arXiv:2112.03283

Resonances in $\overline{\nu}_e - e^-$ scattering below a TeV

Vedran Brdar,[1,2,*] André de Gouvêa,[1,†] Pedro A. N. Machado,[2,‡] and Ryan Plestid[3,2,§]

[1] *Northwestern University, Department of Physics & Astronomy, 2145 Sheridan Road, Evanston, IL 60208, USA*
[2] *Theoretical Physics Department, Fermilab, P.O. Box 500, Batavia, IL 60510, USA*
[3] *Department of Physics and Astronomy, University of Kentucky, Lexington, KY 40506, USA*

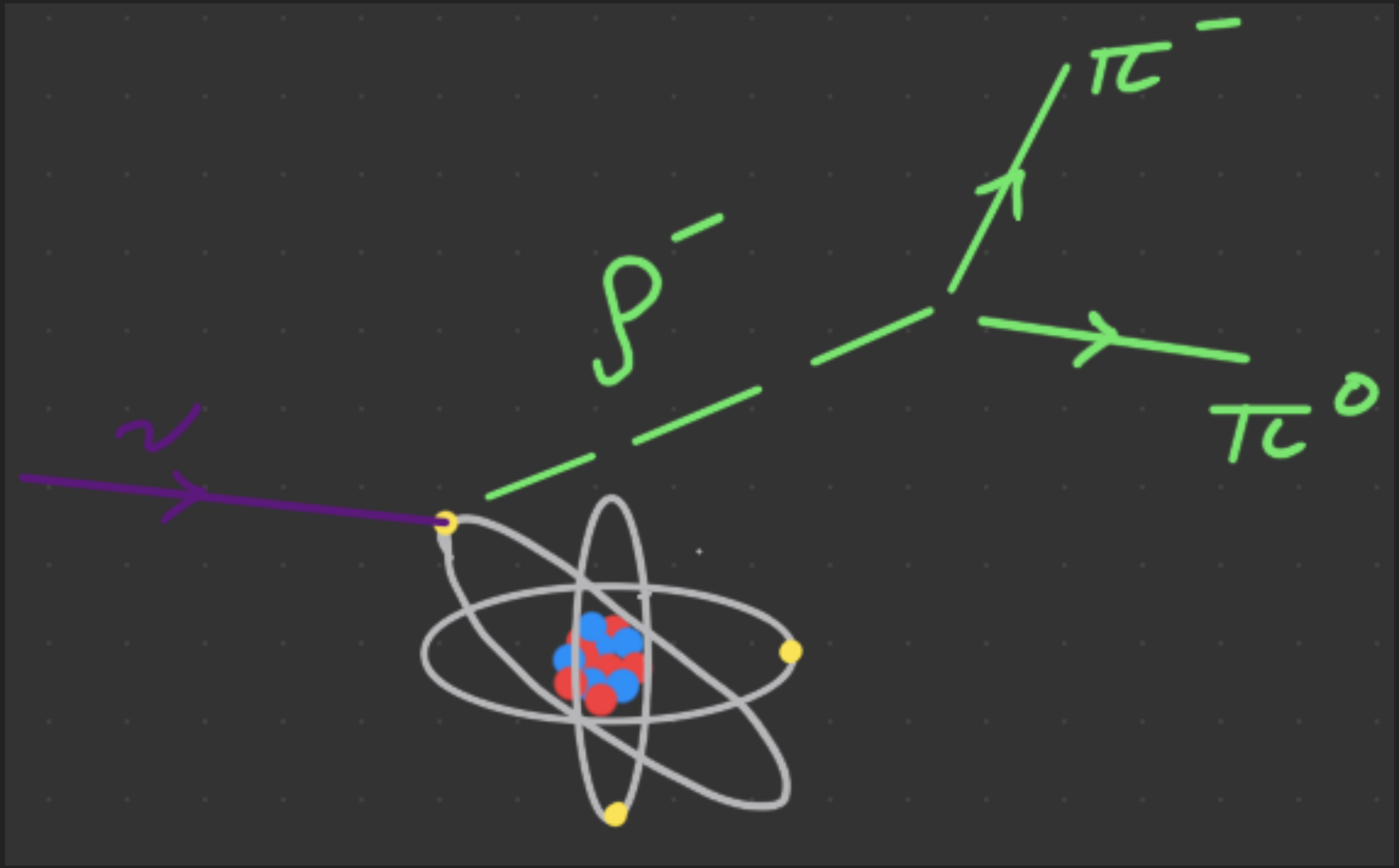
R. PLESTID | V. BRDAR | A. DE GOUVÊA | P. MACHADO

RESONANT ANTI-NEUTRINO ELECTRON SCATTERING AT THE FPF

Northwestern University

ELECTRON ANTI NEUTRINOS CAN ANNIHILATE AGAINST ATOMIC ELECTRONS

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



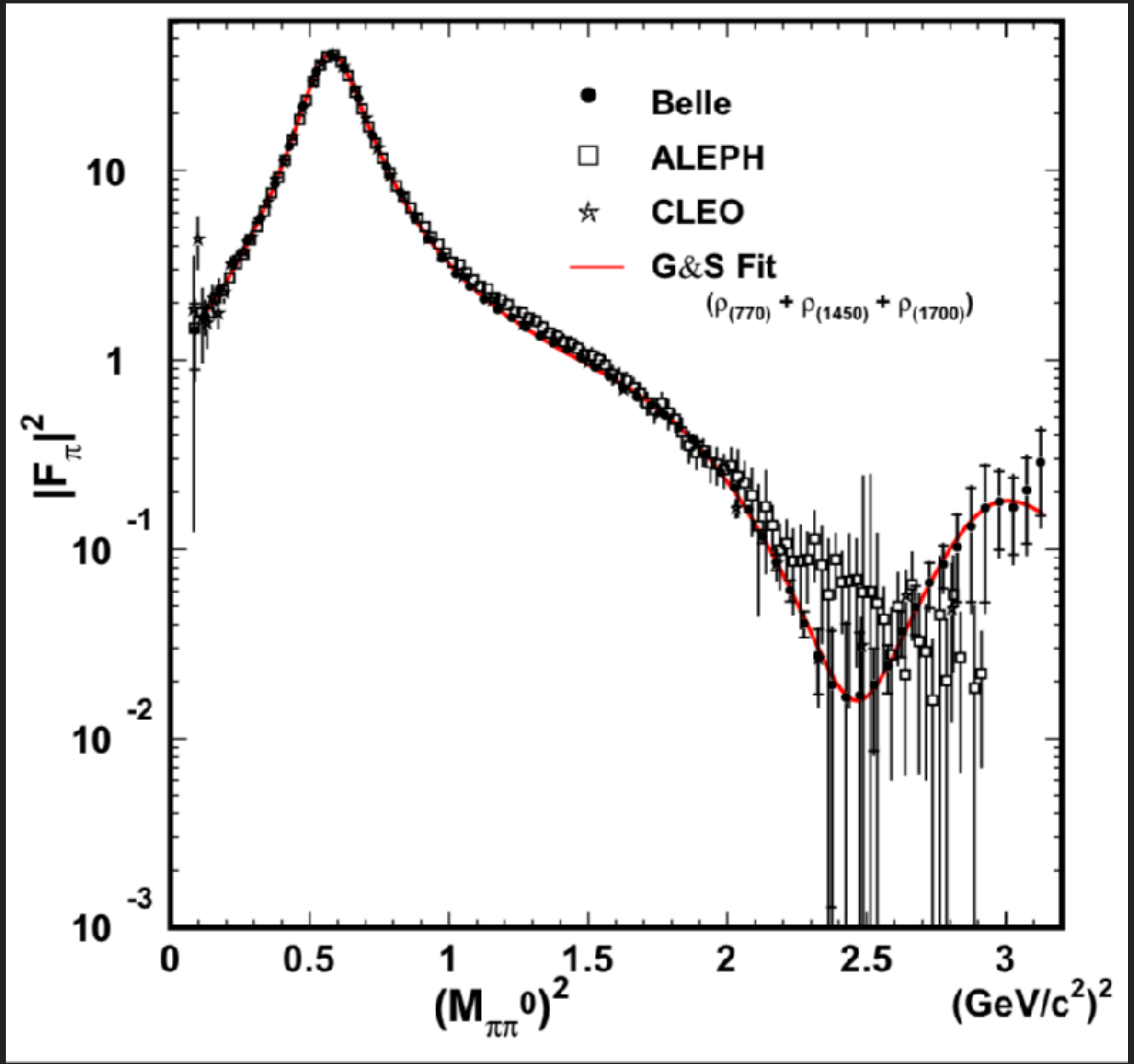
$$s = 2m_e E_\nu + m_e^2$$

$$E_\nu \approx 580 \text{ GeV}$$

DOMINANT MEASUREMENT CHANNEL IS A TWO-PION FINAL STATE

$$\langle \pi^-(k_1)\pi^0(k_2)\,|\,V_\mu\,|\,\Omega\rangle = F_1(Q^2)\ (k_1 - k_2)_\mu$$

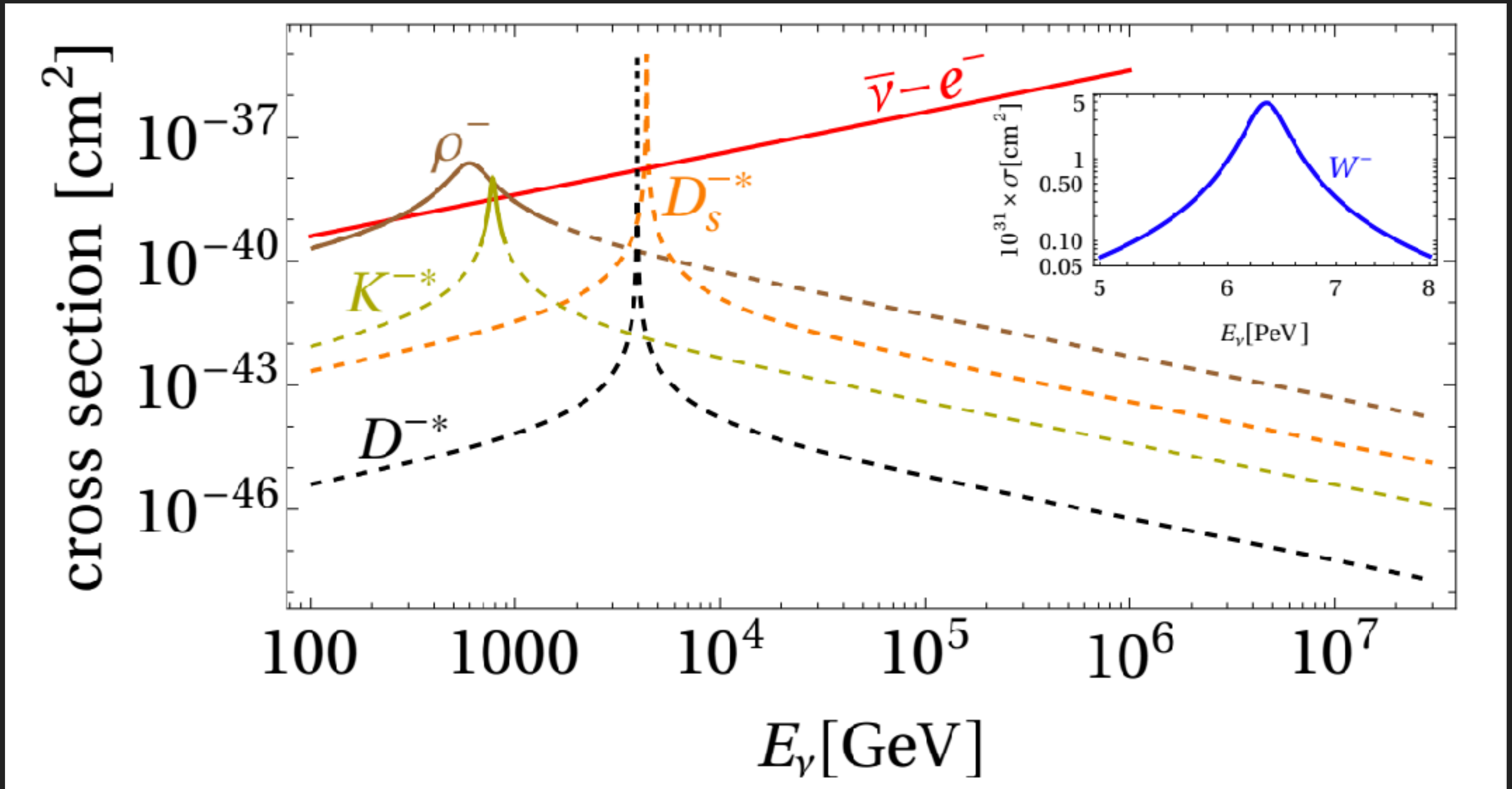
- Hadronic physics is simple. Just one form factor enters (can be extracted from data).



- BELLE Collaboration, PHYSICAL REVIEW D 78, 072006 (2008)

RATE ESTIMATES ARE PROMISING

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

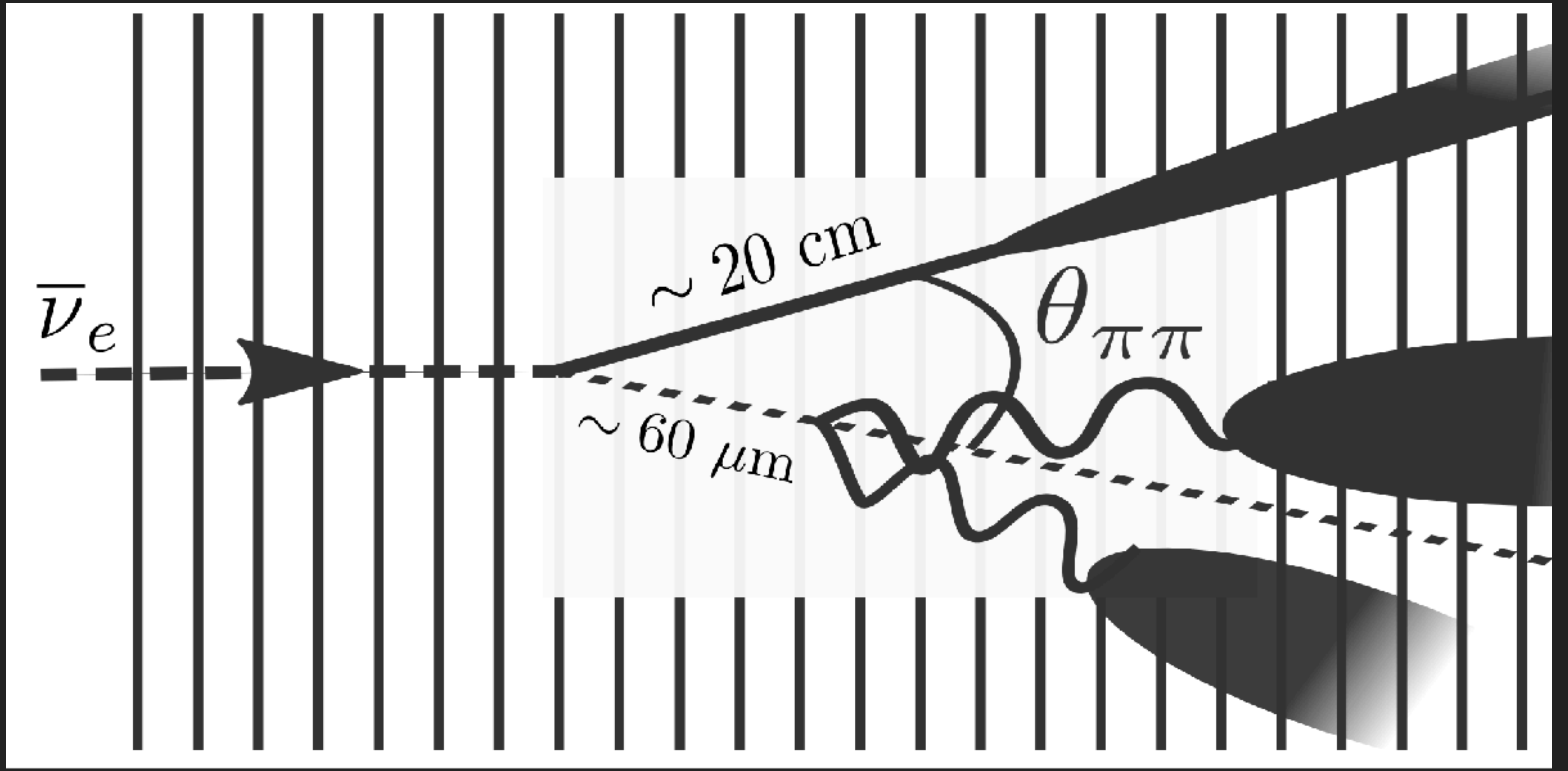


- Larger versions of FASERν can see ~10s of events.

"SMOKING GUN" SIGNATURE OF ρ^- RESONANCE

- Hadronic and/or EM shower from highly relativistic π^-.
- Displaced π^0 decay with two EM showers.
- Opening angle is small

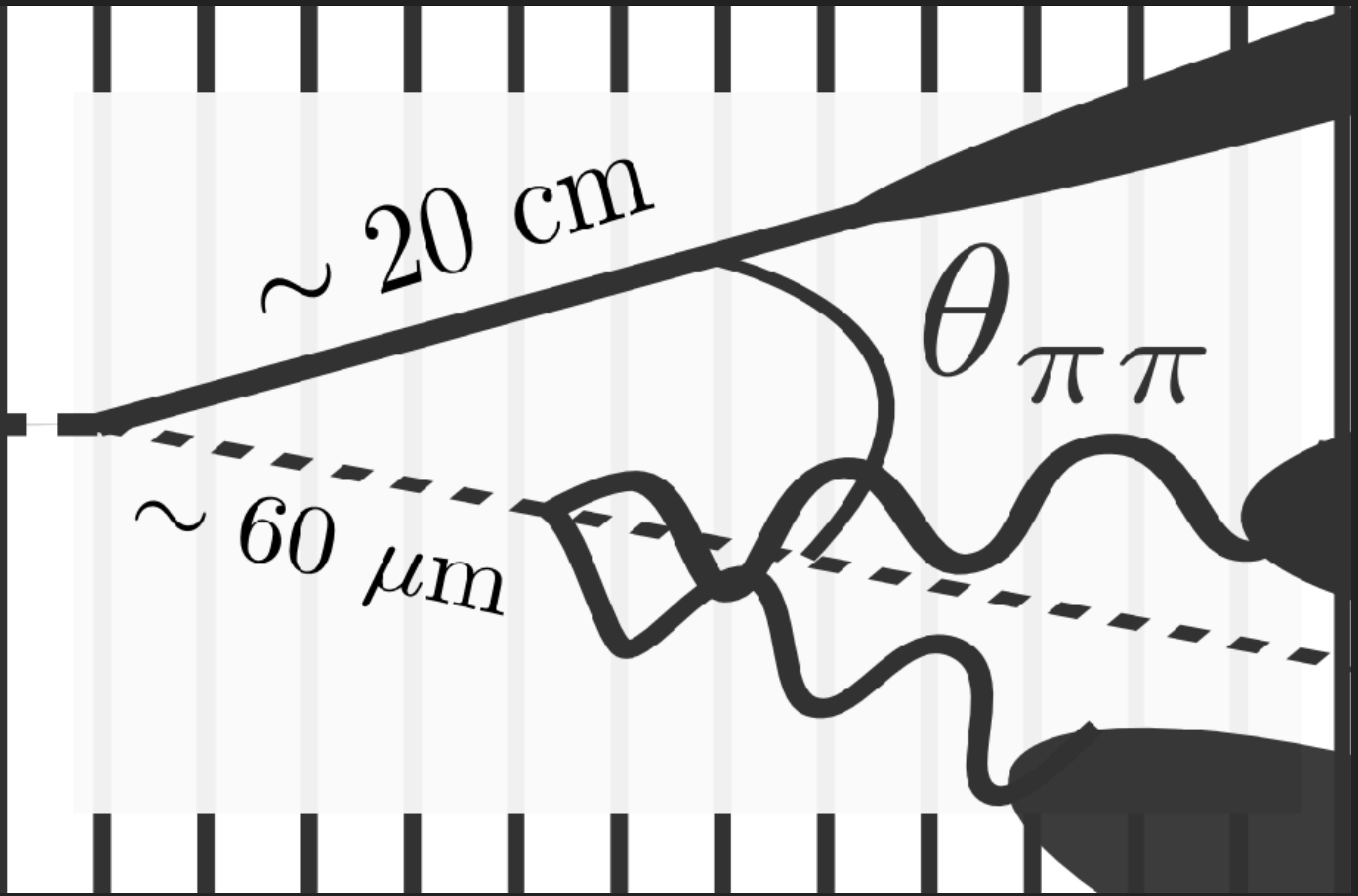
$$\theta_{\pi\pi} \sim \frac{1}{\gamma_{\rm cm}} \sim \frac{m_e}{m_\rho} \sim \frac{1}{1500}$$



KINEMATIC VARIABLES FOR CUTTING

$$\omega = E_1 + E_2 \qquad \theta_{\pi\pi}$$

$$m_{\pi\pi} \approx 2m_\pi^2 \; + \; E_1 E_2\, \theta_{\pi\pi}^2$$



$$\theta_{\pi\pi} = \text{ angle between center of EM tracks \& } \pi^- \text{ track}$$

KINEMATIC VARIABLES FOR CUTTING

1. Cut on ω. Demand reconstucted energy be close to resonant energy.

$$\omega = E_1 + E_2 \qquad \theta_{\pi\pi}$$

$$m_{\pi\pi} \approx 2m_\pi^2 \; + \; E_1 E_2 \, \theta_{\pi\pi}^2$$

$$\theta_{\pi\pi} = \text{ angle between center of EM tracks \& } \pi^- \text{ track}$$

KINEMATIC VARIABLES FOR CUTTING

$$\omega = E_1 + E_2 \qquad \theta_{\pi\pi}$$

$$m_{\pi\pi} \approx 2m_\pi^2 \; + \; E_1 E_2\, \theta_{\pi\pi}^2$$

1. Cut on ω. Demand reconstucted energy be close to resonant energy.
2. Cut on the angle. Require $\theta_{\pi\pi} \lesssim 3 \text{ mrad.}$

$$\theta_{\pi\pi} = \text{ angle between center of EM tracks } \& \; \pi^- \text{ track}$$

KINEMATIC VARIABLES FOR CUTTING

$$\omega = E_1 + E_2 \qquad \theta_{\pi\pi}$$

$$m_{\pi\pi} \approx 2m_\pi^2 \; + \; E_1 E_2 \, \theta_{\pi\pi}^2$$

1. Cut on ω. Demand reconstucted energy be close to resonant energy.
2. Cut on the angle. Require $\theta_{\pi\pi} \lesssim 3 \text{ mrad.}$
3. Cut on chaged track and photon multiplicity. This is very low here.

$$\theta_{\pi\pi} = \text{ angle between center of EM tracks \& } \pi^- \text{ track}$$

KINEMATIC VARIABLES FOR CUTTING

$$\omega = E_1 + E_2 \qquad \theta_{\pi\pi}$$

$$m_{\pi\pi} \approx 2m_\pi^2 \; + \; E_1 E_2 \, \theta_{\pi\pi}^2$$

1. Cut on ω. Demand reconstucted energy be close to resonant energy.
2. Cut on the angle. Require $\theta_{\pi\pi} \lesssim 3 \text{ mrad.}$
3. Cut on chaged track and photon multiplicity. This is very low here.
4. Use reconstructed invariant mass. Should lie close to rho resonance.

$$\theta_{\pi\pi} = \text{ angle between center of EM tracks } \& \; \pi^- \text{ track}$$

PROSPECTS AT OTHER EXPERIMENTS

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

FLArE

- Event rates are reasonably high, but resolution is much lower.
- Background mitigation strategies are more difficult.

IceCube

- Resolution is a huge problem. Large backgrounds.
- Signature will be cascade like. Difficult to identify two pion topology.

SUMMARY

1. Rho-meson resonant events should (will) happen in the FASERν(2) detector, as well as FLArE.

2. In nuclear emulsion detectors we are optimistic that event-by-event detection can take place.

3. Key tools are spatial, angular, and energy resolution & PID capabilities.

OUTLOOK

1. Resonant rho production is a SM target (guaranteed signal) to reach for & motivates new detection topology.

2. Searching for resonant rho production can motivate new search strategies (spin off value).

3. This measurement can be a standard candle for FASERν2. Event-by-event flavor tagging of $\bar{\nu}_e$.