Resonances in $\bar{\nu}_e - e^-$ scattering at FLArE

based on arXiv:2112.03283 (PRD 2022)
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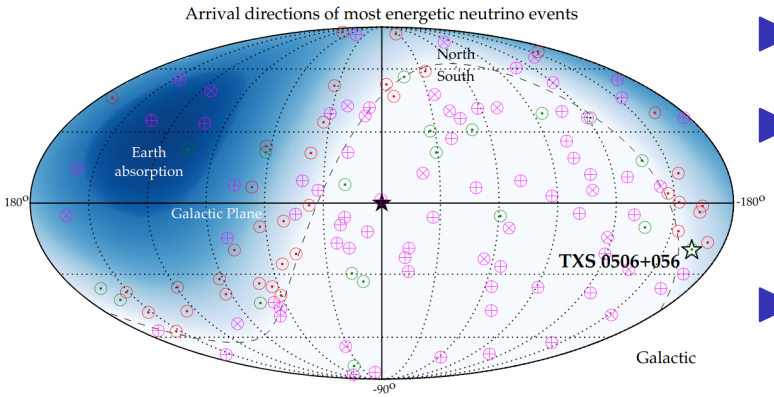
First Glashow Resonance Event at IceCube

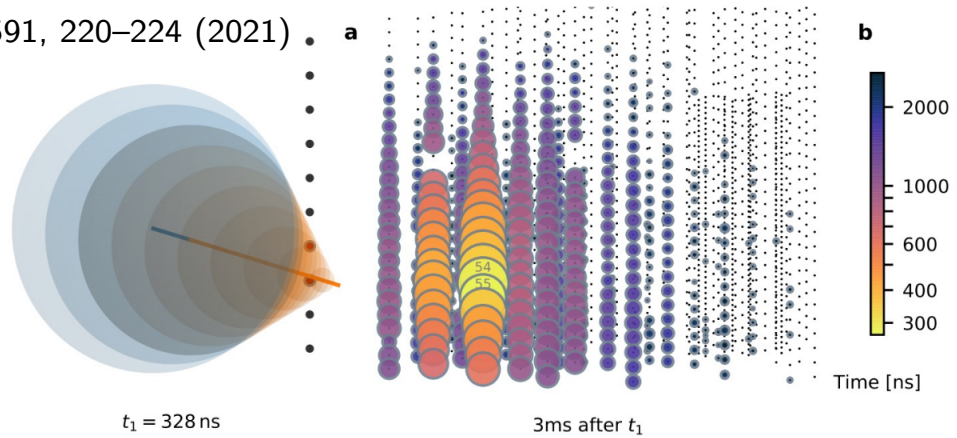
Bull. Am. Astron. Soc. 51, 185 (2019)



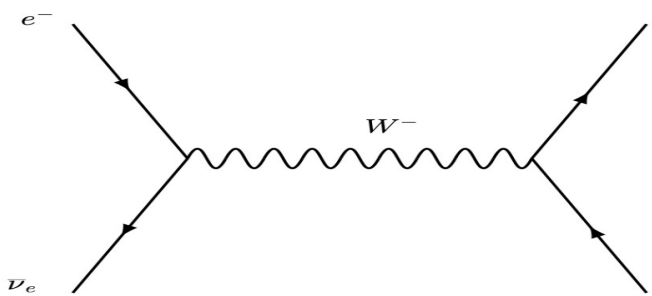
- $\mathcal{O}(100)$ upgoing tracks and HESE events
- Glashow resonance: cross section enhancement from on-shell W^- production
- $\sigma \propto \frac{1}{(E-E_0)^2+\Gamma^2}$, $E_0 = \frac{M_W^2}{2m_e} \approx 6.3$ PeV

- $\bar{\nu}_e$ in the astrophysical flux $\Longrightarrow$ way to distinguish ν from $\bar{\nu}$
- PeV partially contained events: shower with energy of 6.05 ± 0.72 PeV
- $\mathcal{O}$(PeV) cosmic muon as BKG yields 10^{-7} events $\Longrightarrow$ rejected at 5σ

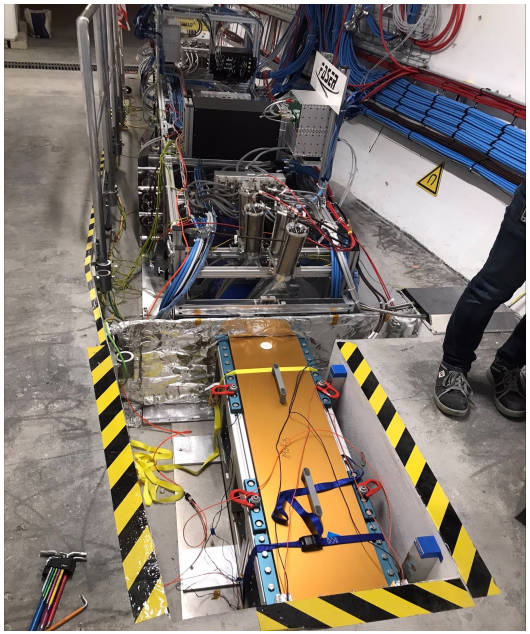
Nature 591, 220–224 (2021)



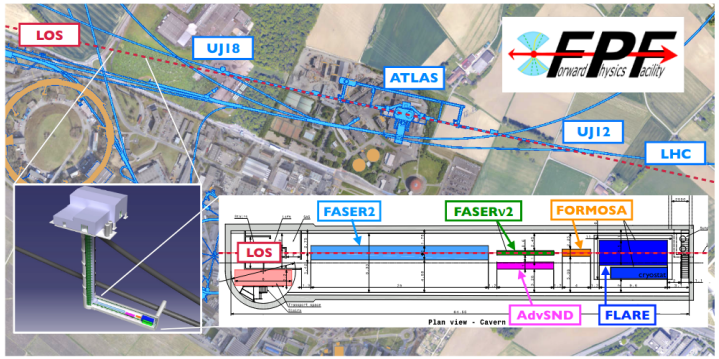
S. Glashow, Phys. Rev. 118, 316



First Neutrino Interaction Candidates at LHC

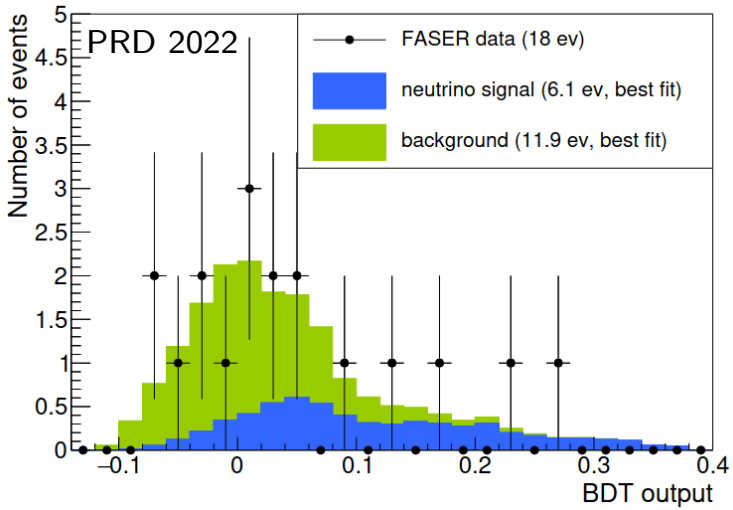


- FASERν is a 1.2 tonne detector located 480 m from the ATLAS interaction point containing emulsion films and tungsten plates

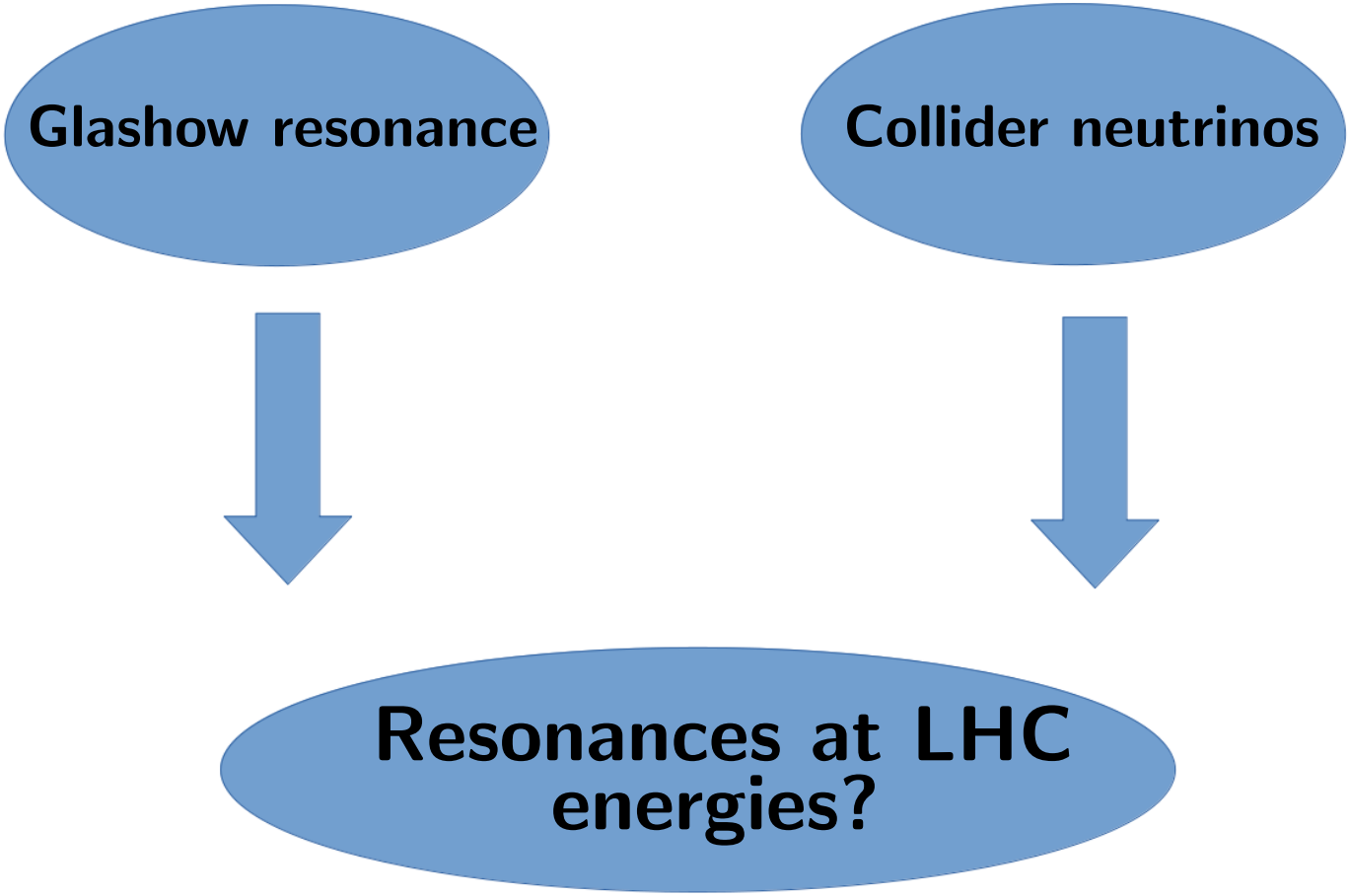


- FASERν2 will be a 10 tonne detector at FPF

- 2018 Pilot Run with 29 kg target during LHC Run 2
- background-only hypothesis is disfavored at $2.7\sigma \implies$ hint for ν-N scattering events



"Glashow-like" Events at Low Energies?



"Glashow-like" Events at Low Energies?

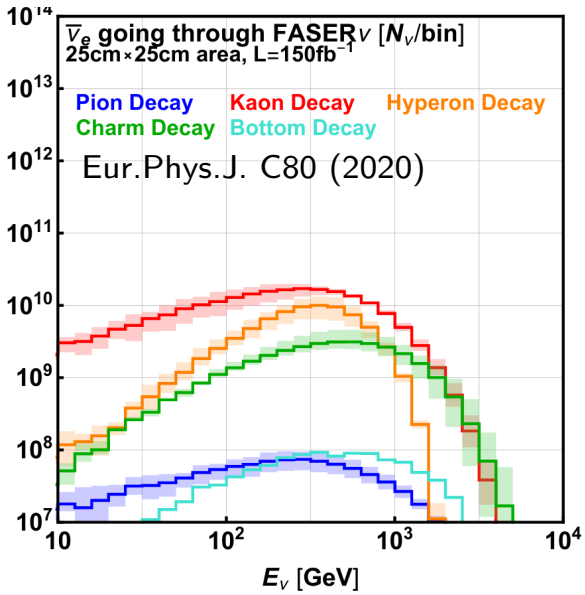
$$\bar{\nu}_e e^- \to R^-$$

- electrically charged
- no baryon number
- no lepton number

W^- works but mesons as well!

$$s = 2E_\nu m_e \sim \text{GeV}^2$$

- there are many GeV-scale charged mesons



"Glashow-like" Events at Low Energies?

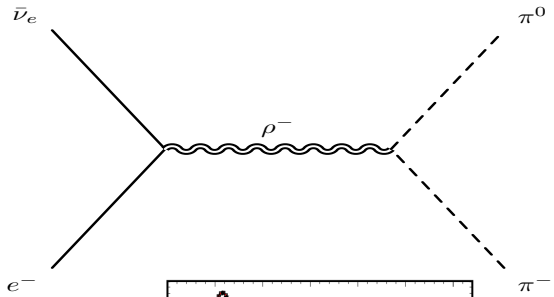
$$\bar{\nu}_e e^- \to \text{meson} \to \text{anything}$$

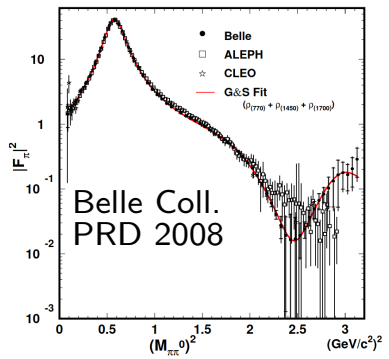
Breit-Wigner: $\sigma_{\rm res} = (2J+1)8\pi\,\Gamma^2\,{\rm Br}_{\rm in}\,{\rm Br}_{\rm fi}\,\dfrac{s/M^2}{(s-M^2)^2+M^2\Gamma^2}$

- pseudoscalar mesons: $\Gamma(\mathfrak{m} \to \bar{\nu}_e e^-) = \dfrac{G_F^2}{8\pi} f^2 m_{lep}^2 M \left(1 - \dfrac{m_{lep}^2}{M^2}\right) |V_{\rm CKM}|^2$
- vector mesons: $\Gamma(\mathfrak{m} \to \bar{\nu}_e e^-) = \dfrac{G_F^2}{12\pi} f^2 M^3 |V_{\rm CKM}|^2$

$$\bar{\nu}_e e^- \to \rho^- \to \pi^0\pi^-$$

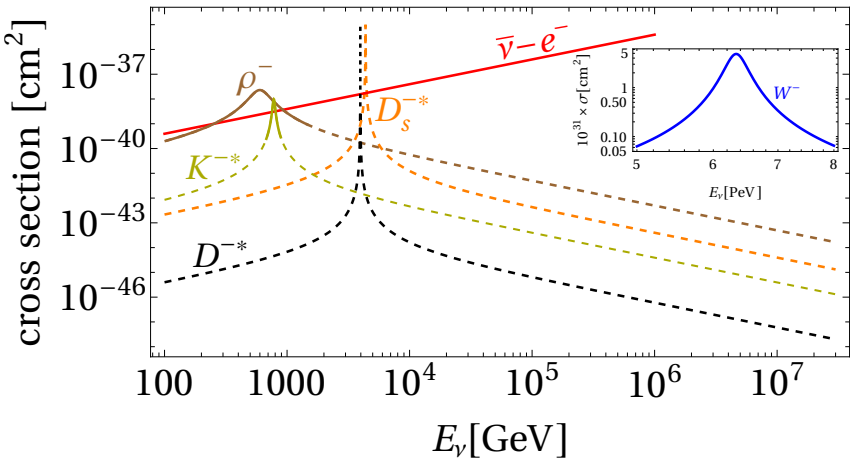
$$E_\nu^{res}(\rho^-) = \frac{(770\text{MeV})^2}{2m_e} \approx 580\ \text{GeV}$$
$$E_\nu^{res}(K^{-*}) \approx 780\ \text{GeV}$$





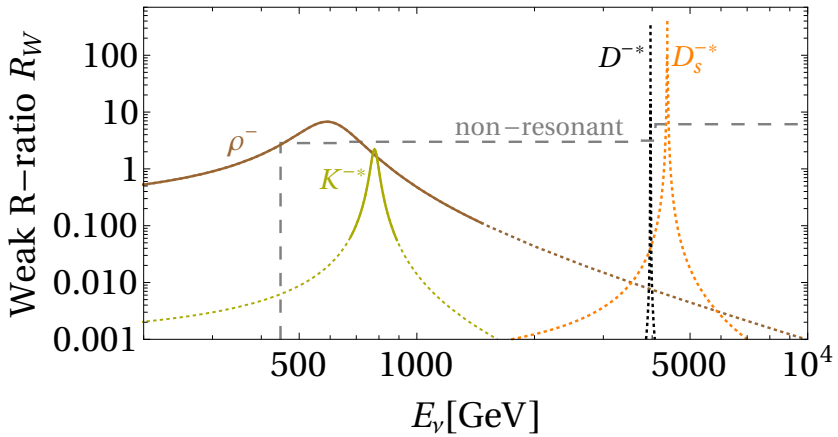
- alternative calculation using
  $\langle \pi^-(k_1)\pi^0(k_2)|V_\mu|0\rangle = (k_1-k_2)_\mu F(q^2)$

Event Rates

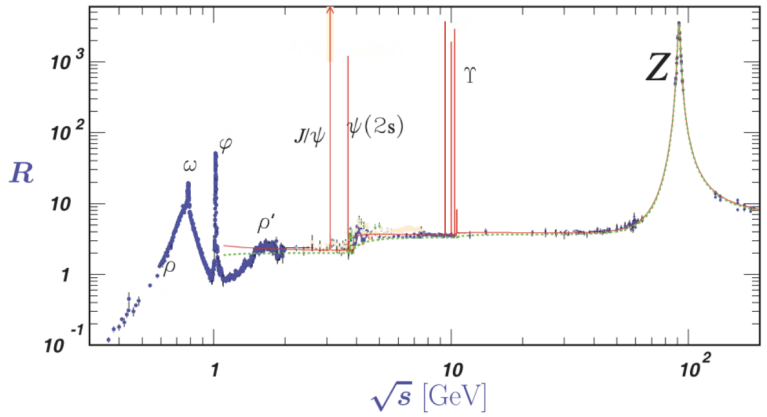


Experiment	ρ^-, $\pm\Gamma/2$	ρ^-, $\pm 2\Gamma$	K^{-*}, $\pm\Gamma/2$	K^{-*}, $\pm 2\Gamma$
FASERν	0.3	0.5	–	–
FASERν2	23	37	0.7	3
FLArE-10	11	19	0.3	2
FLArE-100	63	103	2	8
DeepCore	3 (1)	5 (2)	–	–
IceCube	8 (40)	17 (83)	–	–

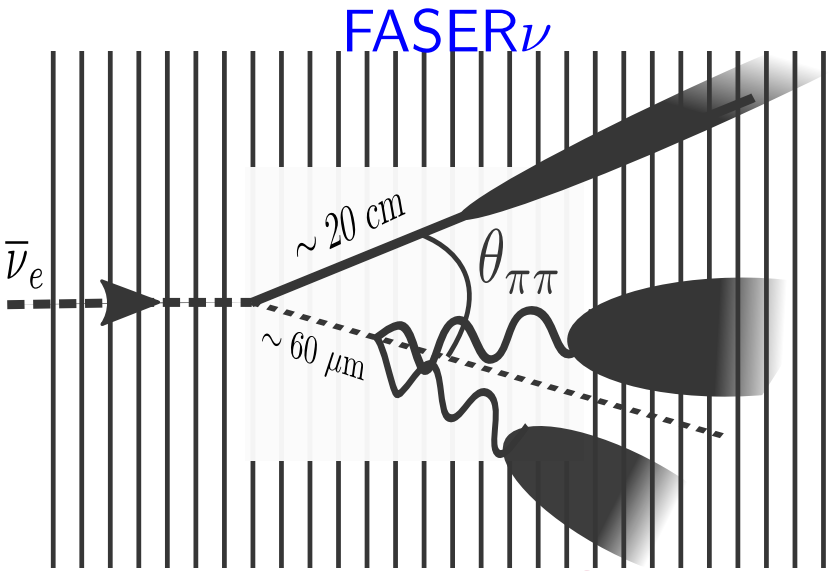
$$R_W = \frac{\sigma(\bar{\nu}_e e^- \to \text{hadrons})}{\sigma(\bar{\nu}_e e^- \to \bar{\nu}_\mu \mu^-)}$$



$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



Signature of ρ^- Resonance



S:B $\approx 1:5000 \Rightarrow$ S:B > 1

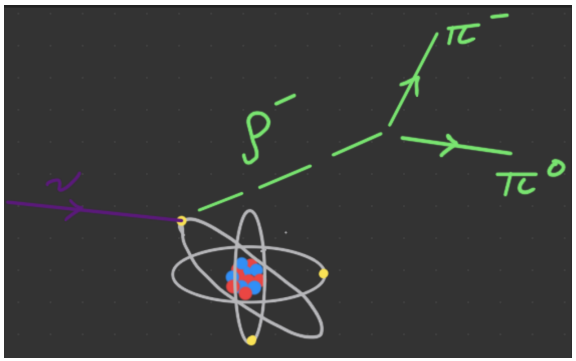
- cut on $E_{\pi^-} + E_{\pi^0}$ to lie near 580 GeV
- $\theta_{\nu N} \sim 1/\gamma_{\rm cm} \sim 28\ {\rm mrad} \times \sqrt{600\ {\rm GeV/E_\nu}}$ for deep inelastic scattering
- $\theta_{\pi\pi} = 28\ {\rm mrad}\sqrt{m_e/m_N} \times \sqrt{600\ {\rm GeV/E_\nu}} = 0.7\ {\rm mrad} \times \sqrt{600\ {\rm GeV/E_\nu}}$ for $\bar{\nu} - e$ scattering
- cut on charged track and photon multiplicity
- reconstruct the invariant mass of the $\pi^0\pi^-$ pair, $m^2_{\pi\pi} = m^2_{\pi^0} + m^2_{\pi^-} + E_{\pi^0}E_{\pi^-}\theta^2_{\pi\pi}$, and require it to lie within $\Gamma_\rho \sim 150$ MeV of $m_\rho \approx 770$ MeV

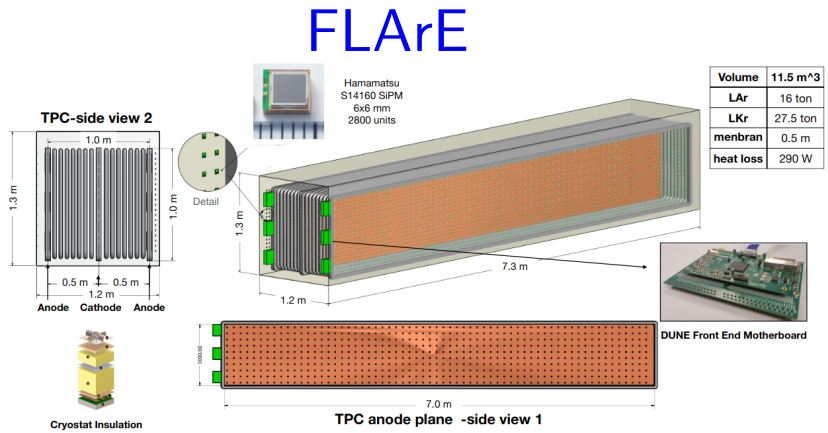
- Sweeper Magnet for FASERν2

IceCube:

- large background and difficult to identify $\pi^-\pi^0$ topology
- $S : B \approx 1 : 100$

Signature of ρ^- Resonance at FLArE





- given $\mathcal{O}(\text{mrad})$ angular resolution π^- track and $\gamma\gamma$ would overlap
- nevertheless, efficient PID using dE/dx can be employed

(i) for the first 10 cm or so only the π^- will be visible

(ii) the emitted photons will not appear until only $\mathcal{O}(10)$ cm down the track where each of the γ will convert to e^+e^- pair

(iii) bremsstrahlung photons produced by the π^- will also pair produce

- forward-pointing "hadronic flashlight" that has discrete jumps in dE/dx and no hadronic activity from interaction vertex

Summary

- The production of charged-meson resonances in $\bar{\nu}_e - e$ scattering is an interesting and previously inaccessible SM neutrino reaction

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- The production of charged-meson resonances in $\bar{\nu}_e - e$ scattering is an interesting and previously inaccessible SM neutrino reaction
- We estimate $\mathcal{O}(100)$ ρ^- meson resonance events at proposed FPF detectors
- Detection prospects at FLArE are promising? More ideas?