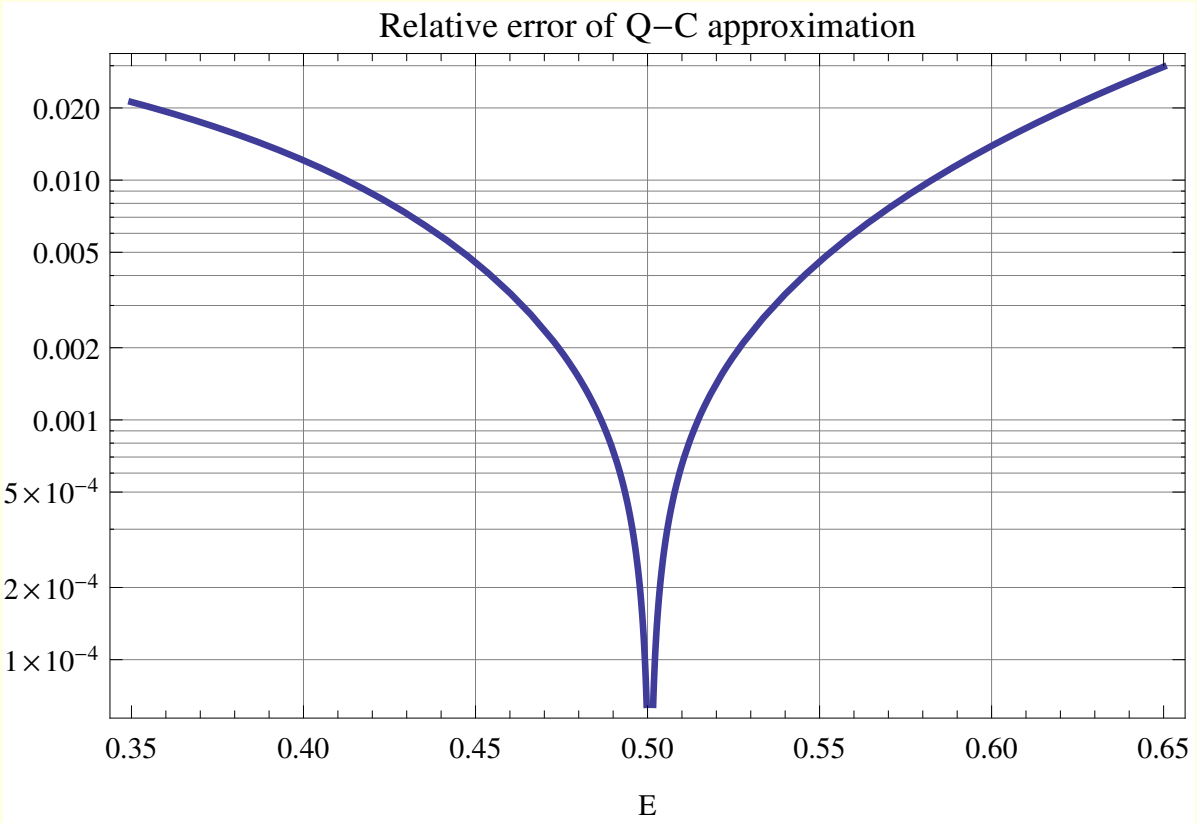
Quasi-Classical approximation



Error $\sim \frac{(Z\alpha)^2}{l^2}$ but region $E_e \sim m_\mu$ dominated by low l.

$$l = r \times p \sim \frac{1}{m} m \sim 1$$

Quasi-Classical approximation



Works better for $E_e \sim \frac{m_\mu}{2}$, region dominated by high values of l.

$$l = r \times p \sim \frac{1}{mZ\alpha}\frac{m}{2} \sim \frac{1}{Z\alpha}$$

Outlook and conclusions

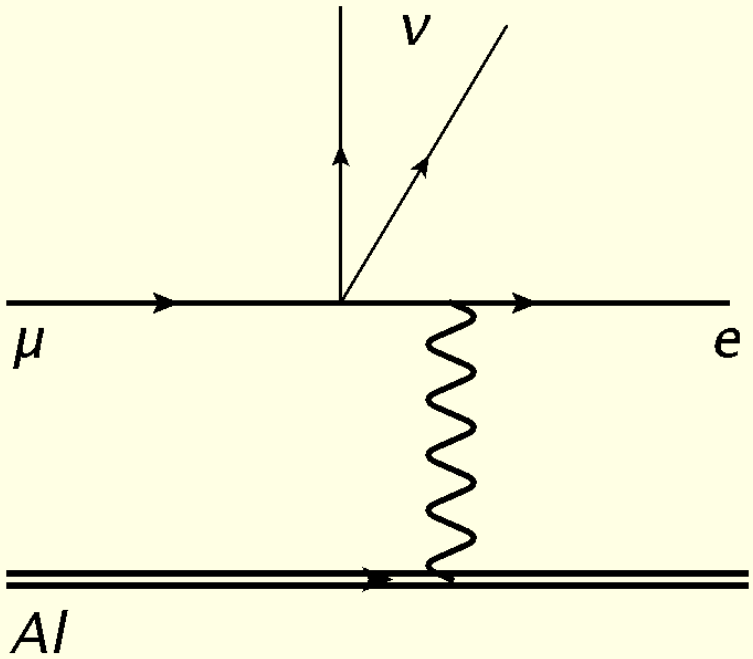
- Exciting time for discoveries at the intensity frontier
- Proper understanding of the background is crucial for obtaining expected accuracy of new experiments
- pQCD methods are used to improve background evaluation (shape function, fragmentation function, etc.)
- For Mu2e we need a theory that allows us to take into account
  - interaction of both muon and electron with the field of nucleus
  - finite size of nucleus
  - recoil effects
  - radiative corrections

Next step: Radiative corrections

- vacuum polarization in the hard photon
- self energy correction
- real radiation

Final goal:

- Smooth matching of the electron spectrum in all energy regions
- Effective field theory description



Thank You!