PAUL SCHERRER INSTITUT PSI Universität Zürich[UZH]

LTP seminar

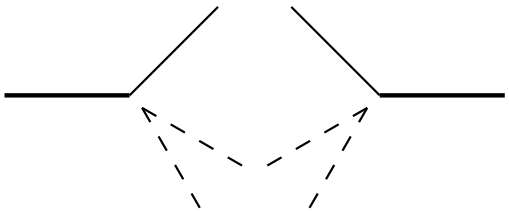
Higher order corrections for muons

Yannick Ulrich

Paul Scherrer Institut / Universität Zürich

20TH MAY 2019

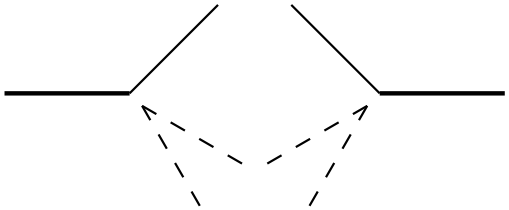
higher order corrections...



'tree level'

α^0
(LO)

higher order corrections...



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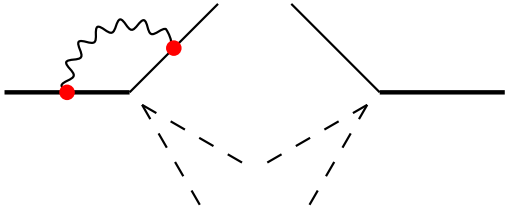
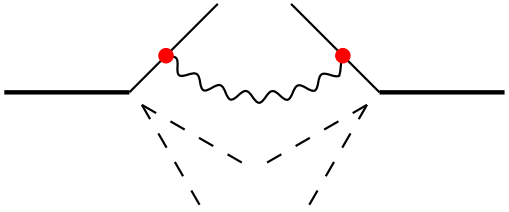


'virtual one-loop'



'real correction'

α^1
(NLO)

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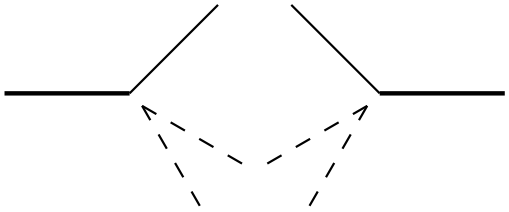

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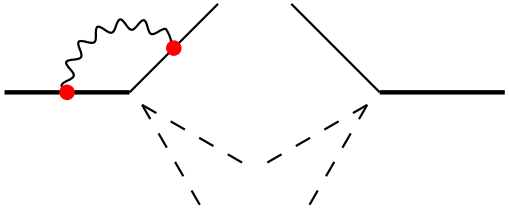

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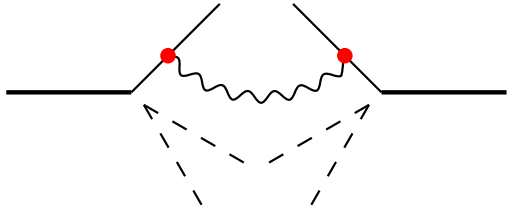

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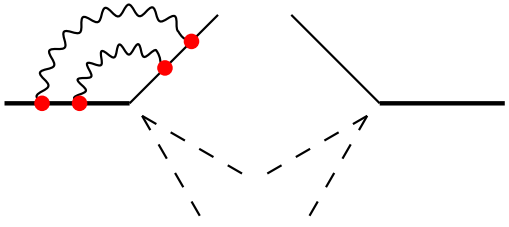

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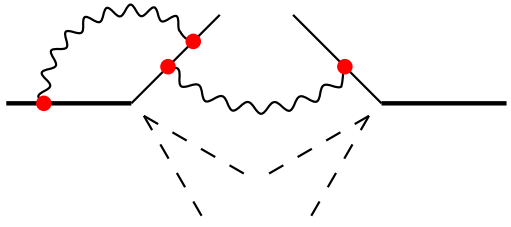

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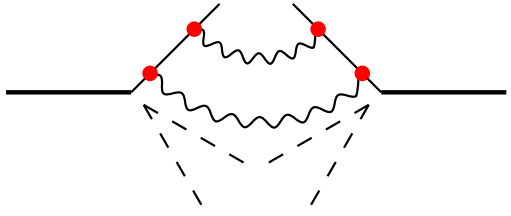

'double real'

α^2
(NNLO)

... for muons

- MEG, Mu3e, MUonE, MUSE etc. need to understand relevant (background) SM processes very precisely
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$\Rightarrow$ minimal requirement:

- NLO for $\mu \to e\nu\bar{\nu}\gamma$, $\mu \to e\nu\bar{\nu}ee$ (PiBeta, MEG, Mu3e)
- NNLO for $\mu \to e\nu\bar{\nu}$ (TWIST, MEG$_{\mathcal{J}}$)
- at the very least NNLO for $\mu e \to \mu e$ and $\mu p \to \mu p$ (MUonE, MUSE)

$$\mu \to e\nu\bar{\nu} + \gamma$$

and

$$\mu \to e\nu\bar{\nu} + e^+e^-$$

[Pruna, Signer, YU 16, Pruna, Signer, YU 17, YU 17]

PiBeta branching ratio

$E_\gamma > 10\,\mathrm{MeV}$ and $\theta > 30^\circ$

- Our prediction $\mathcal{B}_{\mathsf{PSU}} = (4.26 - 0.04_{\mathrm{NLO}}) \cdot 10^{-3}$ agrees perfectly with [Fael, Mercolli, Passera 2015]

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- assuming $m_e = 0$: $\mathcal{B}^{m_e=0}_{\mathrm{PSU}} = (4.35_{\mathrm{LO}} + 0.06_{\mathrm{NLO}}) \cdot 10^{-3}$
- $3.7\sigma \rightarrow \sim 1\sigma$

$\Rightarrow$ details matter!!

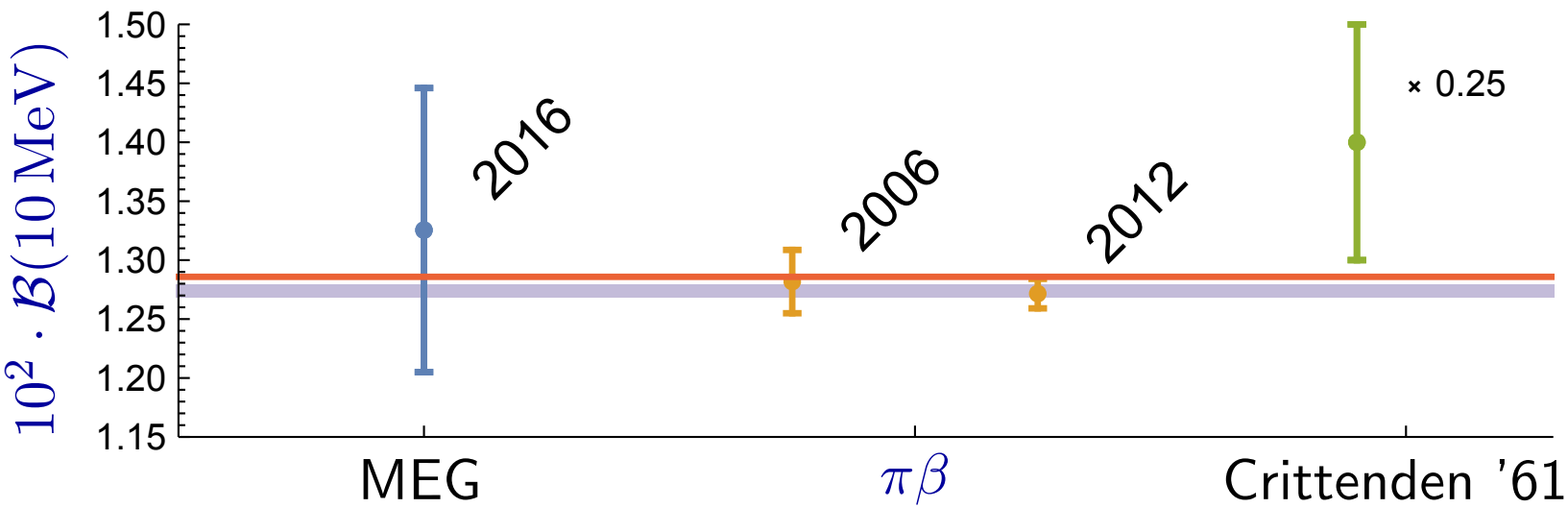
global comparison: $\mathcal{B}(10\,\mathrm{MeV})$

Relate all data using NLO Monte Carlo to $E_\gamma > 10\,\mathrm{MeV}$

- Compute kinematic acceptance ϵ

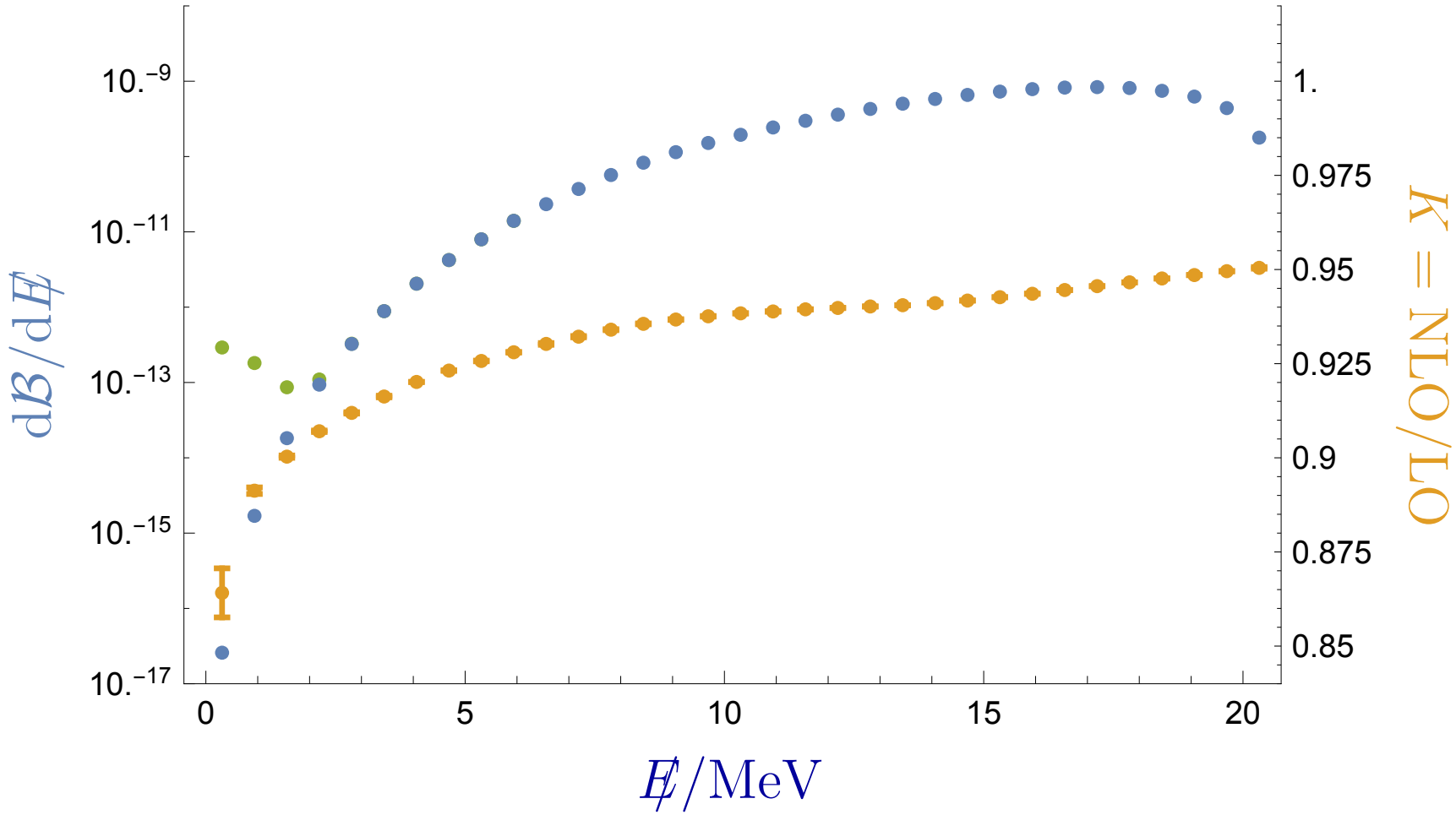
$$\mathcal{B}(10\,\mathrm{MeV}) = \underbrace{\frac{\mathcal{B}_{\mathrm{PSU}}(10\,\mathrm{MeV})}{\mathcal{B}_{\mathrm{PSU}}(\text{exp. cuts})}}_{\epsilon} \mathcal{B}_{\mathrm{exp}}(\text{exp. cuts})$$

- $\epsilon_{\mathrm{MEG}} \approx 2 \cdot 10^5$, $\epsilon_{\pi\beta} \approx 3$
- combined experimental $\bar{\mathcal{B}}(10\,\mathrm{MeV}) = 1.27(1) \cdot 10^{-2}$



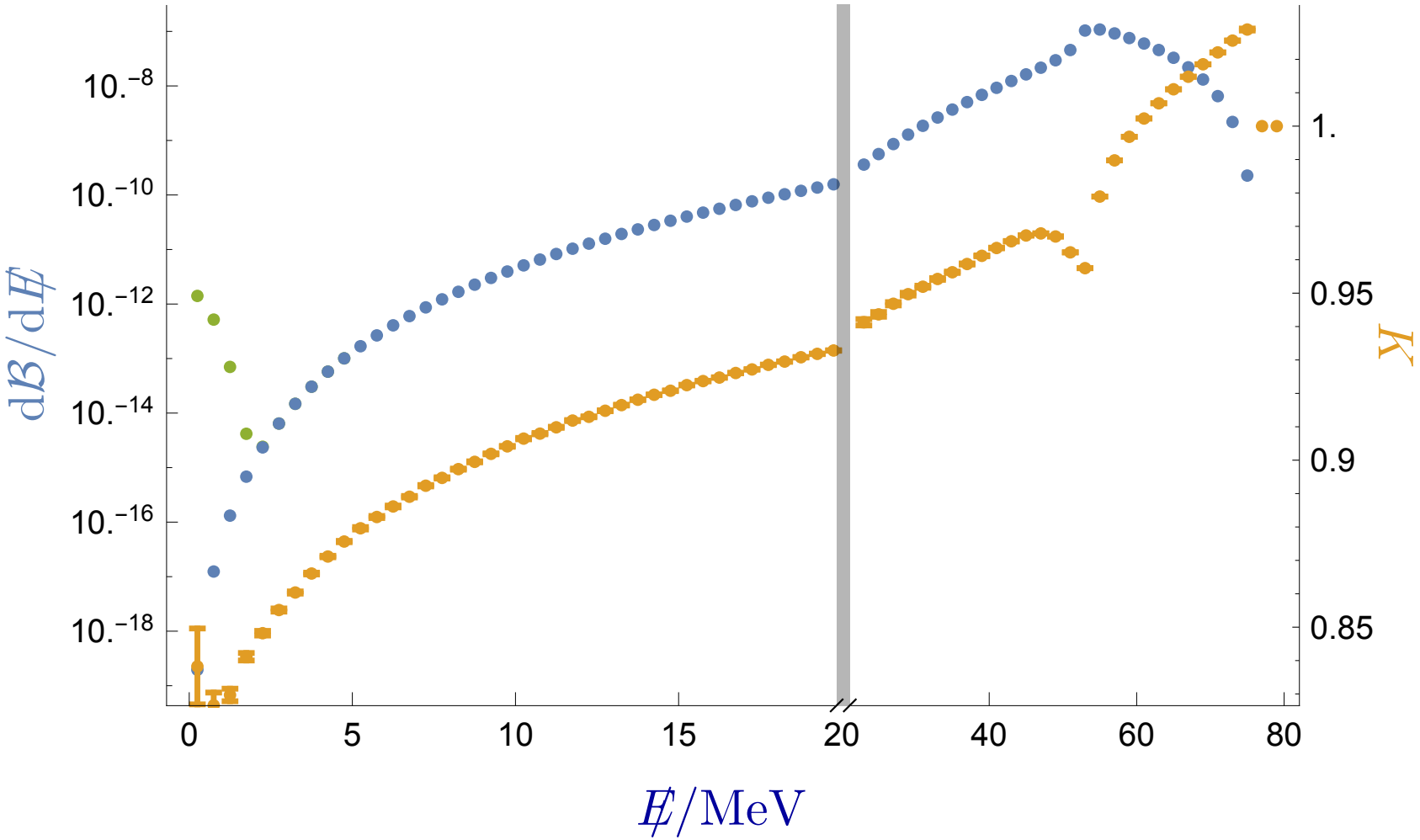
invisible energy spectrum MEG

exactly one photon $E_\gamma > 40\text{MeV}$ in the detector. $\mathcal{B}_{\text{NP}} \simeq 4.2 \cdot 10^{-13}$



invisible spectrum Mu3e

assuming $E > 10\text{MeV}$ and geometry cuts. $\mathcal{B}_{\mu\to 3e} \simeq 10^{-12}$

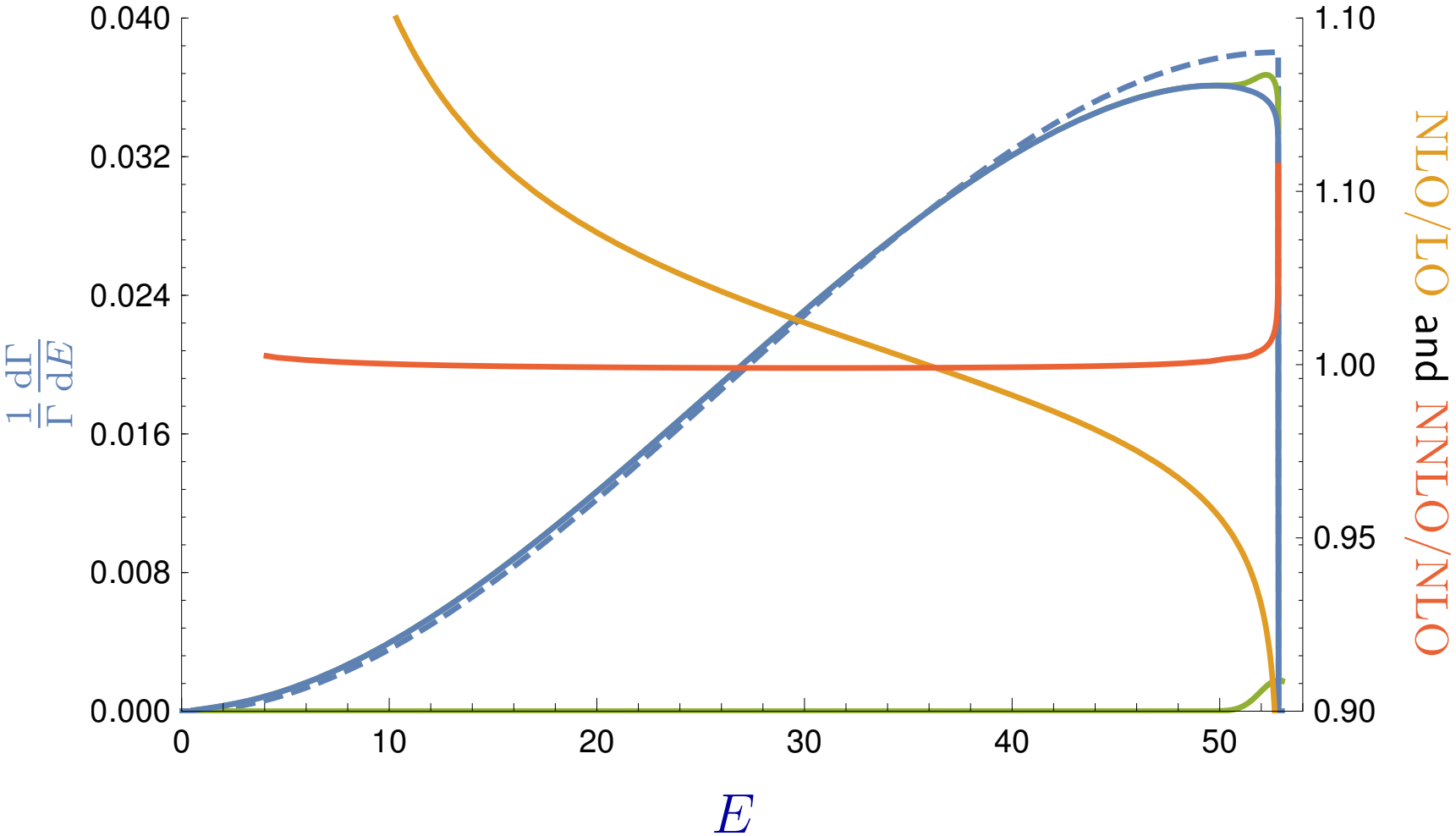


$$\mu \to e\nu\bar{\nu}$$

[Engel, Gnendiger, Signer, YU 18, Banerjee, Engel, Signer, YU soon]

example: Majoron searches in MEG

Majoron with $m_J \sim 0$, $\mathcal{B}_{\mu\to eJ} \sim 2\times 10^{-3}$



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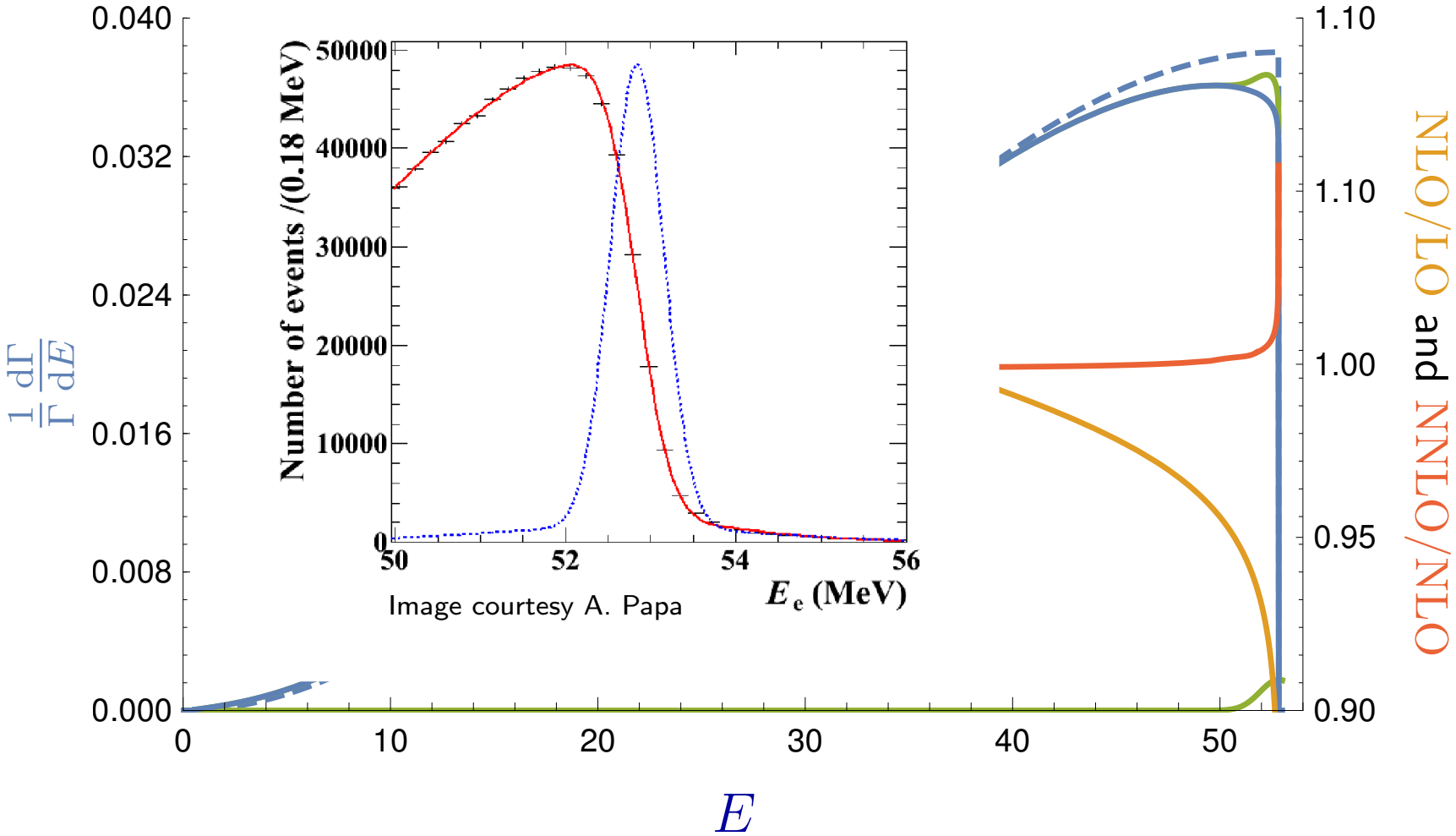


Image courtesy A. Papa

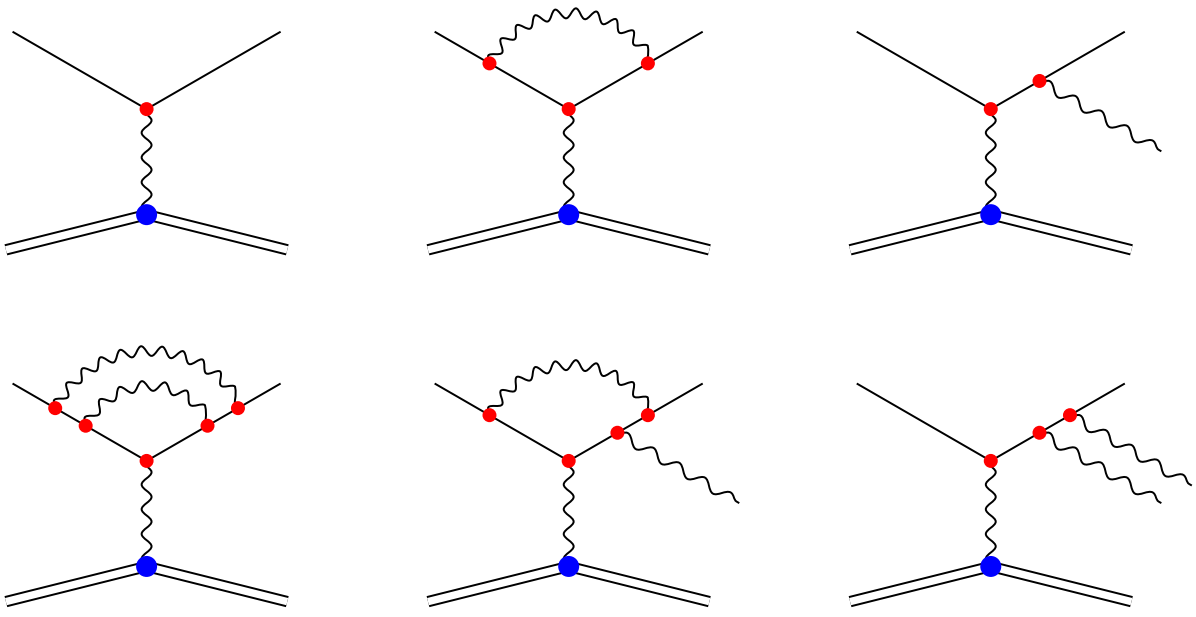
$$\mu e \to \mu e$$

and

$$\mu p \to \mu p$$

$\mu p \to \mu p$ scattering

- leptonic NNLO done [Bucoveanu, Spiesberger 18]
- second calculation using new methods in progress [Banerjee, Engel, Signer, YU soon-ish]
- hadronic correction $\Rightarrow$ someone else's problem



NNLO $\mu\, e$ scattering

- recent proposal to measure a_μ^{HLO} with $\mu\, e$ scattering

$\rightarrow$ LTP Colloquium Graziano Venanzoni 28$^{\text{th}}$ March

- requires theoretical uncertainties below 10^{-5} $\Rightarrow$ at least NNLO (electronic contribution almost done)
- $\mathcal{O}(\alpha^3 \log^3 \frac{m_e^2}{m_\mu^2}) \gg 10^{-5}$
- NNLO not enough $\Rightarrow$ resummation and exploratory N^{3}LO studies

conclusion

details matter!

- $\mu \to e\nu\bar{\nu}\gamma$ and $\mu \to e\nu\bar{\nu}ee$ at NLO
- input into PiBeta reanalysis $\Rightarrow$ current best value
- $\mu \to e\nu\bar{\nu}$ at NNLO: large corrections at the endpoints
- $\mu e \to \mu e$ and $\mu p \to \mu p$ at NNLO: ongoing