1st PRISMA Interactive Research Symposium

Precise Standard Model predictions for the Mu3e and MEG experiment

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21st February 2017

Outline

Motivation

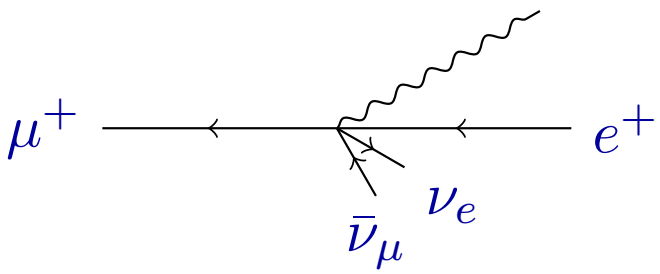
The radiative decay (MEG)

The rare decay (Mu3e)

Outlook

Outline

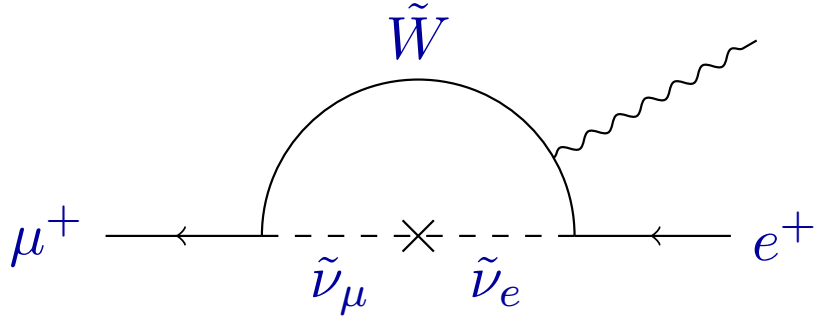
Importance of background



Radiative decay

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

$E_{\nu\bar{\nu}} < \Delta E_{\text{exp.}}$



LFV decay

$(\mu \to e\gamma)$

Status quo

	Experimental	Theoretical (4-Fermi)

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Normal $\mu \to \nu\bar{\nu}e$	TWIST $\mathcal{O}(10^{-4})$	NLO (polarised, MC) [?] NNLO (unpolarised, analytic) [?]

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Radiative $\mu \to \nu\bar{\nu}e + \gamma$	MEG $\mathcal{O}(1\%)$	NLO (polarised, MC) [?] [?]

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Normal $\mu \to \nu\bar{\nu}e$	TWIST $\mathcal{O}(10^{-4})$	NLO (polarised, MC) [?] NNLO (unpolarised, analytic) [?]
Radiative $\mu \to \nu\bar{\nu}e + \gamma$	MEG $\mathcal{O}(1\%)$	NLO (polarised, MC) [?] [?]
Rare $\mu \to \nu\bar{\nu}e + e^+e^-$	Mu3e $\mathcal{O}(10\%)$	NLO (polarised, MC) [?] [?]

Open theoretical issues

Use muon as toy process: clean QED

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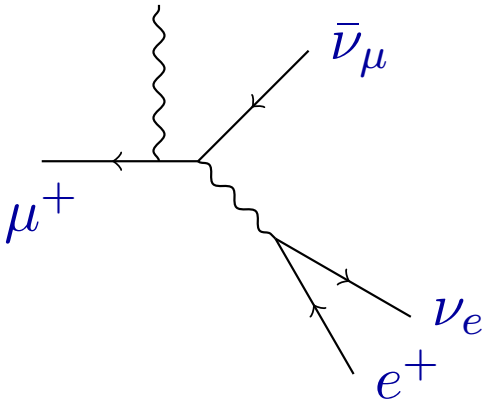
- Large logs, esp. $\tau \to \nu\bar{\nu}e + \gamma$
- NEW: NLO for rare decay

Outline

The radiative decay



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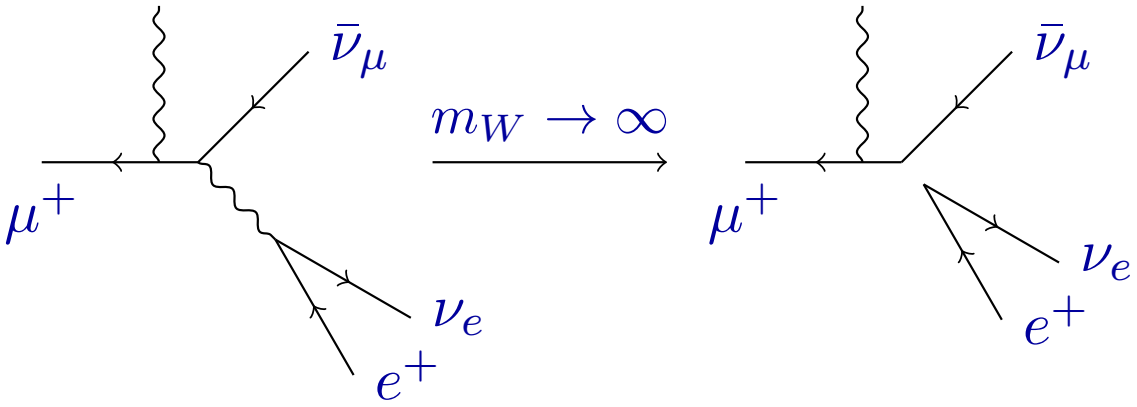

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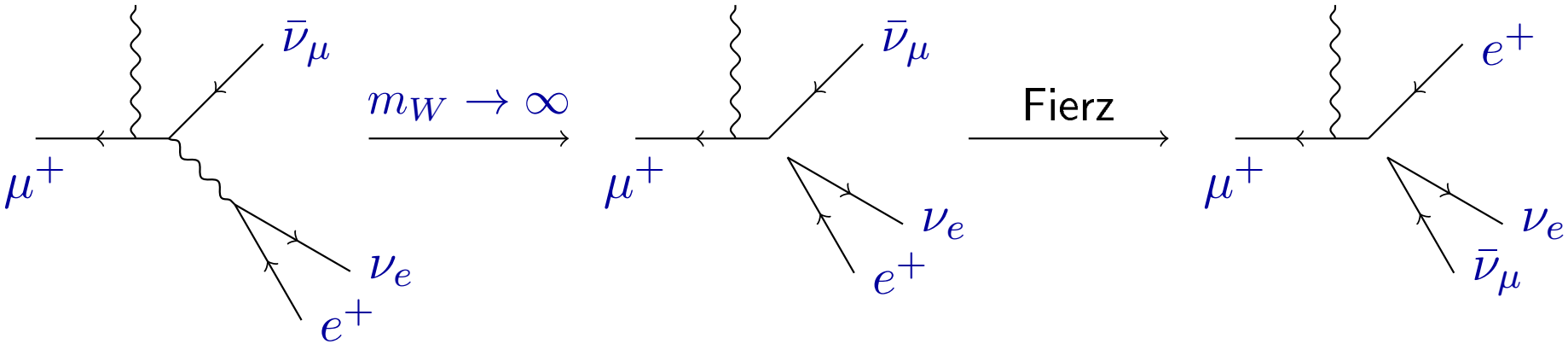

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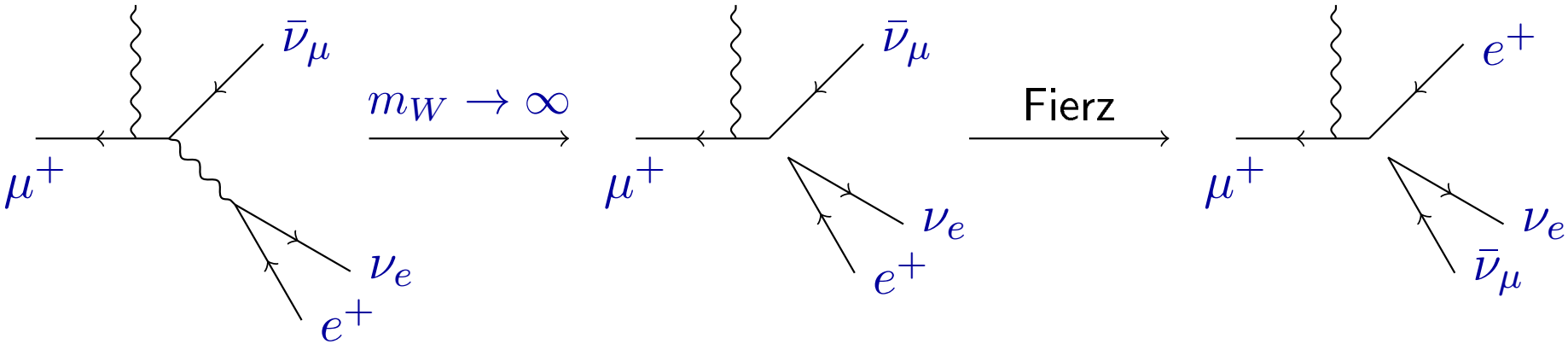
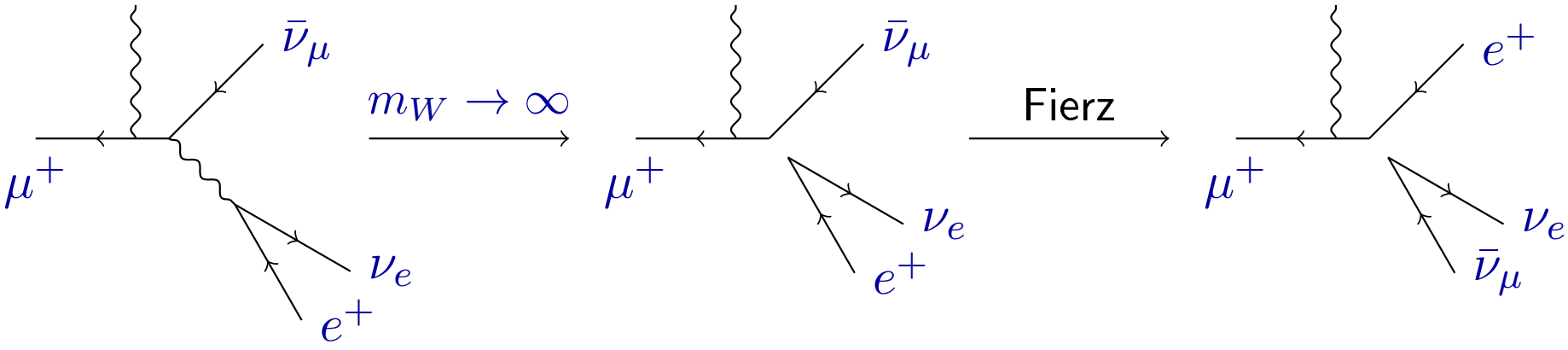


- 4-Fermi interaction, fierzed at the Lagrangian

$$\mathcal{L} = \mathcal{L}_{\text{QED}} + \frac{G_F}{\sqrt{2}} j_{V-A}(\mu, e) \cdot j_{V-A}(\nu_\mu, \nu_e)$$

The radiative decay



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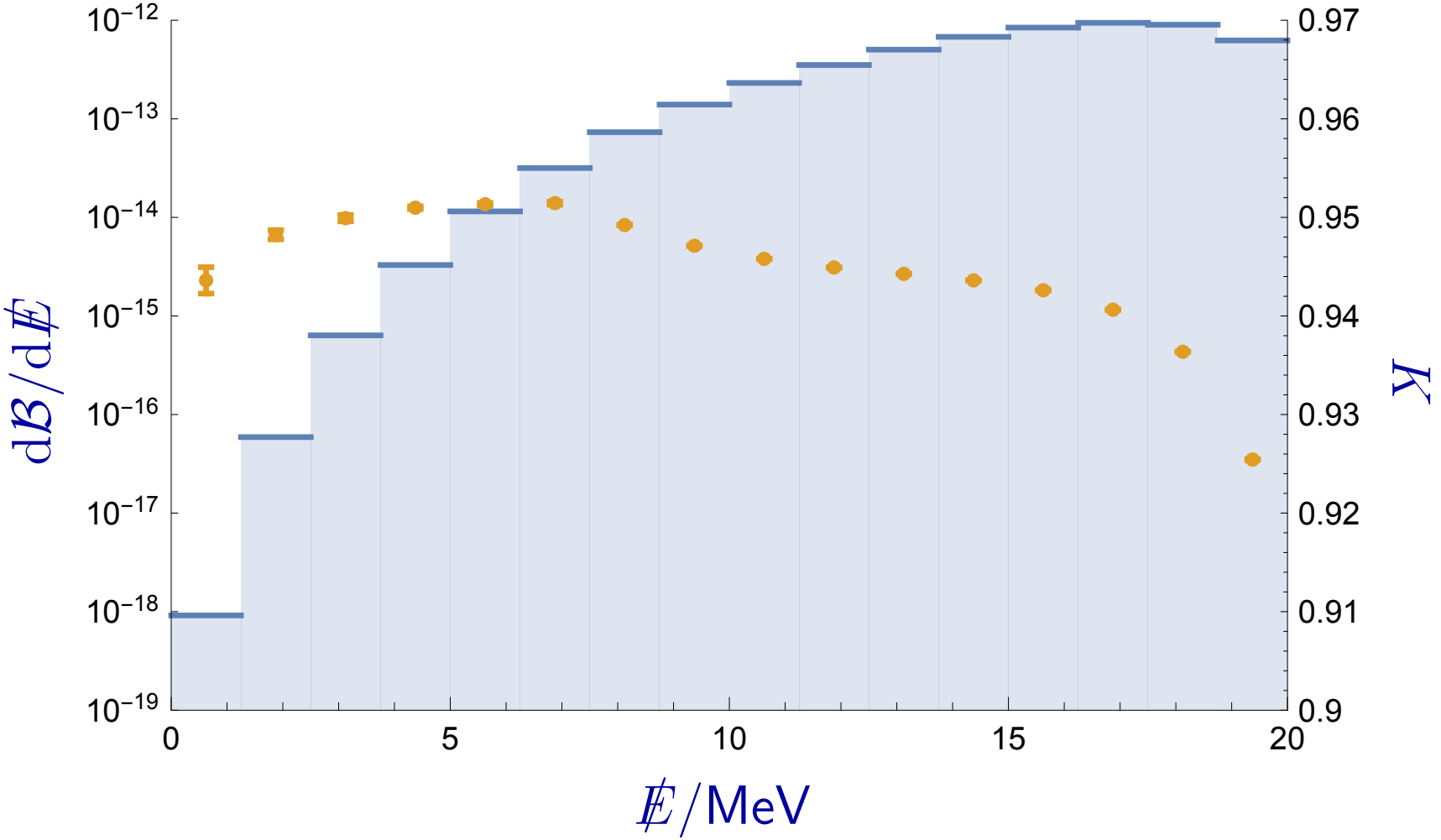
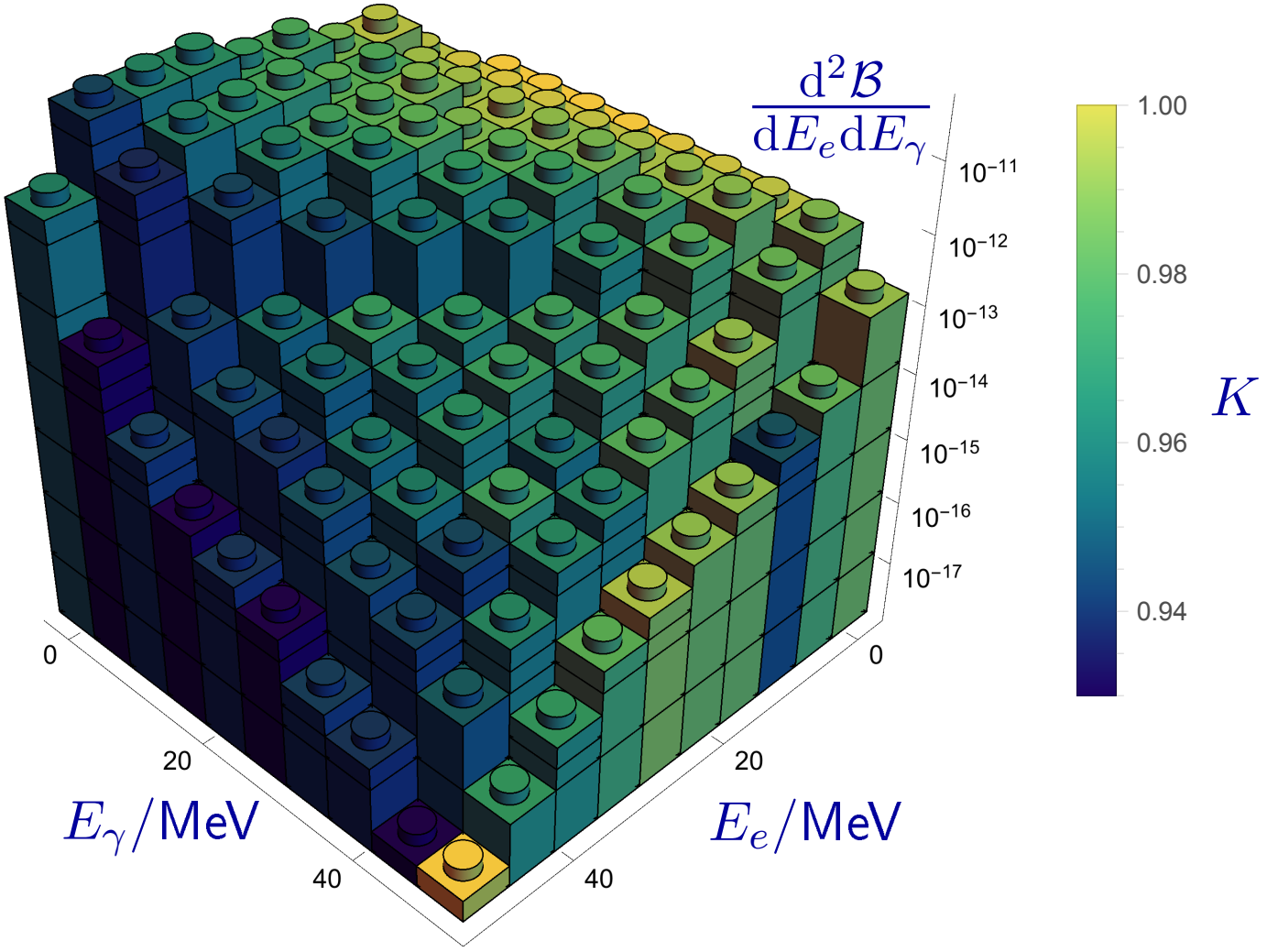
- GoSam [?] / FKS subtraction [?] / VEGAS [?]

Invisible energy spectrum

- Using theorist's MEG cuts



Double differential energy distribution



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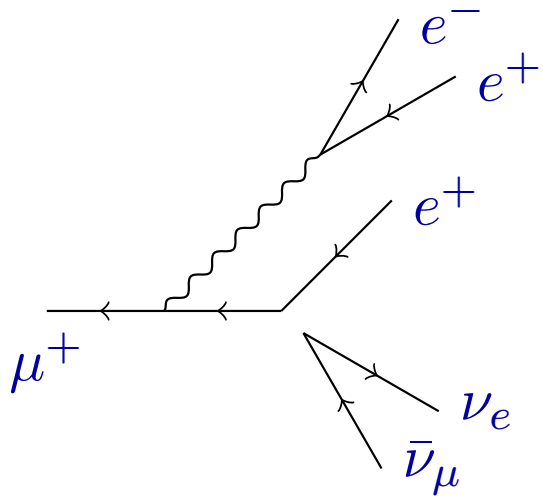
The rare decay



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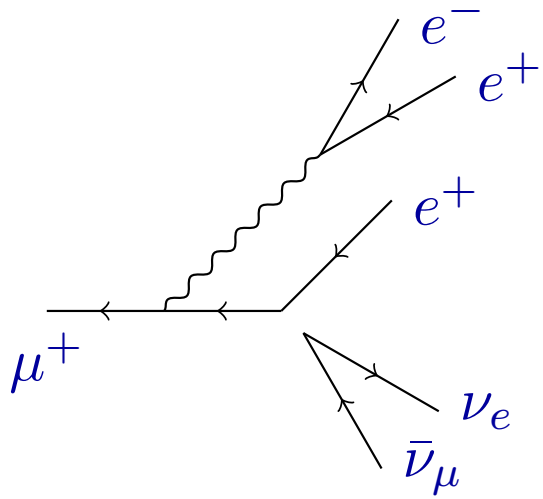

- $4_{\text{Born}} + 40_{\text{1-loop}} + 20_{\text{real}}$ diagrams up to pentagons

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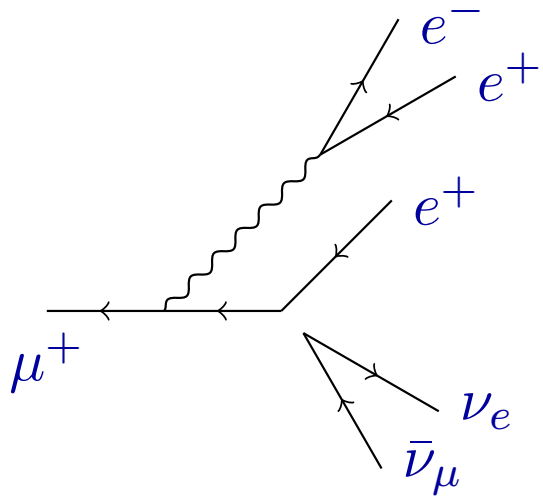

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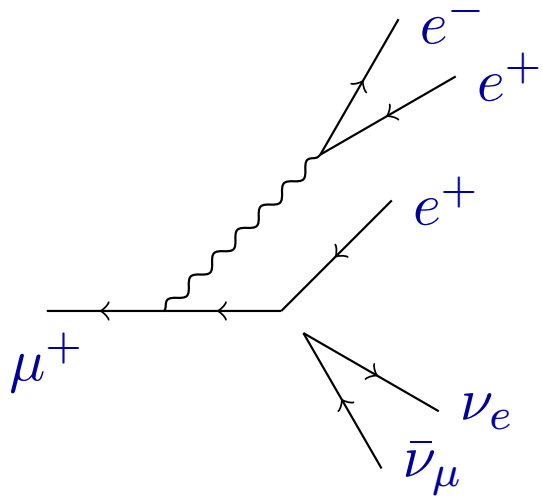

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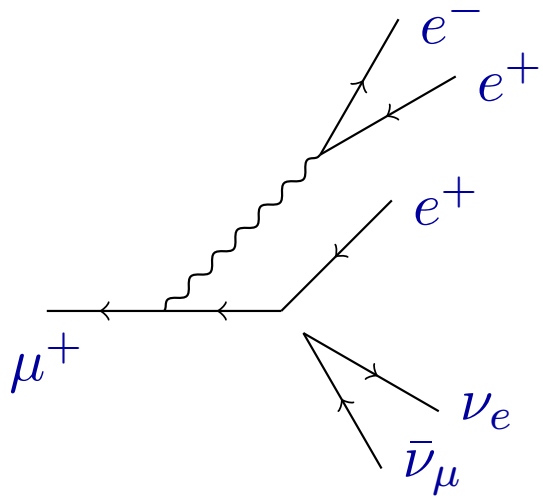

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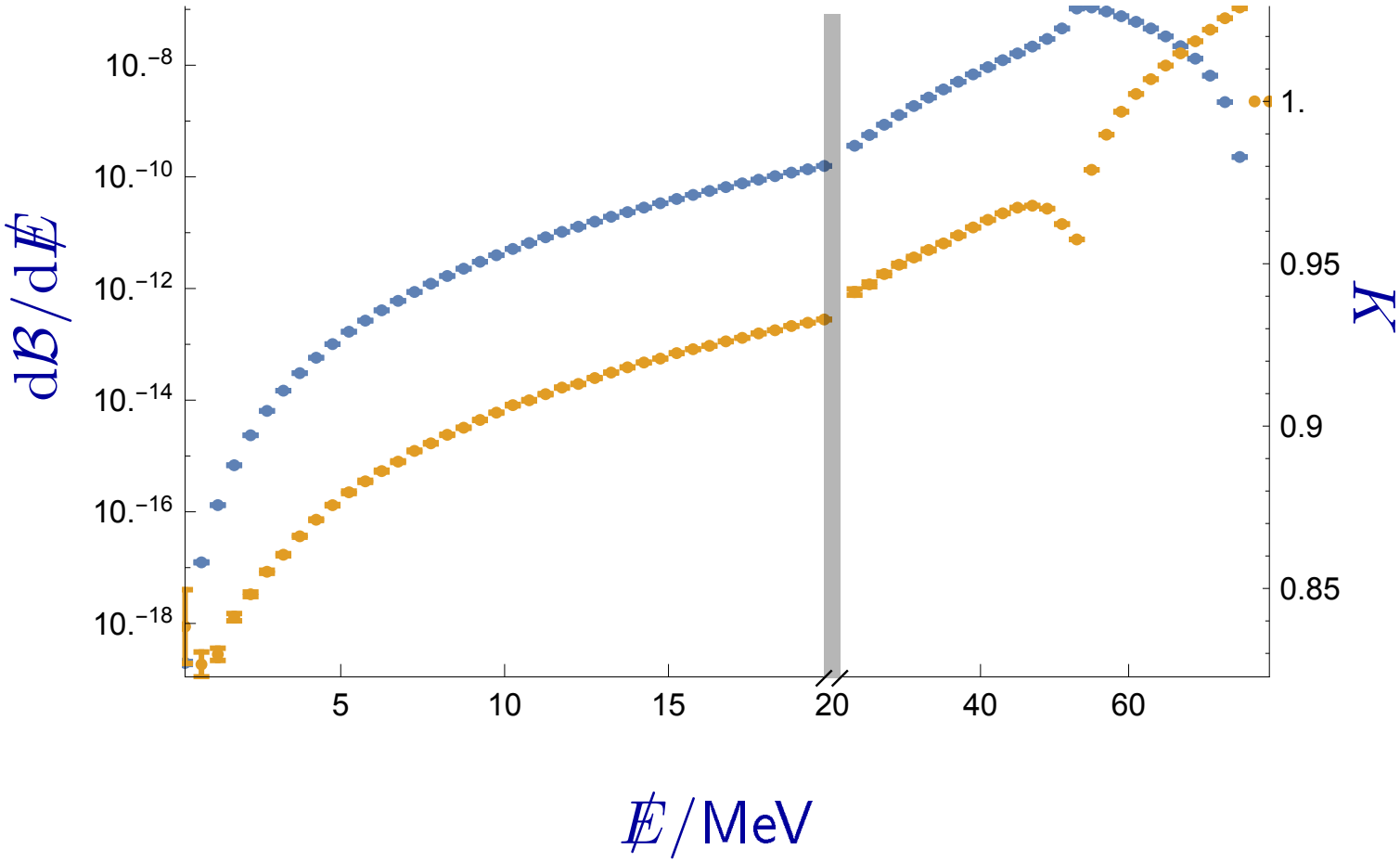
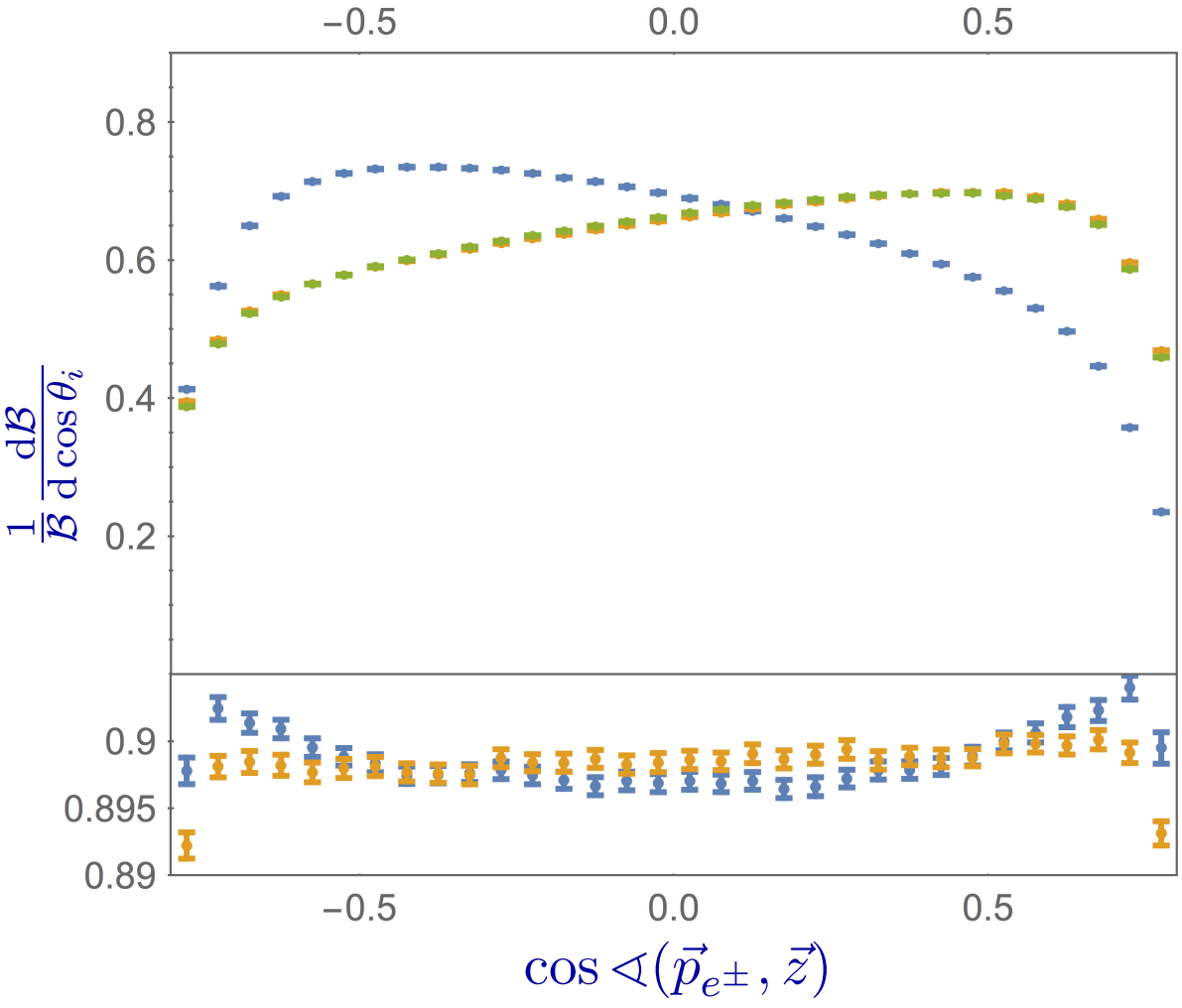
- Use same approach (GoSam, FKS, VEGAS)
- Good parametrisation of phase space very important
- Mu3e cuts $E_{e^\pm} > 10\,\text{MeV}$, $|\cos \sphericalangle(\vec{p}_{e^\pm}, \vec{e}_z)| < 0.8$

Invisible energy spectrum



The angular distribution

- Distributions for the hard e^+, soft e^+ and e^- with $\not{E} < 10\,\text{MeV}$



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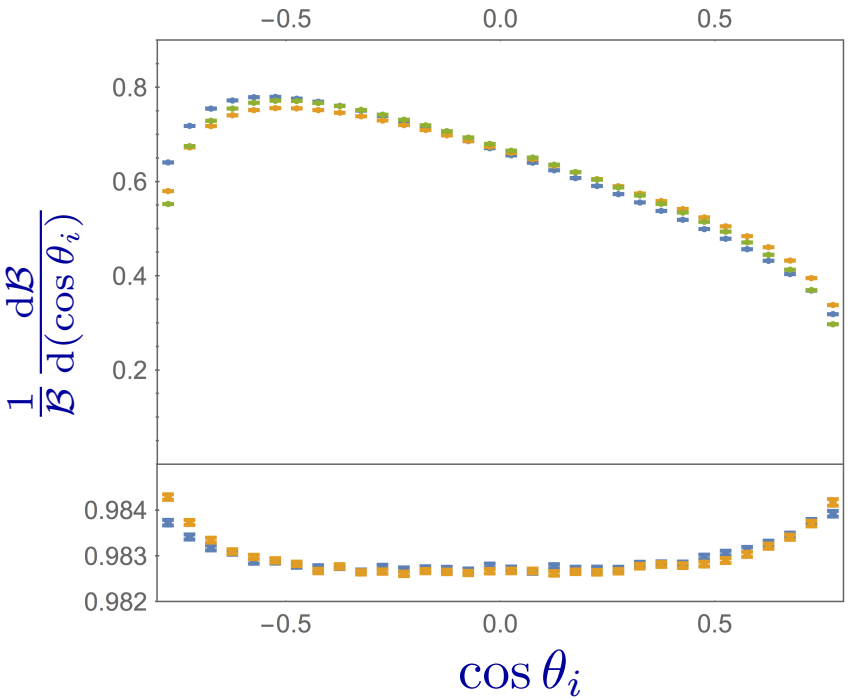
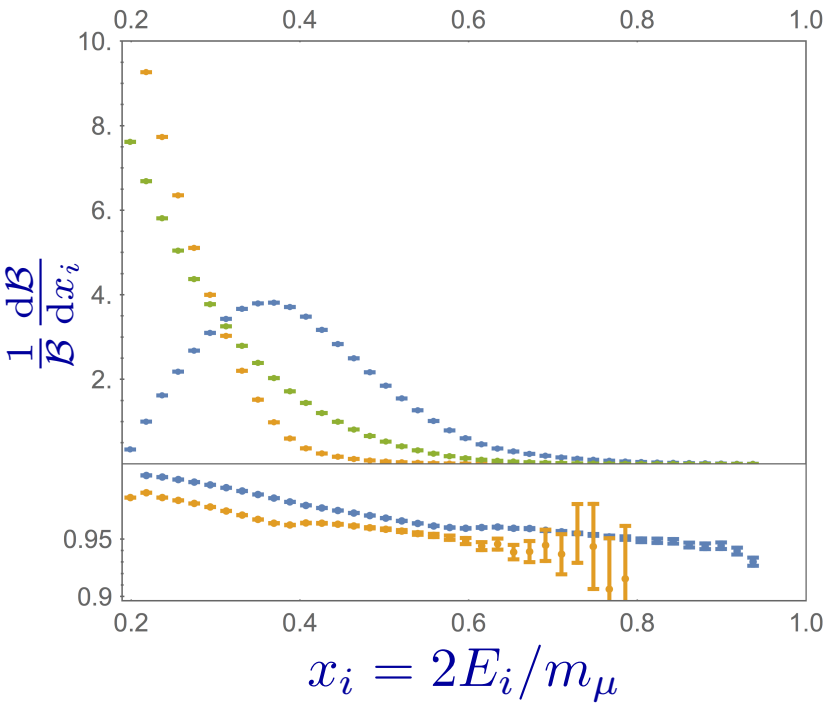
- Ready to compute "experiment-specific" observables
- Clarify role of real emissions

Backup slides

Flipping in angular distribution

- Distributions for the hard e^+, soft e^+ and e^-





No cut on $\not{E}$

Flipping in angular distribution

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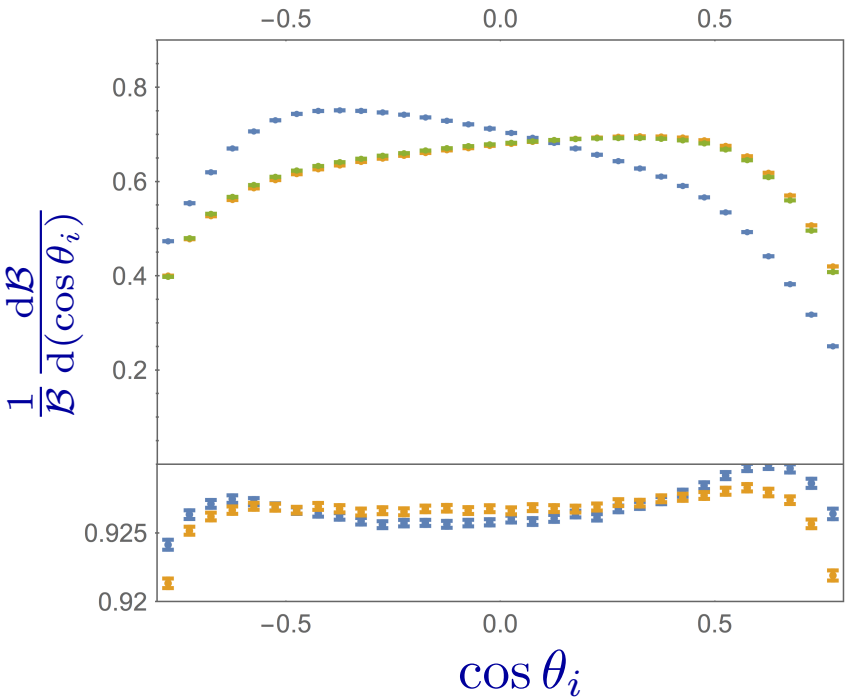

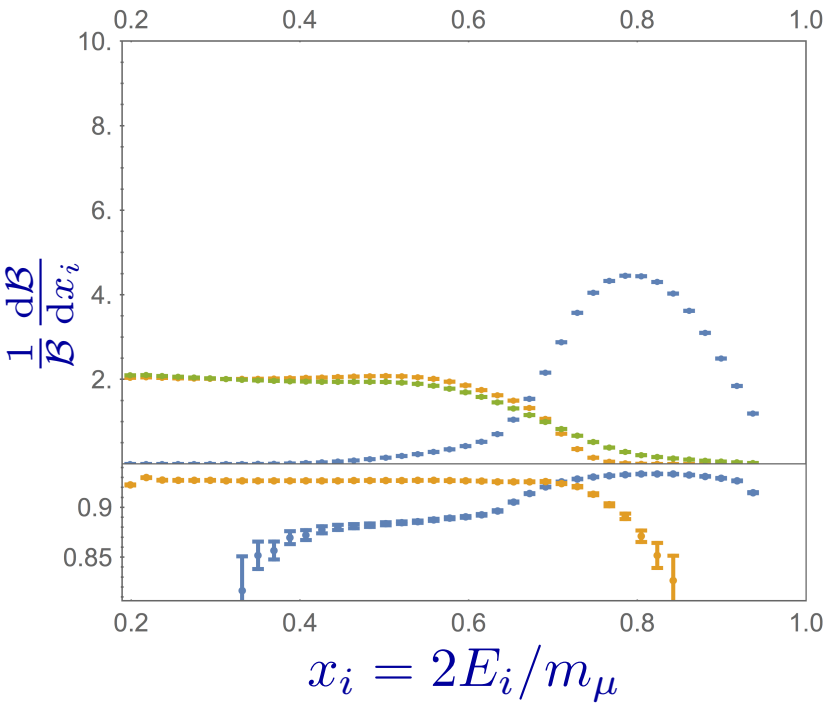

$\not{E} \leq 20\,\mathrm{MeV}$

Flipping in angular distribution

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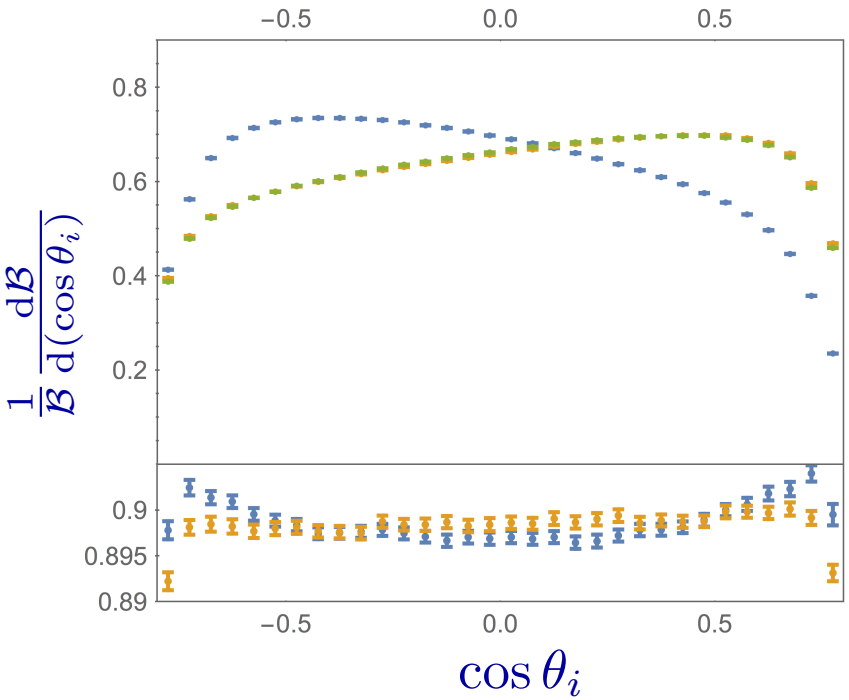
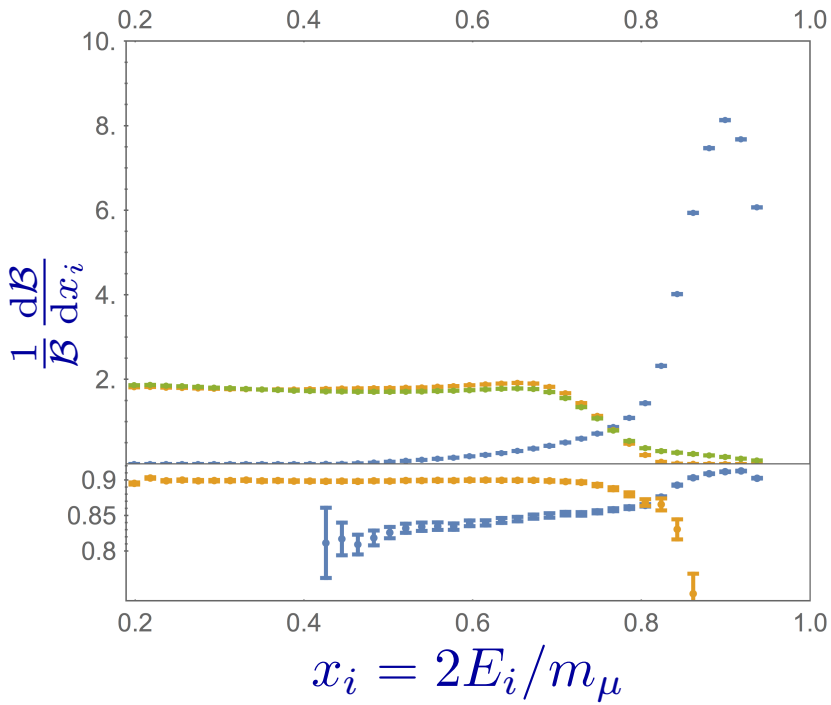




$\not{E} \leq 10\,\mathrm{MeV}$

Polarisation

- Two equivalent ways of introducing polarisations dependence
  - "Closing the trace" $u(p)\bar{u}(p) = (\not{p} + m)\dfrac{1+\gamma^5 \not{s}}{2}$
  - Massive spinor helicity formalism

$$u_\pm(p) = \langle \ell^\pm | + \frac{m}{\langle \ell^\pm n^\mp \rangle} \langle n^\mp |$$

$$\ell = k - \frac{m^2}{2k \cdot n}\, n$$

Lightlike reference vector $n = (1, -\vec{s}/|\vec{s}|)$, combine $\mathcal{A} = \frac{1+|\vec{s}|}{2}\mathcal{A}^+ + \frac{1-|\vec{s}|}{2}\mathcal{A}^-$

- Both introduce a γ^5!

Treatment of γ^5

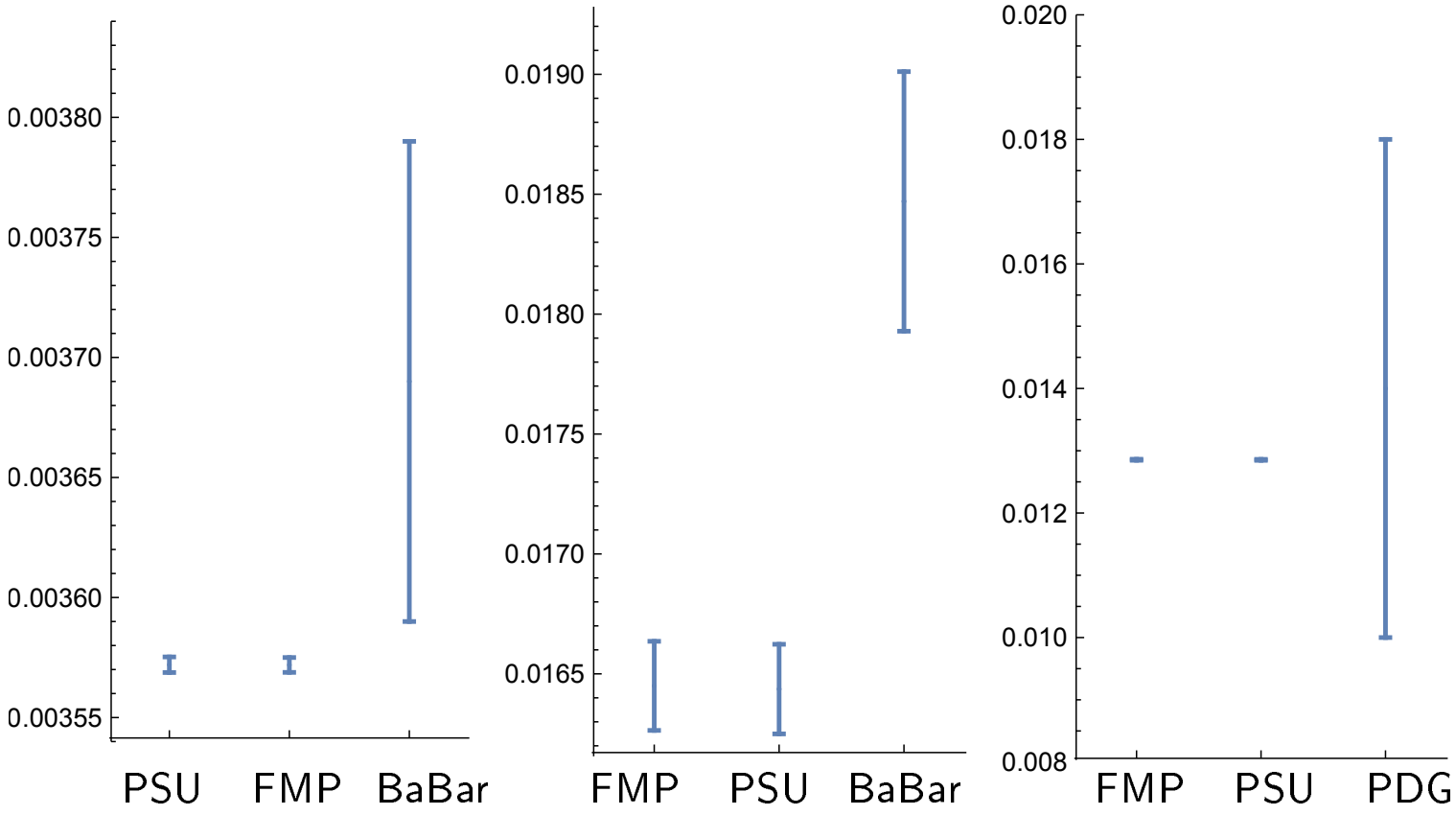
- $\gamma^5 = \mathrm{i}\gamma^0\gamma^1\gamma^2\gamma^3$ is not well defined in d dimensions
- There are at two sources of γ^5:
  - The 4-Fermi vertex $j^\mu_{V-A}(a,b) = \bar{\psi}_a\gamma^\mu(1-\gamma^5)\psi_b$: [?]

$$j^\mu_{V-A}(a,b) = \underbrace{\bar{\psi}_a\gamma^\mu\psi_b}_{j^\mu} - \bar{\psi}_a\gamma^\mu\psi'_b$$

    $\psi'_b = \gamma^5\psi_b$ corresponds to an electron with $m = -m_e$.
  - Polarisation: Spinor helicity formalism in FDH (external particles in $d = 4$)

Radiative branching ratio

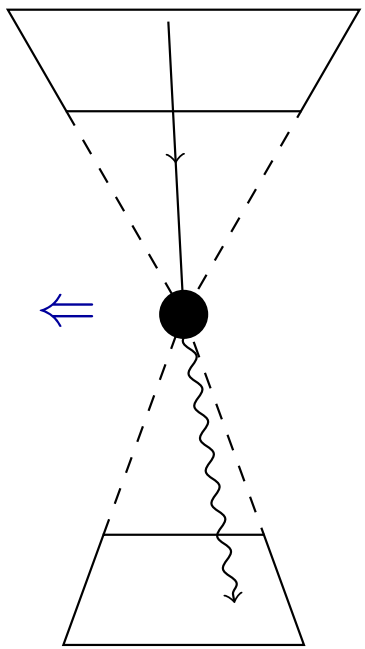
$$\delta\mathrm{BR}^{\mathrm{NNLO}} \approx \frac{\alpha}{\pi} \log \frac{m}{M} \log \frac{\omega_0}{M} \mathrm{BR}^{\mathrm{NLO}} \qquad [?]$$

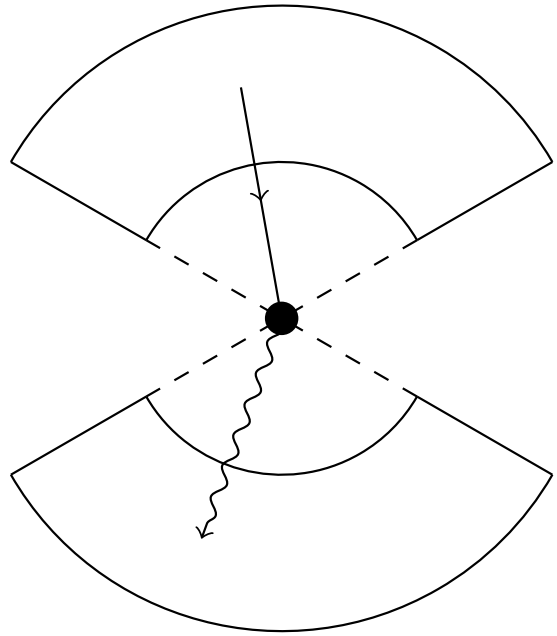


$\tau \to \nu\bar{\nu}\mu + \gamma$ $\tau \to \nu\bar{\nu}e + \gamma$ $\mu \to \nu\bar{\nu}e + \gamma$

MEG geometry

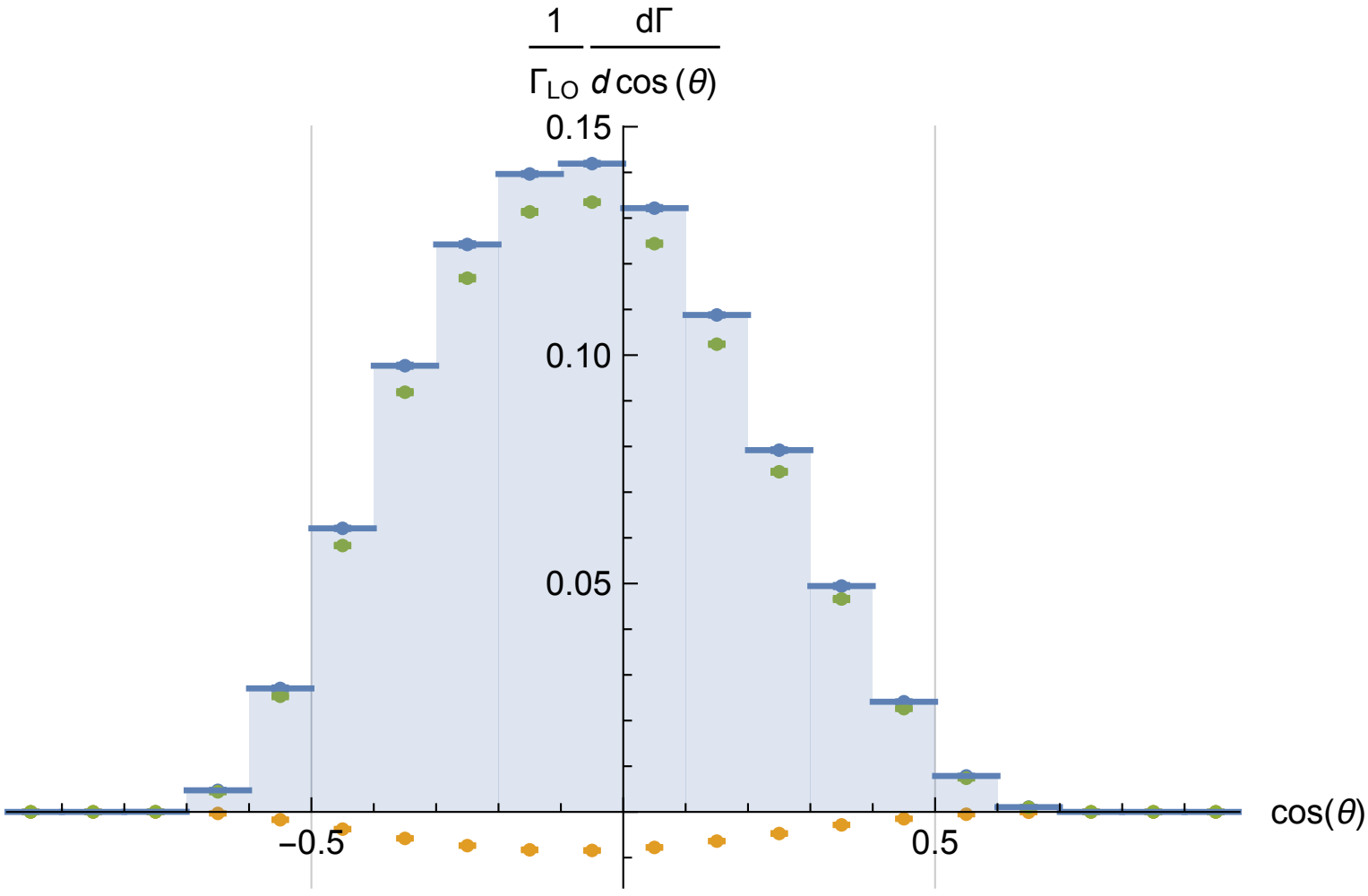
Theorist's version of the MEG detector @ PSI





$E_\gamma > 40\,\text{MeV}$ $\quad |\cos\theta_e| < 0.5$ $\quad E_e > 45\,\text{MeV}$

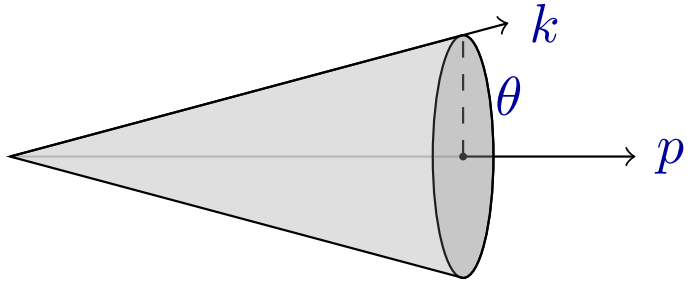
$\cos\theta_e$ distribution



MEG cuts on the electron loose $4.10\,\%$ of the events

Phase space parametrisation

- Standard (recursive): $p_1 \to p_2 + q \to p_2 + p_3 + q' \to \ldots$
- Problem: Pseudo-singularities like $\frac{1}{(k+p)^2} \approx \frac{1}{\xi^2} \frac{1}{1-c_\theta+\epsilon(m_e)}$ are not aligned with VEGAS grid
- Idea: Parametrise energies and angles of "problematic" particles



References I