Identifying Neutrino Flavors in Radio Neutrino Telescope Experiments

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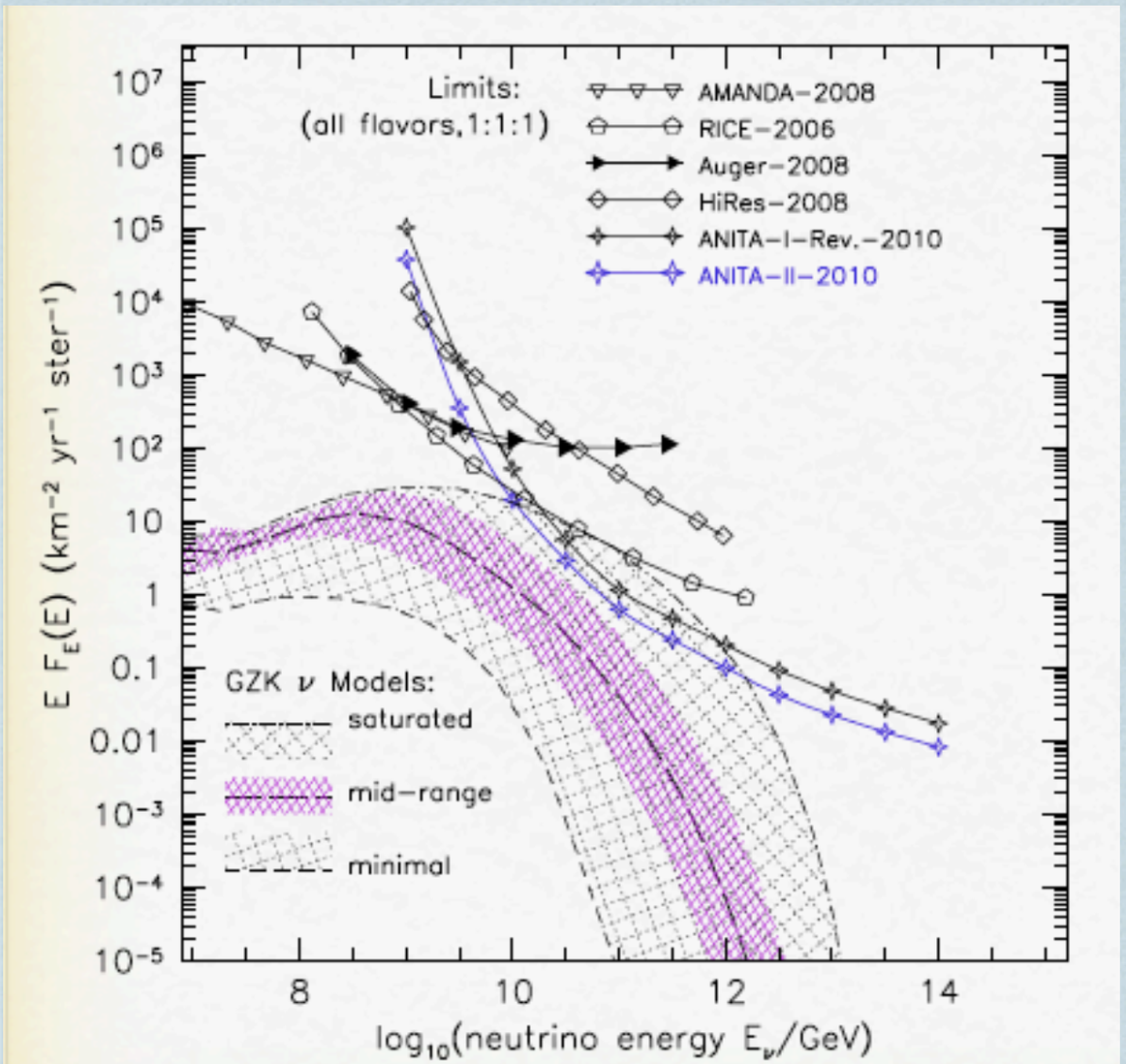
Cosmogenic Neutrinos



curtesy to: ANITA

- UHE protons interact CMB photons
- $(\nu_e, \nu_\mu, \nu_\tau)_O=(1, 2, 0)$ at the source
- $(\nu_e, \nu_\mu, \nu_\tau)=(1, 1, 1)$ on Earth

Askaryan Radio Array (ARA)

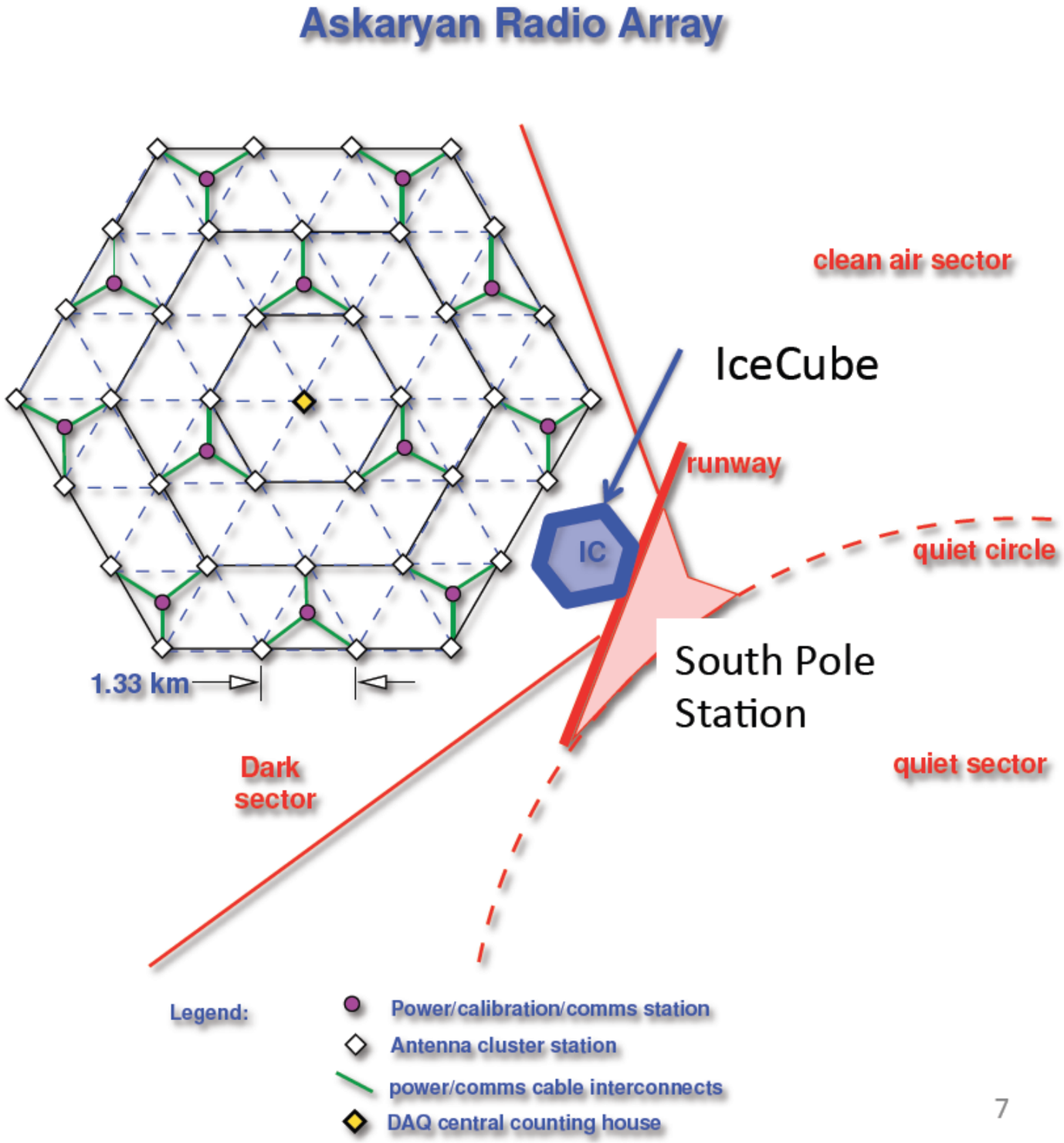
37 detector stations

- **Each station has 4 strings of 200m depth**
- **Each string has 2 Vpol + 2 Hpol broadband, deep antennas (200 MHz - 1 GHz)**
- **Area: ~80 km^2**

Depth of ice sheet at the South Pole: 2.8km

Effective Volume at high energies:

~2.5km*80km^2 = 200 km^3

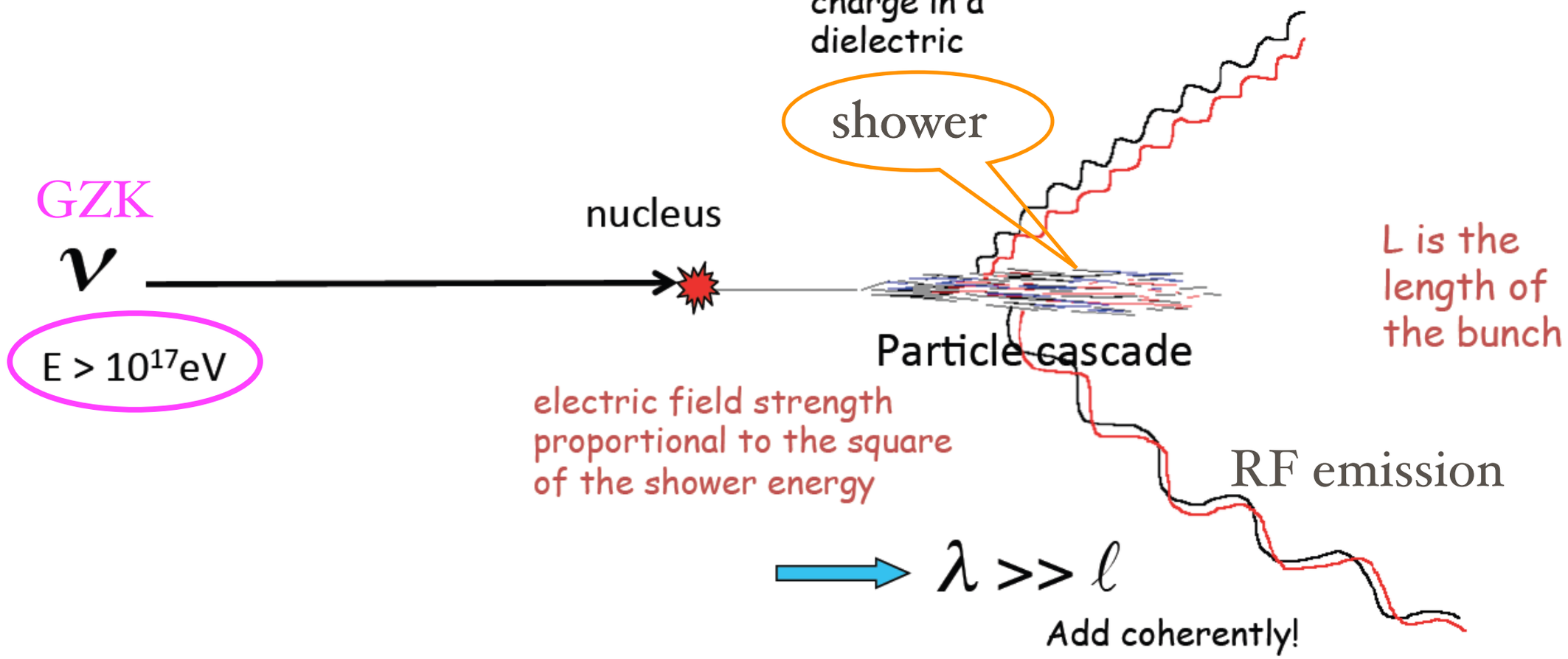


Detection mechanism proposed by G. Askaryan (1962):
Measure the coherent RF signal generated by neutrino interaction in dielectric media (such as ice)

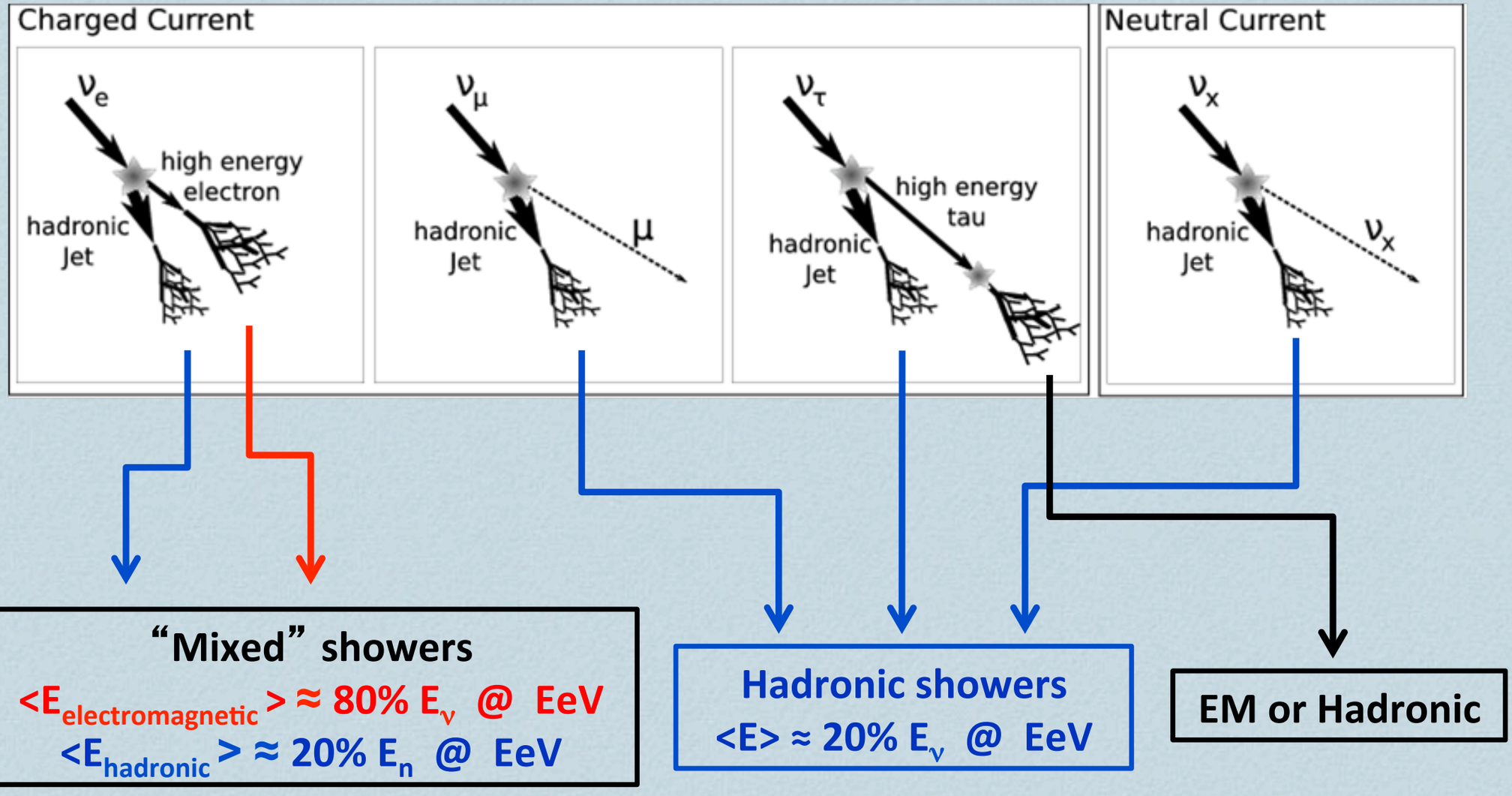
charge asymmetry in particle shower development results in a 20% excess of electrons over positrons in a particle shower

→ moves as a compact bunch, a few cm wide and ~1cm thick → Moving net charge in a dielectric

→ wavelengths shorter than the bunch length suffer from destructive interference



ν-induced showers

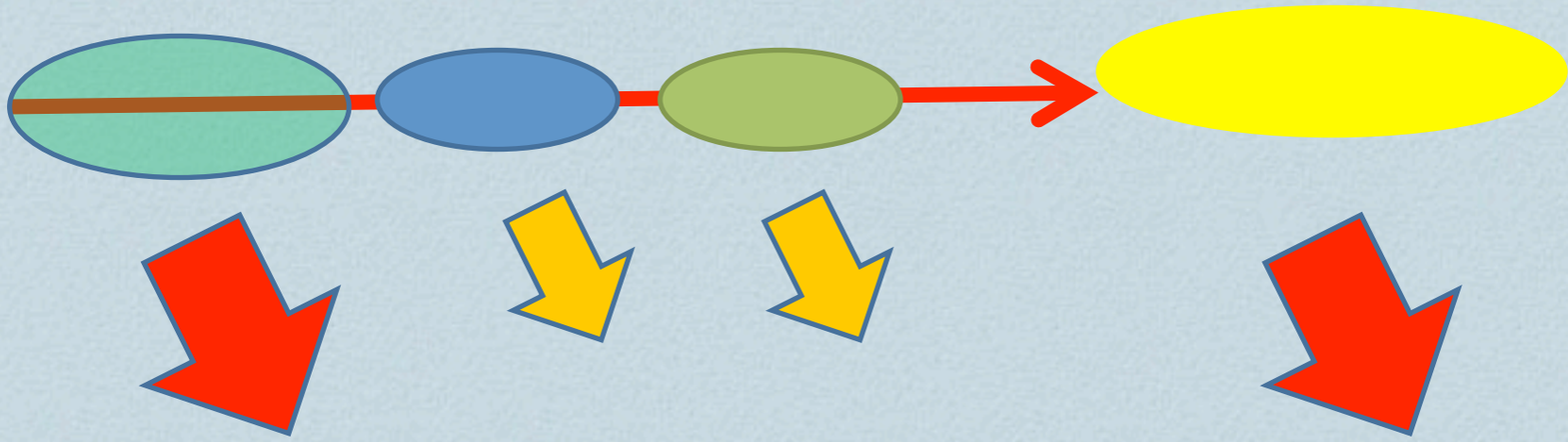


Neutrino Signals

Neutrino flavor	ν_e	ν_μ	ν_τ
Neutral current	Hadronic	Hadronic	Hadronic
Changed current	Hadronic EM shower	Hadronic propagation	Hadronic propagation

- Charged current induced leptons produce observable signals
- Electrons induce electromagnetic (EM) showers--ν_e detection
- Muons/Tau leptons propagate through matters and lose energy leaving behind tracks

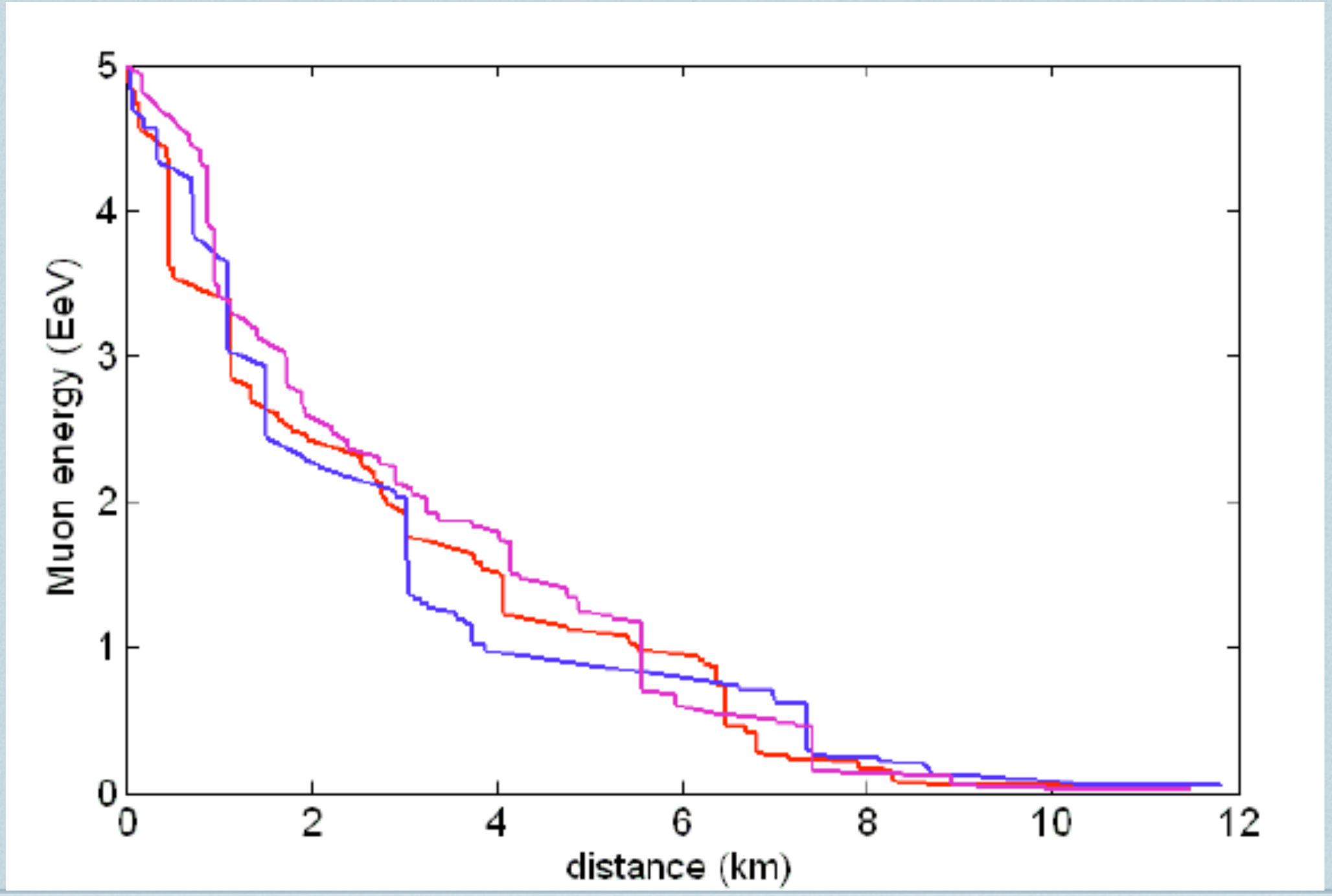
Track in Ice



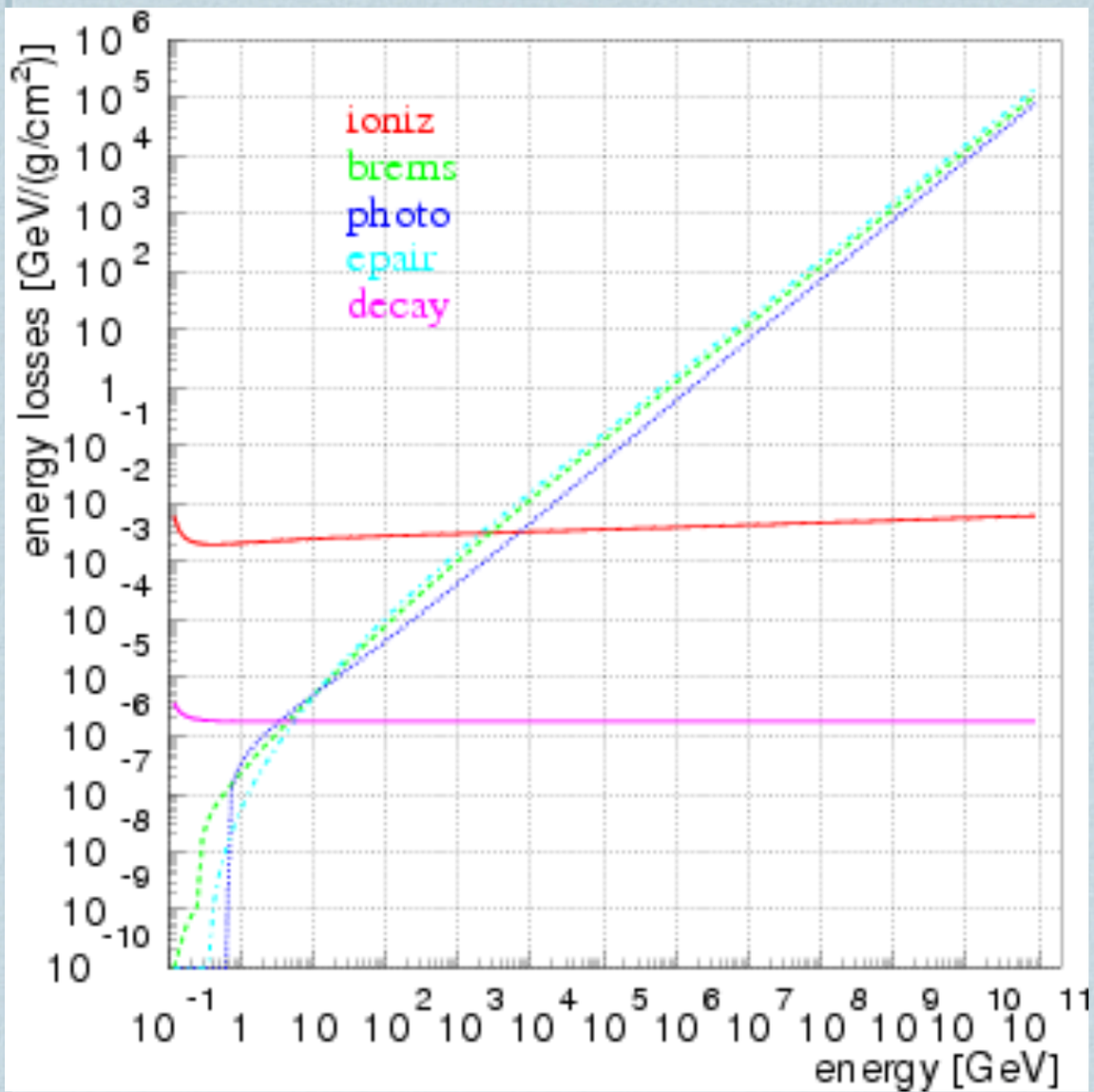
$$\left[\frac{dE}{dx}(E)\right]_{Total} = \left[\frac{dE}{dx}(E)\right]_{Shower} + \left[\frac{dE}{dx}(E)\right]_{Cont.}$$

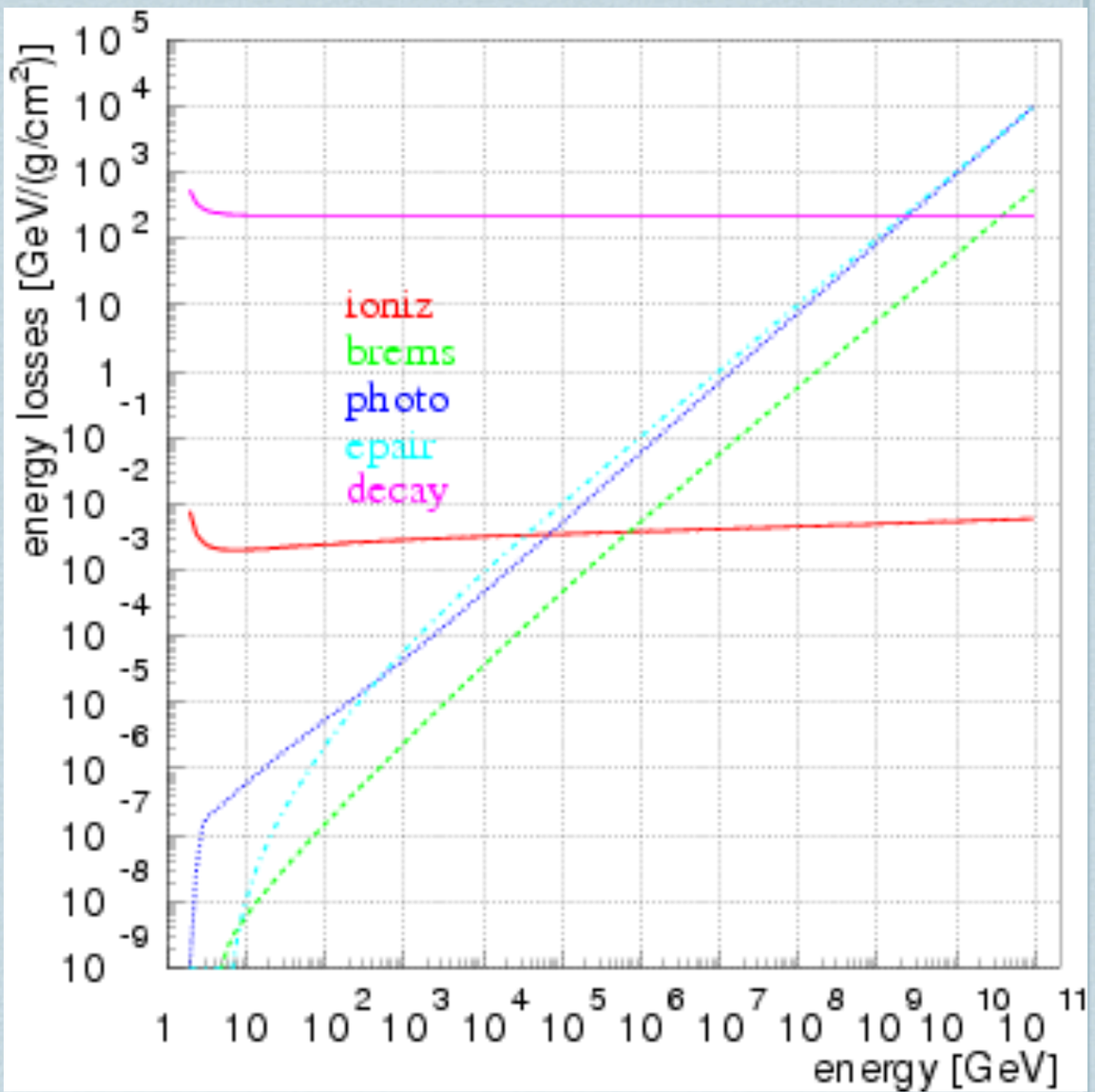
- Lepton energy loss: shower and constant loss
- Shower identification: EM and hadronic
- Track reconstruction

Lepton Energy Loss

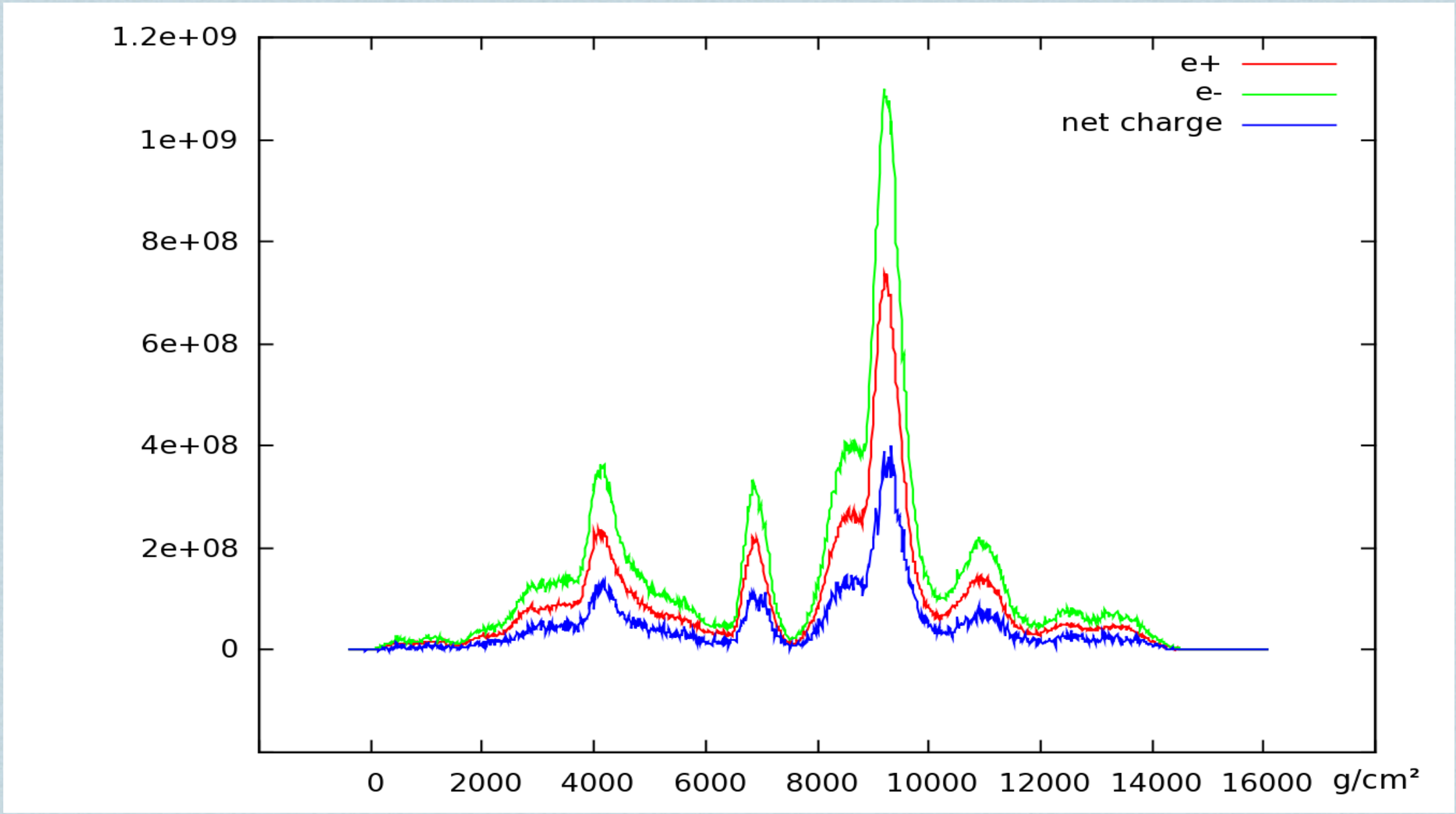


Lepton Energy Loss

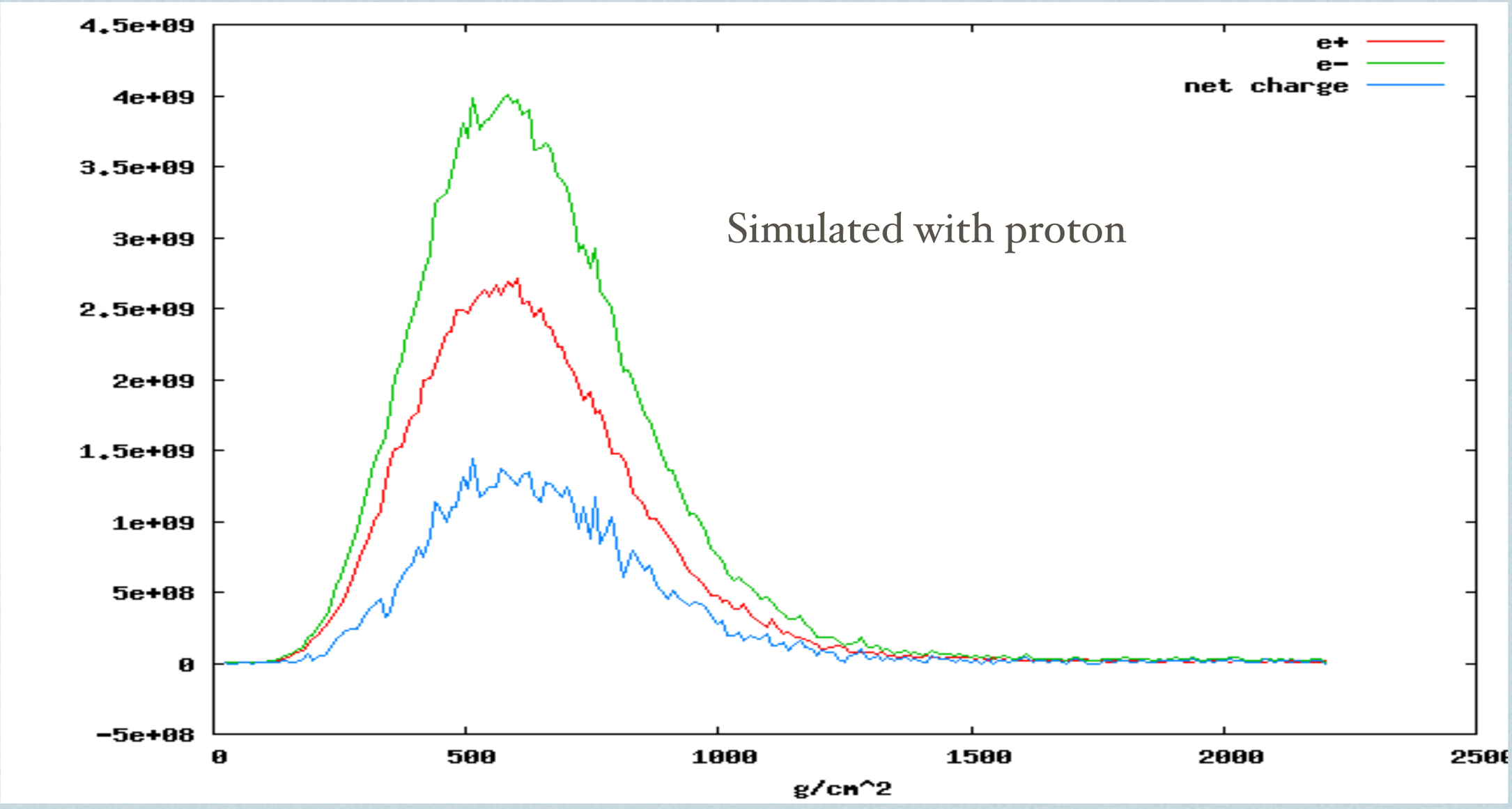




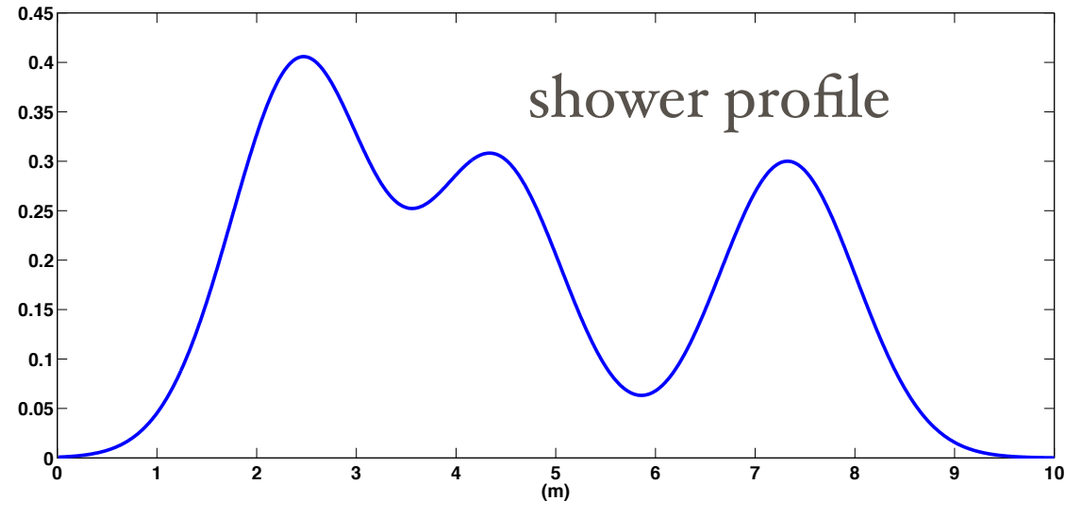
EM shower: 10^{19}eV

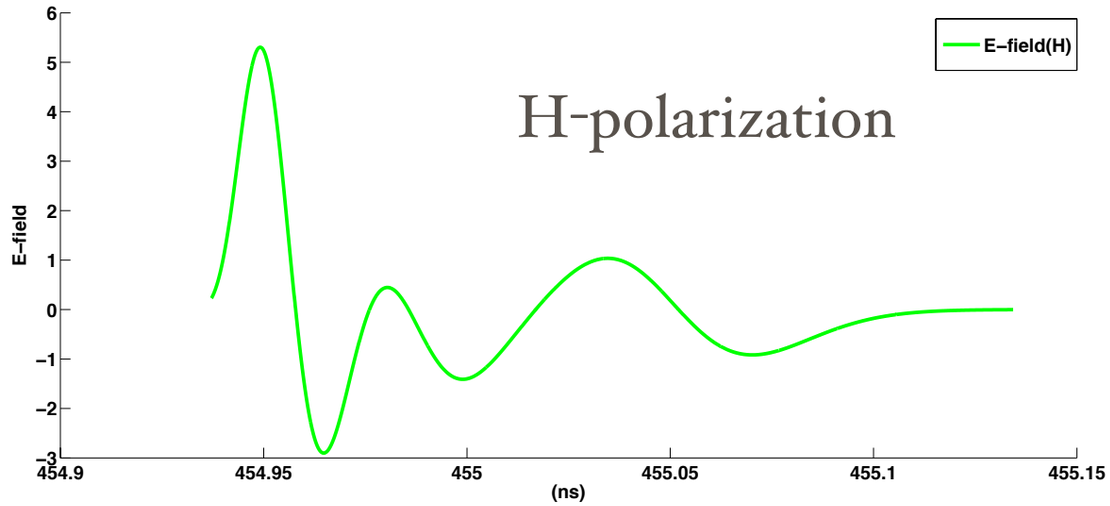


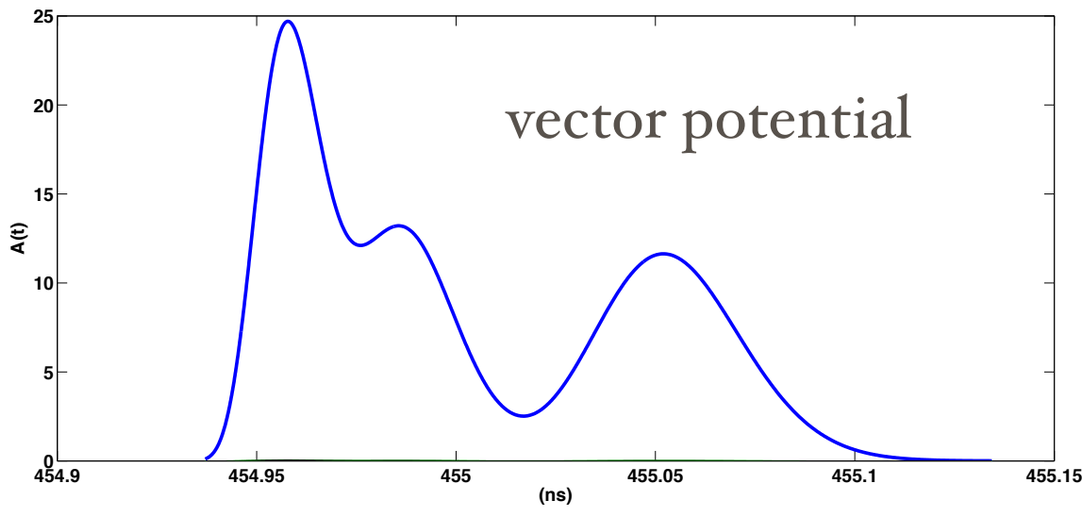
Hadronic shower: 10^{19}eV

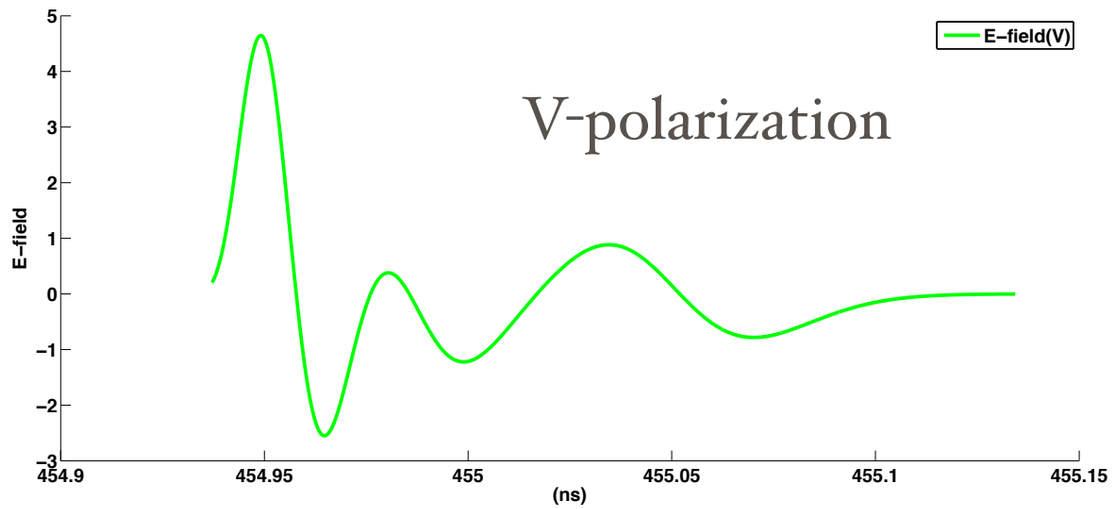


EM Signal

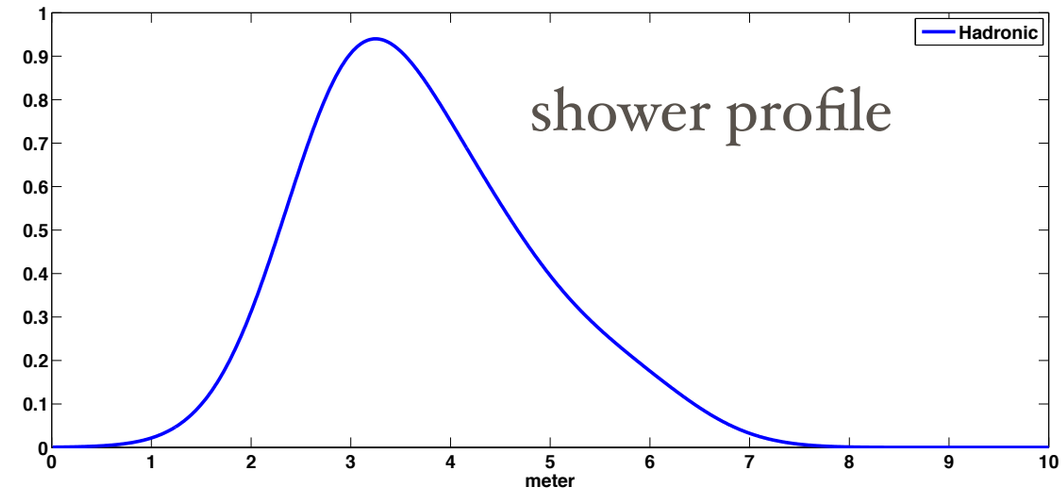

shower profile
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
(m)

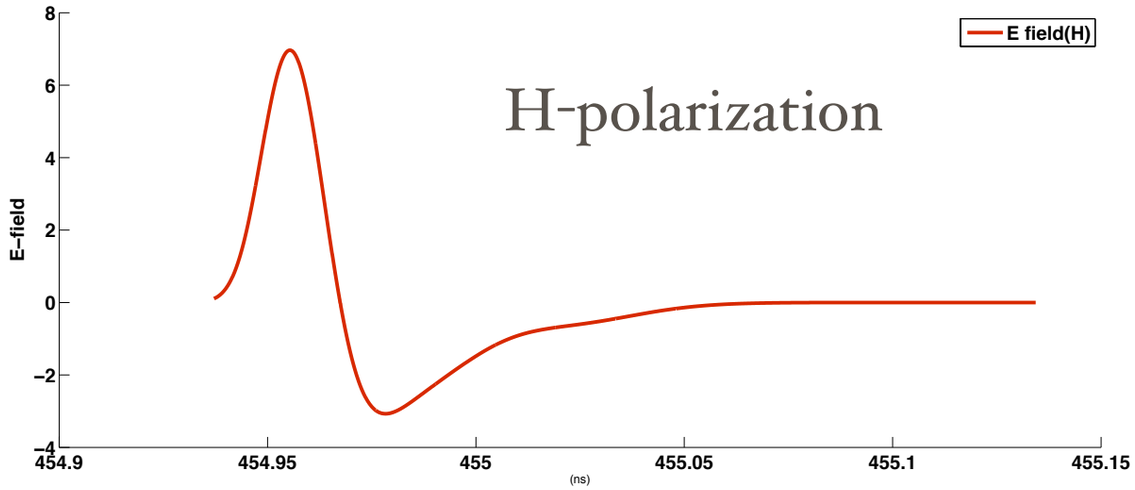

H-polarization
E−field(H)
E−field
6
5
4
3
2
1
0
−1
−2
−3
454.9
454.95
455
455.05
455.1
455.15
(ns)

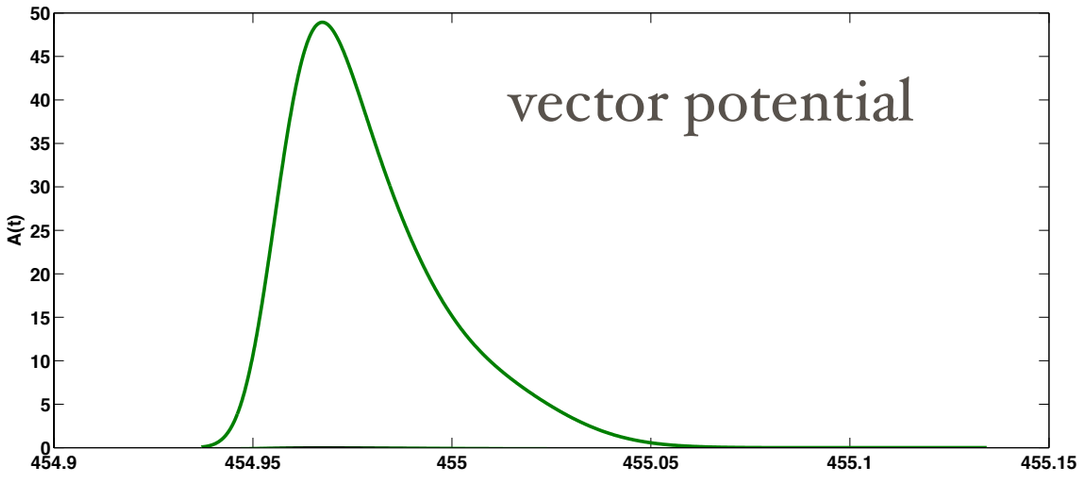

vector potential
A(t)
25
20
15
10
5
0
454.9
454.95
455
455.05
455.1
455.15
(ns)

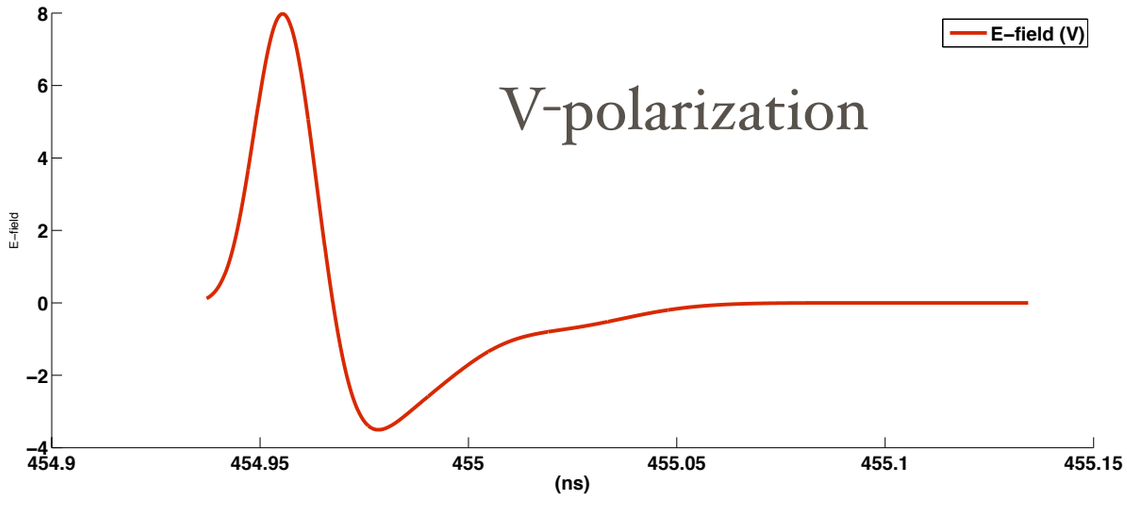

V-polarization
E−field(V)
E−field
5
4
3
2
1
0
−1
−2
−3
454.9
454.95
455
455.05
455.1
455.15
(ns)

Hadronic Signal





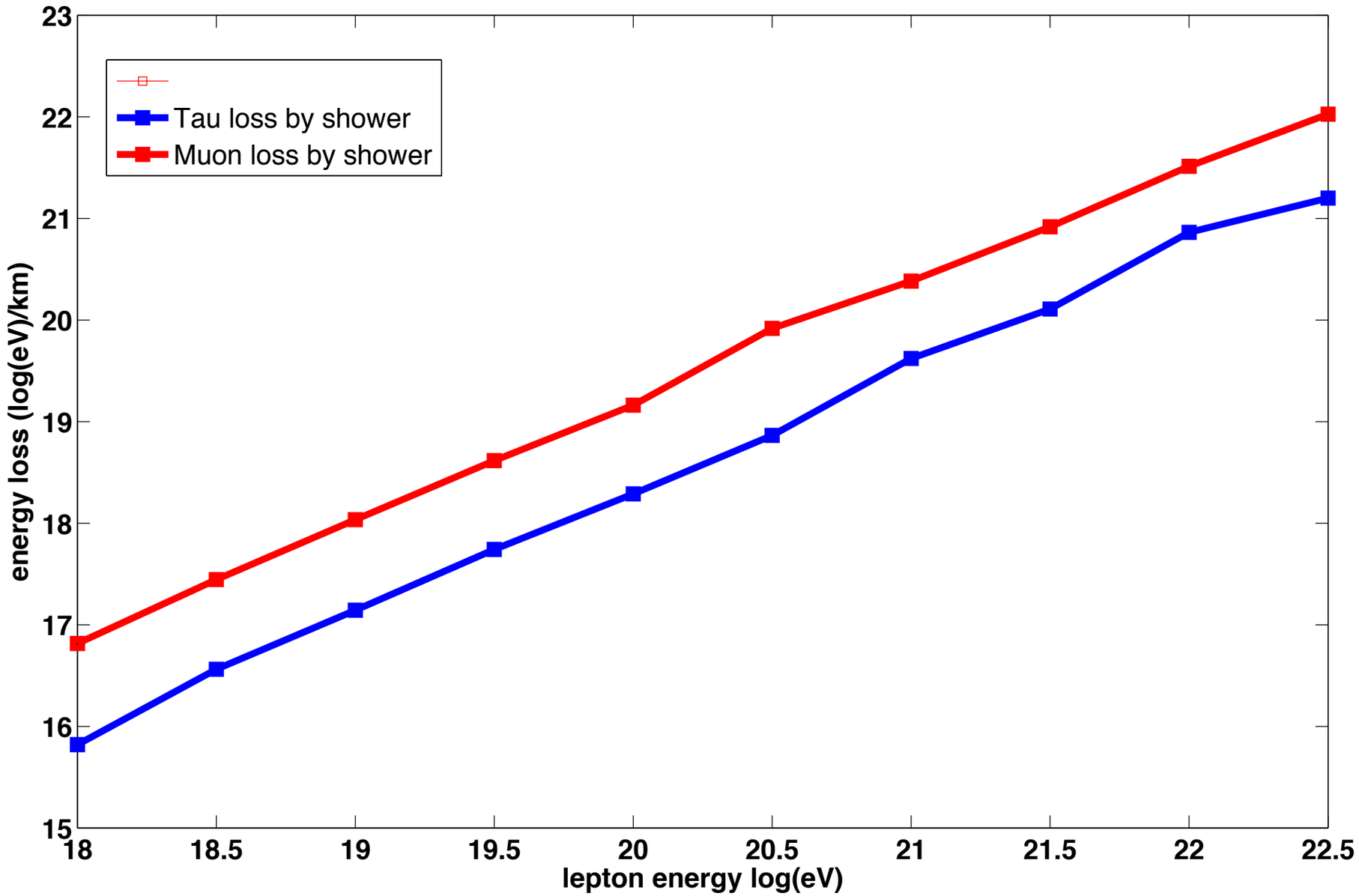




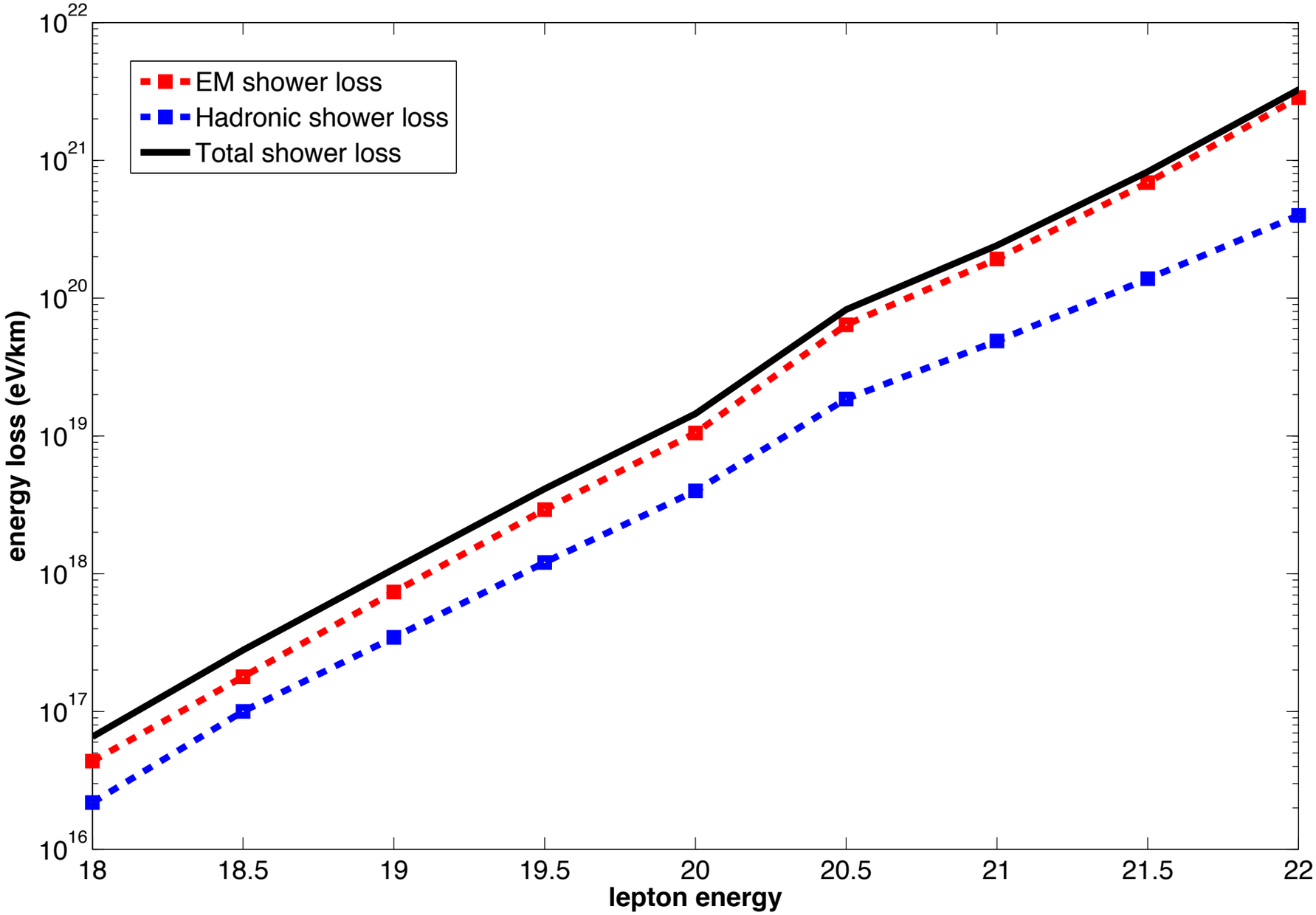
Shower/Track Identification

- Longitudinal development:
  - EM, ~100m, several peaks due to LPM effect;
  - Hadronic, ~10m, one typical maximum
- Different shower profile, Different patterns of radio signals
- Energy loss composition by shower makes ν_μ and ν_τ distinguishable in between
  - Muon, more; more by EM, less by hadronic
  - Tau, less; less by EM, more by hadronic

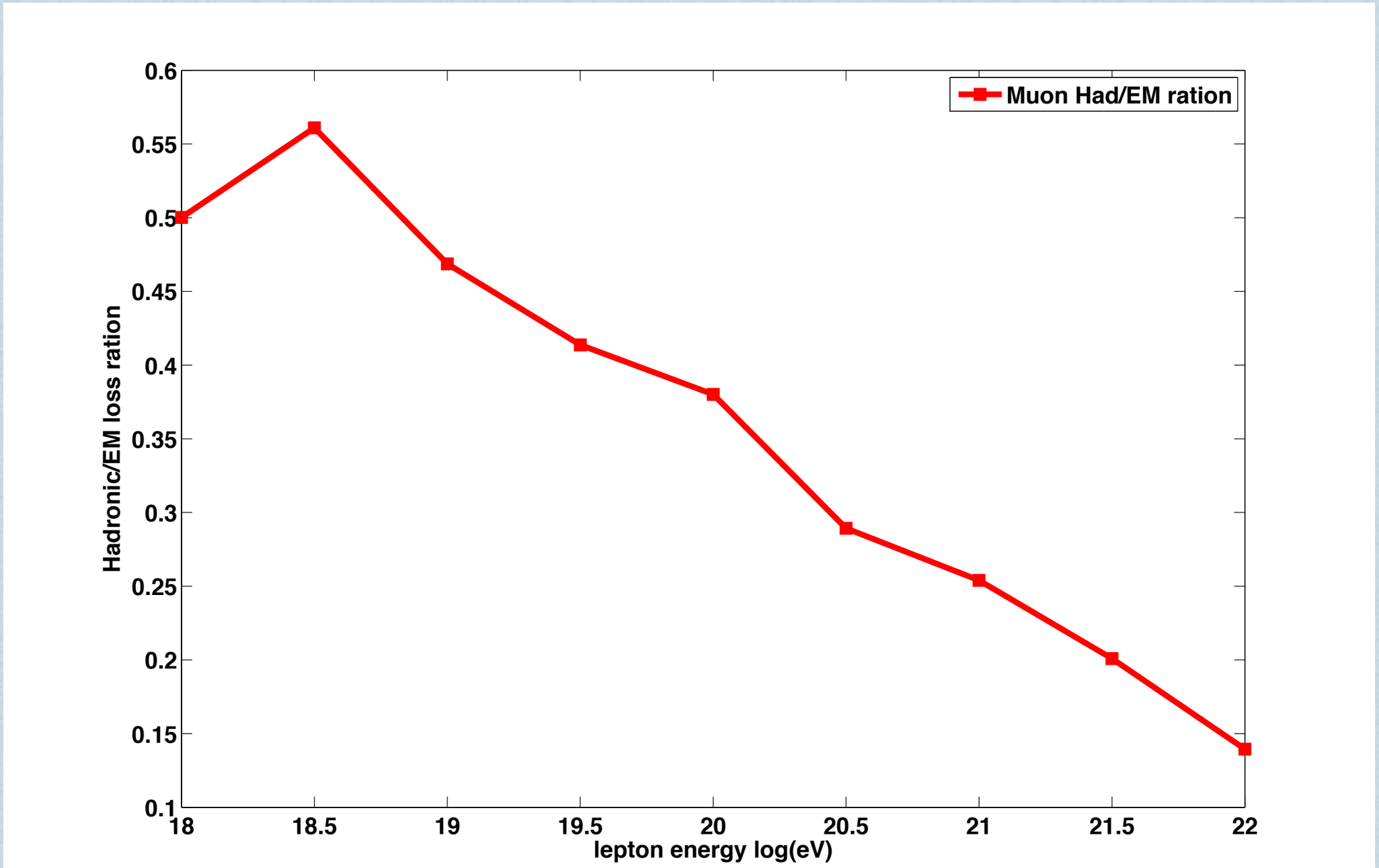
Energy Loss via Showers



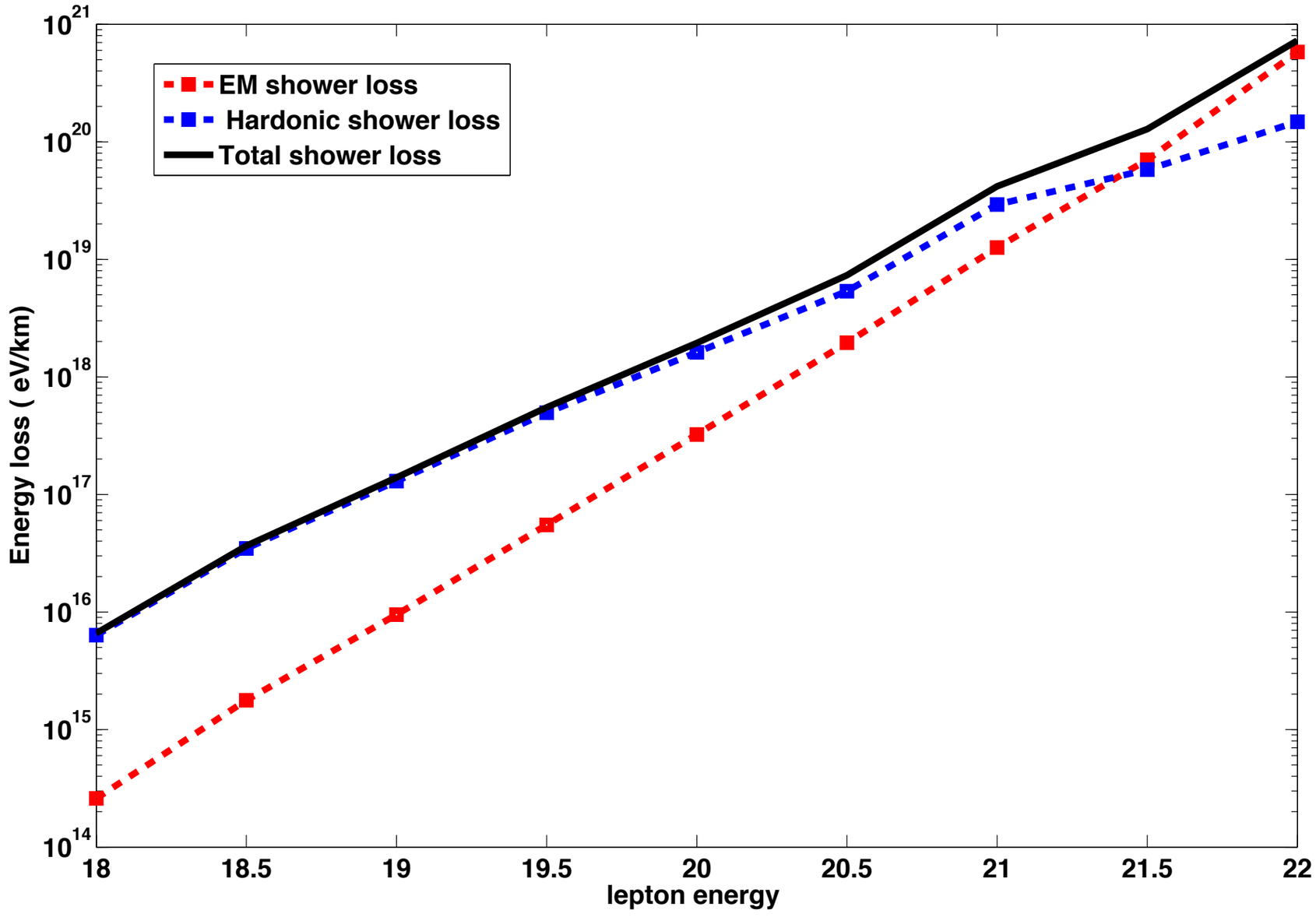
Energy Loss: Muon Track



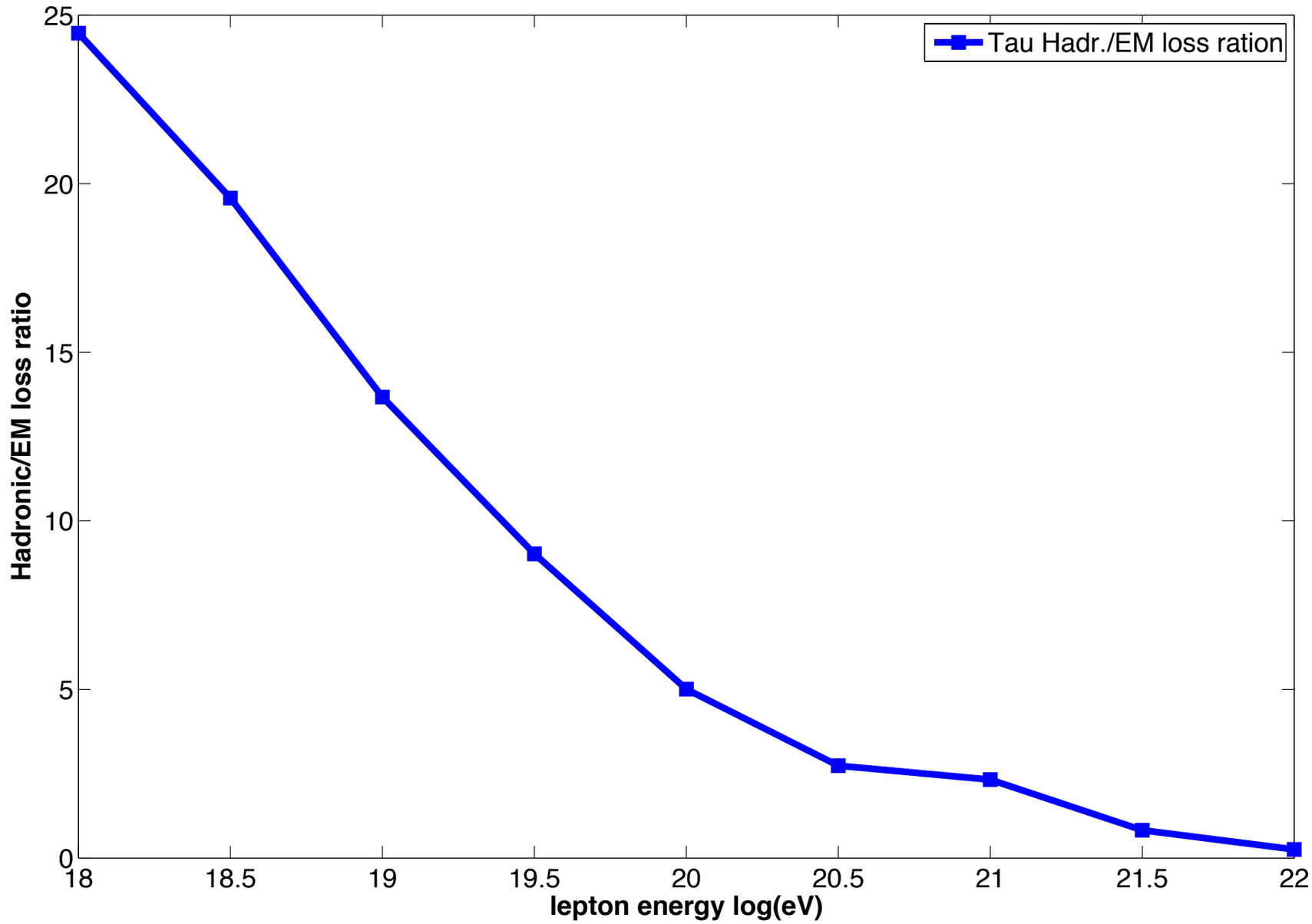
Energy Loss: Muon Track



Energy Loss: Tau Track



Energy Loss: Tau Track



Summary

- Showers can be detected by radio neutrino telescopes.
- A track is reconstructed with a series of showers. A shower is then isolated from tracks and ν_e is identified.
- EM and hadronic showers are distinguishable with their radio signals. Shower energy loss and compositions are different for muon and tau tracks. ν_μ and ν_τ are also identified, respectively.