Muon trident process at FASERν and FASERν2 detectors

Based on arXiv:2510.18943

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9th FPF Meeting

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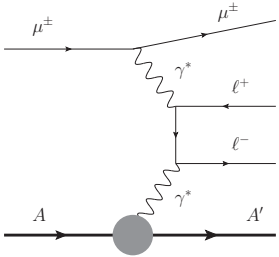
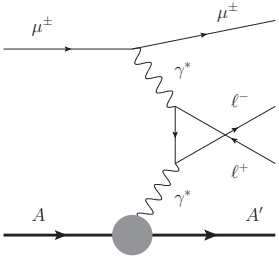
Motivation

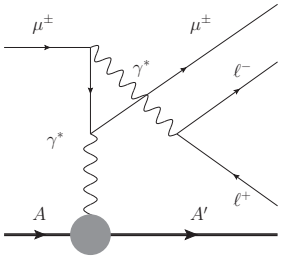
- Feasibility of muon trident process at FASERν and FASERν2;
- Analysis of pair production e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$;
  - $\tau^+\tau^-$ not yet observed in this process;
- Production of QED bound states:
  - Muonium $(\mu^+\mu^-)_s$ – Never yet observed experimentally;
  - Positronium $(e^+e^-)_s$;

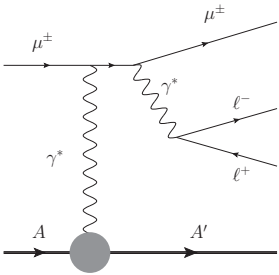
Muon Trident Process – FeynCal





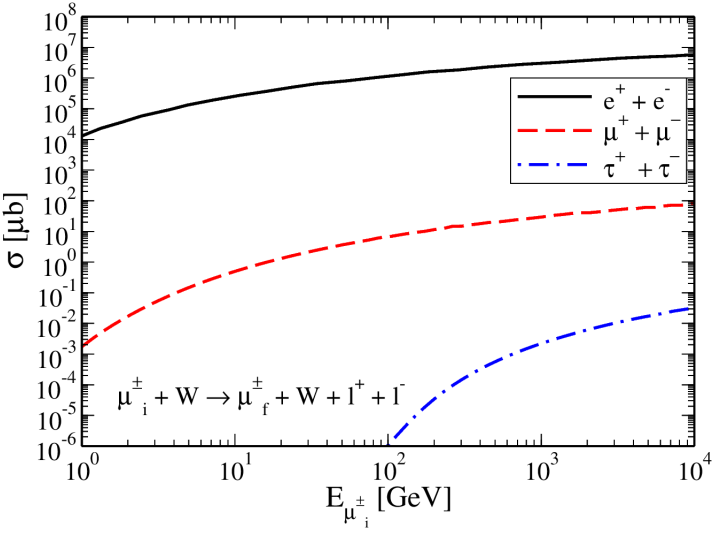
Bethe-Heitler process





Bremsstrahlung

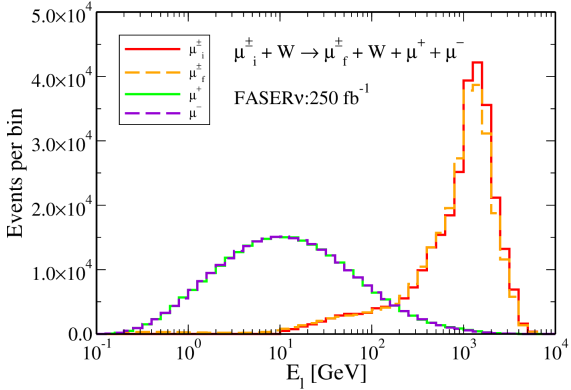
Total Cross-Section

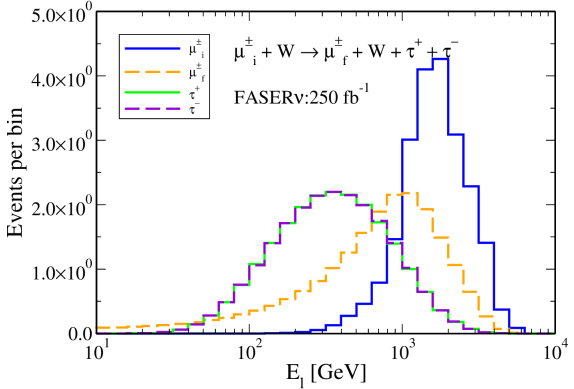


N_{events} binned on the energy – FASERν – RUN 3

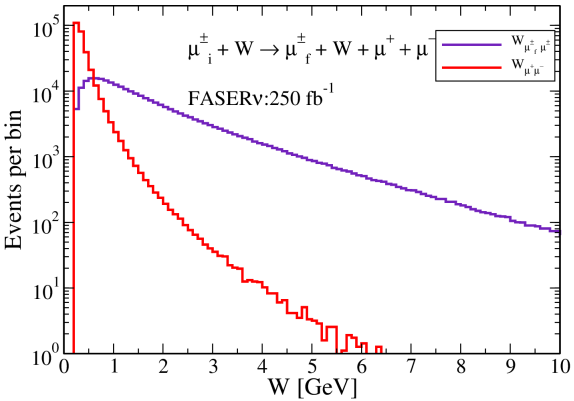
$$N_{\text{events}} = \int_0^1 \mathrm{d}x_{\mu^\pm} f(x_{\mu^\pm}) \sigma_{\mu^\pm + W}(E_{\mu_i^\pm})$$

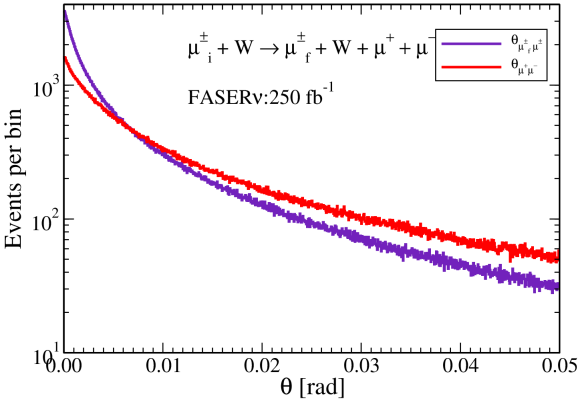
- $f(x_{\mu^\pm})$ – Muon Flux – Obtained from FLUKA;





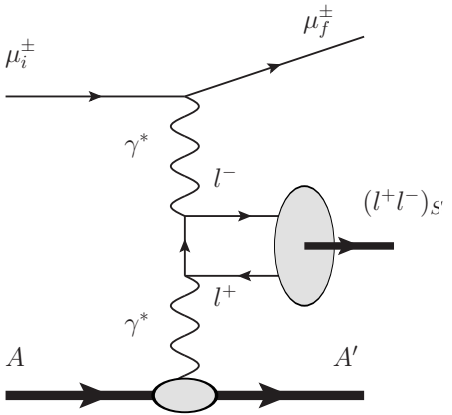
N_{events} of $\mu^+\mu^-$ production – FASERν – RUN 3





- Bin of 0.1 GeV for W and 0.05 mrad for θ.

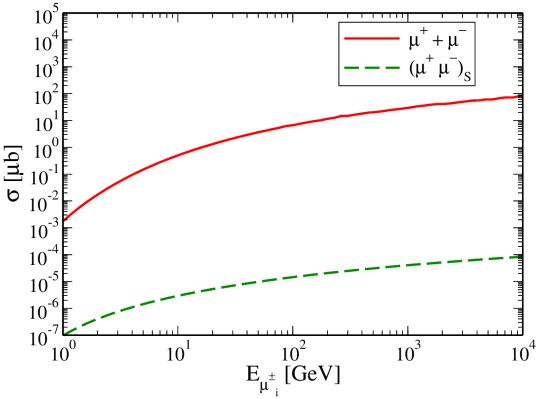
QED Bound State - $(e^+e^-)_s - (\mu^+\mu^-)_s$

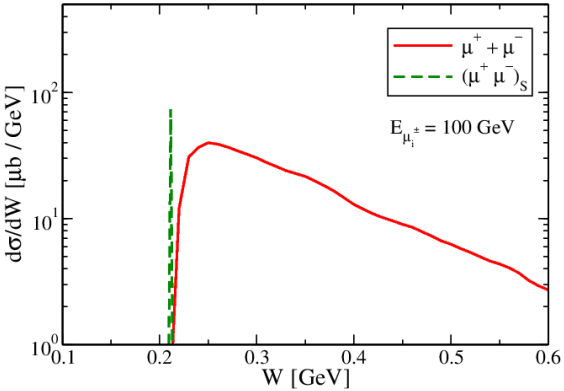


- Lepton bound state
  - $(e^+e^-)_s$ – Positronium;
  - $(\mu^+\mu^-)_s$ – Muonium;
- Singlet state;
- From photon–photon fusion;
- Equivalent photon approximation;
- $\sigma_{\gamma W}$ – Photo–Nuclear cross section;
- $f_{\gamma/\mu}$ – Equivalent photon–flux;

$$\sigma_{\mu_i^\pm + W \to \mu_f^\pm + W + (l^+l^-)_S} = \frac{1}{2\pi E_{\mu_i^\pm}} \int \mathrm{d}p_t^2 \, \mathrm{d}\phi \, \mathrm{d}E_{(l^+l^-)_S} \, \mathrm{d}(\cos\theta) f_{\gamma/\mu} \left(\frac{E_{(l^+l^-)_S}}{E_{\mu_i^\pm}}, q_t^2 \right) \frac{\mathrm{d}\sigma_{\gamma W}}{\mathrm{d}(\cos\theta)},$$

True Muonium predictions





- Bound pair of $\mathcal{O}(10^{-6})$ of magnitude compared to the open pair;

- $E_{\mu_i^\pm} = 100$ GeV – Typical energy of incident muons;
- $(\mu^+\mu^-)_s$ peak at $2m_\mu$;

N_{events} at FASERν (RUN 3) and FASERν2 (HL-LHC)

Final state	FASERν	FASERν ($E_l \geq 10$ GeV)	FASERν2	FASERν2 ($E_l \geq 10$ GeV)
$e^+ + e^-$	4.10×10^{10}	7.23×10^{8}	6.10×10^{12}	1.08×10^{10}
$\mu^+ + \mu^-$	2.61×10^{5}	1.03×10^{5}	3.87×10^{7}	1.53×10^{7}
$\tau^+ + \tau^-$	21.83	19.97	3.25×10^{3}	2.97×10^{3}

Table: N_{events} – electromagnetic dilepton production, $\mathcal{L}_{\text{pp}} = 250$ fb^{-1} (FASERν) and 3 ab^{-1} (FASERν2)

Final state	FASERν	FASERν ($E_l \geq 10$ GeV)	FASERν2	FASERν2 ($E_l \geq 10$ GeV)
$(e^+e^-)_S$	1.51×10^{5}	9.30×10^{3}	2.24×10^{7}	1.38×10^{6}
$(\mu^+\mu^-)_S$	0.38	0.20	57.04	29.76

Table: N_{events} – electromagnetic production of QED bound states, $\mathcal{L}_{\text{pp}} = 250$ fb^{-1} (FASERν) and 3 ab^{-1} (FASERν2).

Conclusions and Next Steps

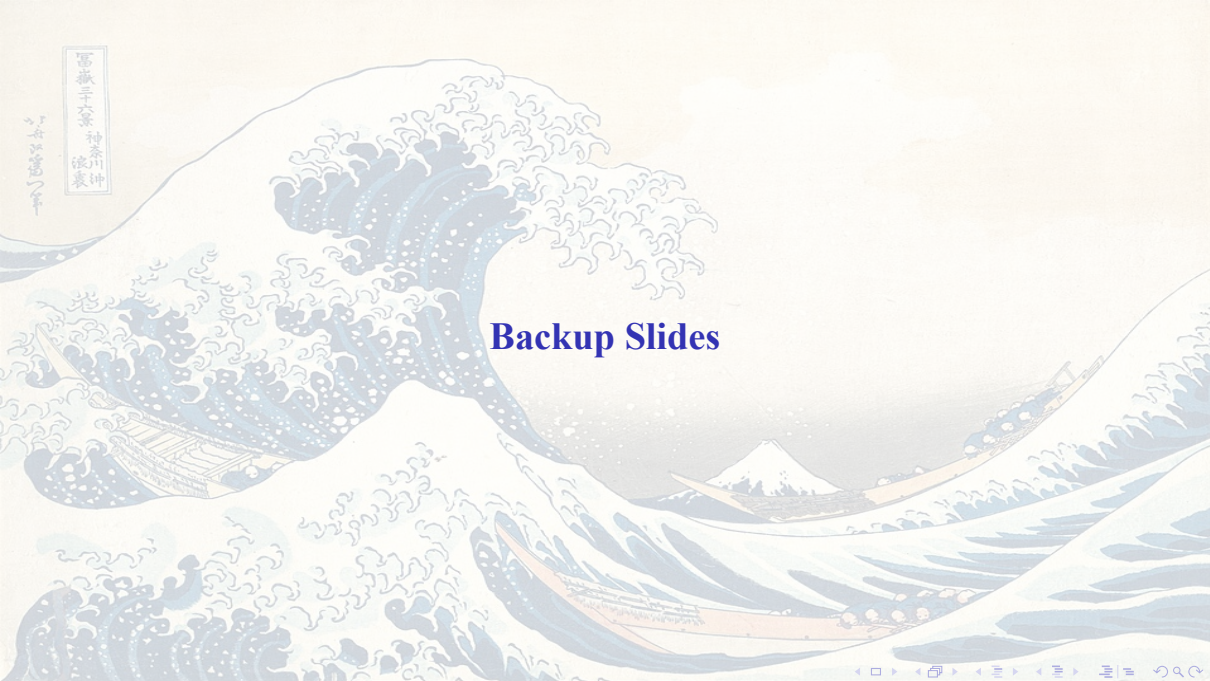
- Predictions for the $\mu^+\mu^-$ at the FASERν – RUN 3 – $\mathcal{O}(10^5)$ events;
- Predictions for the $\tau^+\tau^-$ at the FASERν – RUN 3 – $\mathcal{O}(10^1)$ events;
- Predictions for the muonium at FASERν2 – HL–LHC – $\sim$ 60 events;
- The background analysis and its impacts - Work in Progress

Acknowledgment

I also thank the organizers of the 9th Forward Physics Facility Meeting

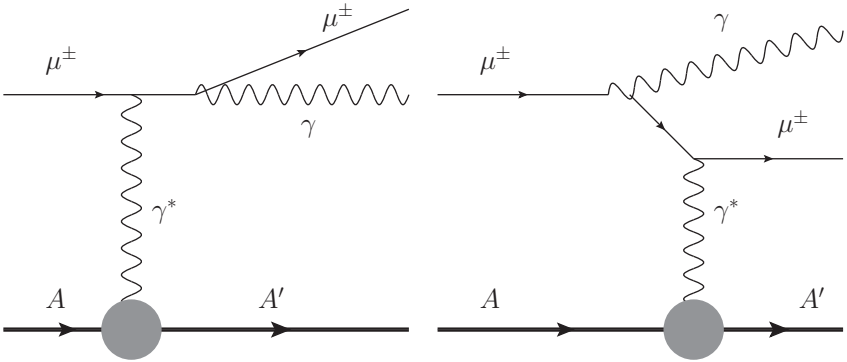
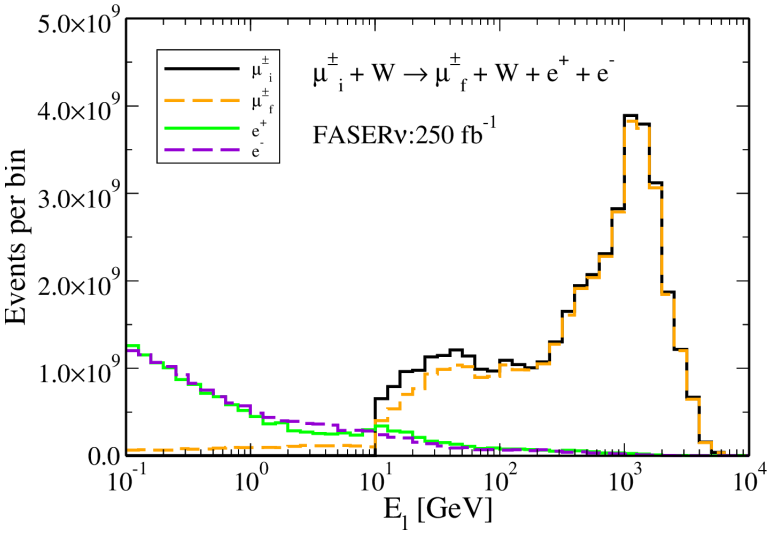
Thank you :)

Feel free to get in touch – *rabelosoares21@gmail.com*



Backup Slides

Background



N_{events} per Energy for e^+e^-