Search for muonic trident production in SND@LHC

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Scattering and Neutrino Detector at LHC

- SND@LHC studies neutrinos produced in pp collisions at the LHC.
- Operates in the unexplored forward region, $7.2 < \eta < 8.4$ in the TI18 tunnel.

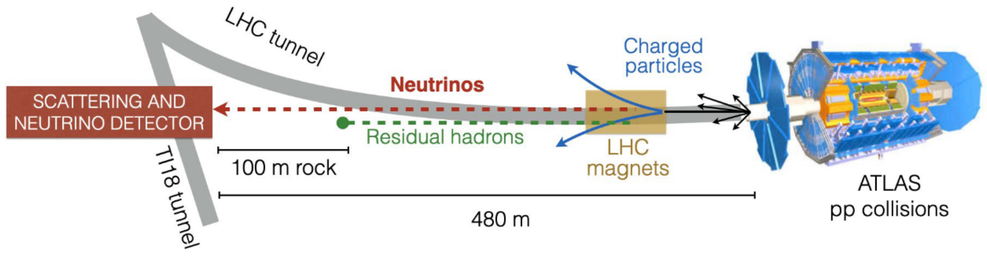

Figure 1. Sketch of the experiment site (not to scale).

- The SND@LHC detector consists of Veto, vertex detector & EM calorimeter and hadronic calorimeter & muon subsystems and is capable of identifying all neutrino flavors and studying physics beyond the standard model such as light dark matter.

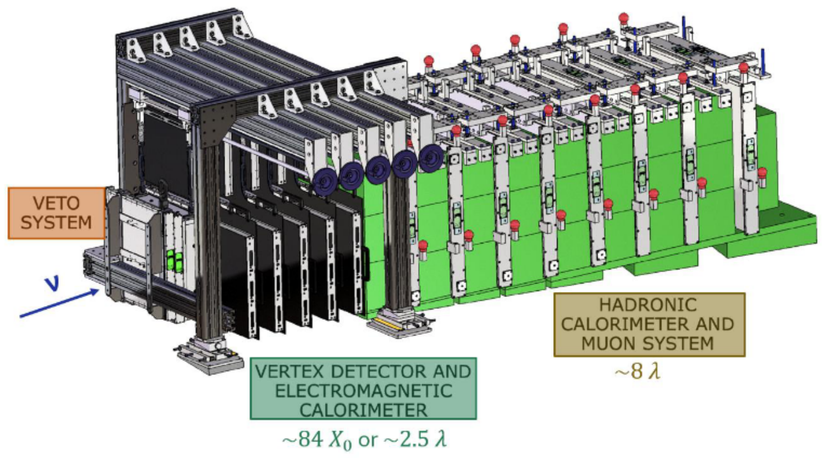

Figure 2. The SND@LHC detector layout, See also Giulia Paggi's talk.

Muonic Tridents

- The process is a pure QED phenomenon and it is particularly interesting as it can be used to confirm **Fermi-Dirac statistics**.
- The cross section of muonic trident production was measured in Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS) in 1971 **[1]** with a 10.5-GeV muon beam impinging on a lead target.
  - $\mu^{\pm} + Pb \rightarrow \mu^{\pm} + Pb + \mu^{+} + \mu^{-}$
  - The cross-section measured to be 51 ± 7 nb per nucleus
- The most recent observation made by CosmoALEPH with cosmics in 2006 **[2]**
- The process was implemented in GEANT4 **[3]**
  - This study will serve as a means of verification.

- **Events in SND@LHC, interactions inside the rock**
  - Three parallel tracks reconstructed in the detector.
  - Possible sources:
    - $\mu^{\pm} + N \rightarrow \mu^{+}\mu^{-}\mu^{\pm} + N$ (The genuine trident)
    - $\mu^{\pm} + N \rightarrow \mu^{\pm} + N + \gamma, \gamma + N \rightarrow N + \mu^{+}\mu^{-}$ (muon brems followed by γ conversion, background)
    - $\mu^{\pm} + N \rightarrow \mu^{\pm} + N + \gamma,\ \gamma + N \rightarrow N + e^{+}e^{-},\ e^{+} + e^{-}$(atomic) $\rightarrow \mu^{+}\mu^{-}$(positron annihilation, background)

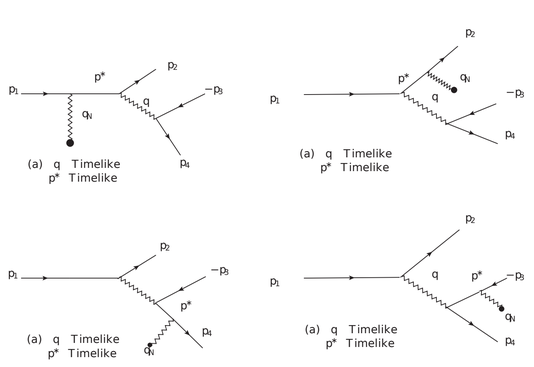

Figure 3. Feynmann Diagram of Muon Tridents

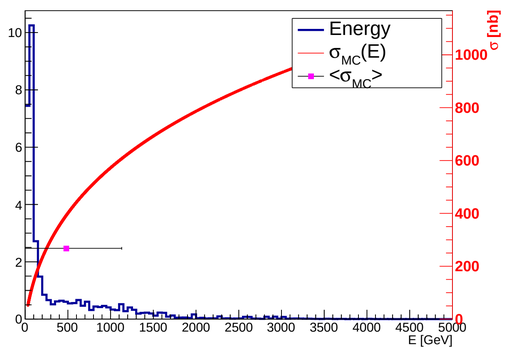

Figure 4. MC (magenta) flux-averaged cross section with spectrum of incoming muons (blue) and cross section as a function of incoming muon energy per nucleus (red).

- SND@LHC is sensitive to muon trident production in the rock about 100 m upstream of the detector, such that the individual muon tracks can be resolved.

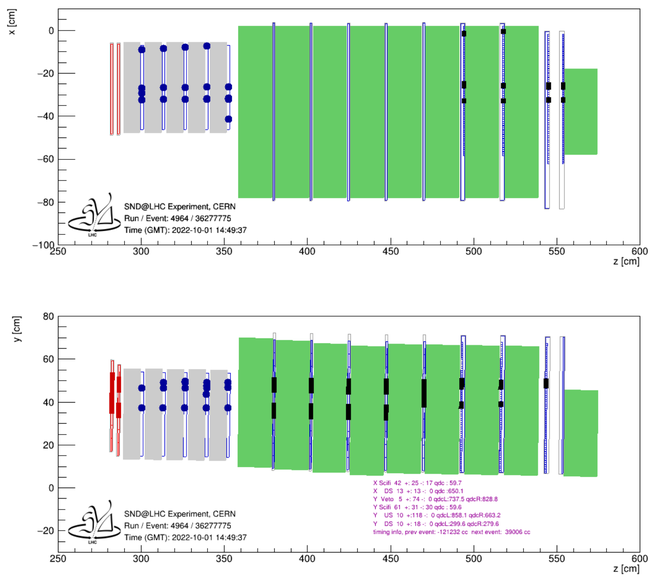

Figure 5. A reconstructed muonic trident candidate

Analysis

- Data collected in the 2022 and 2023 campaigns corresponding to integrated luminosity of 13 fb^{-1} were used.
- The event reconstruction is done by combining doublets of clusters in subsequent SciFi planes in 2D.

- The signature of muonic trident events: Three parallel tracks, two of them are close (d_{min}) and the third one is separated (d_{max}).

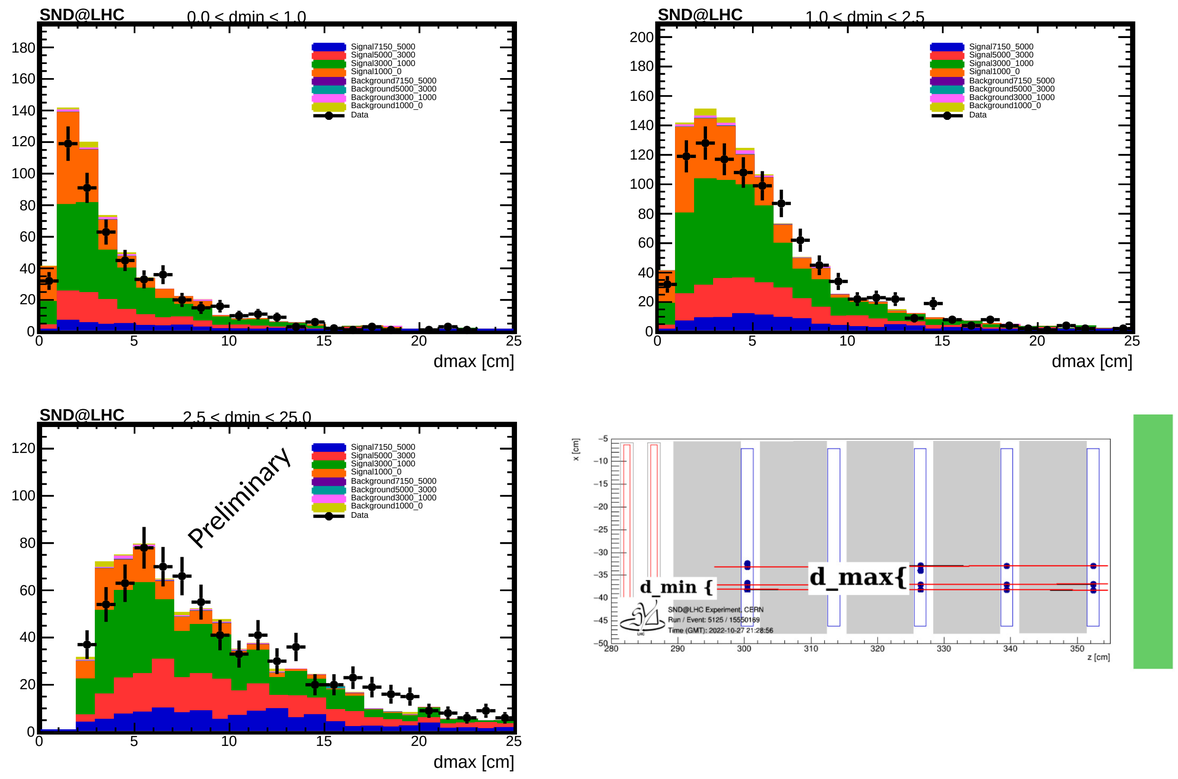

Figure 6. d_{max} distribution in d_{min} slices for MC and data. A clear correlation is visible between these parameters that validates the trident hypothesis. Inset shows the d_{max} and d_{min} definition.

- The contribution of background processes is estimated to be 3.75 %.
- The detection efficiency is parametrized as a function of vertex position.

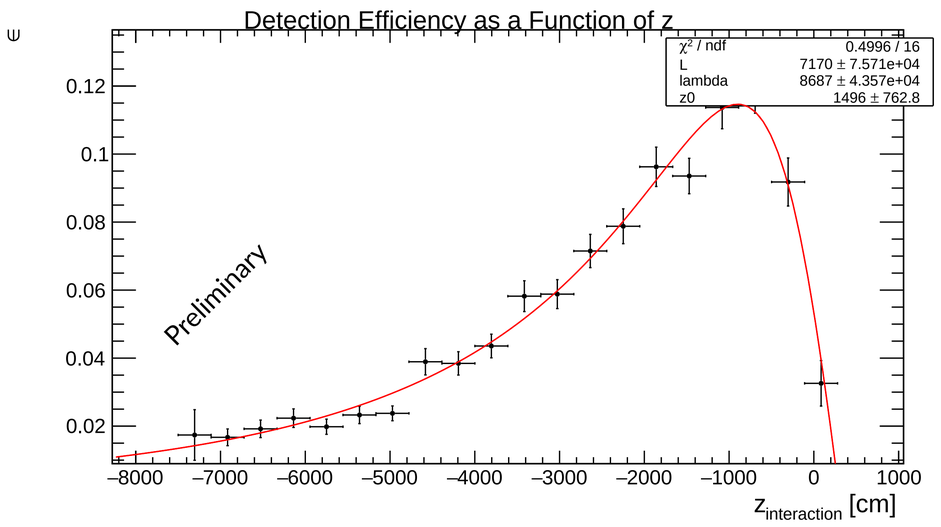

Figure 7. Detection efficiency as a function of z coordinate of the vertex position.

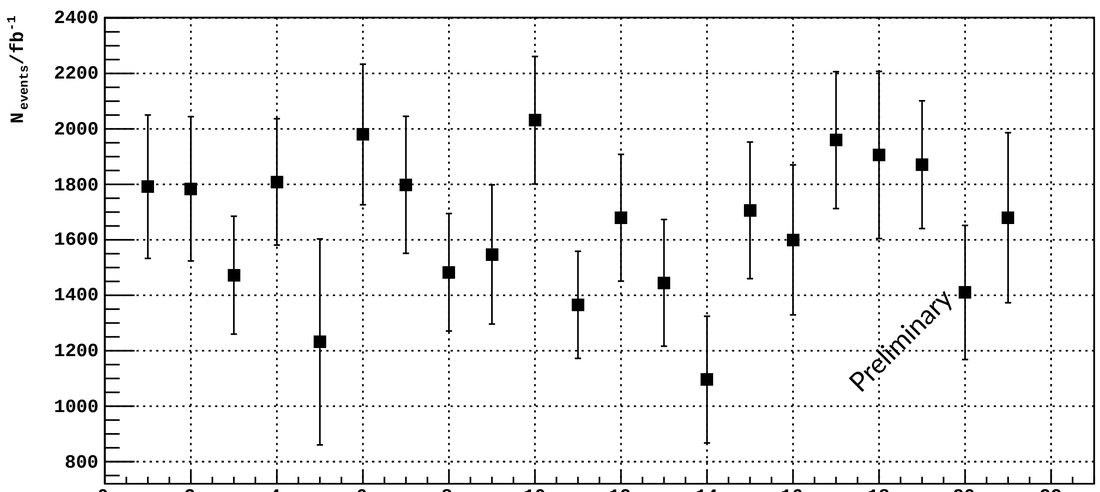

Figure 8. Background subtracted and efficiency corrected number of observed events in different runs. Errors are only statistical.

Summary

- The first observation of muonic trident events at the LHC has been reported.
- MC expectation of flux-averaged muonic trident cross section in the rock is 281 nb per nucleus.
- The cross section extraction is ongoing using single muon event rates **[4]**.

References

[1] J. J. Russell et al., "Observation of muon trident production in lead and the statistics of the muon," *Phys. Rev. Lett.*, vol. 26, no. 2, p. 2, 1971.
[2] F. Maciuc et al., "Muon-pair production by atmospheric muons in CosmoALEPH," *Phys. Rev. Lett.*, vol. 96, p. 021801, 2006.
[3] S. Agostinelli *et al.*, "GEANT4—a simulation toolkit," *Nucl. Instrum. Meth. A* **506** (2003) 250–303.
[4] R. Albanese et al., "Measurement of the muon flux at the SND@LHC experiment," *Eur. Phys. J. C*, vol. 84, no. 90, 2024.