Experimental Lecture #2
Landscape

D. Jason Koskinen

NBIA PhD School: Neutrinos Underground and in the Heavens
June 23-27, 2014

Niels Bohr Institutet

The Niels Bohr International Academy

Discovery centre for particle physics

Experimental Landscape

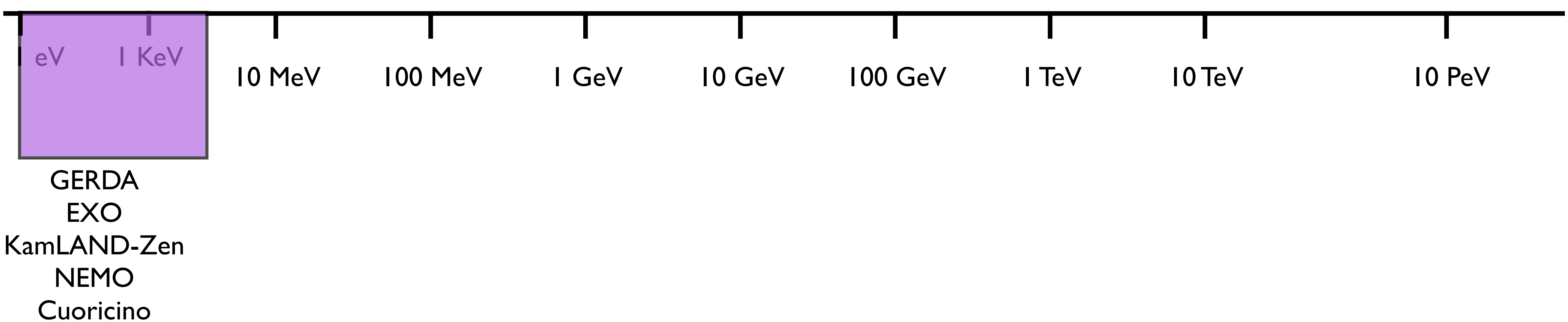
Accelerator based

Non-accelerator based

*Boxes provide sense of scale for physics sensitive regions

Experimental Landscape

Accelerator based



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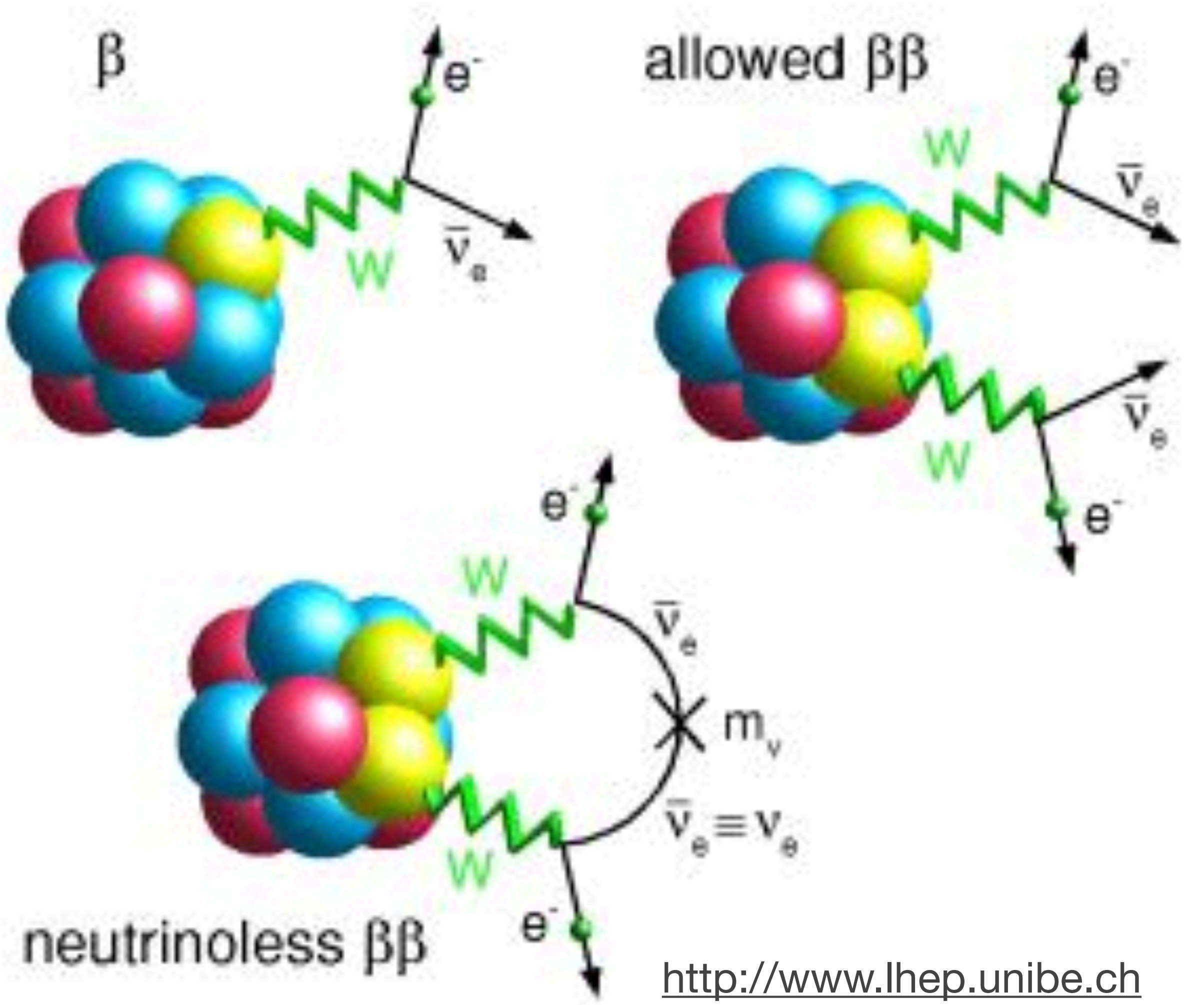
Lowest Energies

Neutrinoless double-beta decay



http://www.lhep.unibe.ch
EXO

arXiv:0109033

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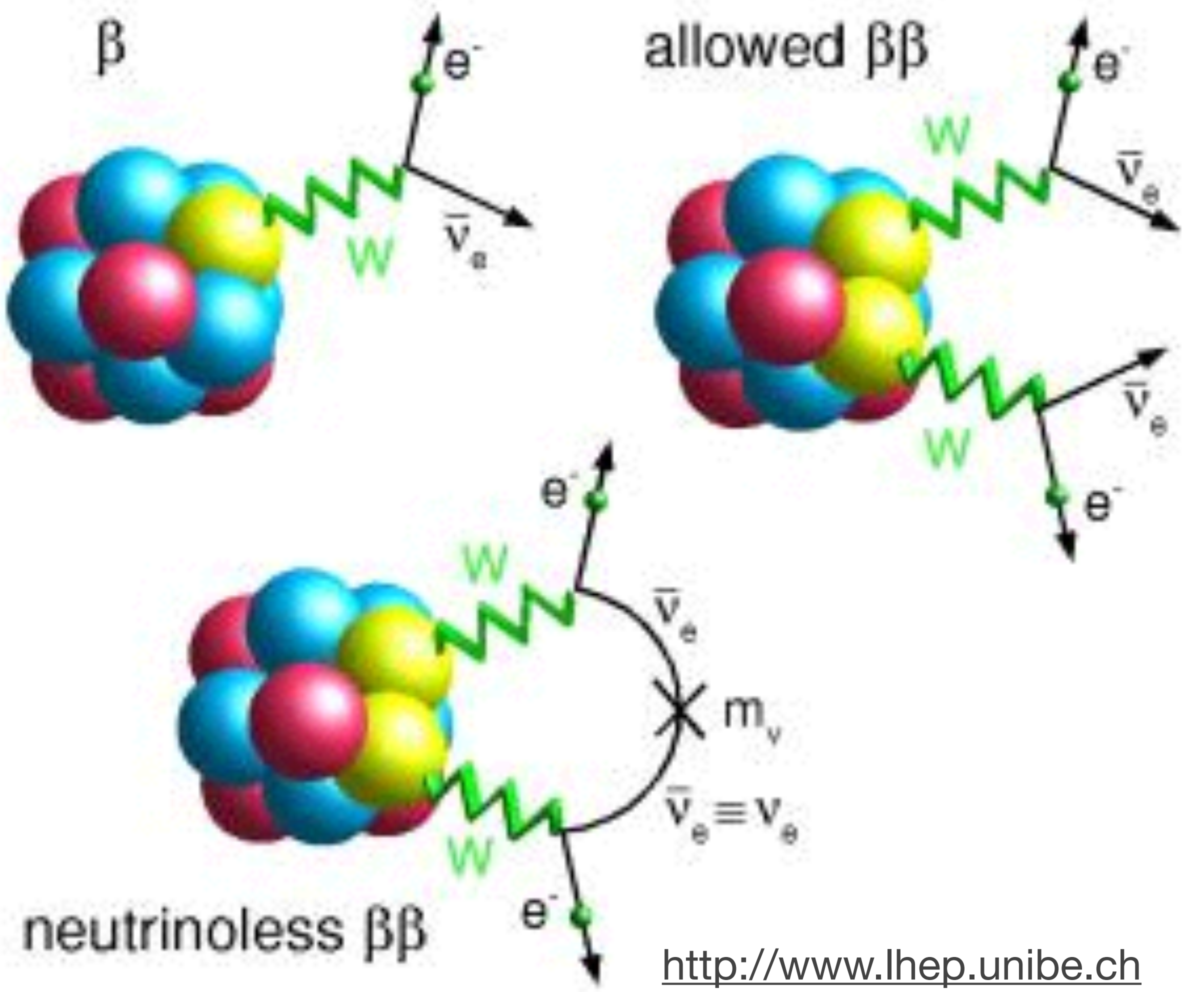

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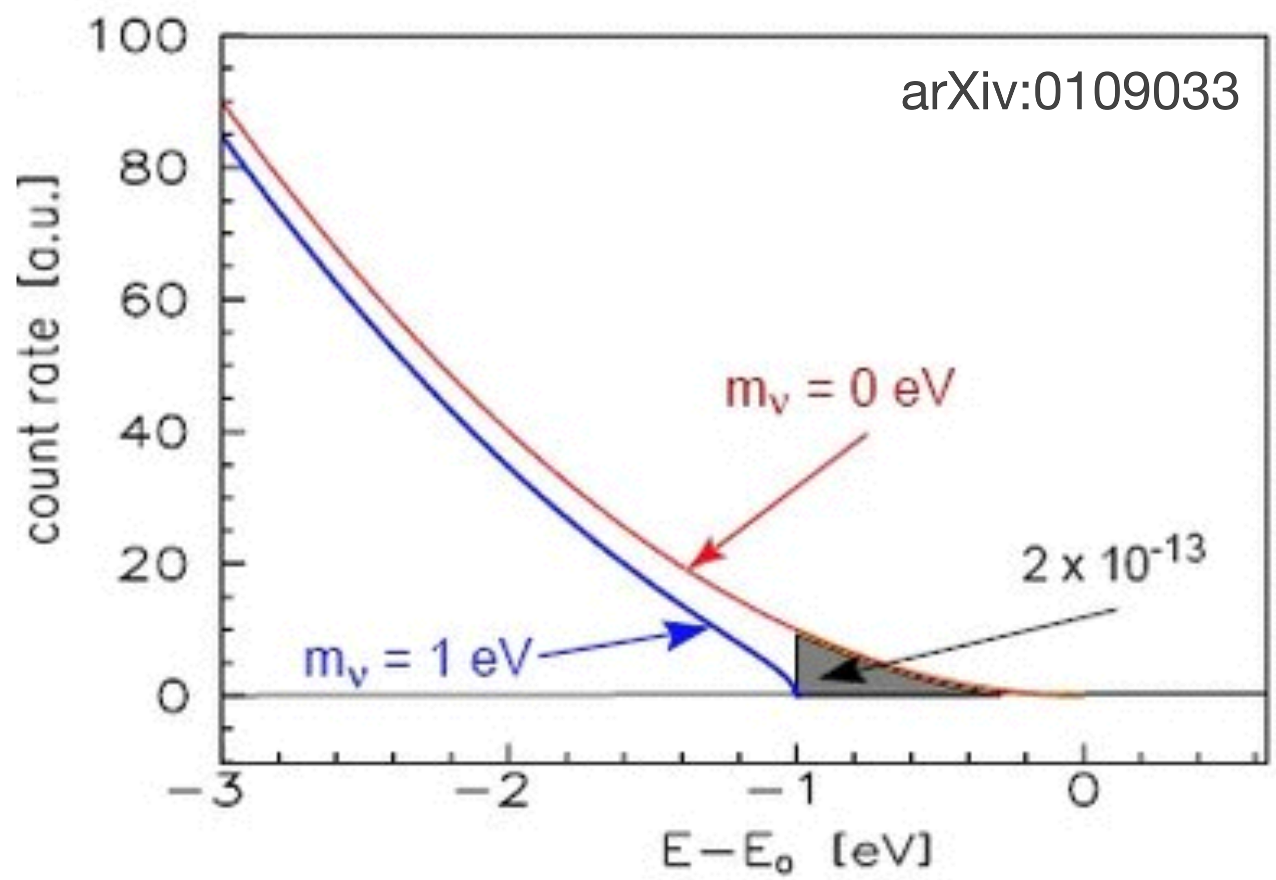
Absolute neutrino mass via beta-decay energy spectrum



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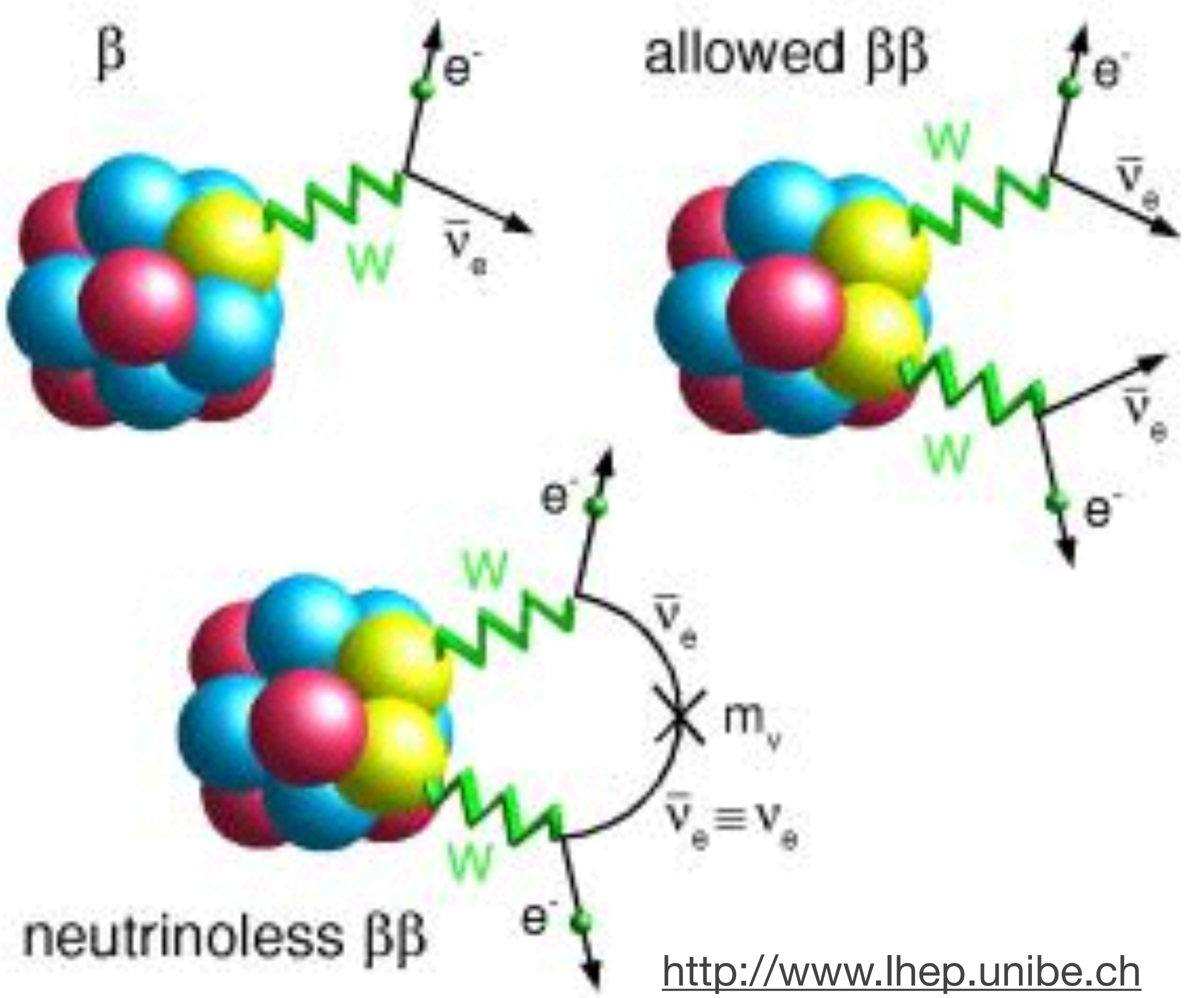

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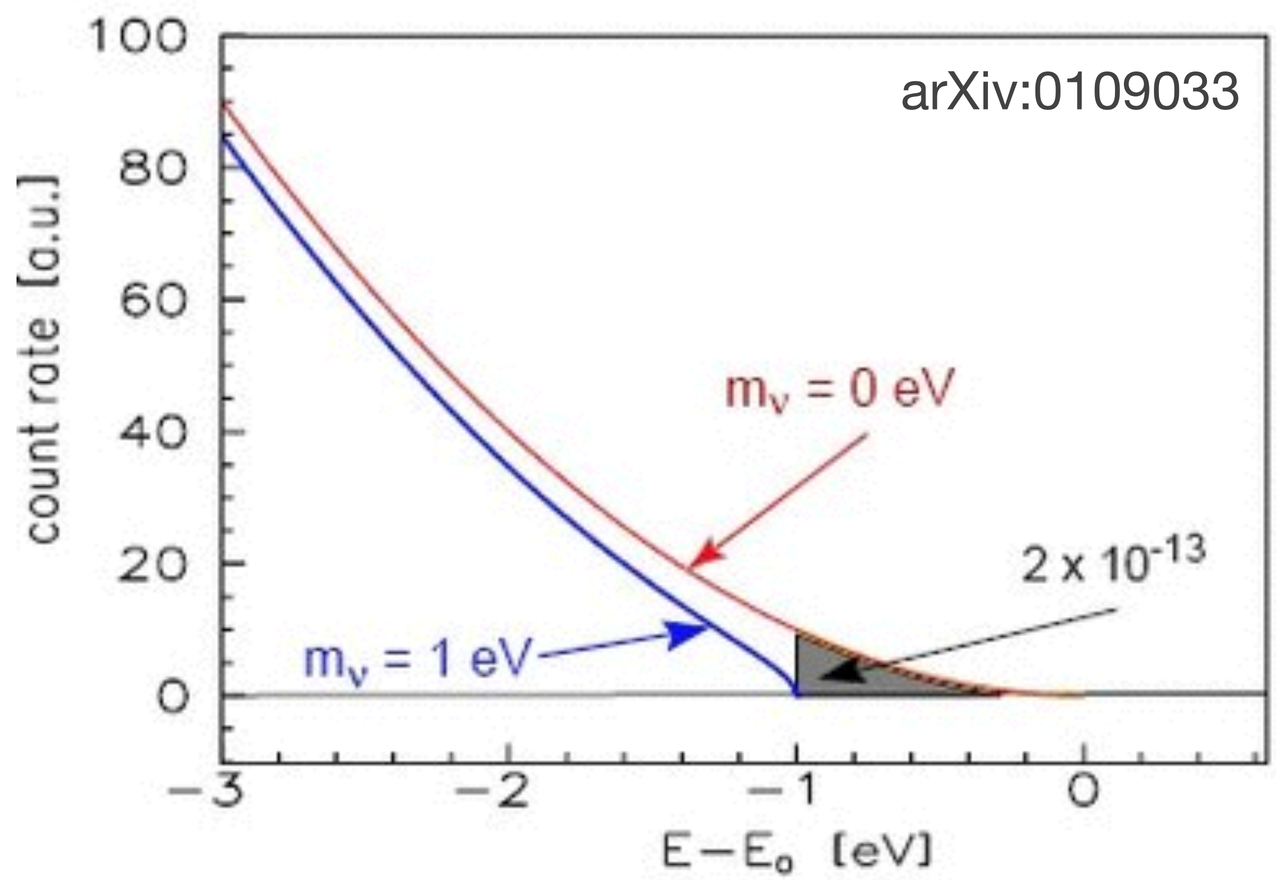
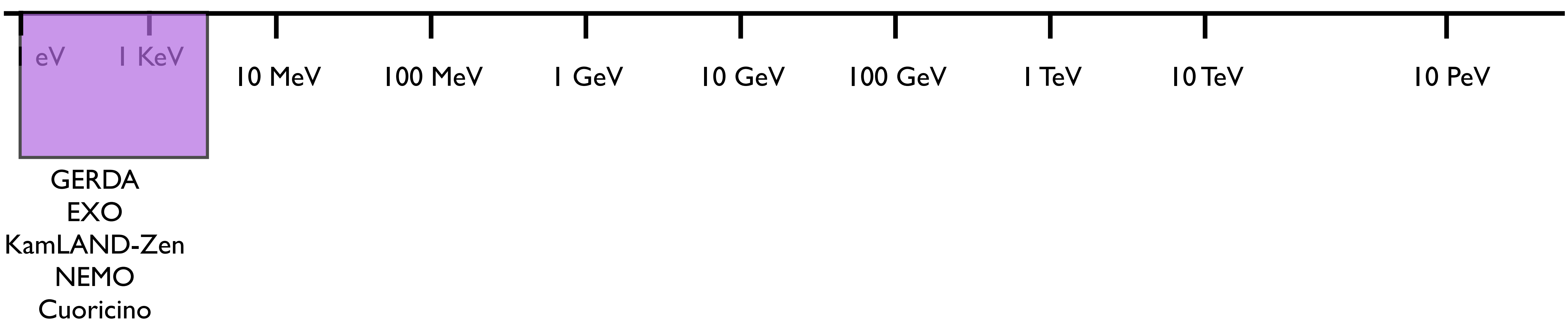


- Neutrino physics energy is at the eV scale, but the signal is the indirect effect of the neutrino on the measured *electrons*

Experimental Landscape

- Neutrino mass and Dirac vs. Majorana are the major features of the lowest energy region neutrinos studies

Accelerator based



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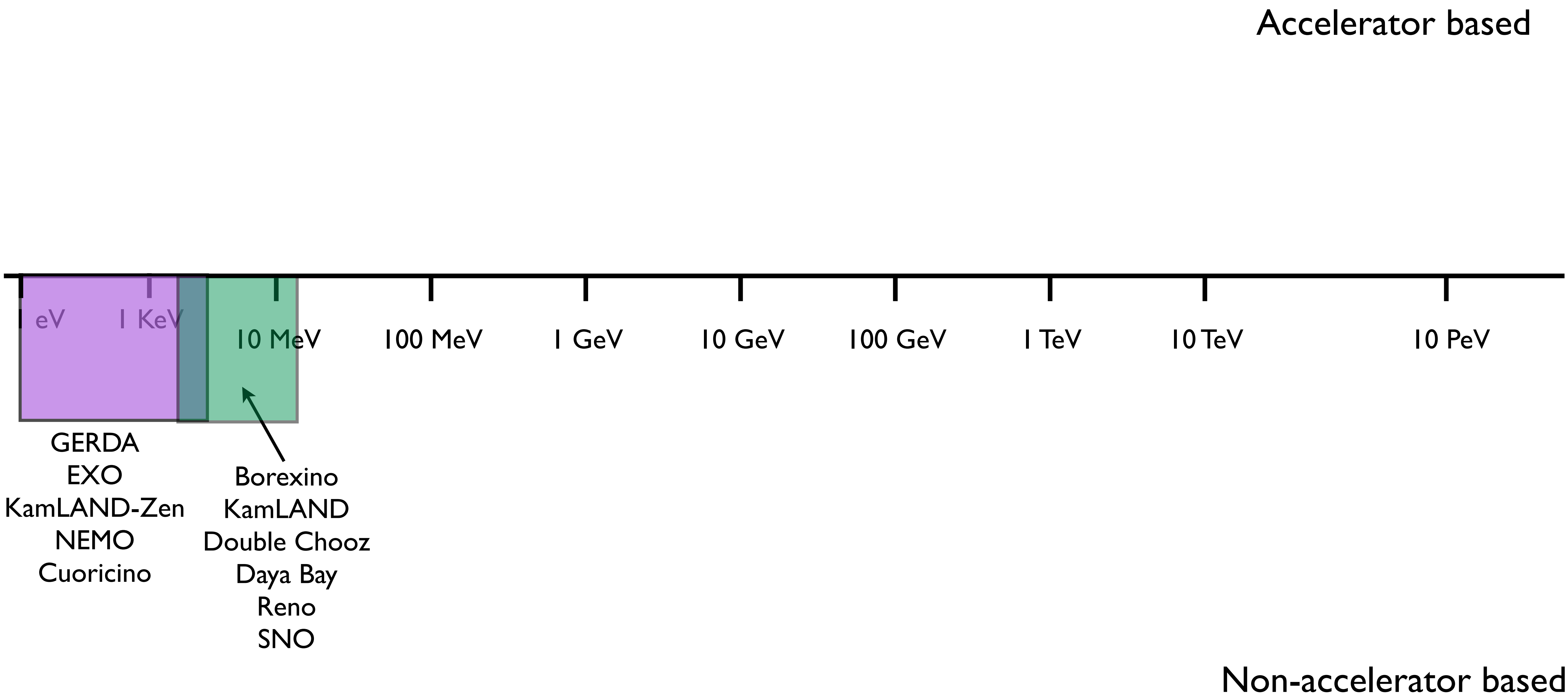

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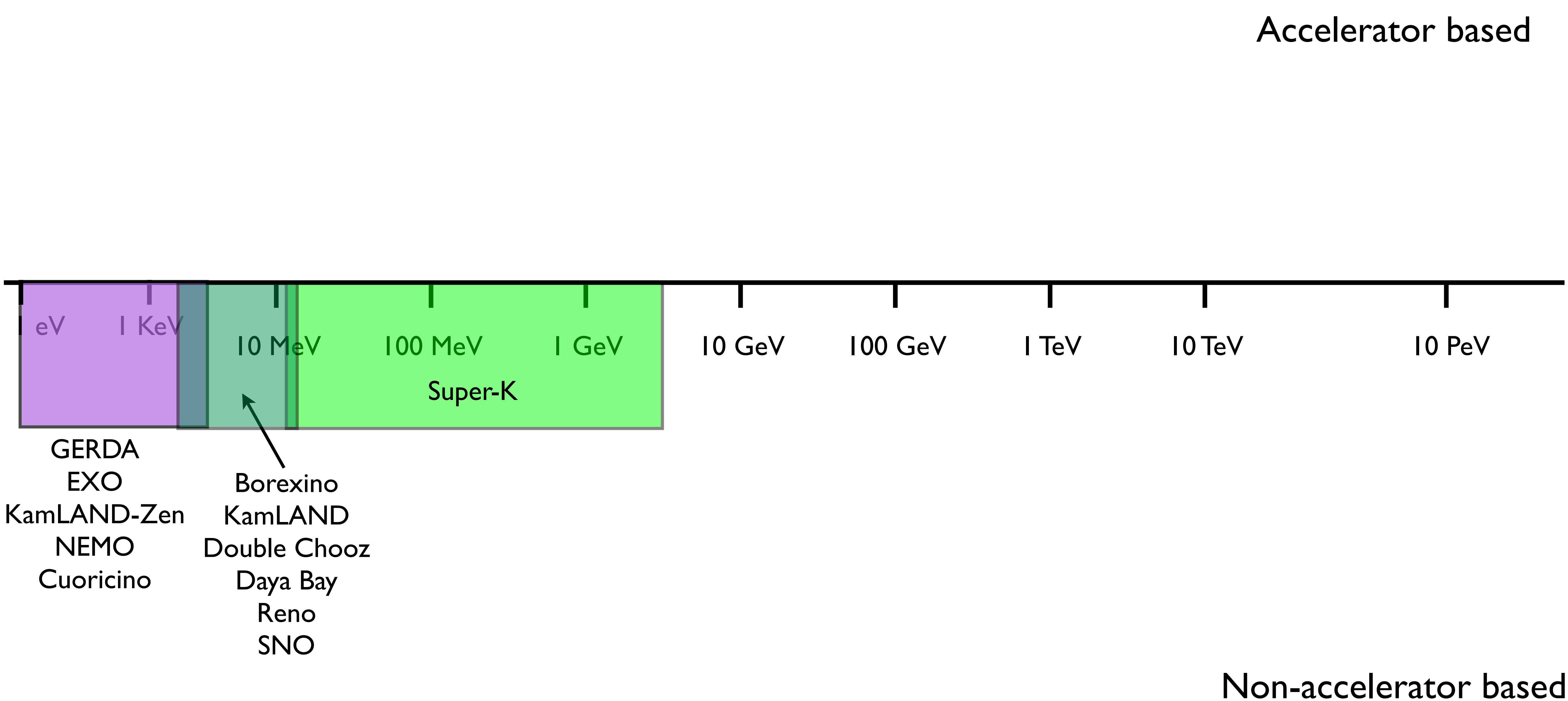

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KeV-MeV Energy - Solar/Reactor Neutrinos

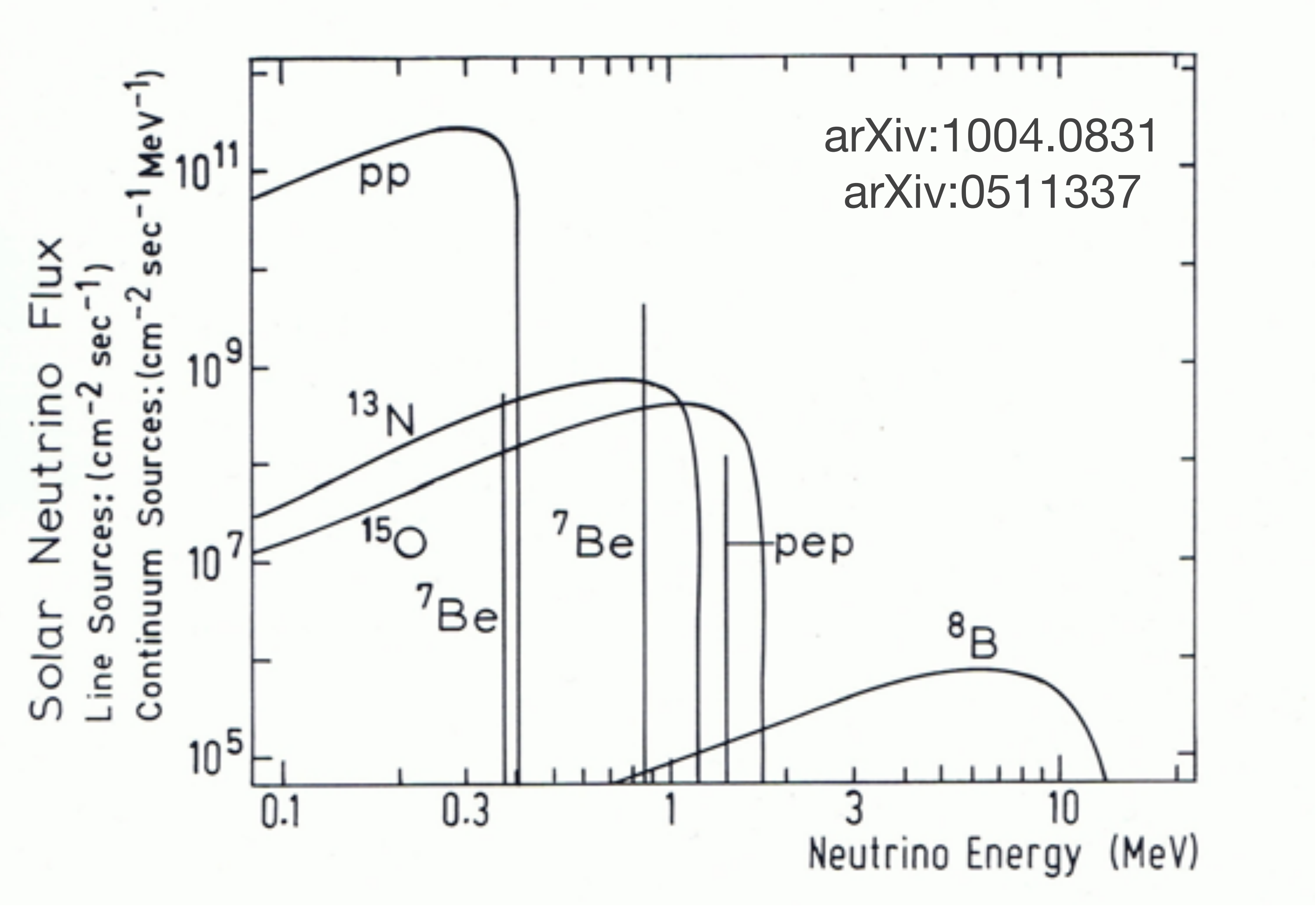
arXiv:1101.2663

arXiv:1004.0831
arXiv:0511337

KeV-MeV Energy - Solar/Reactor Neutrinos

Solar Neutrino Flux

arXiv:1101.2663



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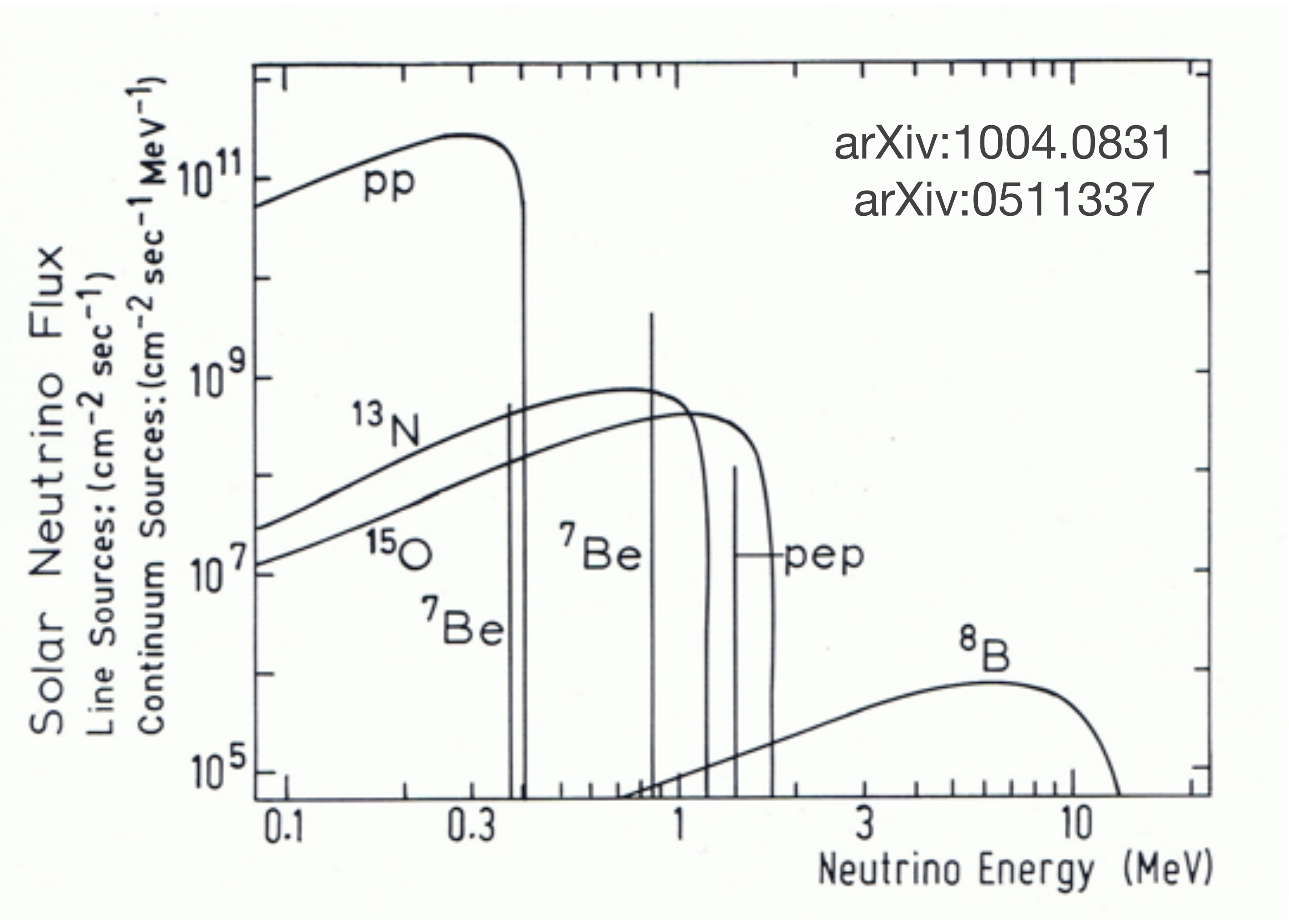
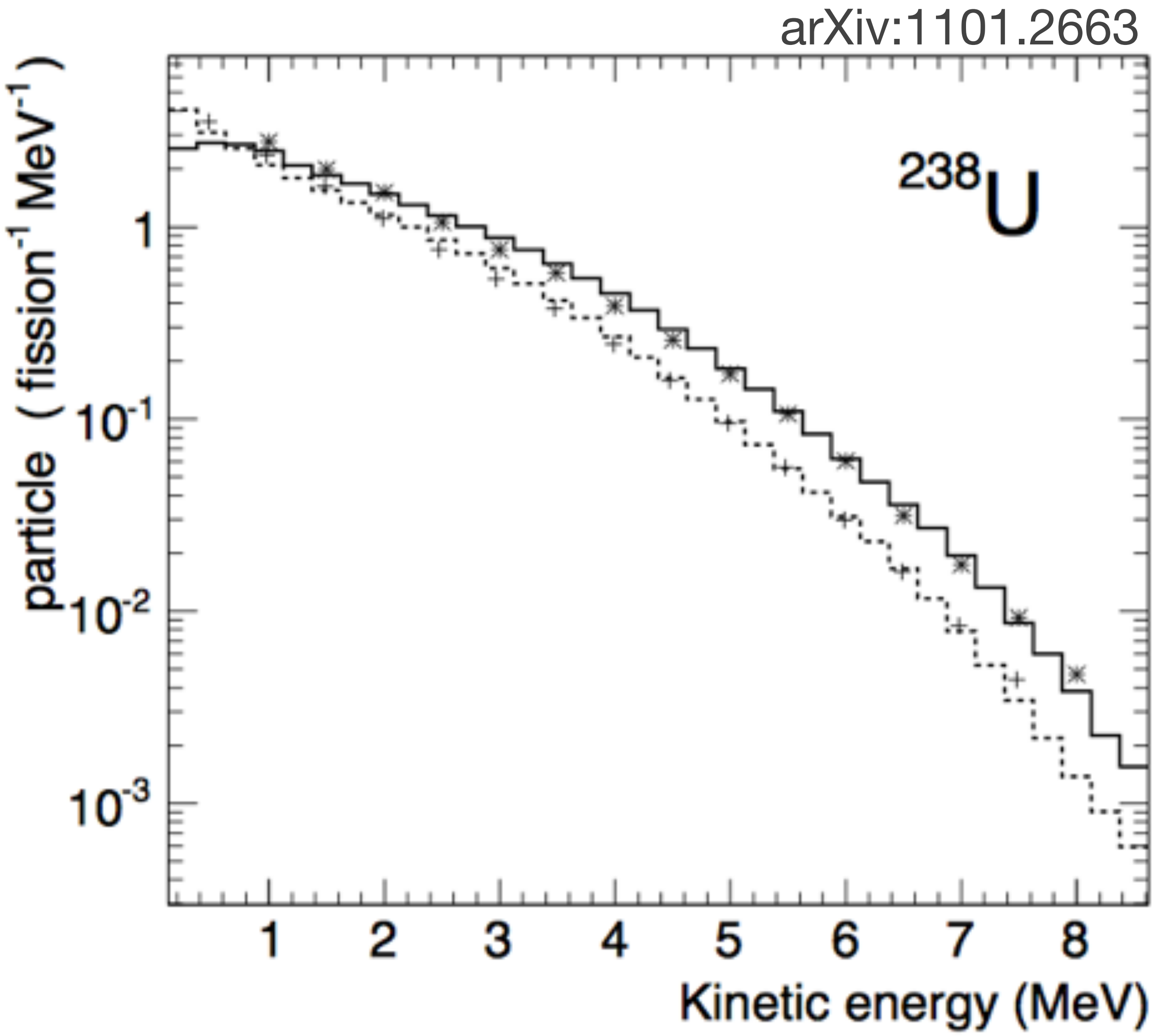


Reactor Neutrino Flux



Experimental Landscape

- Reactor neutrino experiments dominate(d) the non-accelerator region

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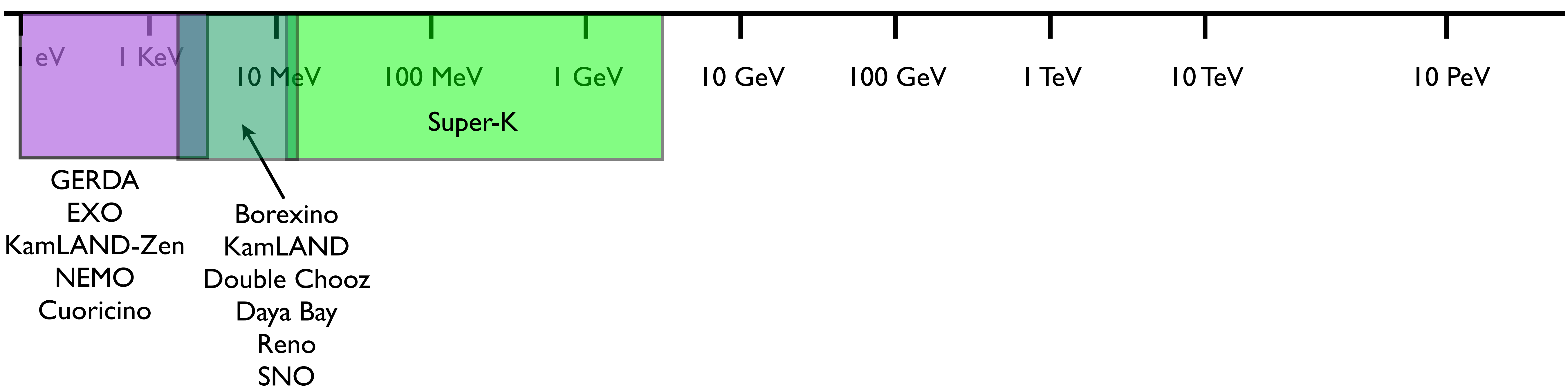

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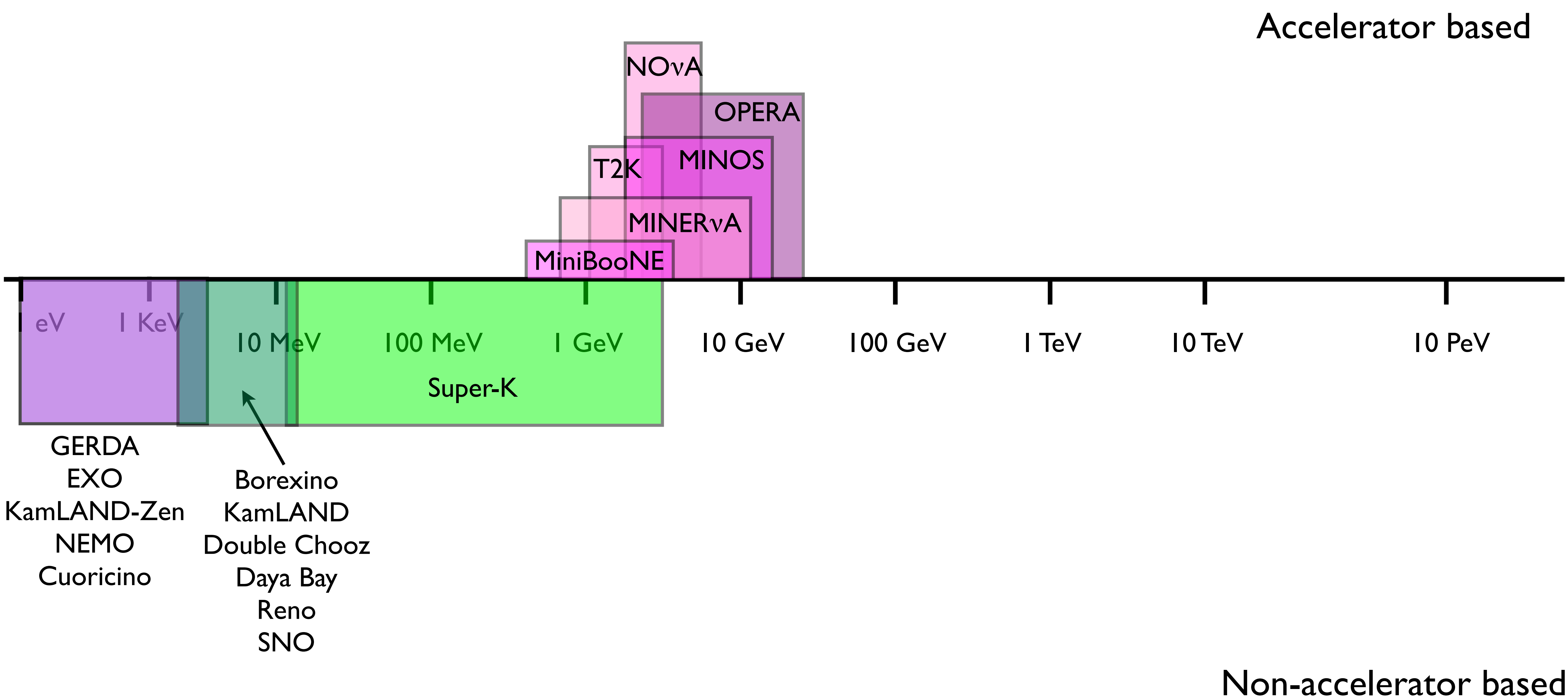

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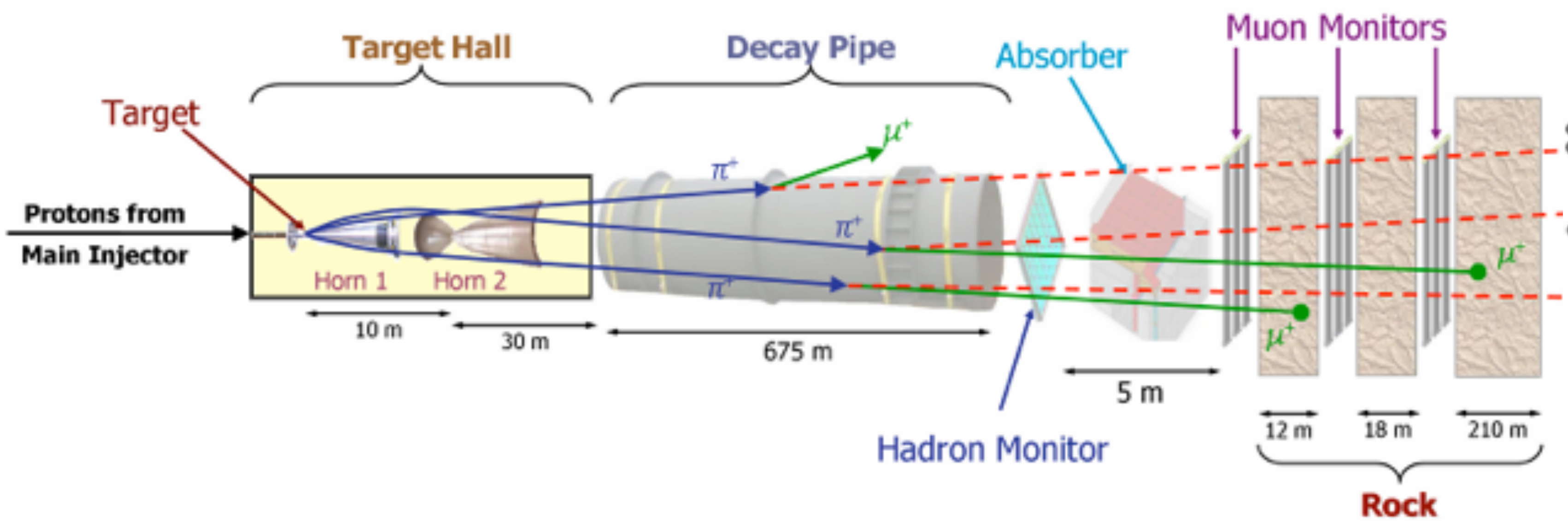
Accelerator Experiments in GeV Range

NuMI Beamline at Fermilab



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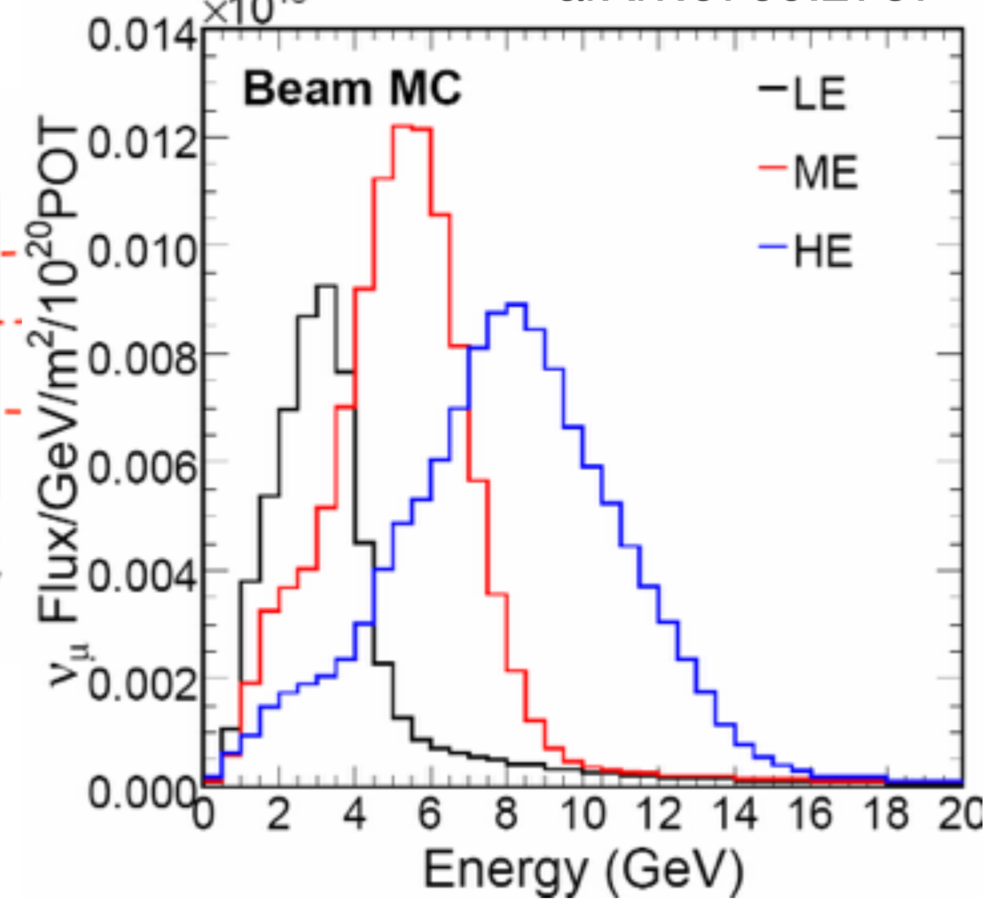

Accelerator Experiments in GeV Range

- Accelerators produce a neutrino beam over an energy region

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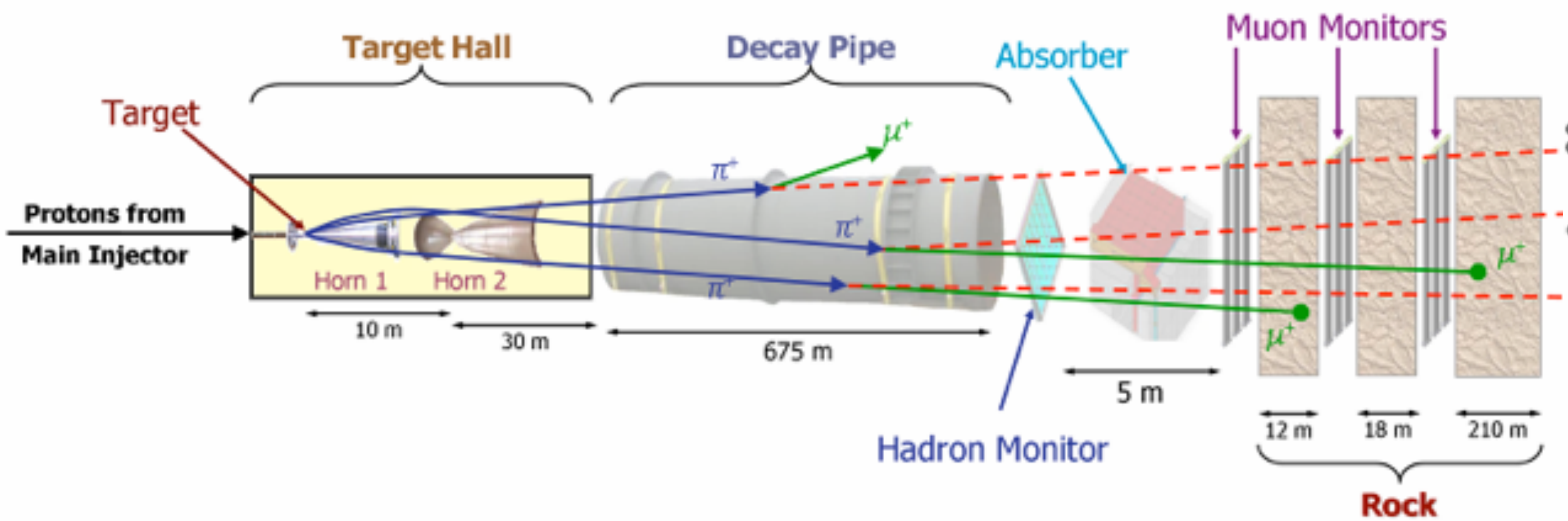

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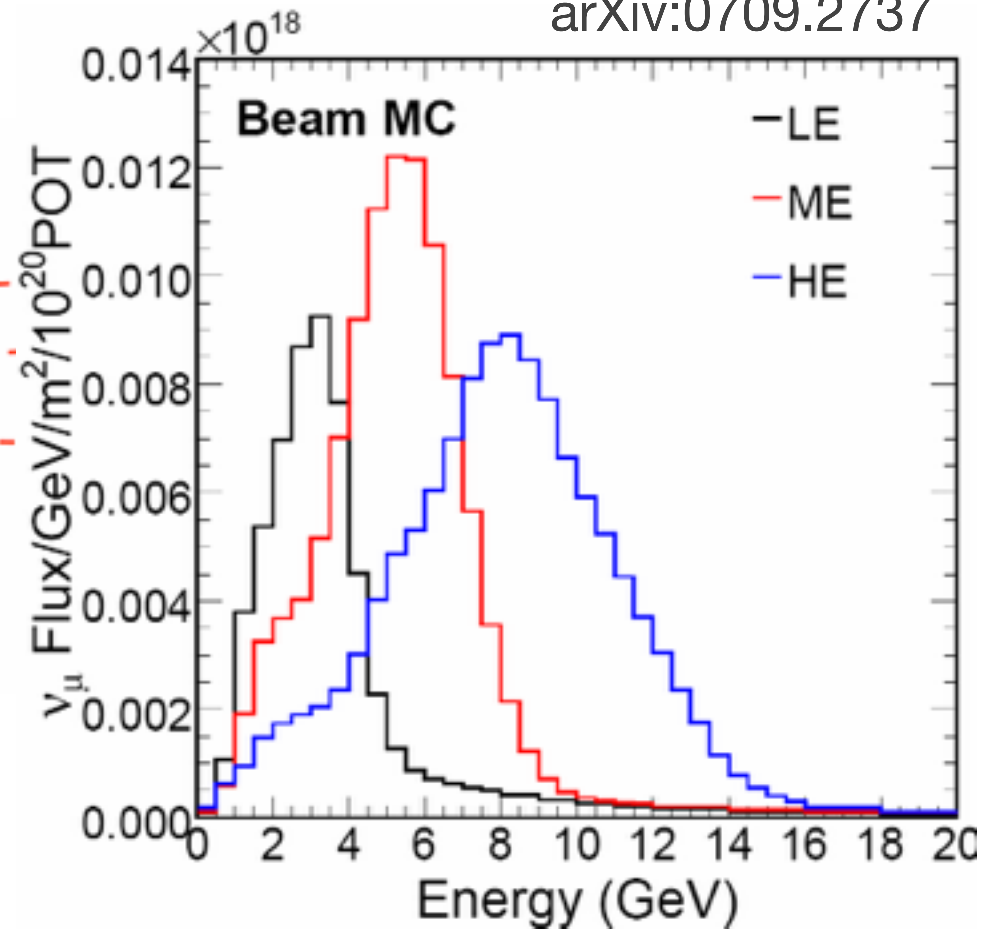
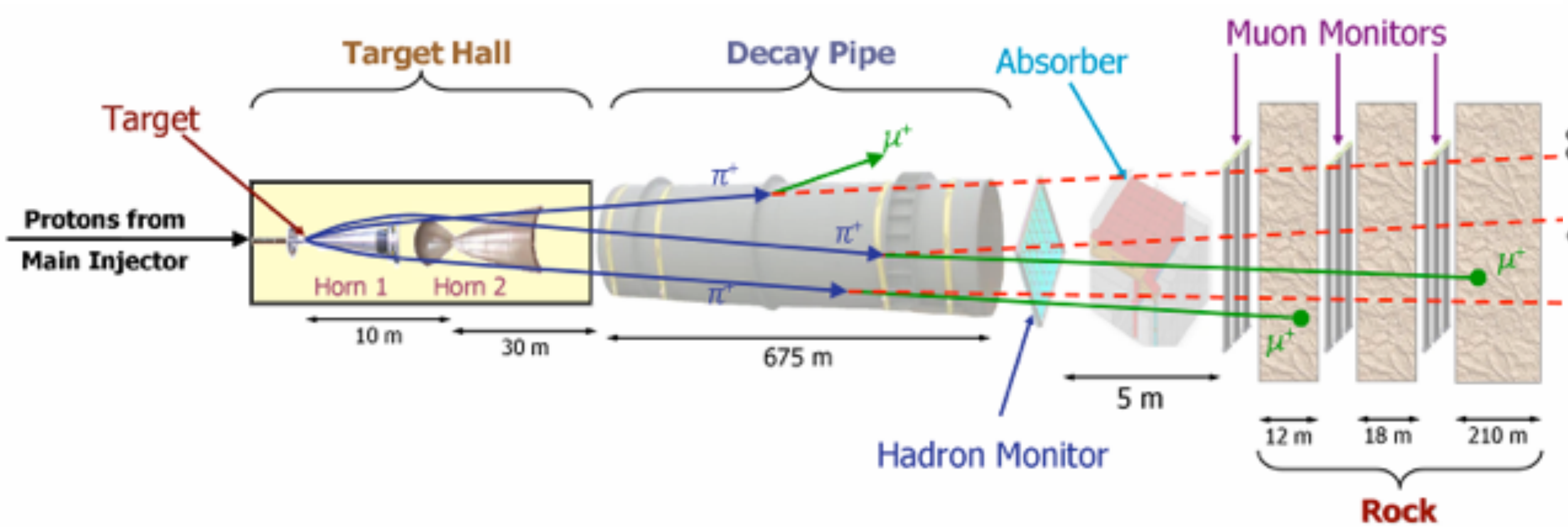


Accelerator Experiments in GeV Range

- Accelerators produce a neutrino beam over an energy region
- Place Far Detector meters to kilometers away from source

NuMI Beamline at Fermilab



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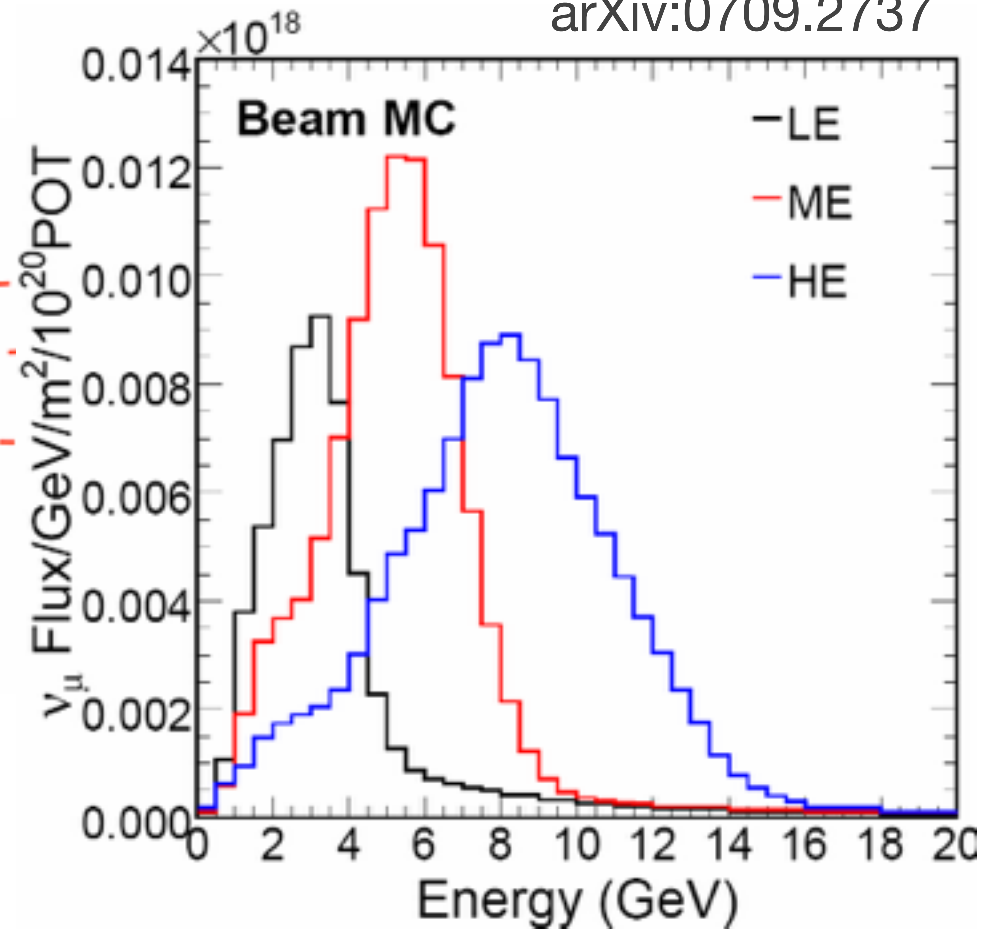
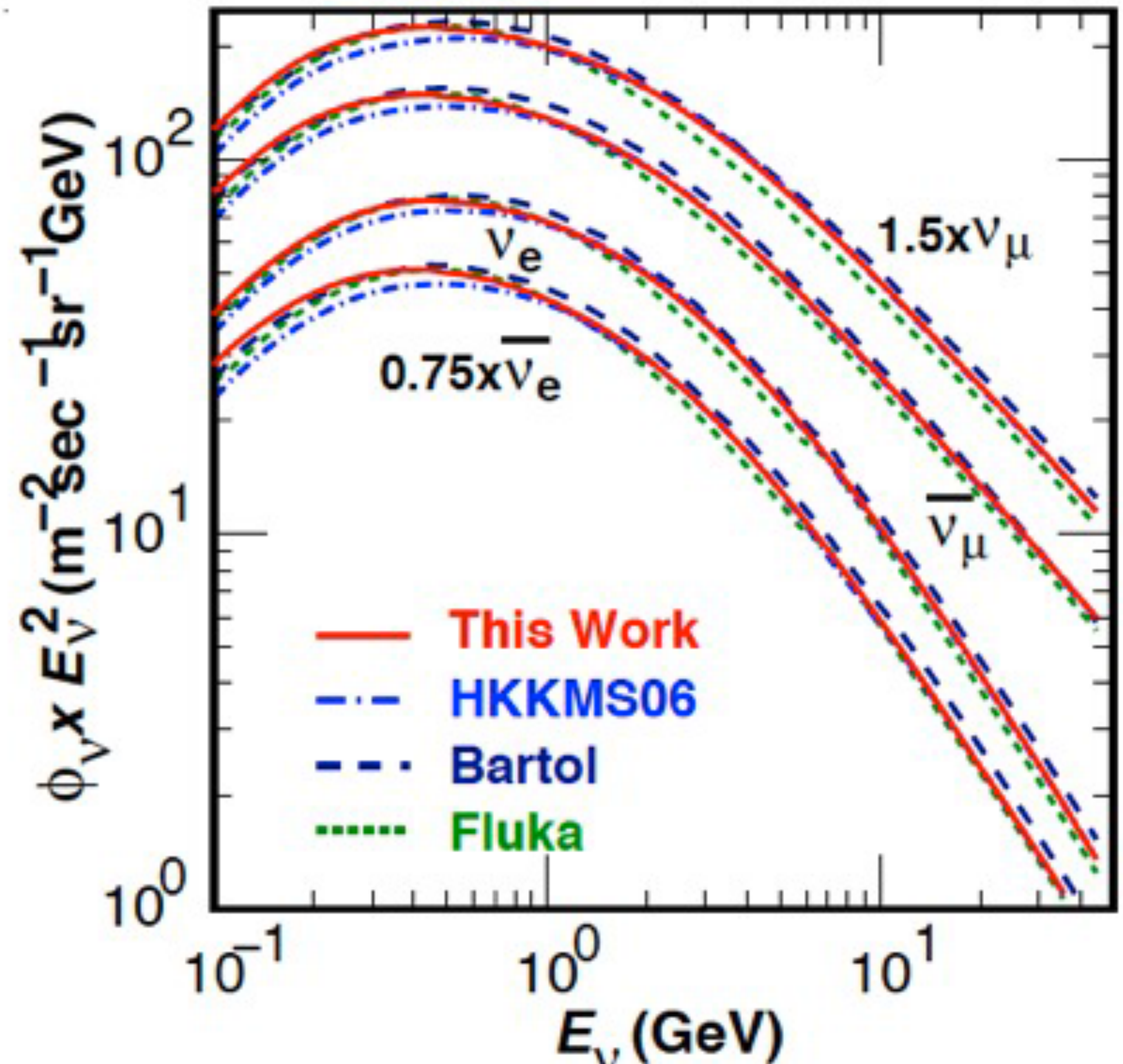


Accelerators/Atmospheric

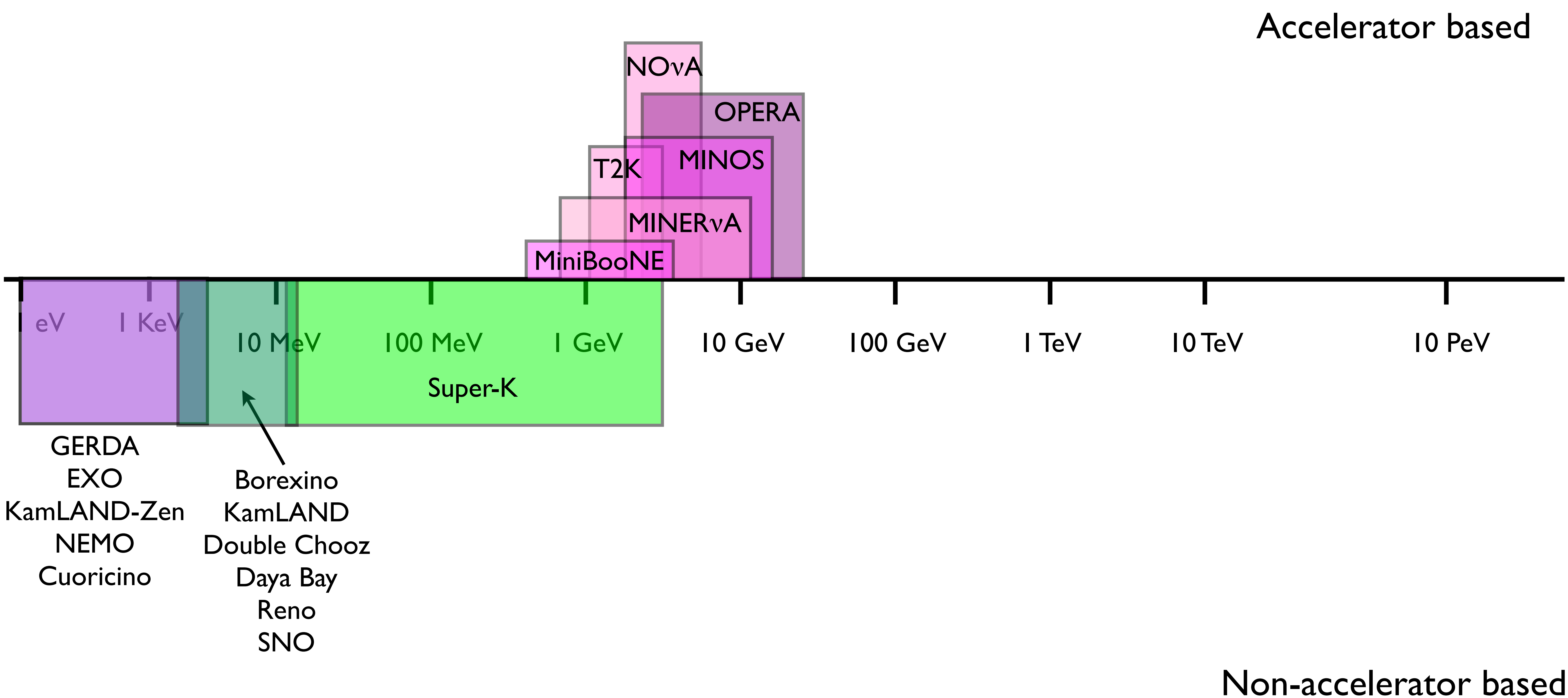
- Significant flux of naturally occurring atmospheric neutrinos in energy regions where accelerator experiments are designed

arXiv:0203272



Experimental Landscape

- Accelerator experiments are prime contributors to oscillation physics



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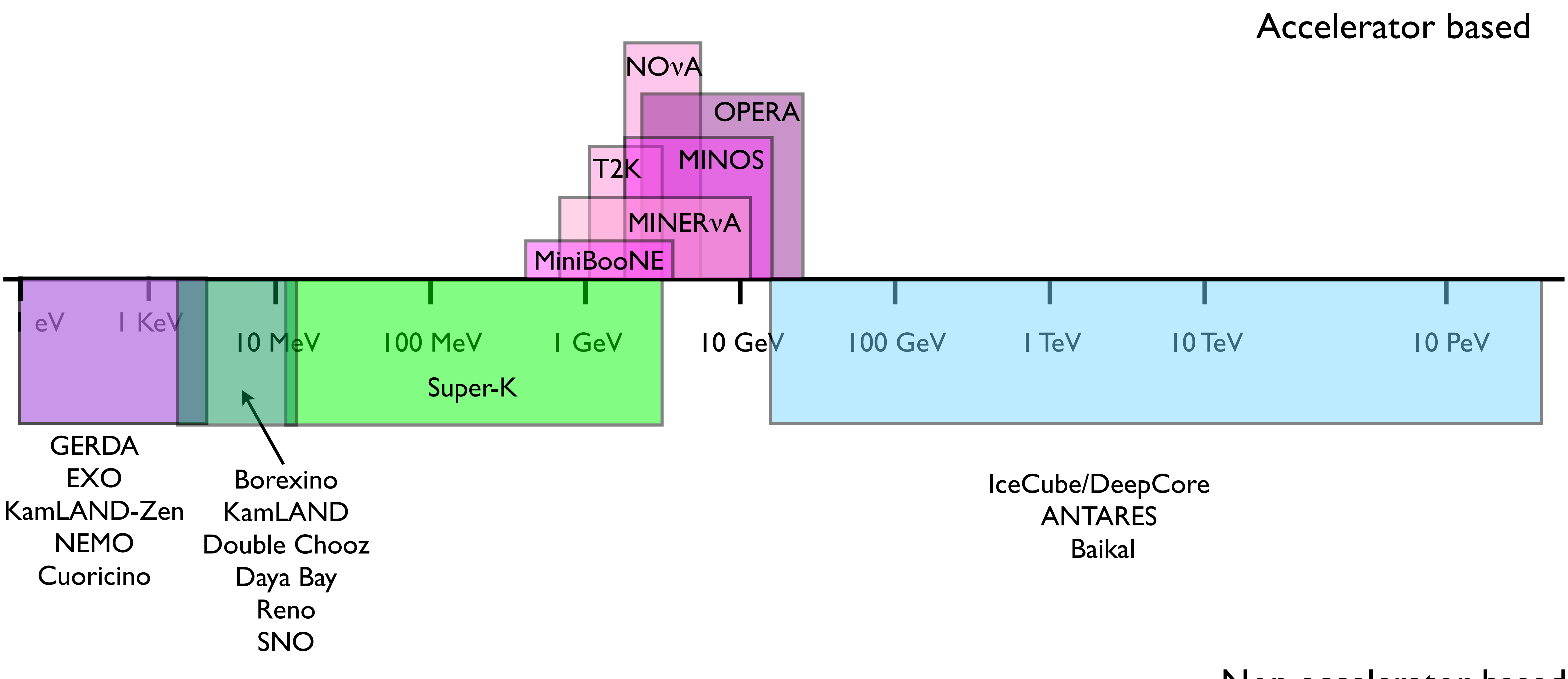

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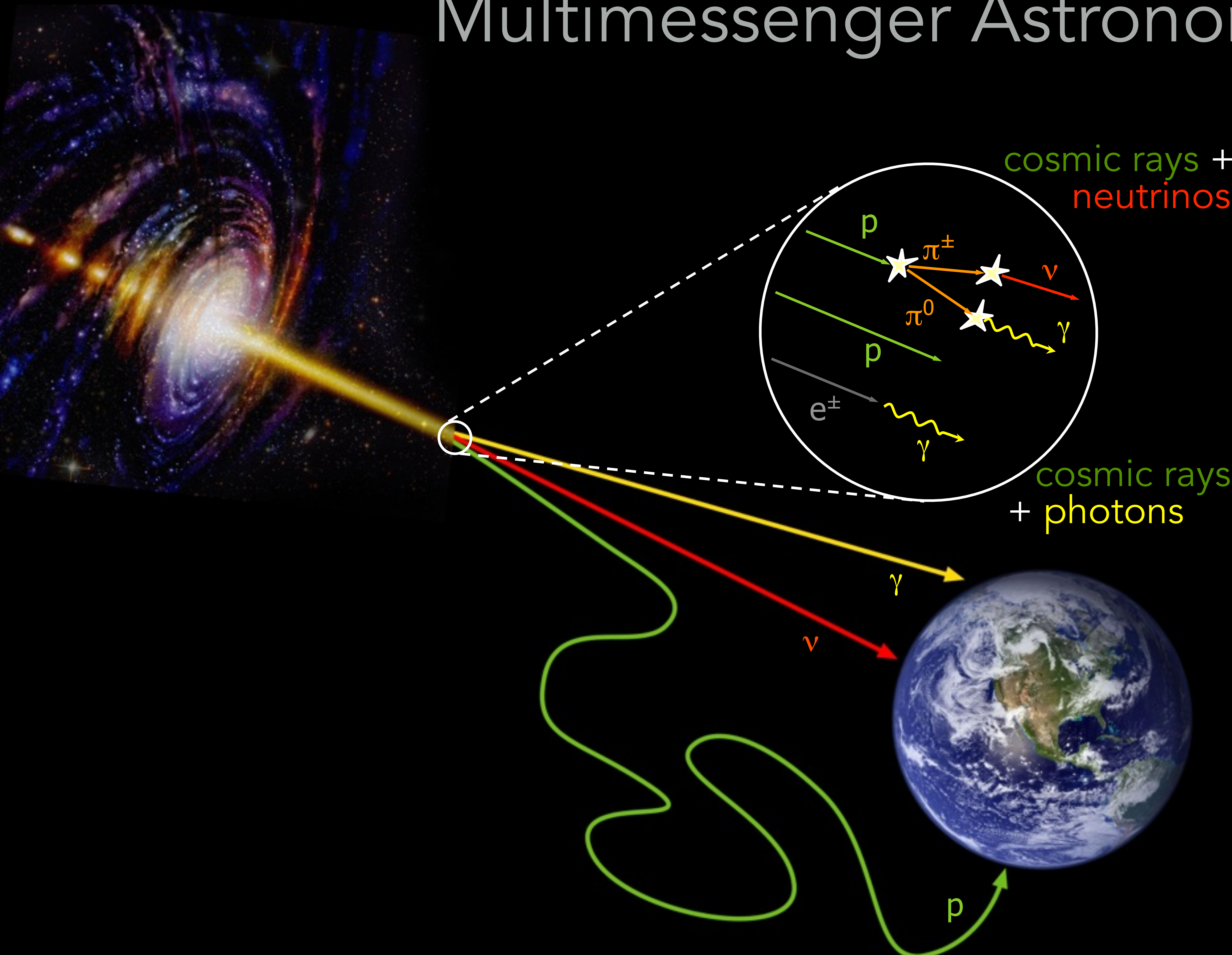
TeV Region

- Needs some motivation (which will covered more by G. Raffelt)

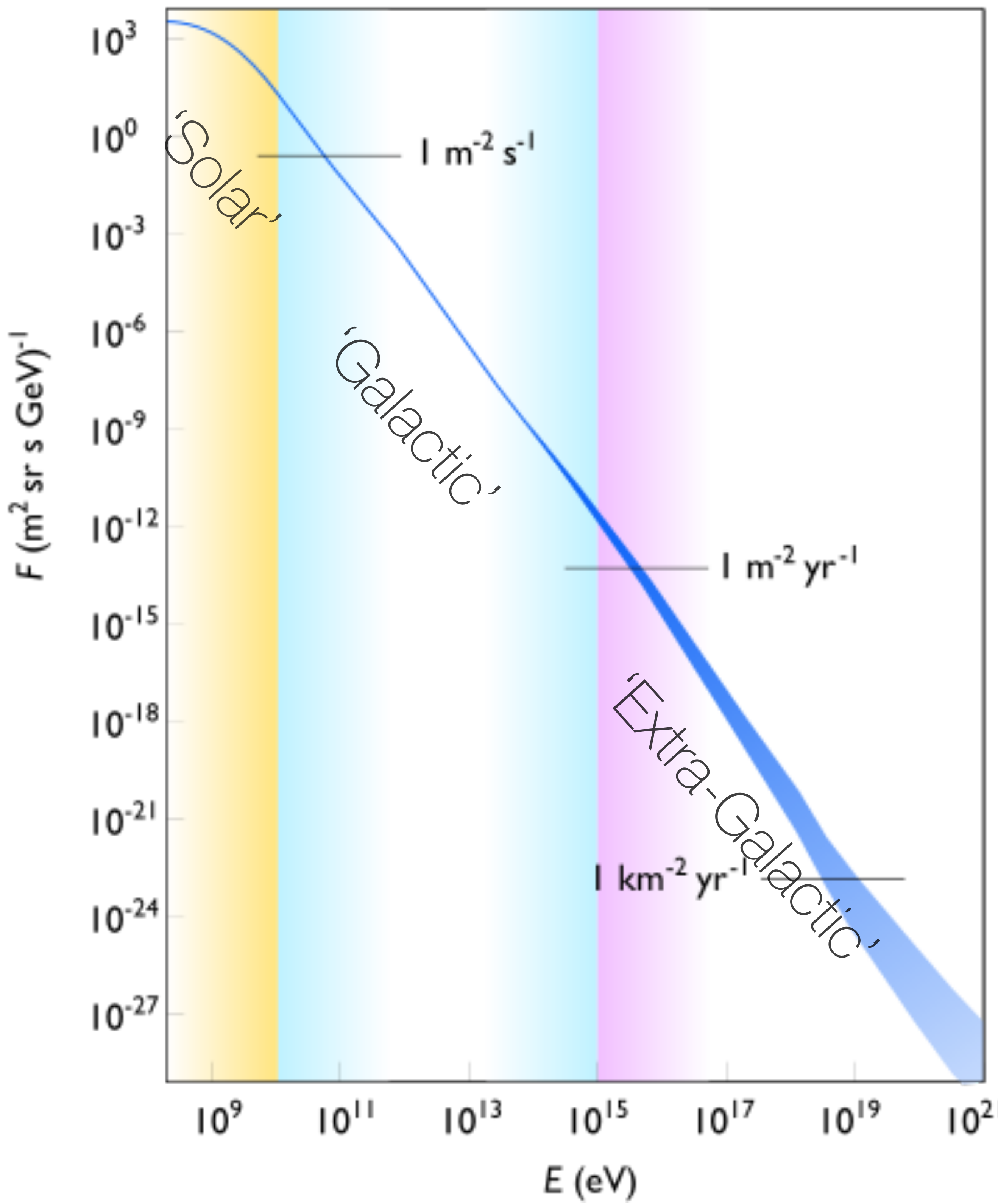
Multimessenger Astronomy



TeV Motivation

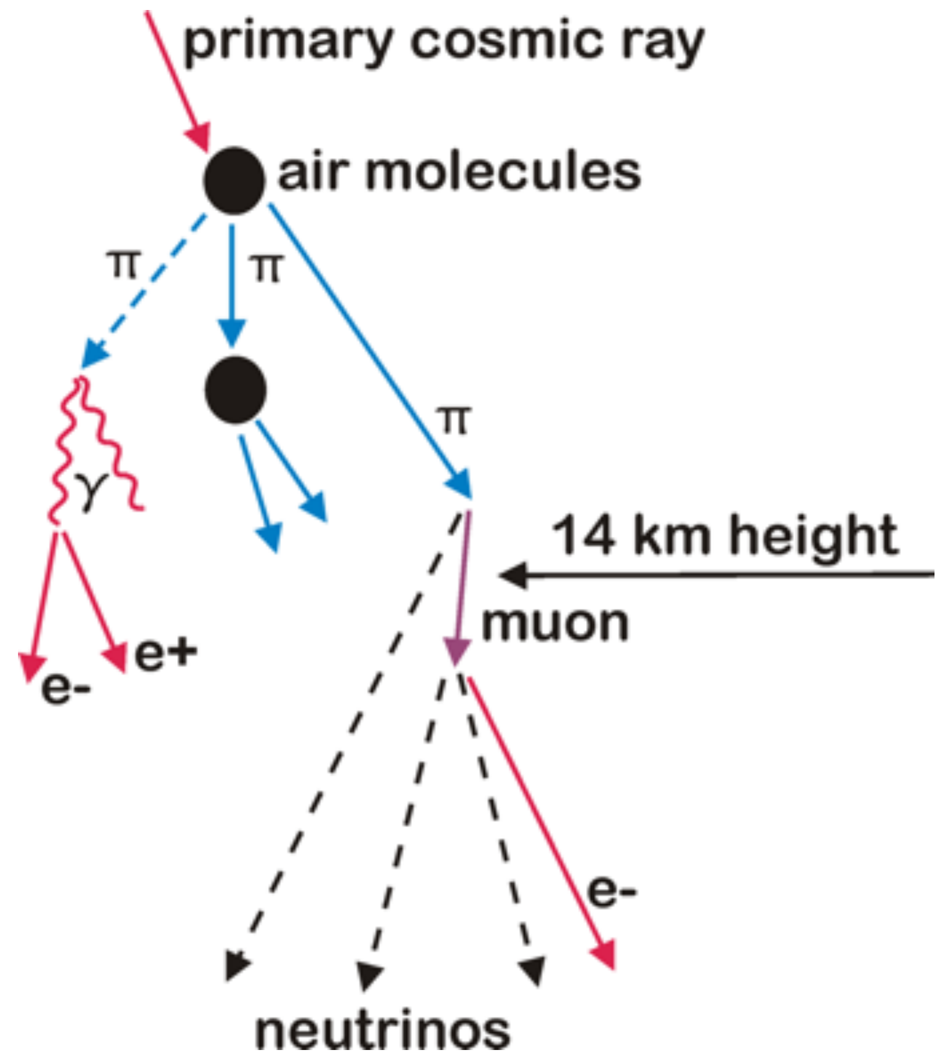
- Experiments have made extensive measurements of the cosmic ray flux
- The cosmic accelerators are unknown
- Neutrino detection can provide location and information on the acceleration process… hopefully

Cosmic Ray Flux

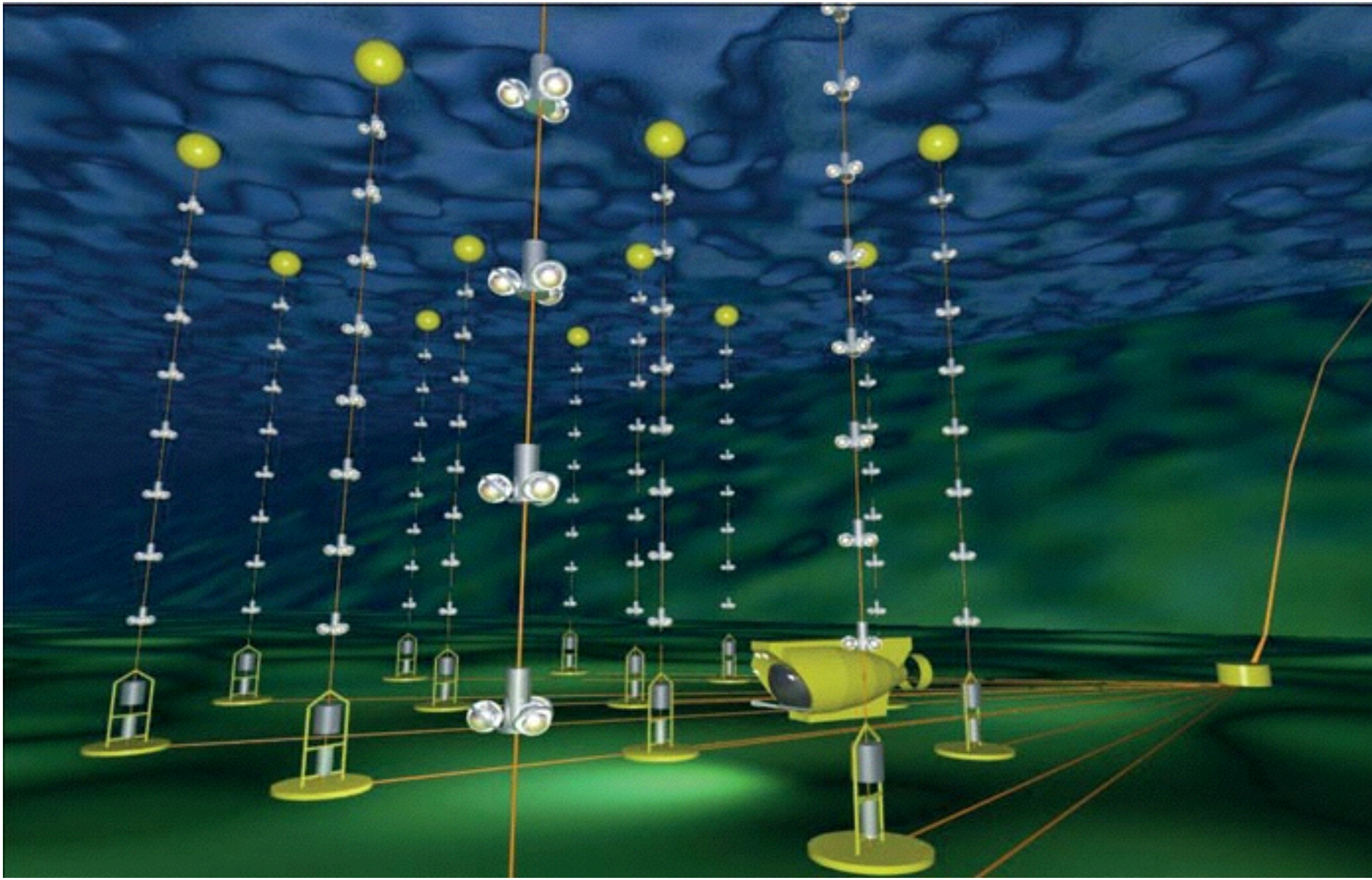


TeV Region

- Needs some motivation: mostly astrophysical
- Low flux and cross-section requires very large detectors
- Atmospheric neutrino information as well

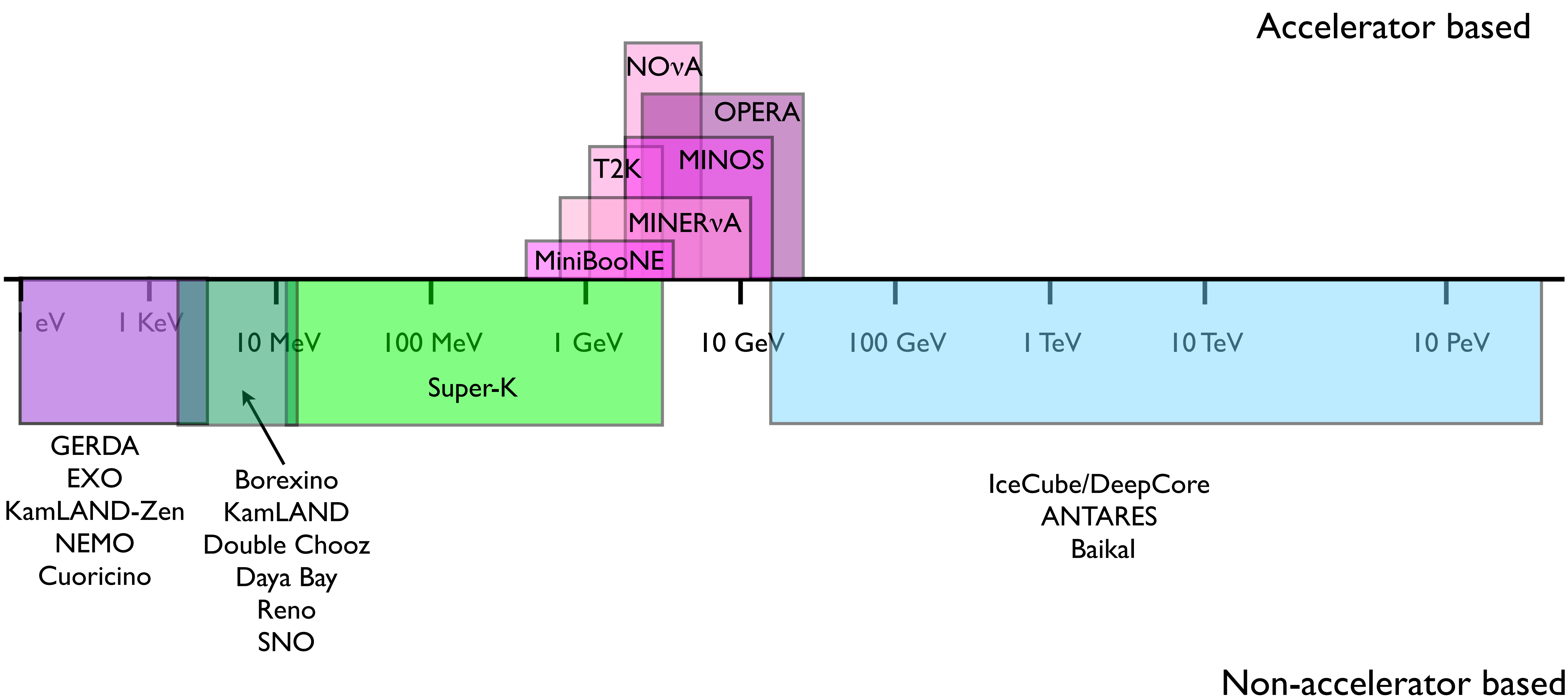


Antares Neutrino Telescope



Experimental Landscape

- TeV non-accelerator experiments are optimized for astrophysical neutrinos



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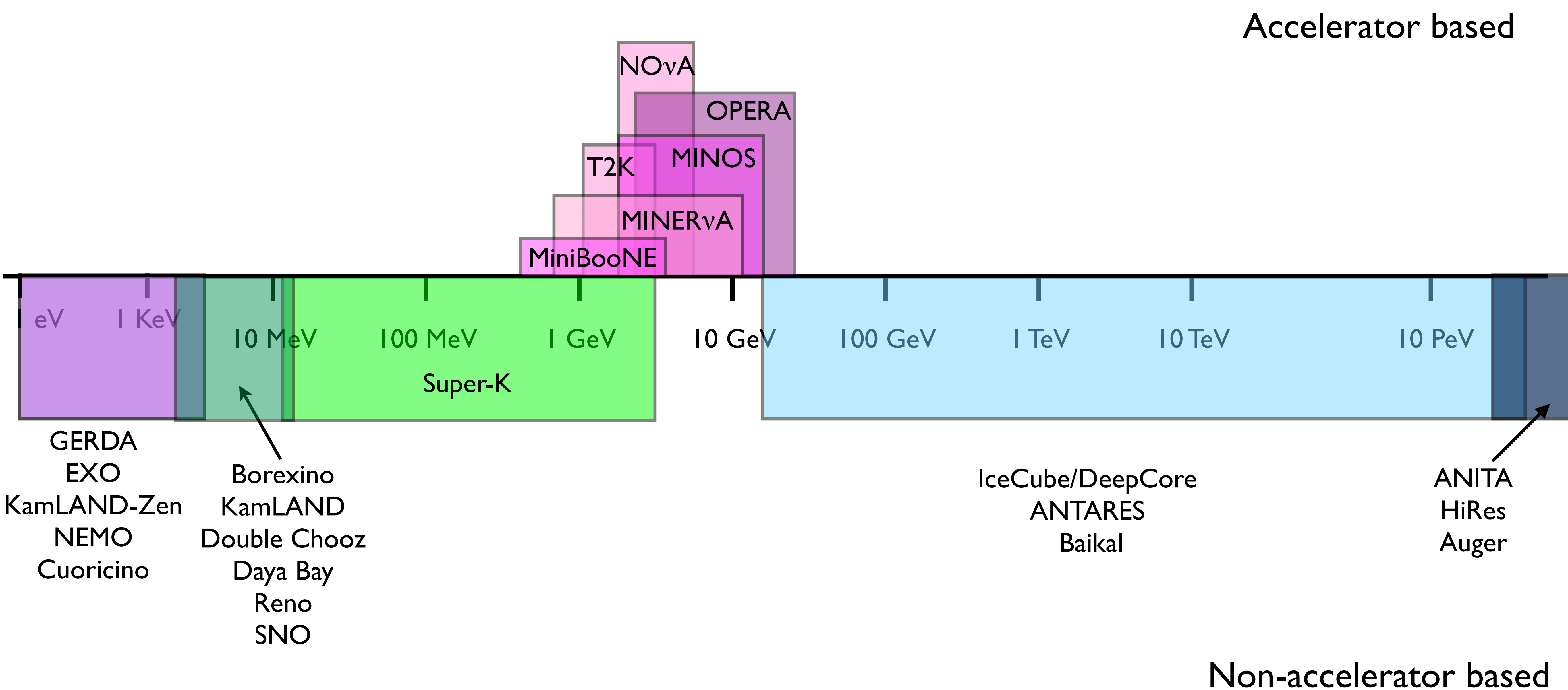

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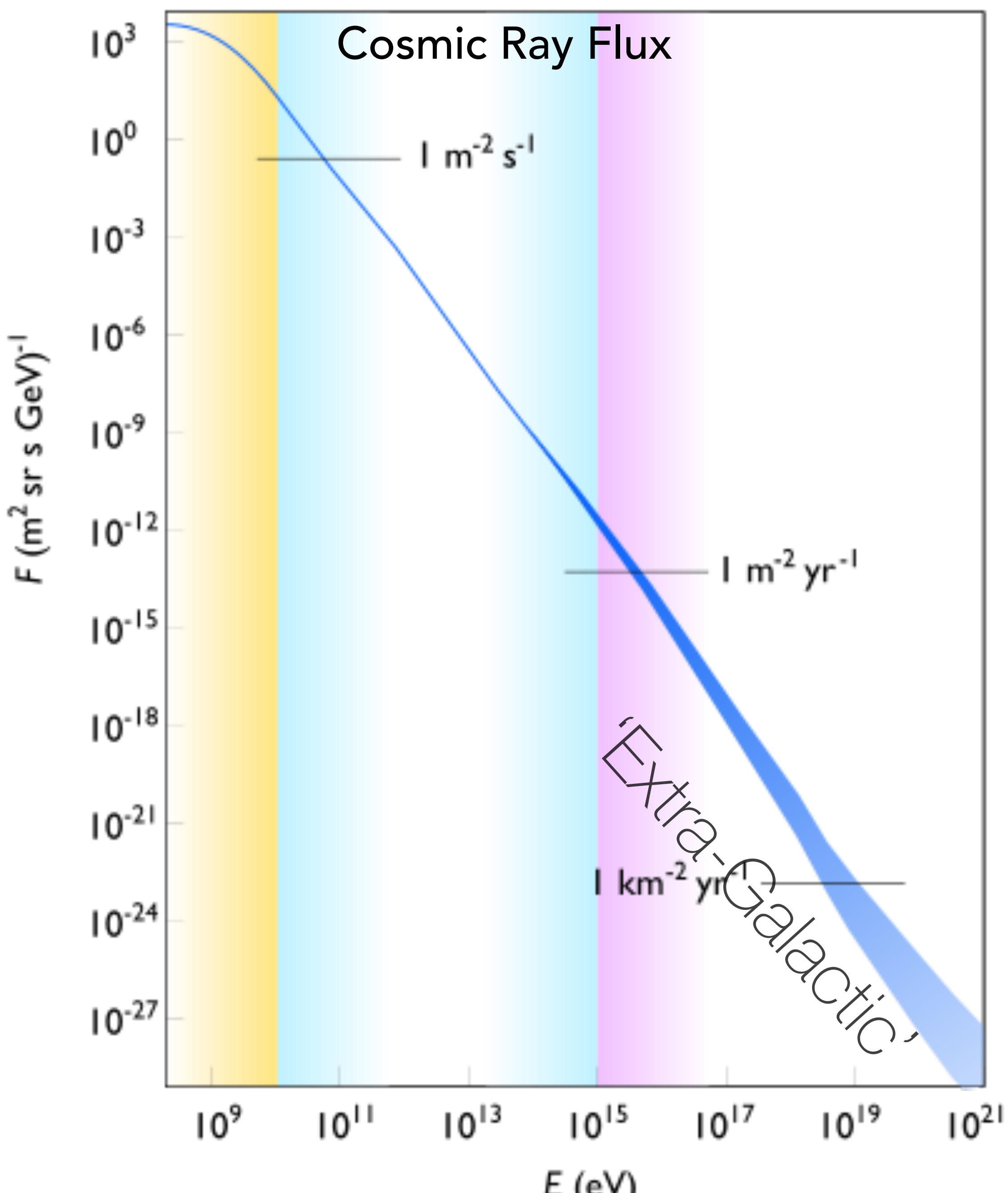
Highest Energies

- Greisen-Zatsepin-Kuzmin (GZK) limit



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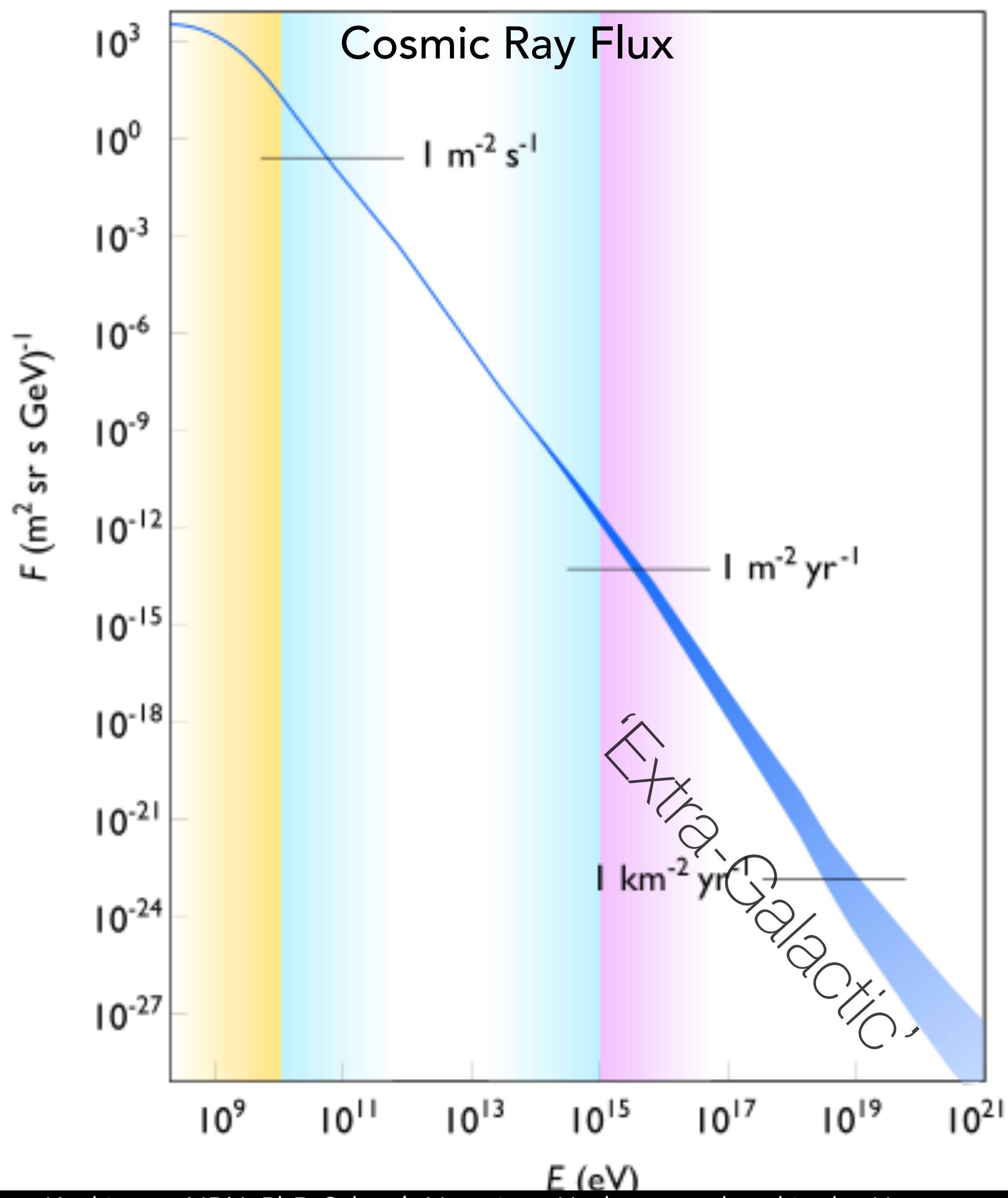
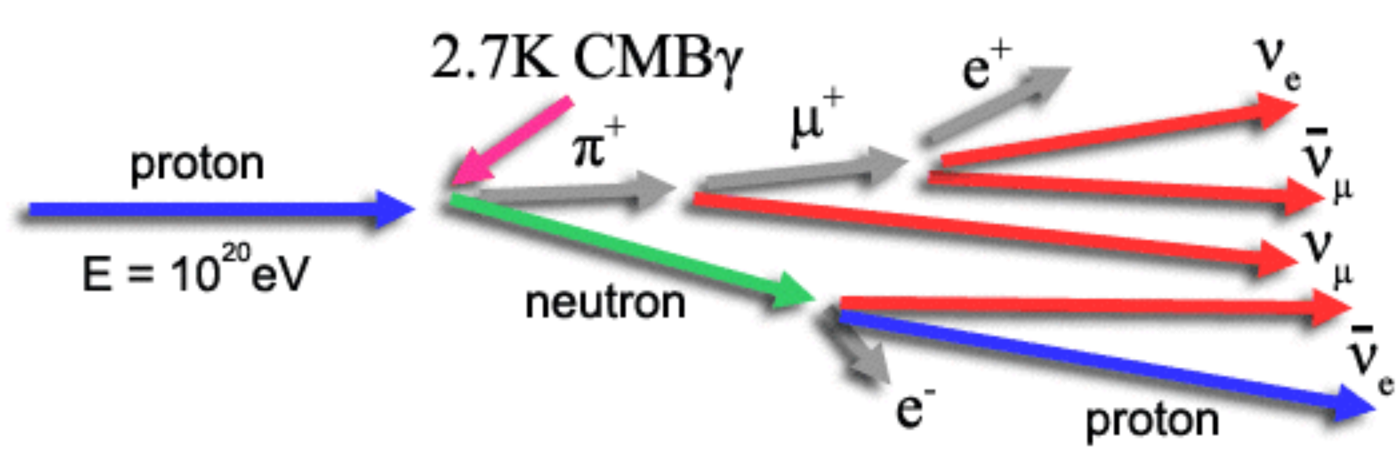
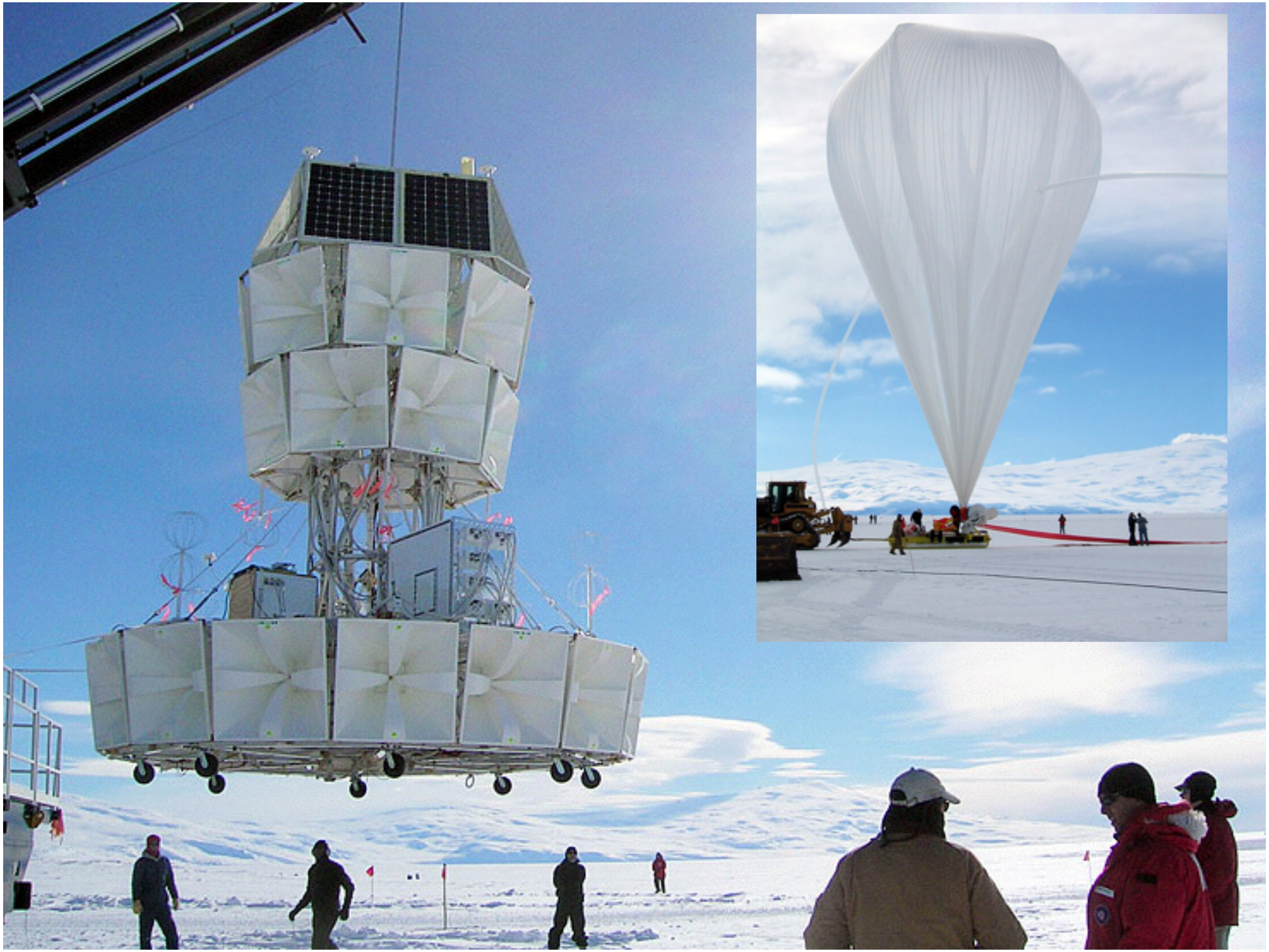


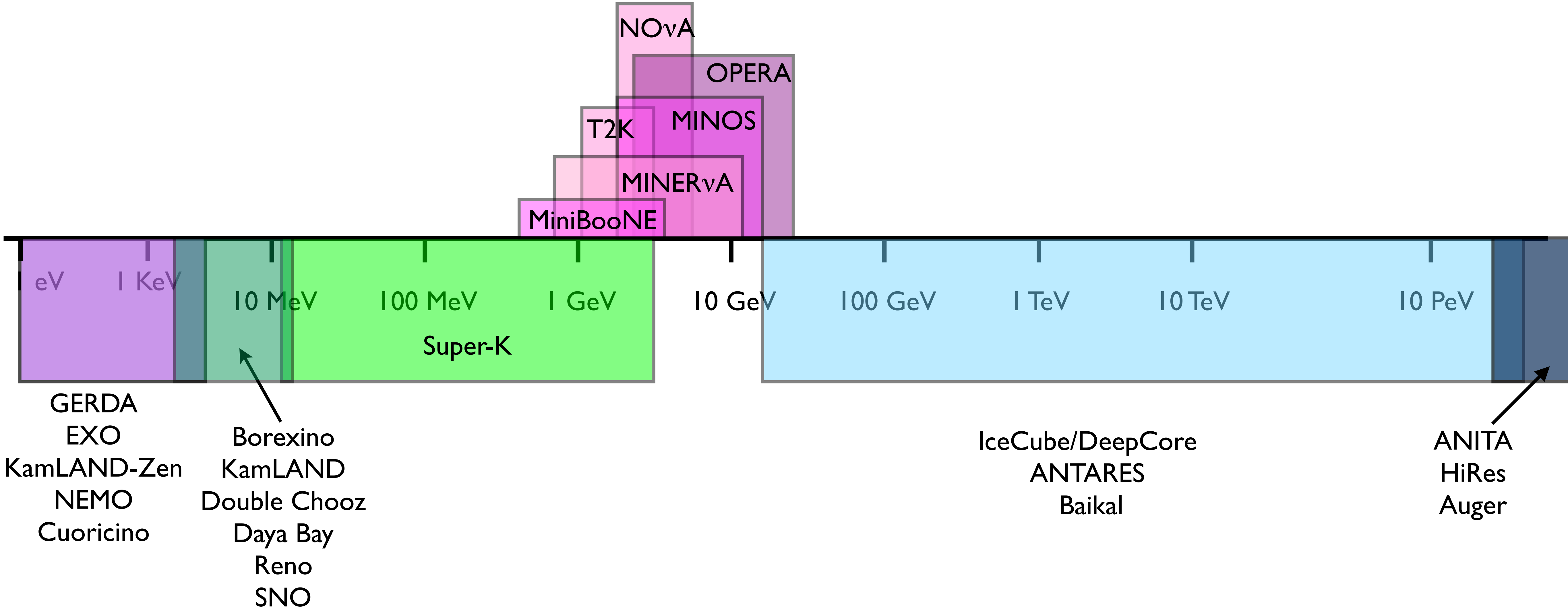


ANITA Payload & Balloon



Experimental Landscape Overview

- Lowest energy experiments focus on neutrino mass and Dirac vs. Majorana
- Reactor/Solar experiments dominate the < 1 GeV non-accelerator region
- Accelerator coupled experiments are mainly probing oscillation physics
- Highest energy experiments are involved with astro-physics and cosmic neutrinos

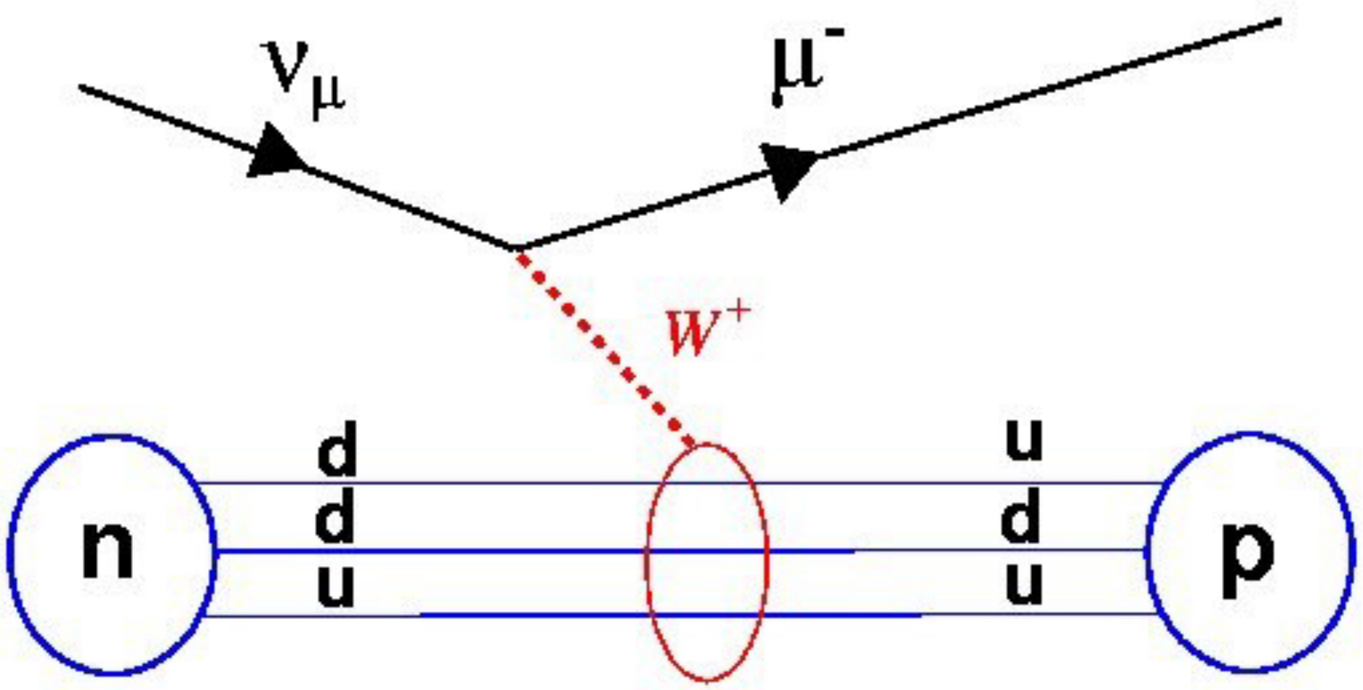


Neutrino Interaction

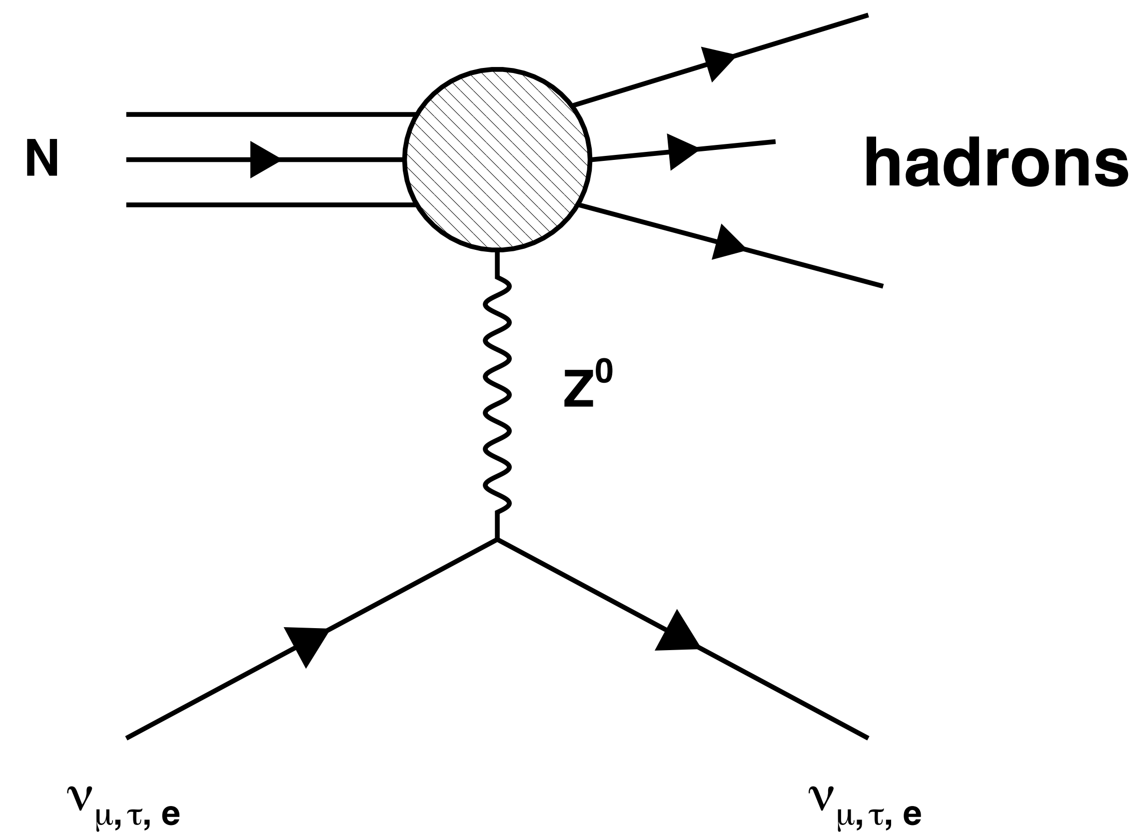
Interaction Types

- The neutrino event is always an indirect signature
  - Common is Charged Current (CC) and Neutral Current (NC)
  - Look for something happening in a detector

Charged Current



Neutral Current

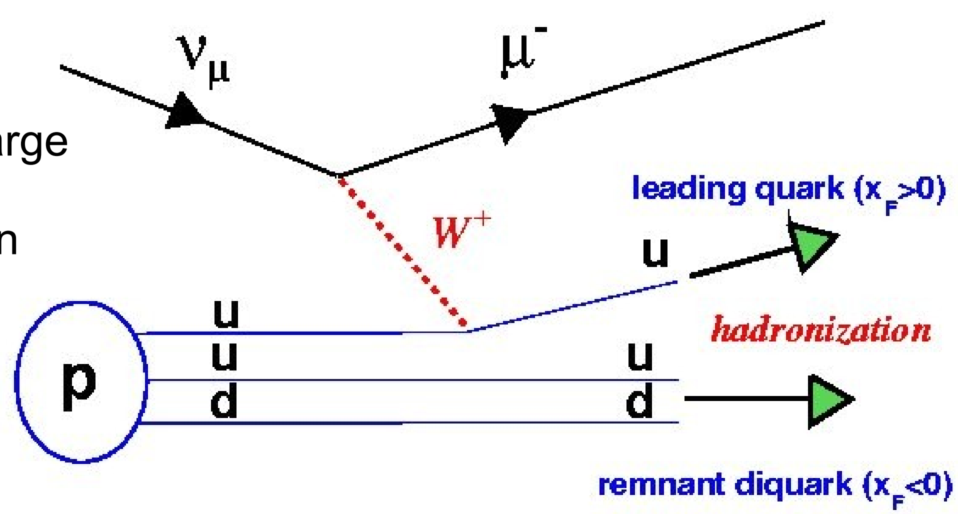


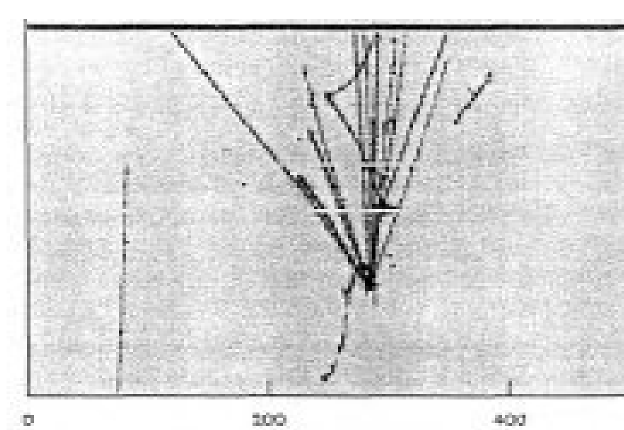
Neutrino interactions

QEL, RES, DIS dominant in different kinematical regimes

Increasing multiplicity

q, qq materialize to give large number of f/s.
At low masses though can look like RES



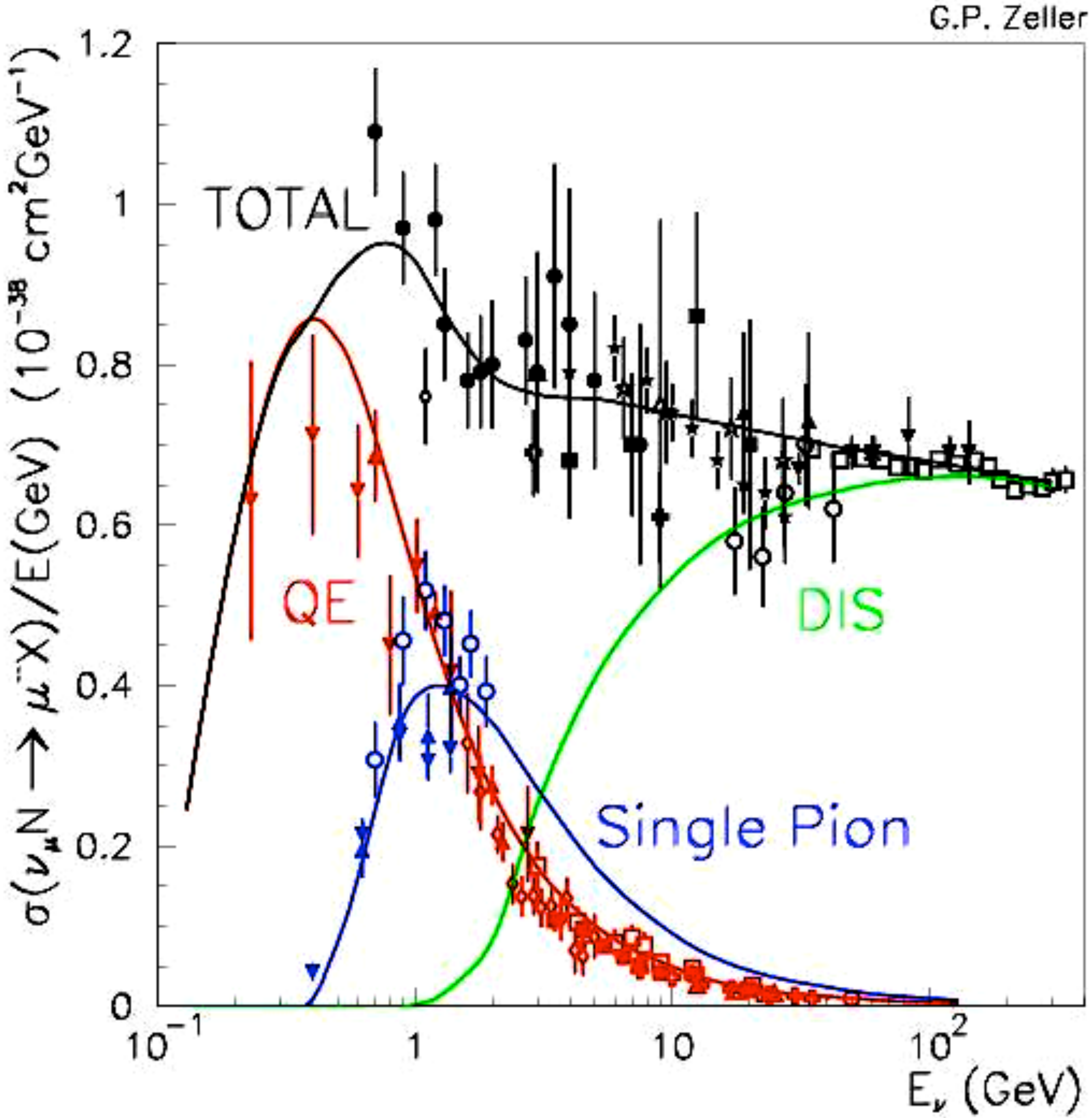


DIS

Note: Free Nucleon interactions

*Costas Andreopoulos - "GENIE Tutorial"

Neutrino Charged Current Cross-Section



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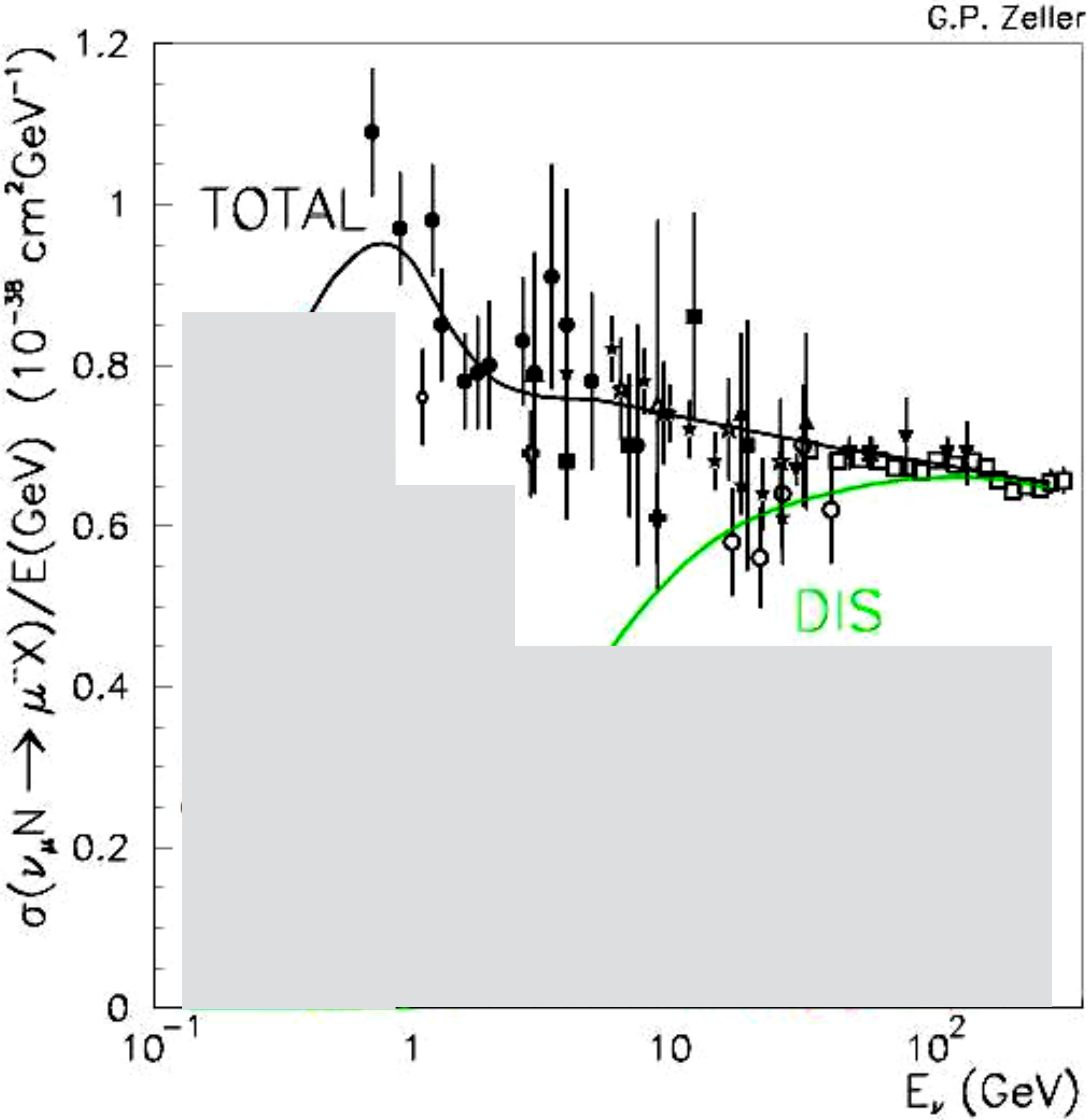

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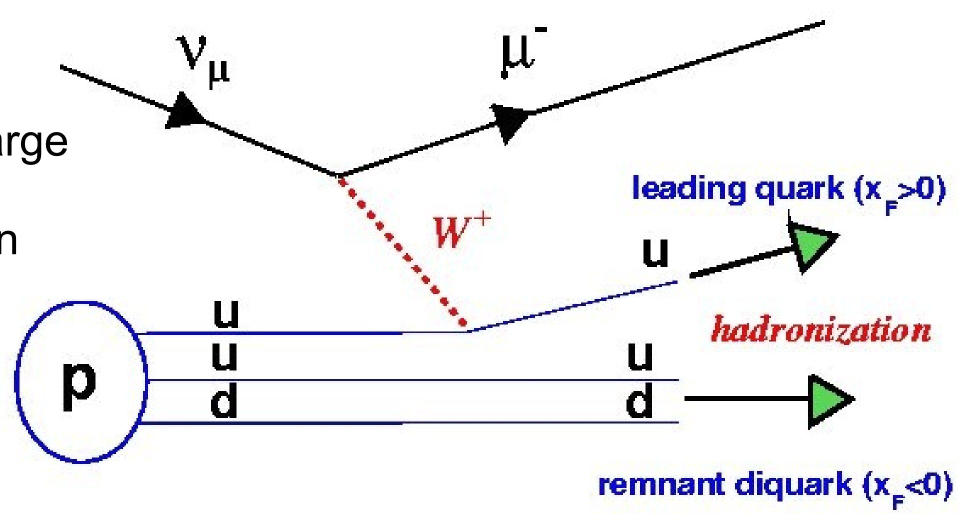

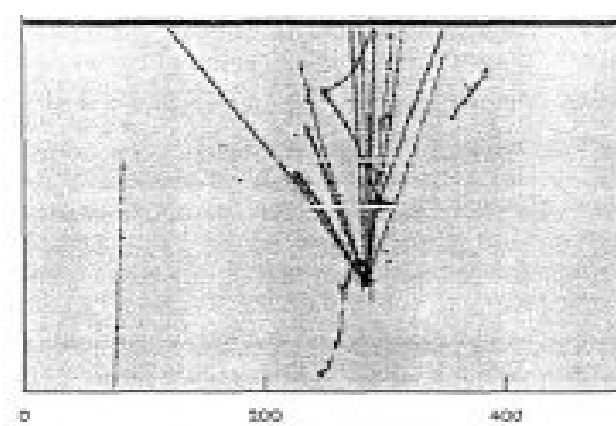

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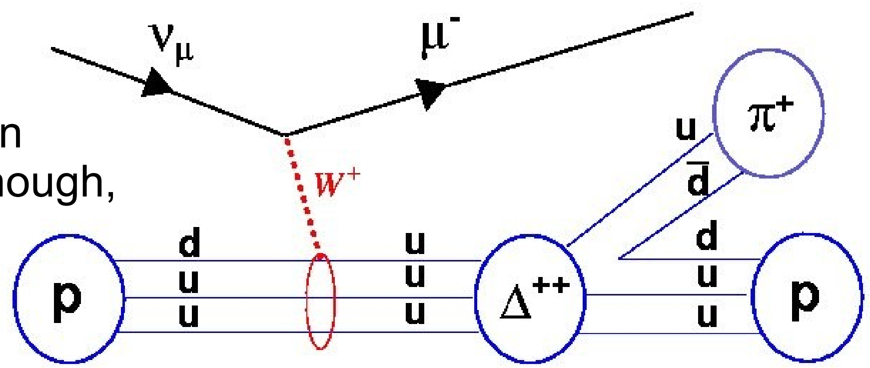

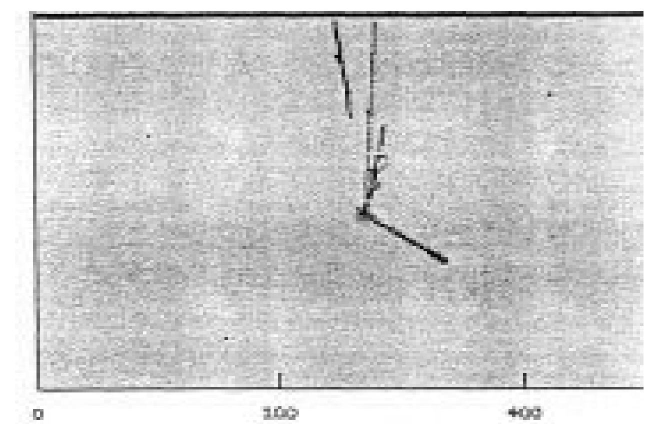

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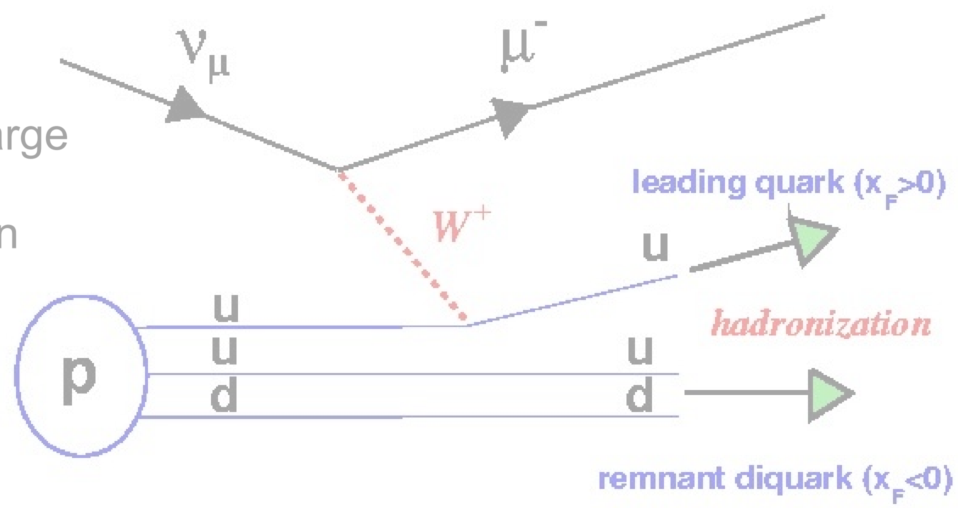

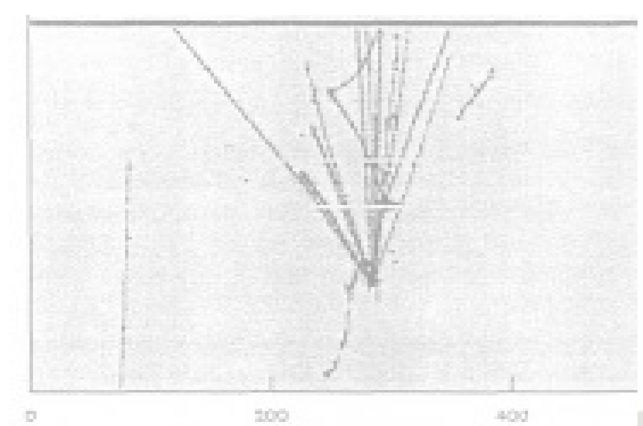

DIS

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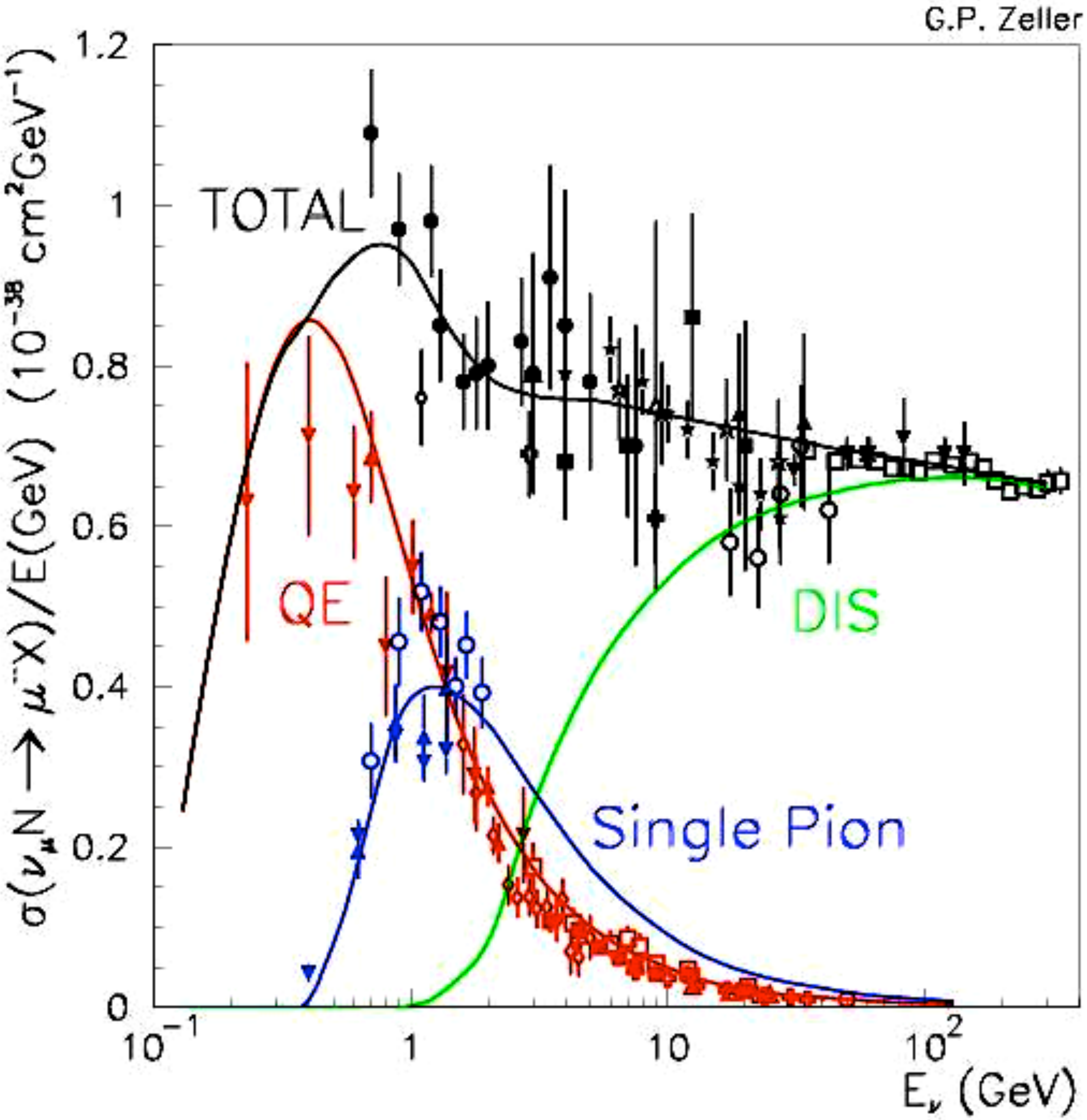
Neutrino Charged Current Cross-Section



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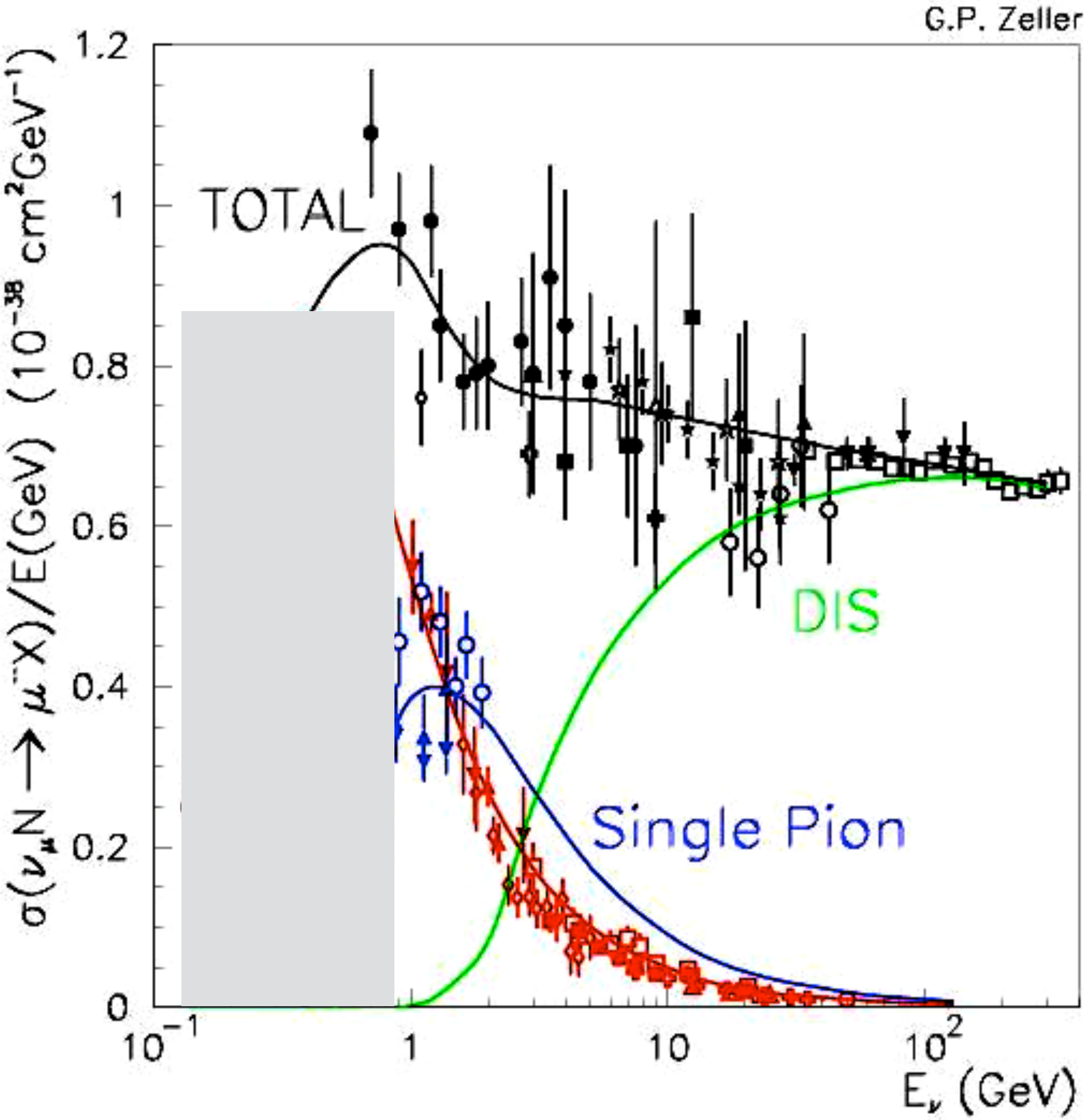

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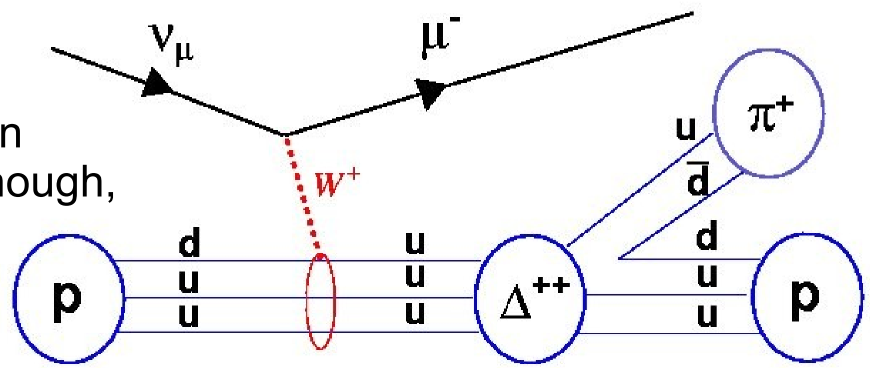

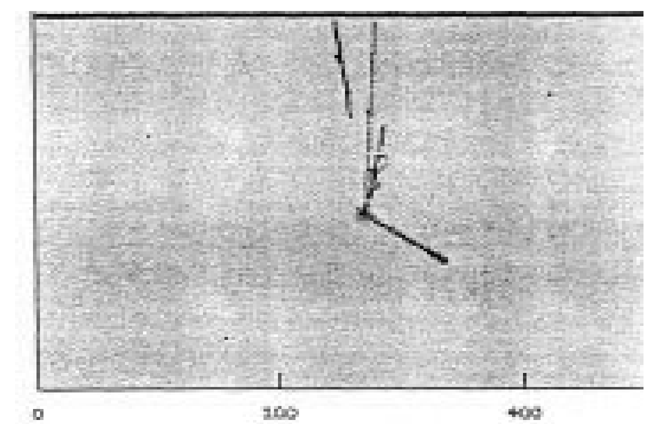

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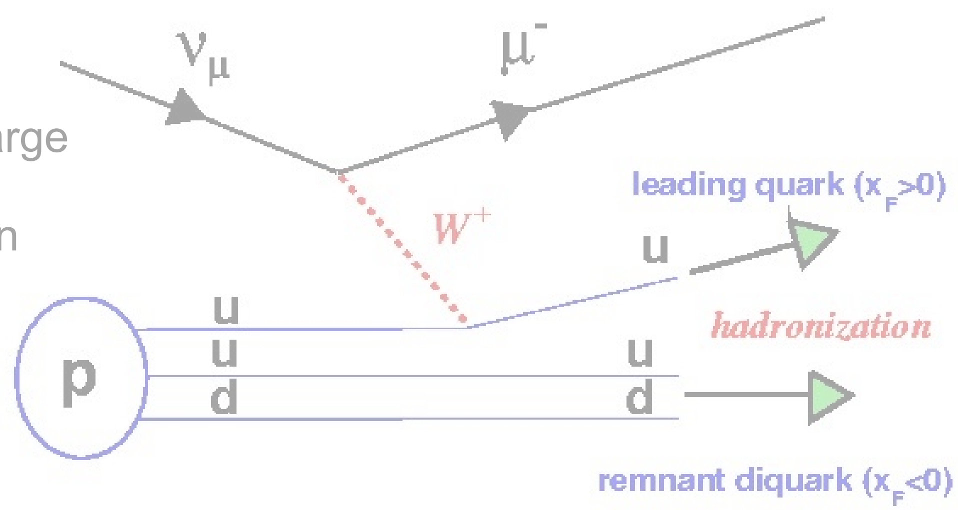

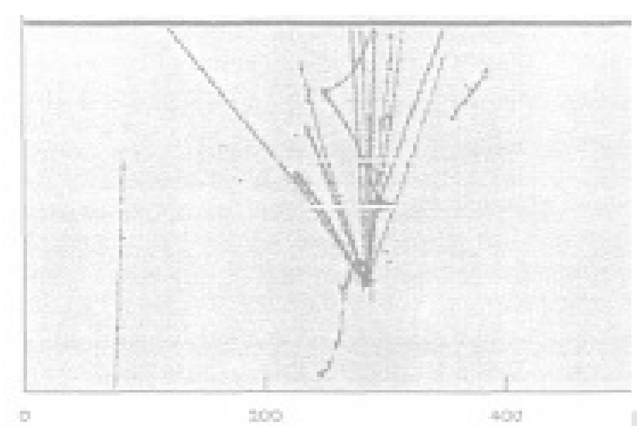

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Science & Technology Facilities Council

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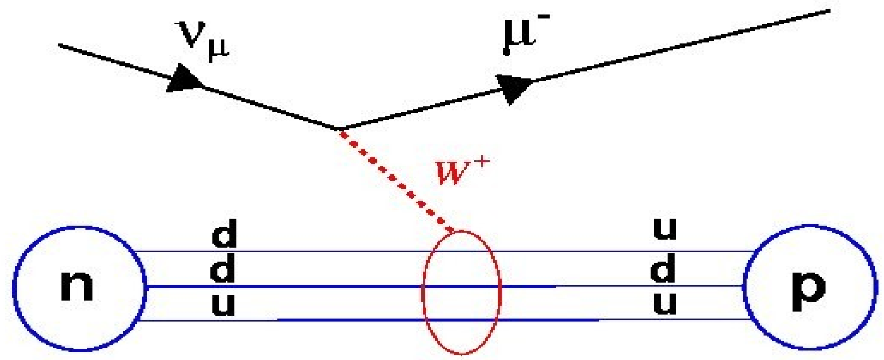

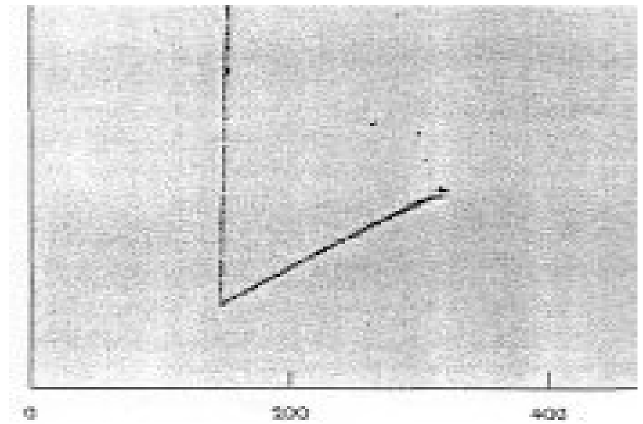

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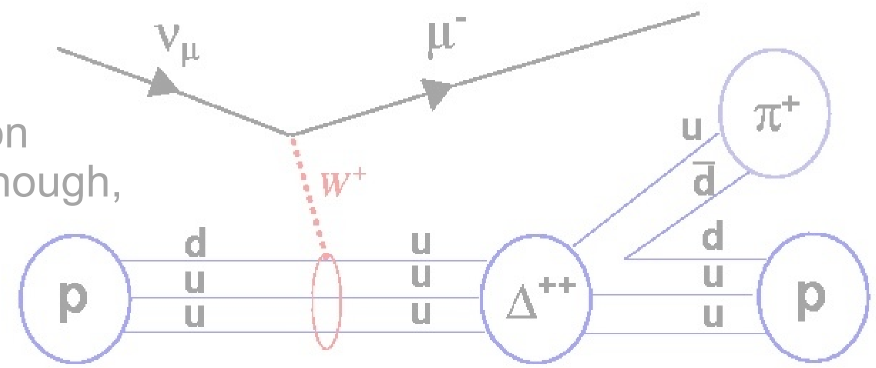

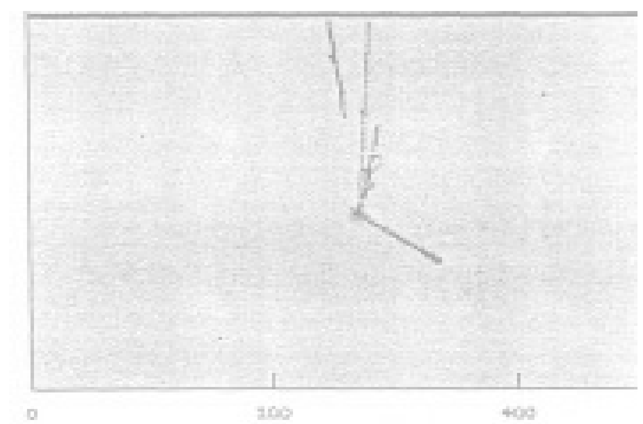

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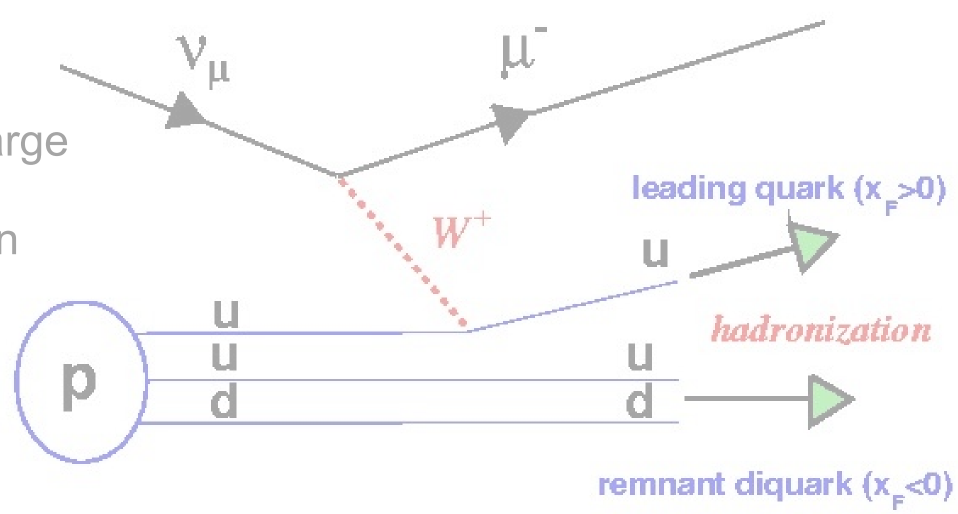

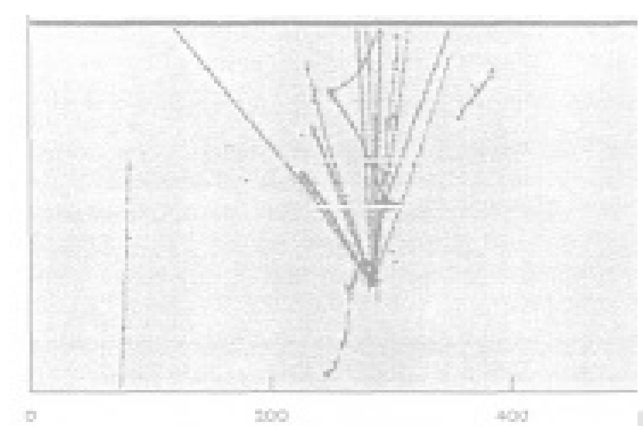

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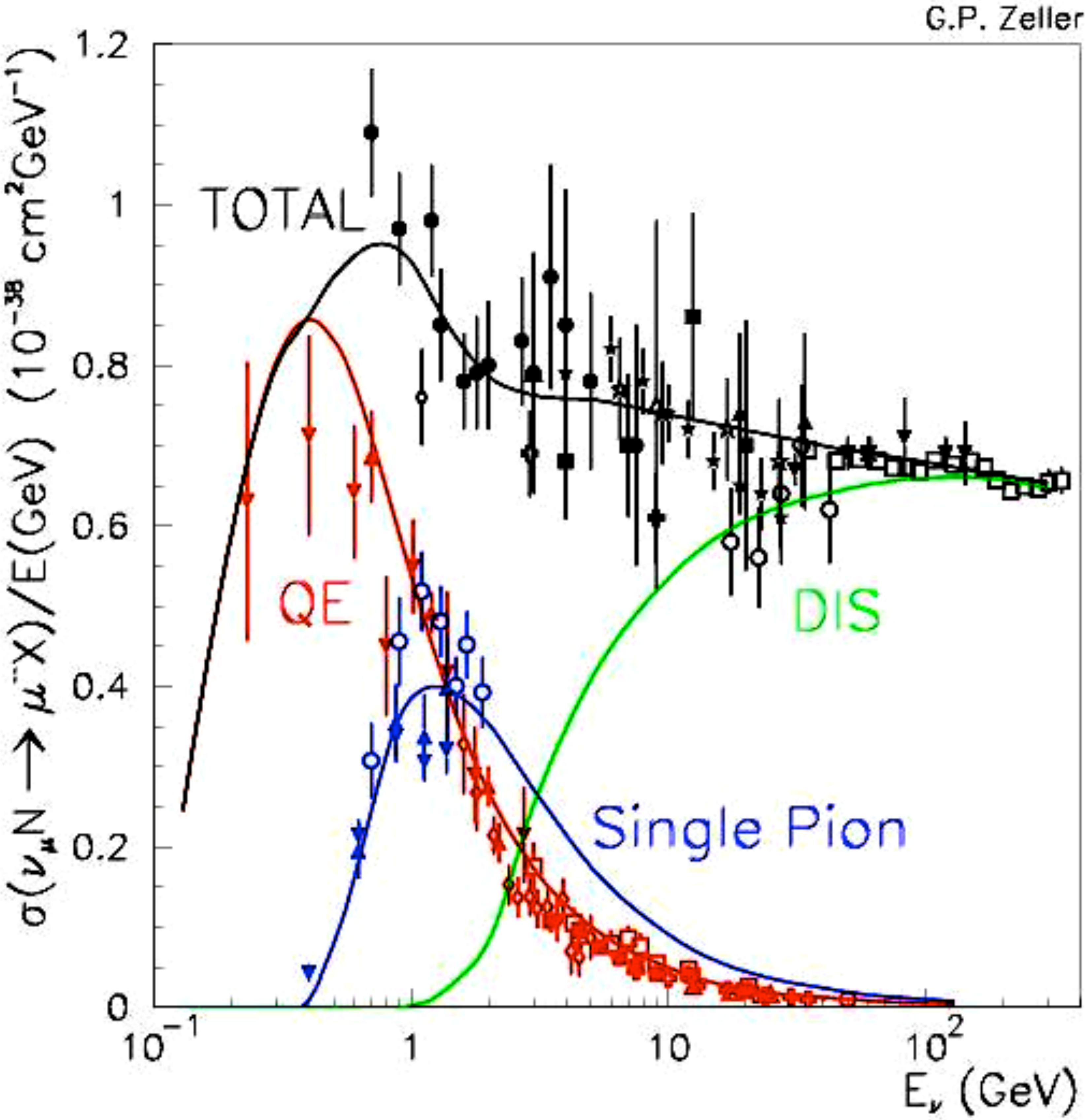
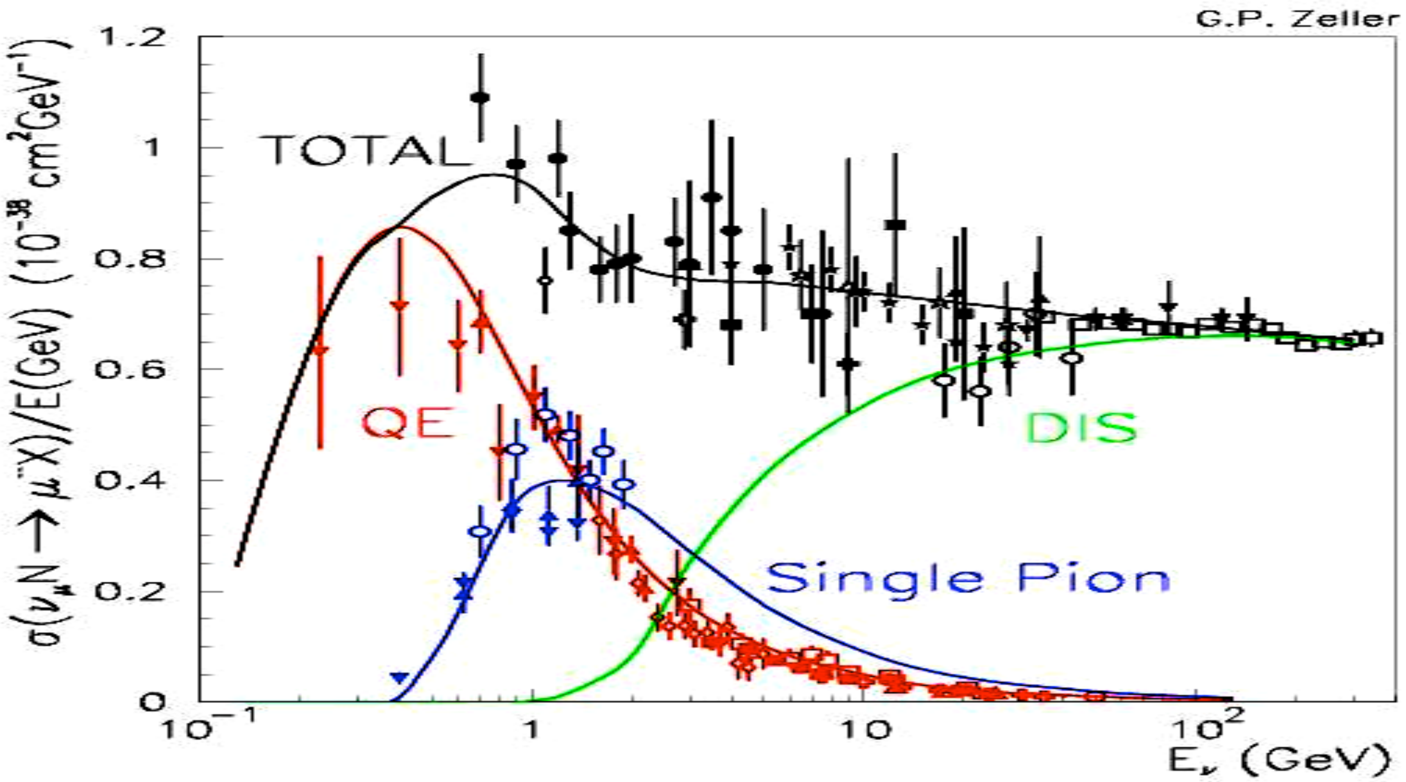
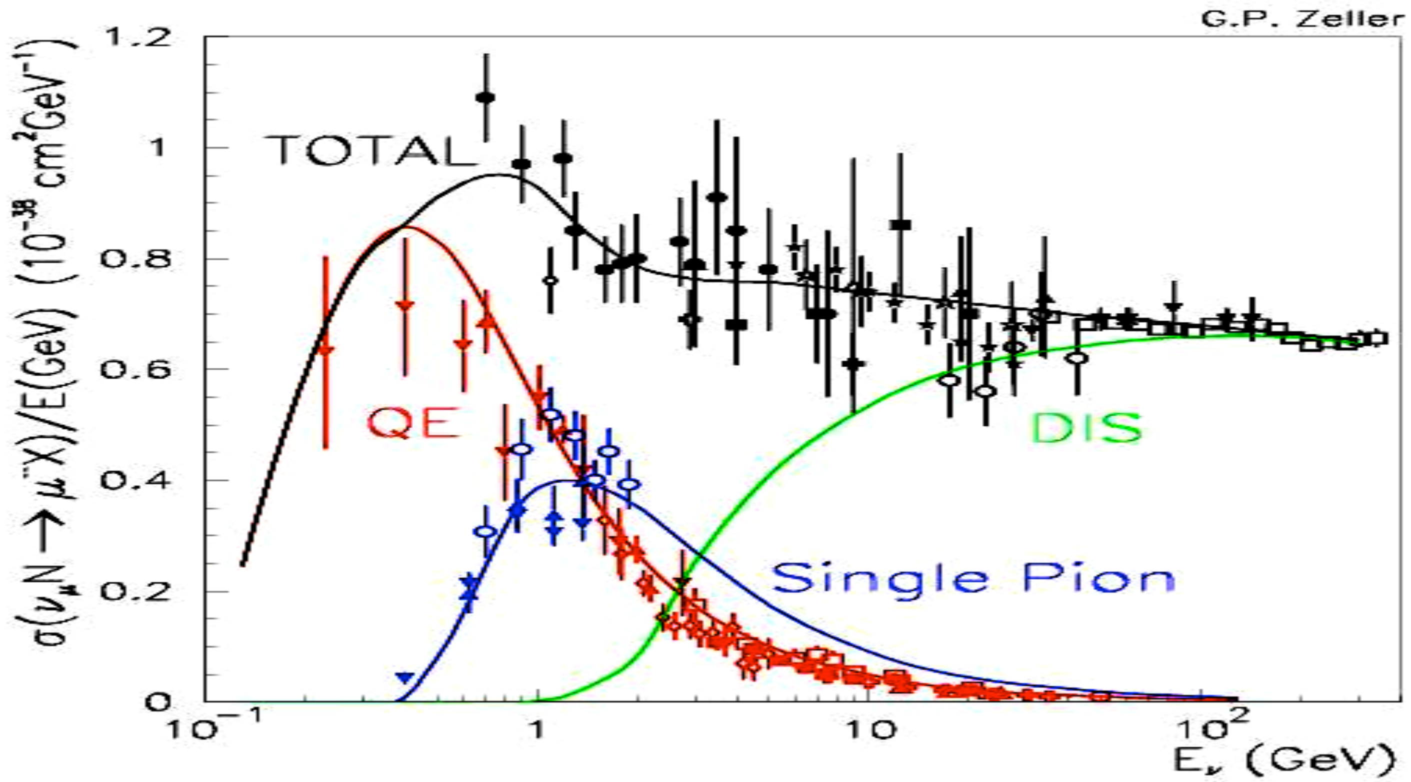


Charged Current Types

- There are different types of Charged Current interactions
  - At high(er) energies Deep-Inelastic Scattering (DIS): Nucleon is destroyed created a shower of secondary hadrons
  - At ~1 GeV neutrino energy Resonance (RES): Nucleon ‘emits’ a low number of secondary mesons or resonant states
  - At lowest energies Quasi-Elastic (QE or QEL): Nucleon stays intact
- Above interactions are accompanied by an outgoing charged lepton
- Higher energies have higher cross-sections
- Others: Inverse beta-decay, coherent scattering



Cross-sections do extend
to lower energies than shown



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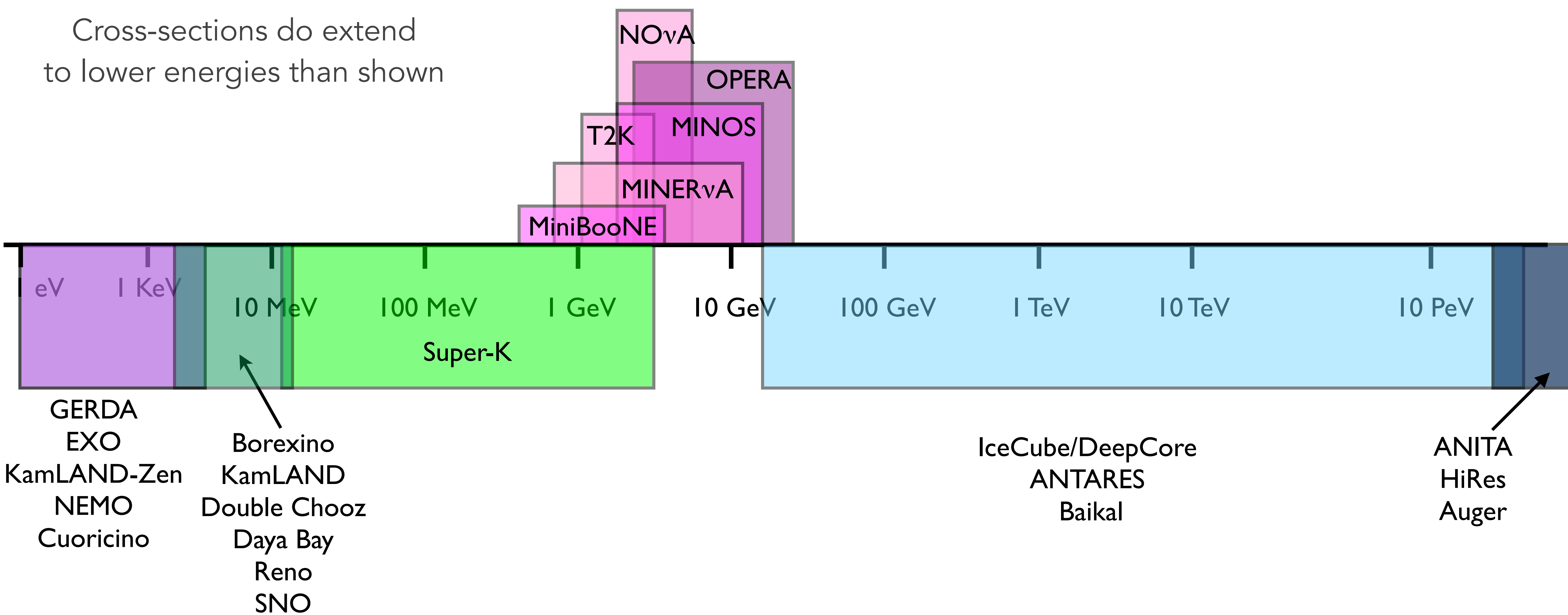
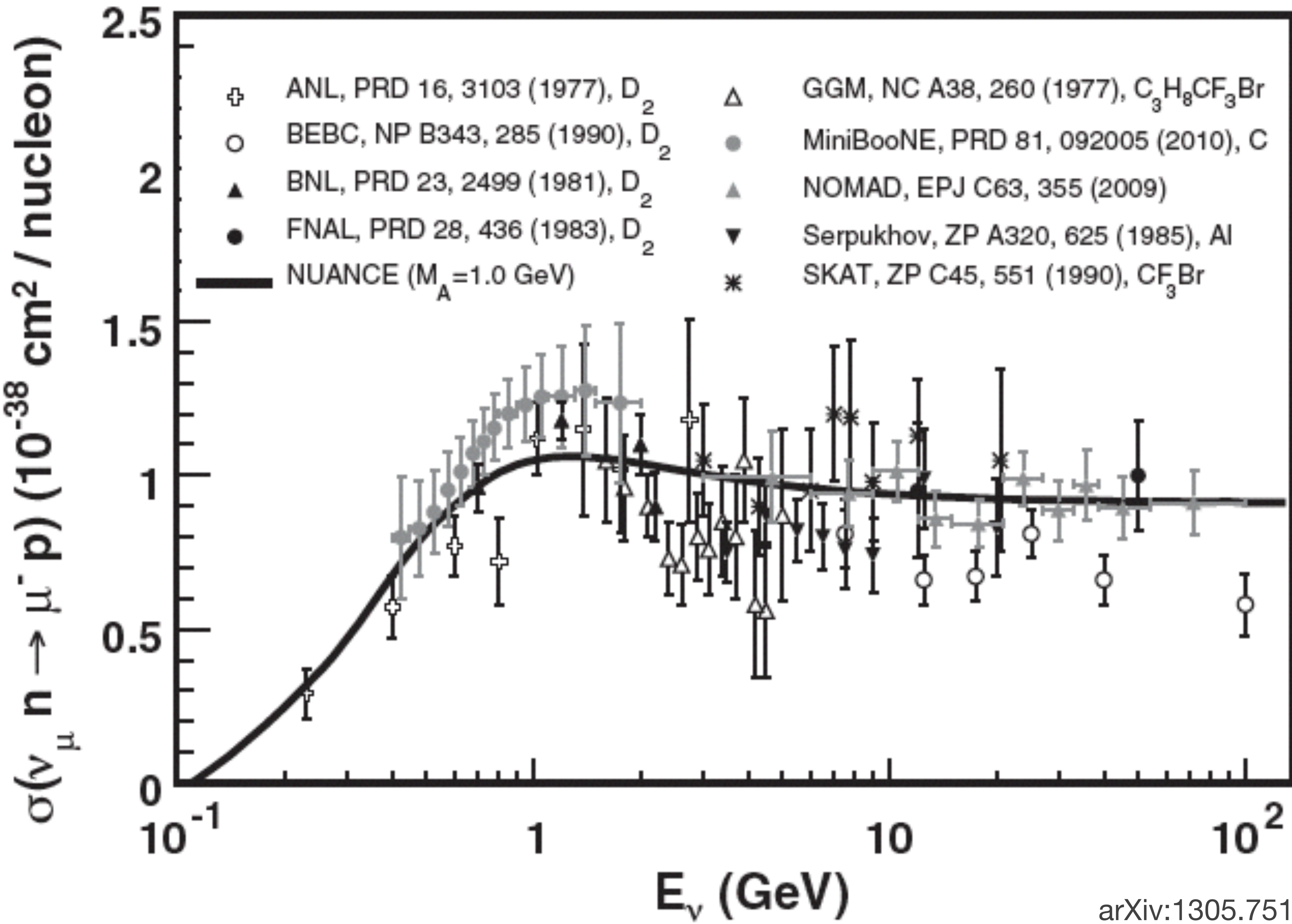


Cross-Section Comments

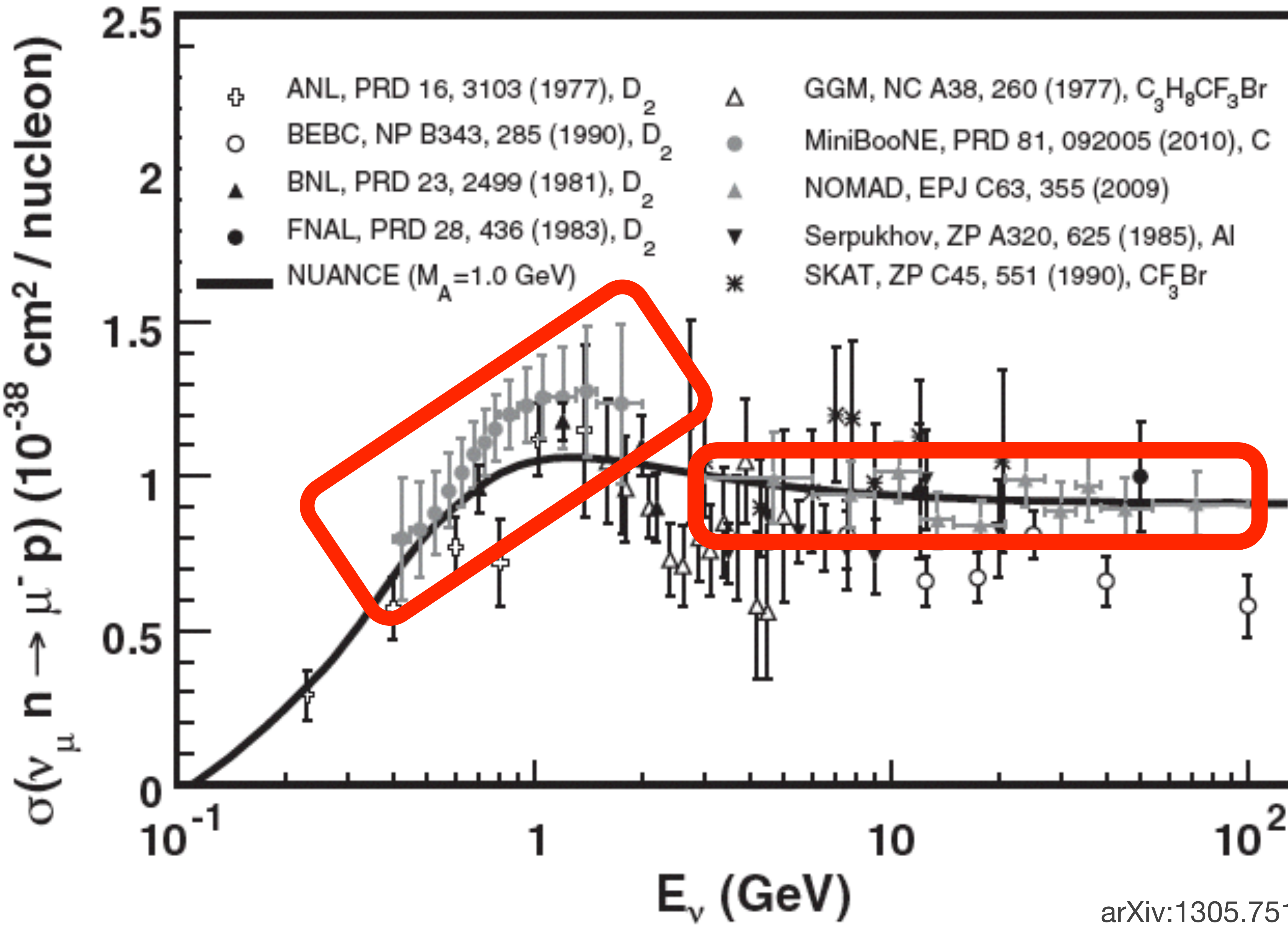
- Deep Inelastic is generally experimentally advantageous
  - Total event energy is high
  - Low contribution to event rate from QE/RES
- Resonance is difficult
  - Overlap region with QE and DIS
  - Identify pion and separate from out-going nucleon
- Quasi-Elastic
  - Low enough energies where the interaction can be influenced by atomic/nuclear physics of the struck atom
  - Low final state multiplicity: charged lepton and out-going nucleon
  - Dominant signal from many neutrino oscillation experiments

Notable Issue with QE and RES



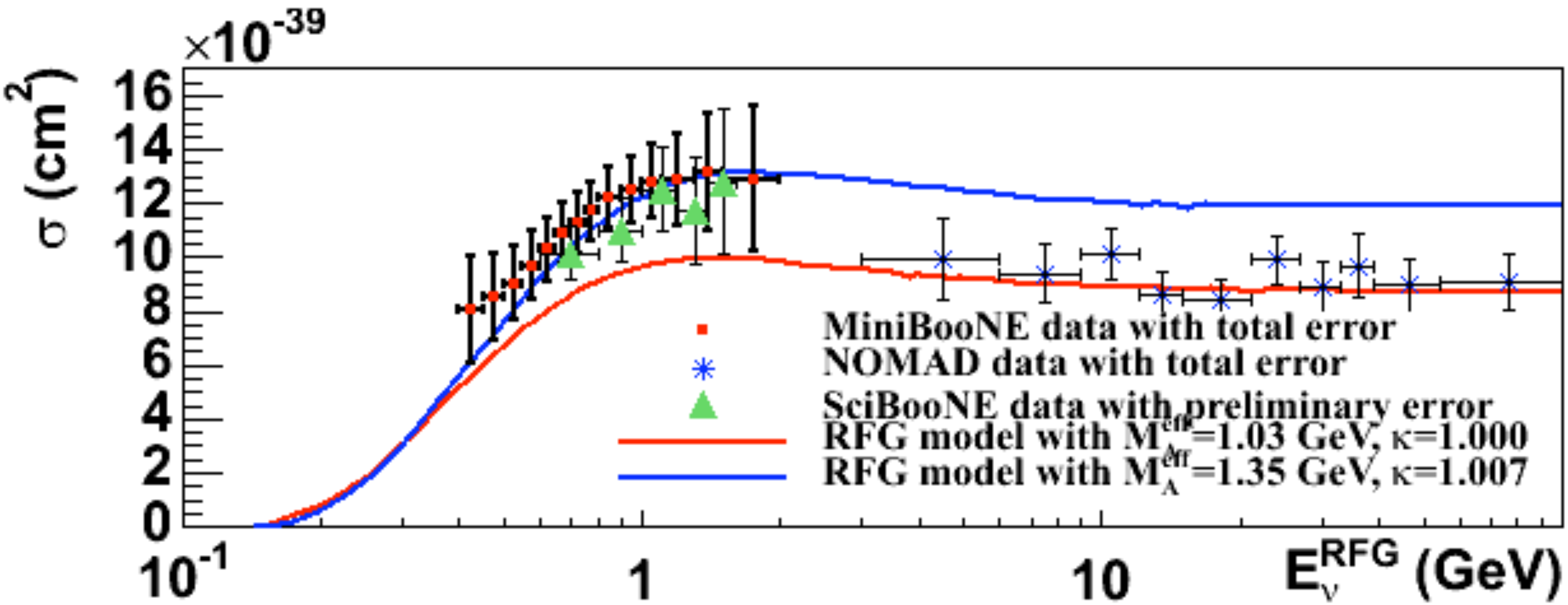
arXiv:1305.7513

Notable Issue with QE and RES



arXiv:1305.7513

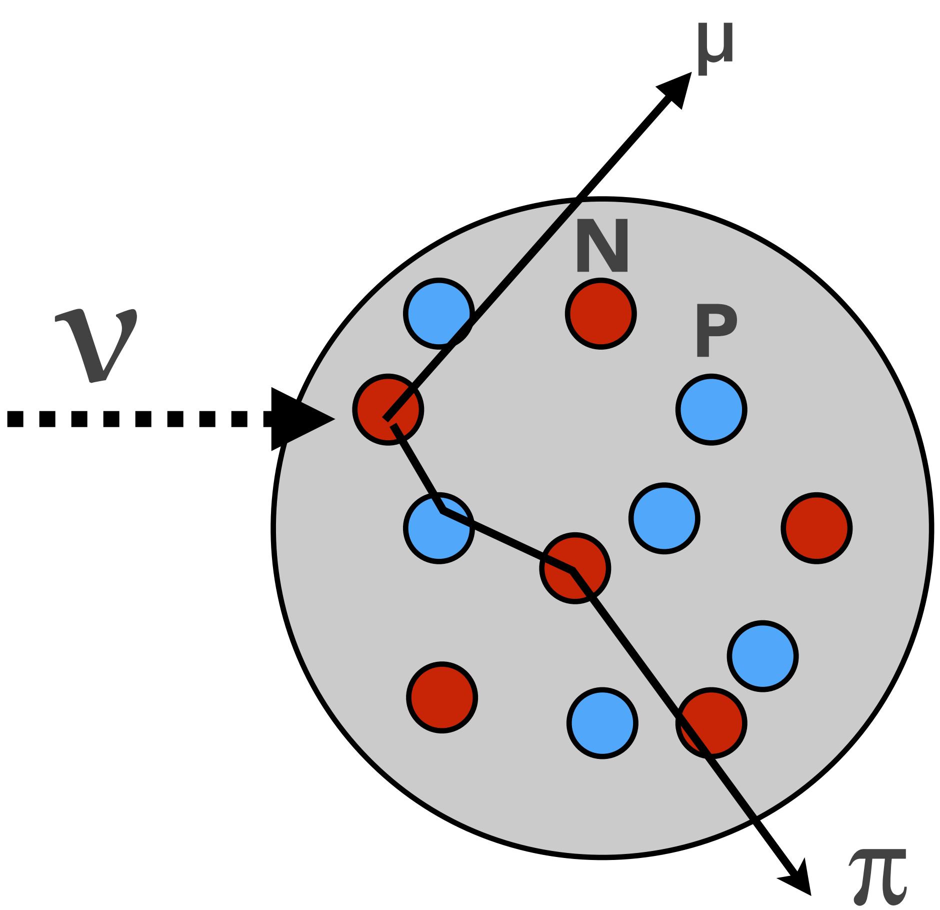
Notable Issue with QE and RES

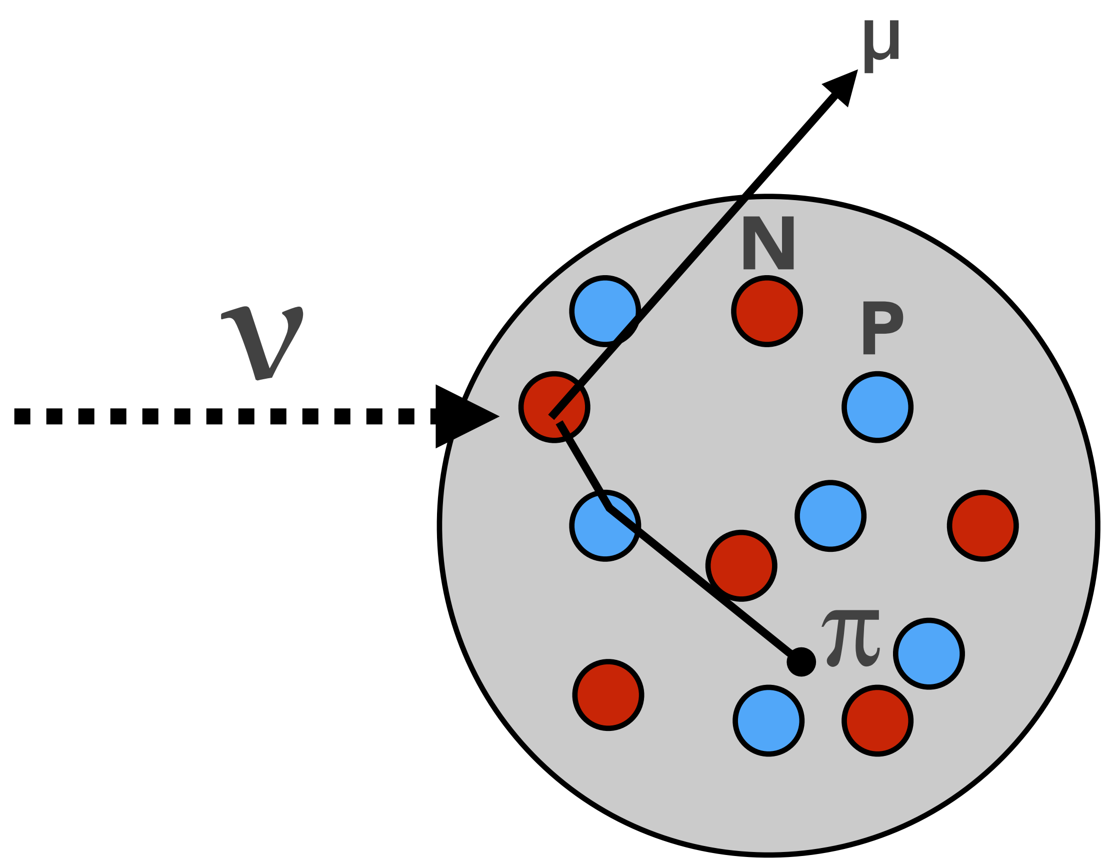


*T. Katori, NuInt09

Nuclear Effects

- Struck nucleon has some momentum
- Outgoing particles must traverse the target atom
  - Leptons don't generally have an issue
  - Mesons are likely to have intra-target interactions and possibly absorption





Wrap-Up

- Neutrino experiments extend from eV-KeV up to PeV-EeV
- Neutrino interactions are varied and at low-energies are complicated by nuclear physics

Backup and Additional Info

More Info

- For cross-sections
  - "From eV to EeV: Neutrino cross-sections across energy scales" - J. Formaggio and G. P. Zeller
  - Lecture handouts from Mark Thomson - http://www.hep.phy.cam.ac.uk/~thomson/partIIIparticles/handouts/Handout_10_2011.pdf